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A TECHNIQUE FOR EVALUATING THE EFFECTS OF THE UPSTREAM WATERSHED PROGRAM ON DOWNSTREAM RUNOFF

APPROVED BY

DISSERTATION COMMITTEE

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

A TECHNIQUE FOR EVALUATING THE EFFECTS OF THE UPSTREAM WATERSHED PROGRAM ON DOWNSTREAM RUNOFF

CHAPTER I

INTRODUCTION

General

Water is unique in that it is vital not only for human existence but for having a role in almost every advancement civilization has made. Unfortunately about 97 per cent of the world's water is saline and unfit for most uses unless it is desalted. Of the remaining three per cent of the world's water which is fresh water, over 99 per cent is in the form of polar ice and glaciers and groundwater. Only 0.3 per cent of the fresh water is found in lakes and 0.03 per cent in rivers. The distribution of this relatively small amount of fresh surface water is not uniform over the land masses of the earth, a fact that contributes to the problem of meeting the world's water demands.

The per capita demand for fresh water in the United States has grown tremendously and forecasts are for continued increases. Industrialization and power requirements have played prominent parts in increasing water usage. A great population increase has coupled with increased unit usage to send the total water usage figure spiralling upwards. Other water uses such as navigation and recreation, which themselves are non-consumptive, have created a competition for the water resources by demanding that river stages and lake levels be maintained and that facilities be expanded. The development of irrigation systems and agricultural techniques has made it possible to farm land previously considered unusable. Urbanization has developed a heterogeneous population pattern in the United States, causing areas of great water demand.

While the demands for water have increased, the overall supply remains constant within the hydrologic cycle. Although it was always apparent that certain areas of the country did not have adequate water resources to support a high population density or other activities with large water demands, some areas that were previously considered as having adequate water resources are now considered as having water resources that are inadequate. In these areas a conflict exists over the water resources that are not sufficient to meet all requirements. The extensive development of water resources programs has placed other regions of the country in a vulnerable position if they were faced with a period of low yield.

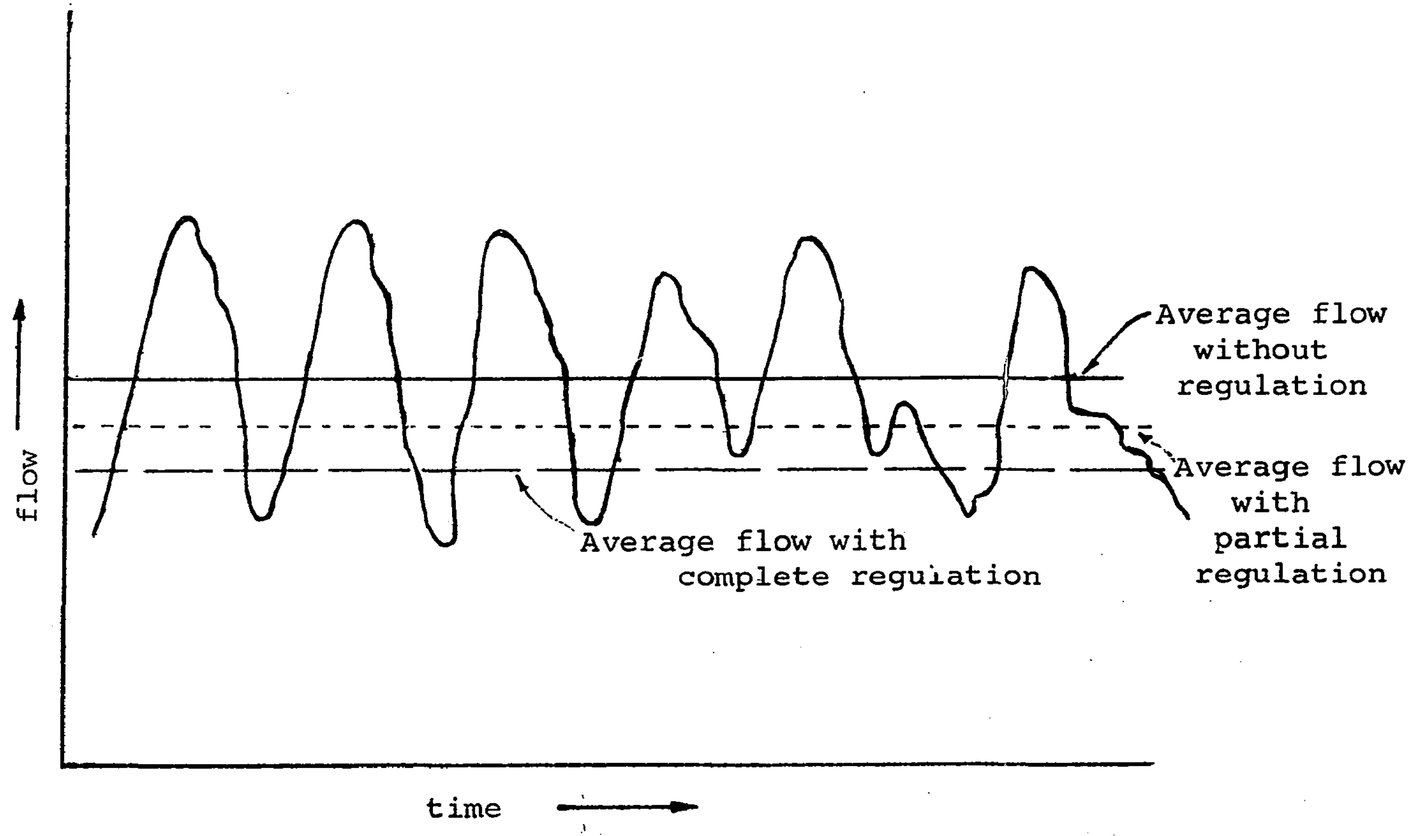
Conflicts which exist involving direct water withdrawals are obvious. However, the conflict between retention structures on tributaries and programs aimed at holding rainfall on the land on which it falls and major river projects has not been accurately evaluated. The Soil Conservation Service (SCS) is the primary agency engaged in upstream programs while the Corps of Engineers, The Bureau of Reclamation (Reclamation), and others are developing downstream programs.

Although flow regulation has many benefits, regulation is also accompanied by increased losses. As regulation is increased the associated losses increase. The sketch in Figure 1 represents a typical situation.

In a significantly large area of the United States, available surface water is generally insufficient for the requirements of upstream and downstream water resource programs as practiced in humid climates. In areas where the surface water is obviously not sufficient to satisfy

FIGURE 1

TYPICAL EFFECTS OF FLOW REGULATION



either program, as is the situation in most of the United States West of the 103rd meridian, a conflict between the programs does not develop. Coexistence of the programs is generally possible East of the 95th meridian in the United States because there is sufficient surface water, with the present use rates, to satisfy full upstream and downstream programs without either adversely affecting the other.

In the transitional area, which is bounded approximately by the 103rd and 98th meridians at the Texas border and coastline on the South and the 98th and 93rd meridians at the Canadian border on the North, the water resource development groups are extremely competitive. It is in this area that a significant climate change occurs from arid or semiarid in the West except for high mountain areas to subhumid or humid conditions East of the transitional zone. Figures 2 and 3, from DOC 156 Water Resources Council, United States Situation Paper, International Conference on Water for Peace, show the changes effectively. In the same region a division in the soil types of the United States occurs.

Objectives

The purpose of this study is to delineate the physical aspects of the problem and establish technology by which

FIGURE 2

Average Annual Precipitation in United States

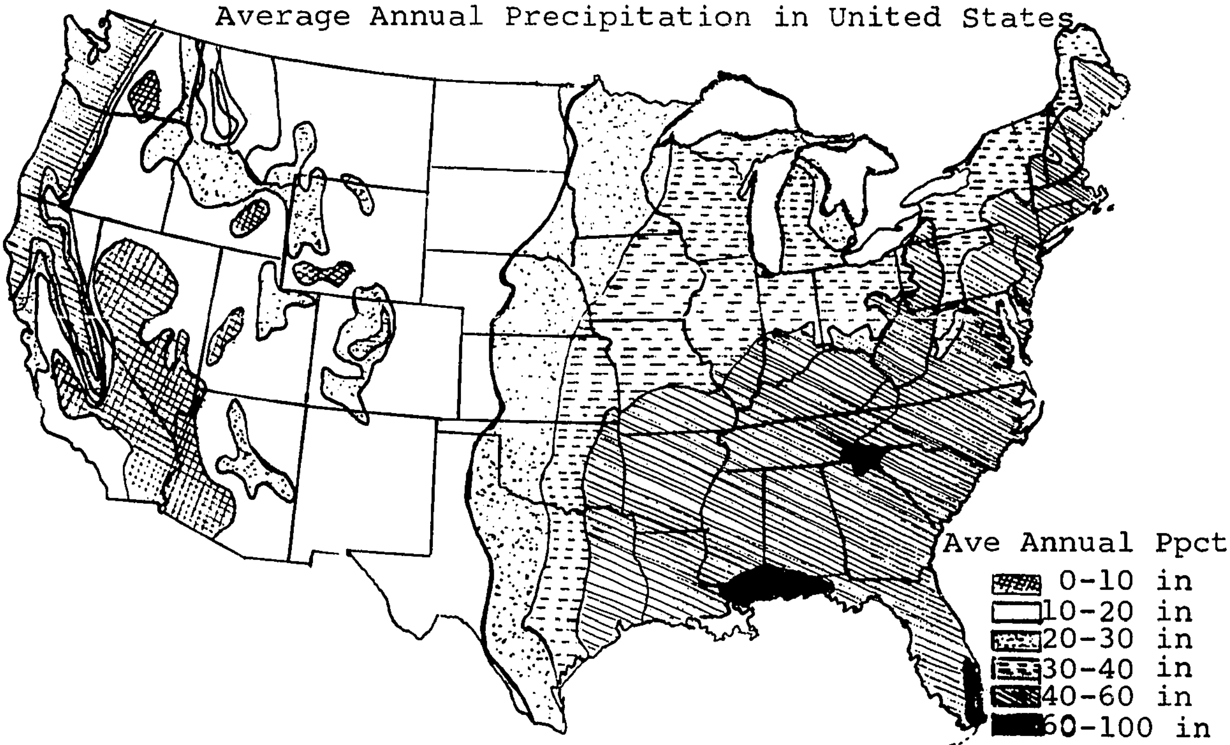
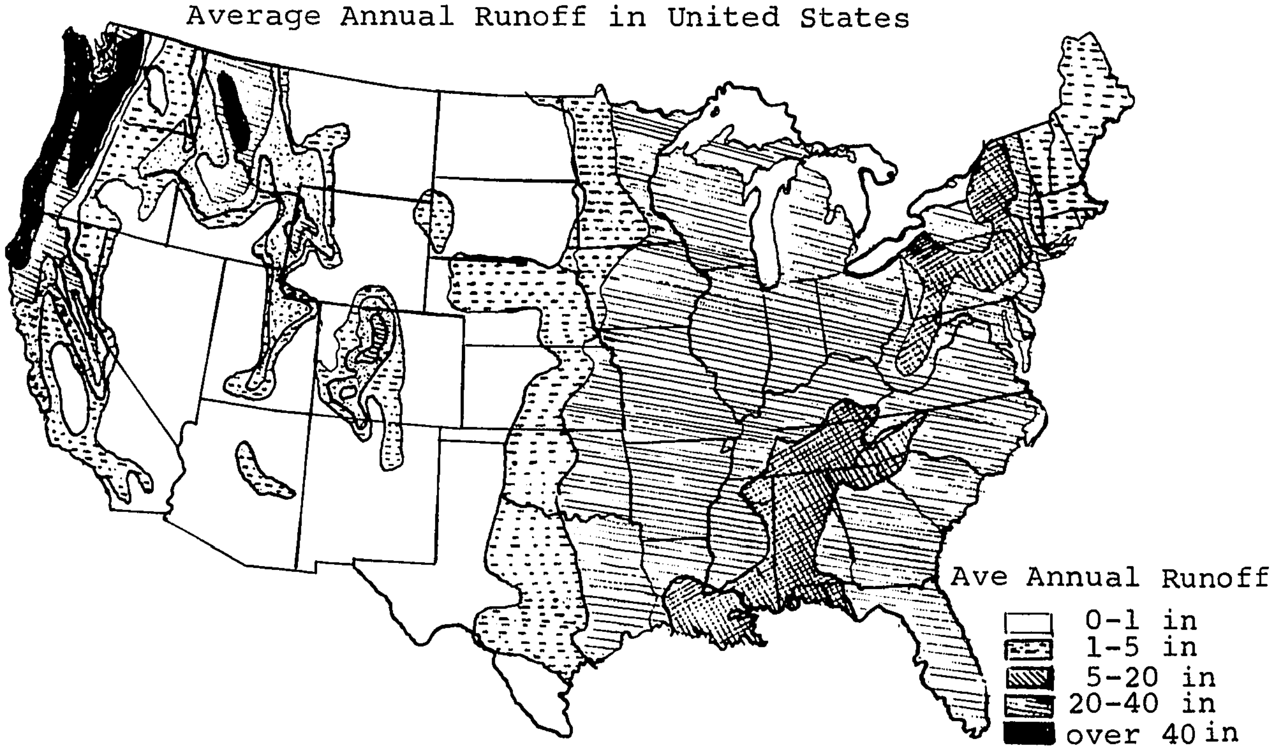


Figure 3

Average Annual Runoff in United States



expected downstream yields can be determined under varying upstream programs and climatic conditions. The study is to determine departures from normal or natural conditions and will not generate predicted flows for specific years.

By application of available data to a mathematical model a means will be provided for predicting runoff depletions caused by future upstream programs. The model is to be simple and the future independent variable values reasonable to estimate so that the model can be readily applied. The general equation form desired is

$$y = \beta_o + \sum_{i=1}^{n} \beta_i x_i.$$

There are limited data at this time; all additional data, as they become available, should be used to refine the model. The variables in the model, however, will remain unchanged. This study will not provide an end to competition for limited water resources. Conflict will continue to exist. Through clarification of the problem and definition of the effects, overdevelopment of programs can be controlled by responsible parties.

Need for Study

The condition which now exists in Foss Reservoir on the Upper Washita River near Foss, Oklahoma,--namely, that of significantly reduced streamflow into the reservoir and a water quality unacceptable to the potential water consumers of the area--is considered adequate justification for the study. A model which will permit the downstream water resource developer to anticipate and evaluate the extent of the streamflow depletion is paramount in preventing an occurrence of the problem now experienced at Foss Reservoir at other locations.

Although a downstream project may be first in time it is still subject to depletion of inflow by development of subsequent upstream program. It is therefore apparent that the problem applies to existing as well as future downstream structures.

The conflict cannot be meaningfully mediated until all aspects of it are clarified. A major step toward this goal will be achieved, it is believed, with the accomplishment of a mathematical model which includes variables whose magnitude can be accurately forecast and describes their interaction. There is of course, a difference between design and management. Design clarification cannot control management but better understanding through better analytical tools can improve management.

General Problem

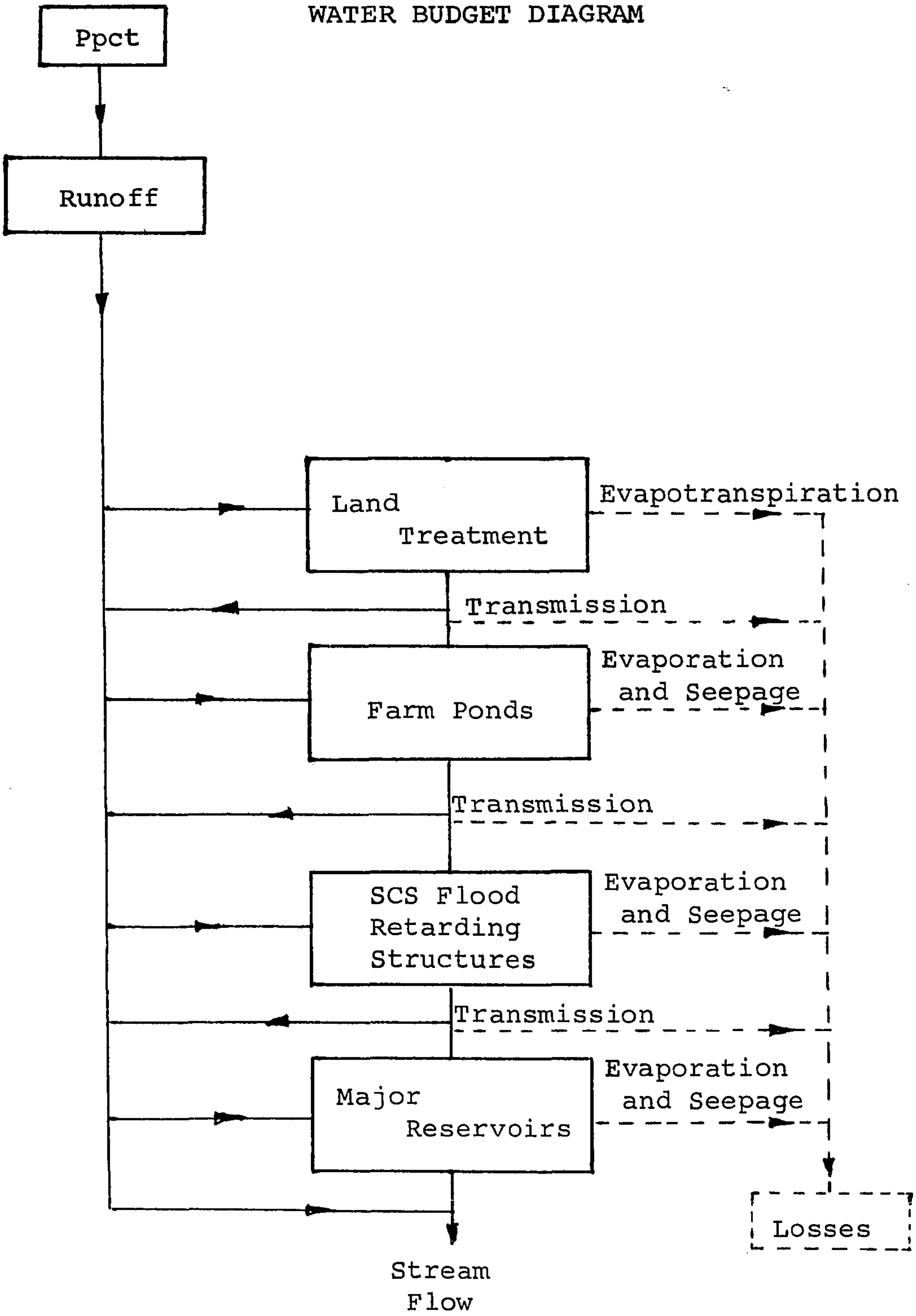
Approximately midway across the United States there is a rather narrow belt, about five degrees longitude in width, across which a major change in precipitation level and run-off takes place. As is shown in Figures 2 and 3, precipitation increases from about twenty to thirty inches in the belt while a corresponding increase in runoff from one to five inches annually occurs.

The area is characterized by high transmission and evapotranspiration losses, and much of the area has geologic conditions that impart high mineralization to runoff. Wide variability in annual precipitation is experienced throughout the belt. Annual precipitation has been as low as 55 per cent of the annual average figure and as high as 135 per cent. The precipitation pattern in this section of the country is also subject to significant fluctuation.

The following water budget diagram, Figure 4, shows the possible routings of precipitation to the stream. It should be noted that most runoff will be affected by land treatments. However, the precentage of runoff going through the full sequence will depend on the degree of development of the other programs (farm ponds and SCS flood retarding structures). Losses occur at each level and also during

FIGURE 4

WATER BUDGET DIAGRAM



transmission from one level to another.

Upstream water resource programs include land treatment measures, farms ponds, and flood retarding structures on tributary streams. The upstream program is supported primarily by the Department of Agriculture, through SCS and Agricultural Stabilization and Conservation Program. The Great Plains Program also provided for similar conservation measures. Although the private land owner does some land treatment work, particularly those practices that have a favorable dollar return and do not need technical supervision, most of the farm pond construction and all flood retarding structure construction is supported by SCS.

Downstream programs are defined herein to be any major impoundment located downstream on a river or major tributary.

McDonald (1) reported that Western Oklahoma was covered with a heavy carpet of grass before 1890 which protected the soil from wind and water erosion, but several factors led to the dust storms which occurred on the Great Plains in the early 1930's. Unlike many areas in the United States most of the territory in question was converted from grass land to cultivated land in a very short period of time. The farmers moving into the area attempted to apply farming practices which they had used in humid and subhumid climates and to raise crops unsuited for the land. Rainfalls above normal in the early 1900's led farmers to anticipate similar rainfalls annually and agriculture expanded rapidly, creating an increased erosion hazard. The first serious erosion was water erosion in 1905-8. In 1908 Western Oklahoma had one of its largest amounts of precipitation with most of it coming in the form of heavy storms in April, May, and June.

Farmers, particularily tenant farmers, were interested in cash crops and not soil conservation measures which would not provide a quick dollar return. Even after early failure of wheat, cotton, and corn crops in the area the shift was to traditional feed crops which could not withstand the drought suffered by the area from 1909 through 1913.

The sandy soil types of the area no longer protected by the heavy sod cover were subject to drifting by the strong winds which are common in the area. The custom of burning off the land before each year's planting decreased the humus content of the soil. Cultivation of the soil with decreased humus content coupled with the drought increased the problem of wind erosion.

Even in many drought periods significant water erosion was caused by the high intensity storms which characterize Western Oklahoma. It is not unusual for the maximum monthly rainfall to be in excess of twenty five per cent of the annual precipitation. One or two storms during the year may also account for as much as twenty per cent of the annual rainfall.

Although some farmers attempted to control erosion the seriousness of the problem increased until the extreme drought conditions of the 1930's resulted in the Dust Bowl. Under the Soil Erosion Act of April 27, 1935, the Secretary of Agriculture was given extensive powers for the protection of land resources against soil erosion and was specifically directed to establish an agency to be known as the Soil Conservation Service. SCS thus became a permanent, Congressionally created agency in the Department of Agriculture and became the successor to the Soil Erosion Service.

The Reclamation Act of 1902 provided authority for Reclamation to work in the 16 Western states, and in 1905 and 1906 the Act was amended to include Texas, thus expanding Reclamation's authority to its present scope. Included in this area is the transitional region between semiarid and semihumid climates, which includes territory in the two Dakotas, Nebraska, Kansas, Oklahoma, and Texas.

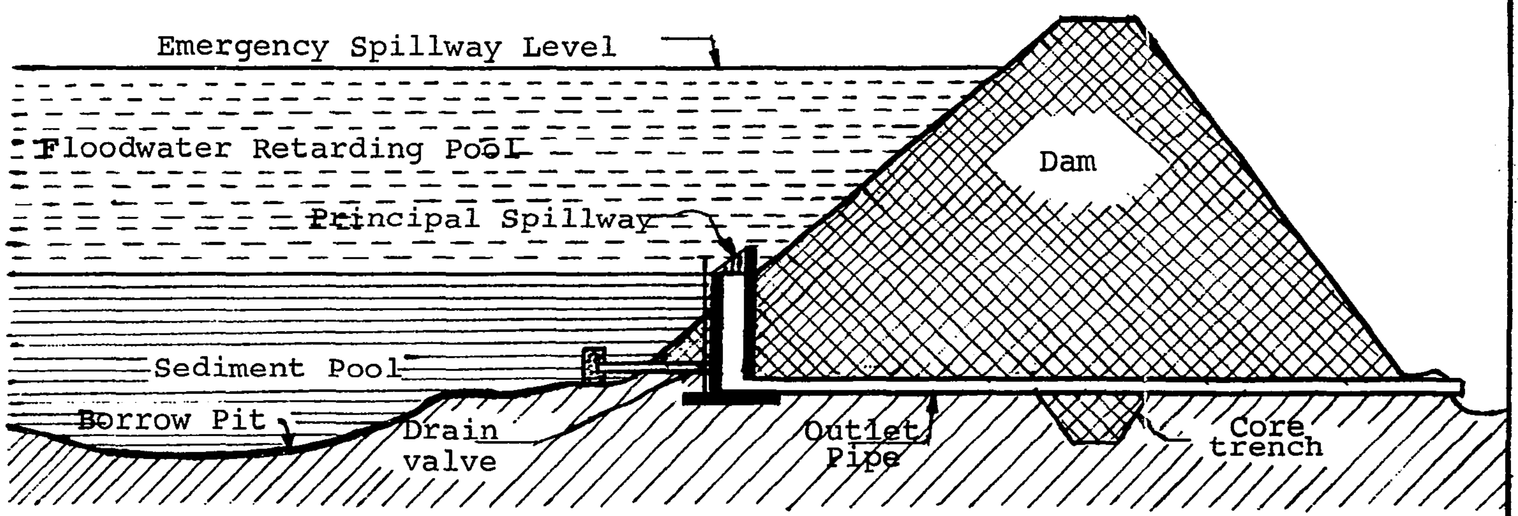
The early program of SCS was mainly land treatment measures (terracing, contour farming, wind breaks, etc.) and small farm ponds for livestock watering. As the SCS program developed, construction of flood retarding structures became an important and prominent agency activity. Much of the SCS program has been within the transitional area. The majority of the existing SCS flood retarding structures have been built since 1960.

The flood retarding structure program in the Upper Washita River Basin is one of the most highly developed and one of the first watersheds affected by the program. The Upper Washita basin will be used as a detailed example in this study.

The Flood Control Act of June 22, 1936, established a national flood control policy and authorized a nationwide program of flood control. The Department of Agriculture was given authority to investigate and improve the watersheds for soil erosion, flood control, and runoff retardation. The 1944 Flood Control Act gave the Department of Agriculture authority to build flood retarding structures and institute a comprehensive erosion prevention plan on eleven watersheds. Figure 5 is a schematic drawing of a typical floodwater retarding structure.

FIGURE 5

TYPICAL FLOODWATER-RETARDING STRUCTURE WITH OUTLET WORKS



CHAPTER II

LITERATURE REVIEW

An appreciable amount of work attempting to evaluate the effects of upstream program on downstream runoff has been done by others. However, the previous studies were generally hindered by the insignificant amount of flood retarding structure construction prior to the late 1950's.

Sharp, Gibbs, and Owen (2) in their development of a procedure for estimating the effects of land and watershed treatments on streamflow, recognized that the partial completion of the flood retarding structure program in most river basins hampered their study. They used data through calendar year 1960.

Sharp, et al. stated that the seemingly ideal statistical model, multiple regression, was not applicable to the data which they had. They conceded that, in general, evidence indicated that conservation measures did affect on-site runoff and further that in drier areas, ponds and flood retarding structures did affect on-site water yield.

Their attempts to find a single equation that would be consistent for all basins in the Great Plains probably failed not only because of the data limitations but also because they were looking at watersheds which extended through climate changes as well as some that were totally within semiarid and subhumid climates.

Their approach to analysis of the problem was with a rational method, breaking the problem into all conceivable, significant components. Data requirements included streamflow, precipitation, evaporation, percolation, land-use and treatment practices, and information on farm ponds and flood retarding reservoirs. In addition the effects of individual land treatments including terraces contour tillage, seeding, irrigation, and drainage, were estimated. The list included only a few of the many land treatments that may be expected to be present in most watersheds but accurate estimation of their future quantity is still most difficult. Estimates, by agricultural experts, as to the effect each of the land treatments had on runoff varied widely, generally from five to fifty per cent, so an average value was used. In addition to estimation of the land treatments, projected data on farm ponds and flood water retarding structures is also required if the method is to be used for determining future depletions. Depletion from the ponds and reservoirs was computed using evaporation data applied to the average water surface area. Quantities for initial filling and saturation of the soil around the structure were also included. When seepage losses were considered significant for a watershed, they were also included. While the method is comprehensive, in that it includes many aspects of the SCS program, the number of projections, estimates, and calculations make the method complex and subject to major error. It is best used for an analysis of what has occurred and not for a method of forecasting effects under different program conditions.

The method provides an estimate of the average effects only and therefore does not provide information on stream flow depletion during drought periods which are most critical. The results from the use of annual data were practically the same as those obtained from the use of storm and monthly data. It appears that the complexity of the problem is such that it does not warrant analysis on a storm or monthly basis.

Oey (3), in a study of data through 1960, concluded that farm ponds did reduce the water yield on the Upper Washita, Clear Boggy, and Black Bear watersheds to a greater degree than did the land treatments he examined. Most of the data used in Oey's work was collected prior to much flood retarding structure construction. However, when flood retarding structures were present he apparently either considered them as farm ponds and grouped them together or disregarded them.

Regardless of which approach he used, most of Oey's results would not have been strongly influenced by flood retarding structures because the Clear Boggy watershed had no structures before 1961 and Black Bear Creek had only about one per cent of the watershed controlled by structures prior to 1960. The Upper Washita did have approximately 15 per cent of the total watershed area controlled by flood reservoirs. Their influence on the Upper Washita may account for the lower correlation coefficient between runoff and precipitation that Oey obtained for the Upper Washita (0.79 as compared to 0.83 for Clear Boggy and 0.92 for Black Bear).

Kennon (4) in a study confined to Sandstone Creek, a tributary of the Upper Washita River, found that 22 flood retarding structures, controlling about 75 per cent of the watershed, reduced streamflow by approximately 19 per cent during the 1959 and 1960 water years. Both years had above normal precipitation (1959 about 116 per cent of the normal annual value and 1960 approximately 130 per cent). Corresponding streamflow reductions were 26 per cent in 1959 and 12 per cent in 1960. Kennon's work was focused at the flood retarding structure program and did not include the collection and analysis of any data on farm ponds and land treatments.

It is considered noteworthy that the per cent streamflow depletion in 1959 was more than twice the 1960 figure although the annual precipitation amounts differed by only 12 per cent. This indicates that the flood structures effect becomes increasingly significant in drier years and that precipitation amount alone is not an adequate hydrologic variable for determining runoff.

Kennon concluded that almost all seepage reappeared as surface flow below the structures. The amount of seepage was about the same as the net evaporation loss for the above normal precipitation years studied.

Bliss' (5), evaluation data from the same watershed for 1953-6 water years, found that about 75 per cent of the inflow to the reservoir was lost. About half of the loss could be accounted for by evaporation, but no measurable seepage was reported as reappearing as streamflow below the structures. The general drought conditions experienced during the period of Bliss' study and the fact that the structures were newer, and therefore subject to initial insoak are possible causes for the disparity between the findings of Bliss and Kennon.

SCS's publication "Effect of Agricultural Programs on Annual Water Yield" (6) studied the Red River Basin by dividing the basin into several sub-basins and segments. The study employed a simplified version of the rational procedure. The effects of land treatments were lumped together but depletions caused by stock ponds and floodwater retarding structures were calculated separately. The study considered drought (70 per cent of average precipitation), average, and wet (130 per cent of average precipitation) conditions.

The key to evaluating the reduction in on-site runoff caused by land treatment measures was a curve developed from field research data relating per cent reduction to annual rainfall, assuming 70 per cent effectiveness and 80 per cent participation. It was assumed that the program would be completed by the year 2000 and a straight line projection was made from the 1958 data point to 100 per cent in 2000.

The only computed depletions for farm ponds and reservoirs was on-site evaporation using average water surface area. For flood retarding structures the sediment pools' average surface area was used with adjustments for sediment fill up. The projection of the flood retarding structure program for the Upper Washita was unrealistic because completion of the program was estimated at 1980 when the program actually was finished in 1964. The depletion figures computed by the study would be less than experienced because of the inaccurate program completion estimate.

The effect of flood retarding structures on the Upper Washita above Cheyenne was computed to be more than twice that of farm ponds and land treatments. The study concluded that, in general, land treatment measures had smaller percentage depletion effects on larger watersheds.

A joint study by Southwestern Power Administration and SCS (7) to determine the possible effects of upstream watershed development on power generation at Denison Hydroplant, Lake Texoma used essentially the same procedure as appeared in SCS's Red River Basin Study (6) cited earlier. The area East of the 95th meridian contributes most of the runoff to Lake Texoma so that the effects of upstream programs would be much less than watersheds further West. Projected reductions for the year 2000 average 6.6 per cent with a 3.7 per cent reduction during the wet years to 14.6 per cent reduction during the driest year.

Culler's (8) study was confined to stock ponds and a few larger reservoirs in the Upper Cheyenne River Basin. The study, covering the period 1951-4, was concerned primarily with the depletions that took place after runoff reached the ponds and reservoirs and not what took place before flow reached them or after it spilled from them. Annual inflow, volume retained, and depletion by seepage and evaporation were computed for a selected sample of farm ponds in the watershed. Estimated losses, associated with the upstream ponds and reservoirs that controlled about 55 per cent of the total watershed, were computed to average 32 per cent of the undepleted runoff that would have reached the gaging station had the upstream reservoirs not been installed. Seepage was computed to be about as large as evaporation losses, but it was pointed out that not all seepage should be considered as a permanent loss since some might reappear as surface runoff. It is considered significant that for the four year period average seepage and evaporation totaled 93 per cent of the runoff retained in the reservoirs; this means that almost all of the water retained in the sediment pools was lost to downstream use.

Texas Water Development Board Reports Numbers 3 (9) and 39 (10) were concerned, in part, with determining the effect of flood retarding structures on downstream streamflow. These studies are for small watersheds with data collected from a number of rain gages, water stage recorder installations and staff gage readings at the structure pools, and stream gaging. For Escondido Creek the structures were found to consume 40 per cent of the surface inflow into them during a year of average annual precipitation. Evaporation again accounted for only about half of the consumption with the other half attributed to seepage and evapotranspiration from around the ponds' pools. The results of the Deep Creek study indicated that average reservoir consumption of inflow from natural runoff was 25 per cent. The following formula was used to determine natural runoff:

$$Q_a = (Q_i - R_p)\left(\frac{A}{A - A_p}\right)$$

where Q_a is natural runoff in acre-feet

Q_i is total inflow as measured in acre-feet

R_p is rainfall on pool in acre-feet

A is drainage area at the site in acres

A_p is mean surface area of pool in acres during rainfall.

Both studies found the structures efficient in trapping sediment and controlling floods. The importance of the precipitation distribution in time and space (referred to as precipitation pattern later in this study) was evident; two years of practically the same rainfall produced runoff which varied by about seven times.

Mr. Monroe Hartman, hydraulic engineer with the Agriculture Research Survey (ARS), testified before the Department of Interior's Consulting Board on Foss Reservoir. Mr. Hartman said that studies conducted by ARS on the Washita River have shown transportation losses as great as one per cent per mile and that typical losses are about 0.1 per cent per mile. He indicated that generally land treatments have only a minor effect on streamflow where transportation losses are high and there are a significant number of upstream structures. He felt that the flood retarding structrues had, by far, the greatest effect on streamflow depletion.

Included in the 1963 Annual Research Report for the Washita River Watershed (11) is a paper titled "Exploratory

Study of the Regimen of Washita River Mainstem Flows" by Donn G. DeCoursey. DeCoursey found that rainfall-runoff relationships for individual watersheds could be developed effectively by combining all climatic factors into a single variable, that included precipitation, precipitation intensity, and an antecedent precipitation index. Using regression analysis he developed separate equations for each watershed, and selected a geologic factor to improve the fit of the data.

CHAPTER III

MODEL REQUIREMENTS

General Model Requirements

One of the principal decisions in the establishment of a mathematical model is determining the variables to be tested in the model. It is desirable to represent the relationship adequately with a minimum number of explanatory variables. Any variables that do not add materially to the significance of the regression should not be included. It is also helpful to keep the prediction equation linear. Discussion of the methodology used in this study is included in Chapter IV. Details of the data collection, preparation and analysis are included in Chapter V.

Care must be exercised to insure that the independent variables in the model actually account for the correlation obtained and that the explanatory variables are not correlated with other unincluded variables which truly account for the relationship. When the explanatory variables in the model are not independent of each other but are interdependent a problem identified as multicollinearity or intercorrelation is encountered. This problem is generally not serious in predictive type models, which is the case under investigation, if the interdependency may reasonably be expected to continue. However, multicollinearity does make determining the contribution of each independent variable ambiguous and even very high coefficients of determination (R^2) may be misleading because of the large resultant errors in the coefficients.

A modified stepwise multiple regression technique was employed and is discussed in detail in Chapter IV. The number of independent variables would be a few as possible and accepted engineering calculations would be used whenever possible to select the independent variables that actually account for the obtained correlation.

Dependent Variable

The dependent or explained variable ($\hat{y}$) in all aternative formulations would be a representation of streamflow data available from gage records. No attempt was made to obtain base flow data since the total flow was considered of interest. Standardized data, streamflow in cubic feet per second (cfs) or acre-feet (ac-ft), and percentage of natural streamflow were investigated to determine the best form for the dependent variable.

Standardization, to eliminate the dimensional aspects of the data, was developed by use of $\frac{\hat{y} - \bar{y}}{\sigma y}$, where y is the observed value, $\bar{y}$ the sample mean, and σy the sample standard deviation. It would of course, be meaningless to standardize the dependent variable without performing similar treatment to all of the independent variables. Any variable put in standardized form using the above equation has zero mean and a unit variance. Although standardization aids in measuring the importance of each independent variable since they all have the same mean and variance, results are difficult to interpret and restandardization is required with the addition of each new sample event since $\bar{y}$ and σy will be changed.

Representation of the dependent variable as a percentage of the natural flow was obtained by dividing the observed value by the mean and multiplying the result by one hundred $\frac{\hat{y}}{\bar{y}}$ x 100. This is obtained by averaging all streamflow data available at the subject gaging station prior to the watershed alteration programs of interest, namely, land treatments, farm ponds, and flood retarding structures in this study. It is assumed that all other factors are either constant or that they do not influence the streamflow gaging appreciably. When it was determined that land treatments and farm ponds, in the example basin studied, did not influence streamflow significantly the period of record for determining the natural flow was extended to include all data prior to the presence of an evident flood retarding structure program. If the length of stream gaging record is considered too short to provide an accurate estimate of the natural mean flow, this method cannot be used directly. A relatively short time period may yield a good estimate of the mean streamflow if the precipitation and precipitation pattern were near normal during the period of record. For most watersheds the precipitation records are of sufficient length to permit the investigator to attain a good estimate of the normal precipitation. Other alternatives are extension of the streamflow record by use of the obtained correlation between precipitation and streamflow or streamflow from another basin with a longer period of record. Extension of the streamflow record is attained in this study by use of a multiple regression equation with precipitation amount and runoff gaged at an adjacent station as independent variables. If the runoff records are of sufficient length and precipitation conditions appear normal over the period, it is advisable to use the arithmetic average of the recorded flows because possible error is eliminated.

Independent Variables

The independent variables selected for investigation were of two general categories, hydrologic and management. Hydrologic variables investigated were precipitation, antecedent precipitation, precipitation excess, precipitation intensity, and evaporation and transmission losses. Management variables are those man-made modifications to the watershed that are considered important in affecting streamflow. The management variables selected were flood retarding structures, farm ponds, and land treatment practices. Variables which would represent a combination of several of the management variables were also selected for trials.

Selection of the independent variables was influenced by coarse screening by professionals in the field and findings of other investigators. It is not the interest of this study to include all variables which affect streamflow but rather to include as few variables as possible and still achieve an acceptable degree of accuracy. Much of the effort went into data collection and preparation and methods of selection of the independent variables which actually accounted for the cause-and-effect relationship and conversely elimination of those variables which did not contribute significantly to the relationship. After only a few trials of various equations on the example basin, a formula was obtained, which withstood all subsequent attempts at improvement.

A relationship between runoff and precipitation amount is a widely used starting point, and it was this relationship that was initially employed in this study. It is reasonable that antecedent conditions, size and shape of the watershed, soil conditions, geology, topography, cultural development, land treatments, and the distribution of precipitation over the time interval studied and over the area are also factors that influence runoff. Some of these factors (size and shape of watershed, soils, geology, topography, and cultural developments) can be considered to be constant for a watershed over a finite time period. It is recognized that while they are considered to be constant during the period studied for a particular watershed, they may vary drastically from watershed to watershed.

Areal distribution of storms, while of some interest, is almost impossible to accurately obtain for any large watershed from available data. Localized thunderstorms predominately cause peak rates of discharge for small watersheds, but as the drainage area increases in size the influence of thunderstorms on peak discharges generally diminishes. Precipitation covering a large portion of the watershed and continuing for a long period causes the major runoff in big watersheds.

Antecedent precipitation, from at least the time period immediately preceding and sometimes several time periods, was also considered for inclusion. If the time basis is selected so that each interval terminates at the period of lowest precipitation and streamflow, so that little runoff results from rainfall in the preceding time intervals, a better correlation can be expected between annual precipitation and runoff. Antecedent precipitation is of interest because of the effect it has on reducing the precipitation necessary to produce runoff. Generally as the time interval is lengthened the importance of antecedent precipitation diminishes. This is because the conditions caused by the antecedent precipitation do not persist over very much of the next time interval.

The distribution of precipitation over the time period is referred to as the precipitation pattern through the remainder of the study. Precipitation excess is defined as the summation of all precipitation over the watershed in excess of the amount necessary to cause runoff. Precipitation excess cannot be exactly determined because not only is the estimated precipitation amount somewhat in error but the precipitation amount necessary to cause runoff varies with the antecedent conditions including air and soil temperatures and the moisture content of the soil. In this study an estimate of the precipitation amount required to cause runoff is made for the watershed. Any more detailed approach would be very difficult to apply.

An approximate method for determining precipitation intensity can be obtained by dividing the annual precipitation amount by the number of days per year precipitation occurred. Generally all variables relating to precipitation are combined into a single equation variable because of their interdependence.

A method of including a generalized form of precipitation pattern in the absence of sufficient data is to consider the pattern to have a few selected values; a normal precipitation pattern for the gaged annual precipitation amount, a precipitation pattern considered favorable to increased runoff, and a precipitation pattern that results in a streamflow less than normally expected from the annual precipitation quantity.

Evaporation and transmission losses were desirable as variables in the model because of their recognized importance in the water budget. Evaporation from the surfaces of flood retarding structures and farm ponds and transmission losses in the tributaries and upstream from the gaging station are obvious sources of streamflow depletion. Data on transmission losses are not available on a routine basis and evaporation data are available for only a few major lakes and a few pan evaporation stations. The conversion of evaporation data from pan to lake is subject to error, as is the conversion of data from a lake in one location to another lake or pond some distance away. Although the use of evaporation data was employed in some previous studies, it is of best use in the inventory or water budget type study. To accurately use evaporation data the investigator must also have the associated surface areas. It was concluded that the inclusion of evaporation and transmission loss data in the model would weaken it.

Evaporation data were used in calculations to make a rough estimate of the effect a change in operation of the flood retarding structures would make on streamflow and to determine what percentage of the depletion could be directly attributed to evaporation.

The management variables were selected because it was their effect that was of primary concern. No previous study had looked at all of the management variables by the method of multiple regression. Available knowledge of hydrology was not abandoned and replaced by statistics. The statistical methods in this study are used as a tool for evaluating relationships that appeared reasonable.

The SCS program is active in three areas, land treatment, farm ponds, and flood retarding structures. Although farm ponds are usually considered as a land treatment practice, they were separated because they were thought to play a more critical role in reducing streamflow. Oey's work (3) indicated a higher negative correlation between numbers of farm ponds and streamflow then between land treatments and streamflow.

SCS data revealed a rather wide variation between the average pond capacities, drainage areas, and surface areas for the counties of Texas and Oklahoma. Within larger watersheds the variation in the ponds' dimensions was also significant. The use of a variable form that would take into consideration the variation in the physical characteristics of the ponds appeared better than equal weighting of ponds, which results from a farm pond count. The use of cumulative capacity, drainage area, or surface area for farm ponds can be combined with flood retarding structure data in a similar form.

Alternative forms for flood retarding structure data were sediment pool capacity or surface area and drainage area. The form selected would be influenced by the resulting multiple regression equations and the predictability of the variable form. A reasonable forecast of the cumulative drainage areas of the flood retarding structures or the area controlled by them in a watershed appeared as if it could be more easily estimated than the cumulative surface area or capacity of all their sediment pools.

Representation of land treatment practices in the model appeared as the most difficult task. The number of practices, about thirty, made it unrealistic to include all or most of them in a model with a limited number of observations. Accumulation of the land treatment data on a watershed basis could be a major undertaking and the reliability of the "on-land" data was questionable. The effect of certain land treatments on runoff is different in watersheds with different soil conditions. Many of the land treatments are interdependent but the degree of the interdependence is variable over time and also different for each watershed. Individual land treatment practice data, would not be included in the model if satisfactory results could be attained without them.

Oey's (3) findings showed that farm ponds caused greater depletions than did land treatments on the three watersheds he studied. It is believed that the effect of land treatments decreases as the watershed size and, the number of farm ponds and flood retarding structures increases. Hartman's testimony mentioned in the literature review supports this viewpoint.

It was felt that the best approach from many aspects, would be the use of one variable that would replace several or possibly all of the management variables. The use of the area controlled by flood retarding structures was one such approach. It is an SCS practice that at least 70 per cent of the drainage area of a proposed flood retarding structure be under basic plan agreement and that land treatments are applied to a minimum of 50 per cent of the drainage area prior to construction of the structure.

Sources of Data

United States Weather Bureau Climatological Records were used as the source for precipitation and evaporation data. Records included daily, monthly, and annual precipitation amounts and monthly pan and lake evaporation measurements.

Streamflow data were obtained from United States Geologic Survey (USGS) Records of Surface Flow. Drainage areas and gage station locations were also determined from the USGS records.

Land treatment practices and farm pond data were obtained from SCS work sheets and summary reports. Information on estimated farm pond drainage area, surface area, and capacity was provided by the respective State SCS offices from data collected from a sample survey of ponds.

Flood retarding structure data were obtained from SCS basin development and construction record documents made available by the SCS state offices.

Observation Groupings

After review of the findings of Sharp, et. al. (2), and the general form of available data, it was decided that the observation groupings initially would be on an annual basis. Since Sharp, et. al. had obtained similar results using yearly, monthly, and storm data, the use of annual data was not considered as a sacrifice in accuracy and was desirable from a standpoint of simplicity.

Data for farm ponds and land treatments were available on a calendar year basis prior to 1958 and on a fiscal year basis after that date. Runoff data were available on a calendar and water year basis as well as a monthly and daily basis. Rainfall records were available for the calendar year, month, and day. The flood retarding structures' completion dates were given to the day. However, this completion date may not actually represent the date the sediment pool started to collect runoff.

An analysis of runoff and rainfall records for several Oklahoma river basins for the period 1950-66 (the general period of interest) revealed that streamflows during the month of January averaged less than October and that the average precipitation was less in December than September. These results indicate that carryover runoff, (runoff caused by rainfall occurring in the preceding time period), would be less using calendar year data than water year data. Calendar year data were therefore selected for the original analyses.

Time Frame

The critical variable in establishment of the time frame for a basin will be, in almost all cases, the period of the flood retarding structure program. All included variables should have values throughout the time frame. The flood retarding structure program was evident on only a pilot basis prior to the passage of the Watershed Protection and Flood Prevention Act (Public Law 566) in 1954. Public Law 566 made it possible for soil conservation districts, watershed districts, counties, towns, or states to receive Federal technical and financial assistance for flood-prevention and related water-management purposes on watersheds less than 250,000 acres in total area. In some basins a pilot program on one or two tributaries was completed in the early 1950's after which there was no additional construction until the early 1960's. The majority of the flood retarding structure program is still incomplete and in many basins only a small percentage of the planned work has been completed.

Although it is desirable from a sample size standpoint to have as many observations as possible, it was arbitrarily decided that the flood retarding structure program would not be considered as evident until at least one per cent of the watershed was under control of the program. Any model using flood retarding structures as a variable was therefore restricted to data covering only about 10 years on the average.

Limitations of Data

Precipitation Data

Records at precipitation gaging stations are generally available for a period longer than that of any other variable considered for inclusion in the model. Certain limitations are inherent in any long period of record. Precipitation stations in almost all basins have been relocated during the record period. It is also not unusual to find precipitation records missing for a few days or even several months at several stations in a watershed. Some of the data are reported as estimated amounts from a nearby station. On almost all watersheds except those especially equipped with additional gages for specific studies, the number of precipitation gages is inadequate to provide data on the precipitation pattern on an annual basis for the entire watershed.

Streamflow Data

Because of the limited number of gages, the streamflow gage dictates the exact watershed area the investigator must use. Frequently the gage location includes an area different from the ideal area the investigator would select.

The accuracy of results during floods and very low flows is subject to great error. This becomes critical in many rivers in the plains region because they frequently experience floods and periods of low flow. The variability in annual flows is very great in the study area (a factor of 50 times for many of the rivers).

Farm Pond Data

Data for both farm ponds and land treatment practices are available on a SCS work unit basis. The SCS work unit frequently coincides with a county area. However, a few counties are subdivided into more than one work unit. It is unlikely that a watershed includes only complete county or work unit areas, since neither was established on a basin concept. It is therefore necessary to make an assumption as to the distribution of farm ponds and land treatments within these work units partially within the watershed. The simplest procedure is to assume a uniform distribution but such a distribution may be very inaccurate. A work unit which includes a major river channel would be more likely to have a nonuniform distribution of practices because of the difference in land uses.

Physical data on the farm ponds were obtained from a sampling program conducted by SCS. No census has been conducted on farm ponds' physical data. Since no records are maintained on the ponds' water level, data on the surface area of the ponds throughout a time period are not available. There is no separation, in the work unit data sheets, between construction of new ponds and those which are replacing ponds previously built under the program and filled with sediment. Some ponds are subject to heavy sediment loads and over the 21 years of record some of the older ponds have definitely been filled. A cumulative total of ponds, not taking into consideration any replacements, would be expected to give a slightly inflated value.

Land Treatment Practice Data

In addition to the limitations that land treatment and farm pond data have in common land treatment practice data have numerous other limitations.

Some land treatment practices are effective for only one year while others are semi-permanent. Deferred grazing and stubble mulching are examples of practices that have only an annual effectiveness. The effect of terracing and pasture seeding carry over for several years. Since those practices which are recognized as having carry over effects do not have an indefinite effectiveness a procedure for phasing out their effectiveness with time should be established.

Separation of all practices, out of the data, is not possible because of changes in classification of practices and groupings of practices. Examples of this occurred in pasture and range seeding and use and crop residue use. Differences in recording procedures between SCS work unit field men is also a source of possible variation in data.

Prior to 1959 in Oklahoma "on-land" estimates of land treatments were not recorded and only data for treatments on which SCS provided technical assistance were available. There was also a change in the reporting period from calendar year to fiscal year in 1958.

Evaporation Data

Evaporation data are available from only a few stations and the records are usually not complete because freezing interfers with readings in winter months.

Although methods are available for calculating evaporation rates the methods require extensive climatological data much of which is not available throughout many watersheds.

Flood Retarding Structure Data

Available flood retarding structure physical data provides designed data and not "as built" measurements. Reportedly these differences are usually small. The date reported as the completion date is somewhat ambiguous and does not coincide with the date collection of water in the sediment pool began.

No data are available on the amount of water in the structures or the inflow and outflow.

The sediment storage capacity for the structures generally has a 50 year design, however, in recent years a 100 year design has been used on a few SCS sediment pools. The initial location of the principal spillway is still placed at the 50 year sediment capacity with relocation of the spillway proposed after the sediment pool becomes nearly full. Texas, however, limits sediment pools of the structures to 200 ac.-ft. unless a special water permit is requested and granted.

Design of the sediment pools is accomplished by use of the SCS's "Guide to Sedimentation Investigations" (12). SCS takes into consideration the anticipated effects of land treatment practices, that will occur within the watershed. (One of the principal benefits claimed for the flood retarding structure program has been the structures effectiveness at reducing sediment loads downstream). Sediment studies in the Upper Washita River basin indicate that the sediment pools are filling at a slower rate than that for which they were designed, but sediment data are not available for each structure. Several years of below normal precipitation could account for the reduced sediment loads.

Data Adjustments

Precipitation Data

Use of the Thiessen (13), arithmetic mean, and isohyetal methods are possible methods of determining annual areal precipitation from any station network within and/or adjoining a watershed. For larger watersheds, particularily when they include mountainous country or a transition in climate, the arithmetic mean method is generally not desirable. The Thiessen Method, which assumes that the precipitation amount at a station applies halfway to the next station in all directions, was selected as the method of choice when there was an appreciable difference in the annual data at the watershed precipitation gaging stations.

Farm Ponds and Land Treatments

A uniform distribution of farm ponds and land treatment practices was assumed to exist throughout the SCS work unit. The amounts of practices and ponds in a work unit partially within a watershed were obtained by applying the percentage of the SCS work unit in the watershed to work unit total figures. This was accomplished by obtaining maps with the watershed areas and SCS work unit boundaries on them from SCS. The selected streamflow gaging stations were then located on the maps by the use of the stations coordinates, furnished from USGS records. The area within the watershed of each SCS work unit was planimetered from the map and the percentage of the work unit within the watershed calculated.

No consistent relationship was apparent between "on-land" treatment data and SCS technical support data. SCS maintains records on a work unit basis compiled from the daily work logs of their field men. The work record for each SCS work unit was reported on Form SCS-195 through June 30, 1961. This form includes a record of the amount of the practices established during the reporting period with SCS technical support, the amount planned, the technicians man-hour record, and narrative comments on the conservation activities. In 1962, Forms 253 and 99 were established. In these reports, "on-land" estimates (this includes land treatments accomplished with and without SCS cooperation) are presented. After 1962 data are also available on a watershed basis but it appears to have been initially obtained by assuming a uniform distribution of the practices throughout the work unit. Also, although data are available on a watershed basis these data cannot be applied directly to a watershed area associated with a USGS gage. In making the "on-land" estimate the technician takes into consideration previous estimates and makes an assessment of the treatment practices applied within his work unit during the reporting period. No formal census or sampling program is conducted to determine "on-land" treatments. Data, therefore, are dependent on the technicians familiarity with activities in his work unit as well as his ability to accurately estimate the quantities of practices applied. The data on practices receiving SCS technical support would be expected to be much more accurate than the "on-land" estimates.

Figures 6 through 10 show plots of both "on-land" and SCS data for selected land treatments for the Cheyenne Work Unit. These data are considered typical. It was concluded that the use of SCS technical supported practices to obtain estimates of "on-land" treatment would yield poor estimates. Since no "on-land" data are available prior to 1959 the problem could not be resolved.

Flood Retarding Structures

The only adjustment necessary for the structure data was handling structures that were completed near the end of a year and the problem of initial filling of the sediment pools. Since most of the annual runoff occurs prior to September all structures with completion dates later than October 1, were considered as not being completed until the next calendar year. This adjustment also takes into consideration that the SCS reported completion date in most cases actually was earlier than the date the structure's sediment pool gate was closed and collection of water started. After the SCS completes the structure it is turned

FIGURE 6

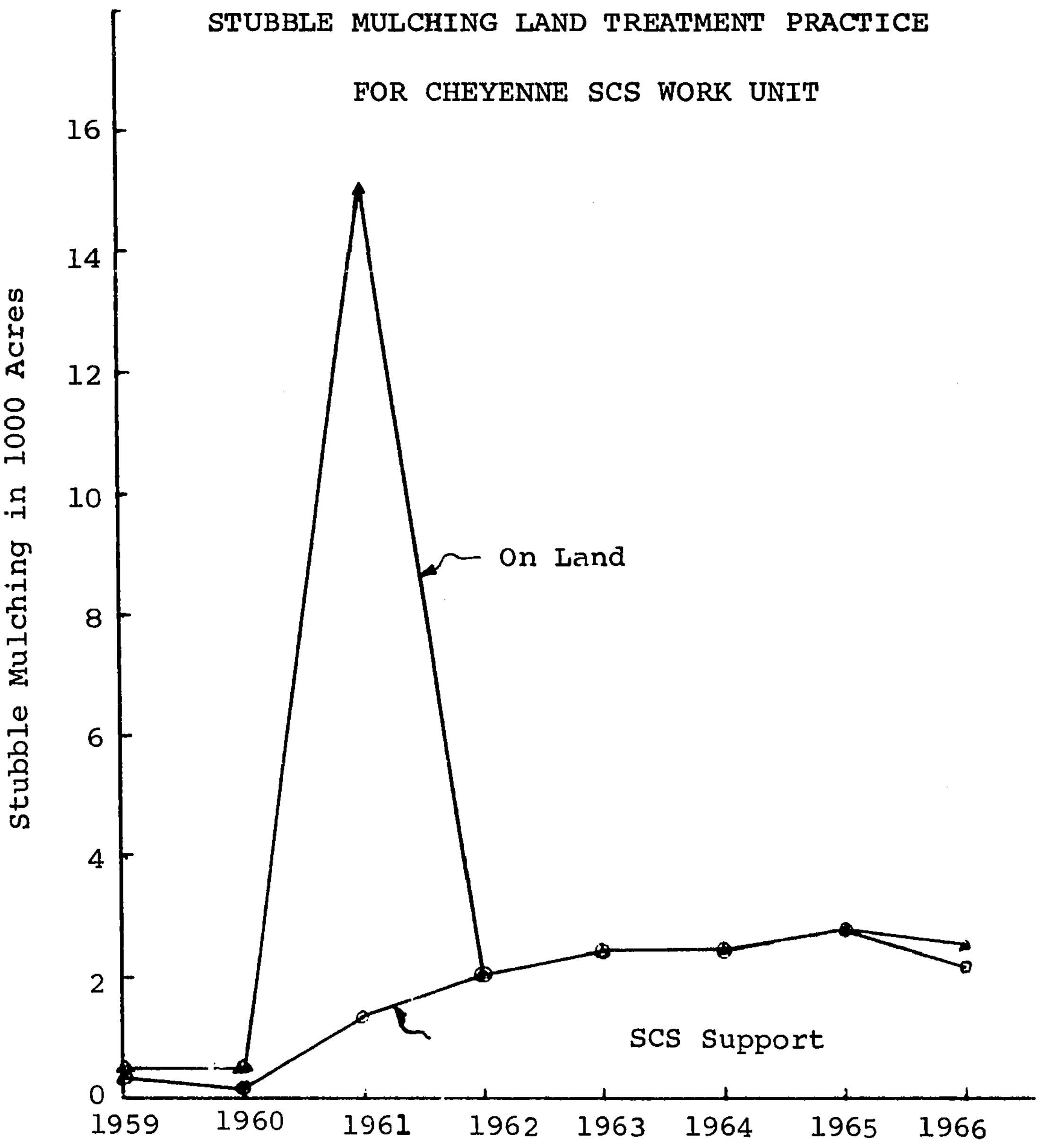

STUBBLE MULCHING LAND TREATMENT PRACTICE
FOR CHEYENNE SCS WORK UNIT
Stubble Mulching in 1000 Acres
16
14
12
10
8
6
4
2
0
On Land
SCS Support
1959
1960
1961
1962
1963
1964
1965
1966

FIGURE 7

RANGE SEEDING LAND TREATMENT PRACTICE

FOR CHEYENNE SCS WORK UNIT

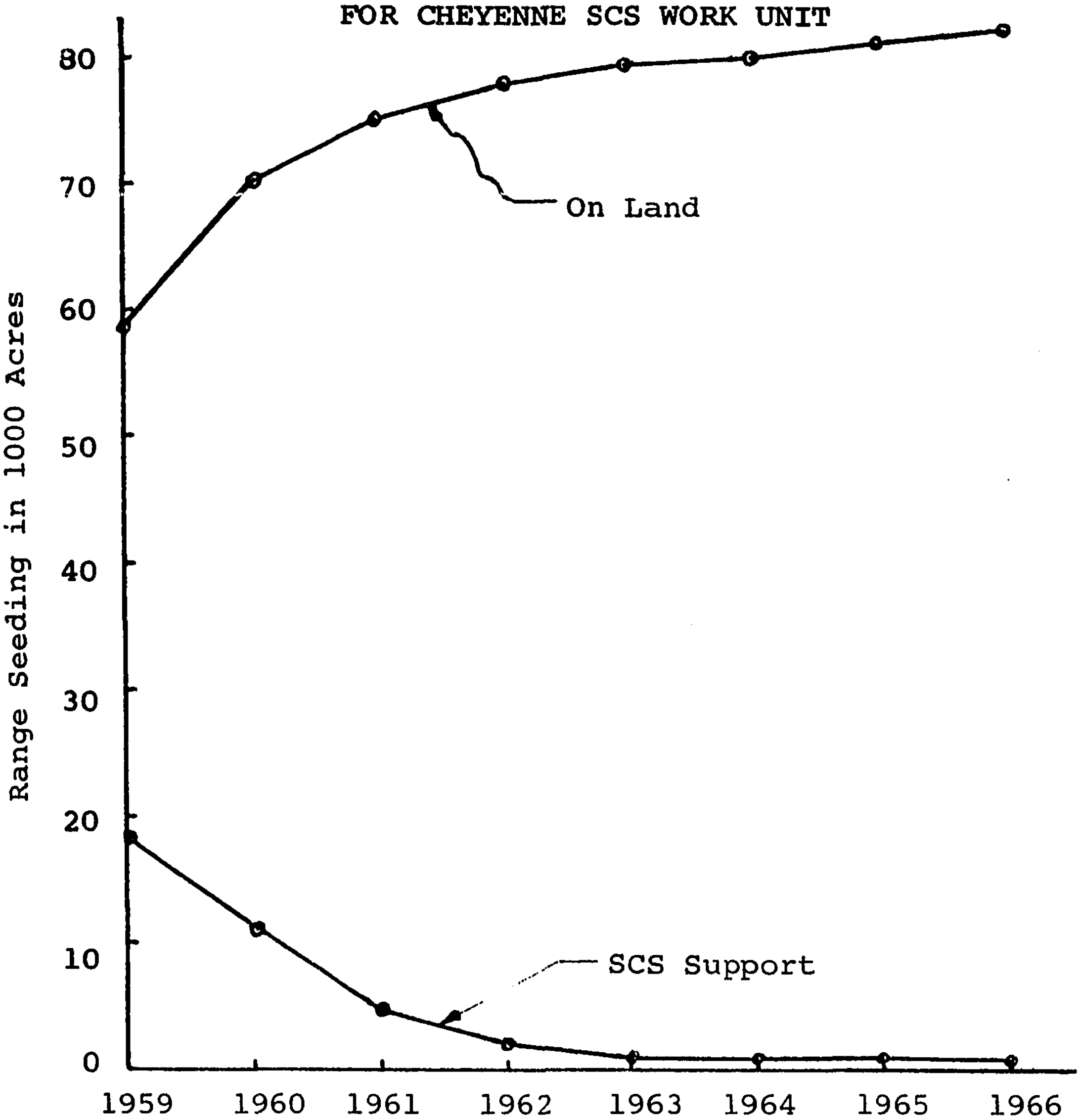


FIGURE 8

RANGE PROPER USE LAND TREATMENT PRACTICE

FOR CHEYENNE SCS WORK UNIT

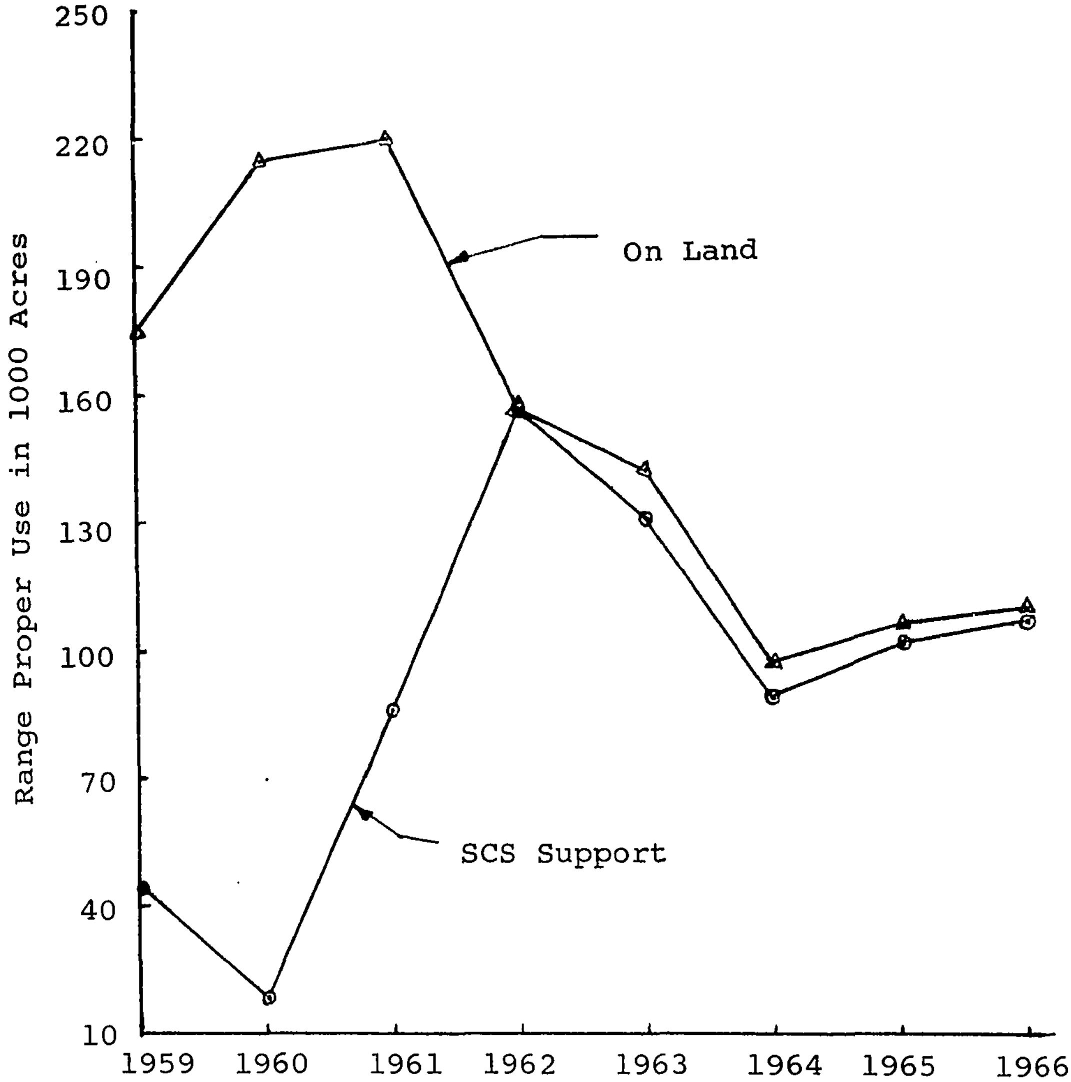


FIGURE 9

COVER CROPPING LAND TREATMENT PRACTICE

FOR CHEYENNE SCS WORK UNIT

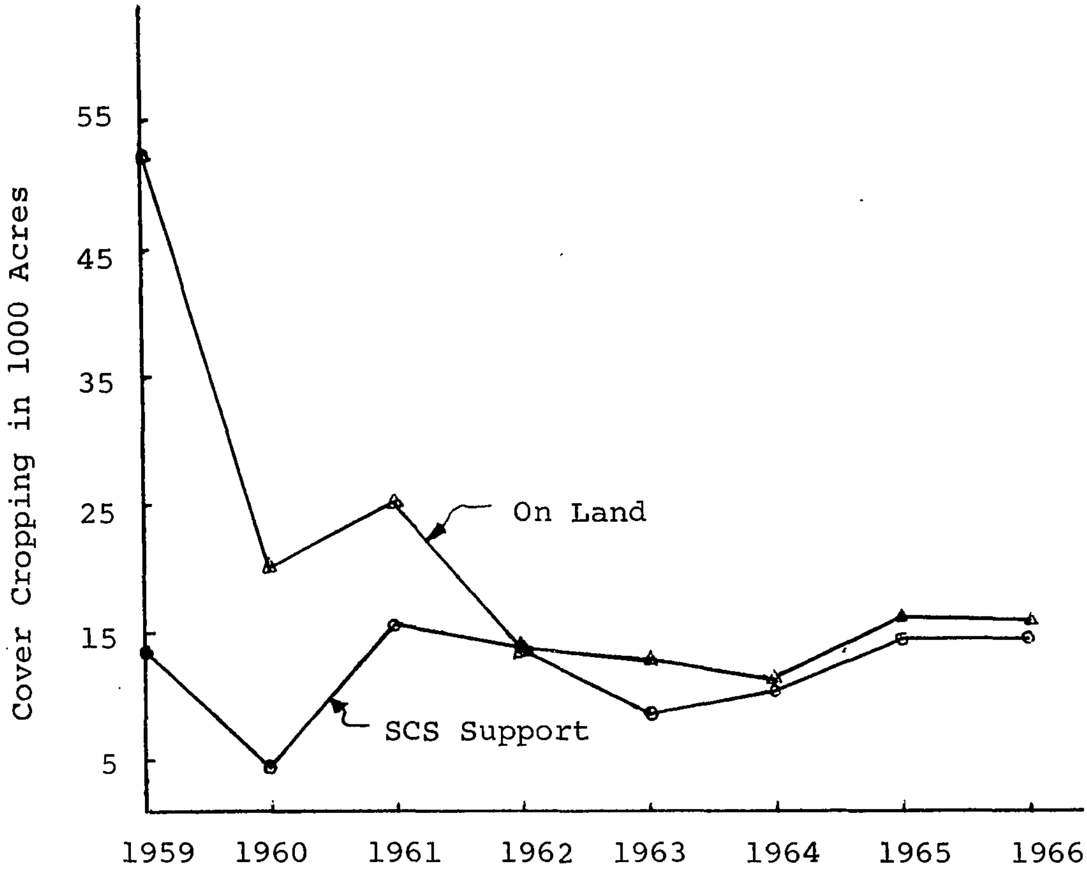
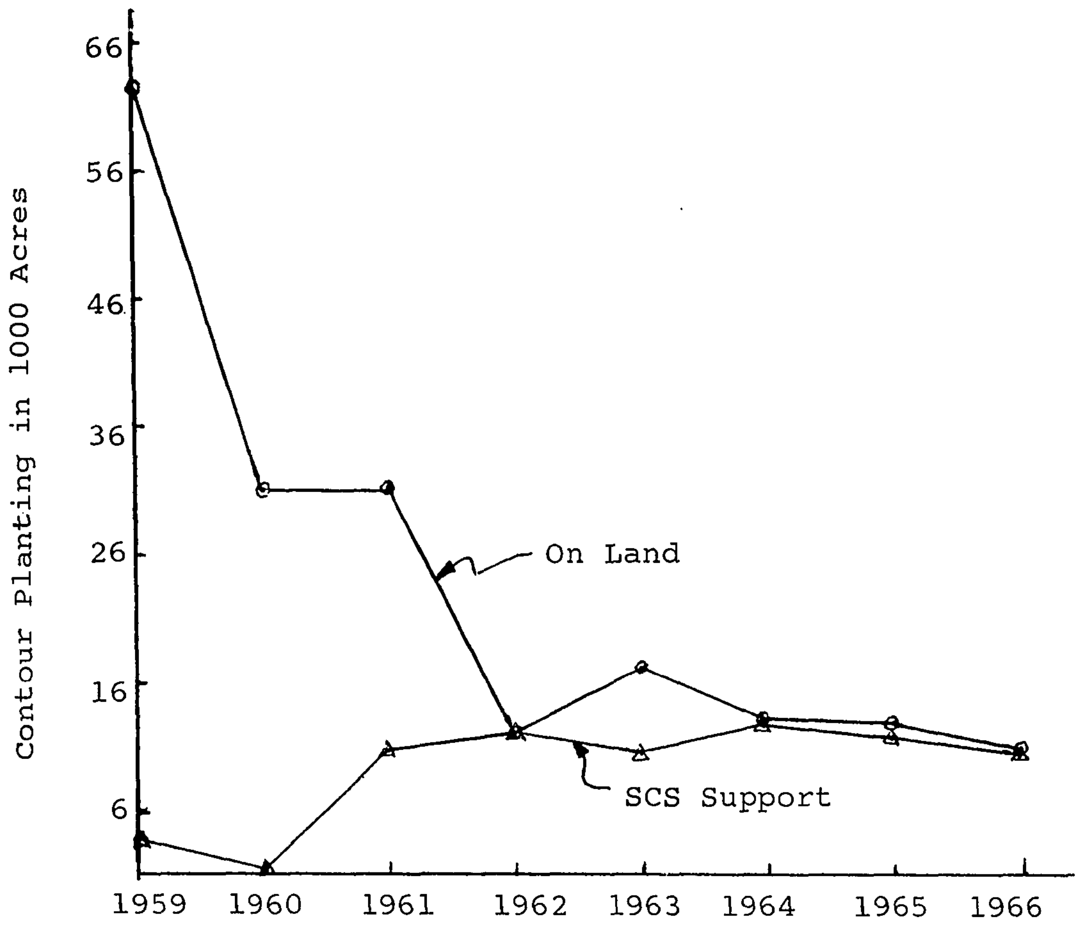


FIGURE 10

CONTOUR PLANTING LAND TREATMENT PRACTICE

FOR CHEYENNE SCS WORK UNIT



over to the local district which conducts inspections and turns over operation of the structure to the farmer.

Although initial filling of the sediment pool appears to be a large amount of water it is not believed to exceed the evaporation and seepage losses during a typical year. In one approach it was decided that the initial fill concept would be compensated for by not considering the structures as being completed until they were first estimated to be filled.

The problem of the sediment storage capacity reducing with time, as it filled with sediment was also considered. This is more of a management or operation problem it is thought. As the sediment pools become filled the farmer will demand and most likely be given storage capactiy similar to the initial design figure. The presence of 100 year design sediment pools with the initial location of the primary spillway at the 50 year level is a move toward this end. However, a measure could be included to compensate for the reduction in permanent water storage due to filling of the sediment storage.

Streamflow

No adjustments were made to the streamflow data. The observed downstream runoff was assumed to reflect the changing upstream conditions. In the regression equation decreases in expected runoff from an annual precipitation amount and pattern were explained by the associated increases in the upstream water resources program.

CHAPTER IV

METHODOLOGY

This chapter discusses the selection, employment, and justification of the engineering procedures and statistical techniques.

Engineering Procedures

Double-Mass Curves

The double-mass curve is a plot of one cumulative variable versus another over the same time period. If the data are proportional throughout the time period the plot will be a straight line and the slope of the line indicates the constant of proportionality between the variables.

A significant break in the double-mass plot reflects a change in the proportionality, assuming a constant relationship had previously existed. The double-mass plot in this study was used to detect any such change and was not used in a quantitive sense. The relationship between runoff and precipitation as mentioned earlier is affected by many variables even when the same watershed is studied over time.

Geological Survey Water-Supply Paper 1541-B (14) cautions that the relationship between precipitation and runoff does not follow the double-mass assumption. The paper therefore recommends the following procedure, which was used. For the complete period of available record, the observed runoff and annual precipitation are ranked, starting with the largest values of each as number one and progressing through all the data. The difference in rank between precipitation and the runoff for each event is squared and the total sum of squares obtained. Then trials are made, using an annual effective precipitation which is made up of an arbitrary proportion of the preceding year's precipitation and the current year's precipitation. The combined proportions must equal unity. A ranking of the calculated effective precipitation is made and the sum of squares between the rank of effective precipitation and runoff calculated. The trial with the smallest sum of squares is selected. Using least-squares on the annual runoff and effective precipitation data an equation, $Y = a + bx$, is obtained where Y is runoff and x is effective precipitation. Finally, a double-mass plot of cumulative computed runoff, obtained from an equation of the above form, versus cumulative observed runoff is plotted.

The F-test can be used to determine if a break in the curve can be attributed to chance or a change in the precipitation-runoff relationship. Another method used to determine if there has been a change in the precipitation runoff relationship for a particular watershed is by comparison of double-mass curves, over the same time period, for two watersheds that are similar in size and located in the same general precipitation region.

Thiessen Polygon Method

The Thiessen Polygon Method (13) is used for determining average amount of precipitation over an area. All rain gages in and near the watershed are located on a map and straight lines are drawn between each station and all adjacent stations. Polygons are formed by the extension of perpendicular bisectors of the lines drawn between stations. The method thus assumes that the precipitation amount observed at a station applies over the polygon area. The area of each polygon in the watershed in planimetered and the percentage of the total area computed. The weighted precipitation for each polygon is obtained by multiplying the observed precipitation by the respective percentage of the total area associated with the polygon.

When a watershed is large and covers an area in which the precipitation values vary from one section to another, particularly through a climate transition, the use of the Thiessen Method is advisable. If the precipitation stations are more numerous in one sub-area than in another, as is the case of the Upper Washita River watershed the use of a numerical average will not be representative of the areal precipitation.

Statistical Methodology

Correlation Coefficients

The correlation coefficient between two random variables, x and y, with a joint distribution is defined as:

$$r = \frac{\text{covariance }(x,y)}{\left[\text{var }(x),\ \text{var }(y)\right]^{\frac{1}{2}}} \qquad (1)$$

The range of values of the correlation coefficient is from -1 to +1. A non-zero simple correlation coefficient implies that there is an association between the observed values of two variables and does not imply that there is a relationship between the two variables. Although independent variables are uncorrelated, that is, their correlation coefficient is zero, a correlation coefficient of zero can exist between variables that are independent. This occurs because only the linear relationship is explained by the correlation coefficient.

Correlation coefficients were used as one of the screening procedures to select those variables which appeared to explain the magnitude of the dependent variable, runoff. Correlation coefficients were also used to determine which independent variables had a high association between their respective values and therefore the use of either variable in the regression equation would yield a similar regression equation in terms of parameters.

When all aspects of the SCS program (flood retarding structures, farm ponds, and land treatment practices) are present in a watershed the elements of a correlation coefficient matrix for cumulative data over time will tend to have positive values near unity because all aspects of the program, with the exception of a few land treatment practices, have increasing values.

Since the general pattern of length of record, arranged in decreasing order, is precipitation, runoff, land treatments and farm ponds, and flood retarding structures, separate analyses can be computed at each stage of additional data availability. Calculation of correlation coefficients at each stage provides some insight into determining which variables best explain the changes in runoff, which variables may only appear to explain the changes because of a high correlation with a variable that actually explains the relationship, and which variables appear not to be an important factor in influencing runoff.

When dealing with more than two variables at a time the partial correlation coefficient can be used to measure the linearity between observations of two variables with all others held constant. The partial correlation coefficient is useful in that it removes the influence of the other variables. Using simple correlation coefficients two variables may be correlated because of a common relationship with another variable and not a relationship between each other.

Expressed in terms of simple correlation coefficients the partial correlation coefficient of x_1 and x_2 with x_3 held constant is defined as follows:

$$r_{12\cdot3} = r_{21\cdot3} = \frac{r_{12} - r_{13}r_{23}}{\left[(1-r_{13}^2)(1-r_{23}^2)\right]^{\frac{1}{2}}} \qquad (2)$$

The order of the subscripts to the left of the period in partial coefficients is arbitrary ($r_{12\cdot3}$ and $r_{21\cdot3}$ have the same meaning).

Multiple Regression

The problem of best-fitting a hyper plane to a set of joint observations on a dependent variable which is a linear function of several independent variables can be accomplished by the least-squares principle. For any linear model, least squares minimizes the residual sum of squares and provides an unbiased, linear estimate with minimum variance of the parameters.

The use of matrices is convenient since the computations increase tremendously as the number of variables and observations increase. The use of a digital computer is essential if investigation of many possible predictive equations is desirable.

Suppose $\mathbf{Y}$ to be a n by 1 vector of observations of a dependent variable, $\mathbf{X}$ to be a n by (p + 1) matrix of independent variables which explains the dependent variable's value, β to be a (p + 1) by 1 vector of unknown parameters to be estimated and ϵ to be a n by 1 vector of residuals. The intercept term, β_0, dictates that each of the elements of the first column of the matrix $\mathbf{X}$, $[x_{10}, x_{20}, \ldots, x_{no}]'$, equal one. Matrices representing a sample of n sets of observations on y and (p values of x) are:

$$Y = \begin{bmatrix} y_1 \\ y_2 \\ \cdot \\ \cdot \\ \cdot \\ y_n \end{bmatrix} \quad X = \begin{bmatrix} x_{10} x_{11} \cdot \cdot \cdot x_{1p} \\ x_{20} x_{21} \cdot \cdot \cdot x_{2p} \\ \cdot \quad \cdot \quad \cdot \\ \cdot \quad \cdot \quad \cdot \\ \cdot \quad \cdot \quad \cdot \\ x_{n0} x_{n1} \cdot \cdot \cdot x_{np} \end{bmatrix} \quad \beta = \begin{bmatrix} \beta_o \\ \beta_1 \\ \cdot \\ \cdot \\ \cdot \\ \beta_p \end{bmatrix} \quad \epsilon = \begin{bmatrix} e_1 \\ e_2 \\ \cdot \\ \cdot \\ \cdot \\ e_n \end{bmatrix}$$

Matrix formulation of the observations is

$$\mathbf{Y} = \mathbf{X}\beta + \epsilon$$

The least-squares hyperplane minimizes the sum of the squared residuals $\epsilon'\epsilon$ in matrix form or $\sum_{i=1}^{n} e_i^2$.

where

$$\begin{aligned} \epsilon'\epsilon &= (\mathbf{Y}-\mathbf{X}\beta)'(\mathbf{Y}-\mathbf{X}\beta) \\ &= \mathbf{Y}'\mathbf{Y} - 2\beta'\mathbf{X}\mathbf{Y} + \beta'\mathbf{X}'\mathbf{X}\beta \end{aligned} \qquad (3)$$

The least-squares estimate of β is b, which when substituted in the above equation minimizes $\epsilon'\epsilon$. Differentiating and setting the resultant matrix equation equal to zero provides the normal equation.

$$(\mathbf{X}'\mathbf{X})b = \mathbf{X}'\mathbf{Y} \qquad (4)$$

A detailed discussion of the method of least-squares is available in many texts.

A modified stepwise regression procedure was employed. Typical stepwise regression uses a simple correlation matrix for the selection of the first independent variable, choosing the independent variable with the largest absolute value correlation coefficient with the dependent variable. The selection of subsequent variables in the typical stepwise regression is made by the selecting from the independent variables the variable having the highest partial correlation coefficient with the response. The decision of acceptance or rejection of each newly added variable is based on the results of an overall and a partial F-test. Then stepwise regression examines the contribution the previously added variables would have made if the newly added variable had been entered first. A variable once accepted into the regression equation may later be rejected by this method.

The only modification made to the typical stepwise regression procedure was that the variable's order of entry was determined by the results of screening procedures and studies by others and not a correlation matrix alone.

Selection of Best Equation

The square of the multiple correlation coefficient or the coefficient of multiple determination (R^2), the ratio of the sum of squares due to the regression to the total sum of squares, is one possible criterion for selection of the best equation. However, the importance of an R^2 close to unity, its maximum value, can be misleading. This is particularly the case when only a small number of observations are used because the increase in the number of variables may have more of an influence on the accompanying increase in R^2 than the related explanation contributed by the variables. The addition of another variable to a regression equation will never decrease R^2 because the regression sum of squares will either increase or remain the same and the total sum of squares will remain unchanged.

Draper and Smith (15) point out that if a set of observations on a dependent variable has only four different values a four-parameter model will provide a perfect fit. Since this study has only ten or eleven years of record available (this corresponds to 10 or 11 observations when annual data are used), large R^2 values must not be over emphasized.

One procedure which takes into consideration the number of observations and the number of parameters is the corrected coefficient of determination ($\bar{R}^2$) defined by Goldberger (16) as $\bar{R}^2 = R^2 - \left(\frac{K}{T-K-1}\right)(1-R^2)$ where R^2 is the coefficient of determination, K is the number of variables, and T is the number of observations. The degrees of freedom, it should be noted, is T-K-1. The corrected coefficient of determination does not always increase with the addition of a new variable to the regression equation. One of the techniques used to evaluate alternative equations was the corrected coefficient of determination.

The standard error of estimate, defined as the square root of the residual mean square, has incorporated into it consideration of the degrees of freedom of the residual and, therefore, is also a usable indices for evaluating alternative regression equations.

The simple F-test, a ratio of the regression mean square to the residual mean square, is not necessarily a measure of the equation's usefulness as a predictor. A significant F-value means only that the regression coefficients explain more of the variation in the data than would be expected by chance, under similar conditions, a specified percentage of the time. So it must also be used cautiously. It should be further noted that use of the

F-test requires that the residuals are normally distributed. Normal distribution of hydrologic data cannot be arbitrarily assumed to exist. Normal distribution is not required for regression analysis.

The sequential F-test was used to determine if the addition of a new variable into the regression equation explained more of the variation than would be expected by chance. A ten per cent level of significance was used. The sequential or partial F-test as it is sometimes called is the ratio of the regression sum of squares explained by the addition of the new variable divided by the residual mean square.

Examination of Residuals

Residual refers to the difference between the observed and regression equation value of the dependent variable. A review of the basic assumptions made about the residuals when using least-squares regression analysis indicates that they are independent, have a constant variance and zero mean and if an F-test is used that they follow a normal distribution. Examination of the residuals therefore should be directed to verifying the assumptions. For time series observations a plot of the residuals by time order is used to give an indication of any change in variance with time.

Another test for time sequence data is examination of the pattern of the residuals' signs to determine if the observed arrangement is statistically unusual. The number of runs test accomplishes this. Since the number of observations was for the most part not of sufficient size to be approximated by a normal distribution the actual cumulative distribution of the total number of runs table in Draper and Smith (15) pages 98-99 was used. The probability of the observed number of runs, considered as the number of sign changes plus one, is obtained from this table and its occurrence evaluated as being random or nonrandom. If the cumulative probability is less than five per cent the arrangement is assumed to be nonrandom.

The runs test was also used to determine if the annual precipitation data distribution and the number of storms observed were unusual. This was done by comparing the observed values to the long term average, a positive sign assigned values greater than the average and a negative sign to values less than the average. When the number of observations was greater than twenty a normal approximation to the actual distribution was used as suggested by Draper and Smith (15) where:

$$\mu = \frac{2n_1n_2}{n_1 + n_2} + 1 \tag{3}$$

$$\sigma^2 = \frac{2n_1n_2\left[2n_1n_2 - (n_1 + n_2)\right]}{(n_1 + n_2)^2\,(n_1 + n_2 - 1)} \tag{4}$$

$$z = \frac{(u - \mu + \frac{1}{2})}{\sigma} \tag{5}$$

with n_1 representing either the number of positive or negative residuals and n_2 being the number of residuals with a sign opposite of those chosen for n_1.

μ and σ^2 are the mean and variance of the discrete distribution of u, the number of runs.

z approximates the unit normal deviate.

A plot of the residuals versus their associated fitted value of the dependent variable yields information on any variation in variance as the magnitude of the fitted value increases.

Preparation of the residuals into unit normal deviate form and comparison of the resulting residuals to an N(0,1) distribution allows another examination of the residuals. Using this technique approximately 95 per cent of the unit normal deviates would be expected to be within -1.96 to +1.96. If the residuals are assumed to have a normal distribution, their unit normal deviate form should satisfy the above criterion.

The method of least-squares always gives a zero sum of the residuals so no check can be made on the assumption that the residuals have zero mean.

Lack of Fit and Pure Error

The residual mean square of the model has the expected value of the error variance, σ^2, only if the model is correct. If it is incorrect the residuals contain errors of two components, the variance error, which is random, and bias error, which is systematic. Generally prior information on the expected error variance is not known, but if repeat measurements of the dependent variable are made with all independent variables retaining their same value for two or more observations they can be used to determine an estimate of the variance error or "pure error" as it is frequently called. The other component of the residual error is "lack of fit" or bias error.

The procedure used to determine the "pure error" estimate of σ^2, S_{pe}^2, is outlined by Draper and Smith (15) and is as follows:

Suppose $Y_{11}, Y_{12}, \ldots, Y_{1n_1}$ are n_1 repeat observations at X_1

$Y_{21}, Y_{22}, \ldots, Y_{kn_k}$ are n_k repeat observations at X_k

The contribution to the pure error sum of squares from the X_1 readings is

$$\sum_{u=1}^{n_1} (Y_{1u} - \overline{Y}_1)^2 = \sum_{u=1}^{n} Y_{1u}^2 - n_1 \overline{Y}_1^2 \qquad (7)$$

where $\overline{Y}_1$ is the mean value of the $Y_{11}, Y_{12}, \ldots, Y_{1n_1}$ observations.

Similar sum of squares calculations are made for each X_i. The total pure error sum of squares is

$$\sum_{i=1}^{k} \sum_{u=1}^{n_i} (Y_{iu} - \overline{Y}_i)^2 \qquad (8)$$

and the total degrees of freedom equals $\sum_{i=1}^{k} (n_i - 1)$. The mean square for the "pure error" is

$$S_{pe}^2 = \left\{ \frac{\sum_{i=1}^{k} \sum_{u=1}^{n_i} (Y_{iu} - \overline{Y}_i)^2}{\sum_{i=1}^{k} n_i - k} \right\} \qquad (9)$$

In this study the only common occurrence of repeat values is in the flood retarding structure data. This occurs because of a lag of several years between the construction of pilot programs and the generally accelerated construction programs that were completed in the early 1960's. Repeat values of precipitation, precipitation pattern, and land treatment practices are unusual and if cumulative data are used for farm ponds no repeat values would be expected. Therefore the only way repeat values can be used is to include the flood retarding variable as the initial independent variable in the regression equation for runoff.

The use of repeated values is not too important on the data now available, but as additional data becomes available the likelihood of repeats will increase. When repeated values for all variables included in the final regression equation occur they should be used to measure the adequacy of the model.

CHAPTER V

BASIN ANALYSIS, UPPER WASHITA RIVER ABOVE CHEYENNE GAGE

Reason for Selection of Upper Washita Basin

This watershed was selected for investigation because it was considered to best satisfy the conditions under examination. The Upper Washita basin was one of the first in which the SCS flood retarding structure program became prominent and its development is believed to be greater than that of any watershed of comparable size. Other SCS programs, namely land treatments and farm ponds, were also quite evident throughout the watershed. Precipitation and streamflow records were also available.

The problems experienced at Foss Reservoir, that of reduced inflow and water quality undesirable for industrial and municipal uses, indicated that the upstream programs may have affected the downstream yield of the Upper Washita. It appeared probable that if the SCS program is a serious depletion factor anywhere in the study area it would become evident from an analysis of the Upper Washita. A model from Upper Washita data would be representative of much of the area and would provide a realistic approach for use in planning future downstream projects.

Watershed Characteristics

Size and Shape

The Upper Washita River above the USGS gage near Cheyenne, Oklahoma, has a drainage area of 794 square miles. The gage, which is located at mile 543.9 of the Washita, is one half mile downstream from the confluence of Sergeant Major Creek and the Washita and 5.2 miles upstream from Dead Indian Creek. The basin has a maximum length of 53 miles (measured in an East-West direction) and has a width that varies from about 11 to 24 miles (measured in a North-South direction). The Cheyenne gage is 43 river miles upstream from the Foss Dam site.

Location

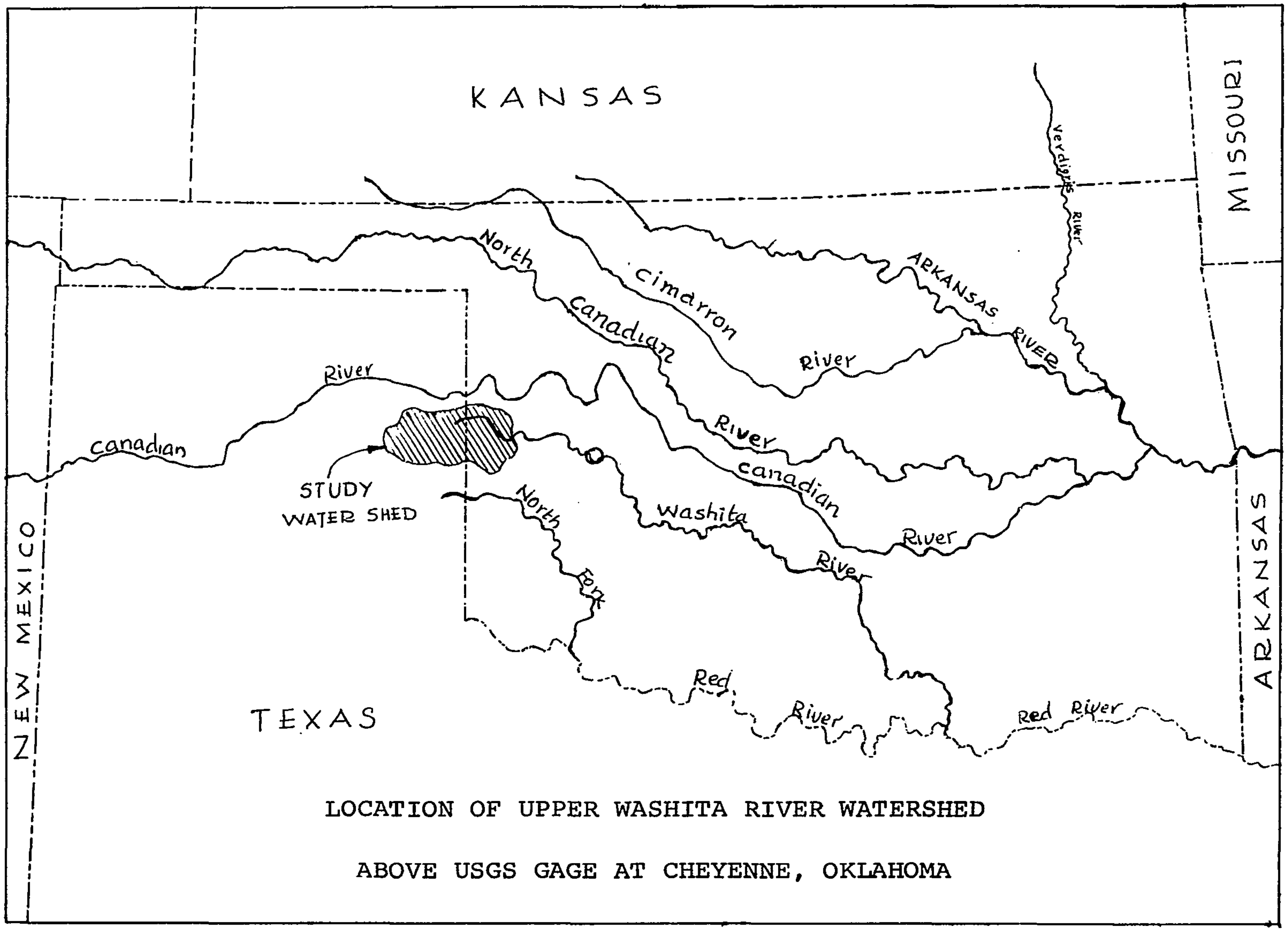
The drainage area is located in west central Oklahoma and the Texas' panhandle. The 350 square mile area in Oklahoma is totally within Rogers Mills County, while the portion in Texas includes parts of Hemphill, Wheeler, and Roberts counties. Cheyenne is located near the center of

Roger Mills County and is approximately 20 miles east of the Texas-Oklahoma state line. Most of the area in Texas is the southern third of Hemphill County. Only the extreme southwestern corner of Roberts County and the northern edge of Wheeler County are in the drainage area. Figure 11 shows the watershed's location on a Texas-Oklahoma map. The Washita River, a tributary of the Red River, flows in an east-southeast direction from its headwaters in the high plains of the Texas panhandle.

Climate

The climate over the watershed is characterized by long hot summers, frequent winds from the Southwest, very little snowfall, a high evaporation rate, and a variable rainfall that averages about 23 inches annually.

The annual mean temperature over the watershed is about 60°F with July and August having the highest average temperatures and January and December the lowest. The temperature conditions during the last decade were typical of those observed over the preceding 30 years. During the last 10 years, the average temperatures for 1962 and 1963 were the highest while 1960 and 1961 had the lowest annual temperatures.



LOCATION OF UPPER WASHITA RIVER WATERSHED

ABOVE USGS GAGE AT CHEYENNE, OKLAHOMA

FIGURE 11

The wind in the spring and summer is usually out of the South or Southwest. During the winter months northern winds are more common. Velocities of about 15 miles per hour are typical with winds in excess of 25 miles per hour not unusual. Net evaporation from free water surfaces averages about 64 inches per year.

The humidity increases over the watershed from West to East, but is generally still lower than experienced in central and southern Oklahoma. The humidity in the Texas panhandle's high plains is considerably lower than the humidity in the lower elevation regions in Roger Mills County.

The average annual rainfall over the watershed is approximately 23 inches with the amount increasing about two inches from the Western to the Eastern edge of the watershed. An indication of the variability in the precipitation amount is that for five of the last ten years the difference between the annual precipitation and the average annual rainfall over the watershed was greater than five inches.[1] Review of 40 years of Weather Bureau records indicate 39 and 13 inches as the annual maximum

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[1] Six gage Thiessen Polygon Method precipitation data from United States Weather Bureau.

and minimum precipitation amounts over the watershed. Normally over half of the annual rainfall occurs during April, May, June, and July. January and December have the lowest monthly precipitation averages. During drought years it is not unusual for a few storms to account for most of the year's precipitation.

Land Use

Agriculture is the principal land use in the watershed. Industrialization, woodland, and urban areas are not important factors from a standpoint of area used. Range and pasture cover approximately seventy-five per cent of the watershed. Beef cattle production is substantial but may be reaching the maximum for the available range.

Wheat and cotton are the prominent cash crops but yields have been highly variable. Although improved farming methods and conversion of marginal crop land to range have raised the overall yield, weather conditions still jeopardize the crops. On the better soil along the bottom lands of the Washita and its tributaries, alfalfa hay is grown and a few farmers still attempt to grow corn. Sorghum acreage has been increasing mainly because of its use as silage for livestock feed.

The trend has been an increase in range and pasture acreage and a concurrent decrease in cultivated land farming. Chicken, sheep, and hog production have all declined very significantly in the past 25 years. The size of farms has increased while the number has steadily decreased.

Geology and Soils

Formations of the Tertiary and Permian Systems are present in the watershed. The Tertiary Ogallala Formation composed of loose sand, some silt, clay, and gravel overlays the Permian age formations and is found throughout all of the Texas portion of the watershed and western Roger Mills County, Oklahoma. The Ogallala deposits have little or no surface concentrations of soluble salts and the runoff is of good chemical quality.

The surface formations that are present from the Permian System are the Quartermaster, Cloud Chief, and Rush Springs. At all elevations above approximately 2250 feet in the western section of the watershed and those above 2150 feet in the east the Permian red sands and shales are covered by Ogallala material. Surface accumulations of soluble salts are common on the Cloud Chief and Rush Springs Formations but the Quartermaster Formation like the Ogallala deposits has little or no surface concentrations of soluble salts.

The Quartermaster Formation's two members, Elk City Sandstone and Doxey Shale, overlay the Cloud Chief and Rush Springs Formations. East of 99° 53' longitude, however, they have been eroded away along and near the Washita and upstream on its tributaries.

The soils in the Texas portion of the watershed are mostly of the Miles-Vernon Group with the Pullman-Richfield Group found in the high plains. The Vernon soils which are easily eroded are thin in many places and the parent formations are exposed. They are present in rolling and steeper sloped areas. The Miles soils are reddish brown or brown and cover most of the flatter land. The Pullman-Richfield Group which has brown to dark-brown top soil, is associated with slow drainage and a good agricultural productivity.

In the Western Oklahoman section of the watershed Pratt-Tivoli and Nobscot-Brownfield-Miles soils dominate. They are sands, loams, and clay loams. Along the Washita channel in the Eastern third of the study basin Woodward-

Cary-Quinlan soils are most common and have been developed in loamy Red Beds.

Preparation of Data and Data Summaries

Extension of Runoff Data Back Through 1926

Runoff records at the Cheyenne gage were initiated by USGS in October, 1937, and have been maintained on at least a monthly basis since that time at the same gage location, latitude 35° 38', longitude 99° 40'. Since all runoff prior to 1956 was considered as undepleted by flood retarding structures, 19 years of record from which the average natural runoff could be computed exist from the available data. The precipitation during the 1937-66 period was somewhat below the average precipitation observed over the watershed during the 1926-66 period, the period of generally available precipitation records at stations in or near the watershed. Since precipitation appeared below normal during the period of gaged streamflow it was considered desirable to calculate runoff for the watershed back through 1926 by using regression equations developed by Reclamation and used in the Definite Plan Report for Foss Reservoir (17). The equations were developed from precipitation and runoff data for the 1938-56 water years. The following relationships were used:

$$X_1 = 6.426 + 3.789X_2 + 10.822X_3 - 3.069X_4 - 10.363X_5 \quad (10)$$

$$X_1 = 7.400 + 3.161X_2 - 3.640X_3 - 3.567X_4 \quad (11)$$

(equation 11 was used for the 1932 water year only)

where X_1 is the USGS Cheyenne gage discharge of Washita River in 1000's of acre-feet,

X_2 is the water year discharge of the Washita River at the USGS Clinton gage in 10,000's of acre-feet,

X_3 is the summation of the daily precipitation greater than 0.19 inches at Miami, Canadian, and Cheyenne stations,

X_4 is the summation of the monthly precipitation greater than 2.70 inches at Miami, Canadian, and Cheyenne stations.

X_5 is the summation of the daily precipitation greater than 0.19 inches at Hammon, Elk City, and Clinton stations.

Equation 11 was used for the 1932 water year only by Reclamation because a check of precipitation, precipitation pattern, and the estimated runoff at the Clinton gage indicated that equation 11 gave a more logical estimate of the streamflow for that year. The correlation coefficients for the years they were used were 0.967 for equation 10 and

0.926 for equation 11.

Although Reclamation developed the equations using data from October 1937 through September 1956 and the period of natural runoff is assumed to terminate in January 1956, only slightly different regression equations would have been developed using data from October 1937 through December 1955. The fact that the equations were developed from water year data and not calendar year data does not affect the equations use since Reclamation developed additional equations to determine the monthly distribution of the annual water year runoff. Therefore, by deletion of the runoff data for October, November, and December 1925 and termination of the data with December 1955, data for the desired period were obtained. The average annual calendar year runoff for 1926-55 inclusive is 38,895 acre-feet. Table 1 lists the calculated runoff for 1926-37 and the recorded values for 1938-66.

Some analyses were conducted on data for the 1957-66 period but it was not considered necessary to recompute the average natural runoff and include calendar year 1956 data, since inclusion would decrease the natural runoff figure by less than three per cent. This change would have relatively no effect on the regression equation

TABLE NO. 1

RUNOFF AT USGS CHEYENNE GAGE, UPPER WASHITA RIVER

Calendar Year	Calculated Runoff in Acre-Feet
1926	42,520
1927	32,380
1928	43,200
1929	37,130
1930	29,620
1931	23,170
1932	16,370
1933	11,320
1934	232,360
1935	16,990
1936	53,760
1937[1]	24,995
	Recorded Runoff in Acre-Feet
1938	33,935
1939	14,020
1940	4,340
1941	92,370
1942	65,300
1943	21,613
1944	23,167
1945	18,270
1946	26,284
1947	37,580
1948	15,040
1949	88,825
1950	32,230
1951	62,320
1952	9,460
1953	6,230
1954	38,660

[1]Calculated runoff from January through September and recorded runoff for October, November, and December, 1937 only.

TABLE NO. 1 (Continued)

Calendar Year	Recorded Runoff in Acre-Feet
1955	13,610
1956	5,060
1957	30,730
1958	9,910
1959	24,850
1960	32,800
1961	19,380
1962	12,780
1963	5,900
1964	2,680
1965	18,080
1966	5,592

parameters. The regression equations can be compared more fairly if the natural runoff figure is held constant. Runoff records at the Cheyenne gage are reported as having poor accuracy so it would be inappropriate to attempt a too sophisticated procedure to determine the average annual natural flow. Change in the value of the average annual natural runoff has the effect of a scale factor only on the regression equation parameters since all values of the dependent variable will be altered by the same amount. Average annual natural runoff is used to divide all observed annual runoff values to obtain a percentage figure and remove the dimensional aspects from the dependent variable.

Average Annual Precipitation for Watershed

Several alternative methods were available for the determination of the average annual precipitation over the watershed. Not only was the length of record subject to many different possible selections but also the selection of the stations to be included and the method of weighting the station's records presented different choices. As discussed earlier, the Thiessen Method was determined to have definite advantages and was used exclusively as the method of weighting the gage records.

Of the alternatives investigated, all of the resulting precipitation averages were very similar. The earliest possible date for data analysis was 1924 since the Cheyenne station was established in that year. The Hammon, Oklahoma gage, which was established in 1914 is about 16 miles east of the Cheyenne station and is the nearest station with a period of record longer than the Cheyenne. Although the average annual precipitation amounts at the Cheyenne and Hammon stations are approximately equal for the common period of record, 1924 to 1966, there are frequently rather large variations in the recorded annual precipitation amounts observed at the two stations. Therefore, it was not considered acceptable to assume that the annual precipitation amounts observed at Hammon would be representative of the annual precipitation that occurred at Cheyenne for each year.

Precipitation data for 1926-55 were obtained as follows:

1926-40 period: Miami, Canadian, and Cheyenne gages were used

1941-55 period: Miami, Canadian, Cheyenne, and Reydon gages were used. (Records were not maintained at Reydon until 1941)

Mean annual precipitation was 22.37 inches.

The above time period is the same as that used for calculation of the average natural runoff and includes 30 years of record. (the same length used by the U. S. Weather Bureau to obtain normals for stations.)

Precipitation data for 1926-66 were obtained as follows:

1926-40 period: Miami, Canadian, and Cheyenne gages were used

1941-66 period: Miami, Canadian, Cheyenne, and Reydon gages were used

Mean annual precipitation was 22.78 inches.

This method uses the complete period of common record available for the watershed.

Precipitation data for 1931-60 were obtained as follows:

1931-40 period: Miami, Canadian, and Cheyenne gages were used

1941-60 period: Miami, Canadian, Cheyenne, and Reydon gages were used

Mean annual precipitation value was 21.38 inches.

This period is the same time frame used by the U. S. Weather Bureau to establish their current normal precipitation amounts.

Precipitation data for 1924-66 were obtained as follows:

1924-40 period: Miami, Canadian, and Cheyenne gages were used

1941-66 period: Miami, Canadian, Cheyenne, and

Reydon gages were used

Mean annual precipitation was 22.72.

The two mean annual precipitation values which appear to be most justifiable for use are the 1926-55 period and the value obtained using data from the complete period of record, 1924 to 1966. Because of the similarity in the 1924-66 and 1926-66 values, 22.72 and 22.78 inches respectively, use of either of these values would not alter the regression equation results significantly. Comparison of the 1926-55 period value of 22.37 inches with the value for 1924-66 or 1926-66 reflects only minor variation. Work was done using an average value of 22.72 inches.

Annual Precipitation Amounts for Watershed

Data from six gages--Miami, Canadian, and Gageby in Texas and Reydon, Cheyenne, and Roll in the Oklahoma area of the watershed--were available for 1956 to 1966. The station locations are shown on Figure 12. Data from all gages were used to provide the best available estimate of areal precipitation over the watershed. Because the Roll gage was not established until 1956 and continuous data

LOCATIONS OF U. S. WEATHER BUREAU PRECIPITATION STATIONS

USED IN ANALYSIS OF UPPER WASHITA RIVER

WATERSHED ABOVE USGS GAGE AT

CHEYENNE, OKLAHOMA

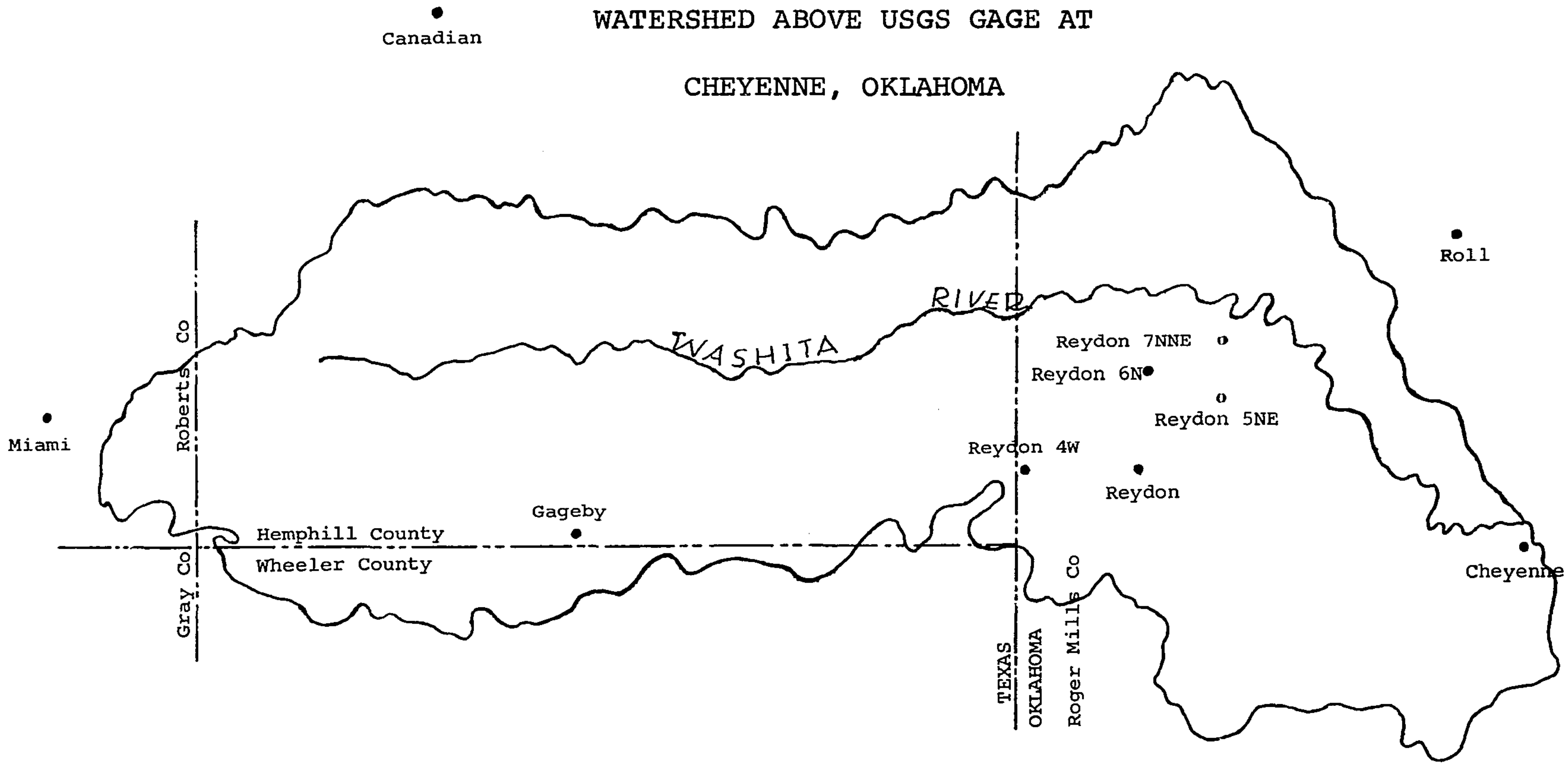


FIGURE 12

at Gageby were not available until 1952, data from these stations were not available for calculations of the average annual precipitation for the watershed for most of the period used to calculate the average annual amount. The 1955 precipitation amount for the watershed was computed without the Roll gage.

Table 2 lists the annual observed precipitation amounts at each of the six gages and the areal precipitation for the watershed obtained by use of the Thiessen polygon method for 1955 to 1966.

During the 1955 to 1966 period there have been two gages in the Reydon area. The hourly recording station has had the following locations during the period:

Inclusive Period	Station	Location
1955-58	Reydon 5NE	Lat 35°43', Long 99°52'
1959-62	Reydon 6N	Lat 35°44', Long 99°55'
1963-66	Reydon 7NNE	Lat 35°45', Long 99°52'

The other gage, a non-recording station has had the following locations:

Inclusive Period	Station	Location
1955-58	Reydon	Lat 35°39', Long 99°55'
1959-66	Reydon 4-W	Lat 35°40', Long 100°00'

Because the hourly recording station was moved shorter distances and a complete record is not available during 1956

TABLE NO. 2

OBSERVED ANNUAL PRECIPITATION AT STATIONS AND CALCULATED

AREAL PRECIPITATION FOR WATERSHED

1955-66 Precipitation in Inches

United States Weather Bureau Stations

Year	Miami, Texas	Canadian, Texas	Gageby, Texas	Reydon, Okla	Cheyenne, Okla	Roll, Okla	Watershed Value
1955	18.99	16.82	19.16	20.55	24.23	--[1]	20.21
1956	14.14	10.76	11.81	15.88	12.42	11.55	13.57
1957	18.85	27.11	25.54	24.70	30.40	26.63	25.34
1958	30.51	26.87[2]	24.04	22.13	28.89	22.82	24.56
1959	24.30	27.32	24.87	30.23	32.80	25.61	27.94
1960	28.84	29.93	28.16	30.80	35.97	32.27	30.31
1961	29.41	20.99	20.12	20.51	23.44	22.29	21.53
1962	18.99	16.28	21.24	25.25	29.67	24.71	23.43
1963	12.43	17.08	12.28	16.56	12.92	16.91	14.29
1964	21.38	20.21	18.56	25.47	33.30	25.95	23.41
1965	21.45	22.42	27.27	30.48	28.24	23.29	27.75
1966	17.32	11.81	13.20	12.28	13.19	12.28	13.11

[1]Roll, Oklahoma station not operated until 1956.

[2]Data for four months not recorded, estimated values, however, were provided by United States Weather Bureau

and 1958 at the Reydon non-recording station, the hourly station records were selected for use. For 1960, 1961, 1963, 1965, and 1966, however, complete records were not available at the hourly stations so precipitation data from the appropriate non-recording station were used. Records for the years of common data, when data were available at two Reydon stations, show that the differences in annual precipitation amounts at the two stations did not exceed two inches and it was usually only about one inch. When the Thiessen Method is applied, the effective difference is reduced to a smaller value and the overall effect considered negligible.

Precipitation Excess

An approximation of the average precipitation amount necessary to cause runoff into a flood retarding structure with an average drainage area was made from an analysis of data for the Sandstone Creek Watershed by Saing (18). He found that 0.5 inch of areal precipitation was the average threshold value for the sub-watersheds studies in Sandstone Creek. Typical land treatment practices had been applied to these sub-watersheds.

An alternative approximation of the excess precipitation amount was computed using one inch as the threshold precipitation value. Because the study watershed is larger and transmission losses would be expected to be greater, the larger value was also selected for examination. The decision as to which calculation appeared better was determined from analysis of the resulting regression equations.

Daily precipitation records for Cheyenne, Reydon, Canadian, and Miami gages were used for the calculations. Data were not available for Gageby and since the contribution of the data from the Roll gage would be so small (only 1.85 per cent) it was not included. The Thiessen Method was used for weighting the four gages.

Groupings of the annual number of storms ≥0.5 inches, ≥1.0 inch, and ≥2.0 inches for each gage were made. In addition because of their expected impact on runoff the actual precipitation amounts of all storms greater than two inches were recorded. An assumption was made that the storms equal to or greater than 0.5 inches but less than one inch averaged 0.75 inches in amount and that the storms equal to or greater than one inch but less than two inches averaged 1.5 inches in amount. The annual precipitation excess amount was calculated by summing all the daily excess amounts. Using the 0.5 inch threshold the excess for each storm in the ≥0.5 to ≤1.0 inch grouping was 0.25 inches, one inch excess for those storms ≥1.0 to<2.0 inches, and the observed value of storms equal to or greater than two inches minus 0.5 inches. When one inch was used as the threshold precipitation excess value the storm groupings ≥0.5 to ≤1.0 inch were not used because they were assumed to contribute no excess precipitation. Table 3 lists the precipitation excess amounts for each station and for the watershed with both the 0.5 and one inch threshold. Sample calculations are also included in Table 3.

Other factors, of course, influence the amount of runoff from precipitation but it appeared impossible, in view of the available data limitations, to include them in the model. Even when data are available other factors are difficult to incorporate into a model because of the lack of knowledge about the functional relationship that exists between them and runoff.

Farm Pond Data

A survey of farm ponds in Texas was conducted in 1957 by SCS (19) by a sampling process using aerial photographs and SCS work unit records. Texas was divided into 12 regions and the total number of ponds, average surface area,

TABLE NO. 3

STORM DATA

Storm Interval In Inches	U. S. Weather Bureau Station: Reydon, Okla			Cheyenne, Okla			Miami, Texas			Canadian, Texas		
	≥0.5 <1.0	≥1.0 <2.0	≥2.0	≥0.5 <1.0	≥1.0 <2.0	≥2.0	≥0.5 <1.0	≥1.0 <2.0	≥2.0	≥.5 <1.0	≥1.0 <2.0	≥2.0
Year	Number of Occurrences											
1956	7	3	0	4	4	0	9	2	0	4	2	0
1957	15	3	1	13	8	1	10	2	0	11	8	0
1958	8	3	0	16	4	2	11	7	3	8	5	2
1959	6	8	4	9	8	4	7	6	2	9	7	2
1960	7	10	1	14	8	3	12	8	1	12	7	1
1961	10	4	0	11	7	0	11	4	3	11	6	1
1962	8	6	0	11	7	3	7	2	2	5	6	1
1963	7	3	1	5	3	0	4	3	0	4	2	1
1964	7	7	1	10	14	1	7	6	1	8	6	1
1965	12	7	2	8	10	1	7	3	2	9	6	1
1966	9	0	0	8	0	0	5	1	2	7	2	0

TABLE NO. 3 (Continued)

Observed Precipitation Amount for those Daily Precipitation Events _2.0 Inches

	U. S. Weather Bureau Station			
	Reydon	Cheyenne	Miami	Canadian
1956	--	--	--	--
1957	2.50	2.25	--	--
1958	--	(4.10,2.25)	(2.15,2.50,3.2)	(2.18,2.82)
1959	(2.10,2.35,2.50,2.55)	(2.30,3.86,2.00,2.90)	(2.01,2.03)	(2.00,2.20)
1960	3.53	(2.40,6.17)	2.17	3.8
1961	--	--	(4.27,3.4,2.45)	2.12
1962	--	(2.00,2.00)	(2.02,2.58)	--
1963	2.89	--	--	(2.05,2.89)
1964	2.58	2.60	2.7	2.28
1965	(2.00,3.15)	3.95	(2.27,2.46)	2.04
1966	--	--	(2.15,2.12)	--

TABLE NO. 3 (Continued)

Year	Precipitation Excess in Inches Using 0.5 Inch Threshold — Station				Precipitation Excess in Inches Using 1.0 Inch Threshold — Station			
	Reydon	Cheyenne	Miami	Canadian	Reydon	Cheyenne	Miami	Canadian
1956	4.75	5.00	4.25	3.00	1.50	2.00	1.00	1.00
1957	10.75	13.00	4.50	10.75	4.00	5.25	1.00	4.00
1958	5.00	13.35	16.10	11.00	1.50	6.35	8.35	5.50
1959	17.00	19.31	10.79	12.45	9.50	11.06	5.04	5.70
1960	14.78	19.07	12.67	13.30	7.53	10.57	5.17	6.30
1961	6.50	9.75	15.37	10.37	2.00	3.50	9.12	4.12
1962	8.00	12.75	7.35	7.25	3.00	5.50	3.60	3.00
1963	7.14	4.25	4.00	6.94	3.39	1.50	1.50	3.94
1964	10.83	18.60	9.95	9.78	5.08	8.60	4.70	4.28
1965	14.15	15.45	8.48	9.79	6.65	7.95	4.23	4.04
1966	2.25	2.00	5.52	3.75	0	0	2.77	1.00

TABLE NO. 3 (Continued)

Precipitation Excess Factor[1]
Using 0.5 Inch Threshold

Station

Year	Reydon	Cheyenne	Miami	Canadian	Value for Watershed[2]
1956	.299	.403	.301	.279	.3076
1957	.435	.428	.239	.397	.3911
1958	.226	.462	.528	.403	.3459
1959	.562	.589	.444	.456	.5217
1960	.480	.530	.439	.444	.4710
1961	.317	.416	.523	.494	.4032
1962	.317	.430	.387	.445	.3703
1963	.431	.329	.322	.445	.3703
1964	.425	.559	.465	.484	.4609
1965	.464	.547	.395	.437	.4560
1966	.183	.152	.319	.318	.2320

[1]Precipitation excess factor = precipitation excess in inches/observed annual precipitation amount in inches. Example, for 1956, at Reydon using 0.5 inch threshold precipitation; excess factor = 4.75/15.88 = .299

[2]Watershed value obtained by Thiessen Method weighting of four station excess factors.

TABLE NO. 3 (Continued)

Precipitation Excess Factor
Using 1.0 Inch Threshold

	Station				
Year	Reydon	Cheyenne	Miami	Canadian	Value for Watershed
1956	.094	.161	.071	.093	.0979
1957	.162	.173	.053	.148	.1480
1958	.068	.220	.274	.205	.1519
1959	.314	.337	.207	.209	.2755
1960	.244	.294	.179	.210	.2316
1961	.098	.149	.310	.196	.1626
1962	.119	.185	.190	.184	.1534
1963	.205	.116	.121	.231	.1846
1964	.199	.258	.220	.212	.2128
1965	.218	.282	.197	.180	.2140
1966	.000	.000	.160	.085	.04645

average drainage area, average capacity, and average maximum pond depth estimated for each region. The Upper Washita River watershed in Texas was completely within the Rolling Plains region of the survey. Farm ponds in the Rolling Plains region had an average drainage area of 86.6 acres, an average maximum depth of 12.9 feet, an average surface area of 1.35 acres, and an average capacity of 5.05 acre-feet.

The Oklahoma SCS office in Stillwater, Oklahoma, provided the following data on farm ponds in Roger Mills County from an analysis of SCS work unit records through fiscal year 1964; average maximum depth of 15 feet, average surface area of 2.5 acres, and an average capacity of 11.2 acre-feet. No data were available on the average drainage area of the ponds.

The above data were used for the basin study and assumed to apply for all farm ponds in the respective states' watershed area. Since there was a significant difference between the physical characteristics of the ponds in the two states' portions of the watershed, separate data were maintained for Texas and Oklahoma and summed together; after computations for cumulative capacity were made of a state basis.

Data on the number of farm ponds in the watershed were collected from the SCS work unit reports, assuming a uniform distribution of the ponds throughout the SCS work unit. All reported pond construction was considered as new construction; that is; none of the ponds were considered as replacements. Some of the ponds which were constructed in the early 1940's have probably become filled with sediment but it is also likely that some farm ponds have been constructed without SCS technical support subsequent to the "on-land" estimates of farm ponds and were therefore not reflected in the SCS records. These two errors in the data tend to compensate each other.

To obtain a figure for the number of ponds "on-land" in the states' area of the watershed in 1948, the 1945 "on-land" census of land treatment practices was used for the Cheyenne, Oklahoma SCS work unit and the 1953 study made for the Washita River Basin area in Texas by SCS.

Forty-six per cent of the Cheyenne work unit, 38.7 per cent of the Hemphill work unit, 6.8 per cent of the Wheeler work unit, and 2.6 per cent of the Roberts work unit are within the study watershed. The first available "on-land" estimates of SCS land treatments in Texas were conducted in 1953. However, yearly totals of SCS pond construction are available from 1948 to 1966. The number of ponds "on-land" prior to 1948 was obtained by subtracting the cumulative annual SCS pond figure for the 1948 to 1953 period from the 1953 "on-land" figure.

The 1948 "on-land" estimate of farm ponds in the Oklahoma section of the study watershed was obtained by adding the pertinent SCS pond construction data for 1945, 1946, 1947, and 1948 to the "on-land" estimate data of ponds prior to 1945.

It appears that farm pond construction in the Oklahoma section of the study basin is decreasing and that most future construction will be replacement of ponds that have filled with sediment. Pond construction in Texas shows no such pattern.

In Oey's (3) work on the same watershed the number of farm ponds was significantly larger than the data in this study. This occurred because Oey assumed that the density of ponds in the Texas portion of the watershed was the same as that for the Oklahoma section. He collected data for Oklahoma only and assumed they applied in Texas. This was an invalid assumption as the data in Table 4 reflect.

Land Treatment Practices

Parts of four SCS work units: Hemphill, Wheeler, and

TABLE NO. 4

FARM POND DATA FOR UPPER WASHITA

WATERSHED ABOVE CHEYENNE GAGE

	Oklahoma Section of Watershed			Texas Section of Watershed			
	No. of Ponds	Estimated Capacity in Ac-Ft	Σ Capacity in Ac-Ft	No. of Ponds	Estimated Capacity in Ac-Ft	Σ Capacity in Ac-Ft	ΣCapacity for Watershed in Ac-Ft
Constructed before 1948	181	2028	2028	57	289	289	2317
Constructed during							
1948	20	224	2252	11	56	345	2597
1949	36	403	2655	8	40	385	3040
1950	20	336	2991	6	30	415	3406
1951	58	650	3641	12	61	476	4117
1952	14	157	3798	6	30	506	4304
1953	12	134	3932	5	25	531	4463
1954	11	123	4055	6	30	561	4616
1955	10	112	4167	8	40	601	4768
1956	17	190	4357	5	25	626	4983
1957	10	112	4469	3	15	641	5110
1958	16	179	4648	6	30	671	5319
1959	30	336	4984	6	30	701	5685
1960	45	504	5488	9	45	746	6234
1961	40	448	5936	16	81	827	6763

TABLE NO. 4 (Continued)

	Oklahoma Section of Watershed			Texas Section of Watershed			
Constructed during	No. of Ponds	Estimated Capacity in Ac-Ft	Σ Capacity in Ac-Ft	No. of Ponds	Estimated Capacity in Ac-Ft	Σ Capacity in Ac-Ft	Σ Capacity for Watershed in Ac-Ft
1962	24	269	6205	5	25	852	7057
1963	11	123	6328	9	45	897	7225
1964	7	78	6406	15	76	987	7379
1965	6	67	6473	5	25	998	7471
1966	6	67	6540	5	25	1023	7563
	584			203			

Roberts in Texas and Cheyenne in Oklahoma are within the study watershed. Available land treatment data included estimates of "on-land" practices applied during a period, work unit records of the practices applied with SCS support during a period, and estimates of the "on-land" practices at a designated date. All data were from SCS records but records were not complete. The only SCS data available for the study watershed on a basin basis were "on-land" practices applied in the Texas portion of the basin.

To obtain estimates of the land treatment practices in the watershed section of each work unit, the total work unit figure was multiplied by the percentage of the work unit area within the basin.

Comparison of the SCS support data in Tables 5 and 7 and the "on-land" data in Tables 6 and 8 indicates that inconsistences appear in both the Texas and Oklahoma data. In several cases the "on-land" data are less than that applied with SCS support. Small differences may be explained by differences in the methods used to obtain the data; but for pasture planting, proper range, use and range seeding where the SCS support figures were much larger than the "on-land" data for several years, no satisfactory explanation is available. There is no indication that there

TABLE NO. 5

SELECTED LAND TREATMENT PRACTICES APPLIED WITH SCS SUPPORT[1]

TEXAS SECTION OF UPPER WASHITA WATERSHED ABOVE CHEYENNE GAGE

		Fiscal Year										
Practice	Unit	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966
Contour Farming	Acre	296	295	185	242	123	654	2790	5754	6499	3132	2490
Cover Cropping	Acre	122	878	577	342	111	131	22	190	73	40	61
Crop Residue Use	Acre	461	544	620	1157	971	1985	1360	3690	6575	2980	2673
Pasture Planting	Acre	28	46	317	51	71	208	149	127	324	2433	3707
Proper Range Use	Acre		No Data Reported			31,236	17,381	87,334	126,251	145,089	29,735	38,530
Range Seeding	Acre	490	742	1588	846	1455	1280	294	208	324	2433	3707
Strip Cropping	Acre	7	162	16	0	0	0	0	0	0	0	0
Terracing	Mile	9	10	7	11	4	16	24	18	33	20	22
Diversions	Mile	1	1	1	1	1	4	4	2	2	2	3

[1]Source of data SCS Work Unit Summary furnished by SCS, Temple, Texas

TABLE NO. 6

SELECTED LAND TREATMENT PRACTICES ESTIMATES OF "ON-LAND" PRACTICES[1] APPLIED

TEXAS SECTION OF UPPER WASHITA WATERSHED ABOVE CHEYENNE GAGE

		Year									
Practice	Unit	1956[2]	1957[2]	1958-9[3]	1960[4]	1961[4]	1962[4]	1963[4]	1964[4]	1965[4]	1966[4]
Contour Farming	Acre	14	162	275	172	1355	4938	11,771	15,177	6378	4609
Cover Cropping	Acre	614	1872	No Data	80	377	0	133	110	0	0
Crop Residue Use	Acre	2559	3830	No Data	2462	5816	2842	8434	14,495	5478	5248
Pasture Planting	Acre	51	301	No Data	71	381	188	131	368	127	0
Proper Range Use	Acre	No Data Reported			42,395	18,112	88,601	124,281	143,280	19,549	13,627
Range Seeding	Acre	461	1802		3673	2213	1092	425	40	354	39
Strip Cropping	Acre	64	16	20	0	0	0	0	0	0	0
Terracing	Mile	15	7	13	12	19	51	33	64	26	57
Diversions	Mile	2	1	1	3	2	7	4	4	3	6

[1]Source of data; for 1956-9 SCS Work Unit Reports, for 1960-6 SCS Summary for Study Watershed
[2]Calendar Year
[3]Data available for combined period from January 1, 1958 to June 30, 1959
[4]Fiscal Year

TABLE NO. 7

SELECTED LAND TREATMENT PRACTICES APPLIED WITH SCS SUPPORT[1]

OKLAHOMA SECTION OF UPPER WASHITA WATERSHED ABOVE CHEYENNE GAGE

		Year										
Practice	Unit	1956[2]	1957[2]	1958[3]	1959[4]	1960[4]	1961[4]	1962[4]	1963[4]	1964[4]	1965[4]	1966[4]
Contour Farming	Acre	1201	2463	0	2144	504	4936	5486	4749	5581	5338	4789
Cover Cropping	Acre	2785	4608	514	6347	2034	7139	6342	4003	4753	6615	6555
Crop Residue Use	Acre	0	0	0	1646	1301	8274	7363	3043	7722	6973	8758
Pasture Planting	Acre	0	0	0	142	0	0	233	286	570	344	2057
Proper Range Use	Acre	5230	16,476	0	20,370	8444	39,754	72,242	60,609	40,999	46,241	49,156
Range Seeding	Acre	1162	1524	6680	8445	5479	2183	917	428	415	511	482
Strip Cropping	Acre	0	75	0	46	0	0	0	18	0	0	0
Terracing	Mile	25	26	14	19	18	17	18	21	7	6	5
Diversions	Mile	3	3	2	5	8	4	3	4	2	4	5

[1]Source of data SCS work Unit Reports
[2]Calendar Year
[3]January 1, 1958 to June 30, 1958
[4]Fiscal Year

TABLE NO. 8

SELECTED LAND TREATMENT PRACTICES ESTIMATED "ON-LAND"[1] AT THE DESIGNATED DATES

OKLAHOMA SECTION OF UPPER WASHITA WATERSHED ABOVE CHEYENNE GAGE

		Year							
Practice	Unit	1959[2]	1960[3]	1961[3]	1962[3]	1963[3]	1964[3]	1965[3]	1966[3]
Contour Farming	Acre	28,697	14,291	14,291	5486	7008	5908	5829	4983
Cover Cropping	Acre	24,053	9220	11,525	6342	5893	5076	7295	7269
Crop Residue Use	Acre	7616	4610	10,142	7838	7653	8459	7688	8758
Pasture Planting	Acre	142	142	142	544	830	1400	1744	2057
Proper Range Use	Acre	81,021	99,115	10,142	72,242	65,219	44,710	48,114	50,546
Range Seeding	Acre	31,621	37,100	39,283	40,723	41,151	41,567	42,077	42,559
Strip Cropping	Acre	0	0	0	0	18	0	0	0
Terracing	Mile	701	720	736	753	774	781	788	793
Diversions	Mile	86	94	98	60	64	65	69	74

[1]Source of data SCS Work Unit Reports, no data available prior to 1959
[2]December 31, 1959
[3]June 30 of designated year

was any difference in the methods of classifying or designating the practices.

For the Oklahoma section of the watershed no applied "on-land" data were available as such. However, the estimated amounts "on-land" at designated dates were available (Table 8) and can be used to obtain estimates of the practices applied in some cases. For practices that require annual renewal there is a problem in that the designated date is a point source and, therefore, does not provide data over a time period. With practices that are relatively cumulative the amount applied can be estimated by assuming the difference in annual values includes no replacement practices and that none of the treatments previously reported have become ineffective during the period. It appears that SCS used this method in preparation of the Annual 99 Reports for Oklahoma, adding the quantities applied during the year to the previously reported cumulative "on-land" figure for those practices which are relatively permanent.

A change in the reporting period from calendar year to fiscal year reports occurred, which further complicates interpretation of the data.

Flood Retarding Structure Data

Data on the 82 flood retarding structures arrayed by the year in which the structures were considered as completed are listed in Table 9. Although the program was started in 1948 only two structures with a combined drainage area of about 0.5 per cent of the Upper Washita Watershed were constructed prior to 1956. The program came into prominence in 1961 when 36 structures were completed in that year alone, and construction continued at a rapid pace with 12 and 21 structures being completed in 1962 and 1963, respectively. The program was completed in 1964 with the construction of the final three units. SCS has indicated that no additional structures will be constructed in the study watershed.

The sediment pools of the structures in Texas have an average depth less than those in Oklahoma (approximately 5.2 feet as compared to 8.3 feet). This difference is explained in part by the 200 acre-feet storage limit imposed on the sediment pools in Texas unless a permit is granted by the Texas Water Commission authorizing additional storage. The average depths ranged from a minimum of three feet to a maximum of just over 11 feet.

The average drainage area of the 39 structures in

TABLE NO. 9

FLOOD RETARDING STRUCTURE DATA FOR THE UPPER WASHITA WATERSHED

ABOVE CHEYENNE GAGE USING REPORTED COMPLETION DATES

Year	Watershed	Structure No.	Sediment Pool Surface Area in Acres	Σ Surface Area in Acres	Sediment Pool Capacity in Ac-Ft	ΣSediment Pool Capacity in Ac-Ft	Drainage Area in Acres	Σ Drainage Area in Acres
1948	Serg. Major	1	15	15	87	87	1178	1178
1949	Serg. Major	2	15	30	152	239	1350	2528
1956	Serg. Major	3	45		470		2960	
	Serg. Major	4	34		492		3735	
			77	107	962	1201	6695	9223
1959	Broken Leg	1	53		444		4556	
	Broken Leg	2	23		128		1280	
	Dead Indian	7	15		58		877	
	" "	8	15		84		922	
			106	213	714	1915	7635	16858
1960	Upper Washita	17-B	6		27		685	
	" "	18	30		156		3181	
	" "	19	20		60		1320	
	" "	52	12		73		1264	
	" "	54	19		140		2542	
			87	300	456	2317	8992	25850

TABLE NO. 9 (Continued)

Year	Watershed	Structure No.	Sediment Pool Surface Area in Acres	Σ Surface Area in Acres	Sediment Pool Capacity in Ac-Ft	Σ Sediment Pool Capacity in Ac-Ft	Drainage Area in Acres	Σ Drainage Area in Acres
1961	Upper Washita	34	14		119		1814	
"	"	35	26		208		5082	
"	"	36	50		361		4416	
"	"	37	14		104		1856	
"	"	38	13		97		2380	
"	"	39	69		665		9171	
"	"	40	76		622		8196	
"	"	41	21		120		2656	
"	"	42	40		337		5191	
"	"	43	26		205		3243	
"	"	44	23		182		2867	
"	"	21	63		200		10843	
"	"	46	34		211		4693	
"	"	47	25		195		3438	
"	"	48	10		64		620	
"	"	49	16		87		1541	
"	"	50	12		59		1022	
"	"	53	46		445		10464	
"	"	55	18		123		1445	
"	"	56	10		66		890	
"	"	57	98		1082		21276	
"	"	58	46		460		4930	
"	"	33	41		375		4333	
"	"	16	23		138		3650	
"	"	20	28		138		3217	

TABLE NO. 9 (Continued)

Year	Watershed	Structure No.	Sediment Pool Surface Area in Acres	Σ Surface Area in Acres	Sediment Pool Capacity in Ac-Ft	Σ Sediment Pool Capacity in Ac-Ft	Drainage Area in Acres	Σ Drainage Area in Acres
1961	Upper							
cont.	Washita	22	21		138		3547	
"	"	23-A	11		52		1318	
"	"	23-B	12		58		1493	
"	"	24	29		198		3900	
"	"	25	37		200		4568	
"	"	17	42		200		6882	
"	"	17-A	8		35		704	
"	"	51	8		58		915	
			1080	1310	7597	9968	143061	168911
1962	Upper							
	Washita	1	71		394		15328	
"	"	2	39		200		11198	
"	"	3	18		125		3361	
"	"	4	38		199		7112	
"	"	5	28		162		4454	
"	"	6	17		85		2136	
"	"	7	16		87		2219	
"	"	8	21		152		3431	
"	"	11	29		200		5916	
"	"	12	10		56		1002	
"	"	13	32		193		5307	
"	"	9	43		192		17413	
"	"	10	36		200		5533	
"	"	14	36		198		4559	

TABLE NO. 9 (Continued)

Year	Watershed	Structure No.	Sediment Pool Surface Area in Acres	Σ Surface Area in Acres	Sediment Pool Capacity in Ac-Ft	Σ Sediment Pool Capacity in Ac-Ft	Drainage Area in Acres	Σ Drainage Area in Acres
1962 cont.	Upper Washita	14-A	17		104		1420	
			451	1761	2547	12515	90389	259300
1963	Upper Washita	61	16		124		1530	
	" "	15	41		194		6021	
	" "	15-A	27		165		2641	
	" "	26	29		174		2270	
	" "	27	38		200		4328	
	" "	28	22		96		2626	
	" "	29	37		140		2893	
	" "	30	39		348		4595	
	" "	31	115		870		22900	
	" "	32	37		200		6325	
	" "	45	31		156		3406	
	" "	60	12		89		909	
	" "	62	17		132		1568	
	" "	59	0		0		2470	
	Serg.Major	5	9		58		608	
	Serg.Major	6	16		107		1139	
	Broken Leg	3	6		45		538	
			492	2253	3098	15613	66767	326067
1964	Upper Washita	63	13		84		941	
	" "	64	10		47		1018	

TABLE NO. 9 (Continued)

Year	Watershed	Structure No.	Sediment Pool Surface Area in Acres	Σ Surface Area in Acres	Sediment Pool Capacity in Ac-Ft	Σ Sediment Pool Capacity in Ac-Ft	Drainage Area in Acres	Σ Drainage Area in Acres
1964 cont.	Upper Washita	65	16		100		1235	
	" "	101	7		48		390	
			46	2299	279	15892	3584	329651

Texas is 5,066 acres, somewhat larger than the average drainage area of the 43 structures in the Oklahoma section of the watershed, 3,055 acres. The larger number of sites further upstream on tributaries in Oklahoma and the five sites in Texas with drainage areas greater than 10,000 acres account for much of the difference in the average drainage area size between the Texas and Oklahoma sections of the watershed.

A review of the sediment pool design, using total sediment storage volume and not taking into account the 200 acre-feet storage limit in Texas, indicates that the sediment storage per drainage area ratio is .067 acre-feet/acre for the Texas sites and .042 acre-feet/acre for those structures in the Oklahoma section of the watershed.

As mentioned earlier in the report since only a small amount of the annual runoff normally occurs in the last three months of the year, an equation scheme using a three month lag of the reported flood retarding structures' completion dates was prepared. Structure data using the three month lag are listed in Table 10.

To take into consideration the locations of the structures relative to the Cheyenne gage and the transmission losses that would occur, the structures were grouped into

TABLE NO. 10

FLOOD RETARDING STRUCTURE DATA FOR THE UPPER WASHITA WATERSHED ABOVE CHEYENNE GAGE

USING THREE MONTH LAG OF REPORTED COMPLETION DATES

Year	Watershed	Structure No.	Sediment Pool Surface Area in Acres	Σ Surface Area in Acres	Sediment Pool Capacity in Ac-Ft	Σ Sediment Pool Capacity in Ac-Ft	Drainage Area in Acres	Σ Drainage Area in Acres
1949	Serg. Major	1	15	15	87	87	1178	1178
1950	Serg. Major	2	15	30	152	239	1350	2528
1957	Serg. Major	3	43		470		2960	
	Serg. Major	4	34		492		3735	
			77	107	962	120	6695	9223
1959	Broken Leg	1	53		444		4556	
		2	23		128		1280	
	Dead Indian	7	15		58		877	
	" "	8	15		84		922	
			106	213	714	1915	7635	16858
1960	Upper Washita	52	12		73		1264	
	" "	54	19		140		2542	
			31	244	213	2128	3806	20664

TABLE NO. 10 (Continued)

Year	Watershed	Structure No.	Sediment Pool Surface Area in Acres	Σ Surface Area in Acres	Sediment Pool Capacity in Ac-Ft	Σ Sediment Pool Capacity in Ac-Ft	Drainage Area in Acres	Σ Drainage Area in Acres
1961	Upper Washita	17-B	6		27		685	
	" "	18	30		156		3181	
	" "	19	20		60		1320	
	" "	35	26		208		5082	
	" "	37	14		104		1856	
	" "	38	13		97		2380	
	" "	39	69		665		9171	
	" "	40	76		622		8196	
	" "	41	21		120		2656	
	" "	42	40		337		5191	
	" "	43	26		205		3243	
	" "	44	23		182		2867	
	" "	21	63		200		10843	
	" "	46	34		211		4693	
	" "	47	25		195		3438	
	" "	48	10		64		620	
	" "	49	16		87		1541	
	" "	50	12		59		1022	
	" "	53	46		445		10464	
	" "	55	18		123		1945	
	" "	56	10		66		890	
	" "	57	98		1082		21276	
	" "	58	46		460		4930	
	" "	33	41		375		4333	
	" "	16	23		138		3650	

TABLE NO. 10 (Continued)

Year	Watershed	Structure No.	Sediment Pool Surface Area in Acres	Σ Surface Area in Acres	Sediment Pool Capacity in Ac-Ft	Σ Sediment Pool Capacity in Ac-Ft	Drainage Area in Acres	Σ Drainage Area in Acres
1961 cont.	Upper Washita	20	28		133		3217	
"	"	22	21		138		3547	
"	"	23-A	11		52		1318	
"	"	23-B	12		58		1493	
"	"	24	29		198		3900	
"	"	25	37		200		4568	
"	"	17	42		200		6882	
"	"	17-A	8		35		704	
"	"	51	8		58		915	
			1002	1246	7360	9488	142017	162681
1962	Upper Washita	34	14		119		1814	
"	"	36	50		361		4416	
"	"	1	71		394		15328	
"	"	2	39		200		11198	
"	"	3	18		125		3361	
"	"	4	38		199		7112	
"	"	5	28		162		4454	
"	"	6	17		85		2136	
"	"	7	16		87		2219	
"	"	8	21		152		3431	
"	"	11	29		200		5916	
"	"	12	10		56		1002	
"	"	13	32		193		5307	
			383	1629	2333	11821	67694	230375

TABLE NO. 10 (Continued)

Year	Watershed	Structure No.	Sediment Pool Surface Area in Acres	Σ Surface Area in Acres	Sediment Pool Capacity in Ac-Ft	Σ Sediment Pool Capacity in Ac-Ft	Drainage Area in Acres	Σ Drainage Area in Acres
1963	Upper Washita	9	43		192		17413	
	" "	10	36		200		5533	
	" "	14	36		198		4559	
	" "	14-A	17		104		1420	
	" "	15	41		194		6021	
	" "	15-A	27		165		2641	
	" "	26	29		174		2270	
	" "	27	38		200		4328	
	" "	28	22		96		2626	
	" "	29	37		140		2893	
	" "	30	39		348		4595	
	" "	31	115		870		22900	
	" "	32	37		200		6325	
	" "	45	31		156		3406	
	" "	60	12		89		909	
	Serg. Major	5	9		58		608	
	Serg. Major	6	16		107		1139	
	Broken Leg	3	6		45		528	
			591	2220		15357	90124	320499
1964	Upper Washita	61	16		124		1530	
	" "	62	17		132		1568	
	" "	59	0		0		2470	
	" "	63	13		84		941	

TABLE NO. 10 (Continued)

Year	Watershed	Structure No.	Sediment Pool Surface Area in Acres	Σ Surface Area in Acres	Sediment Pool Capacity in Ac-Ft	Σ Sediment Pool Capacity in Ac-Ft	Drainage Area in Acres	Σ Drainage Area in Acres
1964 cont.	Upper Washita	64	10		47		1018	
	" "	65	16		100		1235	
	" "	101	7		48		390	
			79	2299	535	15892	9152	329651

five categories. The groupings, made by straight line map distance from the gage, were those less than 10 miles, 10 to 20 miles, 20 to 30 miles, 30 to 40 miles, and greater than 40 miles. With an approximate average transmission loss of one per cent per mile the weighting factors were .95, .85, .75, .65, and .55 for the respective zones (.95 for those within 10 miles of the gage . . ., .55 for those greater than 40 miles from the gage). The appropriate weighting factors were then applied to the structures' drainage area. The number of structures in each zone was as follows: 0-10 miles, 20 sites; 10-20 miles, 26 sites; 20-30 miles, 10 sites; 30-40 miles, 18 sites; greater than 40 miles, 10 sites. The Western edge of the watershed is approximately 50 miles from the Cheyenne gage. Table 11 includes a listing of the structures grouped by year of completion with a three month lag and their computed weighted drainage areas. The relative locations of the structures in the watershed are shown on Figure 13.

Double Mass Plot

To provide meaningful results only observed precipitation from gages with continuous record throughout the period and streamflow can be used as data for the double mass plot

TABLE NO. 11

TRANSMISSION LOSS WEIGHTING OF FLOOD RETARDING STRUCTURES' DRAINAGE AREAS

IN UPPER WASHITA WATERSHED ABOVE CHEYENNE GAGE USING

THREE MONTH LAG OF REPORTED COMPLETION DATES

Year	Watershed	Structure No.	Drainage Area in Acres	Weighting Factor	Σ Weighted Drainage Area in Acres
1949	Serg. Major	1	1178	.95	1119
1950	Serg. Major	2	1350	.95	2402
1957	Serg. Major	3	2960	.95	
	Serg. Major	4	3735	.95	8762
1959	Broken Leg	1	4556	.95	
	Broken Leg	2	1280	.95	
	Dead Indian	7	877	.95	
	Dead Indian	8	922	.95	16015
1960	Upper Washita	52	1264	.85	
	" "	54	2542	.85	19250
1961	Upper Washita	19	1320	.65	
	" "	35	5082	.85	
	" "	37	1856	.85	
	" "	38	2380	.85	

TABLE NO. 11 (Continued)

Year	Watershed	Structure No.	Drainage Area in Acres	Weighting Factor	Σ Weighted Drainage Area in Acres
1961 cont.	Upper Washita	39	9171	.85	
	" "	40	8196	.85	
	" "	41	2656	.85	
	" "	42	5191	.85	
	" "	43	3243	.85	
	" "	44	2867	.95	
	" "	17-B	685	.65	
	" "	21	10843	.65	
	" "	46	4693	.85	
	" "	47	3438	.85	
	" "	48	620	.85	
	" "	49	1541	.85	
	" "	50	1022	.85	
	" "	53	10464	.85	
	" "	55	1945	.95	
	" "	56	890	.95	
	" "	57	21276	.95	
	" "	58	4930	.95	
	" "	33	4333	.75	
	" "	16	3650	.55	
	" "	18	3181	.55	
	" "	20	3217	.65	
	" "	22	3547	.65	
	" "	23-A	1318	.65	
	" "	23-B	1493	.65	
	" "	24	3900	.75	
	" "	25	4568	.75	

TABLE NO. 11 (Continued)

Year	Watershed	Structure No.	Drainage Area in Acres	Weighting Factor	Σ Weighted Drainage Area in Acres
1961	Upper				
cont.	Washita	17	6882	.55	
	" "	17-A	704	.55	
	" "	51	915	.85	133066
1962	Upper				
	Washita	1	15328	.55	
	" "	2	11198	.55	
	" "	3	3361	.55	
	" "	4	7112	.55	
	" "	5	4454	.55	
	" "	6	2136	.55	
	" "	7	2219	.65	
	" "	8	3431	.65	
	" "	11	5916	.65	
	" "	12	1002	.65	
	" "	13	5307	.65	
	" "	34	1814	.85	
	" "	36	4416	.85	173954
1963	Upper				
	Washita	9	17413	.65	
	" "	10	5533	.65	
	" "	14	4559	.65	
	" "	14-A	1420	.65	
	" "	15	6021	.65	
	" "	15-A	2641	.75	
	" "	26	2270	.75	

TABLE NO. 11 (Continued)

Year	Watershed	Structure No.	Drainage Area in Acres	Weighting Factor	Σ Weighted Drainage Area in Acres
1963	Upper				
cont.	Washita	27	4328	.75	
	" "	28	2626	.75	
	" "	29	2893	.75	
	" "	30	4595	.75	
	" "	31	22900	.75	
	" "	32	6325	.85	
	" "	45	3406	.85	
	" "	60	909	.95	
	Serg. Major	5	608	.85	
	Serg. Major	6	1139	.95	
	Broken Leg	3	538	.95	
	Upper				
	Washita				2399664
1964	Upper				
	Washita	63	941	.85	
	" "	64	1018	.85	
	" "	65	1235	.85	248000

LOCATIONS OF FLOOD RETARDING STRUCTURES IN UPPER WASHITA RIVER

WATERSHED ABOVE USGS GAGE AT CHEYENNE, OKLAHOMA

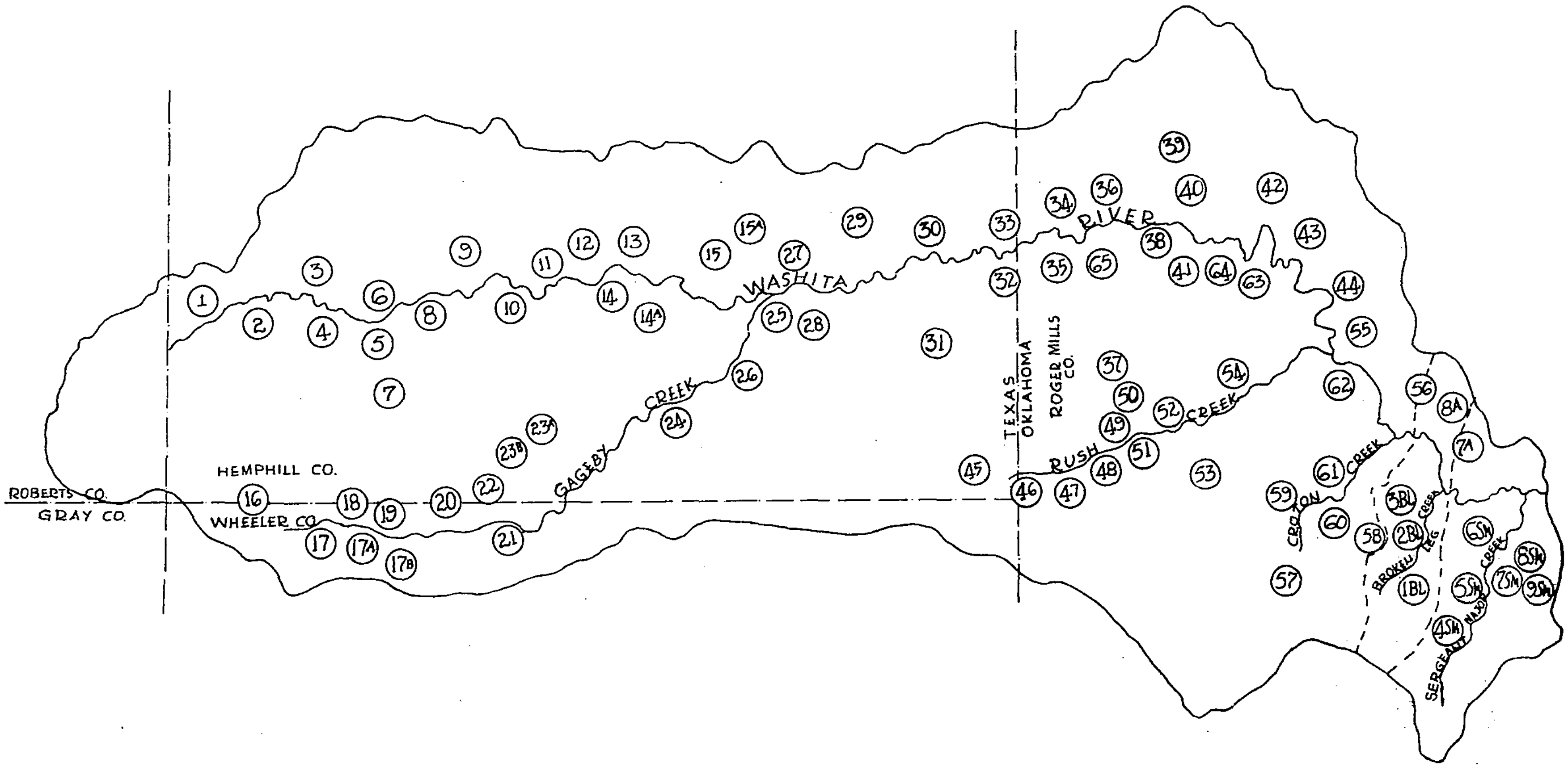


FIGURE 13

since the purpose of the plot is to determine if there has been any change in the constant of proportionality between runoff and effective precipitation over the period. Precipitation records were available at four stations: Canadian and Miami in Texas, and Cheyenne and Reydon in Oklahoma from 1941 through 1966. Streamflow records at the USGS gage near Cheyenne on the Upper Washita River were also available for the same period. Using the Thiessen Polygon Method the annual areal precipitation was computed. The procedures discussed in Chapter IV were followed to determine the best equation for effective precipitation. The result was:

$$P_e = 0.8P_o + 0.2P_1 \qquad (12)$$

where P_e is effective annual precipitation in inches for the year t, P_o is the Thiessen Method weighted annual precipitation in inches for the watershed for the preceding year, t-1, and P_1 is the Thiessen Method weighted annual precipitation in inches for the watershed for the year t. The equation minimized the sum of the squared residuals of rank between observed streamflow and calculated effective precipitation values. Table 12 summarizes the results of sample equations for determination of effective precipitation.

The method of least-squares was then used on the

TABLE NO. 12

EFFECTIVE PRECIPITATION EQUATIONS USING THIESSEN POLYGON METHOD WEIGHTING OF PRECIPITATION AMOUNTS AT CHEYENNE, REYDON, MIAMI, AND CANADIAN STATIONS

Equation	Rank Difference Sum of Squares
$P_e = 1.0P_o$	1274
$P_e = 0.9P_o + 0.1P_1$	1330
$P_e = 0.8P_o + 0.2P_1$	1224
$P_e = 0.7P_o + 0.3P_1$	1261.5

Equation $P_e = 0.8P_o + 0.2P_1$ selected because of smallest sum of squares

Year	Precipitation in inches using 4-gage Thiessen Polygon	P_e, from equation $P_e = 0.8P_o + 0.2P_1$
1941	39.5	--
1942	34.5	36.42
1943	18.0	22.20
1944	27.8	24.79
1945	15.7	19.46
1946	25.2	22.66
1947	19.7	21.14
1948	24.6	23.46
1949	29.8	27.98
1950	24.4	24.33
1951	26.6	24.62
1952	13.3	17.08
1953	17.0	16.28
1954	16.8	17.88
1955	20.1	19.88
1956	12.5	15.56
1957	21.0	24.12
1958	27.1	25.79
1959	28.7	29.96

TABLE NO. 12 (Continued)

Year	Precipitation in inches using 4-gage Thiessen Polygon	P_e, from equation $P_e = 0.8P_o + 0.2P_1$
1960	31.4	32.37
1961	23.6	25.85
1962	22.5	25.54
1963	14.7	15.95
1964	25.1	24.02
1965	25.6	28.30
1966	13.6	17.75

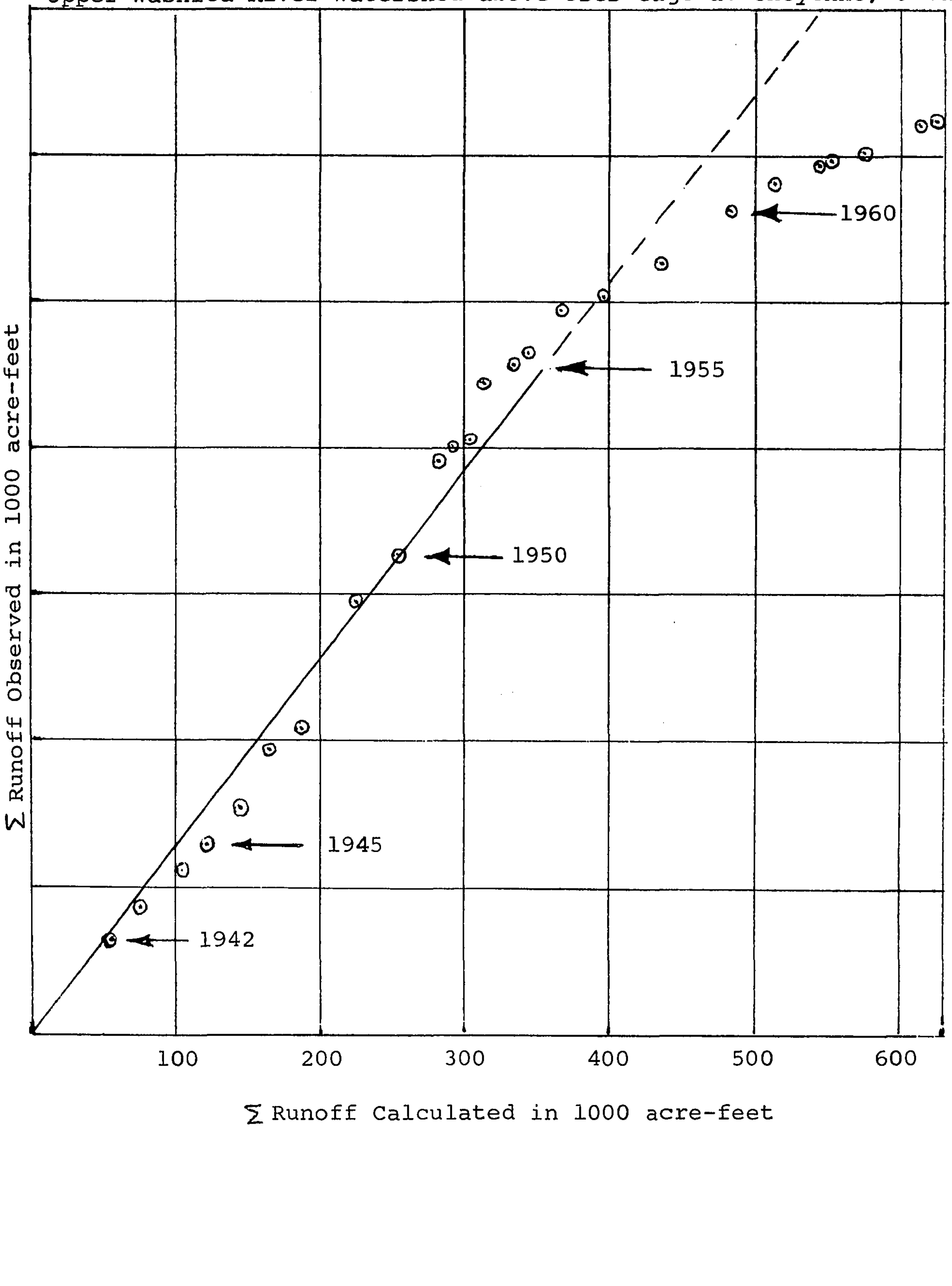
observed runoff and computed effective precipitation data to obtain the linear regression equation, Y = -24.8575 + 2.1387X: where Y is runoff in 1000 acre-feet and X is computed annual effective precipitation in inches (see Table 12 for calculations). Annual runoff was computed from the regression and the double mass gradient, Figure 14, plotted for the cumulative observed runoff versus the cumulative calculated runoff. A line of best fit was drawn for the 1942-55 data, the period when less than one per cent of the watershed was controlled by flood retarding structures.

In Figure 14 a pronounced break begins in 1959 and becomes more pronounced in 1962. It must be recognized that drought conditions tend to reduce the slope, the drought in 1952, 1953, and 1954 is an example of such an effect. The low precipitation amounts in 1963 and 1966 explain in part the break in the plot, but the proliferation of flood retarding structures over the watershed during the early 1960's appears also to be a strong factor in causing the break. The buildup of land treatment practices and farm ponds prior to 1959 did not cause a noticeable break in the plot.

FIGURE 14

DOUBLE MASS PLOT

Upper Washita River Watershed above USGS Gage at Cheyenne, Okla.



Correlation Matrices

When the structure completion dates are lagged by one year less than one per cent of the drainage area was controlled in 1956. Since it was initially determined that the structure program would not be considered to be in evidence until the one per cent level was exceeded. Two different sets of data were required, 1957-66 and 1956-66. Tables 13-16 are the resulting correlation matrices for the data. Regression equations were developed for both periods and the results compared. All variables that were considered for inclusion in the regression equations were included in a correlation matrix for each time period.

Of course, although the units of some of the data in matrices for the same time period--such as runoff, precipitation, and the drainage area concepts--were changed, the correlation coefficients between these variables were the same as those obtained in the matrices with the same time frame but different units.

All of the correlation coefficients associated with runoff and a precipitation variable (including precipitation amount, excess factor, and the product of precipitation amount and excess factor) increased when the 1956-66 period was used, compared to the 1957-66 period. The negative

TABLE NO. 13

CORRELATION MATRIX

1957 - 1966 Data

	Runoff Ac-Ft (1)	Ppct. Inches (2)	Ppct. Excess Factor 1 Inch Threshold (3)	Ppct. Excess Factor 0.5 Inch Threshold (4)	Ppct. x Ppct. Excess Factor 1 Inch Threshold (5)	Ppct. x Ppct. Excess Factor 0.5 Inch Threshold (6)	Σ Farm Pond Capacity Ac-Ft (7)	Σ Sediment Pool Capacity in Ac-Ft (8)	Σ Combined Capacity of Farmponds & Sed.Pools in Ac-Ft (9)	Σ Drainage Area of Flood Retarding Structures in Acres: Reported Completion Dates (10)	Σ Drainage Area of Flood Retarding Structures in Acres: 3 Month Lag of Completion Dates (11)	Σ Drainage Area of Flood Retarding Structures in Acres: 1 Year Lag of Completion Dates (12)
(1)	1.0000	0.7031	0.3858	0.4737	0.5760	0.6643	-0.6069	-0.7187	-0.7075	-0.7270	-0.7300	-0.7051
(2)		1.0000	0.6925	0.7337	0.8759	0.9404	-0.4944	-0.5953	-0.5867	-0.5953	-0.5989	-0.5071
(3)			1.0000	0.9764	0.9279	0.8695	-0.1879	-0.2686	-0.2612	-0.2753	-0.2723	-0.2484
(4)				1.0000	0.9247	0.9025	-0.2022	-0.2723	-0.2665	-0.2836	-0.2796	-0.2644
(5)					1.0000	0.9797	-0.3031	-0.4272	-0.4153	-0.4343	-0.4306	-0.3516
(6)						1.0000	-0.3647	-0.4773	-0.4670	-0.4846	-0.4822	-0.4027
(7)							1.0000	0.9575	0.9672	0.9520	0.9474	0.8753
(8)								1.0000	0.9994	0.9979	0.9982	0.9361
(9)									1.0000	0.9969	0.9965	0.9326
(10)										1.0000	0.9983	0.9432
(11)											1.0000	0.9531
(12)												1.0000

TABLE NO. 14

CORRELATION MATRIX

1957 - 1966 Data

	Runoff Ac-Ft	Ppct. Inches	Ppct. Excess Factor		Ppct. x Ppct. Excess Factor		Σ Farm Pond Capacity Ac-Ft	Σ Sediment Pool Capacity in Ac-Ft	Σ Combined Capacity of Farmponds & Sed.Pools in Ac-Ft	Σ Drainage Area of Flood Retarding Structures in Acres		
			1 Inch Threshold	0.5 Inch Threshold	1 Inch Threshold	0.5 Inch Threshold				Reported Completion Dates	3 Month Lag of Completion Dates	1 Year Lag of Completion Dates
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1)	1.0000	0.7371	0.4578	0.5327	0.6281	0.7050	-0.3533	-0.5079	-0.4897	-0.5410	-0.5399	-0.5450
(2)		1.0000	0.7430	0.7726	0.8977	0.9516	-0.1522	-0.2998	-0.2830	-0.3298	-0.3283	-0.2841
(3)			1.0000	0.9794	0.9383	0.8889	0.0270	-0.0860	-0.0730	-0.1126	-0.1070	-0.1089
(4)				1.0000	0.9342	0.9145	0.0056	-0.0978	-0.0862	-0.1277	-0.1213	-0.1300
(5)					1.0000	0.9830	-0.0458	-0.2033	-0.1841	-0.2330	-0.2263	-0.1847
(6)						1.0000	-0.0805	-0.2309	-0.2137	-0.2635	-0.2576	-0.2182
(7)							1.0000	0.9600	0.9694	0.9486	0.9460	0.8757
(8)								1.0000	0.9993	0.9971	0.9976	0.9393
(9)									1.0000	0.9953	0.9955	0.9351
(10)										1.0000	0.9984	0.9479
(11)											1.0000	0.9566
(12)												1.0000

TABLE NO. 15

CORRELATION MATRIX

1957 - 1966 Data

	Runoff Per cent Normal	Ppct. Per cent Normal	Ppct. Excess Factor 1 Inch Threshold	Ppct. Excess Factor 0.5 Inch Threshold	Per cent Ppct x Ppct Excess Factor 1 Inch Threshold	Per cent Ppct x Ppct Excess Factor 0.5 Inch Threshold	Σ Drainage Area of Flood Retarding Structures Per Cent Watershed Controlled: Reported Completion Dates	3 Month Lag of Completion Dates	1 Year Lag of Completion Dates	Transmission Loss Weighting to 3 Month Lag Data
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1)	1.0000	0.7031	0.3856	0.4737	0.5760	0.6643	-0.7270	-0.7300	-0.7052	-0.7255
(2)		1.0000	0.6924	0.7338	0.8759	0.9405	-0.5953	-0.5988	-0.5071	-0.5989
(3)			1.0000	0.9763	0.9278	0.8694	-0.2751	-0.2721	-0.2483	-0.2721
(4)				1.0000	0.9247	0.9025	-0.2835	-0.2795	-0.2644	-0.2772
(5)					1.0000	0.9797	-0.4342	-0.4306	-0.3516	-0.4307
(6)						1.0000	-0.4846	-0.4822	-0.4027	-0.4813
(7)							1.0000	0.9983	0.9432	0.9980
(8)								1.0000	0.9531	0.9996
(9)									1.0000	0.9461
(10)										1.0000

TABLE NO. 16

CORRELATION MATRIX

1957 - 1966 Data

	Runoff Per cent Normal	Ppct. Per cent Normal	Ppct. Excess Factor 1 Inch Threshold	Ppct. Excess Factor 0.5 Inch Threshold	Per cent Ppct x Ppct Excess Factor 1 Inch Threshold	Per cent Ppct x Ppct Excess Factor 0.5 Inch Threshold	Σ Drainage Area of Flood Retarding Structures Per Cent Watershed Controlled: Reported Completion Dates	Σ Drainage Area of Flood Retarding Structures Per Cent Watershed Controlled: 3 Month Lag of Completion Dates	Σ Drainage Area of Flood Retarding Structures Per Cent Watershed Controlled: 1 Year Lag of Completion Dates	Σ Drainage Area of Flood Retarding Structures Per Cent Watershed Controlled: Transmission Loss Weighting to 3 Month Lag Data
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1)	1.0000	0.7371	0.4577	0.5326	0.6281	0.7050	-0.5410	-0.5400	-0.5450	-0.5315
(2)		1.0000	0.7429	0.7726	0.8977	0.9516	-0.3297	-0.3283	-0.2842	-0.3231
(3)			1.0000	0.9793	0.9382	0.8888	-0.1125	-0.1069	-0.1088	-0.1031
(4)				1.0000	0.9342	0.9145	-0.1277	-0.1213	-0.1300	-0.1158
(5)					1.0000	0.9830	-0.2330	-0.2263	-0.1847	-0.2221
(6)						1.0000	-0.2635	-0.2576	-0.2182	-0.2523
(7)							1.0000	0.9984	0.9479	0.9981
(8)								1.0000	0.9566	0.9996
(9)									1.0000	0.9500
(10)										1.0000

value correlation coefficients between runoff and the capacity and drainage area data decreased in absolute value when the 1956-66 period data were used compared to the 1957-66 time frame, but still were of significant magnitude.

For both time frames the correlation coefficients between the various capacity and drainage area data and between the capacity concepts were positive values all in excess of 0.87. These high values indicate that the use of any of these variables would result in a regression equation with similarly valued parameters. It is apparent from the high correlation coefficient between drainage area and capacity concepts that the 200 acre-feet limit of storage in sediment pools in Texas affects only slightly the value of the correlation coefficient between the variables from these two concepts.

The correlation coefficients between the cumulative capacity of the farm ponds and the cumulative capacity of the flood retarding structures' sediment pools were 0.96 for both the 1956-66 and 1957-66 data. Therefore, both variables had similar correlation coefficients with runoff. However, it was determined that the flood retarding structures and not farm ponds were the cause of reduced downstream runoff. Using standardized data the correlation coefficient between the summation of the farm ponds' capacities and runoff data for 1945-55 was only -0.07. Although the negative sign indicates that an increase in farm ponds reduces runoff, the correlation coefficients for the same variables for the 1956-66 or 1957-66 periods were -0.35 and -0.61, respectively. This result coupled with the double mass plot made it apparent that the larger absolute valued negative correlation coefficients between farm ponds and runoff occurred because of the high correlation that existed between the farm pond and flood retarding structure data.

The correlation coefficients between the excess factors obtained from use of both one inch and one-half inch thresholds, and rainfall were somewhat lower than might be expected. This means that the larger annual precipitation amounts are not always associated with the larger excess factors. It is, therefore, important that both the precipitation amount and excess factor be included in the regression equation.

The slightly lower correlation coefficients between runoff and X_1X_3, where X_1 is the per cent annual precipitation and X_3 is the excess factor for either one-half or one inch threshold, compared to the coefficients between runoff and precipitation amount have several explanations. First, the use of the excess factor for the few available precipitation stations may not be representative of the watershed excess factor. Second, although the correlation coefficient is slightly lower, it may more accurately represent the true relationship. This can be supported by the fact that another of the important factors in the runoff relationship has been accounted for when the excess factor is included. The overall objective is to develop the best equation: and as is seen later, this does not always result from equations containing those variables that have the highest, absolute value correlation coefficients with the dependent variable. Third, the relationship between precipitation and runoff may not be linear. The correlation coefficient between precipitation amount and runoff for 1941-55 was significantly higher (0.80) than the 1957-66 period (.70). While it can only be postulated that most of the reduction in the correlation coefficient was due to the construction of flood retarding structures, it is a fact that certain water losses (seepage and evapotranspiration) can be directly attributed to the structures. Examination of the precipitation pattern for the two periods (1941-55 and 1957-66) at the Cheyenne station indicated no significant change in the observed precipitation amounts.

A slight shift occurs in the order of the absolute values of the correlation coefficients between the drainage area concepts and runoff when the time frame of the data is modified. For 1956-66 the one year lag of completion dates data had a slightly larger absolute value (0.545) than either the actual completion dates data (0.541) or the three months lag of completion dates data (0.540). As mentioned earlier all were negative. For the 1957-66 data the correlation coefficients between the drainage area concepts and runoff were: three month lag of completion dates, -0.730; actual completion dates, -0.727; and one year lag of completion dates, -0.705. These results indicate that not only does the one year lag of completion dates compensate for the initial fill of the sediment pools but also the fit of the equation to the data will be comparable to that of other concepts.

A measure of the precipitation intensity index for each station was calculated by dividing the annual precipitation amount by the number of days precipitation occurred. The station data were weighted using the Thiessen Polygon Method to obtain an estimate of the areal intensity.

The correlation coefficients between the intensity index and runoff had smaller values than did the correlation coefficients between the precipitation excess factors and runoff. The precipitation intensity variable was, therefore, not investigated any further since the excess factor was considered to represent better the same type of variable.

The larger valued correlation coefficient between the precipitation variables and runoff for the 1956-66 data (0.737 compared to 0.705 for 1957-66 data) may be due to the fact that a very small amount of flood retarding structure construction was completed by 1956 and the coefficient would more closely approximate that of natural conditions which was also larger (0.80).

Attempts to utilize monthly precipitation amounts and monthly precipitation from the preceding month to explain monthly runoff provided correlation coefficients significantly less than those coefficients obtained using annual data for the same periods. Values were approximately 0.2 less using monthly data than the respective coefficients using annual data.

Regression Equations

Regression equations using all reasonable combinations of the explanatory variables listed below were made to explain the observed runoff recorded at the USGS Cheyenne gage for the 1956-66 and 1957-66 periods. Limited work was also done for the 1949-66 period. Explanatory variables used in regression equations were:

1. Annual precipitation amount,

2. Annual precipitation amount for preceding years,

3. Per cent normal annual precipitation,

4. Precipitation excess factor, using 0.5 and one inch thresholds,

5. Per cent drainage area controlled by flood retarding structures using actual reported completion dates, three month lag of completion dates, and a one year lag of completion dates,

6. Cumulative capacity of farm ponds,

7. Cumulative capacity of flood retarding structures' sediment pools,

8. Combined cumulative capacity of farm ponds and flood retarding structures' sediment pools,

9. Transmission loss weighting applied to per cent drainage area controlled by flood retarding structures.

The procedures and criteria discussed in Chapter IV were used to develop and evaluate the regression equations.

Typical resultant equations from three groupings--first-order equations containing per cent drainage area controlled variables, equations using capacity concept variables, and higher-order equations containing per cent drainage area controlled variables,--are presented in Tables 17, 18, and 19, respectively. A discussion of the equations in each grouping is included in this section as is a discussion that compares all the equations

Discussion of First Order Per Cent Drainage Area Controlled Equations in Table 17

There is little difference between regression equations that use different completion dates for the structures when they have a common hydrologic variable (X_1, X_1X_3, X_1X_{3A}) and time frame. This occurs because of the high correlation between the values of X_2, X_{2A}, and X_{2B}. (See Table 17 for definition of variables)

The parameters in the transmission loss concept equation have values similar to equations using the same time frame, hydrologic variable, and the various completion dates for the structures. The relatively uniform distribution of the structures over the watershed probably accounts for the similarity in the equations. Since most watersheds would

TABLE NO. 17

FIRST-ORDER PER CENT DRAINAGE AREA CONTROLLED EQUATIONS

Period	Equation		R	R^2	
1956-66	$Y = -14.11 + .645X_1 - 0.307X_2$	(**)	0.802	0.643	(13)
1957-66	$Y = 10.16 + .465X_1 - 0.443X_2$	(**)	0.801	0.642	(14)
1956-66	$Y = -14.40 + .646X_1 - 0.309X_{2A}$	(**)	0.802	0.643	(15)
1957-55	$Y = 10.49 + .461X_1 - 0.451X_{2A}$	(**)	0.802	0.643	(16)
1956-66	$Y = -15.60 + .652X_1 - 0.344X_{2B}$	(**)	0.816	0.666	(17)
1957-66	$Y = 1.98 + .517X_1 - 0.439X_{2B}$	(**)	0.811	0.658	(18)
1956-66	$Y = 10.82 + .985X_1X_3 - 0.351X_2$	(*) (**)	0.795	0.632	(19)
1957-66	$Y = 29.50 + .699X_1X_3 - 0.491X_2$	(*) (**)	0.810	0.656	(20)
1956-66	$Y = 10.39 + .994X_1X_3 - 0.470X_{2C}$	(**)	0.794	0.630	(21)
1956-66	$Y = 10.52 + .998X_1X_3 - 0.356X_{2A}$	(*) (**)	0.797	0.635	(22)
1957-66	$Y = 29.41 + .698X_1X_3 - 0.500X_{2A}$	(*) (**)	0.812	0.659	(23)
1956-66	$Y = 9.00 + 1.003X_1X_3 - 0.387X_{2B}$	(*) (**)	0.811	0.658	(24)
1957-66	$Y - 22.94 + .779X_1X_3 - 0.489X_{2B}$	(*) (**)	0.818	0.669	(25)
1956-66	$Y = 24.85 + 1.502X_1X_{3A} - 0.384X_2$		0.748	0.560	(26)
1957-66	$Y = 43.21 + 0.944X_1X_{3A} - 0.545X_2$	(*) (**)	0.782	0.612	(27)
1956-66	$Y = 24.51 + 1.509X_1X_{3A} - 0.388X_{2A}$		0.749	0.561	(28)
1957-66	$Y = 43.00 + 0.946X_1X_{3A} - 0.554X_{2A}$	(*) (**)	0.785	0.616	(29)

TABLE NO. 17 (Continued)

Period	Equation		R	R^2	
1956-66	$Y = 22.75 + 1.545X_1X_{3A} - 0.418X_{2B}$	(*)	0.765	0.585	(30)
1957-66	$Y = 36.51 + 1.102X_1X_{3A} - 0.537X_{2B}$	(*)(**)	0.787	0.619	(31)

where X_1 = per cent normal annual precipitation

X_1X_3 = per cent normal annual precipitation x excess precipitation factor using 0.5" threshold

X_1X_{3A} = per cent normal annual precipitation x excess precipitation factor using 1.0" threshold

X_2 = per cent drainage area controlled, using actual reported completion of data

X_{2A} = per cent drainage area controlled, using three month lag of completion of data

X_{2B} = per cent drainage area controlled, using one year lag of completion data

X_{2C} = per cent drainage area controlled, using transmission loss weighting

Y = per cent average natural annual runoff

* = satisfies sequential F-test criterion

** = satisfies corrected coefficient of determination

TABLE NO. 18

FIRST-ORDER CAPACITY CONCEPT EQUATIONS

Period	Equation		R	R^2	
1956-66	$Y = 4690 + 1232.4X_4 - 2.628X_5$	(**)	0.776	0.602	(32)
1957-66	$Y = 18786 + 1014.3X_4 - 3.953X_5$	(**)	0.764	0.584	(33)
1956-66	$Y = -5968 + 1132.1X_4 - .486X_6$	(**)	0.796	0.634	(34)
1957-66	$Y = 4167 + 810.8X_4 - .736X_6$	(**)	0.796	0.634	(35)
1956-66	$Y = -4221 + 1146.2X_4 - .414X_7$	(**)	0.793	0.629	(36)
1957-66	$Y = 6781 + 835.1X_4 - .630X_7$	(**)	0.792	0.627	(37)
1957-66	$Y = 33635 + 340.9X_1X_3 - 4.845X_5$	(**)	0.771	0.594	(38)
1956-66	$Y = 4005 + 393.7X_1X_3 - .562X_6$	(**)	0.789	0.622	(39)
1957-66	$Y = 11924 + 277.6X_1X_3 - .823X_6$	(*)(**)	0.806	0.650	(40)
1956-66	$Y = 6217 + 398.9X_1X_3 - .481X_7$	(**)	0.786	0.618	(41)
1957-66	$Y = 15272 + 285.0X_1X_3 - .711X_7$	(*)(**)	0.802	0.643	(42)

where X_1X_3 = per cent normal annual precipitation x excess precipitation factor, using 0.5" threshold

X_4 = annual precipitation amount in inches

X_5 = cumulative farm pond capacity in ac-ft

X_6 = cumulative capacity of flood retarding structures' sediment pools in ac-ft

TABLE NO. 18 (Continued)

where X_7 = combined cumulative capacity of farm ponds and flood retarding structures' sediment pools

Y = runoff in ac-ft

* = satisfies sequential F-test criterion

** = satisfies corrected coefficient of determination

TABLE NO. 19

HIGHER-ORDER REGRESSION EQUATIONS

All Equations From 1957-66 Data

Equation		R	R^2	
Sample Three Variable Equations:				
$Y = 53.25 - .870X_1X_3 + .0201(X_1X_3)^2 - .527X_{2B}$		.841	0.707	(43)
$Y = 36.89 + .0098(X_1X_3)^2 - 0.614X_{2B} + .0017X_{2B}^2$		.835	0.697	(44)
$Y = 5.82 + 0.494X_1 - 0.769X_{2B} + .0049X_{2B}^2$		.813	0.661	(45)
$Y = 141.15 - 2.631X_1 + .016X_1^2 - .488X_{2B}$		.877	0.769	(46)
Two Hydrologic Variable Equations:				
$Y = 7.73 + 0.305X_1X_3 + .0103(X_1X_3)^2$		.672	0.452	(47)
$Y = 72.96 - 1.782X_1 + .0137X_1^2$		.765	0.571	(48)
Two Variable (One hydrologic, One Management) Equations:				
$Y = 21.41 + .00300X_1^2 - .427X_{2B}$	(*) (**)	.832	0.692	(49)
$Y = 33.99 + .0127(X_1)(X_3^2) - .525X_{2B}$	(*) (**)	.813	0.661	(50)
$Y = 29.36 + .00556(X_1^2)(X_3) - .464X_{2B}$	(*) (**)	.841	0.707	(51)
$Y = 36.01 + .00997(X_1^2)(X_3^2) - .499X_{2B}$	(*) (**)	.835	0.697	(52)

TABLE NO. 19 (Continued)

$Y = 40.88 + .0179\ (X_1{}^2)(X_3{}^3) - .524X_{2B}$	(*)(**)	.825	0.681	(53)
$Y = 44.44 + .0320(X_1{}^2)(X_3{}^4) - .541X_{2B}$	(*)(**)	.813	0.661	(54)
$Y = 33.23 + .0000414(X_1{}^3)(X_3) - .457X_{2B}$	(*)(**)	.855	0.731	(55)
$Y = 37.92 + .0000773(X_1{}^3)(X_3{}^2) - .487X_{2B}$	(*)(**)	.849	0.721	(56)
$Y = 41.69 + .000142(X_1{}^3)(X_3{}^3) - .510X_{2B}$	(*)(**)	.838	0.702	(57)
$Y = 44.62 + .000261(X_1{}^3)(X_3{}^4) - .527X_{2B}$	(*)(**)	.825	0.681	(58)
$Y = 36.08 + .000000312(X_1{}^4)(X_3) - .457X_{2B}$	(*)(**)	.864	0.746	(59)
$Y = 39.60 + .000000595\ (X_1{}^4)(X_3{}^2) - .483X_{2B}$	(*)(**)	.857	0.734	(60)
$Y = 42.54 + .00000112(X_1{}^4)(X_3{}^3) - .502X_{2B}$	(*)(**)	.846	0.716	(61)
$Y = 44.94 + .00000208(X_1{}^4)(X_3{}^4) - .517X_{2B}$	(*)(**)	.833	0.694	(62)
$Y = 38.40 + .00000000234(X_1{}^5)(X_3) - .462X_{2B}$	(*)(**)	.869	0.755	(63)
$Y = 43.38 + .00000000869(X_1{}^5)(X_3{}^3) - .497X_{2B}$	(*)(**)	.851	0.724	(64)
$Y = 17.27 + 0.843X_1X_3 - .00696X_{2B}^2$	(*)(**)	.808	0.653	(65)
$Y = 16.32 + .00323X_1{}^2 - .00605X_{2B}^2$	(*)(**)	.826	0.682	(66)
$Y = 40.36 + .000000000176(X_1{}^6)X_3 - .467X_{2B}$	(*)(**)	.871	0.759	(67)

TABLE NO. 19 (Continued)

$Y = 42.41 + .0000000000345\,(X_1^{\,6})(X_3^2) - .483X_{2B}$	(*)(**)	.864	0.746	(68)
$Y = 42.03 + .000000000000131(X_1^{\,7})(X_3) - .473X_{2B}$	(*)(**)	.870	0.757	(69)
$Y = 43.57 + .000000000000261(X_1^{\,7})(X_3^{\,2}) - .484X_{2B}$	(*)(**)	.864	0.746	(70)

* = satisfies sequential F-test criterion

** = satisfies corrected coefficient of determination

be developed upon a similar pattern the transmission loss concept did not appear to make a worthwhile contribution to explaining the observed runoff.

The use of 1957-66 data, compared with 1956-66 data, resulted in equations with larger absolute valued β_2's, the parameter associated with the per cent drainage area controlled variables. The associated increased valued intercepts, β_o's, however, tend to moderate the overall depletion effect.

For the equations from the 1957-66 period data there was a decrease in the unit effect of drainage area control for the one year lagged completion dates compared to the actual and three month lag completion dates. This decrease was anticipated and would compensate for the initial fill requirements of the sediment pools.

Equations 26-31, all contain the excess precipitation factor using a one inch threshold, X_{3A}. All of these equations had multiple correlation coefficients less than equations with a common management variable and the same time period using either the excess precipitation factor obtained with a 0.5 inch threshold (X_3) and/or per cent normal precipitation (X_1).

Although the correlation coefficient between runoff and precipitation amount was larger than that between runoff and the product of per cent normal annual precipitation and excess precipitation factor using the 0.5 inch threshold, the resulting equations of the form $Y = \beta_0 + \beta_1 X_1X_3 + \beta_2X_2$ had multiple correlation coefficients about as large as equations of the form $Y = \beta_0 + \beta_1X_1 + \beta_2X_2$. In fact the equation with the largest R value was equation 19, which had X_1X_3 as the hydrologic variable.

When the sequential F-test, using a ten per cent significance level, is used to justify the acceptance of each variable into the regression equations, equations number 19, 20, 22, 23, 24, 25, 27, 29, 30, and 31 are satisfactory. All other equations in Table 17 are rejected.

By the criterion of the corrected coefficient of determination, $\bar{R}^2$, all two variable equations for the 1957-66 period must have an R value greater than .747 and those for the 1956-66 period must exceed .771. Only equations number 26, 28, and 30 are rejected by this criterion, equations number 26 and 28 were previously rejected by the sequential F-test.

From the resulting equations it was determined that the use of X_1X_{3A}, per cent normal annual precipitation times excess precipitation factor using one inch threshold, would be not used as a hydrologic variable in subsequent higher-order equation runs because of the lower relative R values associated with equations containing X_1X_{3A}. The use of a one year lag of the flood retarding structures completion dates was also adopted as the best management variable form from a standpoint of the largest R and the fact that the initial filling requirements of the sediment pool are considered by use of a one year lag.

Although all of the independent variables had small values in 1956, X_1 was 59.73, X_1X_3 was 18.37, X_2 was 1.81, and X_{2A} and X_{2B} both were 0.50, the management variables were smaller relative to their mean value then were the hydrologic variables. The low runoff recorded in 1956, 5060 ac-ft or 13.01 per cent of the average natural annual runoff, is not adequately explained by a first-order, linear equation which is applicable to 1957-66 data. Since the hydrologic variables in 1956 are not as small relative to their mean as is the management variable, the result is a significant increase in the depletion effect assigned to control of drainage area by flood retarding structures. Since the flood retarding structure program was in such little evidence, less than one per cent of the drainage area was controlled using a three month or a one year lag, it was decided that it would be preferrable to use 1957-66 data for determination of the best regression equation.

Equations were developed for the 1949-66 period but were not included in Table 17 because of the complete unacceptability of studies for this time period. This occurred because for over half of the period the flood retarding structures controlled less than two per cent of the study drainage area. The maximum multiple correlation coefficient obtained was .673 from the following equation:

$$Y = -39.56 + 1.178X_1 - .712\ X_{2A} \qquad (71)$$

Discussion of First-Order Capacity Concept Equations in Table 18

Those equations with cumulative sediment pool capacity (X_6) and combined cumulative capacity (X_7) generally had slightly higher valued multiple correlation coefficients for 1957-66 than the 1956-66 period. This also occurred in the equations using per cent drainage area controlled. Those equations that had cumulative farm pond capacity (X_5) as an independent variable did not follow this pattern.

Larger R values resulted from the use of X_6 and X_7 , sediment pool and combined capacity respectively, than from the use of X_5, cumulative farm pond capacity.

Significant increases in the absolute value of the parameters associated with the management variables occurred when data from 1957-66 were used, compared to the 1956-66 data results. The explanation that applied to the equations in Table 17 is also applicable to this discussion.

The use of X , cumulative combined capacity, may not be advisable from an engineering standpoint because a double count effect may occur. Some runoff that would flow into a flood retarding structure sediment pool if there were no farm ponds in the structures' drainage area is retained by any farm ponds that are in the drainage area. If stage data were available for the sediment pools and farm ponds both could be used in an inventory type system, like the rational method but since these are not available the use of combined capacity data does not appear sound.

Applying the sequential F-test to the capacity concept equations in Table 18 only equations 40 and 42 contained acceptable variables. Equations 40 and 42 also satisfied the corrected coefficient of determination criterion. These results for the capacity data concepts are in general agreement with the results using per cent drainage area controlled data for the equations having the same hydrologic variable and time frame and a management variable of the same general nature. All the equations with cumulative flood retarding structure sediment pool capacity used a three month lag of the structures' reported completion dates. If a one year time lag were used for the capacity concept equations both the 1956-66 and 1957-66 equations with X_1X_3 and X_7 would have been accepted.

The smaller relative increase in the cumulative capacity of the farm ponds (X_5) over both the 1956-66 and 1957-66 periods compared to the much greater increase experienced in the combined capacities (X_7) and flood retarding structures' sediment pool capacities (X_6) caused the parameters associated with the X_5 to be significantly larger than that of X_6 or X_7.

The most important aspect of the capacity concept equations is that the farm pond capacity variable does not explain enough of the sum of squares to justify inclusion in the model at a ten per cent significance level.

Higher order equations forms using capacity concept management variables were not developed because they did not appear to offer as much promise as per cent drainage area controlled concept variables.

Discussion of Higher-Order Per Cent Drainage Area Controlled Equations in Table 19

The addition of a second-order or higher-order form of the variables X_1, X_1X_3, and X_{2B} into previously acceptable two variable equations containing the first-order form of the same variables did not explain enough of the previously unexplained variation to satisfy the sequential F-test requirements. Therefore none of the equations with three or more variables were acceptable, although some of the equations had corrected coefficients of determination greater than the best first-order, two variable equation in Table 17. The variable X_1X_3, per cent normal annual precipitation amount multiplied by the excess precipitation factor, is considered to be one transformed variable. The use of higher-order forms of the hydrologic independent variables instead of the first order form of the same variable did improve equation results (increased values of R) and were therefore investigated thoroughly. The use of higher-order forms of the management variable in place of the first-order form decreased the R values of the resultant equations (comparison of equations 49 with 66 and 65 with 25).

All of the two variable equations listed in Table 19 that contain one hydrologic and one management variable satisfy the sequential F-test and corrected coefficient of determination criteria. As was the case for first-order equations, the equations using X_1X_3 as the hydrologic variable had higher R values, comparison of the second order equations 49 and 52 verifies this.

Attempts to incorporate a second-order hydrologic variable (equations of the form $Y = \beta_o + \beta_1 X_1 X_3 + \beta_2 (X_1 X_3)^2$ and $Y = \beta_o + \beta_1 X_1 + \beta_2 X_1^2$) failed the equation selection criteria.

Certain patterns were observed in the higher-order equations of the form $Y = \beta_o + \beta_1 X_1^A X_3^C + \beta_2 X_{2B}$. When A was set equal to two, three, four, five, six, and seven and C run through a set of increasing integers for each value of A, the R value for the resulting equations decreased as C was increased. The R value for the equations increased, when C was held constant and A was increased for each integer value up to six. A slight decrease occurred when A was increased from six to seven.

General Discussion of Regression Equations

The use of a combined hydrologic variable, the product of precipitation amount and excess factor, and a management variable of drainage area controlled by flood retarding structures provided the best equations. The comprehensive measure attached to drainage area controlled, that of land treatment practices as well as the retarding structures' sediment pools, is believed to be one of the primary reasons for improved results.

The increased R values associated with the higher-order forms of the combined hydrologic variable (X_1X_3) were not unexpected, since other investigations have shown similar findings. The relative increase associated with each increase in the order of the equation is rather small but the comparison of the first-order equation with the sixth-order (R maximum of .818 to .871) reflects a worthwhile improvement.

The best equation is:

$$Y = 40.36 + .0000000000176(X_1^{6})(X_3) - .467X_{2B}$$

Examination of the residuals from all equations with X_1X_3 and X_{2B} as independent variables satisfied the criteria established in Chapter IV. Although pure error and lack of fit calculations were made, the only condition under which these calculations could be made was in the equation that had only one independent variable, a management variable, that represented flood retarding structure construction. Because of this limitation the results of calculations were not conclusive but they did indicate that pure error was appreciable.

Although the equation of choice, may at first appear to have a multiple correlation coefficient less than would be desirable, it must be remembered that the study has been concerned with hydrologic phenomena that are inconsistent and faced severe data limitations. A more complex equation form may have provided more favorable results, in terms of a higher multiple correlation coefficient, but the objective was development of an equation that included only a few variables that could be reasonably forecase to provide a basis for the design of downstream structures.

Application of the equation to field study data available on Sandstone Creek (4), Deep Creek (9), and Escondido Creek (10), all of which are in the mid-continent belt, provided excellent verification of the equation. Calculations of resultant runoff and per cent depletion attributed to the upstream program by the regression equation were in reasonable agreement with observed data. Use of limited available evaporation data for 1961-66 indicated that average annual evaporation from the sediment pools surfaces accounted for about 45 per cent of the sediment pools' total capacity, but the regression equation indicated an average annual loss equal to 78 per cent of the sediment pools' total capacity. This is in agreement with studies cited earlier that found the depletion effect to be approximately twice the evaporation loss and points up the inaccuracy associated with methods that determine depletion from flood retarding structures by evaporation losses.

CHAPTER VI

RECOMMENDATIONS AND CONCLUSIONS

An adequate mathematical model using regression analysis has been generated from available data for the Upper Washita River. The results of the model when compared to the findings of field investigations made on watersheds within the mid-continent belt, herein described, were favorable and indicated that the model could be used for watersheds in the subject region.

The equation of choice can be expected to yield sufficiently accurate forecasts of downstream runoff for planning purposes over the range of hydrologic conditions experienced during the past decade. The effects of the upstream program for precipitation amounts and excess factors larger than experienced in the available data may contain more error because examination of these conditions was not possible.

It is possible that the model could be refined by the inclusion of additional hydrologic variables which would explain more completely the relationship between hydrologic conditions and runoff. However, it is unlikely that sufficient data would be generally available to permit such refinement. The effect of the management variable was modified only slightly in the models established using various hydrologic variables and higher order forms of the hydrologic variables. It seems plausible, therefore, that a more refined model would not alter the apparent upstream program effect, but would permit more accurate forecasts of downstream runoff.

Data were not available to determine what effect modification in the operation of the flood retarding structures, namely discontinuance of water storage in the sediment pool, would have on downstream runoff. Since it is unlikely that this will occur, the result if available would not be too significant.

The model established is linear, contains only three factors that require projection, and provides reasonable results when the complexity of the runoff phenomenon is considered. The effect of the upstream program is significant, particularly during below normal precipitation conditions. When a watershed experiences drought conditions the depletion effect of a full upstream program becomes critical in the mid-continent belt.

Sufficient data were not available for watersheds in Eastern Oklahoma to permit development of regression equations for areas outside of the mid-continent belt. Some construction of flood retarding structures has been completed and more is programmed for several watersheds in Eastern Oklahoma. When data are available a model using the procedures used on the Upper Washita can be developed.

The developed equation should not be indiscrimenately applied to watersheds in areas with hydrologic conditions different from the mid-continent belt.

As additional data become available for the Upper Washita watershed, the new data should be used to maintain and verify the established relationship. Several years of above normal precipitation amounts and excess factors would be very useful in determining the effects of the upstream program for wet conditions.

It would be extremely helpful to future investigations in many areas if SCS and USGS coordinated their programs to provide collection of data for common areas. The collection of additional water quality data would also permit an evaluation of the effect the upstream program has on water quality downstream.

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