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Development Of A Procedure For Estimating The Effects Of Land And Watershed Treatment On Streamflow

Technical Bulletin No. 1352

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Washington, D.C. Issued March 1966

*For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C., 20402 - Price 55 cents*

FOREWORD

Water, of the necessary quality in the desired amounts delivered at the proper place and time, is a resource of the utmost importance. The development and continuance of agriculture, the growth and prosperity of municipalities and industry, and the well-being of all our citizens are dependent on this resource. It is apparent that water resources in many areas are definitely limited. The conservation and wise use of this resource is therefore, becoming more and more important, not only in more arid areas but in hitherto amply supplied humid areas.

Our water supplies, initially provided by precipitation, are intimately and inextricably related to that other greatest of resources—soil. It has long been conjectured that our abuse or wise use of soil affects the amounts, quality, and timing of water yielded by streamflow. Opinions differ widely as to the magnitude of such effects. Public officials and private citizens charged with responsibilities of planning, managing, and using our soil and water resources have long needed to know definitely whether or not land and watershed treatment affect water yields and, if so, the magnitudes of such effects.

A 5-year study of this problem was initiated in 1957 by three of the Federal agencies most concerned with the conservation and wise use of our soil and water resources—the Bureau of Reclamation, U.S. Department of the Interior; and the Soil Conservation Service and the Agricultural Research Service, U.S. Department of Agriculture. A work group of three experienced hydrologists, one from each agency, was established at Lincoln, Nebr., to "develop and test procedures for evaluating the effects of watershed treatments on the yield of streamflow." The work group received guidance from an advisory group, also composed of one representative from each of the three agencies. This report and the procedure developed as described herein are the culmination of the combined efforts of these groups and many other agencies and individuals that assisted along the way. The methodology explained herein was derived by the work group and reflects the status of present knowledge of precipitation–streamflow relations and the availability of data.

In commenting upon this Technical Bulletin, D. A. Williams, Administrator of the Soil Conservation Service, states:

> The publication of this document reflects the spirit of cooperation which has existed between the Agricultural Research Service, the Bureau of Reclamation, and the Soil Conservation Service during the period of the Cooperative Water Yield Procedures study. The Soil Conservation Service has always been interested in the influence of agricultural programs on the Nation's soil and water resources, since they are so essential to a permanent agriculture and to the welfare of the Nation. We

have participated in this effort in order to improve the planning for the future of these resources.

The planning of a water supply involves the investigation of all factors which may have a significant influence on the water yield. This is particularly important when the needs require the full development of the water resource. Physical changes within the watershed such as urban development or major changes in land use or treatment need to be considered. This document presents a method that may be used to estimate changes in water yield resulting from upstream watershed treatment. In our opinion, the method tends to overestimate the effects of watershed treatment on water yield. This may be desirable, since an overestimate will normally result in a more "conservative" design and therefore a more "dependable" water supply.

This study has provided the opportunity for detailed examination of the effects of land treatment and other conservation measures on the water yield of streams. Although the results will show, as reported in other documents still to be published, that existing data are not of sufficient accuracy and duration to determine the magnitude of such effects with any degree of accuracy, they serve to point out the complexity of the problem and may provide a guide to further research in this field.

W. B. Bennett, Acting Commissioner of the Bureau of Reclamation, in his comments on this bulletin states:

> The publication of this report is the culmination of a mutually agreeable cooperative effort by the Bureau of Reclamation, Soil Conservation Service, and Agricultural Research Service to advance the science of hydrology in an area heretofore virtually unexplored. The intensive work by the trio of hydrologists from the three agencies, embracing a period of more than 5 years, will be of considerable value in the study and evaluation of the effects of watershed practice upon water yield. In turn, the studies will contribute to better understanding of such watershed practices as terracing, land treatment, stripcropping, contour farming, and other aspects of watershed practice which are of vital importance to land-and-water-resource undertakings in many areas of our country, as well as in other countries of the world.

It is the sincere hope of the Agricultural Research Service that this major cooperative effort of the three agencies will contribute to the use and development of the soil and water resources of the Nation and to the benefit of all its people.

G. W. Irving, Jr.,
Administrator,
Agricultural Research Service.

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THE COOPERATIVE WATER YIELD PROCEDURES STUDY

Introduction

Water is a natural resource of unique value. In many areas, it is the resource limiting the development of agriculture, industry, recreation, and population growth. The preservation of the quality and the conservation and wise use of this resource are becoming ever more important to the general economy and well-being of people everywhere. In the United States, concern over water as an indispensable resource is evidenced by studies of water use and conservation by Presidential commissions, the Congress, several Federal agencies, many States, local communities, national and international commissions, professional and philanthropic organizations, and individuals. Rights to use of water have been, or are being, defined by legislation on water rights by many of the States. Interstate compacts are being entered into by several groups of States to divide equitably limited water resources of interstate rivers. International treaties have been, or are being, negotiated and consummated, to divide equitably the water of international rivers.

Federal, State, and local agencies involved in the control and use of the Nation's water resources are, therefore, vitally interested in knowing more about the efficiency of water use and about the many factors that may influence water yield. Among these factors is the effect that conservation activities may have on the yield of streamflow. To gain some comprehension of the magnitude of these effects and, if such effects existed, to develop and test methodology for estimating them, the Bureau of Reclamation, Soil Conservation Service, and Agricultural Research Service conducted the Cooperative Water Yield Procedures study.

Objectives

The study was initiated in March 1957 by means of a Memorandum of Understanding among the three agencies. In defining the objectives of the study the memorandum states:

> The primary purpose of the work contemplated is to develop and test procedures for evaluating the effects of watershed treatments on the yield of streamflow. Any consideration given to economics, or to the effects of treatment measures on sediment movement or flood peaks, will be incidental to the primary purpose. Watershed treatment includes land treatment measures such as

changed land use, strip cropping, terracing, and contour farming, and structural measures such as retention and retardation reservoirs and water spreading systems. In the course of the investigation it may be necessary to develop procedures for evaluating the effect of certain individual treatment measures. The primary aim of the investigation will be to develop procedures for evaluating the effects of combined watershed treatment measures on watersheds ranging in size from the very small upstream watersheds to major river basins.

Data used in the investigation may be drawn from all available sources, but emphasis will be placed on application of the results in those areas where streamflow is deficient. When data are obtained from other agencies such as the Geological Survey or the Forest Service, their representatives will be consulted with respect to their best use.

The procedure developed in this cooperative project will be made available to the Soil Conservation Service for use in planning, installing, operating, and maintaining works of improvement for watersheds on which applications for assistance under the Watershed Protection and Flood Prevention Act have been received; to the Bureau of Reclamation for use in planning, design, construction, and operation of Reclamation projects under the Act of June 17, 1902 (32 Stat. 388) and Acts amendatory thereof or supplementary thereto; and to other interested Federal, state, and local agencies.

This project of analytical hydrology will utilize data from small research watersheds as well as larger, more complex river basins on which extensive land treatment programs have been carried out. Trends and changes in the water yield from the larger watersheds will be analyzed in conjunction with and correlated with research data so as to interpret the changes which are observed.

Administrative Arrangements

The Memorandum of Understanding provided for each agency to furnish an experienced hydrologist for the 5-year study, for establishment of this "work group" at Lincoln, Nebr., for adequate subprofessional and clerical assistance, and for sharing of the necessary costs.

Further, it provided for an "advisory group," consisting of a representative from each of the three agencies, to meet with the work group no less often than once every 6 months to furnish guidance and review. The Agricultural Research Service representatives on the work group and advisory group were to serve as leader and chairman of the respective groups.

The membership of the two groups was:

Agency	*Work group*	*Advisory group*
Agricultural Research Service.	A. L. Sharp, Supervisory Hydraulic Engineer.	L. L. Kelly, Chief Hydrologist, Soil and Water Conservation Research Division, Beltsville, Md.
Soil Conservation Service	W. J. Owen, Hydraulic Engineer.	H. O. Ogrosky, Chief, Hydrology Branch, Engineering Division, Washington, D.C.
Bureau of Reclamation	A. E. Gibbs, Hydraulic Engineer.	H. S. Riesbol, Chief, Hydrology Branch, Denver, Colo.

Exploratory Studies and Findings

At the first meeting of those engaged in the study it was concluded that it would be necessary, in order to meet the objectives stated above in the excerpt from the Memorandum of Understanding, to proceed according to the following steps:

1. Determine for selected areas whether land and watershed treatment affects water yields in quantities measurable by use of presently available data.

2. If such measurable effects are found, develop methods of evaluating them quantitatively.

3. Apply methods developed to a sufficient number of stream and river basins to test the efficiency and practicability of the method, or methods, developed.

It was also agreed, at that first meeting, that the work group should confine its studies largely to the Great Plains agricultural area. The advisory group specifically advised the work group not to undertake studies of the effects of forest land treatment on water yields. Also the work group was advised not to include studies of snowmelt runoff in the western mountain snow country.

The work group reviewed all available literature pertaining to effects of land and watershed treatment on runoff and the yield of streamflow. Though the literature is voluminous and many bits and pieces of information are available, it was found that none described a comprehensive solution of the problem.

For about the first 3 years of the 5-year period, the work group addressed itself to the first step above, i.e., to determine for selected areas whether land and watershed treatment affects water yields in quantities measurable by use of presently available data.

The processes involved in the generation of water yield by streamflow were examined, as were the sources and kinds of data pertaining to the subject. The precipitation-runoff relationship is very complex, involving some 30 phenomena. Also, the data on many factors are extremely variable and only approximate. No data are available on some seemingly important factors.

All available applicable data from hydrologic research stations were analyzed rather exhaustively. These analyses were directed toward determining the manner and magnitude of the effect on small-watershed runoff due to conservation treatment. The purpose was to obtain basic information for possible use in studies of larger watersheds and river basins.

Findings at Waco and Spur, Tex.; Guthrie and Cherokee, Okla.; Hastings, Nebr.; and Lafayette, Ind., indicate that the conservation use and treatment of land may reduce *surface runoff* from small watersheds from 25 to 40 percent, particularly in dry years. The data were not so conclusive regarding effects of treatment during wet years. It should be emphasized that these reductions were for surface runoff from small upland areas and do not necessarily indicate the magnitude of reductions, if any, that might be effected on larger stream and river basins. No means has yet been discovered for directly translating small-watershed-research results to large complex watersheds.

The streamflow, precipitation, and other records for many river basins were analyzed. Various studies were on annual, seasonal, and storm basis. Most intensive studies of river basins were confined to those where considerable soil-and-water-conservation work had been done. These included the Little Blue River in Nebraska, the Delaware River in Kansas, the Upper Washita River in Oklahoma, the Clear Fork of the Brazos River in Texas, and the Cheyenne River above Angostura Reservoir in Wyoming, Nebraska, and South Dakota.

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River basins less intensively studied included the Salt, Nemaha, Big Blue, and Elkhorn in Nebraska; Soldier, Stranger, Pawnee, and Wakarusa in Kansas; Little Missouri in the Dakotas, Wyoming, and Montana; the Leon, Concho, and East Fork Trinity and Brazos above Waco in Texas; Barnitz and Sandstone Creeks (tributaries of the Washita) in Oklahoma; about 15 creek watersheds near Los Angeles, Calif.; the Petit Jean, Ark.; Kentucky River, Ky.; the Nishnabotna, Tarkio, Nodaway, Grand, Thompson, Weldon, Locust, Medicine, Chariton, North Fabius, Fox, and Wyaconda in the Iowa-Missouri State-boundary area; and the Bad River in South Dakota. Very brief examinations were made of precipitation-streamflow relations of another 70-odd river basins east of the Rocky Mountains. Some 40 additional basins were investigated in relation to "best" water, or hydrologic, years.

Many methods of evaluating effects of watershed treatment on streamflow were tried. Included were simple correlations and regressions, multiple correlations and regressions (linear and curvilinear), analyses of variance, time-series studies, double-mass diagrams, "before and after" comparisons, hydrograph analyses, and others. All the methods were basically directed toward determining if there had been changes in the precipitation-streamflow relations of the river basins. No statistical approach was found that would consistently assess effects of land treatment on streamflow from river basins, or even prove conclusively that such effects do or do not exist. In a few cases, streamflow appeared to be increasing. In some, it appeared to be decreasing. In all cases, streamflow fluctuated considerably, due to climatic or other causes. This lack of positive findings should not be interpreted to mean, however, that the conservation use and treatment of upstream land has no effects on downstream water yields by streamflow. It is axiomatic that there must be such effects in dry subhumid-to-arid areas where available soil moisture, not solar energy, consistently limits evapotranspiration.

It may also be that the statistical models used to analyze these data were not appropriate. Indeed it is strongly suspected that the seemingly ideal statistical model—multiple regression—is not applicable to the hydrologic data now available.

Another difficulty encountered was that only part of the needed conservation program has been installed in most river basins. Even in the Upper Washita River basin of Oklahoma and the Clear Fork Brazos in Texas, two river basins where outstanding amounts of conservation work had been installed, much remains to be done before all conservation needs are met. Furthermore, most of the conservation work has been accomplished in the last few years, and thus has had a very short time in which to function. A very large change in the precipitation-streamflow relation in a few late years in a long streamflow record will not show up statistically significant, so great are the variances involved.

Much of the data regarding streamflow, watershed precipitation, rainfall intensities, land use, land treatment, and related factors are fraught with uncertainties. These are so great that it is believed it cannot ever be demonstrated satisfactorily by statistical analyses, and with only the types and characteristics of watershed, streamflow, and climatic data now generally available, that the conservation use and treatment of land affects water yield by streamflow. To be able to accomplish this objective would require acquisition of very detailed data by research methods. To obtain the required data would be so expensive as to be prohibitive in costs under present-day economic conditions.

The Rational Procedure

Overall, the many investigations carried out demonstrated that a procedure, based only on statistically significant results obtained from studies of river basins and research watersheds, could not be developed. Yet, the evidence on the whole indicated that conservation measures such as contouring did affect on-site runoff, and it is self-evident that, in drier areas, storage in ponds and reservoirs, drainage of potholes, and irrigation affect on-site water yield. Since a procedure could not be demonstrated statistically, a rational procedure was developed. The best available information relating to the various components of the hydrologic processes involved in the generation of precipitation excess and delivery of water yields by streamflow was the basis for the procedure.

It should be emphasized that the rational procedure described hereafter was developed to provide reasonable estimates of average annual effects of watershed treatment on streamflow in the dry subhumid-to-arid areas such as the Great Plains, Midwest, and Southwest. The use of the procedure should therefore be restricted within these limits.

DEVELOPMENT OF THE RATIONAL METHOD

Introduction

The rational method of analysis consists essentially of applying logic and known effects to the problem. A central tenet of the method is breaking the problem down to its elements on the basis of climate, evapotranspiration, soils, topography, vegetation, land use and treatment, and streamflow, then treating only those elements subject to effects of conservation use and treatment of land.

Applying logic to the water-yield problem indicates that water yields are residuals from precipitation after the demands of evapotranspiration are met. In humid to perhumid areas,[1] evapotranspiration is near potential evapotranspiration as limited only by the solar energy available; the vegetation seldom suffers from protracted periods of soil moisture stress, because frequent and adequate precipitation keeps soil-moisture quantities at relatively high levels.

In arid areas, on the other hand, available soil moisture, and not solar energy, limits evapotranspiration. Vegetation suffers nearly every year, and for protracted periods, from high soil-moisture stress. In dry subhumid areas, most years will be dry enough that lack of soil moisture limits evapotranspiration. In moist subhumid areas, most years will have largely adequate soil moisture, and it is only in the drier years that evapotranspiration will be markedly limited by soil-moisture exhaustion.

[1] Classifications of climate used in this report after Thornthwaite, C. W., An Approach Toward a Rational Classification of Climate. Geog. Rev. 38(1): 55-94. 1948.

From the above and from known effects of the conservation use and treatment of land on on-site runoff, it is apparent that the conservation use and treatment of land, as we know it today, will have only very limited effects on water yield from large watersheds in humid climates. In dry subhumid-to-arid climates, there will be effects from these practices. In moist subhumid climates, there will be no effects in the wet years, but there may be effects in dry years.

Further rationalization of the processes involved in the generation of water yields and studies of the streamflow regimen of many Great Plains rivers indicated that the great bulk of the water yield from most rivers in the Great Plains results from surface runoff. Generally, one or two major storms, in most years, cause the greater part of the water yield. Except for a few streams, such as those in the Sand Hills of Nebraska and those entrenched into and draining groundwater aquifers, water yields by base flow are insignificantly low. It was reasoned that the effects of the conservation use and treatment of land and watersheds are most direct, immediate, and important on this surface runoff component of streamflow, since the soils are only rarely fully recharged. Efforts were, therefore, mainly directed toward defining such effects.

During the development of the method those elements of the problem that were deemed germane were isolated, and working tools necessary for easy application of the method were developed.

Watershed Characteristics

An examination of the physical characteristics of the watershed was necessary, to indicate the necessity of evaluating the effects of conservation treatment. Perhaps the first watershed characteristic that should be examined is that of the uniformity, or lack of uniformity, of water yields over the watershed under study. It was estimated from available records, for example, that 40 percent of the water yielded by the Cheyenne River to Angostura Reservoir in southwestern South Dakota comes from less than 6 percent of the watershed. This is only part of the Black Hills area tributary to the reservoir. Conversely, some watersheds may have large areas that, because of climatic, soils, or other characteristics, do not yield proportionate amounts of water. Such abnormally high or low water-yielding areas should be isolated and studied separately.

Soils

The soil characteristics of a watershed largely control land use and dictate the conservation treatment needed. The soils (dune sands) of the Nebraska Sandhills, for example, are so pervious that there is practically no surface runoff. The topography is dunelike, with no fully developed drainage system, and nearly all streamflow is from interflow or groundwater. Such soil characteristics negate any pronounced effects of conservation treatment on water yields by streamflow. There are similar areas in northeastern Colorado, in parts of Kansas and Oklahoma, and elsewhere.

At the other extreme of soils are the heavy clays, typified by the Badlands of South Dakota and vicinity, where some of the soils, developed from Pierre shale, are nearly impervious. In such areas, impoundments (ponds, etc.) are about the only conservation measures that can affect water yields by streamflow because infiltration rates of the nearly impervious soils cannot be significantly altered by presently known, economically feasible methods.

Between the two soil extremes discussed above are the medium-textured soils amenable to treatment and protection. The water-deficient Great Plains has mostly such soils; hence, land-and-watershed-conservation treatment may affect most river basins in the Great Plains.

Topography

The topography of watersheds must also be generally considered in deciding whether to estimate the effects of the conservation use and treatment of land on water yielded by streamflow. Topographic features considered should be both natural and man made. A number of watersheds in the Great Plains have relatively large portions of interior drainage. The North Fork of the Republican River in northeastern Colorado, for example, has a total reported drainage area of 816 square miles, but only 136 square miles of this total, or 17 percent, are considered to be directly tributary to the river. Treatment of the 680 square miles of noncontributing land was not considered to affect water yields from surface runoff.

In some watersheds, faulting or other geologic formations allow streamflow from some parts of the watershed to be discharged directly to the ground water. What happens to the land upstream from these geologic formations will have no effect on downstream water yields by surface runoff.

Large reservoirs may similarly serve to eliminate from consideration parts of some river basins. Land treatment above such reservoirs may affect inflow to the reservoirs, but it should have little effect on streamflow below such large reservoirs, if all the stored water is consumed in irrigation or by industry and municipalities, or otherwise diverted outside the watershed. Fort Phantom Hill and three smaller reservoirs, with a combined storage capacity of some 88,000 acre-feet, probably serve to isolate the 478-square-mile drainage area of Elm Creek from the Clear Fork of the Brazos River, Tex., for instance.

Land Use and Treatment

Some whole watersheds and large parts of other watersheds, due to climatic and/or soils limitations, markets, or cultural habits, have rather fixed land-use-and-treatment patterns.

Desert watersheds of the Southwest are so limited by climatic and soil conditions that they are, in effect, not used and can't be until or unless some scientific breakthrough occurs that will provide water supplies, or new crops, or something else that is not now envisioned. The effects of conservation treatment on water yields of such watersheds need not be estimated.

Several watersheds in the Great Plains have lands in only two uses—wheat and range. All the arable land is in a wheat-and-fallow rotation, due to climatic conditions. Wind erosion is a hazard; hence, most of the cultivated land may be laid out in long, narrow windstrips across the direction of the prevailing wind. Rangeland is relegated to rough, broken land, or land with shallow soils, or other soil characteristics that prevent cultivation. Nothing can, nor will, under foreseeable future conditions, change the land-use pattern. Consideration of cultivated land, in such watersheds, was eliminated at once in evaluating conservation effects on streamflow. If ponds are commonly used in the rangeland as a source of stockwater, their effects were evaluated. If, on the other hand, perennial streams or ground water are commonly utilized to supply stock water, this part of the problem became negligible. The whole problem of evaluating conservation effects, for such a watershed, was thus eliminated.

In a few places it was found that market conditions, systems of landownership and tenure, or cultural backgrounds of landowners and operators precluded changes in land use and treatment, at least for the foreseeable future. Such areas were eliminated from consideration when estimating the effects of the conservation use and treatment of land on water yielded by streamflow.

The more-or-less-unusual land use and treatment patterns discussed above are characteristic of only a few watersheds, or parts of watersheds, in the water-deficient Great Plains. Much of the Great Plains, particularly the more humid parts, has a mixed agriculture where improved crop rotations, terraces, contour tillage, mulch or trashy fallow tillage, and other conservation practices are recommended. It is generally recommended that marginal lands (steep, shallow, or badly eroded) in this area be retired from cultivation and used as pasture or meadow. Many farm ponds have been, and are being, constructed. In selected watersheds, larger flood-prevention reservoirs are being planned and constructed. It is in these areas that the conservation use and treatment of land and watersheds are likely to have some effects on water yields.

Character of Streamflow

The character of streamflow is also important in considering the probable effects of the conservation use and treatment of land on water yields. Conservation-treatment measures in more arid areas are partially designed to "hold the raindrop where it falls." The greatest effect of such measures on water yield is to reduce the surface runoff component of streamflow. If the streamflow of a watershed is nearly all base (ground water) flow, effects of conservation treatment on streamflow will be minimal. If, on the other hand, most streamflow is from surface runoff, the effects of conservation are potentially larger.

As examples, nearly all the streamflow of the Clear Fork of the Brazos River in Texas is surface runoff. Nearly all the flow of the White River at Crawford, Nebr., is base flow. In one very wet year, only 20 percent of the flow of the Little Blue River near Fairbury, Nebr., was base flow. In one very dry year, base flow was 97 percent of total flow of this river.

Occasionally, in the northern Great Plains in particular, severe spring floods result from the rapid melt of heavy snowpacks. The severity of such floods and amounts of water yields seem related to the amount of water in the snowpack, rapidity of melt, and soil-frost conditions. The effects of soil frost seem, in turn, to be related to the winter temperature regime, the depth (insulation) of the snowpack, and soil-moisture conditions. Soil that is wet when frozen is relatively

Figure 1.—Average annual potential evapotranspiration in inches. (From Thornthwaite, C. W., Physical Basis of Water Supply and its Principal Uses. U.S. Cong. House Int. and Insular Affairs Com. 1952.)

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impermeable and results in a high percentage of runoff from snowmelt in the spring. If soils are dry, on the other hand, the frozen soils are more permeable and less runoff results.

Under snowmelt conditions described above, the only conservation measures that can materially affect runoff are those that provide storage, such as ponds and level, closed-end terraces. The effects of these types of structures, in turn, are limited by the remaining storage capacities available.

In view of the above, where a very large percentage of water yield results from spring snowmelt on frozen ground, the problem of evaluating the effects of conservation-treatment measures on water yields was reduced to evaluating effects of storage-type structures only. Where only an occasional flood results from snowmelt on frozen ground, the snowmelt flood volume was removed from annual water yield of the surface-runoff component of streamflow and treated separately.

The flow characteristics of any stream under consideration was thus examined to determine whether it was necessary to estimate the effects of the conservation use and treatment of land on water yielded by streamflow. In examining the flow characteristics of many streams in the Great Plains, it was found that their flow characteristics are such that water yields of a great majority of them may be affected to some extent by the conservation use and treatment of the land within their watersheds.

Effects of Conservation

Research Results

As indicated in the first section of this bulletin (p. 3), exhaustive statistical analyses were made of all available applicable-research data. As the rational method began to evolve, it was necessary to reexamine the available research data in order to select and rank those land-treatment measures deemed important and to devise procedures for their use in watershed computations.

The effects of land-treatment measures on runoff should vary, percentagewise, inversely with annual rainfall, or more specifically with the ratio of annual rainfall to average annual potential evapotranspiration (PET). A map of PET for the United States is shown in figure 1. It was reasoned that, as moisture supplies (rainfall) near PET, soil moisture storage capacities and infiltration rates would decrease and, conversely, on-site runoff would increase. Available research data were reexamined in light of this reasoning.

Results of this reexamination are shown in figures 2 to 4. An examination of these illustrations will indicate a decided downward trend of effects of treatment as the ratio of annual rainfall to PET increases. Where calibration-period data were obtained, no such trends are apparent during calibration periods.

Selection of Specific Conservation Measures

The reexamination of research data discussed above and rationalization of water-yield processes led to the selection of specific conservation land-treatment measures generally recommended for the agricultural lands of the Great Plains that were deemed to have appreciable effects

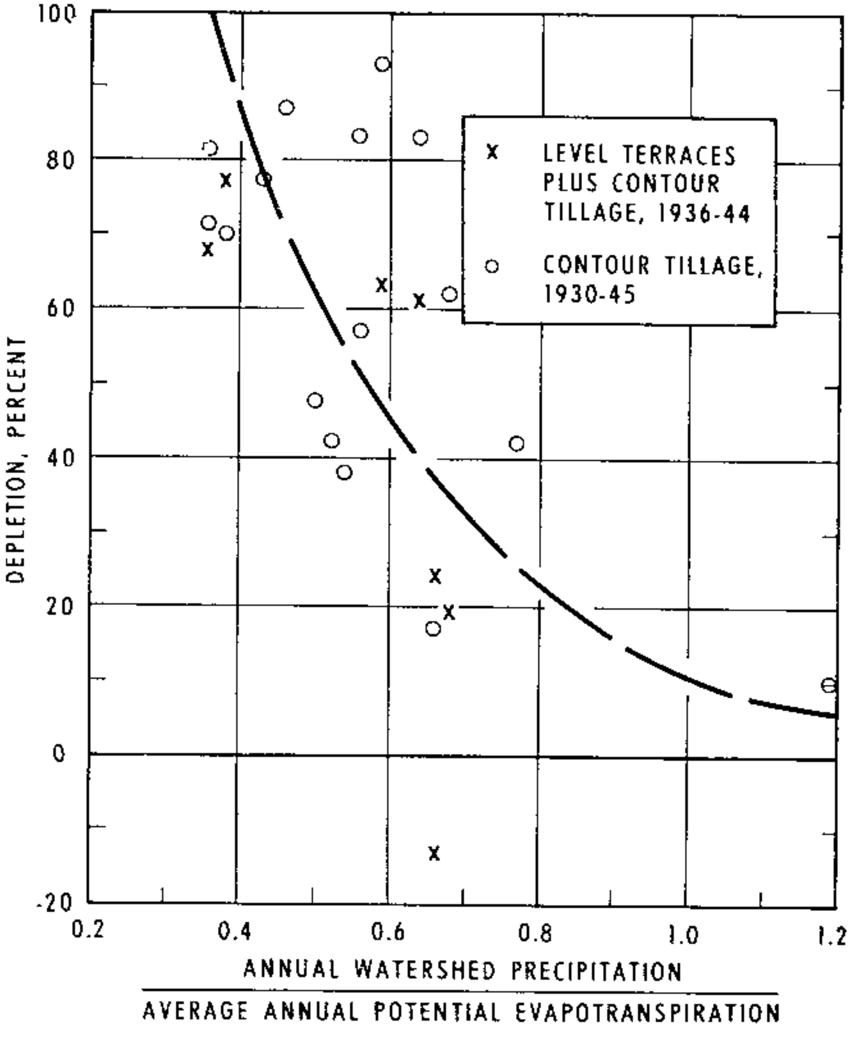

FIGURE 2.—Effects of contour tillage (average of 3 plots) of cotton and level terraces on surface runoff as compared to surface runoff from straight row (3 plots up and downhill) cotton and as related to the ratio of annual watershed precipitation to average annual potential evapotranspiration, Spur, Tex.

on runoff. The selected measures are shown in table 1. Row crops in straight rows (not contour tilled) were selected as a base with which to compare the effects of other crops on conservation treatment, since it is generally considered that unit-source-area surface runoff is highest from row crops as compared with other crops or methods of tillage.

It is necessary to have a companion working tool to use the indices shown in table 1. This is shown by the curve in figure 5. This curve is a generalized one developed from the level-terrace research data obtained at the Texas Agricultural Experiment Station at Spur, and as adjusted on the basis of other limited information available. This curve shows the relations of conservation measure effects to the ratio of annual precipitation to average annual PET.

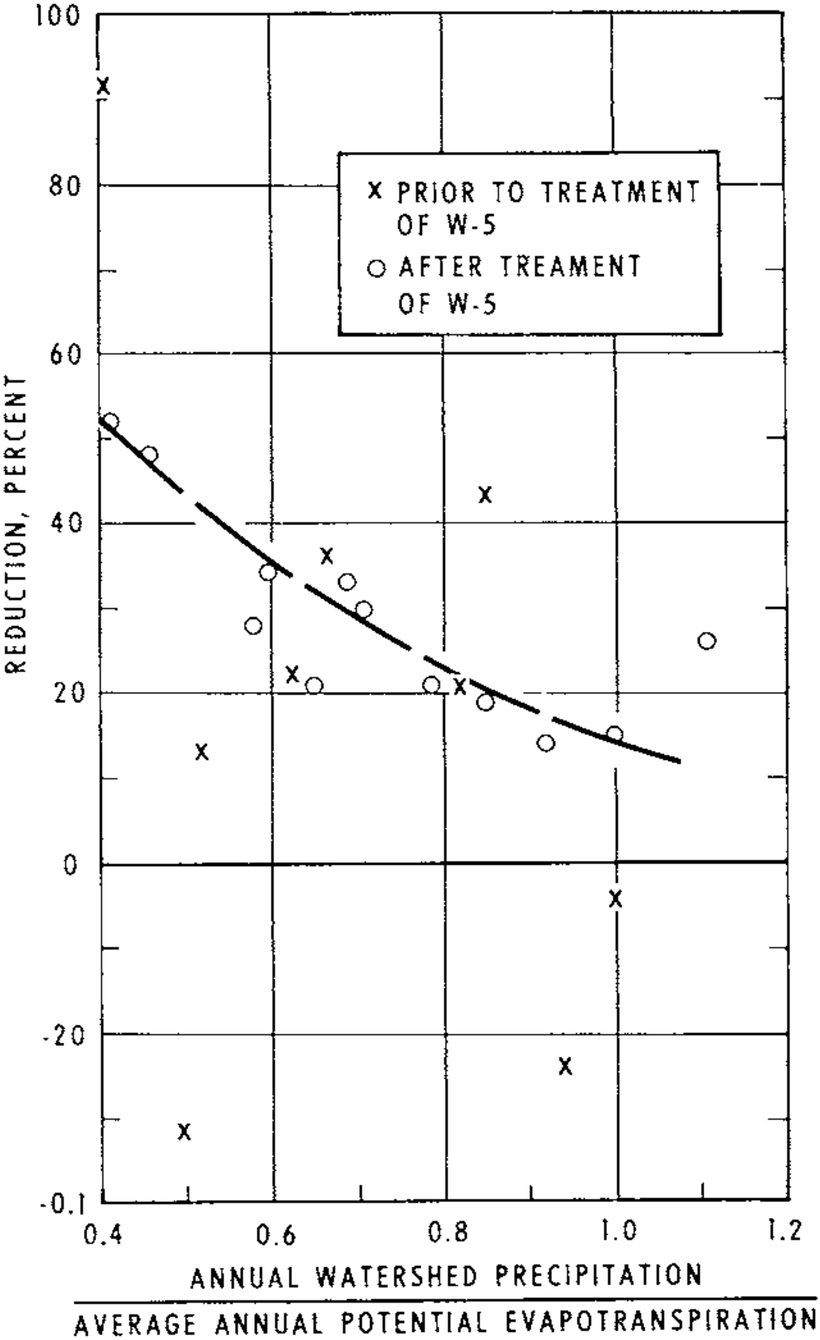

FIGURE 3.—Apparent reduction in surface runoff on watershed W–5 due to conservation treatment as a percentage of surface runoff on watershed W–3, conventionally farmed, as related to ratio of annual watershed precipitation to average annual potential evapotranspiration, Central Great Plains Experimental Watershed, Hastings, Nebr.

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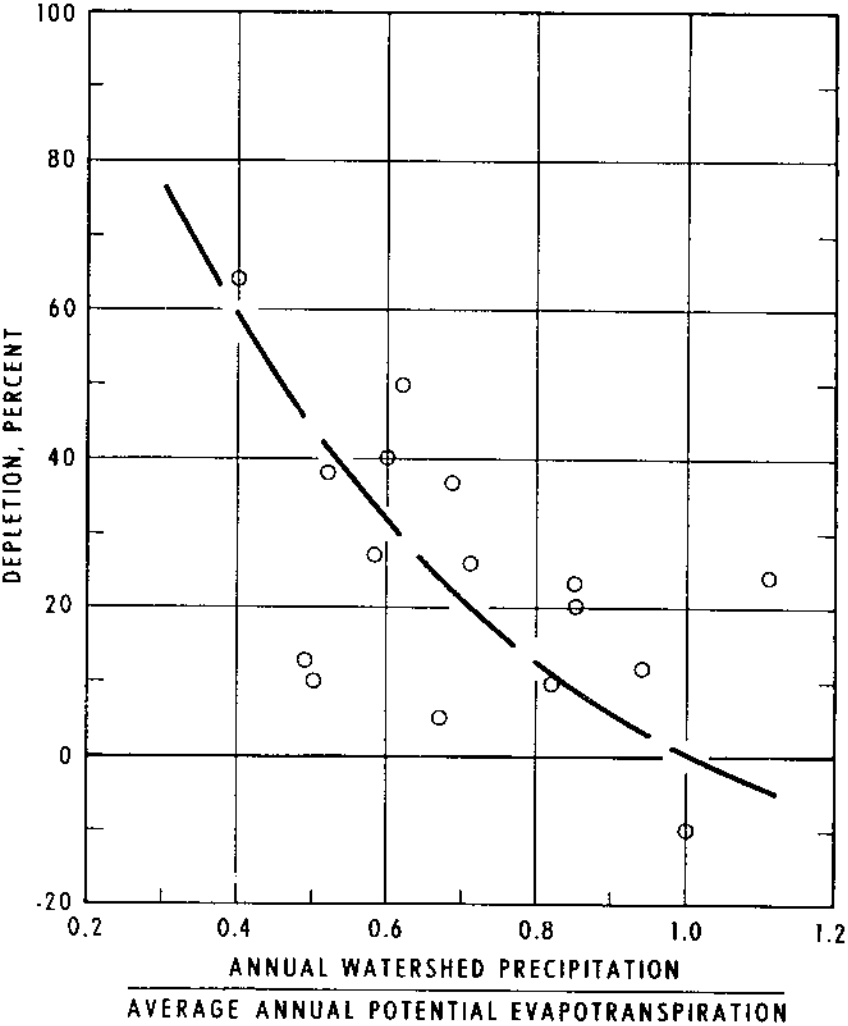

FIGURE 4.—Apparent reductions in surface runoff due to contour tillage as compared to surface runoff from straight-row tilled plots of about half of 12 four-acre watersheds at the Central Great Plains Experimental Watershed, Hastings, Nebr., as related to the ratio of annual watershed precipitation to average annual potential evapotranspiration, 1939–54.

Several conservation measures in general use in the Great Plains are not included in table 1. The most important of these are mulch tillage and rangeland treatment. The available research data (Nebraska and Oklahoma) indicate that mulch tillage (leaving crop residues on the soil surface) perhaps reduces on-site surface runoff during dry years and small storms but tends to increase runoff in wet years, large storms, and later storms occurring one after another. These contradictory data indicate that, since most water yields in dry climates result from large storms or years of above-normal rainfall, mulch tillage effects cancel out and this conservation measure may not significantly affect water yields.

TABLE 1.—*Estimated relative effects of land use and treatment measures in depleting or increasing water yields by surface runoff on Great Plains soils*

Practice [1]	Index to convert from base curve [2]	Effect on runoff
All level closed-end terraces	1.0	Depleting.
Row crops:		
Straight-row [3]	0	Base.
Contour tillage with or without graded terraces	.5	Depleting.
Level open-end terraced with contour tillage	.7	Do.
Small grain:		
Straight-row	.3	Do.
Contour tillage with or without graded terraces	.6	Do.
Level open-end terraces with contour tillage	.7	Do.
Land use conversion:		
Cultivated to noncultivated range, pasture, and meadow on deep, permeable soils (good land).	.7	Do.
Cultivated to noncultivated range, pasture, and meadow on shallow, eroded, slowly permeable soils (poor land).	.4	Do.
Irrigation (as compared to former dryland farming)	-.4	Increasing.

[1] To be used in conjunction with curve in figure 5.
[2] These are, in effect, percentages of the maximum depleting effect of closed-end level terraces, as compared to straight-row crops, shown by the curve in figure 5.
[3] This is the base from which effects of all other practices are referenced.

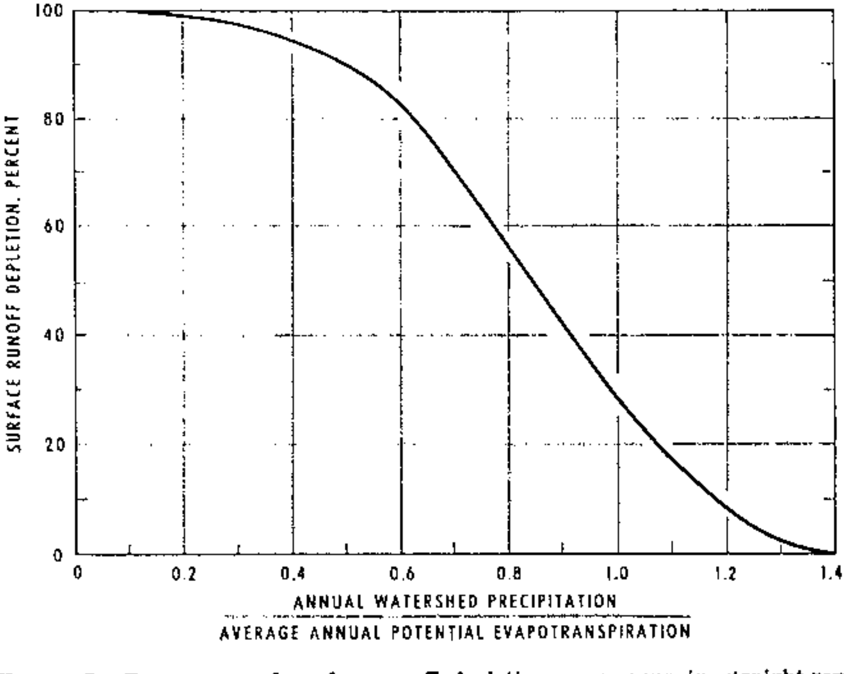

FIGURE 5.—Base curve of surface-runoff depletion, row crops in straight-row farming to level closed-end terraces with contour tillage, as related to relative aridity of climate.

There are practically no watershed-runoff data available to indicate effects, if any, of rangeland treatment. It was reasoned that in the Great Plains only the land not suitable for cultivation is left in range. Vegetation conditions on such land are very sensitive to climatic conditions; hence, the amount of vegetation may vary considerably, despite the best efforts of rangeland operators to maintain good range conditions. It was, because of the reasoning partially outlined above, considered inadvisable to include rangeland treatment among the conservation measures that significantly affect water yields.

Land Drainage Effects

The drainage of land no doubt affects water yields. The drainage of swamps may result in increases in water yields due to lowering of transpiration by eliminating hydrophytes and phreatophytes and lowering evaporation from open-water surfaces as compared to the conditions resulting after drainage is complete. No such swampy areas of any significant size were observed in the Great Plains by the Cooperative Water Yield Procedures study.

The only type of drainage encountered in the Great Plains that might affect water yields was "pot hole" drainage. As has been indicated earlier in this report, some river basins in the Great Plains have large areas of interior drainage. In some of these watersheds, land owners are opening up drains in such areas or leveling land to eliminate "pot holes." This type of land drainage simply increases the active drainage area of a basin. It was reasoned, therefore, that this type of land drainage can be evaluated on direct proportional basis.

Water Spreading

Water spreading, as practiced in the Great Plains is of two types—i.e., flow-type systems and detention-type systems. In the flow-type system, streamflow from the tributary area is diverted and spread onto the irrigated area. In the detention-type system, runoff from the tributary area is temporarily stored above a dam for more slowly and orderly spread on the irrigated area. Water-spreading systems are also classified as to dependability of the water supply, as follows:[2]

Class of system	*Description*	*Design storm (6-hour duration) frequency*
Dependable	Frequent flooding can be expected to provide increased production nearly every year.	1.25-year frequency; 80-percent chance of occurrence.
Questionable	Beneficial flooding; increased production can be expected about half the time.	2-year frequency; 50-percent chance of occurrence.
Undependable	Uncertain flooding; increased production can be expected occasionally.	5-year frequency; 20-percent chance of occurrence.

The purpose of water spreading is to supply as much water to the irrigated area as the vegetation can use. This objective and the dependability of the systems provide a means of evaluating the on-site or upstream effects of water spreading on runoff.

Because of uncertainties involved in this type of irrigation, the systems should be considered to supply potential evapotranspiration

[2] U.S. DEPARTMENT OF AGRICULTURE, SOIL CONSERVATION SERVICE, NEBRASKA ENGINEERING HANDBOOK FOR WORK UNIT STAFFS. Part 14, p. 14–2. [No date.]

for only those percentages of time shown in the class of system—80, 50, and 20 percent, for dependable, questionable, and undependable classes, respectively.

Pond and Reservoir Effects

In drier climates, it is axiomatic that farm ponds and reservoirs must reduce streamflow, because they intercept and store water en route downstream. Evaporation from water stored in ponds and reservoirs is generally much greater than was natural evapotranspiration from the dry site before the pond or reservoir was constructed and filled with standing water. There are, however, practically no research data available on the overall effects of ponds and reservoirs on water yields.

Ponds and reservoirs also lose some water by seepage through and around the dams constructed to create the ponds and reservoirs and by deep percolation into and through the soils and geologic formations underlying the sites. How much of this seepage and percolation is lost to streamflow depends on its ultimate disposition.

Seepage, for instance, may create a wet area in the valley below the pond or reservoir, which supports luxuriant vegetation that transpires essentially all of the seepage water, thus preventing its going on downstream. It was considered that most such seepage water is used on-site, hence is a loss to downstream water yields. It was further considered, however, that, since great care is exercised in constructing dams to keep seepage at a minimum, water losses by seepage, on a watershed basis, are negligible and need not be considered in evaluating the effects of ponds on streamflow.

Deep percolation from ponds and reservoirs may be rapid or slow, depending on the geology of the site. Percolation is practically zero in many areas of the Great Plains where soil and subsoil conditions are favorable. In southwestern Iowa and western South Dakota, however, percolation is extremely rapid. In some of these and other areas, percolation is so rapid, in fact, that ponds will not provide a reliable water supply for livestock on the range.

It appears from the small amount of information available that the clay (< 2 microns) content of the soil, or more particularly the subsoil, where ponds are built is a good indication of the probable rate of percolation of water from ponds. The curve shown in figure 6 was derived from the limited data available for use in estimating the percolation rate from ponds and reservoirs.

Just estimating percolation was not sufficient. A judgment had to be made as to the final disposition of such percolation. Is it, or isn't it, lost from water yields? Again, the problem was rationalized as follows.

Farm ponds are generally small in water-surface area and constructed well up on river-basin hillsides many feet above ground water. Percolation from such ponds is likely to saturate a bulb of underlying subsoil and geologic material beneath the water body. Roots of vegetation and vapor transfer are likely to remove water from the surface of this saturated bulb about as fast as it appears. Such percolated water, therefore, would rarely reach ground water to increase this body of water, hence increase base flow, and thus perhaps increase total water yields. Percolation from farm ponds, therefore, was considered part of the "water cost" of such ponds.

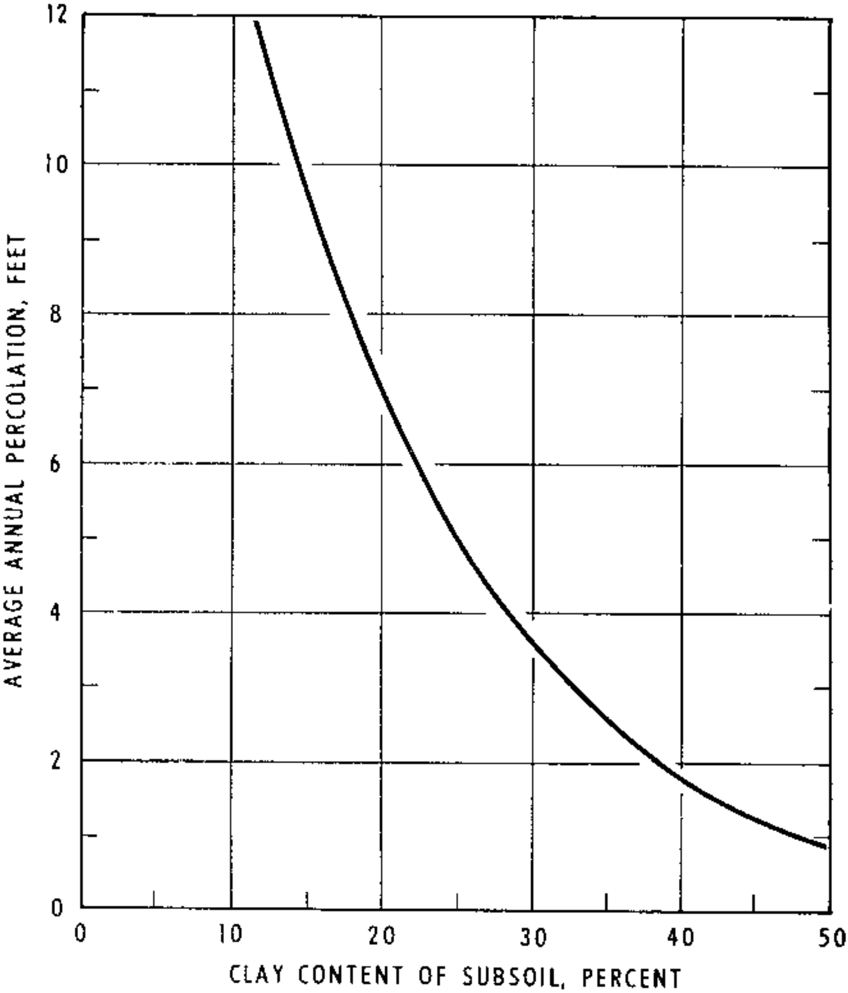

FIGURE 6.—Estimated average annual rates of percolation of water stored in ponds in relation to clay content of soil material (<2 microns) in which pond basin is constructed.

Floodwater-retarding and other larger reservoirs, on the other hand, are generally constructed well down the tributaries to rivers. The bottoms of their basins are near, or may actually intercept, the ground-water table. Percolation from such structures, therefore, probably soon builds a ground-water mound on the regional ground-water table and percolation from floodwater-retarding reservoirs thus becomes a part of regional ground water and augments water yields somewhere, sometime.

There are other minor "water costs" of ponds and reservoirs. These structures, particularly reservoirs, are equipped with principal and emergency spillways. The more-or-less-permanent water surface is at the level of the principal spillway. During periods of runoff, the

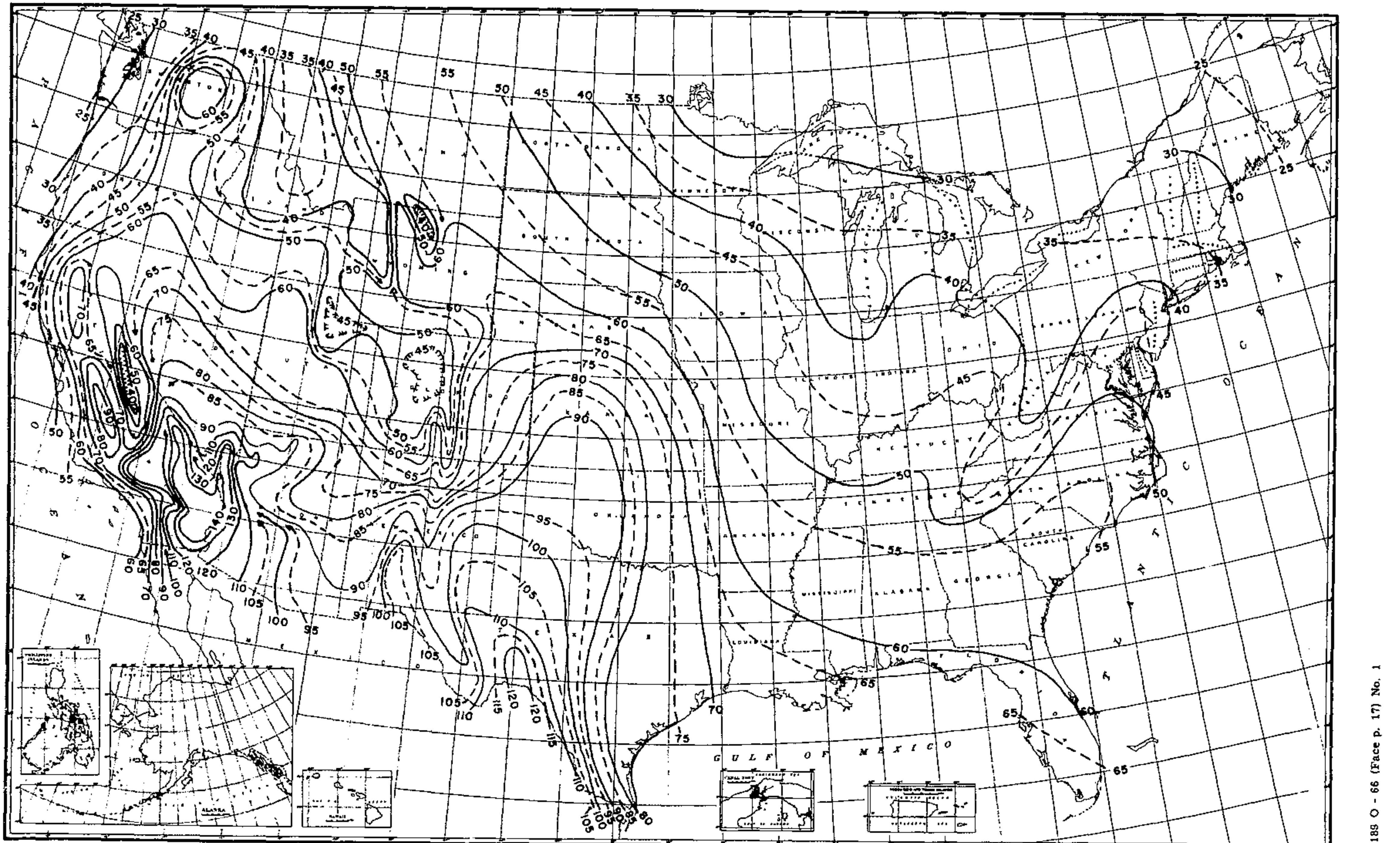

FIGURE 7.—Average annual class A pan evaporation in inches for 1946–55. (From U.S. Weather Bureau Tech. Paper 37.)

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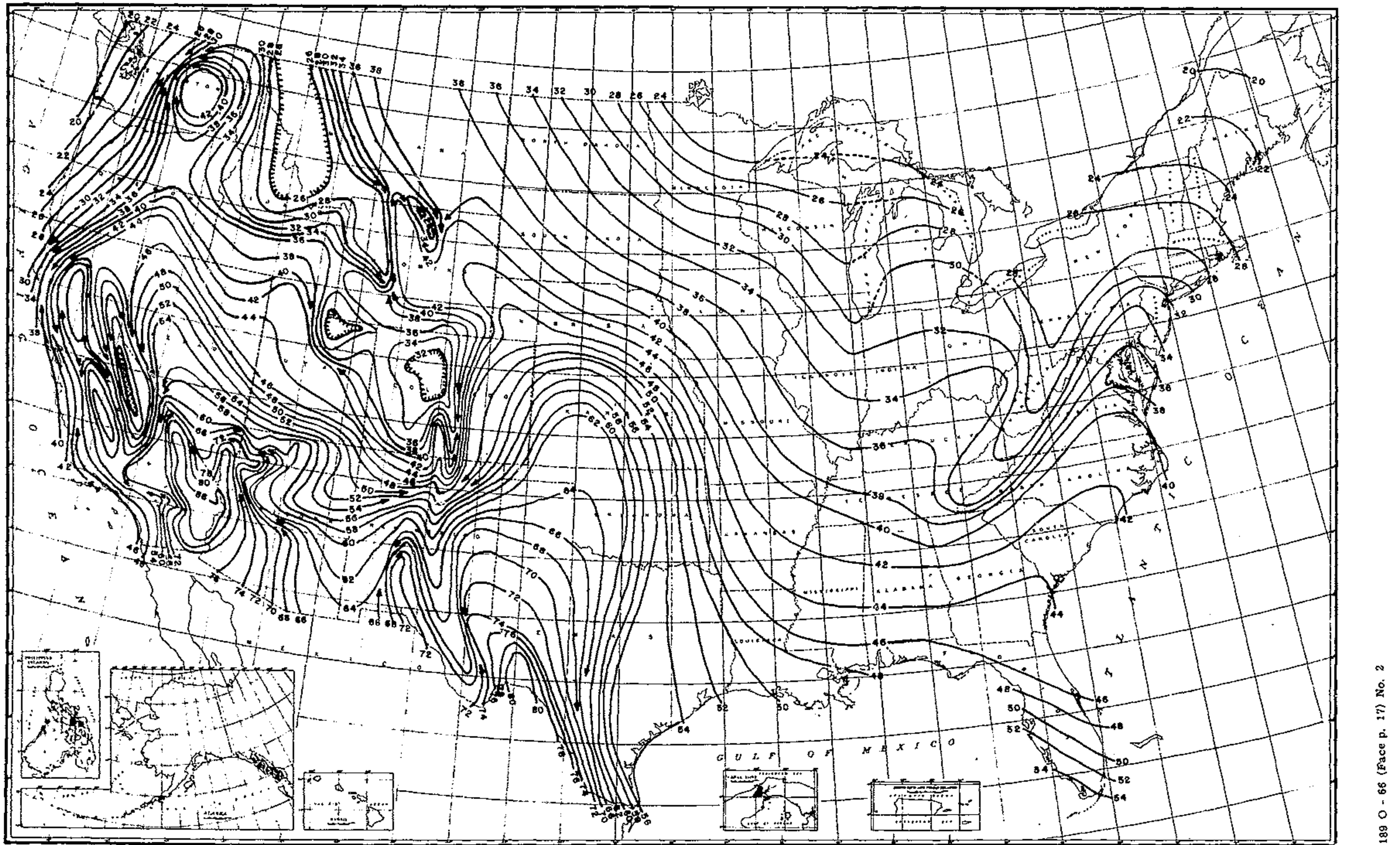

FIGURE 8.—Average annual lake evaporation in inches for 1946–55. (From U.S. (Weather Bureau Tech. Paper 37.)

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periphery of the pond is inundated for varying lengths of time. Water soaking into this peripheral area may be retained and lost later by evapotranspiration. It was reasoned that, on a watershed basis, water thus locally consumed is negligible and need not be considered in a study of a river basin.

It also takes water initially to soak up the site of a pond or reservoir. Again, however, it was reasoned that such water use would be so small on a watershed that it could be neglected.

Based on the reasoning outlined above, the "water cost" of ponds is net evaporation plus percolation. The "water cost" of floodwater-retarding reservoirs is net evaporation. To translate these on-site water uses into volumes that could be used to adjust streamflow, several working tools were necessary.

Pond and reservoir evaporation.—Very little data are available on pond and reservoir evaporation. None were generally available in watersheds being studied, to estimate the effects of the conservation use and treatment of land on water yields. It was necessary, therefore, to develop a method of estimating water losses from ponds and reservoirs by evaporation. It was also necessary that any methodology developed must utilize data and information readily available. The U.S. Weather Bureau publishes records of class A land evaporation pans obtained at widely scattered locations in most States. Maps are also available of the United States, showing estimated average annual pan evaporation and pond and lake evaporation (figs. 7 and 8). It was reasoned that these records and maps could be utilized for obtaining reasonable estimates of pond and reservoir evaporation.

It was thought that annual evaporation losses from ponds and reservoirs should vary from year to year just as pan evaporation varies. The ratios of annual pan evaporation to average annual pan evaporation (computed from the total pan record, or read from the map in fig. 7) could be used to adjust average annual pond evaporation (read from map, fig. 8) to annual values for use in estimating probable pond effects on water yields.

Further reasoning indicated that evaporation so computed represents too great an abstraction from streamflow, because the pond site used water prior to construction of the pond. This original on-site water use is a variable from place to place and year to year, depending on precipitation and runoff from the site. In drier climates, unit area runoff is very low; hence, on-site water use is nearly equal to rainfall (could actually exceed rainfall in pond sites obtaining additional water from tributary areas). It was concluded, in view of this, that the net "water cost" from evaporation from ponds would closely approximate evaporation minus direct rainfall on the pond. This method, therefore, was adopted for estimating evaporation losses, in depth, from ponds and reservoirs. It was found, however, in a few years, that rainfall exceeds estimated evaporation, hence evaporation minus rainfall resulted in negative values. Such values were entered, in the computations, as zeros.

Volumes of pond evaporation and percolation.—The discussions above of evaporation and percolation from ponds pertain to depths of such losses—feet and inches. This lineal dimension does not indicate volumes of water dissipated by these means. To convert these lineal dimensions into volumes of water, it was necessary to develop a method of estimating average annual water-surface areas of ponds and reservoirs. The water-surface area of any pond or reservoir, unless fed by springs, varies—the water-surface area decreases as evaporation and percolation occurs; increases as inflow exceeds losses. In more humid climates, inflow events are frequent and ponds are nearly full all the time. The drier the climate, the less frequently will the pond be replenished and the smaller will the average water surface be.

Only very limited data are available on pond and small reservoir stages (an indication of water-surface area). The curves shown in figure 9 were derived from the limited data available from Oklahoma, Texas, Nebraska, Wyoming, and South Dakota. Pond-stage data and survey data on stage-capacities and stage-water-surface areas, with consideration of climatic conditions (frequencies and seasons of runoff events), were used in developing these curves.

Transmission Losses

In the methodology for estimating effects of conservation measures on water yields, developed as discussed above, the effects of land-treatment practices per se, such as contour tillage and changes in land use,

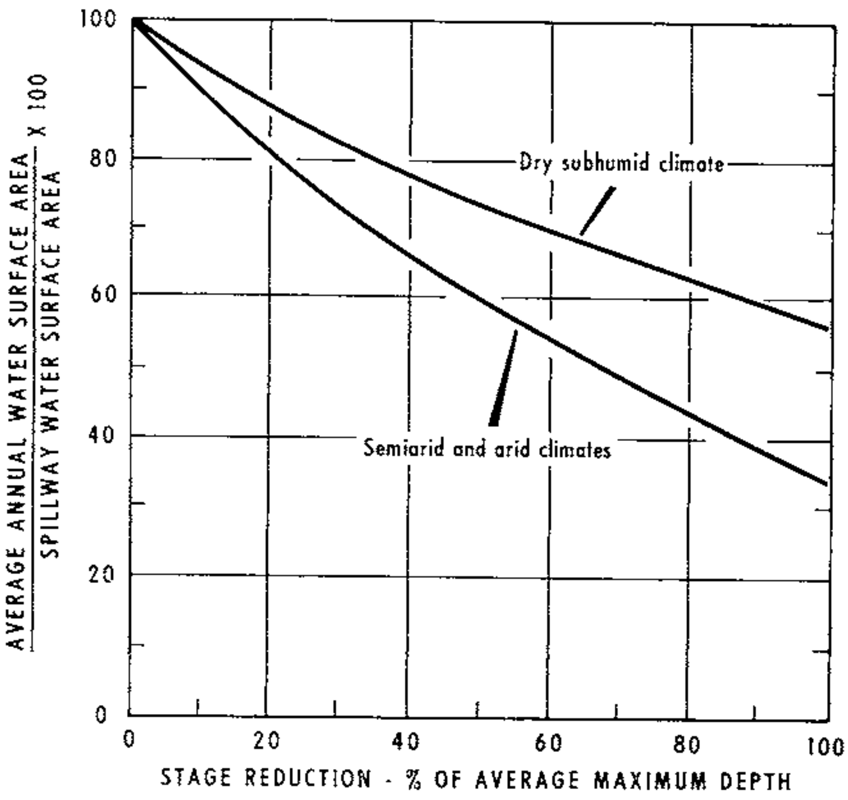

FIGURE 9.—Average water-surface area and stage reduction by percolation and/or evaporation for ponds and flood prevention reservoirs.

are estimated by use of percentages applied to the surface-flow component of observed streamflow. The effects of ponds, reservoirs, and water spreading, however, are estimated as on-site water uses. Studies of many river basins and research data indicate that on-site runoff or water use does not necessarily reflect the resultant losses that may be expected at some downstream point. Transmission losses in channel systems take a toll of upstream runoff.[3 4 5]

In the rational procedure, the downstream runoff (surface-flow component) is "washed back" onto the watershed and adjusted by percentages (developed from research data) for estimating effects of land treatment. It was reasoned that this approach would essentially eliminate the need to give further consideration to transmission losses in estimating the effects of land treatment.

Conversely, on-site loss estimates, such as those from ponds and water spreading, should be adjusted for transmission losses. Logic would indicate that valley transmission losses should be roughly inversely proportional to the ratio of precipitation to potential evapotranspiration. When precipitation is low and evapotranspiration high, vegetation on valley land draws heavily on soil moisture to considerable depths. This creates a large storage capacity for water prior to the next flood event, and hence results in high transmission losses. On the other hand, when precipitation exceeds evapotranspiration, precipitation tends to fill the valley soils to capacity and thus leaves no storage capacity to store flood waters. The result is low transmission losses.

This general theory was followed in developing the curve shown in figure 10. It must be admitted that there was all too little factual information upon which to develop the curve, but it is probably substantially near what actually occurs. At least it is believed to be the best that can be developed in view of our present state of knowledge of this subject. It will probably be necessary to use this, or a similar, curve until research may provide a better method for correcting upstream retentions of water by ponds to amounts that would have appeared downstream had the ponds not been constructed.

Conclusion

The rational method of analysis was developed slowly, step by step, after many trials. It was applied to several watersheds in the developmental process, and, as refinements and improved processes were developed, it was reapplied to the same watersheds. In early trials, the methodology was applied to selected watersheds by use of storm-rainfall and streamflow periods. Later, monthly and annual rainfall and streamflow periods were tried. Comparisons of the results of these

[3] CORNISH, JOHN H. FLOW LOSSES IN DRY SANDY CHANNELS. Jour. Geophys. Res. 66: 1845–1853. 1961.

[4] SHARP, A. L., and SAXTON, K. E. TRANSMISSION LOSSES IN NATURAL STREAM VALLEYS. Jour. Hydraul. Div., Amer. Soc. Civil Engin. Proc. 88 (HY–5, Pt. 1): 121–142. 1962.

[5] ALLIS, J. A., DRAGOUN, F. J., and SHARP, A. L. TRANSMISSION LOSSES IN VALLEYS OF LOESSIAL WATERSHEDS. Amer. Soc. Agr. Engin. Trans. 7 (3): 209–212, 217. 1964.

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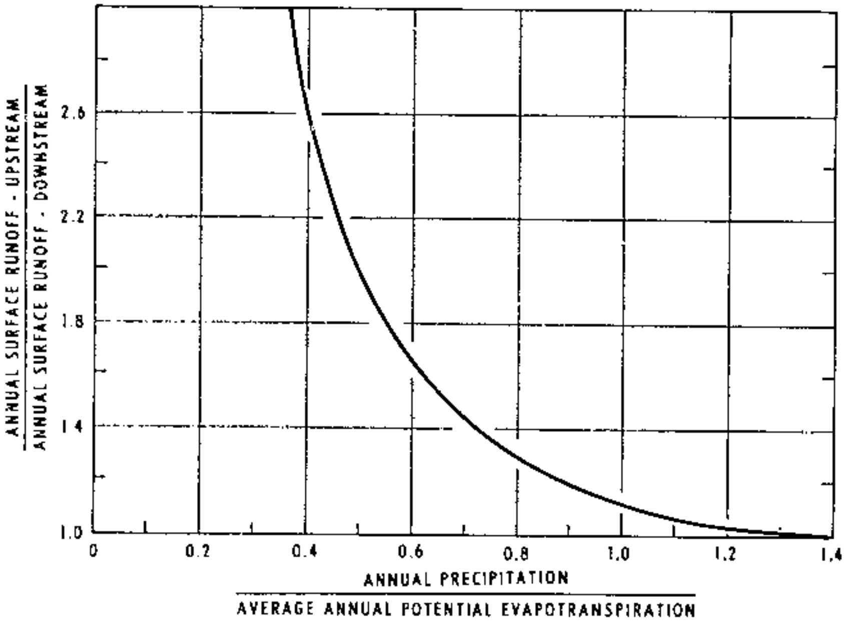

FIGURE 10.—Effects of valley transmission losses on upstream unit-source-area surface runoff en route to downstream gaging stations of large creeks and rivers as related to ratio of average annual precipitation to average annual potential evapotranspiration.

several time-period trials indicated that use of annual data resulted in estimates of effects practically the same as those obtained from use of the more laborious storm and monthly time periods.

DATA TABULATION AND REDUCTION

Once it was decided, after a preliminary examination of the watershed, that estimates of the effects of the conservation use and treatment of land on water yielded by streamflow were necessary and those parts of the basin where such evaluation was required were delineated, several categories of data were required. These included annual streamflow divided into base flow and surface runoff (total flow less base flow and possibly interflow), average watershed precipitation by years, annual class A pan evaporation, average annual pan evaporation, average annual lake evaporation, land-use data, data on conservation treatment in the past, and estimates of conservation treatment likely to be applied in the future. These estimates of future conservation treatment also contained estimates of land-use conversion; i.e., cultivated land likely to be converted to pasture, range, or woodland, and vice versa.

It should also be pointed out, however, by way of warning, that the conservation treatment of land is only one of many factors that may affect streamflow. Other factors, aside from natural phenomena, that may affect streamflow include, but are not limited to, large reservoirs, diversions for one purpose or another, urban and industrial development, highway and airport construction, logging, and forest and range fires. An examination of the effects of these other factors was beyond the scope of cooperative water yield procedures study.

Streamflow Data

The basic requirement for estimating conservation effects on streamflow (and most water-conservation planning) is streamflow records. Such records are available for many larger creeks and rivers, but few such records are available for smaller creeks. Such records, also, are of varying lengths, ranging from a few to 35 or 40 years. Few continuous records are available, except on very large rivers, for more than 50 years. The source of most streamflow records is U.S. Geological Survey Water-Supply Papers.

In using streamflow records for evaluating conservation effects, the first decision that must be made is what water year to use—the normal one used by U.S. Geological Survey in its Water-Supply Papers, October 1 to September 30; the calendar year; or some other. It was decided that the calendar year should be used in evaluating conservation effects, because (1) construction of some conservation measures extends past October 1; (2) the low point in evapotranspiration is not reached until midwinter; and (3) most climatic records are reported by calendar years.

Regardless of the water year selected, it was necessary to separate recorded streamflow into base flow and surface (storm or flood) runoff. In a few areas, it was also necessary to isolate interflow (one form of base flow), because it was a large component of total streamflow. In most of the Great Plains, interflow is relatively small and can be ignored. In rough areas with highly fractured geologic formations and thin, pervious soils, interflow may be large and must be considered. Streamflow may be separated into its several components by any one of several methods. These are explained in many texts and technical papers. Regardless of the method used to separate observed flow into its components, a reasonably approximate separation is required.

In a few cases it was also necessary to remove from annual streamflow the contributions by spring snowmelt on frozen soils. This part of streamflow was treated separately for effects of storage structures only.

Precipitation Data

Average watershed precipitation by years for the period of streamflow records was required. These data were tabulated by the water year selected as discussed above in the subsection on streamflow data. Data from all stations within and adjacent to the watershed were utilized.

The problem of whether to use old station records that were discontinued and records from new stations that have been established during the period of streamflow records immediately arose. No hard and fast rules were followed in these matters. If the old and new records were very short, it was decided to ignore them. If they covered most of the period of streamflow records, they were used. A comparison was always made of estimates of watershed precipitation with and without the part-record stations, since it has been observed that adding more and more stations to a network generally introduces bias into estimates.[6] Use of records from a few stations results, generally, in higher estimates of watershed precipitation than when a greater number of stations are used. When such relations or comparisons were made during periods of concurrent records, the estimates for the few remaining years were adjusted. Relations established during the period of concurrent records were used for the relatively short periods when data from the discontinued old or newly established rain-gage stations were not available.

Another problem was to determine what method to use in computing watershed precipitation from the few and widely dispersed rain-gage-station records that were generally available. The two most frequently used methods are Thiessen weighted averages and simple arithmetic averages. If the rain gages were dispersed reasonably and equally geographically around the watershed, a simple arithmetic average was used, which is just as reliable as one obtained by Thiessen weights. If the gages were not reasonably uniformly distributed, Thiessen weighted values were computed.

Another method that was sometimes used was the preparation of isohyetal maps of the watershed for each year. This method is laborious and did not improve estimates over arithmetic averages or Thiessen weights.[6]

It should be emphasized that none of these methods results in more than guesses as to actual watershed precipitation. A study of the 39 rain gages on the 100-square-mile Sandstone Creek area in Oklahoma[7] indicated that 4 rain gages per township, uniformly spaced, are needed to estimate reasonably accurate watershed precipitation for storms. However, only one or two rain-gage records per county were generally available in watershed studies.

Whichever method was used and regardless of what use was made of partial records, estimates of average watershed precipitation were computed and tabulated for each year of streamflow records.

U.S. Weather Bureau publications are about the only source of data on rainfall.

Evaporation-Pan Data

Evaporation-pan data (Source: U.S. Weather Bureau publications) were needed for each year of streamflow records. It was a rare instance when an evaporation-pan record was found for a station within a watershed. Only a few such stations per State have been operated. In general, it was necessary to use evaporation-pan data from stations at considerable distances from the watershed. Data from one, two, or three pans were generally available. Evaporation pans are operated only during periods of the year when the pans are not subject to freezing. In northern climates, the period of observation generally extends from May through September, inclusive. Further south,

[6] SHARP, A. L., OWEN, W. J., GIBBS, A. E., and HARRIS, B. COMPARISONS OF ESTIMATES OF WATERSHED PRECIPITATION. Unpublished.

[7] THORNTHWAITE, C. W. AN APPROACH TOWARD A RATIONAL CLASSIFICATION OF CLIMATE. Geog. Rev. 38 (1): 55–94. 1948.

April and sometimes October may be added to the period of observation. In areas where freezing hazards are minimal, pans operate the year round.

Two problems immediately arose concerning the use of evaporation-pan data. One of these was to estimate evaporation during those months when the pans were not operated. To do this, evaporation in the month immediately preceding the first month of pan operation was assumed to be half of the first month's measured evaporation. Similarly, evaporation during the month following the last month of operation was assumed to be half that of the last month of operation. It was further assumed evaporation would be negligible during the remaining months of the year (the winter months). These assumptions were based on potential evapotranspiration as reported by Thornthwaite [7] and others.

The other problem concerning the use of pan data was that of estimating evaporation in the watershed from pans many miles away. Where only one pan record is available, this was adjusted, percentagewise, on the basis of average annual evaporation maps available in several publications, one of which is U.S. Weather Bureau Technical Paper No. 37. Figure 7 is a reproduction of one of the maps from the above-mentioned paper. Where a watershed was between two pans or surrounded by three pans, the records of the pans were averaged, either simply or by inversely weighting according to distances of the pans from the watershed.

The average pan evaporation for the entire period of record was also needed. This average was computed from the data tabulated, as discussed above.

Lake or Pond Evaporation

No data are available on amount of evaporation from lakes and ponds—except in very rare instances. These data were, therefore, computed as follows:

1. The ratio of each year's pan evaporation to the average pan evaporation was computed, using pan-evaporation data obtained as discussed immediately above.
2. Average annual lake evaporation for the center of the watershed (or center of area of watershed where ponds are concentrated if they are not uniformly distributed over the watershed) was read from figure 8.
3. The average lake evaporation obtained in step 2 was multiplied by the ratios obtained in step 1 to obtain lake evaporation for each year.
4. Annual watershed precipitation, as computed and discussed above in the section on precipitation data, was deducted from this computed lake evaporation to obtain net pond evaporation.

A word of warning here—in more humid areas, it was frequently found that net pond evaporation was a negative quantity. Even in more arid areas, this occurred in very wet years. These negative quantities will be obtained when annual precipitation exceeds lake evaporation. They were recorded as zeros in the tabulations.

Pond and Reservoir Percolation

Local applicable data on pond and reservoir percolation is almost nonexistent. Estimates of this parameter, therefore, were computed as discussed on pages 15 to 18.

Land-Use Data

Land-use data are available, on a county basis, from the U.S. Farm Census taken each 5 years, or annually from reports compiled or issued by the States in cooperation with Agricultural Statistical Service, U.S. Department of Agriculture. These reports generally have acreages of principal crops planted and harvested. The acres-harvested figures were used, since there is less chance of duplication than in the acres-planted figures. A planted crop, if it fails for some reason, may be replanted in some other crop. Only major crops were tabulated. What was desired, eventually, was a tabulation showing row crops, small grains, pasture and meadow, range, and woodland. This information was needed in order to know what parts of the watershed were affected by particular conservation-treatment practices, and for determining the uses from which land-use conversions were taken or will be taken.

As indicated, data were generally on a county basis. Nearly always county data had to be reduced to a watershed basis, since watershed boundaries usually overlapped two or more counties. It was not deemed safe, in such instances, to divide land use in the county on a proportional basis (developed from areas of the county within and without the watershed) because land use over many counties is not uniform. Rangeland may be concentrated in one part of a county, wheat and fallow in another, and row crops is still another part. Information on the uniformity of land use in a county was obtained from county agricultural extension agents, Agricultural Stabilization and Conservation Service county committees, soil conservation district officials, and Soil Conservation Service work unit and area conservationists. These officials can usually estimate percentages of various land uses within and without watersheds, if they depart from percentages based on proportions of areas. (See example, table 2.)

Land-Treatment Data

Before data on past, and estimated future, land use and treatment were obtained, it was necessary to select those uses and treatments for which data were to be obtained. This required an examination of those treatment practices prevalent in, and recommended for, the given watershed. In preparing to obtain data on land treatment, therefore, it was necessary to obtain preliminary and general information on local conditions and trends, the prevailing land-use and land-treatment practices, and estimates of future developments.

The land-treatment and other practices that were considered effective in changing water yields, and for which data should be obtained, are:

1. Level closed-end terraces (generally contour tilled);
2. Level open-end terraces (generally contour tilled);

3. Contour tillage with or without graded terraces;
4. Land-use conversions;
5. Irrigation;
6. Water spreading;
7. Drainage (pothole);
8. Farm ponds; and
9. Floodwater-retarding reservoirs.

Data on land-treatment measures were obtained from Soil Conservation Service reports (form 195) through June 30, 1961. In 1962, the Soil Conservation Service inaugurated a new machine-reporting system and now prepares form 253 to report progress in establishing conservation measures and practices. These records were not always available for the entire period of streamflow record. An example of the kind of data available is shown in table 3. Treatment of these data—area converted to grass, area terraced (synonymous with area contour tilled), and farm ponds—is illustrated in figure 11.

To reduce the data in table 3 to usable form, it was necessary to make some interpolations and extrapolations. Smoothed curves for these purposes are also shown in figure 11. These smooth curves were extended back in time to values estimated by Soil Conservation Service work unit conservationists. On the basis of their general knowledge of the areas, they can generally estimate when various practices first began to be installed or the quantity of various measures that were in place at the beginning of streamflow records. These points aided in extrapolating the available data.

The data for each work unit within, or partially within, the river basin being analyzed were separately interpolated or extrapolated, rather than combining all the data for the watershed, then interpolating or extrapolating them in one operation.

Once land-treatment data were obtained for Soil Conservation Service work units and interpolated or extrapolated, it was necessary to reduce such work-unit data (often on a county basis) to a watershed basis. As with land-use data, it is not safe to allocate work-unit data to a watershed on the basis of areas of the work unit within and without the watershed. Soil Conservation Service work unit and area conservationists, other conservationists, Agricultural Stabilization and Conservation Service county committeemen, and county agricultural extension agents are best equipped to estimate, practice-by-practice, the proportions of work-unit data within watersheds. Information on these matters was obtained at the same time the data were compiled.

Pond and Reservoir Data

In addition to number, the following information was obtained separately for farm ponds and for flood-prevention reservoirs:

1. Average drainage areas tributary to the ponds and reservoirs.
2. Average water-surface areas of ponds and reservoirs at principal spillway level.
3. Average maximum depths of ponds and reservoirs below principal spillway level.
4. Average clay content of earth material in which the ponds and reservoirs are constructed.
5. Data on stage-water surface areas for ponds and reservoirs.

Table 2.—*Data available on crops harvested, county D, watershed example*

Year	Row crops						Small grain					Total cultivated	Percentage in—	
	Corn	Sorghums		Soybeans	Summer fallow [1]	Total row crops	Wheat	Oats	Barley	Rye	Total small grain		Row crops	Small grain
		Grain	Forage											
	Acres	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*		
1930	115, 493	39	2, 315	-----	-----	117, 847	107, 076	34, 136	1, 608	524	143, 344	261, 191	45	55
1931	124, 400	40	1, 840	-----	-----	126, 280	96, 930	34, 250	2, 070	490	133, 740	260, 020	48	52
1932	149, 840	30	2, 120	-----	-----	151, 990	48, 580	54, 800	3, 320	320	107, 020	259, 010	59	41
1933	141, 510	60	2, 600	-----	-----	144, 170	73, 330	36, 810	2, 300	400	112, 840	257, 010	56	44
1934	64, 780	330	4, 490	-----	-----	69, 600	40, 290	-----	-----	30	40, 320	109, 920	63	37
1935	99, 580	3, 270	2, 810	-----	-----	105, 660	93, 300	38, 930	2, 160	2, 410	136, 800	242, 460	44	56
1936	91, 770	780	1, 840	-----	-----	94, 390	101, 200	26, 180	2, 900	1, 660	131, 940	226, 330	42	58
1937	85, 590	1, 460	2, 230	-----	5, 200	94, 480	132, 570	24, 810	2, 250	1, 660	161, 290	255, 770	37	63
1938	88, 870	3, 220	4, 720	-----	5, 000	101, 810	140, 470	32, 950	4, 730	1, 200	179, 350	281, 160	36	64
1939	83, 830	6, 390	12, 910	-----	21, 000	124, 130	102, 950	29, 310	6, 800	2, 350	141, 410	265, 540	47	53
1940	72, 870	15, 230	19, 590	-----	32, 900	140, 590	58, 440	40, 500	14, 620	890	114, 450	255, 040	55	45
1941	85, 300	10, 850	19, 230	-----	32, 160	147, 540	22, 770	56, 430	31, 610	790	111, 600	259, 140	57	43
1942	88, 680	6, 190	10, 600	-----	28, 590	134, 060	79, 610	35, 450	19, 570	2, 040	136, 670	270, 730	50	50
1943	114, 140	3, 800	6, 060	130	410	124, 540	75, 680	54, 770	11, 780	1, 450	143, 680	268, 220	46	54
1944	128, 630	7, 960	5, 850	100	870	143, 410	62, 660	50, 960	3, 490	800	117, 910	261, 320	55	45
1945	110, 330	970	3, 710	10	450	115, 470	101, 760	50, 720	500	500	153, 480	268, 950	43	57

1946----	109, 830	830	3, 620	10	890	115, 180	113, 210	47, 080	80	280	160, 650	275, 830	42	58
1947----	107, 020	610	1, 530	20	1, 350	110, 530	123, 270	32, 490	20	260	156, 040	266, 570	41	59
1948----	107, 580	1, 210	1, 860	-----	3, 230	113, 880	98, 140	43, 720	120	70	142, 050	255, 930	44	56
1949----	123, 540	2, 170	3, 130	-----	3, 360	132, 200	85, 160	34, 610	210	140	120, 120	252, 320	52	48
1950----	105, 570	10, 280	1, 650	120	3, 500	121, 120	101, 170	40, 770	430	180	142, 550	263, 670	46	54
1951----	108, 730	2, 240	2, 260	280	2, 500	116, 010	103, 260	30, 250	150	190	133, 850	249, 860	46	54
1952----	107, 970	1, 870	1, 770	450	2, 670	114, 730	111, 240	31, 030	180	170	142, 620	257, 350	44	56
1953----	109, 490	6, 270	1, 280	590	6, 000	123, 630	104, 370	31, 380	450	210	136, 410	260, 040	48	52
1954----	104, 610	26, 390	3, 250	640	12, 020	146, 910	88, 970	25, 990	930	740	116, 630	263, 540	56	44
1955----	83, 460	31, 230	3, 250	780	11, 600	130, 320	77, 890	25, 510	820	460	104, 680	235, 000	55	45
1956----	80, 950	43, 120	1, 270	430	15, 120	140, 890	84, 240	18, 500	1, 050	350	104, 140	245, 030	57	43
1957----	73, 150	63, 880	6, 560	40	28, 900	172, 530	77, 390	10, 830	960	480	89, 660	262, 190	66	34
1958----	82, 470	66, 660	2, 160	40	25, 000	176, 330	80, 010	9, 960	980	700	91, 650	267, 980	66	34
1959----	98, 470	60, 450	600	30	14, 500	174, 050	81, 900	8, 270	1, 290	460	91, 920	265, 970	65	35

[1] Included with row crops because of similar runoff characteristics.

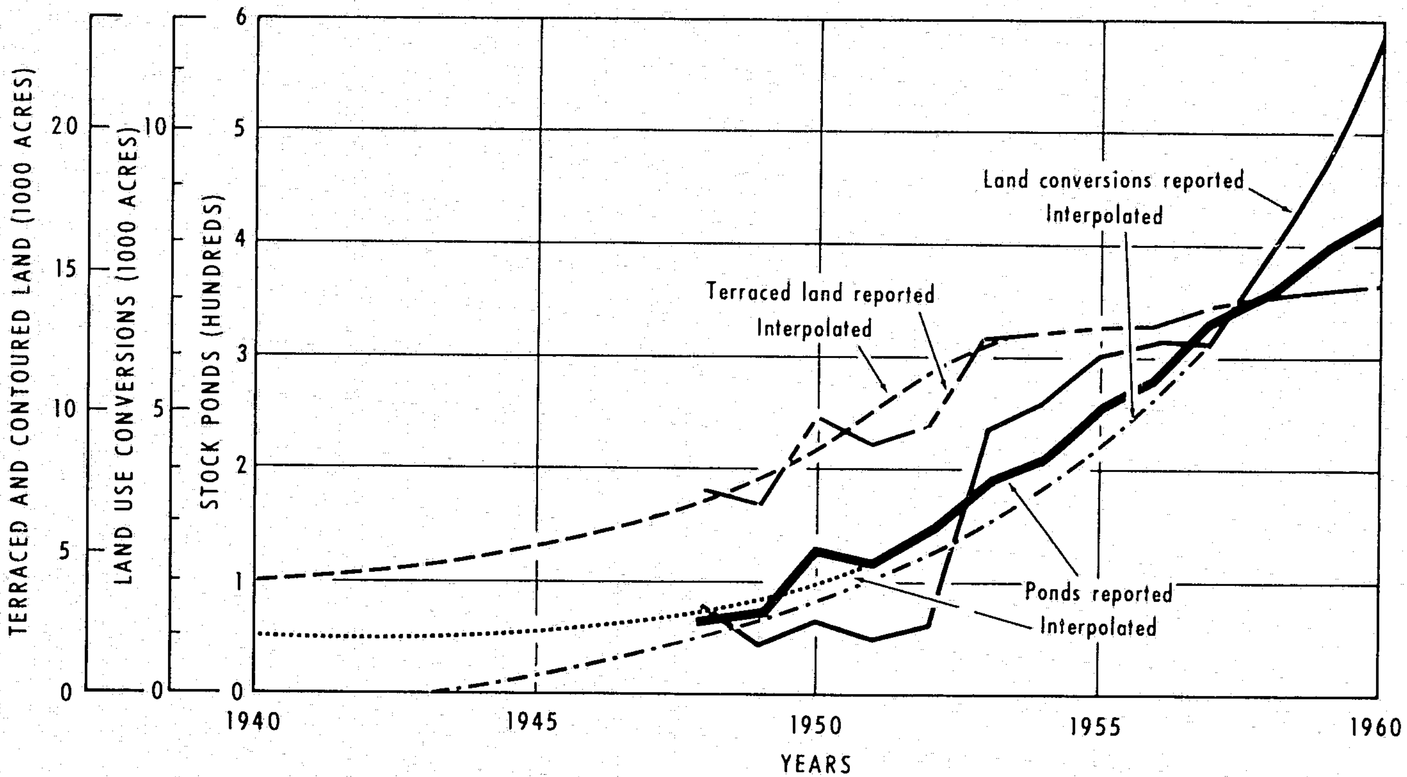

FIGURE 11.—Interpolations necessary to reduce data on land treatment contained in SCS form 195 to usable form, Leedey, Okla., work unit.

TABLE 3.—*A record of land-treatment data applied in the Leedey Work Unit of the Washita River basin, Okla., as obtained from SCS-195 reports*

Year	Land-use conversions [1]	Stock ponds	Terraces	Remarks [2]
	Acres	*Number*	*Miles*	
1948	1, 534	65	450	From 195B.
1949	1, 285	104	625	From 195.
1950	1, 260	130	610	From 195B.
1951	1, 444	173	828	From 195.
1952	1, 806	218	884	From 195.
1953	4, 653	191	788	From 195B.
1954	5, 156	211	806	From 195B.
1955	6, 018	255	816	From 195B.
1956	6, 258	278	819	From 195B.
1957	6, 227	330	860	From 195B.
1958	7, 747	354	881	From 195B.
1959	9, 364	397	902	From 195B.
1960	11, 531	422	915	From 195B.

[1] Application of this practice, which consisted of seeding cultivated land to range is estimated to have begun in 1943.
[2] Form 195 is a report for the entire soil conservation district; form 195B is for that part of the Soil Conservation District in the Washita River basin.

As was indicated earlier (see fig. 6, p 16), the percolation rate of water from ponds is intimately related to clay content of the materials in which the ponds are constructed (although this relation varies with types of clay).

Average drainage areas were required in order to determine if surface runoff from areas tributary to the ponds and reservoirs was sufficient to supply losses from percolation and evaporation. In dry years, particularly, surface runoff, rather than evaporation and percolation, may limit the "water cost" of ponds and reservoirs.

Average water-surface areas of ponds and reservoirs at spillway level, average maximum depths, and stage-water-surface-area data were required for estimating the average annual water surfaces to use in conjunction with percolation and evaporation or with evaporation to compute volumes of on-site water loss. For farm ponds, particularly, no data were generally available on stage-water-surface-area relations.

Data on stage-water-surface areas of floodwater-retarding reservoirs are generally available.

Soil Conservation Service is about the only source of data and information on ponds.

APPLICATION OF THE RATIONAL METHOD TO WATERSHED EXAMPLE

Introduction

The application of the rational method (pp. 30 to 47) for estimating the effects of the conservation use and treatment of land on water yielded by streamflow is illustrated. The purpose is to obtain an estimate of the water that will be available from streamflow under watershed conditions likely to prevail in 1985, and not to correct historical streamflow to a watershed condition without conservation treatment. This latter could be accomplished if such information were desired. This would entail computing corrections for land treatment actually in place during the period of record, rather than computing corrections for the differences in treatment actually in place and those estimated to be accomplished by 1985. It should be recognized that this method does not give consideration to the numerous other factors, such as highways and urban and suburban development that also may influence water yield.

The watershed chosen for this example has a drainage area of 2,296 square miles, or 1,469,440 acres. It is in the dry subhumid zone. All the watershed is farmed (no rough-broken, sandy, or shallow-soil areas to be omitted) in general crops, meadows, and pasture. There are no extensive forested, and only limited range, lands within the watershed. The watershed contains parts of eight counties. Each county is organized into a Soil Conservation District. Some fictional data were introduced to make the example as complete as possible.

A small watershed-protection and flood-prevention project was initiated in 1948 and essentially completed by 1960 in the watershed. A total of 152 floodwater-retarding reservoirs, out of a planned 160, were constructed under auspices of this program by 1960.

One small part of the watershed is devoted primarily to range and has some small water-spreading systems installed. This area is not above ponds and floodwater-retarding reservoirs, and the land above the diversion works has no conservation treatment (other than range treatment, which is not evaluated in the rational procedure); hence, this small area was evaluated separately.

The land tributary to ponds has normal conservation use and treatment, and areas tributary to floodwater-retarding reservoirs have both land treatment and ponds. These several practices and measures were, therefore, evaluated consecutively—land-treatment-measure effects were evaluated first, then farm ponds, because land treatment affects inflow to ponds. The floodwater-retarding reservoirs were then evaluated, as both land-treatment measures and ponds affect inflow to them.

Basic Data

The basic data (that concerning streamflow, climate, etc.) required to evaluate the effects of the conservation use and treatment of land on water yielded by streamflow of a watershed example are shown in table 4.

Land-Use Pattern

As has been indicated earlier in this bulletin, it was necessary to obtain patterns of land use in the watershed under study. The watershed example contains parts of eight counties, designated A, B, C, etc. Crops harvested each year of runoff records were tabulated. The data were obtained from annual reports prepared cooperatively by Statistical Reporting Service, USDA, and the State board of agriculture.

An example of the data available for county D is shown in table 2. The percentage of cultivated land in row crops, year by year, and the average for 1930–53 are shown in figure 12. The percentages of row crops and small grain, 52 and 48, respectively, were needed later to weight the effects of certain land-treatment practices. If strong trends in changes in crops had been found, averages of cropping patterns would not have been used; rather, cropping patterns year by year of the record would have been used.

Evaluating Effects of Land Treatment

The watershed example contains parts of eight Soil Conservation Districts (counties). Data on the installation of those land-treatment practices that appear to affect water yields—level open-end terraces, contour tillage, converting cultivated land to pasture, irrigation, pothole drainage, and water-spreading—were obtained from form 195 maintained by the Soil Conservation Service. Part of these data was available in the Soil Conservation Service work unit offices, and the older data were available in the Soil Conservation Service State office. An illustration of the type of data available is shown in the first section of table 5. No level terraces were listed as practices in county H. The Soil Conservation District was organized in 1939, and its first year of operation was 1940.

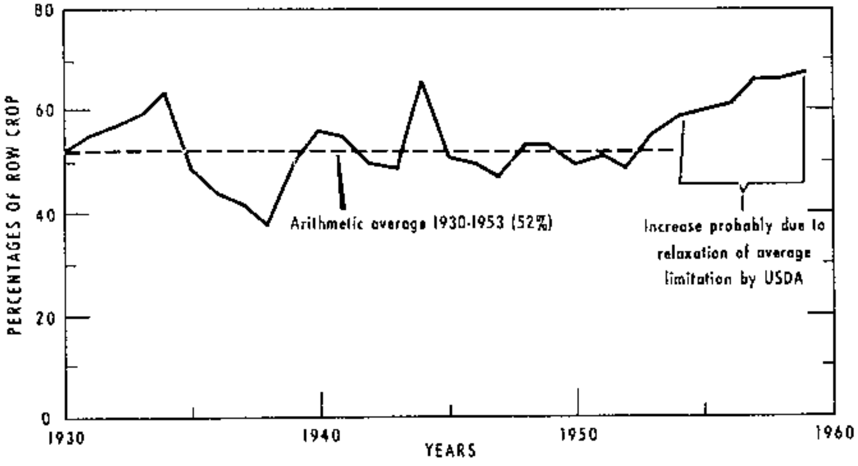

FIGURE 12.—Percentage of total cultivated land in row crops (feed grains) in eight counties partially within watershed example, 1930–59.

TABLE 4.—*Basic data required to compute effects of the conservation by streamflow,*

[Drainage area=2,296 square

Calendar year (1)	Observed streamflow (2)	Base plus interflow (3)	Surface streamflow (4)	Annual watershed precipitation [1] (5)	Ratio: annual precipitation to PET [2] (6)	Annual pan evaporation [3] (7)	Ratio: annual evaporation to average annual evaporation (8)
	1,000 acre-feet	*1,000 acre-feet*	*1,000 acre-feet*	*Inches*		*Inches*	
1930	194	112	82	27.4	0.91	86	1.13
1931	139	99	40	26.2	.87	86	1.13
1932	181	107	74	27.7	.92	81	1.06
1933	112	88	24	21.4	.71	80	1.05
1934	81	77	4	12.3	.41	110	1.44
1935	354	211	143	30.0	1.00	61	.80
1936	106	82	24	15.0	.50	97	1.27
1937	109	77	32	18.4	.61	79	1.04
1938	176	95	81	26.5	.88	71	.93
1939	168	87	81	20.0	.67	97.6	1.28
1940	77.8	72.4	5.4	14.8	.49	92.4	1.21
1941	295.7	116.4	179.3	31.4	1.05	90.5	1.19
1942	309.6	133.6	176.0	33.8	1.13	64.4	.84
1943	257.9	128.7	129.2	21.9	.73	65.8	.86
1944	306.9	116.5	190.4	32.4	1.08	55.9	.73
1945	425.0	168.3	256.7	29.7	.99	62.2	.82
1946	156.2	92.6	63.6	22.8	.76	72.5	.95
1947	371.9	136.1	235.8	29.4	.98	74.5	.98
1948	286.1	113.2	172.9	26.2	.87	81.8	1.07
1949	740.0	193.5	546.5	37.5	1.25	65.4	.86
1950	398.4	157.0	241.4	30.1	1.00	54.3	.71
1951	723.3	198.0	525.3	39.9	1.33	55.8	.73
1952	293.6	157.2	136.4	26.3	.88	76.5	1.00
1953	144.0	111.9	32.1	20.0	.67	84.1	1.10
1954	187.5	110.0	77.5	26.4	.88	76.9	1.01
1955	151.2	89.3	61.9	18.6	.62	94.0	1.23
1956	124.4	84.9	39.5	17.4	.58	87.2	1.14
1957	286.7	84.9	201.8	31.2	1.04	59.6	.78
1958	323.4	108.5	214.9	31.9	1.06	61.8	.81
1959	304.5	123.3	181.2	28.5	.95	69.4	.91
1960	464.0	30.0	334.0	31.9	1.06	70.1	.92

See footnotes at bottom of page 34.

use and treatment of land and watershed treatment on water yielded watershed example

miles, or 1,469,440 acres]

Lake evaporation [4]	Lake evaporation minus direct precipitation [5]	Effects of level closed-end terraces [6]	Ratio: upstream to downstream runoff [7]	Net lake evaporation plus percolation [8]	Lake evaporation plus percolation as percentage of average depths of—		PET minus annual precipitation [11]
					Ponds [9]	Reservoirs [10]	
(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Inches	*Inches*	*Percent*		*Inches*	*Percent*	*Percent*	*Inches*
54.2	26.8	40	1.18	56.8	39	24	2.6
54.2	28.0	46	1.22	58.0	40	24	3.8
50.9	23.2	39	1.17	53.2	37	22	2.3
50.4	29.0	69	1.42	59.0	41	25	8.6
69.1	56.8	94	2.52	86.8	60	36	17.7
38.4	8.4	28	1.11	38.4	27	16	0
61.0	46.0	90	2.00	76.0	53	32	15.0
49.9	31.5	82	1.62	61.5	43	26	11.6
44.6	18.1	45	1.20	48.1	33	20	3.5
61.4	41.4	75	1.49	71.4	50	30	10.0
58.1	43.3	91	2.04	73.3	51	31	15.2
57.1	25.7	21	1.08	55.7	39	23	0
40.3	6.5	13	1.05	36.5	25	15	0
41.3	19.4	66	1.38	49.4	34	21	8.1
35.0	2.6	18	1.07	32.6	23	14	0
39.4	9.7	29	1.12	39.7	28	17	0.3
45.6	22.8	62	1.34	52.8	37	22	7.2
47.0	17.6	31	1.13	47.6	33	20	0.6
51.4	25.2	46	1.21	55.2	38	23	3.8
41.3	3.8	5	1.02	33.8	23	14	0
34.1	4.0	28	1.11	34.0	24	14	0
35.0	0	1	1.00	30.0	21	12	0
48.0	21.7	45	1.20	51.7	36	22	3.7
52.8	32.8	75	1.49	62.8	44	26	10.0
48.5	22.1	45	1.20	52.1	36	22	3.6
59.0	40.4	81	1.59	70.4	49	29	11.4
54.7	37.3	85	1.70	67.3	47	28	12.6
37.4	6.2	22	1.09	36.2	25	15	0
38.9	7.0	20	1.08	37.0	26	15	0
43.7	15.2	35	1.15	45.2	31	19	1.5
44.2	12.3	20	1.08	42.3	29	18	0

TABLE 5.—*Conservation practices*

Year [2]	Practices in Soil Conservation district (county)					
	Contour tilled [3]	Ponds [4]	Terraces [5]	Irrigation [6]	Drainage [6]	Conversion seeding [7]
	Acres	*Number*	*Miles*	*Acres*	*Acres*	*Acres*
1940	1, 339	11	4	340	----------	70
1941	7, 280	25	20	350	----------	426
1942	10, 278	0	36	400	----------	2, 123
1943	14, 503	45	39	450	----------	2, 822
1944	18, 270	0	70	540	73	2, 044
1945	21, 937	4	73	700	216	2, 099
1946	23, 390	22	84	800	513	2, 511
1947	24, 686	16	116	1, 000	553	4, 254
1948	29, 904	25	202	1, 130	823	4, 769
1949	31, 089	36	228	1, 370	2, 323	5, 087
1950	34, 160	52	360	1, 730	2, 897	5, 479
1951	39, 627	69	496	2, 170	3, 377	5, 936
1952	44, 001	87	589	2, 250	3, 539	6, 527
1953	31, 168	83	509	3, 890	3, 873	5, 627
1954	32, 304	84	555	7, 130	4, 666	5, 986
1955	34, 530	86	620	13, 550	5, 141	6, 228
1956	36, 359	89	719	24, 730	5, 256	6, 442
1957	37, 429	90	812	8, 900	5, 376	6, 889
1958	38, 171	91	897	40, 800	5, 396	7, 155
1959	41, 800	100	1, 000	42, 000	5, 265	12, 682
1960	22, 000	105	1, 077	43, 000	5, 400	13, 376

Footnotes for table 4.

[1] Obtained by Thiessen-weighting seven precipitation stations.

[2] PET—Average annual potential evapotranspiration, 30 inches, from map after Thornthwaite (fig. 1).

[3] April through October records plus March and November estimates of 50 percent of April and October evaporation, respectively. 1939–60 data from station in watershed. 1930–38 data from station 100 miles away, adjusted by correlation during years of common record.

[4] Lake evaporation=ratio of annual pan evaporation to average annual pan evaporation (average of column 7) multiplied by average annual lake evaporation (fig. 8).

[5] Negative values entered as zeros.

[6] Values read from curve showing effects related to climate, figure 5, entered with values from column 6.

[7] Read from curve of transmission losses, figure 10, entered with values in column 6.

[8] Column 10 plus 2.5 feet, or 30 inches, read from curve of percolation losses, figure 6, at 35 percent clay content.

[9] Column 13 multiplied by $\frac{100}{12}$, divided by 12 feet, average depth of ponds.

[10] Column 13 multiplied by $\frac{100}{12}$, divided by 20 feet, average depth of floodwater-retarding reservoirs.

[11] Potential evapotranspiration of 30 inches minus column 5. Negative values recorded as zeros.

in county H, watershed example[1]

Estimated practices in watershed[8]				Conversion seeding	Adjusted practices in watershed[9]			
Contour tilled	Ponds	Irrigation	Drainage		Contour tilled	Conversion seeding		Ponds
						Poor land	Good land	
Acres	*Number*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*
937	9	340	-------	57	937	57	-------	9
5, 096	20	350	-------	349	5, 096	700	-------	9
7, 195	0	400	-------	1, 741	7, 195	1, 200	-------	10
10, 152	37	450	-------	2, 314	10, 152	1, 700	-------	11
12, 789	0	540	73	1, 676	12, 789	2, 100	-------	13
15, 356	3	700	216	1, 721	15, 356	2, 400	-------	15
16, 373	18	800	513	2, 059	16, 373	2, 800	-------	18
17, 280	13	1, 000	553	3, 488	17, 280	3, 100	-------	23
20, 933	20	1, 130	823	3, 910	18, 600	3, 400	-------	28
21, 762	30	1, 370	2, 323	4, 171	19, 600	3, 700	-------	35
23, 912	43	1, 730	2, 897	4, 493	20, 600	4, 000	-------	44
27, 739	56	2, 170	3, 377	4, 868	21, 500	4, 200	-------	56
30, 801	71	2, 250	3, 539	5, 352	22, 300	4, 500	-------	63
21, 818	68	3, 890	3, 873	4, 614	23, 200	4, 614	-------	67
22, 613	69	7, 130	4, 666	4, 908	24, 000	4, 908	-------	69
24, 171	70	13, 550	5, 141	5, 107	24, 171	5, 107	-------	70
24, 451	73	24, 730	5, 256	5, 282	25, 451	5, 282	-------	73
26, 200	74	38, 900	5, 376	5, 649	26, 200	5, 649	-------	74
26, 720	75	40, 800	5, 396	5, 867	26, 700	5, 867	-------	75
29, 260	82	42, 000	5, 265	10, 399	27, 400	6, 000	4, 400	82
15, 400	86	43, 000	5, 400	10, 968	28, 000	6, 200	4, 770	86

Footnotes for table 5.

[1] 82 percent of county, 500 square miles in watershed, county area=610 square miles.

[2] 1940 is first year of operation of Soil Conservation District.

[3] Estimated 70 percent within watershed.

[4] Estimated 82 percent in watershed. Water surface=1.5 acres, drainage area=120 acres, average depth=9 feet, clay content=38 percent.

[5] Estimated 70 percent in watershed. No level terraces; all are graded and all the acreage contour tilled.

[6] Estimated 100 percent in watershed.

[7] 82 percent in watershed.

[8] Quantities in Soil Conservation District multiplied by percentages in watershed.

[9] From smoothed curves in figure 13.

The Soil Conservation District data were reduced to the percentages shown in the footnotes of table 5 of the watershed example. The irregular graphs of watershed data in figure 13 were smoothed, and the adjusted values read from the interpolated curves for entry in the adjusted practices section of table 5.

The data in each Soil Conservation District were treated similarly to those discussed above. The individual Soil Conservation District adjusted data were summarized as illustrated for contour tillage in table 6. Estimates of increases in contour tillage likely to be installed

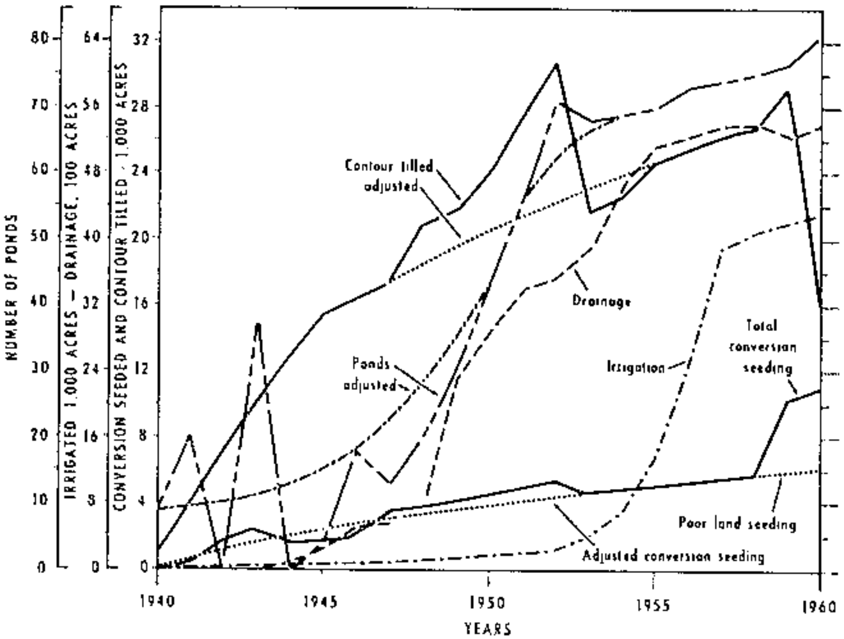

FIGURE 13.—Graphs of land treatment practices, county H, used to adjust data for watershed example.

in the several counties by 1985 are shown near the bottom of table 6. The total contour-tillage averages expected in the watershed example by 1985 are the sums of practices in effect in 1960 plus the estimated increases by 1985. Incidentally, actual estimates to 1985 were for each Soil Conservation District (county); hence, had to be adjusted on the basis of percentages within the watershed, just as the installed Soil Conservation District practices were adjusted.

Once the data on land-treatment practices were summarized, their effects on water yields were evaluated as shown in tables 7 to 12, inclusive. The index of effects for each practice from table 1 had to be weighted for percentages of land in row crops and small grain, 52 and 48 percent, respectively (see fig. 12) since the indices in table 1 are related to runoff from row crops as a base. The weighting of these indices, as shown in footnotes of the tables, resulted in a weighted factor or index arrived at as follows:

$$\text{Factor}=\frac{(RC)\,(RCTI)+(SG)\,(SGTI-SGI)}{100}$$

Where RC=Average percentage of clean-tilled land in row crops=52 percent in watershed example.

RCTI=Row-crop-treatment index from table 1.

SG=Average percentage of clean-tilled land in small grain=48 percent in watershed example.

SGTI=Small-grain-treatment index from table 1.

SGI=Small-grain index (as compared to row crops—0.3) from table 1.

TABLE 6.—*Illustration of summarization of adjusted individual land-treatment practices, counties in watershed example*

Year	Contour tillage by counties—								Total in watershed
	A	B	C	D	E	F	G	H	
	Acres	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*
1940					12			937	949
1941					100			5, 096	5, 196
1942					160			7, 195	7, 355
1943					247	2, 250		10, 152	12, 649
1944					329	3, 700		12, 789	16, 818
1945					387	5, 000		15, 356	20, 743
1946	11		151	68	450	6, 200	582	16, 373	23, 835
1947	355		1, 878	153	525	7, 200	701	17, 280	28, 092
1948	737	232	2, 091	198	625	8, 200	993	18, 600	31, 676
1949	1, 022	392	2, 142	200	700	9, 100	1, 073	19, 600	34, 229
1950	1, 263	1, 203	2, 200	299	825	10, 000	1, 376	20, 600	37, 766
1951	1, 501	1, 925	2, 270	400	970	10, 800	1, 130	21, 500	40, 496
1952	1, 672	2, 200	2, 330	455	1, 150	11, 600	920	22, 300	42, 627
1953	1, 100	2, 400	2, 400	500	1, 338	12, 308		23, 200	43, 246
1954	940	2, 532	2, 460	538	1, 537	13, 048		24, 000	45, 055
1955	830	2, 710	2, 520	564	1, 927	13, 850		24, 171	46, 572
1956	750	2, 862	2, 570	575	2, 300	14, 448		25, 451	48, 956
1957	680	2, 946	2, 630	582	2, 623	15, 342		26, 200	51, 003
1958	630	3, 073	2, 680	617	2, 994	15, 946		26, 700	52, 640
1959	590	3, 800	2, 730	696	3, 771	18, 094		27, 400	57, 081
1960	550	3, 832	2, 770	762	4, 121	18, 958		28, 000	58, 993
Estimated increase by 1985	6, 250	7, 820	8, 100	1, 500	3, 410	5, 000	900	35, 000	67, 980
Totals in 1985	6, 800	11, 652	10, 870	2, 262	7, 531	23, 958	900	63, 000	126, 973

TABLE 7.—*Computation of effects of level open-end terraces (with contour tillage) on surface runoff, watershed example*

Year	Level terraces (open-end)			Effects of terraces on runoff [3]	Effects of terraces on watershed runoff [4]	Decrease in watershed runoff due to terraces [5]
	Actual in place	Increase to 1985 [1]	Increase as percentage of watershed [2]			
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Acres	*Acres*	*Percent*	*Percent*	*Percent*	*Acre-feet*
1930	----------	51,782	3.52	22.2	0.78	640
1931	----------	51,782	3.52	25.6	.90	360
1932	----------	51,782	3.52	21.7	.76	562
1933	----------	51,782	3.52	38.4	1.35	324
1934	----------	51,782	3.52	52.3	1.84	74
1935	----------	51,782	3.52	15.6	.55	786
1936	----------	51,782	3.52	50.0	1.76	422
1937	----------	51,782	3.52	45.6	1.60	512
1938	----------	51,782	3.52	25.0	.88	713
1939	----------	51,782	3.52	41.7	1.47	1,191
1940	----------	51,782	3.52	50.6	1.78	96
1941	----------	51,782	3.52	11.7	.41	735
1942	----------	51,782	3.52	7.2	.25	440
1943	22	51,760	3.52	36.7	1.29	1,667
1944	27	51,755	3.52	10.0	.35	666
1945	183	51,599	3.51	16.1	.56	1,438
1946	589	51,193	3.48	34.5	1.20	763
1947	2,725	49,057	3.34	17.2	.57	1,344
1948	5,059	46,723	3.18	25.6	.81	1,400
1949	5,946	45,836	3.12	2.8	.09	492
1950	9,921	41,861	2.85	15.6	.44	1,062
1951	13,316	38,466	2.62	.6	.02	105
1952	16,580	35,202	2.40	25.0	.60	818
1953	18,476	32,306	2.20	41.7	.92	295
1954	20,289	31,493	2.14	25.0	.54	418
1955	21,614	30,168	2.05	45.0	.92	569
1956	22,752	29,030	1.98	47.3	.94	371
1957	24,181	27,601	1.88	12.2	.23	464
1958	25,055	26,727	1.82	11.1	.20	430
1959	26,138	25,644	1.75	19.5	.34	616
1960	25,217	26,565	1.81	11.1	.20	668

[1] Total expected in 1985, 51,782 acres minus column 2.
[2] Column 3 multiplied by 100, divided by 1,469,440 acres.
[3] $\text{Factor} = \frac{(52 \text{ (row crops)} \times 0.7) + (48 \text{ (small grain)} \times (0.7 - 0.3))}{100} = 0.556.$

Factor multiplied by column 11, of table 4.
[4] Column 4 multiplied by column 5, divided by 100.
[5] $\frac{\text{Column } 6 \times \text{column 4 of table } 4 \times 1{,}000}{100}$

TABLE 8.—*Computation of effects of contour tillage on surface runoff. watershed example*

Year	Contour tillage			Effects of contour tillage on runoff [3]	Effects of contour tillage on watershed runoff [4]	Decrease in watershed runoff due to contour tillage [5]
	Actual in place	Increase to 1985 [1]	Increase as percentage of watershed [2]			
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Acres	*Acres*	*Percent*	*Percent*	*Percent*	*Acre-feet*
1930	----------	126, 973	8. 64	16. 2	1. 40	1, 148
1931	----------	126, 973	8. 64	18. 6	1. 61	644
1932	----------	126, 973	8. 64	15. 8	1. 36	1, 006
1933	----------	126, 973	8. 64	27. 9	2. 41	578
1934	----------	126, 973	8. 64	38. 0	3. 28	131
1935	----------	126, 973	8. 64	11. 3	. 98	1, 401
1936	----------	126, 973	8. 64	36. 4	3. 14	754
1937	----------	126, 973	8. 64	33. 1	2. 86	915
1938	----------	126, 973	8. 64	18. 2	1. 57	1, 272
1939	----------	126, 973	8. 64	30. 3	2. 62	2, 122
1940	949	126, 024	8. 58	36. 8	3. 16	171
1941	5, 196	121, 777	8. 29	8. 5	. 70	1, 255
1942	7, 355	119, 618	8. 14	5. 3	. 43	757
1943	12, 649	114, 324	7. 78	26. 7	2. 08	2, 687
1944	16, 818	110, 155	7. 50	7. 3	. 55	1, 047
1945	20, 743	106, 230	7. 23	11. 7	. 85	2, 182
1946	23, 835	103, 138	7. 02	25. 0	1. 76	1, 119
1947	28, 092	98, 881	6. 73	12. 5	. 84	1, 981
1948	31, 676	95, 297	6. 49	18. 6	1. 21	2, 092
1949	34, 229	92, 744	6. 31	2. 0	. 13	710
1950	37, 766	89, 207	6. 07	11. 3	. 69	1, 666
1951	40, 496	86, 477	5. 88	. 4	. 02	105
1952	42, 627	84, 346	5. 74	18. 2	1. 04	1, 419
1953	43, 246	83, 727	5. 70	30. 3	1. 73	555
1954	45, 055	81, 918	5. 57	18. 2	1. 01	783
1955	46, 572	80, 401	5. 47	32. 7	1. 79	1, 108
1956	48, 956	78, 017	5. 31	34. 3	1. 82	719
1957	51, 003	75, 970	5. 17	8. 9	. 46	928
1958	52, 640	74, 333	5. 06	8. 1	. 41	881
1959	57, 081	69, 892	4. 76	14. 1	. 67	1, 214
1960	58, 993	67, 980	4. 63	8. 1	. 38	1, 269

[1] Total expected in 1985, 126,973 acres minus column 2.
[2] Column 3 multiplied by 100, divided by 1,469,440 acres.
[3] Factor on effects of contour tillage equals

$$\frac{(52\times 0.5(\text{table 3}))+(48\times(0.6-0.3)\ (\text{table 3}))}{100}=0.404.$$

Multiply factor by column 11 of table 4.
[4] Column 4 multiplied by column 5, divided by 100.
[5] $\frac{\text{Column 6 multiplied by column 4 of table } 4\times 1{,}000.}{100}$

TABLE 9.—*Computation of effects of seeding poor land to grass on surface runoff, watershed example*

Year	Poor land seeding			Effects of seeding poor land to grass on runoff [3]	Effects of seeding poor land to grass on watershed runoff [4]	Decrease in watershed runoff due to seeding poor land to grass [5]
	Actual in place	Increase to 1985 [1]	Increase as percentage of watershed [2]			
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Acres	*Acres*	*Percent*	*Percent*	*Percent*	*Acre-feet*
1930	----------	40,267	2.74	10.24	0.28	230
1931	----------	40,267	2.74	11.78	.32	128
1932	----------	40,267	2.74	9.98	.27	200
1933	----------	40,267	2.74	17.66	.48	115
1934	----------	40,267	2.74	24.06	.66	26
1935	----------	40,267	2.74	7.17	.20	286
1936	----------	40,267	2.74	23.04	.63	151
1937	----------	40,267	2.74	20.99	.58	186
1938	----------	40,267	2.74	11.52	.32	259
1939	----------	40,267	2.74	19.20	.53	429
1940	57	40,210	2.74	23.30	.64	35
1941	700	39,567	2.69	5.38	.14	251
1942	1,200	39,067	2.66	3.33	.09	158
1943	1,853	38,414	2.61	16.90	.44	568
1944	2,260	38,007	2.59	4.61	.12	228
1945	2,914	37,353	2.54	7.42	.19	488
1946	4,208	36,059	2.45	15.87	.39	248
1947	4,656	35,611	2.42	7.94	.19	448
1948	5,896	34,371	2.34	11.78	.28	484
1949	6,556	33,711	2.29	1.28	.03	164
1950	7,710	32,557	2.22	7.17	.16	386
1951	8,641	31,626	2.15	.26	.01	53
1952	9,746	30,521	2.08	11.52	.24	327
1953	10,754	29,513	2.01	19.20	.39	125
1954	11,774	28,493	1.94	11.52	.22	170
1955	13,175	27,092	1.84	20.74	.38	235
1956	14,224	26,043	1.77	21.76	.39	154
1957	15,775	24,492	1.67	5.63	.09	182
1958	17,219	23,048	1.57	5.12	.08	172
1959	18,685	21,582	1.47	8.96	.13	236
1960	20,247	20,020	1.36	5.12	.07	234

[1] Total expected in 1985, 40,267 acres minus column 2.
[2] Column 3 multiplied by 100, divided by 1,469,440 acres.
[3] Factor on effects of converting poor cultivated land to grass equals

$$\frac{(52\times 0.4 \text{ (table 3)}) + (48\times(0.4-0.3) \text{ (table 3)})}{100} = 0.256.$$

Multiply factor by column 11 of table 4.
[4] Column 4 multiplied by column 5, divided by 100.
[5] Column 6 divided by 100, multiplied by column 4 of table 4, multiplied by 1,000.

TABLE 10.—*Computation of effects of seeding good land to grass on surface runoff, watershed example*

Year	Good land seeding			Effects of seeding good land to grass on runoff [3]	Effects of seeding good land to grass on watershed runoff [4]	Decrease in watershed runoff due to seeding good land to grass [5]
	Actual in place	Increase to 1985 [1]	Increase as percentage of watershed [2]			
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Acres	*Acres*	*Percent*	*Percent*	*Percent*	*Acre-feet*
1930	----------	36, 551	2. 49	22. 2	0. 55	451
1931	----------	36, 551	2. 49	25. 6	. 64	256
1932	----------	36, 551	2. 49	21. 7	. 54	400
1933	----------	36, 551	2. 49	38. 4	. 96	230
1934	----------	36, 551	2. 49	52. 3	1. 30	52
1935	----------	36, 551	2. 49	15. 6	. 39	558
1936	----------	36, 551	2. 49	50. 0	1. 24	298
1937	----------	36, 551	2. 49	45. 6	1. 14	365
1938	----------	36, 551	2. 49	25. 0	. 62	502
1939	----------	36, 551	2. 49	41. 7	1. 04	842
1940	----------	36, 551	2. 49	50. 6	1. 26	68
1941	----------	36, 551	2. 49	11. 7	. 29	520
1942	----------	36, 551	2. 49	7. 2	. 18	317
1943	----------	36, 551	2. 49	36. 7	. 91	1, 176
1944	----------	36, 551	2. 49	10. 0	. 25	476
1945	----------	36, 551	2. 49	16. 1	. 40	1, 027
1946	----------	36, 551	2. 49	34. 5	. 86	547
1947	----------	36, 551	2. 49	17. 2	. 43	1, 014
1948	----------	36, 551	2. 49	25. 6	. 64	1, 106
1949	----------	36, 551	2. 49	2. 8	. 07	383
1950	----------	36, 551	2. 49	15. 6	. 39	941
1951	----------	36, 551	2. 49	. 6	. 02	105
1952	----------	36, 551	2. 49	25. 0	. 62	846
1953	----------	36, 551	2. 49	41. 7	1. 04	334
1954	----------	36, 551	2. 49	25. 0	. 62	480
1955	901	35, 650	2. 43	45. 0	1. 09	675
1956	3, 847	32, 704	2. 23	47. 3	1. 05	415
1957	3, 995	32, 556	2. 22	12. 2	. 27	545
1958	5, 803	30, 748	2. 09	11. 1	. 23	494
1959	12, 754	23, 797	1. 62	19. 5	. 32	580
1960	16, 531	20, 020	1. 36	11. 1	. 15	501

[1] Total expected in 1985, 36,551 acres minus column 2.
[2] Column 3 multiplied by 100, divided by 1,469,440 acres.
[3] Factor on effects of converting good cultivated land to grass equals

$$\frac{(52\times 0.7\ (\text{table 3}))+(48\times(0.7-0.3)\ (\text{table 3}))}{100}=0.556.$$

Multiply factor by column 11 of table 4.
[4] Column 4 multiplied by column 5, divided by 100.
[5] Column 6 divided by 100, multiplied by column 4 of table 4, multiplied by 1,000.

TABLE 11.—*Computation of effects of irrigation on surface runoff, watershed example*

Year	Irrigation: Actual in place [1]	Irrigation: Increase to 1985 [2]	Irrigation: Increase as percentage of watershed [3]	Effects of irrigation on runoff [4]	Effects of irrigation on watershed runoff [5]	Increase in watershed runoff due to irrigation [6]
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Acres	*Acres*	*Percent*	*Percent*	*Percent*	*Acre-feet*
1930	----------	345, 545	23. 52	16. 0	3. 76	3, 083
1931	----------	345, 545	23. 52	18. 4	4. 33	1, 732
1932	----------	345, 545	23. 52	15. 6	3. 67	2, 716
1933	----------	345, 545	23. 52	27. 6	6. 49	1, 558
1934	----------	345, 545	23. 52	37. 6	8. 84	354
1935	----------	345, 545	23. 52	11. 2	2. 63	3, 761
1936	----------	345, 545	23. 52	36. 0	8. 47	2, 033
1937	----------	345, 545	23. 52	32. 8	7. 71	2, 467
1938	----------	345, 545	23. 52	18. 0	4. 23	3, 426
1939	----------	345, 545	23. 52	30. 0	7. 06	5, 719
1940	940	344, 605	23. 45	36. 4	8. 54	461
1941	3, 450	342, 095	23. 28	8. 4	1. 96	3, 514
1942	5, 100	340, 445	23. 17	5. 2	1. 20	2, 112
1943	7, 861	337, 684	22. 98	26. 4	6. 07	7, 842
1944	10, 375	335, 170	22. 81	7. 2	1. 64	3, 123
1945	12, 875	332, 670	22. 64	11. 6	2. 63	6, 751
1946	14, 899	330, 646	22. 50	24. 8	5. 58	3, 549
1947	17, 043	328, 502	22. 36	12. 4	2. 77	6, 532
1948	20, 951	324, 594	22. 09	18. 4	4. 06	7, 020
1949	24, 225	321, 320	21. 87	2. 0	. 44	2, 405
1950	27, 508	318, 037	21. 64	11. 2	2. 42	5, 842
1951	30, 490	315, 055	21. 44	. 4	. 09	473
1952	33, 867	311, 678	21. 21	18. 0	3. 82	5, 210
1953	46, 081	299, 464	20. 38	30. 0	6. 11	1, 961
1954	66, 234	279, 311	19. 01	18. 0	3. 42	2, 651
1955	93, 763	251, 782	17. 13	32. 4	5. 55	3, 435
1956	138, 860	206, 685	14. 07	34. 0	4. 78	1, 888
1957	188, 006	157, 539	10. 72	8. 8	. 94	1, 897
1958	198, 032	147, 513	10. 04	8. 0	. 80	1, 719
1959	202, 411	143, 134	9. 74	14. 0	1. 36	2, 464
1960	207, 705	137, 840	9. 38	8. 0	. 75	2, 505

[1] Data obtained from annual statistical reports of Statistical Reporting Service, USDA, and the State board of agriculture, rather than from Soil Conservation Service Form 195. County data adjusted to the watershed on basis of local estimates.

[2] Total expected in 1985, 345,545 minus column 2.

[3] Column 3 multiplied by 100, divided by 1,469,440 acres.

[4] 0.4 from table 1 multiplied by column 11 of table 4. No weighted factor needed because all crops affected.

[5] Column 4 multiplied by column 5, divided by 100.

[6] Column 6 multiplied by column 4 of table 4, divided by 100, multiplied by 1,000.

TABLE 12.—*Computation of effects of pothole drainage, watershed example*

Year	Pothole drainage			Increase in watershed runoff due to drainage [3]
	Actual in place	Increase to 1985 [1]	Increase as percentage of watershed [2]	
(1)	(2)	(3)	(4)	(5)
	Acres	*Acres*	*Percent*	*Acre-feet*
1930		25, 148	1. 7	1, 394
1931		25, 148	1. 7	680
1932		25, 148	1. 7	1, 258
1933		25, 148	1. 7	408
1934		25, 148	1. 7	68
1935		25, 148	1. 7	2, 431
1936		25, 148	1. 7	408
1937		25, 148	1. 7	544
1938		25, 148	1. 7	1, 377
1939		25, 148	1. 7	1, 377
1940		25, 148	1. 7	92
1941		25, 148	1. 7	3, 048
1942		25, 148	1. 7	2, 992
1943		25, 148	1. 7	2, 196
1944	73	25, 075	1. 7	3, 237
1945	408	24, 740	1. 7	4, 364
1946	1, 203	23, 945	1. 6	1, 018
1947	1, 708	23, 440	1. 6	3, 773
1948	2, 331	22, 817	1. 6	2, 766
1949	4, 170	20, 978	1. 4	7, 651
1950	5, 394	19, 754	1. 3	3, 138
1951	6, 308	18, 840	1. 3	6, 829
1952	7, 237	17, 911	1. 2	1, 637
1953	8, 798	16, 350	1. 1	353
1954	10, 929	14, 219	1. 0	775
1955	12, 432	12, 716	. 9	557
1956	14, 028	11, 120	. 8	316
1957	15, 005	10, 143	. 7	1, 413
1958	15, 410	9, 738	. 7	1, 504
1959	16, 654	8, 494	. 6	1, 087
1960	17, 195	7, 953	. 5	1, 670

[1] Total expected in 1985, 25,148 acres minus column 2.
[2] Pothole drainage increases runoff in direct proportion to area drained; hence, these values directly represent potential increases.
[3] Column 4 divided by 100, multiplied by column 4 of table 4.

Table 13 is a summary of the effects of the several individual practices and a new computation of watershed runoff. The new watershed runoff data shown in the last column of this table (column 13) were needed later to determine if inflow to farm ponds limits their "water cost," rather than evaporation plus percolation.

TABLE 13.—*Summary of effects of land treatment on surface runoff of watershed example*

Year	Decreases in surface runoff due to [1]—				Total decreases	Increases in surface runoff due to [2]—		Total increases	Net change in runoff [3]	Observed surface runoff [4]	Surface runoff corrected for effects of land treatment [5]	Watershed depth [6]
	Level terracing	Contour tillage	Seeding poor land	Seeding good land		Irrigation	Drainage					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	Acre-feet	*Acre-feet*	*Acre-feet*	*Acre-feet*	*Acre-feet*	*Acre-feet*	*Acre-feet*	*Acre-feet*	*Acre-feet*	*1,000 acre-feet*	*Acre-feet*	*Inches*
1930	640	1, 148	230	451	2, 469	3, 083	1, 394	4, 477	2, 008	82. 0	84, 008	0. 686
1931	360	644	128	256	1, 388	1, 732	680	2, 412	1, 024	40. 0	41, 024	. 335
1932	562	1, 006	200	400	2, 168	2, 716	1, 258	3, 974	1, 806	74. 0	75, 806	. 619
1933	324	578	115	230	1, 247	1, 558	408	1, 966	719	24. 0	24, 719	. 202
1934	74	131	26	52	283	354	68	422	139	4. 0	4, 139	. 034
1935	786	1, 401	286	558	3, 031	3, 761	2, 431	6, 192	3, 161	143. 0	146, 161	1. 194
1936	422	754	151	298	1, 625	2, 033	408	2, 441	816	24. 0	24, 816	. 203
1937	512	915	186	365	1, 978	2, 467	544	3, 011	1, 033	32. 0	33, 033	. 270
1938	713	1, 272	259	502	2, 746	3, 426	1, 377	4, 803	2, 057	81. 0	83, 057	. 678
1939	1, 191	2, 122	429	842	4, 584	5, 719	1, 377	7, 096	2, 512	81. 0	83, 512	. 682
1940	96	171	35	68	370	461	92	553	183	5. 4	5, 583	. 046
1941	735	1, 255	251	520	2, 761	3, 514	3, 048	6, 562	3, 801	179. 3	183, 101	1. 495
1942	440	757	158	317	1, 672	2, 112	2, 992	5, 104	3, 432	176. 0	179, 432	1. 465
1943	1, 667	2, 687	568	1, 176	6, 098	7, 842	2, 196	10, 038	3, 940	129. 2	133, 140	1. 087
1944	666	1, 047	228	476	2, 417	3, 123	3, 237	6, 360	3, 943	190. 4	194, 343	1. 587
1945	1, 438	2, 182	488	1, 027	5, 135	6, 751	4, 364	11, 115	5, 980	256. 7	262, 680	2. 145

1946	763	1, 119	248	547	2, 677	3, 549	1, 018	4, 567	1, 890	63. 6	65, 490	. 535
1947	1, 344	1, 981	448	1, 014	4, 787	6, 532	3, 773	10, 305	5, 518	235. 8	241, 318	1. 971
1948	1, 400	2, 092	484	1, 106	5, 082	7, 020	2, 766	9, 786	4, 704	172. 9	177, 604	1. 450
1949	492	710	164	383	1, 749	2, 405	7, 651	10, 056	8, 307	546. 5	554, 807	4. 531
1950	1, 062	1, 666	386	941	4, 055	5, 842	3, 138	8, 980	4, 925	241. 4	246, 325	2. 011
1951	105	105	53	105	368	473	6, 829	7, 302	6, 934	525. 3	532, 234	4. 346
1952	818	1, 419	327	846	3, 410	5, 210	1, 637	6, 847	3, 437	136. 4	139, 837	1. 142
1953	295	555	125	334	1, 309	1, 961	353	2, 314	1, 005	32. 1	33, 105	. 270
1954	418	783	170	480	1, 851	2, 651	775	3, 426	1, 575	77. 5	79, 075	. 646
1955	569	1, 108	235	675	2, 587	3, 435	557	3, 992	1, 405	61. 9	63, 305	. 517
1956	371	719	154	415	1, 659	1, 888	316	2, 204	545	39. 5	40, 045	. 327
1957	464	928	182	545	2, 119	1, 897	1, 413	3, 310	1, 191	201. 8	202, 991	1. 658
1958	430	881	172	494	1, 977	1, 719	1, 504	3, 223	1, 246	214. 9	216, 146	1. 765
1959	616	1, 214	236	580	2, 646	2, 464	1, 087	3, 551	905	181. 2	182, 105	1. 487
1960	668	1, 269	234	501	2, 672	2, 505	1, 670	4, 175	1, 503	334. 0	335, 503	2. 740

[1] From last columns of tables 7 to 10 of effects for each depleting practice.
[2] From last columns in tables 11 and 12, of increasing practices.
[3] Algebraic sum of columns 6 and 9.
[4] From column 4 of table 4.
[5] Column 11 plus column 10.
[6] Column 12 converted to inches of depth on the watershed.

Evaluating Effects of Farm Ponds

Data on farm ponds (stockponds and similar erosion-control dams) were obtained for the watershed example at the same time and in the same manner as data on land-treatment measures were obtained. In addition to numbers of ponds installed year-by-year, information was obtained in each Soil Conservation District on the factors outlined in the section on data tabulation and reduction (p. 20) and on:

1. Opinions as to seepage through and around dams—negligible.
2. Estimates of percentages of ponds in the Soil Conservation District that were in the watershed example.
3. Estimates of increases in numbers of ponds from 1960 to 1985.

The raw pond-numbers data, after adjusting to numbers in the watershed example, were plotted by years, as illustrated in figure 13. Interpolated and extrapolated numbers were read from the smoothed curve and tabulated for each Soil Conservation District. These data were summarized for the watershed, as shown for contour tillage in table 6. Increases expected by 1985 were added to the 1960 quantities to obtain an estimate of numbers of ponds likely to be in operation in 1985 (this is on the assumption that ponds that fail or silt up will be rebuilt).

The computations of effects on ponds were carried out as shown in table 14. Computations carried through column 11 indicate the downstream "water cost" of evaporation and deep percolation from ponds (it will be remembered that percolation from ponds is considered as streamflow depletions—contrary to floodwater-retarding reservoirs). At this point, net water yield, in inches depth, after adjusting observed surface runoff for effects of land-treatment measures, was introduced to determine if inflow to ponds was sufficient to supply depletion due to evaporation plus percolation.

The last column in table 14 shows new annual watershed runoff figures, in inches depth, to use in checking the runoff-depletion effects of floodwater-retarding reservoirs that have both land-treatment measures and farm ponds in their tributary drainage areas.

Evaluating Effects of Floodwater-Retarding Reservoirs

Data on numbers of floodwater-retarding reservoirs in place and anticipated, depths, drainage areas, water-surface areas, etc., were obtained from the Soil Conservation Service.

Data were available for floodwater-retarding reservoirs in the watershed example as shown in table 15. Computation of effects of these reservoirs on streamflow was similar to those for ponds illustrated in table 14. There was one major difference, however. Since reservoirs are generally located closer to ground water and may even intercept it, it was assumed percolation from such structures soon becomes base flow or interflow, and was thus not depleting, as in the case of ponds. Net lake evaporation only (column 10, table 4) and average water-surface area were used to compute volume of water loss by evaporation. Evaporation plus percolation, as a percentage of average reservoir depth (column 15, table 4), however, was required to enter the curve in figure 9, to read average water-surface areas.

It should be pointed out here that sedimentation in future years will probably decrease water surfaces of, and may reduce water losses from, floodwater-retarding reservoirs. It is believed this problem will vary so much from watershed to watershed that individual watershed characteristics must be considered in the evaluation. No adjustments were made in table 15 for this factor in the watershed example.

Evaluating Effects of Water Spreading

The evaluation of effects of water-spreading works is rather unique in that this is a practice for rangeland where there is not likely to be much land treatment or enough flood-prevention benefits to warrant floodwater-retarding reservoirs. This item was, therefore, evaluated separately from all other treatment measures (table 16). Data from the last column were carried forward to table 17 to use in estimating streamflow for expected 1985 watershed conditions.

Summary of Watershed Example Data

Table 17 brings together observed streamflow data and the finally adjusted surface-runoff components of flow. The data needed by a planner of a future water-storage or water-use project in the watershed is that shown in column 6 of table 17. Because base flow is a large component of the total flow of the river used in the example, percentage effects of land treatment are relatively low on total flow. It will be noted that percentage reductions of the surface-runoff component only of streamflow are relatively high during dry periods, such as 1931–40, inclusive, but relatively low in wet years like 1949, 1951, and 1957–60, inclusive.

TABLE 14.—*Computation of decreases in surface runoff due to farm ponds, watershed example*

Year	Actual in place	Increase to 1985 [1]	Total drainage area to ponds [2]	Pond drainage area as percent of watershed area	Spillway level water surface [3]	Annual average water surface area as percentage of spillway water level [4]	Annual water surface area of ponds [5]	Annual pond water loss by evaporation plus percolation: Upstream [6]	Annual pond water loss by evaporation plus percolation: Depth on pond drainage area: Upstream [7]	Annual pond water loss by evaporation plus percolation: Depth on pond drainage area: Downstream [8]	Corrected watershed surface runoff [9]	Decrease in runoff due to ponds depth on watershed [10]	Watershed surface runoff corrected for land treatment and ponds [11]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	Number	*Number*	*Acres*	*Percent*	*Acres*	*Percent*	*Acres*	*Acre-inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1930	------	3, 369	437, 970	29. 8	6, 212	78	4, 845	275, 196	0. 628	0. 532	0. 686	0. 158	0. 528
1931	------	3, 369	437, 970	29. 8	6, 212	78	4, 845	281, 010	. 642	. 526	*. 335*	. 100	. 235
1932	------	3, 369	437, 970	29. 8	6, 212	79	4, 907	261, 052	. 596	. 509	. 619	. 152	. 467
1933	------	3, 369	437, 970	29. 8	6, 212	77	4, 783	282, 197	. 644	. 453	*. 202*	. 060	. 142
1934	------	3, 369	437, 970	29. 8	6, 212	70	4, 348	377, 406	. 862	. 342	*. 034*	. 010	. 024
1935	------	3, 369	437, 970	29. 8	6, 212	84	5, 218	200, 371	. 457	. 412	1. 194	. 123	1. 071
1936	------	3, 369	437, 970	29. 8	6, 212	72	4, 473	339, 948	. 776	. 388	*. 203*	. 060	. 143
1937	------	3, 369	437, 970	29. 8	6, 212	76	4, 721	290, 342	. 663	. 409	*. 270*	. 080	. 190
1938	------	3, 369	437, 970	29. 8	6, 212	81	5, 032	242, 039	. 553	. 461	. 678	. 137	. 541
1939	------	3, 369	437, 970	29. 8	6, 212	73	4. 535	323, 799	. 739	. 496	. 682	. 148	. 534
1940	9	3, 369	436, 800	29. 7	6, 196	73	4, 523	331, 536	. 759	. 372	*. 046*	. 014	. 032
1941	9	3, 360	436, 800	29. 7	6, 196	78	4, 833	269, 198	. 616	. 570	1. 495	. 169	1. 326
1942	10	3, 359	436, 670	29. 7	6, 194	85	5, 265	192, 172	. 440	. 419	1. 465	. 124	1. 341
1943	11	3, 358	436, 540	29. 7	6, 192	80	4, 954	244, 728	. 561	. 406	1. 087	. 121	. 966
1944	14	3, 355	436, 150	29. 7	6, 187	86	5, 321	173, 465	. 398	. 372	1. 587	. 110	1. 477
1945	18	3, 351	435, 630	29. 6	6, 179	83	5, 129	203, 621	. 467	. 417	2. 145	. 123	2. 022

1946	30	3,339	434,070	29.5	6,157	79	4,864	256,819	.592	.442	535	.130	.405
1947	42	3,327	432,510	29.4	6,135	81	4,969	236,524	.547	.484	1.971	.142	1.829
1948	49	3,320	431,600	29.4	6,122	78	4,775	263,580	.611	.505	1.450	.148	1.302
1949	90	3,279	426,270	29.0	6,046	86	5,200	175,760	.412	.404	4.531	.117	4.414
1950	122	3,247	422,110	28.7	5,987	85	5,089	173,026	.410	.369	2.011	.106	1.905
1951	162	3,207	416,910	28.4	5,914	87	5,145	154,350	.370	.370	4.346	.105	4.241
1952	216	3,153	409,890	27.9	5,814	79	4,593	237,458	.579	.482	1.142	.134	1.008
1953	268	3,101	403,130	27.4	5,718	76	4,346	272,929	.677	.454	*.270*	.074	.196
1954	298	3,071	399,230	27.2	5,663	79	4,474	233,095	.584	.487	.646	.132	.514
1955	335	3,034	394,420	26.8	5,595	74	4,140	291,456	.739	.465	.517	.125	.392
1956	414	2,955	384,150	26.1	5,449	45	2,452	165,020	.430	.253	.327	.066	.261
1957	468	2,901	377,130	25.7	5,349	85	4,547	164,601	.436	.400	1.658	.103	1.555
1958	529	2,840	369,200	25.1	5,237	84	4,399	162,763	.441	.408	1.765	.102	1.663
1959	667	2,702	351,260	23.9	4,982	82	4,085	184,642	.526	.457	1.487	.109	1.378
1960	728	2,641	343,330	23.4	4,870	83	4,042	170,977	.498	.461	2.740	.108	2.632

[1] Total number expected in 1985, 3,369 minus column 2.

[2] Column 3 multiplied by average drainage area per pond of 130 acres.

[3] Column 3 multiplied by average spillway water surface area of 1.84 acres.

[4] Values read from dry subhumid climates, curve (fig. 9) entered with values in column 14 of table 4.

[5] Column 6 multiplied by column 7.

[6] Column 8 multiplied by column 13 of table 4.

[7] Column 9 divided by column 4.

[8] Column 10 divided by column 12 of table 4.

[9] From column 13, table 13, summarizing land-treatment effects. Values are in italic where data are less than column 12 and indicate they control pond effects.

[10] Column 5 multiplied by the smaller value in column 11 or column 12, divided by 100.

[11] Column 12 minus column 13.

TABLE 15.—*Computation of effects of floodwater-retarding reservoirs on surface runoff, watershed example*

Year	Actual in place	Increase to 1985 [1]	Total drainage area above reservoirs		Water surface area at spillway level [3]	Annual water surface area		Annual reservoir water loss by evaporation			Watershed surface runoff 1985 level of land treatment and ponds [9]	Watershed effects of reservoirs [10]	Watershed runoff corrected for land treatment, ponds, and reservoirs [11]
			Tributary area [2]	Percentage of watershed		Percentage of spillway level area [4]	Water surface [5]	Upstream [6]	Depth on reservoir drainage area				
									Upstream [7]	Downstream [8]			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	Number	*Number*	*Acres*	*Percent*	*Acres*	*Percent*	*Acres*	*Acre-inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1930	------	160	296, 000	20. 1	4, 352	85	3, 699	99, 133	0. 335	0. 284	0. 528	0. 057	0. 471
1931	------	160	296, 000	20. 1	4, 352	85	3, 699	103, 572	. 350	. 287	*. 235*	. 047	. 188
1932	------	160	296, 000	20. 1	4, 352	86	3, 743	86, 838	. 293	. 250	. 467	. 050	. 417
1933	------	160	296, 000	20. 1	4, 352	85	3, 699	107, 271	. 362	. 255	*. 142*	. 029	. 113
1934	------	160	296, 000	20. 1	4, 352	79	3, 438	195, 278	. 660	. 262	*. 024*	. 005	. 019
1935	------	160	296, 000	20. 1	4, 352	90	3, 917	32, 903	. 111	. 100	1. 070	. 020	1. 050
1936	------	160	296, 000	20. 1	4, 352	81	3, 525	162, 150	. 548	. 274	*. 143*	. 029	. 114
1937	------	160	296, 000	20. 1	4, 352	84	3, 656	115, 164	. 389	. 240	*. 190*	. 038	. 152
1938	------	160	296, 000	20. 1	4, 352	87	3, 786	68, 527	. 231	. 192	. 541	. 039	. 502
1939	------	160	296, 000	20. 1	4, 352	82	3, 569	147, 757	. 499	. 335	. 534	. 067	. 467
1940	------	160	296, 000	20. 1	4, 352	82	3, 569	154, 538	. 522	. 256	*. 032*	. 006	. 026

1941		160	296, 000	20. 1	4, 352	86	3, 743	96, 195	. 325	. 301	1. 326	. 061	1. 265
1942		160	296, 000	20. 1	4, 352	90	3, 917	25, 460	. 086	. 082	1. 341	. 016	1. 325
1943		160	296, 000	20. 1	4, 352	87	3, 786	73, 448	. 248	. 180	. 966	. 036	. 930
1944		160	296, 000	20. 1	4, 352	91	3, 960	10, 296	. 035	. 033	1. 477	. 007	1. 470
1945		160	296, 000	20. 1	4, 352	89	3, 873	37, 568	. 127	. 113	2. 022	. 023	1. 999
1946		160	296, 000	20. 1	4, 352	86	3, 743	85, 340	. 288	. 215	. 405	. 043	. 362
1947		160	296, 000	20. 1	4, 352	87	3, 786	66, 634	. 225	. 199	1. 829	. 040	1. 789
1948	1	159	294, 150	20. 0	4, 325	86	3, 720	93, 744	. 319	. 264	1. 302	. 053	1. 249
1949	4	156	288, 600	19. 6	4, 243	91	3, 861	14, 672	. 051	. 050	4. 414	. 010	4. 404
1950	5	155	286, 750	19. 5	4, 216	91	3, 837	15, 348	. 054	. 049	1. 905	. 010	1. 895
1951	23	137	253, 450	17. 2	3, 726	92	3, 428	0	0	0	4. 241	0	4. 241
1952	28	132	244, 200	16. 6	3, 590	86	3, 087	66, 988	. 274	. 228	1. 008	. 038	. 970
1953	29	131	242, 350	16. 5	3, 563	84	2, 993	98, 170	. 405	. 272	. 196	. 032	. 164
1954	52	108	199, 800	13. 6	2, 938	86	2, 527	55, 847	. 280	. 233	. 514	. 032	. 482
1955	63	97	179, 450	12. 2	2, 638	83	2, 190	88, 476	. 493	. 310	. 392	. 038	. 354
1956	85	75	138, 750	9. 4	2, 040	83	1, 693	63, 149	. 455	. 268	*. 261*	. 025	. 236
1957	96	64	118, 400	8. 1	1, 741	90	1, 567	9, 715	. 082	. 075	1. 555	. 006	1. 549
1958	109	51	94, 350	6. 4	1, 387	90	1, 248	8, 736	. 093	. 086	1. 663	. 006	1. 657
1959	126	34	62, 900	4. 3	925	88	814	12, 373	. 197	. 171	1. 378	. 007	1. 371
1960	152	8	14, 800	1. 0	218	88	192	2, 362	. 160	. 148	2. 632	. 001	2. 631

[1] Total of 160 planned minus column 2.

[2] Column 3 multiplied by average drainage area of 1,850 acres per reservoir.

[3] Column 3 multiplied by average spillway level water-surface area of 27.2 acres.

[4] Read from dry-subhumid climate curve, figure 9, and values in column 15 of table 4.

[5] Column 6 multiplied by column 7, divided by 100.

[6] Column 8 multiplied by column 10 of table 4.

[7] Column 9 divided by column 4.

[8] Column 10 divided by column 12 of table 4.

[9] From column 14 of table 14. If values are less than column 11, they are in italic to indicate that these values control pond effects.

[10] Column 5 multiplied by the smaller of the values in column 11 or column 12, divided by 100.

[11] Column 12 minus column 13.

TABLE 16.—*Computation of effects of water-spreading on surface runoff, watershed example*

Year	Actual in place [1]	Increase to 1985 [2]	Increase to 1985 as percentage of water shed [3]	Upstream unit effect of water spreading [4]	Downstream unit effect of water-spreading [5]	Effects of water spreading in water shed depth [6]	Watershed runoff corrected for land treatment, ponds, and reservoirs [7]	Corrected watershed surface runoff [8]	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Acres	*Acres*	*Percent*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Acre-feet*
1930		600	0.041	2.08	1.76	0.001	0.471	0.470	57,553
1931		600	.041	3.04	2.49	.001	.188	.187	22,899
1932		600	.041	1.84	1.57	.001	.417	.416	50,940
1933		600	.041	6.88	4.84	.002	.113	.111	13,592
1934		600	.041	14.16	5.62	.002	.019	.017	2,082
1935		600	.041	0	0	0	1.050	1.050	128,576
1936		600	.041	12.00	6.00	.002	.114	.112	13,715
1937		600	.041	9.28	5.73	.002	.152	.150	18,368
1938		600	.041	2.80	2.33	.001	.502	.501	61,349
1939		600	.041	8.00	5.37	.002	.467	.465	56,941
1940		600	.041	12.16	5.96	.002	.026	.024	2,939
1941		600	.041	0	0	0	1.265	1.265	154,903
1942		600	.041	0	0	0	1.325	1.325	162,250
1943		600	.041	6.48	4.70	.002	.930	.928	113,636
1944	6	594	.040	0	0	0	1.470	1.470	180,006
1945	13	587	.040	.24	.21	0	1.999	1.999	244,783

1946	25	575	. 039	5. 76	4. 30	. 002	. 362	. 360	44, 083
1947	45	555	. 038	. 48	. 42	0	1. 789	1. 789	219, 068
1948	60	540	. 037	3. 04	2. 51	. 001	1. 249	1. 248	152, 821
1949	80	520	. 035	0	0	0	4. 404	4. 404	539, 283
1950	101	499	. 034	0	0	0	1. 895	1. 895	232, 048
1951	126	474	. 032	0	0	0	4. 241	4. 241	519, 323
1952	150	450	. 031	2. 96	2. 47	. 001	. 970	. 969	118, 657
1953	178	422	. 029	8. 00	5. 37	. 002	. 164	. 162	19, 837
1954	208	392	. 027	2. 88	2. 40	. 001	. 482	. 481	58, 900
1955	240	360	. 024	9. 12	5. 74	. 001	. 354	. 353	43, 226
1956	281	319	. 022	10. 08	5. 93	. 001	. 236	. 235	28, 776
1957	325	275	. 019	0	0	0	1. 549	1. 549	189, 680
1958	377	223	. 015	0	0	0	1. 657	1. 657	202, 905
1959	427	173	. 012	1. 20	1. 04	0	1. 371	1. 371	167, 883
1960	478	122	. 008	0	0	0	2. 631	2. 631	322, 174

[1] From Soil Conservation Service Form 195.

[2] Based on estimates by Soil Conservation Service conservationists of total amount likely to be installed by 1985—600 minus column 2.

[3] Column 3 multiplied by 100 divided by 1,469,440.

[4] 80 percent (for dependable system) of column 16 of table 4, divided by 100.

[5] Column 5 divided by column 12 of table 4.

[6] Column 4 multiplied by column 6, divided by 100.

[7] Copied from column 14 of table 15, summarizing effects of land treatment, ponds, and reservoirs.

[8] Column 8 minus column 7, in inches, and converted to acre-feet.

TABLE 17.—*Reconstitution of estimated streamflow with the estimated 1985 level of land and watershed treatment, watershed example*

Year	Observed streamflow [1]			Estimated corrected surface runoff [2]	Estimated streamflow under 1985 watershed conditions [3]	Estimated annual effects of treatment [4]	Annual effects of treatment as percentage of observed—	
	Total	Base plus interflow	Surface flow				Total streamflow [5]	Surface runoff only [6]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	1,000 acre-feet	*1,000 acre-feet*	*1,000 acre-feet*	*1,000 acre-feet*	*1,000 acre-feet*	*1,000 acre-feet*	*Percent*	*Percent*
1930	194	112	82	57.6	169.6	24.4	12.6	29.8
1931	139	99	40	22.9	121.9	17.1	12.3	42.8
1932	181	107	74	50.9	157.9	23.1	12.8	31.2
1933	112	88	24	13.6	101.6	10.4	9.3	43.3
1934	81	77	4	2.1	79.1	1.9	2.3	47.5
1935	354	211	143	128.6	339.6	14.4	4.1	10.1
1936	106	82	24	13.7	95.7	10.3	9.7	42.9
1937	109	77	32	18.4	95.4	13.6	12.5	42.5
1938	176	95	81	61.3	156.3	19.7	11.2	24.3
1939	168	87	81	56.9	143.9	24.1	14.3	29.8
1940	77.8	72.4	5.4	2.9	75.3	2.5	3.2	46.3
1941	295.7	116.4	179.3	154.9	271.3	24.4	8.2	13.6
1942	309.6	133.6	176.0	162.2	295.8	13.8	4.4	7.8
1943	257.9	128.7	129.2	113.6	242.3	15.6	6.0	12.1
1944	306.9	116.5	190.4	180.0	296.5	10.4	3.4	5.5
1945	425.0	168.3	256.7	244.8	413.1	11.9	2.8	4.6

1946	156.2	92.6	63.6	44.1	136.7	19.5	12.5	30.7
1947	371.9	136.1	235.8	219.1	355.2	16.7	4.5	7.1
1948	286.1	113.2	172.9	152.8	266.0	20.1	7.0	11.6
1949	740.0	193.5	546.5	539.3	732.8	7.2	1.0	1.3
1950	398.4	157.0	241.4	232.0	389.0	9.4	2.4	3.9
1951	723.3	198.0	525.3	519.3	717.3	6.0	0.8	1.1
1952	293.6	157.2	136.4	118.7	275.9	17.7	6.0	13.0
1953	144.0	111.9	32.1	19.8	131.7	12.3	8.5	38.3
1954	187.5	110.0	77.5	58.9	168.9	18.6	9.9	24.0
1955	151.2	89.3	61.9	43.2	132.5	18.7	12.4	30.2
1956	124.4	84.9	39.5	28.8	113.7	10.7	8.6	27.1
1957	286.7	84.9	201.8	189.7	274.6	12.1	4.2	6.0
1958	323.4	108.5	214.9	202.9	311.4	12.0	3.7	5.6
1959	304.5	123.3	181.2	167.9	291.2	13.3	4.4	7.3
1960	464.0	130.0	334.0	322.2	452.2	11.8	2.5	3.5
Totals	8,248.1	3,661.3	4,586.8	4,143.1	7,804.4	443.7	----	----
Averages	266.1	118.1	148.0	133.7	251.8	14.3	5.4	9.7

[1] Copied from columns 2, 3, and 4 of table 4.
[2] Copied from column 10, table 16, of water-spreading effects.
[3] Column 3 plus column 5.
[4] Column 2 minus column 6.
[5] Column 7 divided by column 2, multiplied by 100.
[6] Column 7 divided by column 4, multiplied by 100.

DISCUSSION

Some discussion of the foregoing illustration of applying the rational procedure to watershed example is warranted.

First of all, it should be pointed out that the evaluation of effects of irrigation is for surface runoff only (expressed as downstream effects) and is not an evaluation of all the influences of irrigation. In the watershed example, irrigation is from deep wells piercing the Ogallala formation that supplies base flow to the river. It was without the scope of this study to evaluate the eventual effects of withdrawal of irrigation water from the aquifer on total streamflow.

Some developments going on in the watershed, such as urbanization and highway and airport construction, may tend to increase runoff. These were not included in the study, their study not being within the objectives of the project.

Pothole drainage simply increases the area tributary to the river. The drainage area used to compute watershed water yield in inches of depth should, therefore, have been a variable, instead of a constant 1,469,440 acres. There is such a small amount of this practice that using a variable drainage area would have made no practical difference in the computed inches of watershed runoff.

Some water is required to fill and soak up the sites of newly constructed ponds and reservoirs. In a strict accounting, this abstraction of water should be considered.

One average annual value for potential evapotranspiration (PET) was used. It is well known that PET varies from year to year, depending on climatic conditions.

For convenience and practicability, considerable averaging was done. For example, the effects of land treatment and ponds were averaged over the drainage areas tributary to floodwater-retarding reservoirs to determine if runoff controlled the depletion effects of reservoirs. Strictly speaking, drainage-area runoff should have been computed by weighting the areas treated, those above ponds, and those not treated.

In the evaluation of ponds and reservoirs, if water yield from tributary areas was less than losses from percolation and evaporation, the water yield was considered limiting, but no carryover storage capacity was considered the following year. In a strict accounting, this should be done. It would, however, introduce considerable complications relative to water-surface areas to use in computing volumes, the timing of pond and reservoir filling, etc. It was considered that such refinements were not warranted.

Most watersheds in the Great Plains will not have such a large base-flow component as does the river in the example. Likewise, most such watersheds will not have as much irrigation and pothole drainage to compensate for reductions of surface runoff caused by streamflow-depleting conservation treatment practices.

All too few research data are available to support the indices shown in table 1 and the curves in figures 5, 6, 9, and 10. Of great concern, relative to this matter, is the fact that not much research is presently underway that is directly applicable to this problem.

The effects of land use and treatment as computed herein are not likely to be exact for any one year. It is believed, however, that the results obtained from the application of the rational procedure to the watershed will give some indication of what might occur over a period of several years. Those concerned with estimating future water resources in watersheds subject to the effects of the conservation use and treatment of land on water yielded by streamflow may find the method described herein to be a useful tool or guide.

U.S. GOVERNMENT PRINTING OFFICE: 1966 O—789-169

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