RECOMMENDED YIELDS OF SURFACE RUNOFF FROM SMALL WATERSHEDS ON THE HILLSDALE SOIL COMPLEX AND RATES OF SURFACE RUNOFF FOR USE IN THE DESIGN OF FARM PONDS IN SOUTHERN MICHIGAN

Thesis for the Degree of M. S.

MICHIGAN STATE COLLEGE

David Franklin Witherspoon

1952

This is to certify that the

thesis entitled

"Recommended Yields of Surface Runoff from Small Watersheds on the Hillsdale Soil Complex and Rates of Surface Runoff for Use in the Design of Farm Ponds in Southern Michigan"

presented by

David Franklin Witherspoon

has been accepted towards fulfillment of the requirements for

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E H Kidder
Major professor

Date March 10, 1952

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by

David Franklin Witherspoon

AN ABSTRACT

Submitted to the School of Graduate Studies of Michigan State College of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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1952

Approved E A Kidder

4/11/52

David Franklin Witherspoon

ABSTRACT

Recommended Yields of Surface Runoff from Small Watersheds on the Hillsdale Soil Complex and Rates of Surface Runoff for Use in the Design of Farm Ponds in Southern Michigan

The purpose of this thesis is to make recommendations for yields of surface runoff to be used in the hydrologic design of farm ponds. A comparison is made of the peak rates of runoff occurring once in twenty-five years for use in spillway design, modified for Southern Michigan from those recommended for the North Appalachian Region and the Claypan Prairies as well as those recommended for Michigan in the United States Department of Agriculture Farmers' Bulletin Number 1859.

The main factors governing the design of farm ponds are discussed. These are as follows:

1. Evaporation from free water surfaces
2. Precipitation falling on the reservoir
3. Surface runoff
    (a) Total yield from the watershed
    (b) Rates of runoff for spillway design
4. Subsurface runoff (seepage to the pond)
5. Demand use (the required quantity of water to be taken from the pond for livestock and other uses)
6. Seepage (away from the pond)
7. Silting or sedimentation

The recommendations for yields of surface runoff are only applicable to small watersheds of soils of the Hillsdale Soil Complex as it is found in southern Michigan. These soils should have similar textures and profile characteristics to those described in this thesis. Since the rates of runoff are derived from general recommendations for other areas these may have wider application.

The recommended yields of runoff were estimated from a synthesis of fifty years of runoff records. A relationship between rainfall and runoff for the summer and winter seasons was established on the basis of the ten years of record from the cultivated watersheds of the Michigan Hydrologic Research Project. A frequency analysis was made of the fifty years of rainfall records of the United States Weather Bureau at Lansing, Michigan. From the results of the frequency analysis and the rainfall-runoff relationships the runoff was found that could be depended upon seventy-five percent of the time and ninety-six percent of the time.

The amount of runoff for an eighteen month period as found in this study is as follows:

2.69 inches of runoff can be expected seventy-five percent of the time.

1.52 inches of runoff can be expected ninety-six percent of the time.

The degree of safety desired and sound judgment should govern the use of these recommendations. The recommendations contained in this thesis should be considered tentative subject to revision when more complete records are available.

A simplified method of design is given in the Appendix to show the use of the recommendations made here.

RECOMMENDED YIELDS OF SURFACE RUNOFF FROM SMALL WATERSHEDS ON THE HILLSDALE SOIL COMPLEX AND RATES OF SURFACE RUNOFF FOR USE IN THE DESIGN OF FARM PONDS IN SOUTHERN MICHIGAN

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The author wishes to express his sincere thanks to Mr. E.H. Kidder under whose inspiration, supervision, and unfailing interest this investigation was undertaken. He is also indebted to Dr. E.P. Whiteside for his guidance and help in the soil descriptions on the watersheds, as well as their definition for the specified areas of Michigan.

Grateful acknowledgement is also due to Mr. J.O. Veatch for his map of the Soil Associations of Michigan and to Mr. L.L. Harrold and Mr.N.E. Minshall and others of the United States Soil Conservation Service for their helpful suggestions and assistance.

Acknowledgement is also made for the data and negatives of maps of the Michigan Hydrologic Research Project operated by the United States Department of Agriculture, Soil Conservation Service in cooperation with the Michigan Agricultural Experiment Station.

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INTRODUCTION

Farm ponds are a useful surface water conservation practice. In specialized farming areas supplemental irrigation is rapidly becoming an essential practice during the critical periods of crop growth. Farm ponds offer a water supply for this purpose. Water for spraying purposes in orchards, where underground or other surface water supplies are inadequate, may be obtained from a farm pond. In the "grassland" type of agriculture advocated by some conservationists, farm ponds fulfill the need for additional stock-watering facilities. As well as the uses already mentioned farm ponds also provide water supplies for fire protection, wildlife and recreation.

The demand for information concerning farm ponds by the farmer is quite apparent from the volume of extension literature available from state and federal agencies.

Very little basic hydrologic data necessary for the design of a farm pond has been published. This is particularly true in Michigan. At the present time the United States Soil Conservation Service is using generalized data adapted to this area from regional information.

It is the purpose of this thesis to discuss in detail surface runoff as it affects the design of a farm pond in southern Michigan with regard to available data and literature. The other factors governing the design of a farm pond are also discussed.

In farm pond design the following factors are taken into consideration:

1. Evaporation from free water surfaces
2. Precipitation falling on the reservoir
3. Surface runoff:
   (a) Total yield from the watershed
   (b) Rates of runoff for spillway design
4. Subsurface runoff (seepage to the pond)
5. Demand use (the required quantity of water to be taken from the pond for livestock and other uses)
6. Seepage (away from the pond)
7. Silting or sedimentation

The yields of surface runoff recommended in this thesis are only applicable to the Hillsdale Soil Complex. The area of Michigan to which these recommendations apply is designated in black on Plate 1, page 3. The soil series making up the associations designated are Hillsdale, Coloma, Bellefontaine, and Miami. The recommended yields for this area are based on synthesized fifty year runoff records. These were determined from relationships established on the basis of the ten years of record of the cultivated watersheds of the Michigan Hydrologic Research Project.

The rates of runoff are derived by extrapolation of recommendations made for the North Appalachian Region and the Claypan Prairies as well as recommendations for Michigan from the United States Department of Agriculture Farmers' Bulletin Number 1859.

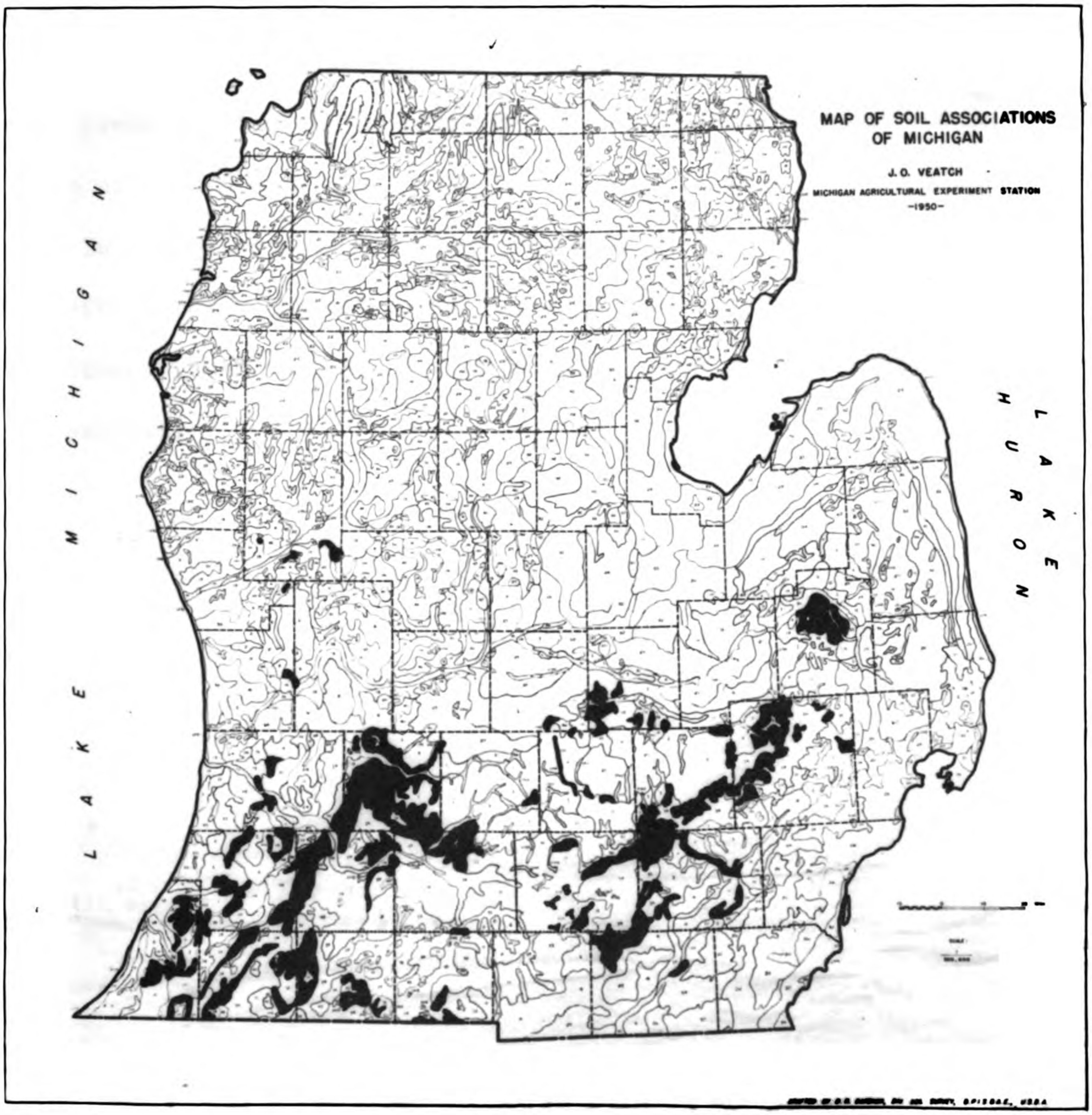


Plate 1.

- Area of Application designated in Black

In most cases the site of pond construction is predetermined by economics and feasibility of construction. The recommendations made in this thesis will aid in checking whether the size of watershed available will yield a water supply which can be depended upon. The recommended rates of runoff will aid in the design of spillways.

In the science of hydrology rigorous proofs are seldom possible. Therefore, the recommendations contained in this thesis should be considered tentative, subject to revision when more complete records are available.

REVIEW OF LITERATURE

General

Most extension publications which comprise the volume of the literature on farm ponds make only general statements concerning farm pond design and construction. These apply only in a specific area.

Calkins (1) lists the essential requirements of the basic structural types of farm ponds as:

1. The pond should meet a definite need, that is, a water supply for livestock, spraying, irrigation, fire protection, wildlife or recreation.
2. Source of water for the pond should be free from barnlot drainage and undesirable industrial wastes.
3. Pond must have an impervious dam and floor. Borings or test holes should be drilled to determine soil conditions.
4. Adequate spillway capacity - ponds through which surface runoff flows require spillways designed for flood runoff. All ponds should have an open auxiliary spillway to prevent water overtopping the earth fill in case the drop inlet becomes clogged or its capacity is exceeded.
5. Inflow should be regulated to the need by adding to or subtracting from natural watersheds by diversion ditches and terraces.
6. Ponds should be constructed on topography which permits construction at reasonable cost, that is, on watercourses of four percent or less slope and side hills of less than eight percent slope.

7. Ponds should have a drain, especially fish ponds.

Evaporation

Estimates of evaporation in Michigan are somewhat variable. Thornthwaite and Holzman (14) state that bodies of free water make available a continuous supply of moisture for evaporation and actual losses are dependent directly upon meteorologic factors. For this reason it has been possible to develop emperical formulae which permit the computation, with reasonable accuracy, the anticipated losses from lakes and reservoirs in terms of meteorologic data alone.

Harrold (7) estimates, based on his knowledge of hydrologic phenomena, that, evaporation from, and precipitation on a pond area in Michigan might be expected to balance over critical dry periods of six months or more.

Follansbee (4) in his study of evaporation notes that the area of lowest evaporation from a free water surface in the United States is the Great Lakes Region where it ranges from fifteen to twenty inches per year. Kimball (9) estimated the evaporation in the area under consideration as a maximum of thirty-five inches a year. Horton (8) interpolated values using data collected at Germfask in the upper peninsula of Michigan. He estimated, by converting the data to a base for the continental United States, the evaporation over this area of southern Michigan under consideration, ranged between thirty-seven and forty-three inches per annum. This was for a Class A Weather Bureau pan.

Thornthwaite (15) estimates the moisture deficiency, that is, the difference between precipitation and water losses in Michigan, as two to three inches during the dry season of the year and surplus as ten inches for the wet seasons of the year. He estimates the potential evapo-transpiration from plants as twenty-four to twenty-six inches a year.

Meyer (11) using his evaporation formula on United States Weather Bureau data found the evaporation over the area under consideration varied from twenty-five to thirty-five inches annually. He shows that there is a surplus of two to seven inches of precipitation on a free water surface over the amount lost by evaporation. At Lansing, Michigan, he calculated that the evaporation has been greater than precipitation only two years in the thirty years of record from 1910 to 1940. This deficiency was six and seven inches during two years in the early thirties.

Surface Runoff

In this particular phase of farm pond design most of the work has been done with reference to large watersheds. Considerable study has been done in areas where the most of the flood peaks are caused by thunderstorm activity instead of the spring freshet as is the case in Michigan.

Hamilton and Jepson (5) state that the watershed characteristics (slope, shape, size, cover and soil) and storm characteristics (amount, duration and intensity of rainfall) have a direct effect on the annual yield and peak flow of surface runoff from any area. Harrold (6) observes that profile drainage differences are of less importance in causing flood peaks than they are in causing differences in annual yield. Minshall (12) found that as the soil became less permeable the relation of rainfall to runoff became more consistent.

Subsurface Runoff

Very little material is available for use in the estimation of this factor of farm pond design. Cook (3) states that the weakest point in most procedures for the design of a farm pond is the assumption that surface runoff constitutes the only source of inflow. He cites as an example the many farm ponds in central Missouri with very small grassed contributing areas. He states that these often receive considerable inflow from rains which produced no surface runoff. Parsons (13) in Alabama found the groundwater flow to a pond which he studied was 14.6 inches where the surface runoff was 5.22 inches from twenty-seven acres of terraced land.

Demand Use

Hamilton and Jepson (6) developed a chart for the estimation of livestock water requirements. These are general over-all recommendations for the continental United States.

Seepage

Parsons (14) in his study in Alabama found that the loss due to seepage from the pond he studied was 0.35 acre-inches per day on a mean-annual basis. The pond area was 1.5 acres at spillway elevation. The soil on the floor of this pond was a sandy topsoil of twenty-five per cent non-capillary porosity with a clay subsoil of 10.5 per cent non-capillary porosity.

There has been considerable work done on losses due to seepage from irrigation canals. However, these investigations for the most part are concerned with lower heads of water than are normally encountered in the design of a farm pond.

Carpenter (2) in his early investigations in Colorado found that the success of the silting process in sealing the reservoir against seepage may be expected to be greater in small reservoirs than in large reservoirs.

Silting

Harrold (6) states that a watershed cover of ninety per cent in grass or woods will reduce silting or sedimentation to a negligible amount. However, the results presented by Harrold in this publication show that under conditions of less cover silting may be serious in reducing the reservoir storage capacity.

METHOD OF STUDY

Descriptions of Watersheds

Three watersheds are included in the Michigan Hydrologic Research Project. The two cultivated watersheds, the data from which is used in this study, are located on the Michigan State College Farms about two miles south of East Lansing, Michigan. The third watershed which has a permanent wooded cover is located on the Rose Lake Conservation Farm about nine miles east and north of East Lansing. The data from this watershed was not used in this study. This hydrologic project was set up in 1941 for the purpose of studying the effect of cover on soil loss and surface runoff.

The two cultivated watersheds are managed in a manner similar to that of an average farm using conservation practices. Across the slope cultivation and four year rotations of corn, grain, hay, hay, are the main conservation practices used.

Climatic instrumentation on the cultivated watersheds is by standard United States Weather Bureau instruments. The runoff measuring installations are the standard Soil Conservation Service Research Type H flumes used on small watersheds. Silting basins and Ramser divisors are used in conjunction with the flumes for the measurement of sediment load in runoff. A detailed instrumentation and soils map of the cultivated watersheds is shown on Plate 2, page 11. A map showing the topography of the cultivated watersheds in detail on Plate 3, page 12.

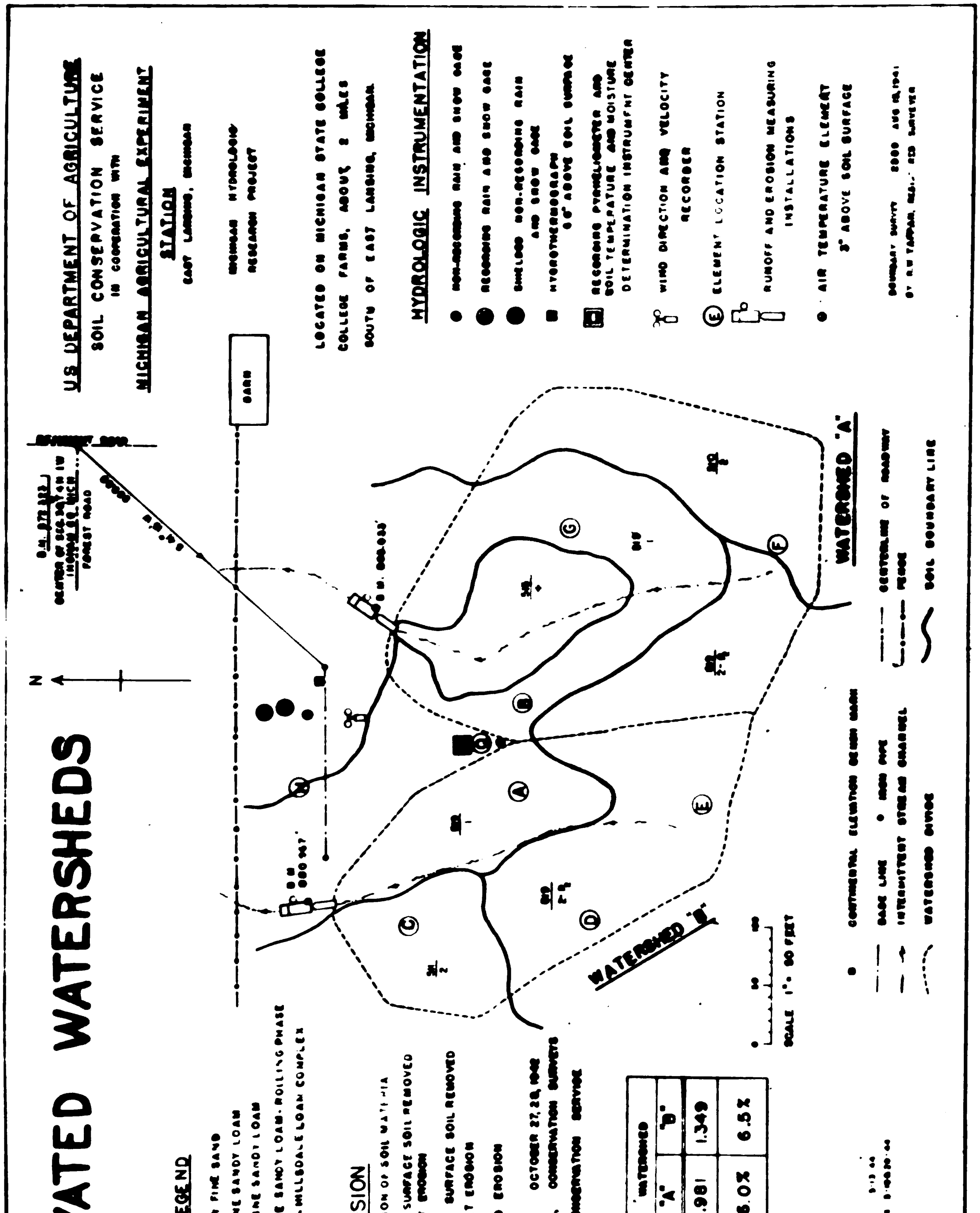

CULTIVATED WATERSHEDS
N
US DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
IN COOPERATION WITH
MICHIGAN AGRICULTURAL EXPERIMENT STATION
EAST LANSING, MICHIGAN
MICHIGAN HYDROLOGIC RESEARCH PROJECT
LOCATED ON MICHIGAN STATE COLLEGE COLLEGE FARMS, ABOUT 2 MILES SOUTH OF EAST LANSING, MICHIGAN.
BARN
FOREST ROAD
SOIL LEGEND
819 - METEA LOAMY FINE SAND
825 - TRAVERSE FINE SANDY LOAM
510 - HILLSDALE FINE SANDY LOAM
511 - TUSCOLA FINE SANDY LOAM - ROLLING PHASE
45 - 410 MIAMI LOAM - HILLSDALE LOAM COMPLEX
EROSION
+ ACCUMULATION OF SOIL MATERIA
1 0 - 25% OF SURFACE SOIL REMOVED BY SHEET EROSION
2 25 - 75% OF SURFACE SOIL REMOVED BY SHEET EROSION
R SLIGHT WIND EROSION
SOILS MAPPED OCTOBER 27, 28, 1942 BY LEO R. JONES, CONSERVATION SURVEYS DIVISION, SOIL CONSERVATION SERVICE
WATERSHED
"A" "B"
AREA - ACRES 1.981 1.349
WEIGHTED AVERAGE SLOPE 6.0% 6.5%
WATERSHED "A"
WATERSHED "B"
SCALE 1" = 50 FEET
HYDROLOGIC INSTRUMENTATION
NON-RECORDING RAIN AND SNOW GAGE
RECORDING RAIN AND SNOW GAGE
SHIELDED NON-RECORDING RAIN AND SNOW GAGE
HYGROTHERMOGRAPH 6.0" ABOVE SOIL SURFACE
RECORDING PYRHELIOMETER AND SOIL TEMPERATURE AND MOISTURE DETERMINATION INSTRUMENT CENTER
WIND DIRECTION AND VELOCITY RECORDER
ELEMENT LOCATION STATION
RUNOFF AND EROSION MEASURING INSTALLATIONS
AIR TEMPERATURE ELEMENT 3" ABOVE SOIL SURFACE
CONTINENTAL ELEVATION BENCH MARK
BASE LINE
IRON PIPE
INTERMITTENT STREAM CHANNEL
WATERSHED DIVIDE
CENTERLINE OF ROADWAY
FENCE
SOIL BOUNDARY LINE

Plate 2.

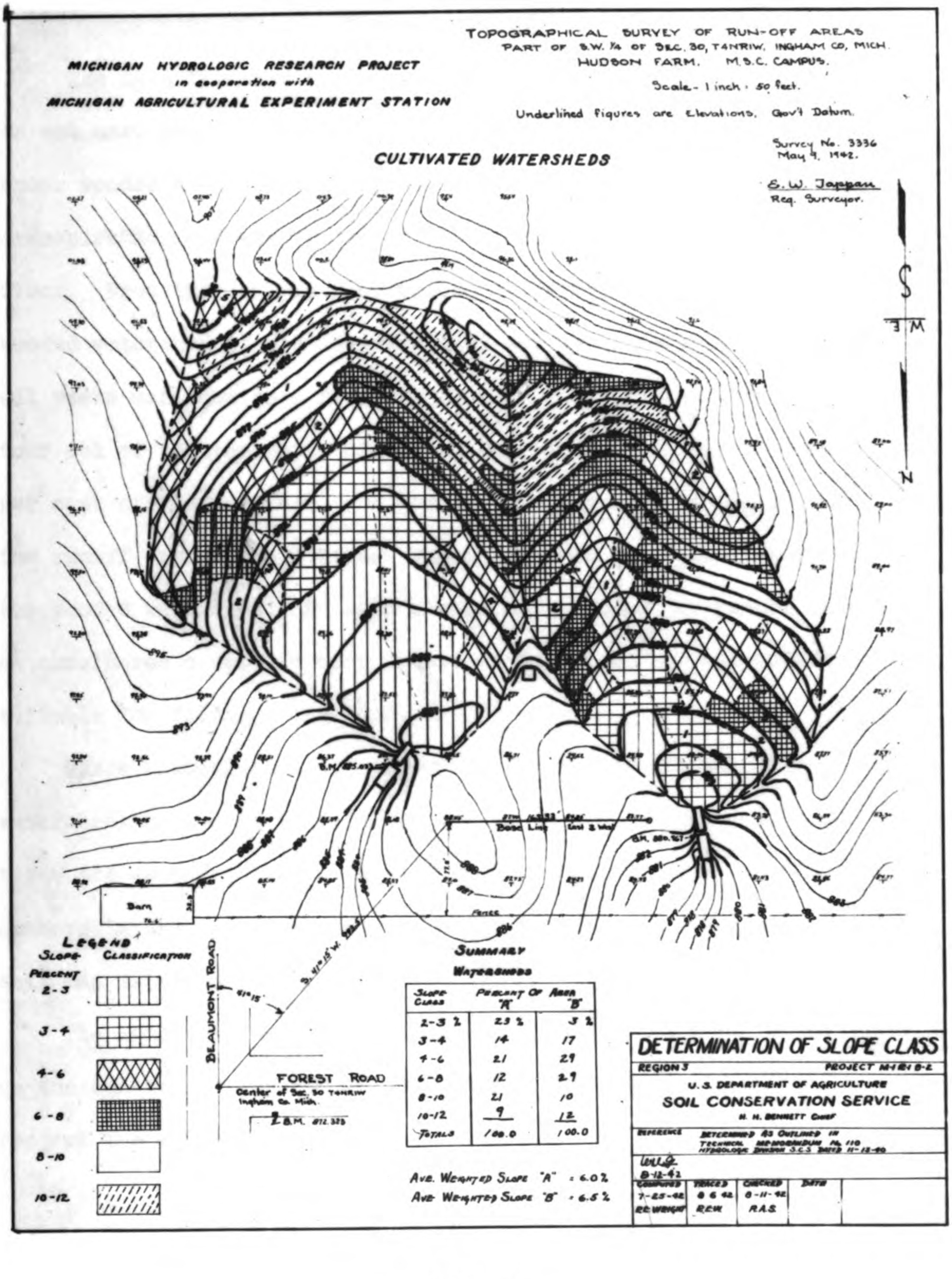

TOPOGRAPHICAL SURVEY OF RUN-OFF AREAS
PART OF S.W. 1/4 OF SEC. 30, T4NR1W, INGHAM CO, MICH.
HUDSON FARM, M.S.C. CAMPUS.
Scale - 1 inch = 50 feet.
Underlined figures are Elevations, Gov't Datum.
Survey No. 3336
May 4, 1942.
E. W. Tappan
Reg. Surveyor.
MICHIGAN HYDROLOGIC RESEARCH PROJECT
in cooperation with
MICHIGAN AGRICULTURAL EXPERIMENT STATION
CULTIVATED WATERSHEDS
Base Line
Barn
Fence
BEAUMONT ROAD
FOREST ROAD
Center of Sec. 30 T4NR1W Ingham Co. Mich.
LEGEND
Slope Classification
Percent
2-3
3-4
4-6
6-8
8-10
10-12
SUMMARY
Watersheds
Slope Class | Percent of Area "A" | "B"
2-3 % | 23 % | 3 %
3-4 | 14 | 17
4-6 | 21 | 29
6-8 | 12 | 29
8-10 | 21 | 10
10-12 | 9 | 12
Totals | 100.0 | 100.0
Ave. Weighted Slope "A" = 6.0%
Ave. Weighted Slope "B" = 6.5%
DETERMINATION OF SLOPE CLASS
REGION 3
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
H. H. BENNETT CHIEF
Computed 7-25-42
Traced 8 6 42 R.E.W.
Checked 8-11-42 R.A.S.
Date

Plate 3.

The data from the wooded watershed was considered inadequate and is not used here. A probable reason for the lack of surface runoff under wooded cover is the increased interception of rainfall, evapo-transpiration and absorption of water by the humus of the forest floor. From the ten years of record of surface runoff from the wooded watershed it was observed that the total surface runoff in all years was less than five per cent of the annual rainfall. In four out of the ten years of record the runoff was less than one per cent of the rainfall. On the average the records showed that the runoff from the cultivated watersheds was eight times that of the wooded watershed. An area producing little or no runoff cannot be considered a satisfactory source of supply of surface runoff suitable for filling farm ponds.

Since Plate 2 page 11 was made the soils of the cultivated watersheds have been re-mapped. The boundaries between the soil types are essentially the same as on the original map. The code numbers in the soil descriptions refer to the code numbers on the soil map on Plate 2 page 11.

The soil descriptions as made by Dr. E.P. Whiteside of the soils on the cultivated watersheds of the Michigan Hydrologic Research Project are as follows:

Code No. 515 Soil Type: Spinks loamy fine sand

Horizon	Depth	Texture	Remarks
Ap	0-9"	loamy fine sand	
Bp	9-13"	loamy fine sand	B is mottled
A2	13-27"	loamy fine sand	Occasional pebble
B	27"-	heavy loamy fine	found.
		sand to light loamy	
		fine sand	Profile drainage
			fair to good

Topography - Rolling, depressional

Original vegetative cover - hardwood forest - beech, maple.

Code No.819 and 511 Soil Type: Coloma loamy fine sand

Horizon	Depth	Texture	Remarks
Ap	0-10"	heavy loamy fine sand	
A2	10-27"	loamy fine sand	
B2	27-37"	loamy fine sand	

Code No.510 Soil Type: Hillsdale fine sandy loam

Horizon	Depth	Texture	Remarks
Ap	0-7"	fine sandy loam	
B2	7-27"	clay loam	
D1	27"-	fine sand to loamy	D1 has streaks
		fine sand	of texture
			difference.

Area of Application of Yield Recommendations

The area of application is shown on Plate 1, page 3, and is designated in black on the Map of the Soil Associations of Michigan. The soil associations of the area are made up of Bellefontaine, Hillsdale, Coloma, and Miami series. These associations cover a total area of 1,099,100 acres of southern Michigan.

General descriptions of these soil series are as follows:

Bellefontaine - Sandy loams and light loams, moderately stony. Reddish sandy and stony friable subsoil and coarse pervious substratum.

Hillsdale - Sandy loams and light loams; light brownish and yellowish surface soil underlain by yellowish friable but moderately retentive sandy loam and gritty clay.

Coloma - Sands or light sandy loams, underlain by yellowish dry sand to three feet or more, then by pervious heterogenous sand, clay, and stones.

Miami - Light brownish loam and silt loam over brownish compact and retentive but granular gritty clay. Clay substratum extends to several feet.

It can be readily seen from these general descriptions that these soil associations contain soil types which can have wide textural differences and consequently profile differences. Therefore, it is imperative that before the yield recommendations made in this thesis can be safely used for any watershed, the soils of the watershed should be mapped in detail with complete profile descriptions. These descriptions should be compared with those given in this thesis for the experimental watersheds of the Michigan Hydrologic Research Project. It can be safely assumed that the recommendations made here can be safely applied to the more impermeable soils of these associations, that is, Miami and Hillsdale series. However, care should be taken when applying these recommendations to the soils of lighter texture than those found on the cultivated watersheds at East Lansing, Michigan. These soils would be made up of the lighter textured soils (sands) of the Coloma series.

Runoff Yield Design Value Determination

In order to synthesize fifty years of runoff records which would have some degree of validity and accuracy, as well as be safe for use in design, it was decided to divide the year into two periods. These were the non-growing season (winter), that is, October to May (8 months) or October to April (7 months), and the growing season (summer) May to September (5 months) or June to September (4 months). Two different length periods were chosen for each season. This was done because May and June are the months of highest rainfall in this area. In May newly planted vegetation may not be well established. Therefore, the month of May was included in both seasons to minimize any variation in runoff caused by this condition.

For the above chosen periods the rainfall records of the United States Weather Bureau at Lansing, Michigan were subjected to a frequency analysis to find the minimum amounts of rainfall which could be depended upon seventy-five and ninety-six per cent of the time. The results of this frequency analysis are shown in Table I, page 17.

TABLE I

MINIMUM DEPENDABLE RAINFALL

Period	Percentage of the Time Dependable	
	75 per cent	96 per cent
Winter 8 months	17.62 inches	14.28 inches
Winter 7 months	13.94 inches	10.21 inches
Summer 5 months	13.10 inches	9.30 inches
Summer 4 months	7.98 inches	5.59 inches

The runoff records of the Michigan Hydrologic Research Project were plotted against the rainfall for the winter periods of eight and seven months and the summer periods of five and four months. This was done on log-log paper as is shown in Figures 1 and 2 pages 18 and 19 respectively.

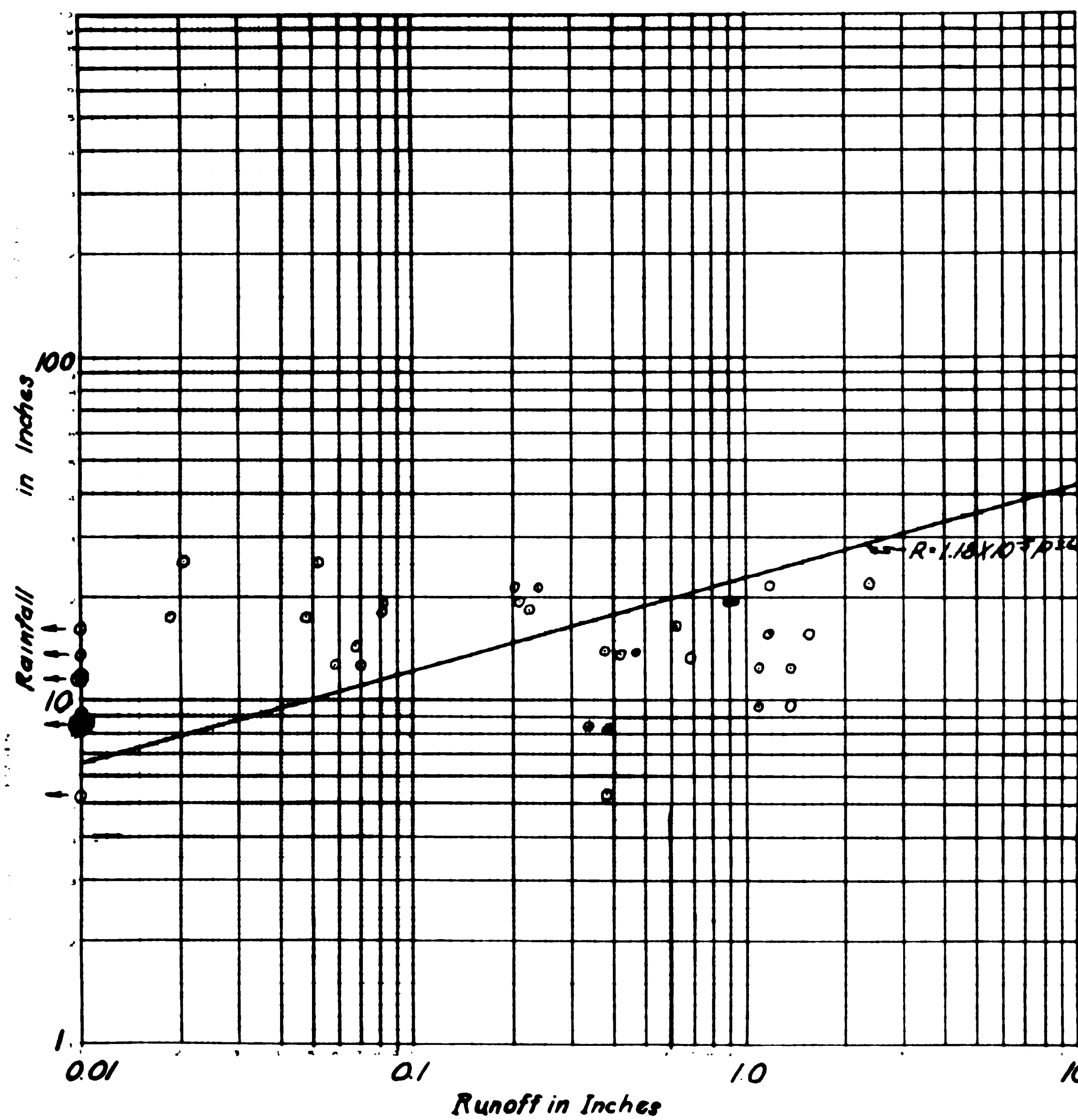
The rainfall-runoff records for these periods were then analyzed by the method of least squares. Various combinations of the data were used to obtain the maximum number of relationships, that is, each watershed separately, both watersheds together to find an over-all relationship.

Relationships were then chosen for the summer season and the winter season. These are as follows:

Summer $R = 1.18 \times 10^{-5} P^{3.61}$ Figure 1 page 18

Winter $R = 2.43 \times 10^{-3} P^{2.41}$ in blue on Figure 2 page 19

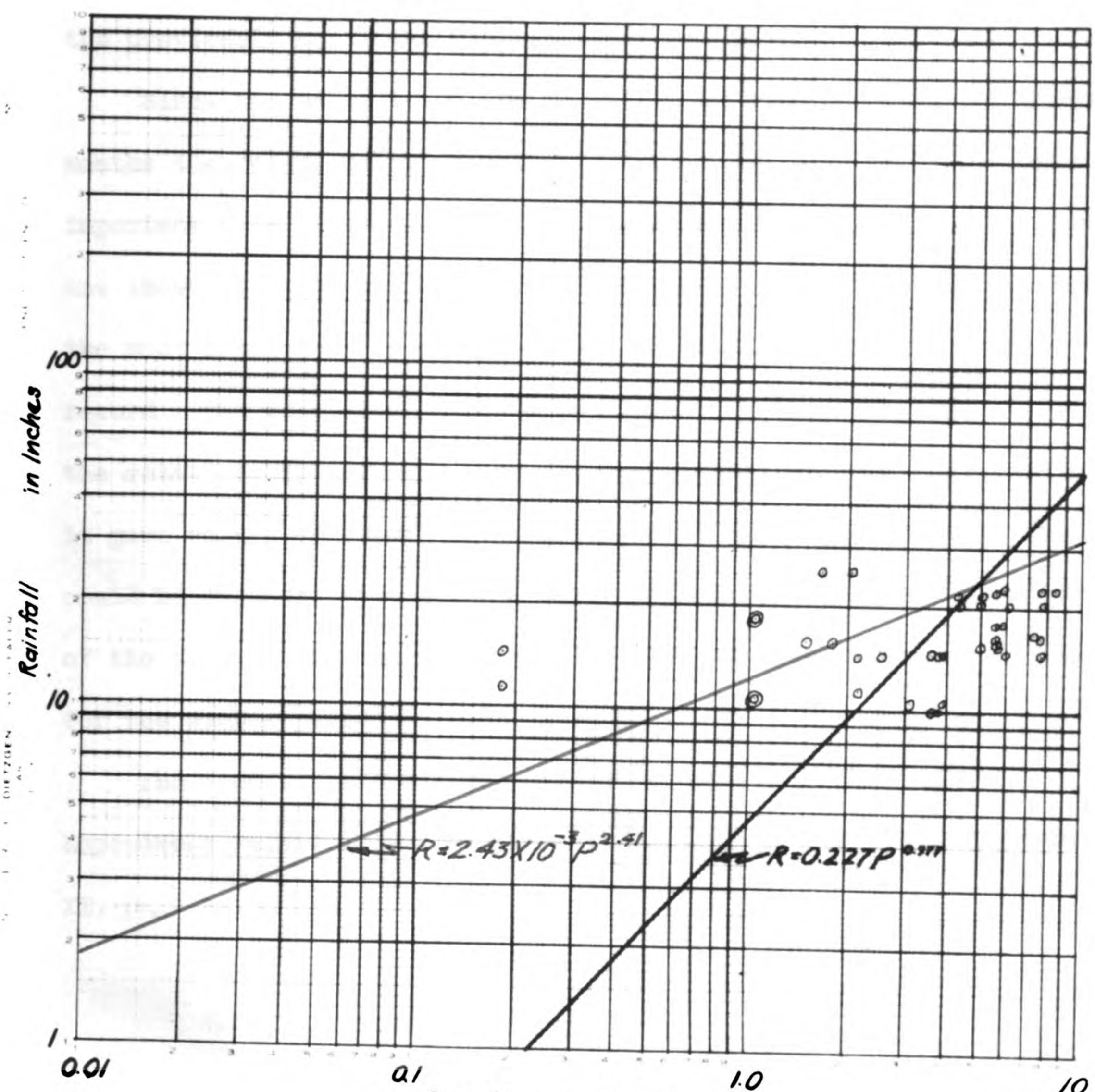
Where R is runoff and P is precipitation



RAINFALL - RUNOFF RELATIONSHIP

Summer 4 or 5 Months

Fig. 1



RAINFALL-RUNOFF RELATIONSHIPS
Winter 7 or 8 Months
Fig. 2

For the summer relationship the one which gave the lowest value of runoff was chosen. As can be seen in Figure 1, page 18, the runoff during the summer months is extremely variable. Therefore, for safety the previously mentioned relationship was chosen.

Since the majority of the runoff yield occurs during the winter months the relationship chosen as reliable for this period is very important. In Figure 2, page 19, two relationships are shown. The one shown in black $R = 0.227 P^{0.977}$ is the relationship which gives the most consistent values of runoff as compared with the actual record. The relationship shown in blue $R = 2.43 \times 10^{-3} P^{2.41}$ is the relationship actually used for the recommendations made here since it gave values of runoff which more nearly approximated those which could be depended upon seventy-five per cent and ninety-six per cent of the time. This relationship also gave the lowest values of runoff for the winter period.

The runoff yield values obtained by applying the minimum dependable rainfall in the chosen relationships are given in Table II, page 21.

TABLE II

ESTIMATED DEPENDABLE RUNOFF YIELDS

Period	Percentage of the Time Dependable 75 per cent	96 per cent
Winter 8 months	2.43 inches	1.46 inches
Winter 7 months	1.37 inches	0.67 inches
Summer 5 months	0.13 inches	0.03 inches
Summer 4 months	0.02 inches	0.00 inches

The most desirable time of construction of a farm pond is in the spring or early summer. Under conditions of runoff found in Michigan the newly constructed pond would have very little water in it the first summer and would probably be filled by the spring snow melt of the following year. If the demand use is to be taken into account in the design of a pond, enough water will have to be stored which will adequately supply the demand for the critical dry periods in eighteen months, that is, the demands of the following spring and summer and any possible winter demands. Therefore, to obtain an eighteen month period for design from Table II, page 21, it is necessary to use one eight month winter period and two five month summer periods.

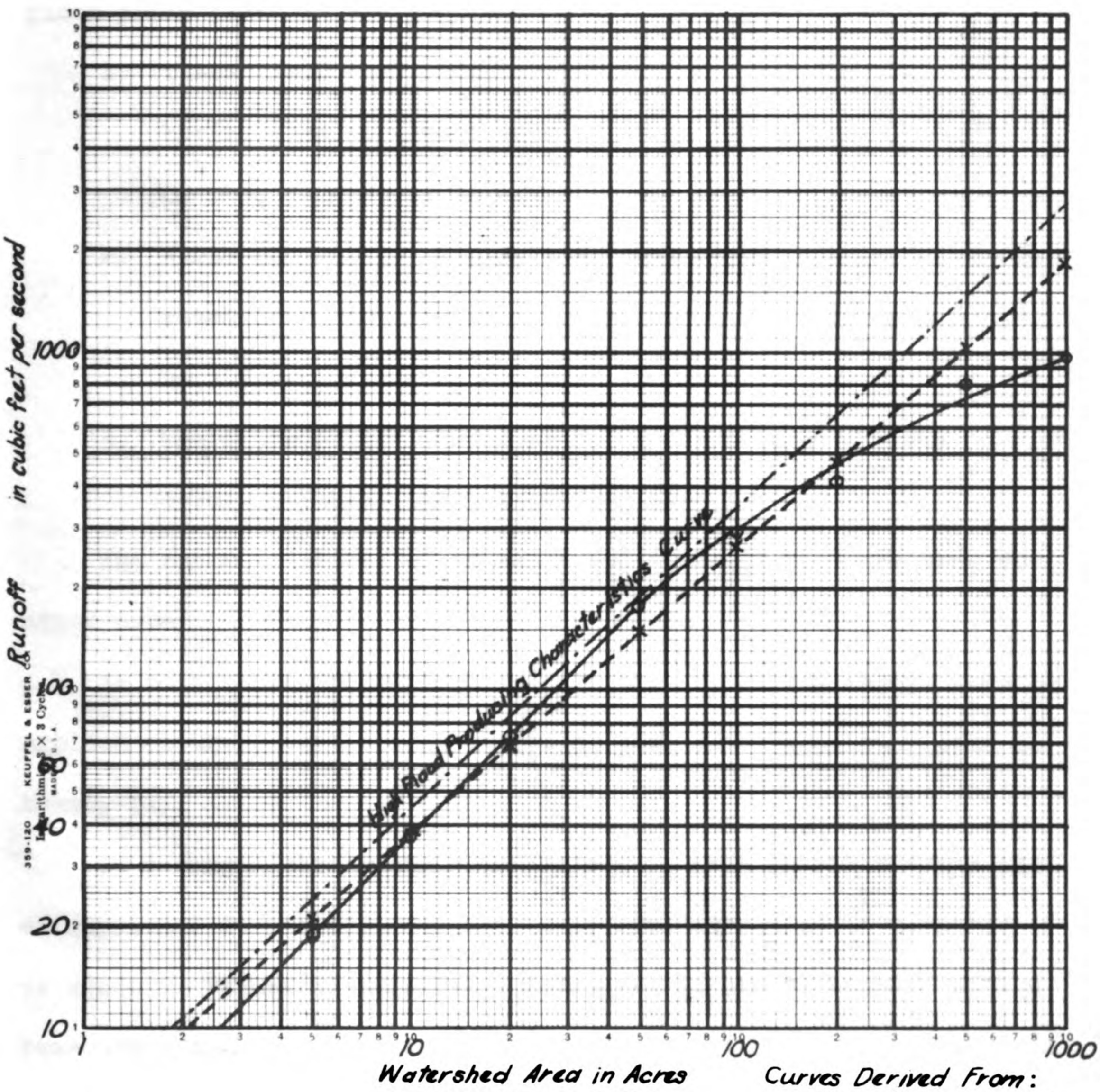
The eighteen month period of design for demand use is used by both Harrold (6) and Krimgold and Minshall (10).

For use of the design recommendations for small farm ponds, a method of design is given in the Appendix.

Rates of Runoff for Spillway Design

The experimental watersheds at East Lansing, Michigan are approximately 1.9 acres in size and data is not available from larger areas in Michigan except from the very large watersheds gaged by the United States Geological Survey. Therefore, estimates of rates of runoff for use in the design of pond spillways cannot be satisfactorily made on the basis of recorded data for Michigan. However, Harrold (6) has made recommendations for rates of runoff for a frequency occurrence in twenty-five years for the North Appalachian Region based on records of the United States Geological Survey and data obtained from the Soil Conservation Service experimental watersheds at Coshocton and Zanesville, Ohio. He gives location factors to be applied to the rates of runoff for the variation in rainfall intensities. Krimgold and Minshall (10) using records obtained from the United States Geological Survey and experimental watersheds within the Claypan Prairies of lower Illinois made recommendations for rates of runoff occurring once in twenty-five years which also can be modified by location factors. In Farmers' Bulletin Number 1859 general recommendations for rates of runoff are made for the continental United States. These rates of runoff are also modified for various locations by recommended factors.

Figure 3, page 23, was obtained for southern Michigan by plotting the recommendations of Harrold (6) and Krimgold and Minshall (10) using their recommended location factors extrapolated parallel to those recommended in Farmers' Bulletin Number 1859. The curve for a watershed with high runoff producing characteristics as given in Farmers' Bulletin



RATES OF RUNOFF

Fig. 3

Curves Derived From:
Harrold —o—
Krimgold & Minshall - -x- -
U.S.D.A. Bulletin No. 1859 —·—

Number 1859 and modified for the area under consideration is also shown for comparison.

Harrold (6) makes the following recommendations for use with the flood peaks given in his publication:

1. These flood peak runoff rates are for watersheds having good permanent vegetal cover (50 to 75 per cent or more in grass or woods)
2. Where the entire watershed is cultivated in a 3- or 4-year rotation (1 or 2 years in grass), multiply the peak values by 1.7.
3. Where the entire watershed is in woods or good grass cover, multiply the peak values by 0.6.

The recommendations of Krimgold and Minshall (10) are made for mixed cover.

In both cases the authors specify that no safety factor need be applied to their recommended values of peak flows occurring once in twenty-five years.

By a comparison of the recommendations made in other areas and extrapolated for Michigan an extremely good agreement is obtained as is shown in Figure 3, page 23. Therefore, it can be assumed with a reasonable degree of safety that these values are valid for Michigan.

Since the recommendations of Harrold (6) and Krimgold (10) are based on actual watershed records, any value used within the range of the two curves would be reasonably satisfactory for a specific area unless the watershed in question has extreme characteristics which might cause greater peak flows than anticipated in these recommendations.

No specific recommendations are made for the area of Michigan under consideration. When designing a pond spillway from this data the rates of runoff used should be governed by the runoff characteristics of the watershed and sound judgment.

DISCUSSION

General

Since the majority of the runoff in this region occurs during the spring runoff, the size of watershed does not necessarily need to be changed by the use of diversion ditches and terraces if found too small for the size of pond. Additional water might be obtained by the use of trees and other obstructions on the watershed which could cause appreciably increased snow accumulation during the winter season. Snow ridging has been used for this purpose in North Dakota.

The essential structural requirements of the basic types of farm ponds (refer to page 5) as listed by Calkins (1) should be strictly adhered to if a pond is to perform in the manner for which it was designed.

Evaporation

According to the literature it would seem that evaporation need not be taken into consideration in the design of a farm pond in southern Michigan. However, some observers have estimated evaporation from a free water surface through a wide range of fifteen to forty-three inches per annum for the area of Michigan under consideration.

Meyer (11) whose work is generally accepted in estimation of this hydrologic factor verifies the assumption that the evaporation equals the precipitation on an annual basis. However, when further study of this factor of farm pond design has been made and additional records from the newly installed Weather Bureau Evaporation Pan at the

Michigan Hydrologic Research Project, are available, this factor could be more accurately estimated for the area. When this has been done evaporation might be taken into consideration in design for the critical summer months and the size of watershed could be more accurately determined.

Precipitation

Over the area designated on Plate I, page 3, the average annual precipitation varies from thirty to thirty-six inches. The mean annual precipitation at Lansing, Michigan is 31.34 inches. Therefore, this analysis is on the safe side for the area under consideration.

Surface Runoff - Yield

The method used in the determination of the estimated runoff yields was derived from suggestions by Minshall (12). The author realizes it does not satisfy the true scientific approach and is not a rigid analysis governed by mathematical laws. However, it does offer a temporary solution to the problem of runoff estimation in the absence of better methods of analysis and more complete data.

The results that were obtained show that 4.46 acres of watershed are required to supply one acre-foot of surface water. This amount would be supplied seventy-five per cent of the time in eighteen months. To supply one acre-foot of water in eighteen months ninety-six per cent of the time it would require 7.89 acres. Hamilton and Jepson (5) recommend five acres of watershed in the area under consideration to supply one acre-foot of surface water. No mention is made of the

frequency these recommendations are made for.

Krimgold and Minshall (10) estimate that for a seventeen month period on the Claypan Prairies 2.55 inches of runoff could be expected seventy-five per cent of the time and 0.30 inches could be expected ninety-six per cent of the time. These recommendations were for Northwestern Illinois and Iowa based on data from watersheds at Edwardsville, Illinois and McCredie, Missouri. Harrold (6) recommends 0.48 inches of runoff could be expected seventy-five per cent of the time and 0.24 inches of runoff ninety-six per cent of the time for well-drained areas having no seeps or springs. These recommendations are made for an eighteen month period in southeastern Ohio.

In Michigan as a result of this study the estimates for an eighteen month period from an area on the Hillsdale Soil Complex are 1.52 inches of runoff ninety-six per cent of the time and 2.69 inches of runoff seventy-five per cent of the time.

The recommendations made here do not agree very closely with those made in Illinois and Ohio. A possible reason for this is that the recommendations made in Illinois and Ohio do not require a safety factor in use whereas those made in this thesis should be modified by field experience and sound judgment. Another possible reason for the variation in the recommendations is the fact that in Illinois and Ohio a larger portion of the runoff is caused by summer storms.

From observation of the records of the Michigan Hydrologic Research Project it was found that for nine out of the ten years of record, over eighty per cent of the total annual runoff occurs during

the first three months of the year. This shows that very little runoff is caused by summer storms in the area of Michigan under consideration.

To further verify the estimates made here for eighteen months the actual records for these periods were examined. The lowest runoff value during the ten years of record is 1.6505 inches from Watershed A and 1.7309 inches from Watershed B. These occurred during the eighteen months covering the growing periods for 1944 and 1945. The precipitation during this period was 12.78 inches for one growing season of five months in 1944, 26.09 inches for the other growing season of five months in 1945, and 14.64 inches for the winter season of eight months. Referring to Table I, page 17, the value 12.78 inches could be depended upon slightly more than seventy-five per cent of the time; 26.09 inches could be depended upon less than seventy-five per cent of the time, and 14.64 inches could be depended upon slightly less than ninety-six per cent of the time. Since the precipitation for the winter months is very near the minimum which could be depended upon ninety-six per cent of the time, the runoff is correspondingly low and within the estimated minimum for this period. This occurrence shows that the relationship chosen is valid for the minimum rainfall obtained from the frequency analysis.

These recommendations are limited in their use. They should only be used as recommended where surface water is the only source of inflow to the pond and for ponds of a capacity of one to twenty-five acre feet.

Surface Runoff - Rates

In Figure 3, page 23, a comparison of the rates of runoff from other areas, modified for Michigan, is shown. Since these curves were derived from general recommendations based on actual occurrence, the rates of runoff for the range of watershed sizes up to two hundred acres should be reliable. For watersheds of larger size than two hundred acres special methods of flood peak flow estimation should be used.

Subsurface Runoff

This hydrologic factor should be estimated for the individual site of pond construction. Seeps and springs are usually not apparent on very small watersheds, but as the size of watershed increases the flow derived from these sources becomes increasingly important. The surface runoff estimates given in this paper are made for areas where there is no subsurface flow to the pond. If there is an estimable amount of subsurface flow to the pond the yields of surface water should be modified accordingly. Under certain conditions of high water-table on the pond site, subsurface flow constitutes a major portion of the water supply.

Demand Use

This factor can be estimated by simple calculation. Irrigation and livestock needs can be estimated from experience and by consultation with the farmer.

Seepage

This factor is probably the most difficult to estimate. Any underestimation of this factor will result in failure of the pond.

The ideal site for construction is on a heavy clay soil where seepage is a minimum. However, this type of site is not always available. Silting after the pond is in operation or puddling of the soil on the pond site may decrease seepage. The best practice is a complete investigation of the pond site with deep borings and where possible a study of its glacio-geology. In this way any permeable material may be avoided and seepage kept at a minimum.

Silting or Sedimentation

Reservoir storage capacity can be severely reduced by silting. More data is required before reliable estimates of this factor can be made. However, silting is a known problem when a large part of the watershed area is cultivated. Therefore, the most advisable practice is to keep as much of the contributing area as possible in permanent vegetation. In particular, the area immediately surrounding the pond should be kept in permanent vegetation to keep the reservoir silting at a minimum.

SUMMARY

The factors governing farm pond design are complex. Those discussed in this thesis with regard to their estimation for conditions in southern Michigan are as follows:

1. Evaporation
2. Precipitation
3. Surface runoff
   (a) Yield of surface runoff
   (b) Rates of surface runoff
4. Subsurface runoff
5. Demand use
6. Seepage
7. Silting

Surface runoff is discussed in detail. A tentative method of analysis is presented for the determination of yield estimates from short period records. These recommendations for determining watershed sizes for ponds of one to twenty-five acre-feet capacity obtained by this method are:

2.69 inches of runoff can be expected seventy-five per cent of the time over an eighteen month period.

1.52 inches of runoff can be expected ninety-six per cent of the time over an eighteen month period.

These recommendations only apply to the soils of the Hillsdale Soil Complex having similar profile characteristics to those found on

the cultivated watersheds of the Michigan Hydrologic Research Project. The recommended yields should be modified by sound judgment in use.

A comparison is made of the most reliable estimates of peak rates of runoff modified for use in southern Michigan. The curves shown in Figure 3, page 23, will serve as a guide for design values for spillways.

When additional data is available the recommendations made in this thesis should be reviewed and modified accordingly.

A method of design of farm ponds is presented in the Appendix.

APPENDIX

A method for the hydrologic design of farm ponds using the recommendations of runoff yields made in this thesis is given here. This method is adapted from a simplified method developed by Harrold (6) for use in the design of small ponds in the North Appalachian Region, the cost of which does not exceed five hundred dollars.

To determine the size of drainage area proceed as follows:

Step 1

For the selected pond site, determine the surface area and depth of the pond at the elevation of the principal spillway. Check the geology of the pond site for possible seepage losses.

Step 2

Determine for the watershed, the predominant type of soil and compare the profile characteristics with those given in the descriptions on page 14. If the soils are lighter than those described the runoff yield values should be decreased according to the judgment of the designer.

Step 3

Calculate the volume of storage using the depth and the mean surface area of the pond (0.4 of the pond area at spillway elevation). Allow for the amount of water contributed by seeps and springs. Using the value of runoff yield dependable seventy-five per cent of the time (2.69 inches) calculate the size of watershed required to fill the pond in an eighteen month period which includes two growing seasons.

Step 4

Estimate the water seepage loss plus the water use demands for the pond for an eighteen month period which includes two growing seasons. If this total exceeds the value of estimated storage in Step 3 the spillway elevation of the pond will have to be raised to increase the storage and the size of watershed will have to be increased. If this amount is less than that found in Step 3 the size of drainage area should be checked using the value of runoff yield dependable ninety-six per cent of the time (1.52 inches) that it will supply the use demands and seepage losses ninety-six per cent of the time.

Step 5

For excessive use demands, determine the additional drainage area required using the value of runoff for ninety-six per cent of the time expectancy (1.52 inches).

Example:

Given a pond site having a surface area at spillway elevation of 2.35 acres and a depth of 7 feet.

Steps 1 and 3:

The mean surface is 2.35 x 0.4 = 0.94 acres.

The watershed is a loamy sand with profile characteristics similar to those mapped on the experimental watersheds. The pond site is a slowly permeable clay soil. Therefore, seepage would be a minimum and the values recommended here would apply.

The volume of storage is $0.94 \times 7 = 6.58$ acre-feet.

Watershed required to fill the pond $= \frac{6.58 \times 12}{2.69} = 29.3$ acres

The watershed contains no seeps or springs.

Step 4:

Seepage is negligible, the demand use is estimated at 7 acre-feet. Therefore, the size of drainage area will have to be increased and the spillway elevation increased if possible.

Additional storage required $7 - 6.58 = 0.42$ acre-feet

Additional drainage area required $\frac{0.42 \times 12}{1.52} = 3.32$ acres

Total drainage area required is 32.6 acres.

If additional drainage area was not required, for example, when the use demand is 6.0 acre-feet, this should be checked to find if additional watershed area is needed to supply this demand ninety-six per cent of the time.

Check $\frac{6.0 \times 12}{1.52} = 47.4$ acres

Therefore, the size of watershed would have to be increased 18.1 acres to provide a watershed which will supply the demand use ninety-six per cent of the time. When the demand use is lower the watershed found which will fill the pond in eighteen months, seventy-five per cent of the time, will often be sufficient to supply a dependable source of water ninety-six per cent of the time.

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