PHYSICAL AND CULTURAL CHARACTERISTICS OF AN URBANIZING WATERSHED

Thesis for the Degree of Ph. D.

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HARRY KENNETH STEVENS

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ABSTRACT

PHYSICAL AND CULTURAL CHARACTERISTICS
OF AN URBANIZING WATERSHED

by Harry Kenneth Stevens

The purpose of this study is to help provide a better understanding of the water resource of a small watershed, a subbasin of the Red Cedar River drainage basin of southern Lower Michigan. Selected natural characteristics and relevant cultural characteristics of this study basin are described.

In addition to the customary review of the formal literature for each topic considered, the unpublished, local information was sought. Local representatives of various governmental agencies, personnel of Michigan State University, and long-time residents of the study basin were interviewed. Field and office work were used to supplement and analyze selected topics. Techniques of geography, geology, engineering, soil science, ecology and hydrology were used.

Some of the findings are given below. The area of the study basin is 335.8 square miles as determined by using the watershed divide bounding the study basin which was delineated by map and field procedures. The pattern of the

stream drainage net is a combination of rectangular and dendritic types reflecting the recent continental glaciation. In terms of stream order the study basin is a fourth order basin. The long profile of the main stream is the usual concave-up type. The history of stream gaging in the study basin is given. Based on a soil type-forest type correlation the presettlement vegetation was essentially a complete forest cover.

The hydrologic cycle is considered in general terms; the major variables are quantified as they occur in the Red Cedar study basin. The long-term temperature and precipitation norms were considered and the base period, 1931-1960, was selected to allow comparisons among hydrologic variables. All available precipitation records were inspected, and the average annual precipitation for the base period is 30.78 inches. By using the inflow-outflow method and the Thornthwaite method, evapotranspiration is estimated at approximately 73% of annual precipitation.

Runoff from the study basin is analyzed by hydrographs, frequency distribution, regional runoff comparison, flow-duration curve, and double-mass curves. Although the Red Cedar is a highly variable stream with occasional very low flows, no evidence was detected to indicate that the known variations in mean annual runoff cannot be accounted for by natural variation in the hydrologic cycle.

In the northwestern portion of the study basin the piezometric surface of the bedrock aquifer has become a part of the growing composite cone of depression created by the metropolitan area adjacent to and encroaching into the study basin.

The population density of the presettlement Indian occupance was probably less than one person per square mile. From the mid-1830's to 1900 the agriculturally oriented occupance of the early white settlers was dominant. By 1900 the density was approximately 39 persons per square mile, and dramatic changes had occurred in both land and water use. Modern occupance of the study basin is a mixture of urban, suburban and agricultural types. In 1960 the overall population density of the study basin was 105 persons per square mile. In the urban segment it was 3,519 and in the most suburbanized township it was 408. In the more rural townships the density was 20 to 50 persons per square mile.

All water uses combined were equivalent to 0.25 inches of water over the entire study basin per year.

PHYSICAL AND CULTURAL CHARACTERISTICS
OF AN URBANIZING WATERSHED

By

Harry Kenneth Stevens

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CHAPTER I

INTRODUCTION

One hundred-forty years ago the land that was to become southern Lower Michigan was covered with a mature forest. The land and water, the biota and the Indian inhabitants comprised a slowly changing ecosystem. With the arrival of the white man and a new culture the system changed abruptly and has continued to change rapidly ever since.

This then is a study focusing on a small drainage basin, refererred to as the study basin, that received the new human culture. It is an attempt to document and understand some of the characteristics of the waters of the study basin as they have responded to the human inhabitants of the last 135 years.

Change seems to be a necessary element of the culture of the present inhabitants of the study basin. It appears inevitable that the waters of the study basin will continue to be altered in response to various cultural changes. Comprehensive plans and policies regarding the use of water as a natural resource have been poorly defined or non-existent. But one of the goals of modern water-use planning is to consider practicable alternative plans (National Acad. Sci. 1966). The formation of such planning alternatives requires an understanding of both the relevant physical and the relevant cultural factors (including the economic ones) that are involved in the complex water resource-human relationship.

There are a variety of ways to view this man-water relation. In the broad view I concur with Dice (1955) that in their essential ecologic features human communities are not different from nonhuman communities and that, "Man also is directly or indirectly dependent upon the physical conditions that occur in the habitats in which he lives." This leads to the hypothesis that the concept of ecologic limiting factors does apply to man in spite of man's relatively great ability to alter his environment. Thus, in addition to economic and social considerations alternative water-use plans should include a thorough appraisal of the physical nature, including the limitations, of the water resource being considered.

No preexisting model was used for this study. Each inhabited watershed is unique in a physical sense and in terms of the culture imposed on it. In as much as this study reflects such a watershed it too is unique. Nonetheless this study may serve as an example of what can be known about similar small drainage basins and their water resource.

For each of the topics studied a general review of the formal literature was made, including correspondence with several of the authors read. For each topic an attempt was made to find the relevant nonpublished, local information. This phase of the study took the form of personal interviews with local representatives (including several retired workers) in various federal, state, county, township and city governmental agencies and units. It also included similar contacts with persons in various departments of Michigan State University and some long-time residents of the study basin. This procedure led to a review of a large quantity of a variety of widely scattered and largely unpublished, open-file and personal information. Field and office work was used to supplement, verify and analyze selected topics of the information available. It was necessary to utilize principles and techniques from several disciplines, mainly, geography, geology, engineering, soil science, ecology and hydrology.

First, the boundary (the watershed divide) of the study basin was delineated and the drainage area was determined to be 336 square miles. The nature of the existing surface waters was considered in terms of extent, drainage pattern, stream order and river profile. A compilation of known stream records was made. The nature and extent of the presettlement forest cover was determined from a forest type-soil type correlation.

Climate, evapotranspiration, runoff and ground water as elements of the hydrologic cycle were considered in general, and as they operate through the study basin.

Human occupance of the basin was considered at three points in time: presettlement, i.e., Indian, prior to 1835; early agricultural occupance by the white man, approximately

1835 to 1900; and modern occupance by a mixed urban-suburban-agricultural society, 1900 to the present. For each type of occupance an attempt was made to estimate the water use and related land uses. Finally, the origin and usage of the geographic name of the main stream of the study basin was reviewed.

This study was designed to consider selected aspects of water and water use in the study basin through an interdisciplinary approach and to complement past and current studies that treat some aspects of the study basin. Fish biology, limnology and pollution of the Red Cedar River are not considered per se in this paper. These topics have been a continuing research area of the Fisheries and Wildlife Department of Michigan State University, and the findings are reported mainly in the graduate theses of Brehmer (1956 & 1958), Meehan (1958), Grzenda (1960), Kevern (1961), Rawstron (1961), Vannote (1961 & 1963), King (1962 & 1964), and Linton (1964 & 1967).

CHAPTER II

SELECTED PHYSICAL CHARACTERISTICS OF THE RED CEDAR STUDY BASIN

Location.--The Red Cedar River is a small, warm-water stream located in the central section of the Lower Peninsula of Michigan (Fig. 1). The focus of this study is a subbasin of the Red Cedar drainage basin. The Red Cedar is one of the main tributaries in the second largest river basin of Michigan, the Grand River basin (Mich. Water Res. Comm. 1961; Brown, no date). From its headwaters in Jackson County the Grand River flows north-northwesterly to Lansing, the state capital. It then flows generally westerly, passing through the city of Grand Rapids as it flows to its mouth at Grand Haven where it empties into Lake Michigan.

The Red Cedar River has its headwaters in Livingston County from where it flows northwesterly to Fowlerville and then westerly to Lansing where it joins the Grand River (Fig. 2, map pocket). The study basin is that portion of the Red Cedar drainage basin which lies upstream of the United States Geological Survey (USGS) stream gaging station at Farm Lane on the main campus of Michigan State University (MSU) at East Lansing, Michigan. The one major tributary flowing into the Red Cedar below (west of) Farm Lane bridge, *

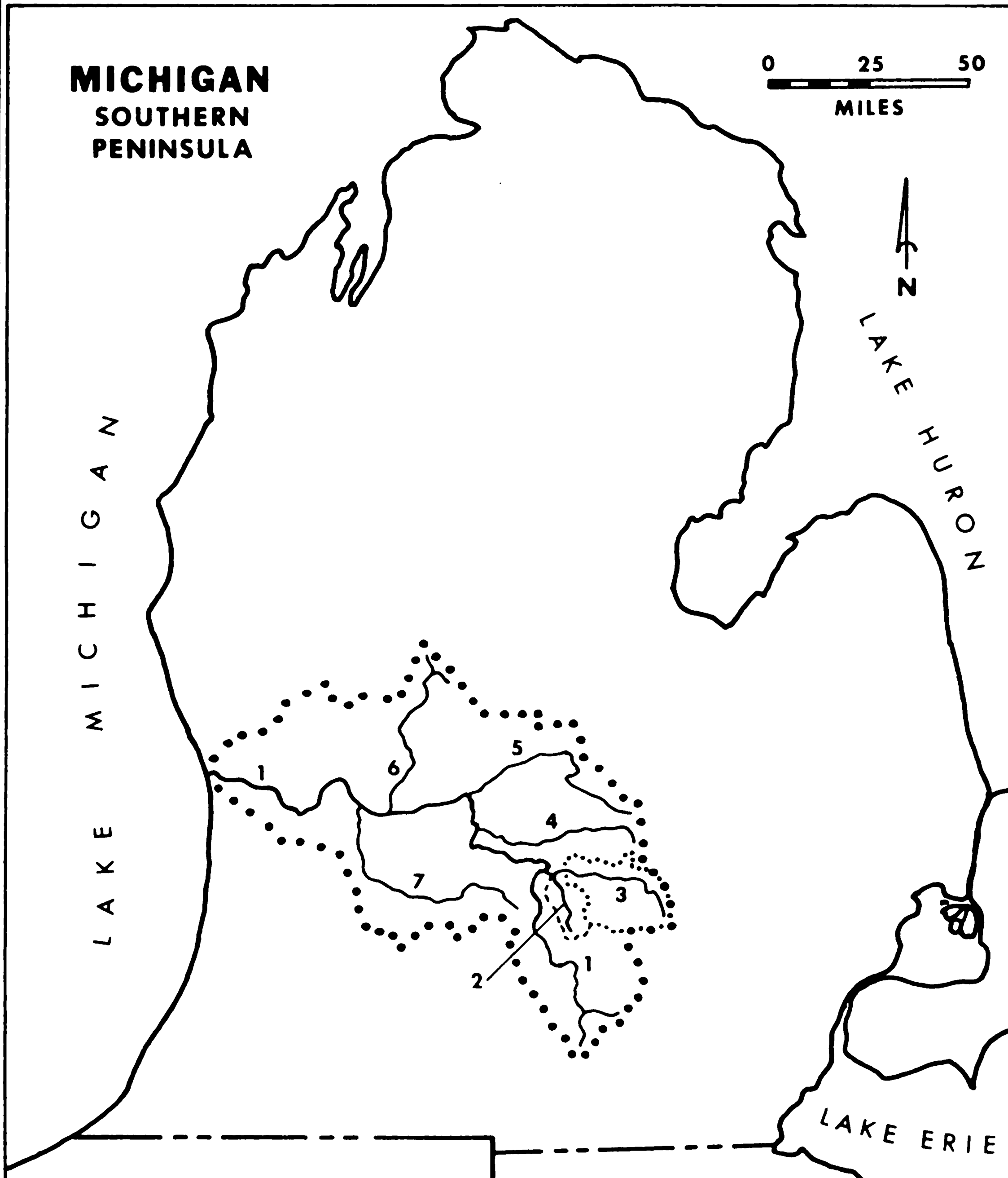

Figure 1.

Location map showing the Grand River and its major tributaries. The watershed divide is given for the Grand River, Sycamore Creek and the Red Cedar study basin.

Streams identified by number:

1 - Grand River
2 - Sycamore Creek
3 - Red Cedar River
4 - Lookingglass River
5 - Maple River
6 - Flat River
7 - Thornapple River

Sycamore Creek, drains approximately 24% of the entire Red Cedar basin. An additional 2% is drained by small streams emptying directly into the Red Cedar below Farm Lane bridge. The study basin lies east of Farm Lane bridge and drains approximately 74% of the entire Red Cedar River drainage basin.

Topography.--The topography of the study basin reflects the work of the most recent continental ice sheet to cover the Central Michigan area, the Cary stage of the Wisconsin glaciation which retreated some fifteen thousand years ago. The surface of the study basin is generally level to rolling except for the three elevated hilly belts which trend east and west. These belts are recessional moraines left by the Saginaw Lobe of the ice sheet as it retreated in a general northeasterly direction. Along the southern perimeter of the study basin the watershed divide is located on the Charlotte Moraine (Mich. Dept. Cons. 1955 & 1958). The Lansing Moraine trends northeastward as it passes south of East Lansing and Okemos; then it turns eastward and forms the northern boundary of the eastern half of the study basin. The western half of the northern divide is located on the east-west trending Grand Ledge Moraine which joins the Lansing Moraine to the east. All three of these moraines are discontinuous as they cross the study basin and both the main stream and some tributaries flow through them.

The major portions of the relatively low, level areas are ground moraines or till plains. Small areas of outwash occur adjacent to and south of the Charlotte Moraine. Glacial river channels and old lake beds account for some of the broad wet lands. The Red Cedar River flows for most of its east-west direction in an oversized glacial river channel which previously carried larger amounts of water westward along the face of the stagnant glacier (Mich. Dept. Cons. 1958). Thus most of the Red Cedar is an underfit stream (Amer. Geol. Inst. 1960).

The study basin contains several eskers, locally called hogbacks, which are low, symmetrical, serpentine ridges. They are of glacio-fluvial origin and made up of water-sorted material, gravel for the most part. All five esker systems in the study basin trend north-south and so are perpendicular to the morainic belts (Mich. Dept. Cons. 1955 & 1958; USGS topographic maps). Parts of these ridges have been removed since their gravel has economic value.

The highest point in the study basin occurs along the eastern divide and is located at the summit of a kame which forms the highest hill of the Howell State Hospital grounds located in Marion Township, Livingston County (T2N, R4E) as shown in Figure 2. The elevation of that summit is 1086 feet above mean sea level. The lowest point in the study basin occurs where the Red Cedar flows westerly out of the study basin as it passes under the Farm Lane bridge, Meridian Township, Ingham County. The river's elevation at that point is about 825 feet above mean sea level.

Boundary and Area Determination.--The Red Cedar River leaves the study basin as it flows westerly under the Farm Lane bridge which is presently a four lane road bridge that is located on the Michigan State University, East Lansing campus. The concrete base of this bridge houses the recording instrument which provides the official flow record published by the USGS. Although extensive drainage projects have been carried out in the study basin, the total area of the drainage basin remains relatively unchanged since settlement by the white man.

The area of the watershed above the Farm Lane gaging station (i.e., the study basin) usually is given in the literature as 355 square miles (USGS 1958; Hariri 1960; Mich. Water Res. Comm. 1961; Vannote 1961). The earliest reference to this 355 square mile value is not in the paper which describes the initiation of the gaging station in the vicinity of Farm Lane in 1931 (Strom and Ackley 1931) or the first official report, Water-Supply Paper 714 (USGS 1933). The Water-Supply Paper which gives observations of the 1936-1937 water year (USGS 1938) is the first to report a drainage area above the gage and the 355 square mile value is given. Apparently this is the value which is repeated in later USGS reports and references by other authors.

In the general introduction of the most recent decennial review and summary of the records of the present gaging station by the USGS it is stated that for some stations drainage area values are not given because of a lack of suitable maps, or because the divides cannot be delimited and so the effective drainage area cannot be determined (USGS 1964). In the station report for the (Red) Cedar River at East Lansing, Michigan the 355 square mile value is given, implying that it was possible to determine the location of the divide and the effective drainage area from available maps.

Although the 355 square mile value is not reported until 1937 a value of 358 square miles is given in reports for the MSU athletic bridge station as early as 1903 (USGS 1904). The athletic bridge is about 0.6 mile below the Farm Lane bridge. Later reports covering the same location also give the 358 square mile value (e.g., Strom and Ackley 1931; USGS 1958).

As early as 1901 the now-famous hydrologist, Robert E. Horton, gave the area of the entire Red Cedar basin as 472 square miles in a paper in an engineering journal (Horton 1901). His value was determined from a road map with a scale of one inch equal to three miles. The same value is given in the early _Water-Supply Paper_ series (USGS 1901 & 1904) and later in other places (Strom and Ackley 1931; Vannote 1963; Mich. Dept. Agr., no date). Thus the value for the drainage area of the Red Cedar River apparently was introduced into the literature by a prominent worker whose calculations were based on inspection of an early road map of relatively small scale. Subsequently, that value became a quotable standard which was not investigated further in the field or office.

The source of the 355 square mile value for the Farm Lane station or the earlier 358 square mile value for the downstream station was not found. The 355 value may have been derived from the larger value by considering the difference in drainage areas between the two gaging stations which is about three square miles. Even so the method of obtaining the 358 square mile value is still in doubt, but it is probable that it originated from a map study during the first few years of the 1900's.

This paper includes a detailed attempt to determine the area of the study basin by utilizing several field and office procedures. I first determined the location of the basin divide by inspection of a topographic base map of the study basin which was a composite map made of USGS 15-minute quadrangles (Fig. 3). This is the "study basin divide" of Figure 2 (map pocket). In some areas the validity of this determination was poor because of the large contour interval of the maps being used compared to the relatively slight local relief. Most of the study basin is given in 20-foot contour intervals (Mason, Fowlerville and Howell sheets) the remainder in ten-foot intervals. Rasmussen and Andreason (1959) encountered the same problem in a study of a watershed in Maryland. They found it necessary to construct maps with a five foot contour interval for some areas.

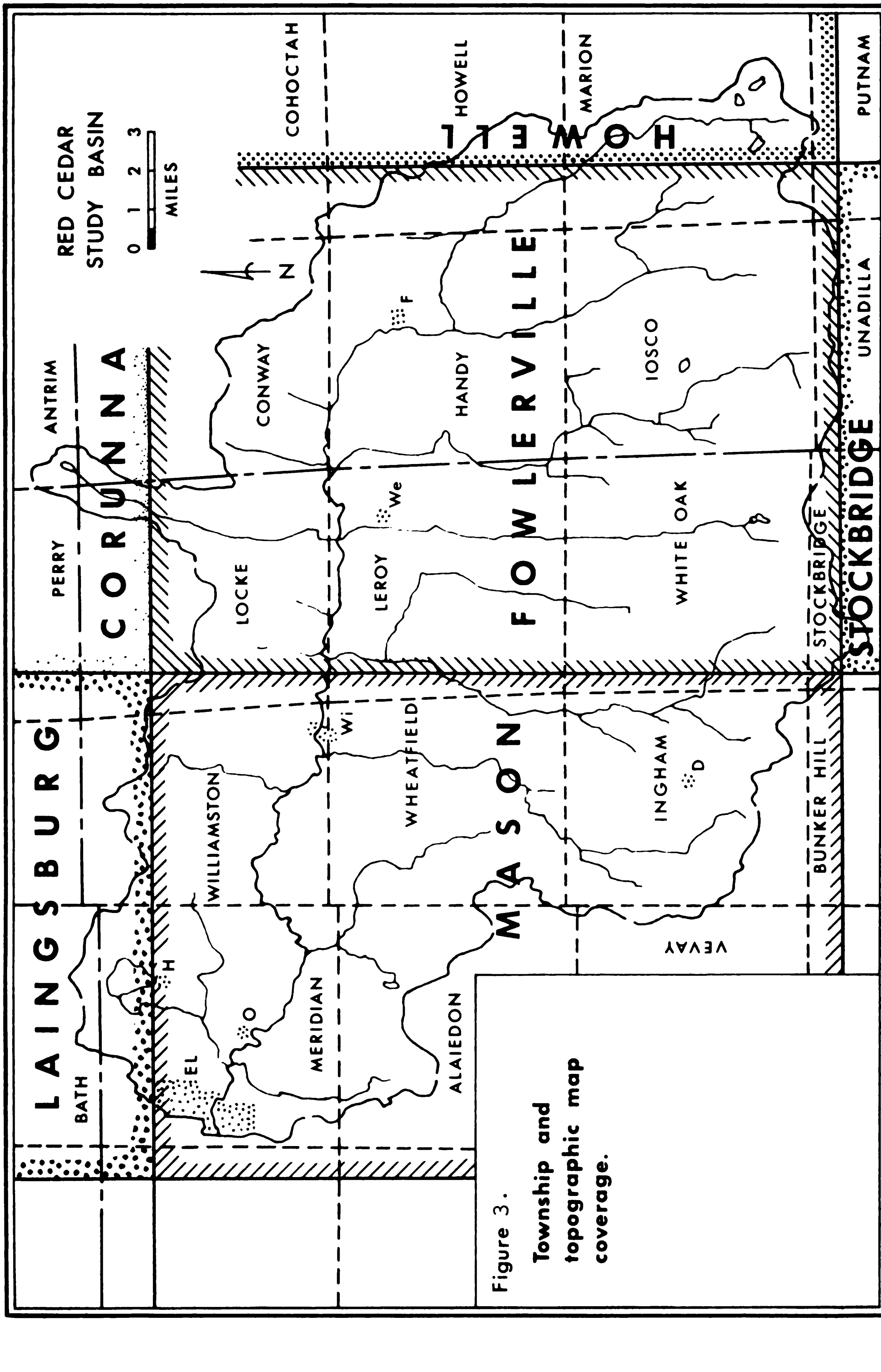

Figure 3.

Township and topographic map coverage.

In fact, the divide is not necessarily a discrete boundary; in some instances the divide varies according to the nature of the precipitation or melt water and the conditions of two or more alternate drainage outlets. For example, in sections 17 and 20, Conway Township, Livingston County (T4N, R3E) the surface runoff may flow either way through a road culvert depending on prevailing conditions (Graham 1964).* Since the roadbed is elevated above the flat fields adjacent to it, it serves as the divide. Because of the reversible flow through the culvert, a discrete, stationary divide does not exist in that locality. In other instances the divide lies in swampland where the divide is also neither discrete nor stationary. An example occurs in sections 14 and 15, Alaiedon Township, Ingham County (T3N, R1W).

In addition to inspection of the topographic maps several other sources and methods were considered in order to arrive at the final approximation of the watershed divide. For the Deer Creek subwatershed Kidder (1964) reported that he had used aerial photographs and detailed field work, which included walking the boundary and talking with local residents when in doubt, to determine the location of the divide. In part, that boundary coincides with the divide of the study basin and it was used as a standard of comparison for the results of other sources and methods (Fig. 2).

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*Also confirmed by local residents.

The drainage district maps which show drainage basins for tax and legal purposes were studied. They are located in the drain commissioner's office in each county represented in the study basin.* These maps are generally prepared from engineering studies where the divide is determined by "walking it out" with some aid from local residents. In order to facilitate governmental actions the natural divides are somewhat modified on the map allowing them to account for field lines and property lines. Mr. Gerald Graham (1964), Ingham County Drain Commissioner, also contributed personal knowledge for a few areas.

Stereoscopic pairs of aerial photographs of several areas of the study basin were also studied. I found they could not be used to replace field work in divide determination but only to supplement it. This agrees with the conclusion of Kidder (1964).

The divide locations from the above sources were plotted on the same base map as the original approximation. In some areas this led to four different boundary estimations; in other areas the several approximations were essentially superimposed. By visual inspection and use of a planimeter, 13 areas were identified in which the determination by the topographic map was sufficiently different from the other determinations to create a watershed surface

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*Drain offices which were visited: Ingham Co., Mason; Livingston Co., Howell; Clinton Co., St. Johns; Shiawassee Co., Corunna.

difference of more than 0.15 square mile (96 acres). After inspecting the size distribution of all the parcels involved, this value was more or less arbitrarily selected as the minimum size of parcels to be considered further.

In each of these 13 cases I inspected the area in question in the field and talked to local residents when still in doubt. In all but one case this procedure resolved the choice of the best estimate of the divide location. The exception is that part of the basin located near the headwaters of the Red Cedar River in Marion Township in Livingston County (T2N, R4E)--the Triangle Lake-Pleasant Lake area. In that area a distinct surface divide does not exist since the local topography is gently undulating with surface depressions which have internal drainage only. The final approximation there was the result of differential surveying and field inspection of the area by Dr. John Hughes (1963), a physical geographer, and myself.

In the urbanized area of the study basin the natural surface divide is modified by the storm sewer network which is reflected in straight map lines in the East Lansing-Michigan State University area. Storm sewer maps of the engineering divisions of the City of East Lansing and Michigan State University were studied in order to locate the man-modified divide. The modified divide is not stationary because the surface inlets (catchment basins) are interconnected by storm sewers which cross under the surface divides in order to allow for the transfer of excess storm runoff water between adjacent parts of the system. The divide shown for the East Lansing-Michigan State University area is believed to be the normal location. The final delineation of the boundary of the study basin is the "study basin divide" of Figure 2 as it is altered in several places by the "modification of divide" symbol.

The final estimate of the drainage area of the study basin is 335.8 square miles (214,912 acres). The frequently quoted value, 355 square miles, is 5.7% larger than this estimate. The area was determined by planimetering the surface within the final estimate of the basin divide. The basin was divided into workable-sized units, and a polar compensating planimeter was used to determine the area of each in square inches. Each reading is the result of three or more separate planimeter trials. The total map area was converted to land surface area by a conversion factor which was determined by comparing linear map distances with the Michigan rectangular coordinate system 10,000-foot grid ticks shown on the margins of some of the topographic sheets. An average value was used since the vertical and horizontal scales of the individual sheets were not identical and the several topographic sheets used had scales which were not exactly identical with each other.

In addition, the area of the study basin was determined by using a "cut and weigh" method similar to those described by Curtis (1959) and Schneider (1965). The boundary of the study basin was traced on a piece of engineering drafting tracing paper. Several quadrilaterals bounded by known lines of latitude and longitude were determined and their areas were found in standard tables (USGS, no date). The various areas were separated by cutting, and each area was weighed on an analytical balance. The areas of the irregularly shaped sections were determined by assuming that surface area is directly proportional to weight and using the area and weight of the standard quadrilaterals as a base for comparison. This result served as a check on the planimeter method and differed from the planimeter result by less than one percent.

Although the contour intervals of the available topographic maps are admittedly too large to allow precise determination of the divide, especially in areas of small local relief, the maps incorporating these intervals did allow for a fairly close approximation without the expenditure of time and money inherent in the other procedures.

The first approximation was determined from detailed topographic map inspection and supplemental field work at only two locations where the maps were obviously inadequate. The final approximation was the result of a modification of the first approximation by a detailed comparison of information from other sources and procedures, including field work in 13 locations. The watershed area as determined by using the first approximation of the divide was only 0.51 square miles (326 acres) larger than the final value attained. This small difference is somewhat misleading however, since some of the changes in area were added and some were subtracted from the original value. Actually, it was necessary to add or subtract 3.60 square miles (2,304 acres). Even so it appears that the existing topographic maps and selected, limited field inspection provide a means for determining the watershed divide with a level of accuracy suitable for many purposes and with more accuracy than is often given in the literature. For greater accuracy the expenditure of effort required to compare other sources and to utilize other methods may be warranted. Part of this decision would depend on the accuracy and availability of other sources.

CHAPTER III

SURFACE WATERS OF THE RED CEDAR STUDY BASIN

Lakes and Swamps

Rivers, creeks, lakes, ponds and swamps are expressions of surface water in the study basin. As used locally, a lake is a body of standing water which is surrounded by land. Pond, hole, pothole, cathole and kettlehole are names applied to bodies of water that are quite small. There is no sharp distinction between lake and pond, or between pond and the other terms. In addition the local usage varies widely (Veatch and Humphrys 1964). For example, in Central Michigan "lake" is the more common term, but in New England "pond" or "reservoir" are commonly used for equally large bodies of water.

The study basin contains only a small number of lakes, the exact number depending on the definition used. There are eleven "lakes" each having a surface area of at least six acres. Lake Lansing, a second order temperate lake, is the largest with a surface area of approximately 452 acres (Mich. Water Res. Comm. 1961) which is larger than the combined surface area of the other ten lakes. The next largest are Cedar and Triangle lakes, each having approximately 50 to 55 acres of surface area. These two lakes are located in the southeast corner of the study basin. Just to the southeast of these lakes is Pleasant Lake which is often included in the drainage basin of the Red Cedar. When Pleasant Lake's basin is full the area of the water surface is approximately 85 acres, but in dry years (such as 1963) the water level drops so that extensive mud flats appear around much of the shoreline until about only half of the original surface area remains. The nearest lakes which are at least as large as Lake Lansing are located about 25 miles from it and outside the study basin. Thus for area which lies in the "Heart of the Water Wonderland," to use chamber of commerce jargon, the study basin offers little to its residents in lake-oriented esthetic and recreational opportunities.

Generally, a swamp is flat wetland which supports trees and shrubs, while a marsh is a flat wetland which supports grasses and sedges (Reid 1961). Originally, Central Michigan had extensive wetlands which impressed the early settlers to such an extent that some wet areas were given names, e.g., Chandler Marsh and Big Swamp which lie near the study basin. Using wetland soil types as an indicator of land that has been or is swampy approximately 23% of the study basin is classified as wetland. Some of this land has been drained for agricultural purposes, and the water table has been lowered correspondingly.

Streams

Introduction.--A stream is a continuous, elongated body of water which flows downslope in a more or less definite channel (modified from Reid 1961). River, creek, brook, rivulet, streamlet, rill and rillet are used to refer to streams of differing size and permanence; and, again, local usage varies widely. Central Michigan is an area of relatively small streams, and its residents tend to use "river" for the larger local streams which in other locations would be called creek or brook. In the study basin the main stream is a "river" and the tributaries are "creeks." Even the distinction between "lake" and "stream" is not distinct, especially when a stream appears to have little or no current, e.g., pond, millpond, reservoir, floodwater or lake are all applied to impounded waters. An example is Webber Pond, the water of the Grand River which is impounded behind the dam near Lyons in Ionia County.

Drainage Pattern.--The main stream, the Red Cedar River, and its tributaries comprise the natural surface drainage system or drainage net of the study basin. The major tributaries trend north and south and join the main stream as it flows westerly (Fig. 2). Recently glaciated areas typically have immature drainage systems; the study basin is no exception. Natural surface drainage is poor with small wet depressions and broad swamps being rather common. Some of the major tributaries are interconnected by swampy lowlands, some of which have ditches through them now. Although the tributaries and the main stream have their sources in wetlands, many of the smaller streams become nearly stagnant during normal seasonal droughts.

The drainage pattern is a combination of the rectangular and dendritic patterns, or disordered drainage (von Engeln 1942). The natural drainage pattern is a type of consequent drainage implying that the drainage pattern was at least partially determined by the terrain left by the most recent glaciation. Since the arrival of the original white settlers, man has made significant changes in stream channels and water courses by cleaning out, straightening and deepening them in order to achieve faster surface drainage. These changes are the "improvements" of drainage engineering terminology.

Stream Order.--Several methods of quantifying drainage nets have been proposed and used. In 1945 R. E. Horton developed the concept of stream order which is now widely used in the United States (Scheidegger 1965). Leopold (1962) briefly discussed stream order using essentially Horton's system. Strahler (1964) reports on his own earlier modification of Horton's system. In Strahler's modification the order numbers are applied to stream channel segments only rather than entire tributary streams.

Scheidegger (1965) presents a different system of stream order numbering. He attempts to eliminate the situation inherent in the other systems where the determination of stream segment numbering depends on the order of stream junctions. Scheidegger feels that his stream order designations are more representative of the hydraulic characteristics of each segment since at each junction the two upstream segment order numbers are added to the designation for the next, lower segment.

Wisler and Brater (1949) and Langbein and Iseri (USGS 1960) present the modified Horton version of stream order. Using the U. S. Geological Survey topographic maps I applied this method to the drainage net of the study basin. For the study basin these maps are 15-minute quadrangles with a scale of 1:62,500, or 1 inch = approximately 1 mile. Each stream segment was assigned an order number with the smallest periennial or intermittant streams which flow in "clearly defined valleys" being designated first order. The stream segment below the junction of two first order segments was designated second order, etc.

Strahler's (1964) terminology may be represented in the following way:

$$R_b = \frac{N_u}{N_{u+1}}$$

where:

R_b = bifucation ratio

N_u = the number of stream segments of order u

N_{u+1} = the number of stream segments of order u+1

The results for the study basin follow:

for N_u where u = 1, N = 94, R_b = 3.48

for N_u where u = 2, N = 27, R_b = 5.40

for N_u where u = 3, N = 5, R_b = 5.00

for N_u where u = 4, N = 1, R_b does not apply

The relatively small number of first order segments causes the corresponding bifurcation ratio (where u = 1) to be smaller than expected considering the values of the other bifurcation ratios in the series since the series should tend to be constant for a given watershed. This anomalous value is probably due to wetlands, existing in some of the broad, poorly defined valleys rather than segments of first order streams in clearly defined valleys. The relatively flat topography and the numerous improved channels were probably contributing factors too, because they contributed to the difficulty of distinguishing natural stream channels in some cases.

According to Strahler (1964), the bifurcation ratio, R_b, usually occurs in the range 3.0-5.0 for a watershed which does not have dominant geologic features. Except for the first order streams the bifurcation ratios of the study basin do occur at or above the upper limit of this range implying that geologic features of the study basin have been influential in developing the drainage net. This is in agreement with the known recent geologic history of the basin.

The study basin is classified as a fourth order basin since the highest stream order designation is of the fourth order. This designation and the bifurcation ratios could be used to help compare the study basin to other watersheds.

River Profile.--The origin of the Red Cedar River is usually taken to be Cedar Lake in sections 28 and 29 of Marion Township, Livingston County. The elevation of Cedar Lake is given as 934 feet above mean sea level on the Howell quadrangle, USGS topographic map (1907). In 1965 the level of the lake was legally established at 936.1 feet above mean sea level (Livingston Co. Drain Off. 1965). The Red Cedar joins the Grand River in the near south side of the city of Lansing at an elevation of approximately 817 feet above mean sea level.

The overall length of the Red Cedar is approximately 50.8 miles and that portion of the river in the study basin is approximately 45.0 miles long. These values were determined by direct measurement of the stream course as shown on the USGS topographic maps utilizing a series of tick marks on the margin of strips of tracing paper. This procedure allowed a fairly accurate measurement of the winding course of the river and yields a substantially larger value than is commonly obtained by using a map measurer.

For selected stations, river miles upstream from the mouth and the corresponding elevations are given in Table 1. These values are presented graphically in Figure 4, and the resulting profile is of the usual concave-up configuration. (The vertical scale is greatly exaggerated for if the vertical and horizontal scales were identical the profile would appear to be a straight horizontal line.)

The total fall of the river is about 117 feet, and the average gradient is approximately 2.3 feet per river mile. But the average gradient above the 900-foot elevation is approximately 7.0 feet per river mile while that below the 900-foot elevation is approximately 1.8 feet per river mile. The relatively low gradient in the lower nine-tenths of the river is reflected in the sluggish flow, numerous meanders and greater flood frequency. The slight rise in the profile at the Farm Lane station is due to the higher than normal elevation of the river which is ponded behind the Michigan State University dam located about 0.2 miles downstream. The natural local base level (the lowest possible erosion

Table 1. Selected long-profile values for the Red Cedar River.

Station	River miles upstream from mouth	Elevation in feet above mean sea level[a]
Junction with the Grand River	0	817
Junction with Sycamore Creek	1.58	
South of Kalamazoo Street Bridge	3.66	820
MSU dam	5.61	
Farm Lane	5.81	827
Hagadorn Road	6.67	
Junction with Lake Lansing Drain	8.02	
Grand River Road	15.86	840
Williamston Dam	22.31	
Junction with Sullivan Creek	26.73	860
Near Junction with the Middle Branch	37.83	880
Section 4, Marion Township	45.97	900
Section 16, Marion Township	48.27	920
Cedar Lake	50.84	936

[a]First and third entries from USGS (Bent 1966), last entry from the Livingston County Drain Office (1965), all others from USGS topographic maps.

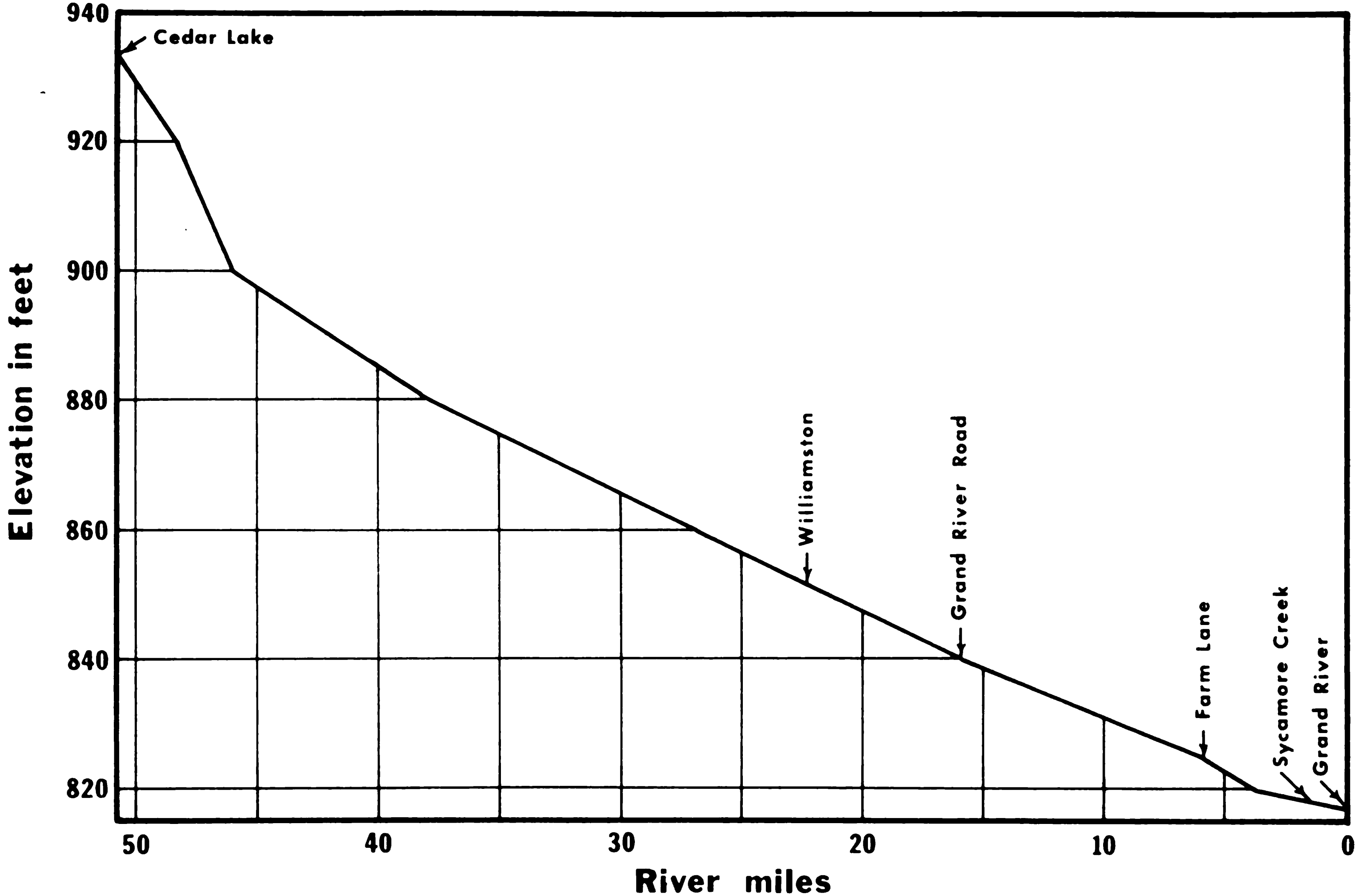

Figure 4. Long profile of the Red Cedar River. Elevations are given in feet above mean sea level. Distance above mouth is given in river miles. Basic data from USGS maps and Bent (1966).

plane) is the elevation of the Grand River at its junction with the Red Cedar.

Available Stream Measurement Records.--Although the flow of the streams of the study basin has not been thoroughly observed and recorded, the records of the Red Cedar River are relatively abundant and continuous compared to other, similar streams of the area. To 1967 the Red Cedar has stage records which were taken in the vicinity of the MSU campus starting in 1902 and covering 45 years completely and parts of 12 additional years. A continuous record extends from March 1931 to the present, more than 35 years. The Williamston station on the Red Cedar has records of flood periods only for all except four years (1934-1937) beginning with 1919. The Sloan Creek and Deer Creek records are continuous from mid-1954 to the present. The gaging station locations are shown in Figure 2.

The United States Geological Survey began its stream gaging activities in the United States in 1888 (Grover and Harrington 1943; USGS 1958). Although the Red Cedar study basin received its first white settlers in the 1830's, the earliest stream gaging in the study basin for which records are known began in 1902 (USGS 1904). However, as early as January 1901 Professor H. K. Vedder of the Michigan Agricultural College supervised the first station which was a staff gage attached to the mid-stream pilings of the railroad bridge on the college campus.* Professor Vedder also supervised the station established on the Grand River in North Lansing.

Beginning with March 1901 the records for the North Lansing station are reported in the USGS Water-Supply Papers for the Grand River at Lansing, but in the same series of reports the Red Cedar River at East Lansing does not have its first recorded report until August 31, 1902 (USGS 1904). This record gives daily gage heights and a rating table for conversion to discharge, and it is continuous from August 31, 1902 to December 31, 1903. These observations were made by a Mr. Clifford Walters for the USGS under the supervision of R. E. Horton, district hydrographer, and originally they were reported in the USGS Water-Supply Paper 97 published in 1904. Later they were checked for consistency and calculational accuracy and summarized in the USGS Water-Supply Paper 1307 published in 1958.

The 1902-1903 readings were taken with a wire gage located on the downstream side of the highway bridge which was located just downstream (west) of the MSU gymnasium (now the Women's Gymnasium) and immediately downstream of the

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*Michigan Agricultural College (MAC) became Michigan State College (MSC) which later became Michigan State University (MSU). In the literature the railroad bridge is referred to in a variety of ways, e.g., Grand Trunk Railroad Bridge, Pere Marquette Railroad Bridge, and the college spur railroad bridge. The spur is currently a part of the Grand Trunk Western Railway. In this paper the bridge is referred to as the railroad bridge on the MSU campus.

present "athletic bridge" at this site (Strom and Ackley 1931; USGS 1904 & 1958). According to Strom and Ackley (1931) the railroad bridge gage and the athletic bridge gage had simultaneous readings which were essentially identical.

Although no additional USGS reports are available until March 1931 some other records are extant. The United States Weather Bureau (USWB) made noncontinuous readings during the period from 1911 through 1930. Most, but not all, of these observations are reported in the Weather Bureau's annual series, Daily River Stages. The reports for January 1, 1911 to October 31, 1919 give daily stage readings taken from a 14-foot wooden gage located on the mid-stream pilings (north face of the downstream side) of the MSU campus railroad bridge. The reports for 1920 through 1930 give the same type of information but for the flood season only (i.e., March, April and May) except that the 1924 report includes readings for the five months January through May and the 1929 and 1930 reports are incomplete.

A rating table for the Red Cedar at MSC is given by Preston and Wrench (1926) in conjunction with their daily stage readings for the period May 1, 1925 through April 30, 1926. This rating table is also given by Sprague and Neff (1930) and Strom and Ackley (1931). Flood period daily gage readings which are not found elsewhere are given by Strom and Ackley for 1929 and 1930. Although Strom and Ackley do not acknowledge them as original observations, they may have been taken in conjunction with the U. S. Weather Bureau office which was located on the MSU campus at that time.

The USGS in cooperation with the Civil Engineering Department of Michigan State College established an automatic recording station on the Red Cedar in March 1931. Under the supervision of a Mr. Berkeley Johnson of the USGS the instrument was housed initially in a small building located on the south bank of the river about 250 feet upstream from the present Farm Lane bridge on the MSU campus (USGS 1958). Apparently Strom and Ackley (1931) worked with Johnson in setting up the new station. In 1967 only a small portion of the concrete pier remained at the site. In November 1940 the recorder location was changed to the downstream (southwest) abutment of the Farm Lane bridge where it is still located (USGS 1958). This record is nearly continuous from 1931 to the present and is annually reported in the appropriate USGS Water-Supply Paper. This record is summarized from 1931 to 1950 in Water-Supply Paper 1307 (USGS 1958) and from 1950 to 1960 in Water-Supply Paper 1727 (USGS 1964).

Relatively few other records are available on either the main stream or the tributaries of the study basin. The U. S. Weather Bureau's Daily River Stages gives stage readings for the Red Cedar at Williamston during March, April and May for the years 1919 through 1928 with the report for 1924 including readings for January through May. The

Williamston readings first appear in the report for 1919 and were taken from a staff gage located on the downstream face of the south abutment of the Bridge Street bridge (presently the Putnam Street bridge). A dam was and still is located a few hundred feet downstream. Beginning with the 1924 readings a chain gage was used which was located below the dam on the downstream side of the Grand River Road (formerly U. S. Route 16, presently Michigan Route 43) highway bridge over Deer Creek (USWB 1925). This site is near the junction of Deer Creek and the Red Cedar River and about 1500 feet downstream from the previous station. No rating tables are given for these readings.

Although not reported in Daily River Stages partial flood period records were taken at Williamston during 1929-1933. These records are missing for 1934-1936, inclusive, but they are complete from 1937 to the present.

The U. S. Geological Survey in cooperation with the U. S. Weather Bureau, the Agricultural Engineering Department of Michigan State University and the Water Resources Commission of the State of Michigan began gaging the Sloan Creek tributary in June 1954 at a station located near Meridian Road in Section 1, Alaiedon Township, Ingham County. Gaging began on the Deer Creek tributary in May 1954 at a station located near Clark Road in Section 33, Wheatfield Township, Ingham County. These records are continuous to the present time and the records are reported in the

appropriate annual series and decennial summary of the *Water-Supply Papers*. The locations of these two gages and the watersheds above them are given in Figure 2. Details regarding the instrumentation and observations on these small agricultural watersheds is given by the Water Resources Commission (1958 & 1960) and Eichmeier, Wheaton and Kidder (1955).

During recent years the local USGS office has taken several low-flow discharge readings for each of several small streams in the study basin: Doan Creek, Squaw Creek, Kalamink Creek and the Red Cedar River near Fowlerville. These data were used to graphically determine the low-flow characteristics of the four streams and are in open-file reports at the USGS Lansing office.

CHAPTER IV

PRESETTLEMENT FOREST COVER

Introduction.--The vegetative cover which was found on the land of the study basin by the pioneer white settlers is referred to in a variety of ways, e.g., "primeval forest," "original forest," "original vegetation," "native vegetation," and "presettlement vegetation." At the time of settlement the natural vegetation was essentially all forest without sizeable areas of wet or dry treeless vegetation (Veatch, no date; Arend 1965; Schneider 1965). However, the forest cover was not uniform; on the contrary it was quite varied reflecting, in part, the variety of forest sites or habitats present. This variety of sites especially reflected the effective moisture available which in turn reflected slope, height of the local water table, soil texture, soil structure, soil reaction and organic content.

The presettlement forest was not necessarily permanent or stable over long periods (Curtis 1959; Spurr 1965). Natural forces such as flood, drought, fire caused by lightning, soil development, climatic change, plant succession and chance interacted after the last glacial retreat tending to produce several forest types in addition to the climatic climax.

Classification and Terminology.--The study basin is located in an area where the regional vegetative climax is usually referred to in terms similar to "Central (Hardwood) Forest Region" (U. S. Forest Service 1948; Soc. Amer. Foresters 1954) or "Broadleaf Deciduous Trees" (Kuchler 1964). The regional forest boundary which separates the Northern Forest from the Central Forest usually is shown near the study basin (e.g., U. S. Forest Service 1948; Soc. Amer. Foresters 1954; Curtis 1956; Kuchler 1964). In such classifications allowance is made to subdivide the region so that the study basin falls in the beech-maple category which was well represented in the study basin.

The other major forest types in the basin are edaphic climaxes, nonclimatic seral stages or possibly disclimaxes due to anthropogenic activity. According to Curtis (1959) Indian food-gathering, domestic planting, accidental plant introduction, hunting and trapping and particularly burning significantly influenced an estimated 47 to 50 percent of the presettlement vegetation in Wisconsin. Although Indians did crop, hunt and use trails in the study basin (Fuller 1924) the evidence does not indicate a great influence on the local presettlement cover. Reasons for this difference probably include differences in Indian land management practices and perhaps population densities, and the fact that Wisconsin had significant amounts of treeless (grassland and savanna) climax vegetation.

There is a variety of patterns of terminology of forest types.* Since I followed Veatch's method for reconstructing forest types I also followed his terminology (Veatch 1928, 1932, 1953 & 1959) with some modification. The forest types used are not formal types recognized by the Society of American Foresters (1954) or professional botanists (e.g., Curtis 1956 & 1959); however, they have been used in the county Soil Surveys, and they are recognizable as more or less distinct forest types (Cantlon 1964).

Although such grouping is based on a reconnaissance forest survey which is basically a species list which is qualitative, subjective and somewhat inconsistent, similar types can be recognized and classified by using such a survey (Spurr 1964). One reason that such forest groups are so elusive is because most of the groups are not neatly delimited seral stages but are intermediate and transitory in nature. This difficulty can be explained in terms of the concept that forest types frequently are not, in fact, discrete entities but rather recognizable phases along a forest-type, space-time continuum (Curtis 1959; Spurr 1964).

The terminology used in this paper is given in Figure 5. It gives reasonable accuracy and is fine enough

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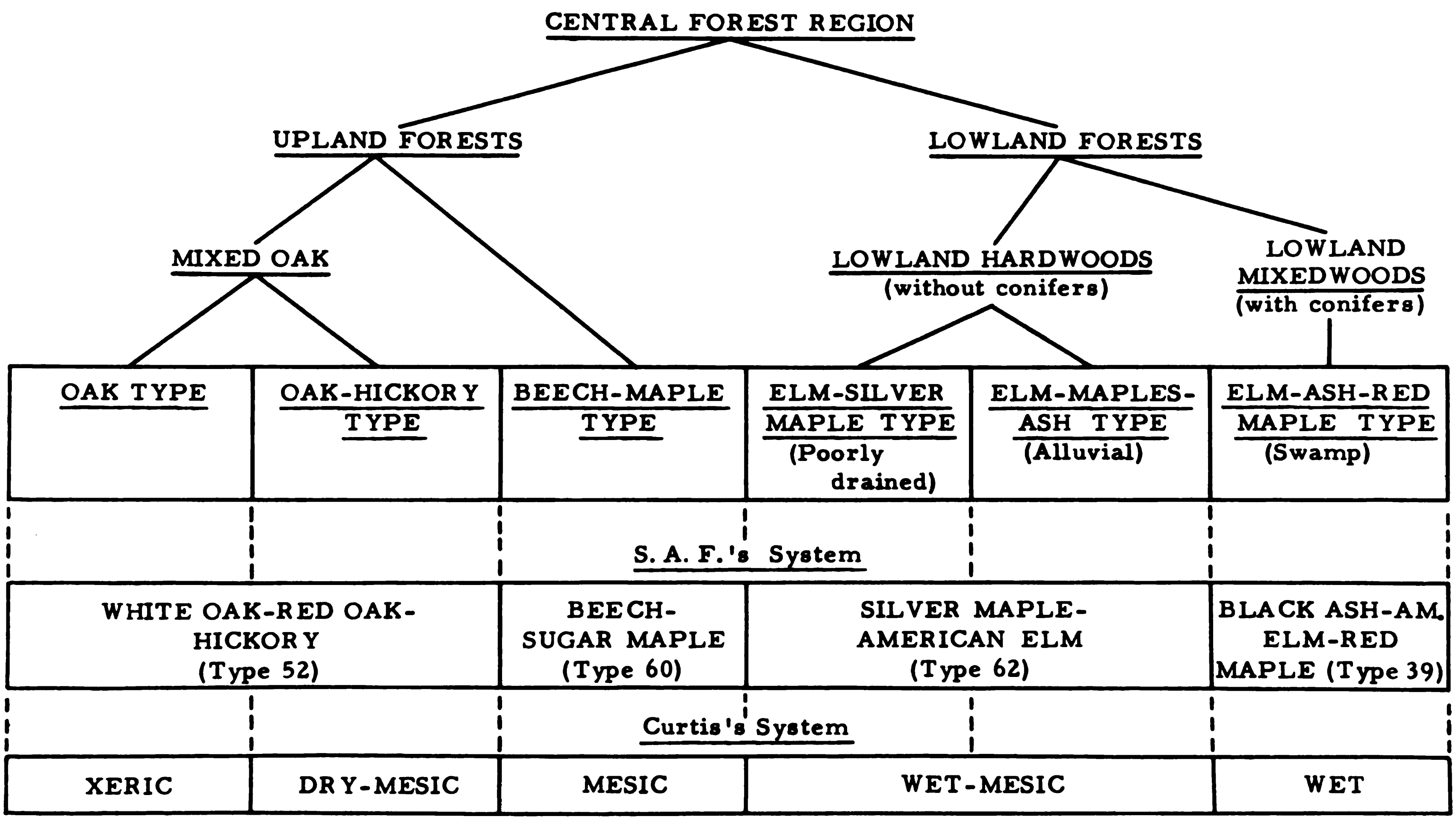
*For example with reference to the same or very similar forests, Curtis (1959) used Xeric, Dry-Mesic, Mesic, Wet-Mesic and Wet to categorize the Southern Hardwoods of Wisconsin; Braun (1950) used dry oak forest, oak-hickory forest, swamp forest and mixed mesophytic forest in reference to subdivisions in the Beech-Maple Forest Region; and the U. S. Forest Survey (Soc. Amer. Foresters 1954) used Oak-Hickory, Elm-Ash-Cottonwood and Maple-Beech-Birch in reference to Eastern Forests.

Figure 5. **Forest Type classification and terminology used in this paper with approximately comparable terms used by the Society of American Foresters (1954) and Curtis (1959).**



to allow flexibility. It may seem to be quite a complex system to describe the forest types of a relatively flat, compact, 336 square mile area, but it is a reflection of the previously mentioned circumstances that the study basin lies on or near both major and minor forest divisions.

Thus, the presettlement forest of the Red Cedar study basin had changed and was gradually changing when the settlers arrived in the watershed. As the numbers of settlers increased the ax and the plow rapidly became the dominant influences on the vegetative cover. At first the trees were considered an obstacle to the main occupation, agriculture; and later, many of the remaining trees were cut for their own value.

Reconstruction of the Original Forest Cover.--There are several methods used to attempt to reconstruct the nature and extent of presettlement forest cover. Each method has its limitations. Historical records include the accounts of early explorers, writings of the earliest settlers, and notes of the early land surveyors, especially with regard to the witness tress used to identify section and quarter-section corners. The usefulness of these sources often suffers from the original observer's lack of knowledge, lack of interest, or both. In addition, the samples reported were often sparse and not selected randomly but were selected according to the interests, or perhaps disinterests, of the observer. For Michigan, Kenoyer's work (1930) is an example of a reconstruction of this type on a county basis (Kalamazoo); Marschner's work (no date) is an example on a state basis.

Another method is to observe remaining woodlots, fence rows and individual trees of the original cover. Although no original forest in the study basin remains completely untouched by man, there are some woodlots where only selected commercially valuable trees have been taken (Bryant 1963). This too, leads to the sampling bias difficulty since the remaining woodlots are mainly of the forest types which had less economic value or are relatively inaccessible because they are wet forest types.

Another method is to determine the correlation between known soil types and the original forest types. The risk here is assuming too great a correspondence between the known soil types and in some cases doubtful forest types. Also, the elements of chance and anthropogenic activities are not completely accounted for. J. O. Veatch (1928 & 1932) proposed and used this method. He also used it in conjunction with his own personal knowledge to work out a map, "Type of Original Forest, Ingham County," about 1948. Following Schneider (1965) I used the same basic method to reconstruct the forest types for the areas of the study basin which lie outside Ingham County. I mapped an area inside Ingham County using the same criteria which I had used for the area outside the county in order to compare the results

of the areas mapped by Veatch with those mapped by me. The two results were essentially identical so the overall presentation is consistent throughout (Fig. 6, map pocket).

Veatch's map (no date) is executed in colored pencil on a Michigan Department of Conservation county map that has a scale of 0.4 inch equals one mile. In order to accurately transfer the information to a base map in black and white with an approximate scale of one inch equals one mile, a 35-millimeter photographic negative was made and its image was projected and adjusted to size on the base map for transfer. The information for Clinton County and Livingston County portions of the basin was based on their respective county Soil Surveys (USDA 1942 & 1928). A Soil Survey has not been published for Shiawassee County, and the information shown is after Schneider (1965). After a transparent overlay was used to determine by inspection and outline the groups of soil series which had the same presettlement forest cover type, the information was transferred to the base map. Because of the limitations inherent in the scale of the base map, isolated forest type mapping units which were smaller than approximately one quarter section (160 acres) were usually not recorded.

Figure 6 presents the composite reconstruction of the presettlement forest cover of the study basin. Table 2 shows the tree species and major soil series associated with each forest type. The complexity of the physical

Table 2. Forest cover types of the Red Cedar River study basin showing corresponding tree species and soil series.

Forest type[a]	Associated tree species[b]	Major Soil series[c]
Oak	Black oak dominant; red and white common. Minimum sugar maple and beech. Infrequent white pine.	Oshtemo Coloma Fox Plainfield
Oak-Hickory	Oaks dominant: Black, red and white. Hickories common and diversity of deciduous spp. Sugar maple, beech, present but not common.	Fox Hillsdale Coloma Bellfontaine
Beech-Maple	Sugar maple-beech; oaks-hickory; elm, basswood, ash.	Miami Hillsdale Conover
Elm-Silver Maple (Poorly drained)	Elm, silver maple, ash, swamp white oak, basswood, shagbark hickory, sycamore, cottonwood, red oak, bur oak.	Brookston Grandby Maumee Washtenaw Wallkill Newton
Elm-Maples-Ash (Alluvial)	Elm, red maple, silver maple, ash, sycamore, cottonwood, tulip, butternut, beech.	Griffin Genesee
Elm-Ash-Red Maple (Swamp)	Elm, ash, red maple, swamp white oak, aspen, tamarack. White pine infrequent.	Carlisle Rifle

[a]Modified from Veatch (ca. 1948, 1953 & 1959).

[b]After Veatch (1959); in addition, Veatch (ca. 1948) gives many of the minor species.

[c]After the county Soil Surveys (USDA 1928 & 1941) and Schneider (1965). Some minor series of small areal extent are not included. In a few instances a soil series occurs in more than one type class because in different locations that particular soil series is associated with different forest types due to local variations in topography and relative size and shape compared to bordering soil units.

characteristics of this glaciated landscape is reflected in the overall complexity of the pattern of the forest cover. The greater complexity of the pattern of the vegetation on the recessional moraines is particularly noticeable along the southern portion and in the northwest corner of the study basin. The dominant overall pattern correlates strongly with the drainage system pattern.

Generally the upland forests occupied the well-drained sites and the lowland forests occupied the poorly drained sites in the broad depressions and the stream bottoms. About 65% of the study basin was covered with the Beech-Maple forest; about 76% was covered by all the upland forest group (Table 3). About 15% was covered with the Elm-Ash-Red Maple forest, and about 23% was covered by all the lowland forest group. Small amounts, less than 1%, were covered with water or were otherwise treeless. Thus this description of the forest cover is virtually a description of the land use in the study basin prior to settlement by the white man for the Indian clearings and trails were an insignificant portion of the total area.

Table 3. Natural drainage of the Red Cedar River study basin by forest cover types.

Forest type	Natural drainage class[a]	Coverage of the study basin: Square miles	% of total
Oak	Well-drained	12.16	3.62
Oak-hickory	Well-drained	25.74	7.66
Beech-Maple	Well-drained and imperfectly drained	218.33	64.98
Elm-Silver Maple (Poorly drained)	Poorly drained	18.01	5.36
Elm-Maples-Ash (Alluvial)	Poorly drained and well-drained	9.58	2.85
Elm-Ash-Red Maple (Swamp)	Very poorly drained	51.04	15.19
The 11 lakes over six acres in size	Water table above the land surface	1.14	0.34
	TOTAL	336.00	100.00

[a]Based on five natural soil-drainage classes which cover the local range of drainage conditions (USDA 1951). The classes are very poorly drained, poorly drained, imperfectly drained, moderately well drained and well drained.

CHAPTER V

THE HYDROLOGIC CYCLE

Introduction

The continuous movement of water from ocean to sky to ocean again is called the water cycle or the hydrologic cycle. In order to understand the water resources of a watershed it is necessary to understand the operation of that portion of the hydrologic cycle which functions in direct contact with the watershed in question. To appreciate the relationship of a small watershed to other small watersheds and to regional watersheds a general understanding of the entire cycle is necessary. First the cycle in general, including relevant terminology, will be presented. Then some of the details of the cycle as they are found in the Red Cedar study basin will be given.

The terminology has varied considerably through time. In addition, at a given point in time (including the present) the usage of terms has varied considerably among the various professions interested in some phase of the hydrologic cycle. One reason for this lack of consistency is that hydrology is a relatively new science. Not until the late 1600's were the fundamental relations of the hydrologic cycle supported by quantitative observations. In 1674 Pierre Perrault reported his three year study of measurements of rainfall and estimates of runoff for a particular watershed (Todd 1959). He found that precipitation was about six times greater than river flow which helped to settle the long-standing question of the source of runoff water. Many persons had believed that precipitation was not adequate to supply runoff and a variety of hypotheses had been proposed without empirical support. Even today, in spite of the almost 400 intervening years of observations and their scientific implications, the hydrologic cycle is commonly misunderstood. For example, interest in dowsing or water witching persists in the United States concurrently with relatively high educational levels and relatively wide dissemination of scientific knowledge.*

The Cycle in General Terms.--A diagrammatic representation of the hydrologic cycle is given in Figure 7. The following discussion refers to Figure 7 by numbers enclosed in parentheses. The terminology used reflects usage in the following references: Wisler and Brater 1949; USDA 1955; Todd 1959; Langbein and Iseri (USGS) 1960; and Hinze 1964. In a few instances the usage reflects local usage or an arbitrary choice.

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*For a two-paged pro and con treatment of this perennially interesting subject see Sowder (1955). For the report of a rigorous investigation of the subject from a psychological frame of reference see Vogt and Hyman (1959).

WATER MOVEMENTS

1. Evaporation from ocean storage
2. Precipitation into ocean storage with some evaporation during precipitation
3. Maritime air becoming continental air
4. Precipitation
5. Evaporation or sublimation from an above-ground object

4. & 5. Interception

6. Evaporation from land surface
7. Overland flow or surface runoff
8. Infiltration into soil water belt
9. Seepage through intermediate belt
10. Percolation through the unconsolidated parent material
11. Septic tank influent & effluent
12. Soil water uptake by roots
13. Transpiration
14. Cone of depression due to well pumping
15. Evaporation from lakes & streams
16. Evaporation of soil water
17. Ground water movement into or out of surface waters.
18. Runoff in stream downslope to ocean storage (not shown in the diagram)
19. Percolation downslope toward the ocean storage
20. Percolation into bedrock aquifers

SURFACES

L--Land surface, S--Lower limit of soil water, W--Water table, B--Bedrock surface

WATER ZONES

Lines and letters correspond to those on the left margin of the diagram

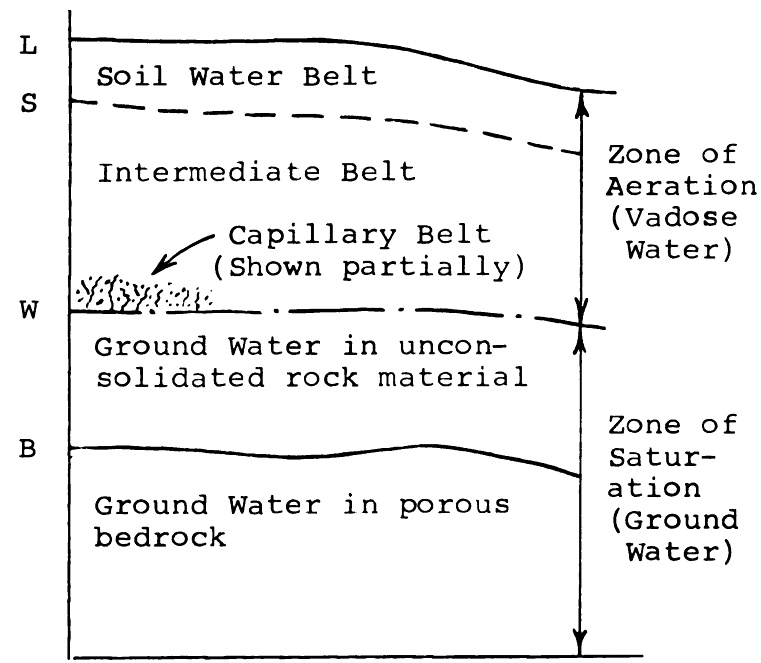

Figure 7. A diagram of the hydrologic cycle.

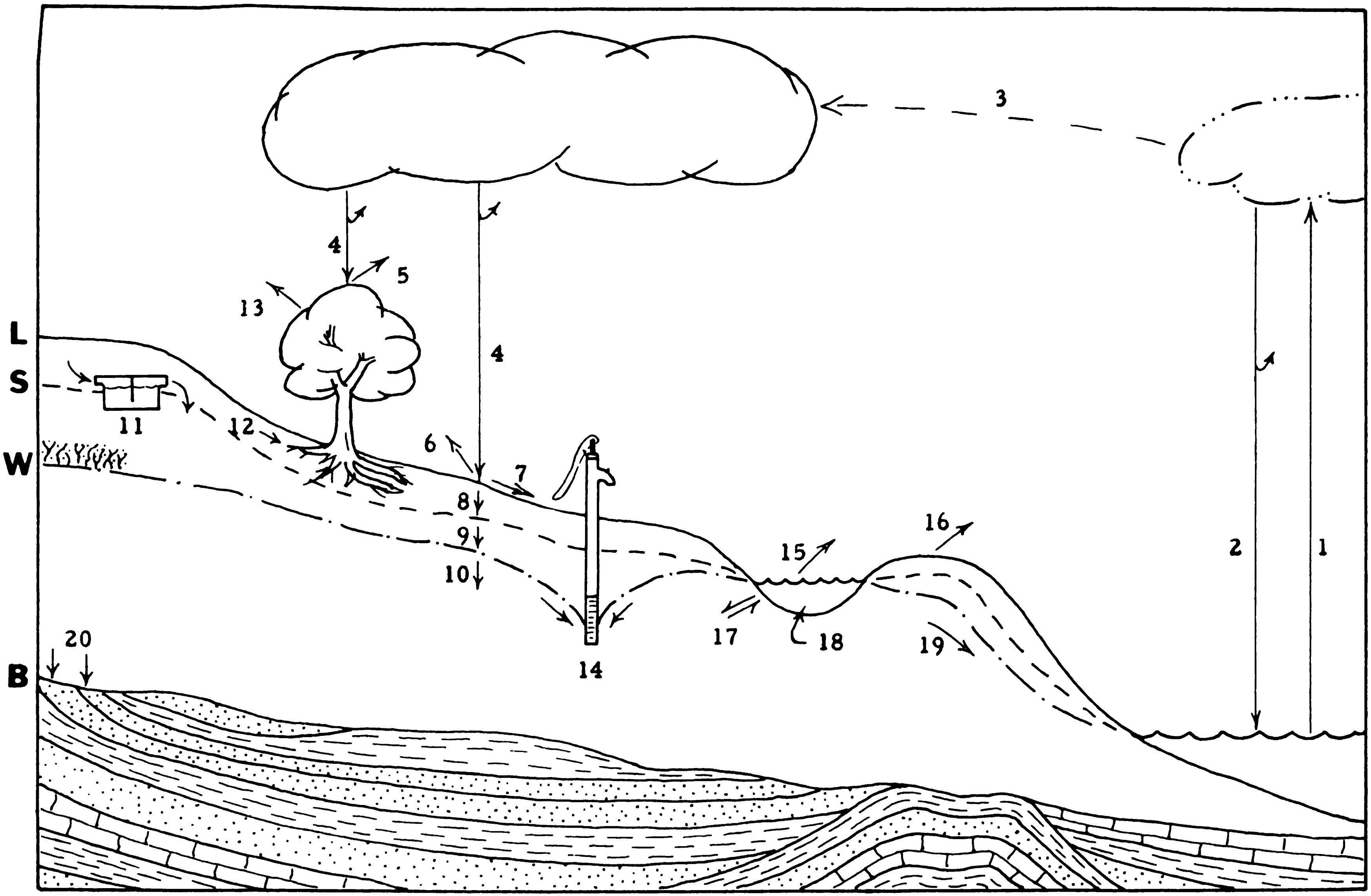

Figure 7. A diagram of the hydrologic cycle.

Since the overall movement of water on the earth is in fact a cycle there is no best place to begin its description. The oceans contain an estimated 97% of the earth's water (Chow 1965) and are continuously being evaporated by the solar radiation striking their surfaces (1). This gaseous form of evaporated water is atmospheric vapor and may condense and return to the ocean (2). If the maritime air mass moves over a land surface (3) condensation may give rise to one of the various forms of precipitation (4). If precipitation strikes an object before reaching the ground surface and subsequently evaporates or sublimes before it flows or falls to the ground the process is called interception (4 & 5). Vegetation is the usual intercepting object. The quantity of interception is difficult to measure but may be a significant portion of total precipitation. During precipitation in the form of summer rain, deciduous trees in leaf intercept more than conifers; but during precipitation in the form of winter snow, conifers intercept more than the bare deciduous trees.

Upon striking the ground the rainwater may run downslope to the stream channels (7). This class of runoff is called surface runoff or overland flow. Snowmelt may also be a part of this class of runoff. Evaporation of some of the rainwater or snowmelt may occur before it reaches a stream channel or enters the soil (6). This is particularly likely to occur if it is temporarily detained in surface depressions.

That portion of the rainwater which penetrates the soil surface and enters the soil body is referred to as soil water and occupies the soil water belt (8). The penetration is called infiltration. The rate of infiltration varies widely depending on the nature of the precipitation and the nature of the soil, particularly the permeability of the uppermost portion and the antecedent soil-water content. The soil water moves downward through the soil saturating each portion before advancing further into unsaturated soil. Thus the additional water moves in a more or less uniform "wetted front" until all of the soil is saturated to its total capacity (field capacity) before water is available for flow to the lower strata. The soil water is an extremely important phase of the cycle for most of the water utilized by plants is taken from this source.

The excess water flows downward through macroscopic and microscopic interstices. Some water may remain in this intermediate belt (9) as a film of water around the unconsolidated mineral particles but most responds to gravity and continues to flow downward. The next lower major zone lies below the water table (W) which is the upper surface of the zone where the pore space is normally filled with water rather than with air. The level of the water table varies seasonally and also in response to multi-year periods of excess or deficient precipitation. Just above the water table the unconsolidated material is usually saturated by water held in the capillary fringe or capillary belt (shown only in part at the left margin). The thickness of this zone may vary from zero to several tens of feet depending on the nature of the interstitial space above the water table.

Water below the water table tends to percolate downward, usually with a considerable horizontal component (10 & 19). The general direction is toward sea level but most ground water returns to the land surface before actually reaching the ocean. Some of this water percolates into permeable bedrock strata (20). The formations which are quite permeable and allow the ground water to pass into and through them are aquifers and are sources of ground water for man. The formations which have relatively low permeability do not permit the flow of water to any extent are aquicludes. Typical aquifers are sand, sandstone, gravel, conglomerate and cavernous limestone. Typical aquicludes are clay, shale, slate and crystaline rocks in general.

If an aquifer is more or less confined by aquicludes the water in a well tapping the aquifer may rise above the bottom of the confining bed. This is an artesian system and the well may or may not be a flowing well. The related piezometric surface is discussed below in the section on ground water. An artesian aquifer may be recharged where it contacts the ground water in the overburden (20) or at the land surface in an outcrop. There may also be leakage of ground water to or from the confining, relatively nonpermeable strata.

Soil water is the main source used by plants for their water needs. The part of soil water which is available for intake by plant roots, available capillary water (12), is a part of the water which remains after the gravitational water has drained away. After a soil has been saturated the amount of soil water which is retained is approximately equal to the gravitational water, but the amount which is available to plants is only about half of the retained water, i.e., 25% of the total soil water. The soil is at "field capacity" when the gravitational water has been removed and at the "wilting point" when the available water has been removed. The water which remains in the soil (unavailable capillary water and hygroscopic water) is held by forces greater than the forces which move water into plant roots and thus is unavailable for plant use. A soil must reach its field capacity before it yields gravitational water to the intermediate belt.

Approximately 95% of the water absorbed by the roots of a plant is returned to the atmosphere as a vapor via transpiration (13) (Ferry and Ward 1959). The remaining 5% is utilized by the plant in the manufacture of plant material, in photosynthesis or in other metabolic processes. Transpirational use of water often accounts for a major portion of precipitation. Soil water is returned to the atmosphere by direct evaporation too (16). As the upper portion of the soil dries out the rate of evaporation of soil water decreases sharply. Normally most of the evaporated soil water comes from the upper foot of the soil (Ackermann, Colman and Ogrosky 1955). The combined vaporization of soil water and surface waters from a land area by both transpiration and evaporation is called evapotranspiration. Since it is difficult to separately measure the evaporation and transpiration, evapotranspiration is commonly used in estimating values for this portion of the hydrologic cycle.

In addition to evaporation from bodies of surface water (15), during the winter season sublimation occurs from the ice and snow cover if it is present. If the bottoms of lakes and streams are permeable movement of water will occur between the surface water and the ground water if an hydrostatic gradient exists (17). In perennial streams the net gain of water flows downslope to larger streams whose net gain flows to the ocean (18).

Two of man's major uses and modifications of the water in the cycle are represented by the septic tank (11) and the well (14). The septic tank represents water being used as a medium to dispose of unwanted materials. In the case of septic tanks the partially treated sewage is returned to the zone of aeration. In the case of municipal sewage effluent the partially treated sewage is usually returned to a surface stream or lake. The well (14) represents a source of water for man. The major source is surface water but groundwater from confined or unconfined aquifers (14) locally may be the major source. A cone of depression develops when the rate of pumping exceeds the rate at which the aquifer can supply water. Ground water obtained in this way may be returned to the cycle via a recharge well or bed to ground water, but more often it is returned to the cycle as atmospheric vapor or surface water.

The Hydrologic Budget.--In order to study the hydrologic cycle for a specific land area a hydrologic budget or balance is commonly used. The budget is often represented by a verbal or symbolic equation. This hydrologic equation, which may be stated or simply implied, rests on the concept that for a given area and for a given time period all water inputs are exactly equal to all water outputs making necessary adjustments, if any, for changes in stored waters. The "given area" may be a natural hydrologic unit as a single aquifer, a unit of soil, or a drainage basin; or it may be an artificial unit such as a county or metropolitan area. Although the natural unit is preferred as the study unit, political and related tax structures frequently give rise to problems of financial support which dictate that artificial units be used.

Local examples of water studies based on natural units are Water Resource Conditions and Uses in the Upper Grand River Basin (Mich. Water Res. Comm. 1961); the U. S. Army Engineer's (1963) comprehensive study of the entire Grand River basin; and this paper. Local examples of studies

based on artificial units are the Alternative Long Range Water Use Plans for the Tri-County Region, Michigan (Tri-County Plan. Comm. 1964) and Ground Water Resources of the Lansing Area, Michigan (Stuart 1945).

For a given area and specified period of time a simple form of the hydrologic equation is:

$$P = ET + R \tag{1}$$

where:

P = total precipitation

ET = evapotranspiration

R = streamflow

To use equation 1 it is necessary to assume that the amount of storage of surface and subsurface waters has remained unchanged during the given time period and that there is either no subsurface flow into or out of the given area or that if such flow does occur its net value is zero. Although equation 1 is frequently used to estimate evapotranspiration it may be of limited use since the assumptions may or may not be valid. It is known that surface divides, water table divides and piezometric surface divides often are not located in the same vertical plane which would create a subsurface lateral component of water flow that would not be readily accounted for in the record of streamflow.

Schicht and Walton (1961) give one version of a more complex form of the hydrologic equation for a drainage basin:

$$P = ET + R + U \pm \Delta S_s \pm \Delta S_g \qquad (2)$$

where:

P = precipitation

ET = evapotranspiration

R = streamflow

U = subsurface underflow

ΔS_s = change in soil moisture

ΔS_g = change in ground water storage

Some of these parameters are difficult or impossible to determine, but by careful selection of the beginning and end of the study period the changes in subsurface-water storage can be estimated or eliminated. Although Schicht and Walton (1961) studied basins where the land use was mainly agricultural, equation 2 holds equally well for basins with urban land uses if man's urban or suburban modifications of the hydrologic cycle are taken into account.

Climate

Classification.--Trewartha (1964), using a modification from Köppen, classified the Lansing area (including the study basin) as Daf which is a humid mesothermal climate type. Specifically this designation refers to a snow-forest climate in which the coldest mean monthly temperature is below 32°F, the warmest mean monthly temperature is above 71.6°F, and the precipitation is more or less equally distributed throughout the year. The climate of the Lansing area is also described as one that alternates between continental and semi-marine types (USWB 1959 & 1965a). The Great Lakes and the prevailing southwesterly winds cause central Michigan to have fewer temperature extremes than it would have under purely continental conditions. In brief then, the climate of the study basin is a humid continental type somewhat modified by the Great Lakes. The average or normal monthly temperatures and precipitation values are given in Table 4 and Figure 8.

<u>Temperature and Precipitation Norms</u>.--Although the complete role of near-surface air temperature with regard to the hydrologic cycle is not known it is important in several obvious ways: it helps to determine the form of precipitation, the rate of evapotranspiration, and the melting rate of snow and ice. Three months (January, February and December) have average temperatures below freezing. Another indication of temperature is the average length of the growing season which is 154 days for the Lansing station (USWB 1965a).

Although the significance of a gradual long-term temperature change would be difficult or impossible to quantify in short-term values, such changes have occurred in the past and most likely will occur in the future. In the recent past Michigan and its neighboring states have gradually registered higher average temperatures as evidenced by an

Table 4. Average or normal monthly temperature and precipitation for Lansing, Michigan.[a]

Month	Normal temperature in ^{o}F	Normal precipitation in inches of rain
Jan.	24.3	1.96
Feb.	24.2	1.95
Mar.	32.4	2.40
Apr.	45.7	2.87
May	57.1	3.73
June	67.4	3.34
July	71.7	2.58
Aug.	70.2	3.05
Sept.	62.0	2.60
Oct.	51.3	2.50
Nov.	37.9	2.21
Dec.	27.5	1.99
Monthly Mean	47.6	2.60
Annual Mean		31.18

[a]Normal refers to the climatological standard normal as used by the USWB. It is an arithmetic mean based on the period 1931-1960. Data from USWB (1965a).

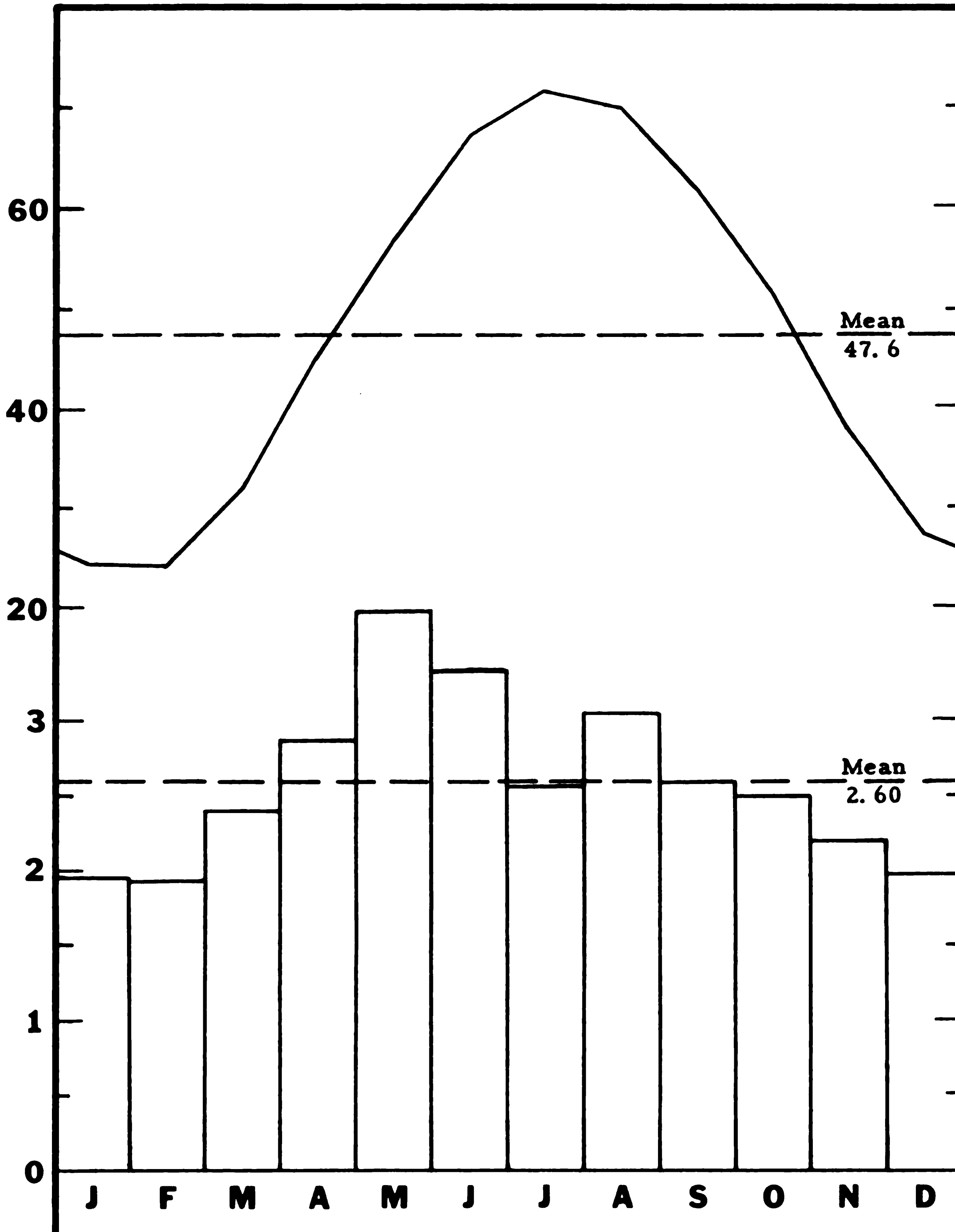

Figure 8. Normal monthly temperature and precipitation for Lansing, Michigan. Temperature in Fahrenheit, precipitation in inches of rain. Data from USWB (1964).

average annual temperature of 44.8°F for 1887-1920 compared to 45.4°F for 1921-1955 for Michigan (Baten and Eichmeier 1956; Eichmeier 1965). Even though the short-range effects of a gradual change in temperature are small, perhaps negligible, the long-range effects will be significant and necessarily will be considered as the effects are understood.

The Lansing-area precipitation is fairly well distributed throughout the year with May, June and August having the highest average monthly precipitation and January, February and December having the lowest average values. The annual mean for the Lansing station is 31.18 inches which includes the water equivalent of about 45 inches of snow. The general rainstorms are associated with frontal weather systems which usually move from west to east over the study basin. In the warmer months the high-intensity rains that occur are normally thunderstorms which may or may not be associated with frontal systems.

Reporting on the same time periods that were cited above as evidence for a trend in annual temperature, Baten and Eichmeier (1956) stated that virtually no change has occurred in average monthly precipitation for Michigan.

The average precipitation values mask the extreme values and the frequency of their occurrence. For the Lansing station for the period 1931-1960 the mean monthly precipitation was 2.60; however, only 0.25 inches were recorded in July 1946, and 9.21 inches were recorded in August

1940. If the period 1864-1964 is considered, no precipitation was recorded in both February 1877 and August 1894, and 11.35 inches were recorded in June 1883 (USWB, no date). The masking effect of average values will be considered in the analysis of runoff data.

Study Basin Precipitation.--The Lansing-area temperature and precipitation values cited above are all point values and care must be used before applying such values to areas. Also, the observations reported for the "Lansing station" were taken at four different geographic locations--two on or near the Michigan State University campus and two at the Capital City Airport (northwest of the city of Lansing). The reported temperature values are probably reasonably representative of the whole study basin, but because of inherent errors of point precipitation observations I attempted to obtain a more representative average for the area of the study basin.

The Thiessen method and other methods of weighting records were considered but not used because only sparse records are available from stations within or near the study basin, and those are scattered in both time and location. Thus, I felt, that the weighted average methods would not give results of greater accuracy than a nonweighted method even though the weighted average calculations would be more involved.

A recent attempt to understand the relationship among rain gages, precipitation and microrelief is reported by Eichmeier, Wheaton and Kidder (1965). In an interim report of their study of precipitation on Deer and Sloan basins they tentatively conclude that only slight variations in topography can significantly alter the catch of a standard rain gage. Thus, in addition to the problem of expanding point values to areas there is a fundamental problem of the correspondence between the rain-gage records and the actual precipitation.

In order to estimate the average annual precipitation for the study basin the records from five stations were used. The station records used were from all the stations with relatively long and complete records and located either on or, in the case of Howell, within approximately three miles of the study basin. For each year with more than one available record the arithmetic mean was derived from the several data available for that year.

The period 1931-1960 was used as a basis for a long-term mean to be used for comparative purposes because this particular 30-year period is used as a base by several organizations which publish information regarding elements of the hydrologic cycle. The USWB currently uses the 1931-1960 period as the basis for their climatological standard normals which are sliding means and are a part of their regular analysis of weather-station records, and thus,

readily obtainable. Also, this 30-year period is now used by the USGS as the long-term period for comparison in order to coincide with the climatological standard period used by the World Meteorlogical Organization (USGS 1963). (Fortunately, continuous stream gaging began on the Red Cedar at Farm Lane in 1931.) Table 5 displays the available records and the study basin average annual precipitation for 1931-1964. The standard 30-year mean (1931-1960) was calculated from the annual average to be 30.78 inches.

Assuming that the above value is as close an estimate as it is possible to obtain for the study basin precipitation, I analyzed several other procedures utilizing readily available published norms to determine if these alternate methods would yield a comparable value, while at the same time eliminating the time-consuming task of finding and analyzing the published and unpublished minor records of the Weather Bureau and other sources. Two procedures were considered in detail: 1) The assumption that the 30-year mean of one station on or near the study basin would approximate the basin mean; and 2) The assumption that the average of all such available 30-year means would approximate the study basin mean. To test these two assumptions I assembled the information presented in Table 6. No continuous records were available for stations located on the study basin itself, but six complete records were available for stations located within approximately 24 miles of the study basin.

Table 5. Annual precipitation for 1931-1964 and the 30-year mean for the Red Cedar study basin.

Calendar year	Recording station precipitation, in inches[a]					Study basin average[b]
	Weather bureau, E.L.	Experimental farm, E.L.	Williamston	Howell	Hydrologic station, E.L.	
1931	28.63					28.63
1932	34.22					34.22
1933	31.66					31.66
1934	21.00					21.00
1935	31.28					31.28
1936	27.65					27.65
1937	33.60					33.60
1938	32.39					32.39
1939	27.18			25.74		26.46
1940	37.84			33.23		35.54
1941	32.28			27.12	26.89	28.76
1942	37.02			32.96[c]	34.03	34.67
1943	36.49		31.05	30.84	33.06	32.86
1944	25.86		26.00	23.17	22.83	24.47
1945	38.95			36.17	37.48	37.71
1946	23.50			21.36	21.65	22.17
1947	39.74			39.32	37.59	38.88
1948				32.86	28.56	30.71
1949		35.93		34.93	34.43	35.10
1950		39.05		36.43	38.59	38.02

1951	30.79		34.73	30.80	32.11
1952	27.56	26.22	29.38	27.49	27.66
1953	23.99	27.50	23.53	24.64	24.92
1954	31.17	35.77	37.33	31.30	33.89
1955	27.26	28.85	26.02[c]	27.74	27.47
1956	28.63	31.64	31.70		30.66
1957	35.58	36.92	32.28		34.93
1958	21.79	24.38	24.24		23.47
1959	32.09	46.17	37.24		38.50
1960	24.94	23.91	22.77		23.87
1961	25.11	31.57	29.23		28.64
1962	20.44	26.70	24.90		24.01
1963	20.78	19.97	20.29		20.35
1964	26.02	30.01	24.91		26.98

The 30-year mean annual precipitation for the study basin is 30.78 inches. This mean is based on the period 1931-1960 and is the arithmetic mean of the study basin averages for those years.

[a]E.L. stands for East Lansing. More precise locations for the various recording stations may be found in the "Station Index and History" section of the appropriate USWB publications.

[b]Average is the arithmetic mean of the available years of record. Blank spaces in the field of the table indicate a lack of record.

[c]An estimated value. One monthly value was missing and it was estimated by finding the mean value for four nearby stations.

Basic data from USWB (1960, 1962, 1963, 1964a, 1964b, 1965a, 1965b, and open file) and USDA (no date).

Table 6. Precipitation norms for stations near the Red Cedar study basin.

Station	Approx. mileage and direction from closest point of the study basin	Normal precipitation, in inches (1931-1960)
Lansing Capital City Airport	now: 7-NW, formerly: 1-NW	31.18
Charlotte	22-SW	32.24
Jackson FAAAP	18-S	31.15
Milford GM Prov Gd	12-E	33.08
Flint WB AP	24-NE	30.14
Owosso Sewage Plt	15-N	29.37

The 30-year mean for the above stations is 31.19 inches.

Basic data from USWB (1960, 1964a & 1965a).

These six stations are spaced more or less evenly around the study basin. Half of them turned out to have means within one inch of the basin mean which is within approximately 3% of the basin mean.

The largest difference from the study basin mean is Milford with 2.30 inches, approximately 7.5% more than the study basin mean. Milford is the second closest to the study basin divide being only about 12 miles distant. No pattern is evident with regard to distance or direction for the three stations with the closer estimates. Apparently, single station estimates are of limited value.

The average of the six nearby stations is 31.19 inches which is close to the study basin estimate. This suggests a tentative generalization for southern Lower Michigan: a ring of several nearby stations yield a usable approximation of the precipitation of a small geographic area such as a small watershed.

Evapotranspiration

In considering the hydrologic cycle as it operates through a particular three dimensional piece of the earth's crust, one of the difficult aspects to quantify is evapotranspiration, the combination of evaporation from the land surface (including surface waters) and transpiration of vegetation. A variety of methods have been designed to estimate evapotranspiration. Bordne (1960) used four methods in a study of the Genesee River basin in western New York. He concluded that the Thornthwaite method gave the best results. Considering the level of hydrologic knowledge and the amount and kind of basic data available in the Red Cedar study basin I will estimate evapotranspiration by the inflow-outflow or difference method and by the Thornthwaite method.

Inflow-Outflow Method.--By rearranging equation 1:

$$ET = P - R \tag{3}$$

For the study basin the 30-year mean annual precipitation is 30.78 inches (see section on climate), and the corresponding value for runoff is 7.66 inches per calendar year (see section on runoff). Therefore, evapotranspiration is 23.12 inches per year.

As mentioned above the use of equation 1 (and its derivative equation 3) requires assuming that net subsurface flow is zero and that storage of surface and subsurface waters remains unchanged during the time period being considered. Although these conditions are not precisely met in the study basin the evapotranspiration value calculated by the inflow-outflow method is useful as one estimate for this hydrologic element.

Thornthwaite Method.--The Thornthwaite method is an attempt to empirically estimate the evapotranspiration by utilizing climatic records and soil water storage capacity in a bookkeeping format. This method gives an estimate of evapotranspiration and runoff by utilizing several concepts, particularly potential evapotranspiration. The climatic water balance, utilizing the evapotranspiration concept, was introduced into the literature by Thornthwaite in 1944 (Thornthwaite 1944; Thornthwaite and Mather 1957), and subsequently has been used by him and others in various ways, e.g., to classify climates (Thornthwaite 1948) and to serve as a guide in scheduling irrigation water application (Thornthwaite and Mather 1955a & 1955b). The water balance is mainly concerned with changes in the relative amounts of soil water or moisture of a given area. Once the values for evapotranspiration are determined estimates of runoff are possible.

The central concept, potential evapotranspiration, is defined as the evaporation and transpiration loss under optimum moisture conditions, i.e., the soil continuously at field capacity (Thornthwaite, et al. 1958). Normally vegetation will transpire at the maximum rate possible under the prevailing climatic conditions some of which will be limiting.

In order to arrive at estimates of evapotranspiration and runoff on a monthly basis it is necessary to have the mean monthly temperatures, the mean monthly precipitation, the latitude of the area in question and an estimate of the average effective soil water depth. The temperature and precipitation are available for the study basin in the U. S. Weather Bureau's Annual Summary of climatological observations, and latitude is readily obtainable from a map or atlas.

The average effective soil water depth is not easily estimated because it is variable in both time and space depending on the nature of the soil and the vegetation being considered. Plants vary in rooting depth from species to species and from seedling to maturity. For example, in a clay loam the water holding capacity for shallow-rooted crops (such as peas or beans) is estimated as 4.0 inches, for deep-rooted crops (such as alfalfa) the estimate is 10.0 inches, and for mature forests the estimate is 16.0 inches (Thornthwaite and Mather 1957). For wide areas four inches was given as a reasonable soil water estimate (Thornthwaite and Mather 1955b). Bordne (1960) used the four inch value with good results.

In the calculations for the Red Cedar study basin I first used the four inch value but found a wide discrepancy between calculated values of runoff and values given by the USGS stream gaging records. I found that for the long-term climatic averages a value of 12 inches gave calculated values which were in reasonably close agreement with the observed stream flow values. This result is in agreement with more recent work of Thornthwaite and Mather (1958) where they suggest that the 12 inch value is applicable over wide areas and also use that value in their calculations for the monthly values of the water balance at Lansing, Michigan.

In working out the water balance of the southern peninsula of Michigan Messenger (1962) used a value of 14 inches.

The calculations for the study basin are summarized on a water year basis in Table 7. The revised Thornthwaite method as given by Thornthwaite and Mather (1957) was followed unless otherwise noted.* The temperature ($^{\circ}F$) and precipitation (P) values used are long-term monthly averages or standard normal values used by the U. S. Weather Bureau (1965a). The monthly heat index (i) is an empirically derived value dependent on the monthly temperature. The annual heat index (I) is the sum of the monthly heat indices. The potential evapotranspiration (PE) is arrived at through two steps which are not shown in the table. The unadjusted potential evapotranspiration is found and adjusted by a correction factor which is based on average insolation and thus latitude. P - PE is the algebraic sum of the two values. When precipitation is less than the potential evapotranspiration a potential water loss exists. This potential loss normally occurs in the period of summer months; even though precipitation is relatively great the potential evapotranspiration is greater. These values are added to give the accumulated potential water loss (APWL). The soil moisture storage (ST) reflects utilization or recharge of the soil water available to vegetation.

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*Evapotranspiration values may also be determined by the use of graphs and nomograms given in Palmer and Havens (1958).

Table 7. Summary of values of the Thornthwaite method applied to the study basin using monthly normal values for temperature and precipitation.

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
°F	51.3	37.9	27.5	24.3	24.2	32.4	45.7	57.1	67.4	71.7	70.2	62.0	47.6
i/I	3.18	0.52				0.01	1.89	4.72	7.95	9.45	8.92	6.19	42.83
PE	1.71	0.49					1.34	3.02	4.99	5.42	4.68	3.12	24.77
P	2.50	2.21	1.99	1.96	1.95	2.40	2.87	3.73	3.34	2.58	3.05	2.60	31.18
P-PE	0.79	1.72	1.99	1.96	1.95	2.40	1.53	0.71	-1.65	-2.84	-1.63	-0.52	
APWL									-1.65	-4.49	-6.12	-6.64	
ST	7.68	9.40	11.39	13.35	15.30	12.00	12.00	12.00	10.46	8.24	7.20	6.89	
ΔST	0.79	1.72	1.99	0.61	0	0	0	0	-1.54	-2.22	-1.04	-0.31	
AE	1.71	0.49	0	0	0	0	1.34	3.02	4.88	4.80	4.09	2.91	23.24
D									0.11	0.62	0.59	0.21	1.53
S	0	0	0	0	0	2.40	1.53	0.71	0	0	0	0	4.64
RO	0.03	0.02	0.01	0	0	1.20	1.36	1.04	0.52	0.26	0.13	0.07	4.64
SMRO	0.03	0.02	0.01	0	0	0.33	0.74	1.12	0.56	0.28	0.14	0.07	3.30
Total RO	0.06	0.04	0.02	0	0	1.53	2.10	2.16	1.08	0.54	0.27	0.14	7.94

All values are given in inches except temperature and heat index. °F = long term average or normal temperature. i = monthly heat index. I = yearly heat index which is the sum of the i-values. **PE** = potential evapotranspiration. **P** = normal monthly precipitation. **P-PE** = the algebraic sum of the two quantities. **APWL** = accumulated potential water loss. **ST** = soil moisture storage. **ΔST** = change in soil moisture. **AE** = actual evapotranspiration. **D** = moisture deficit. **S** = moisture surplus except snow. RO = runoff from rain. **SMRO** = runoff from snow melt. Total RO = total runoff.

Monthly temperature and precipitation values are the standard monthly normals for the Lansing, Michigan station based on the 30-year period 1931-1960 (USWB 1965a). Calculations based on Thornthwaite and Mather (1957).

For the study basin the soil normally reaches maximum capacity during the winter months and is partially depleted during the summer months. As mentioned above a value of 12 inches was used, and the soils of the study basin are normally at this maximum capacity during January through May. Values which are greater than 12 inches are shown for January and February and reflect the above ground accumulation of precipitation as snow during months when the average temperature is below 30°F. (30°F is used rather than 32°F as the temperature above which the snow will be converted to water since the average temperature represents a range of values which extends significantly above the freezing point.)

The change in soil moisture storage (ΔST) indicates the signed difference from the preceding month. Actual evapotranspiration (AE) is the estimation of the water vaporized from both land and vegetation. In months where precipitation is equal to or greater than potential evapotranspiration the actual evapotranspiration equals the potential evapotranspiration. In months where precipitation is less than potential evapotranspiration the actual evapotranspiration is equal to the precipitation plus a portion of the water in soil moisture storage. The amount of soil moisture utilized is not directly proportional to the accumulated potential water loss, rather this relationship is direct and nonlinear. This relation reflects the decreased availability of soil water as the soil goes from field capacity to wilting point. The values shown are based on Thornthwaite's empirically derived tables. The moisture deficit is the difference between potential evapotranspiration and actual evapotranspiration. In essence the vegetation and land surface could have vaporized this much more water had it been available.

The moisture or water surplus is that part of the liquid precipitation, if any, in excess of the demands for both evapotranspiration and an increase in soil moisture recharge (up to its maximum capacity). Surpluses occurred in March, April and May when the soil moisture was at capacity. Runoff (RO) is the direct result of the surplus water but it does not leave the area being considered immediately. Due to the nature of the surface and subsurface drainage ways a time lapse occurs between the availability of the surplus water and the time when it shows up as runoff. Thornthwaite and Mather (1957) suggest that during the first month that the surplus water is available one-half will appear as runoff, and that during each succeeding month one-half will appear as runoff until, for practical purposes, none remains.

The snow melt runoff (SMRO) is that portion of the snow melt which is in excess of the demands for evapotranspiration and soil moisture recharge. The snow is assumed to be held in above ground storage until the first month in which the mean temperature is equal to or greater than 30°F. Then it is released from the watershed slowly over a period of months. The relation used was that one-tenth of the available snow melt would appear as runoff the first month, one-fourth the second month and one-half each successive month until, for practical purposes, none remained. The total runoff (Total RO) is the monthly sum of the runoff (due to rain) and snow melt runoff. These values are comparable to the stream flow as measured by the stream gaging stations of the USGS.

The value calculated for actual evapotranspiration (23.24 inches) is quite close to the corresponding value (23.12 inches) calculated above by the inflow-outflow method. The value calculated for the total annual runoff (7.94 inches) is quite close to the recorded value (7.66 inches) given by USGS.

Another way to represent the average water balance value is shown in Figure 9. This graphic presentation utilizes some of the calculated values from Table 7 to show the basic relationships of the water balance for the area around Lansing, Michigan including the study basin.

The year falls into three distinct periods. The soil becomes fully saturated during January and remains so through May since evapotranspiration is equal to or less than precipitation for the entire period. During the first part of this period the precipitation is in the form of snow and for the most part accumulates as above ground storage. During the last part of the period the precipitation is rain and is

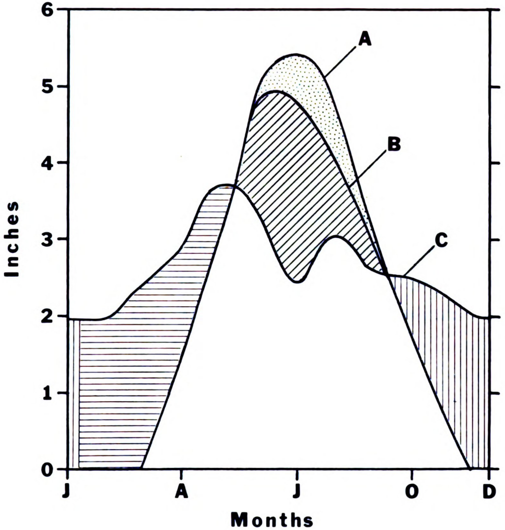

Figure 9. **Average water balance for Lansing, Michigan.**

Soil moisture utilization

Soil moisture recharge

Surplus moisture

Moisture deficit

A--Potential evapotranspiration

B--Actual evapotranspiration

C--Precipitation

Calculations by the Thornthwaite Method. Climatic data from the U. S. Weather Bureau.

directly available as runoff. This is the only period when surplus water occurs. From June through September evapotranspiration exceeds precipitation and some soil water is utilized to partially make up the difference. During this time a moisture deficit occurs. From October through December evapotranspiration is less than precipitation and the excess precipitation is used to recharge the partially depleted soil water.

The three periods occur in all years but their lengths may vary a month or more depending on the variations in weather. Periods would be absent only in years, or perhaps periods of several years, of extreme climatic occurrences.

Runoff

Introduction.--When considering the hydrologic budget for a particular drainage basin, precipitation minus evapotranspiration leaves a quantity of water called the water yield (USGS 1960a). The water yield includes both surface-water and ground-water outflow from the basin. The surface-water outflow is mainly streamflow which is also referred to as runoff. The ground-water outflow may occur in the alluvium underneath the bed of the main stream where it leaves the basin, or it may occur in the consolidated or unconsolidated rock material where the ground-water divide does not lie in the same vertical plane as the surface drainage divide.

One way to detect long-range trends in stream flow patterns is to compare one relatively long time period with another. Generally it is considered that the periods should be at least 30 years long. It would be desirable to compare the most recent 30-year period with records of stream flow before the white man's settlement and the accompanying drastic changes in land use. Unfortunately, such records simply do not exist (the entire continuous gaging record is only 36 years long), and such a comparison for the Red Cedar is impossible. However, the nature of the study basin's runoff as indicated by some characteristics of the one 30-year base period that has been observed and recorded will be considered. Also, the study basin runoff will be compared to study basin precipitation, to runoff from other Michigan basins and to the Midwest regional runoff.

Hydrographs.--The runoff of the Red Cedar study basin is measured at the USGS stream gaging station at Farm Lane bridge (Fig. 2). A hydrograph for the Red Cedar at Farm Lane for 1931-1960 is given in Figure 10. March, April and May comprise over half (53%) of the mean annual runoff. July, August and September comprise less than one-tenth (8%) of the mean annual runoff.

The hydrograph reaches its maximum in March. If floods occur in the study basin they are likely to be the result of a combination of warm spring rains and the consequent snow and ice melt and runoff. The month of greatest

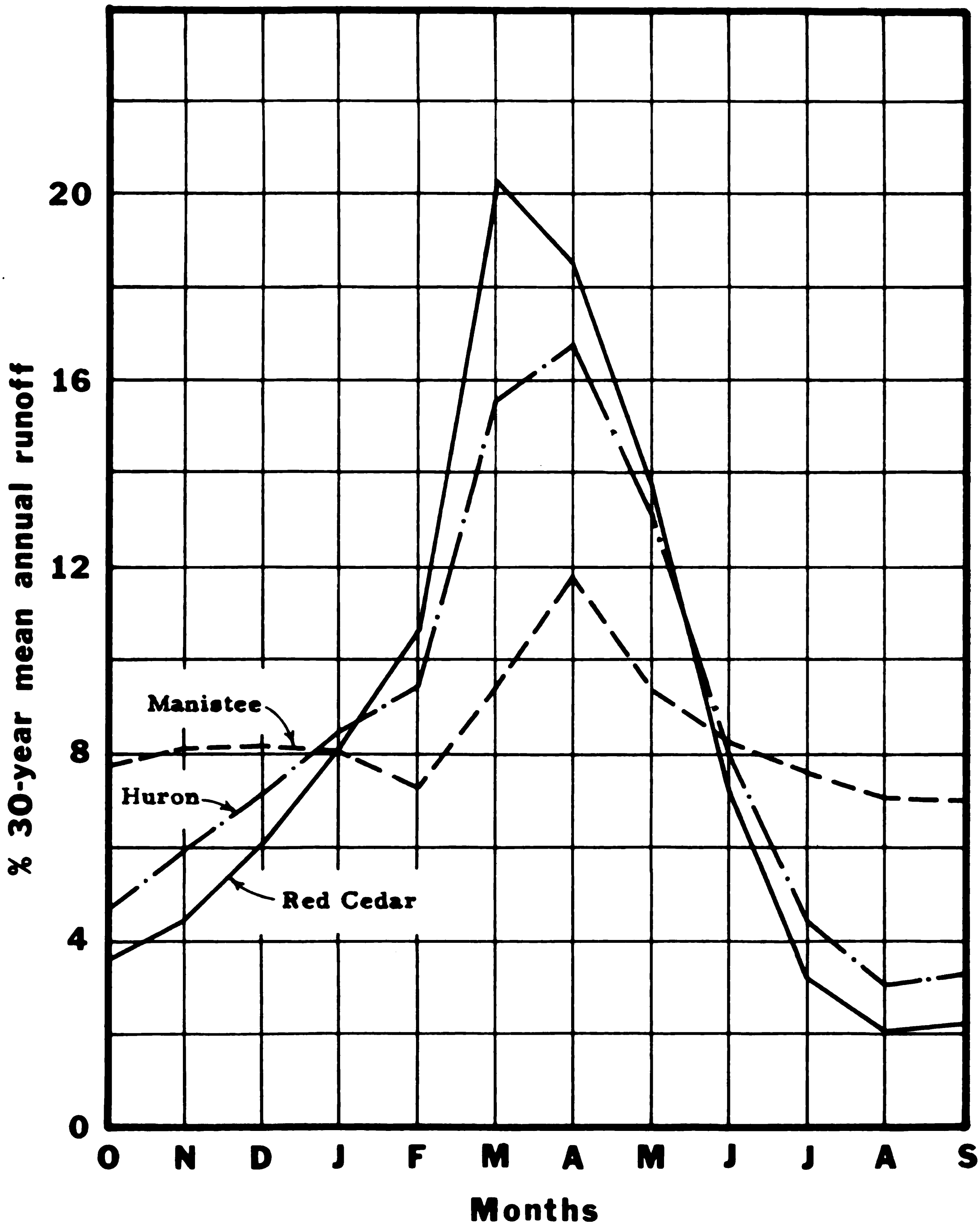

Figure 10. Hydrographs for the Red Cedar River at East Lansing, the Huron River at Ann Arbor and the Manistee River near Sherman. Monthly runoff values are means for 1931-1960, except 1932 and 1933 are not included for the Manistee. Basic data from USGS (1958 and 1964).

runoff for the 1931-1960 period was April of 1947 which had an average discharge of 1494 cfs (cubic feet per second), the equivalent of 4.70 inches of water spread over the entire drainage basin. The maximum momentary flood discharge, 5920 cfs, was recorded on April 7, 1947 at a gage height of 11.58 feet (USGS 1964).

The hydrograph for the Red Cedar reaches its minimum in August indicating that the low flows of the Red Cedar normally occur in late summer. The month of least runoff during 1931-1960 was July 1934 which had an average of 5.70 cfs, the equivalent of 0.02 inches of water over the drainage basin. The minimum momentary low flow, 3 cfs, occurred on July 31, 1931 (USGS 1964).

The greatest monthly runoff is 262 times larger than the lowest monthly runoff. The maximum momentary flood discharge is 1,973 times greater than the minimum momentary low flow. These differences undoubtedly will increase as the stream flow record of 36 years lengthens. The general pattern for the Red Cedar is one of spring floods and late-summer low flows with occassional extremes of each.

For comparison Figure 10 also shows the long-term hydrographs for two other Lower Michigan streams. Since the runoff values are given in percent of the respective long-term means and since the time periods are almost identical, the hydrographs are comparable.

The Huron River basin lies to the southeast of and adjacent to the Red Cedar study basin and is hydrologically similar to the Red Cedar. The long-term mean annual runoff for the Red Cedar is 7.61 inches per water year; the Huron has a corresponding value of 8.32 inches. The pattern of the hydrograph for the Huron is basically similar to that of the Red Cedar, but the Huron does have a smaller range of values with a smaller maximum and a larger minimum. Assuming that the precipitation pattern is essentially identical for the two watersheds, the difference probably is due in part to the larger size of the watershed area of the Huron (711 square miles) and in part to its greater capacity to temporarily retain runoff on and below the surface. The greater surface detention is expressed in the relatively large number of lakes present in the Huron basin. Greater permeability and porosity of the soils and the underlying glacial drift would permit faster infiltration rates which would decrease flood flows and allow a larger contribution of ground water to streamflow during periods of low flow.

The Manistee River is a well-known northern Lower Michigan trout stream which lies about 140 miles north-northwest of the Red Cedar. Its hydrograph (Fig. 10) reflects a basin that is hydrologically quite different from the Red Cedar. The long-term mean annual runoff is 8.99 inches for the Manistee compared with the 7.61 inches for the Red Cedar. The pattern of the hydrograph for the Manistee shows a significant difference from that of the Red Cedar. The Manistee has a smaller range of monthly values and two maxima and two minima rather than one of each. The difference from the Red Cedar is explained partially by the larger size (900 square miles) of the Manistee drainage basin, partially by its more severe winters and partially by its sandy soils and glacial drift which are highly permeable.

Dimensionless Hydrographs.--A procedure utilizing hydrographs to classify streams in the Great Lakes drainage basin is given by Browzin (1962 & 1964a). He uses a variety of meteorlogical parameters, the frequency of monthly coefficients, and a dimensionless hydrograph as the criteria for grouping in his system. The dimensionless hydrograph is a plot of the monthly coefficient against the months of the year where the monthly coefficient is calculated by dividing each average monthly discharge by the mean annual discharge.

This type of comparison appears promising for streams of southern Lower Michigan as a means of classifying main streams and in some cases their tributaries (Browzin 1964b). This type of classification may prove to be useful in helping to determine which streams are hydrologically similar and might respond in similar ways to the same watershed management practices.

Runoff Compared to Precipitation.--Figure 11 presents average monthly precipitation and average monthly runoff for the

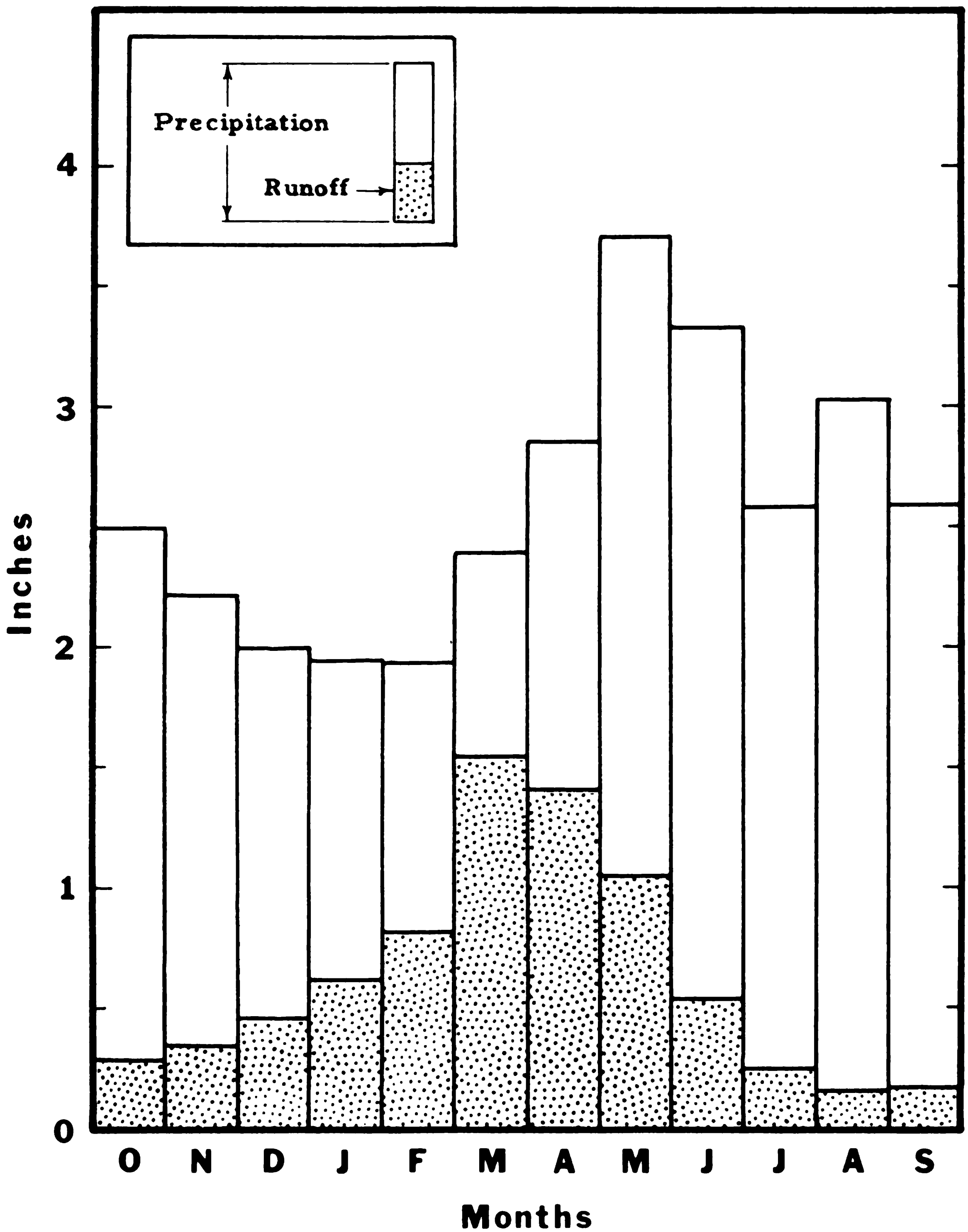

Figure 11. Average monthly precipitation and runoff for the Red Cedar River at East Lansing for 1931-1960. Precipitation based on Lansing-East Lansing records (USWB 1965a). Runoff based on East Lansing records (USGS 1958 and 1964).

study basin for 1931-1960. Both quantities are given in inches of water over the drainage area.

Since runoff from a basin is usually generated by precipitation onto that basin a close correlation might be expected between the two, but the three months of highest runoff (March, April and May) do not correspond to the three months of highest precipitation (May, June and August). Nor do the three months of lowest runoff (July, August and September) correspond to the three months of lowest precipitation (December, January and February). Other demands on precipitation alter the direct cause and effect relationship between runoff and precipitation. Generally, runoff is the remainder of precipitation after a variety of other needs have been satisfied. These other needs are mainly evapotranspiration and soil-water recharge which are relatively constant from year to year. Since precipitation is variable from year to year, runoff is even more variable in most basins.

In addition, runoff for a particular month is not entirely derived from that month's precipitation because surface and subsurface detention of water moving toward the stream channel. During the winter months this also involves water being held as snow and ice, both in and on the soil. In order to describe the relationship quantitatively antecedant precipitation as well as precipitation for the given period should be considered (USGS 1960b). For the study basin Hariri (1960) gave antecedent precipitation a relative weight of one-third and current precipitation a relative weight of two-thirds in establishing the runoff-precipitation relationship on an annual basis.

For the 1931-1960 calendar-year period the mean annual precipitation for the study basin is estimated to be 30.78 inches (see section on climate), and the mean annual runoff is calculated to be 7.66 inches. The remainder, 23.12 inches, leaves the basin in other ways, mainly as evapotranspiration. The study basin mean runoff for the 30-year period is 24.9% of the average precipitation for the same period.

To illustrate the difference between short-term and long-term averages I calculated the driest (1960-1964) and wetest (1947-1951) five-year periods during 1931-1965. The mean annual precipitation for the study basin for 1960-1964 was 24.77 inches while the mean annual runoff for the same period was 4.84 inches. During this period the runoff was 19.5% of the precipitation. The mean annual precipitation for 1947-1951 was 34.96 inches while the mean annual runoff for the same period was 11.60 inches. During this wet period the runoff was 33.2% of the precipitation.

In addition to illustrating the wide differences of absolute values obtained when using short-term periods, the values also show that the runoff not only decreases during periods of low precipitation, but the decrease is relatively more than the decrease in precipitation. Conversely, during periods of high precipitation the increase in runoff is relatively greater than the increase in precipitation.

The variability of annual runoff and of annual precipitation are shown for the study basin in Tables 8 and 9 and Figure 12 where values of each variable are expressed as a percent of its 30-year mean. Although there is general agreement between the two curves, the runoff is much more variable. The precipitation displays a range from 66% to 126% of its 30-year mean while the runoff displays a range from 27% to 184% of its 30-year mean. The average citizen is probably aware of unusually wet or dry years as they are determined by extremes of precipitation. Although the extremes are relatively much greater in streamflow, that same citizen is probably unaware of most of these extremes unless a particular high or particular low flow should directly inconvenience him by a flood or lack of water.

Even though the runoff curve tends to follow the precipitation curve the correlation is not uniform in direction or degree. Wide differences occur between precipitation and runoff in 1931, 1943, 1947, 1948 and 1950 where in each case the difference is greater than approximately 50% of the 30-year mean. In addition, nine other years vary by more than 30%: 1935, 1936, 1940, 1941, 1951, 1952, 1956, 1960 and 1961. The difference is also shown by comparing the standard deviations for the precipitation and the runoff

Table 8. Annual precipitation of the Red Cedar study basin expressed as a percent of the 30-year mean (1931-1960), as the cumulative departure from the 30-year mean, and as an accumulated value.

Calendar Year	In inches	Percent of 30-year mean	Cumulative departure from mean in % units	Accumulated in inches
1931	28.63	93.0	-7	28.63
1932	34.22	111.2	4	62.85
1933	31.66	102.9	7	94.51
1934	21.00	68.2	-25	115.51
1935	31.28	101.6	-23	146.79
1936	27.65	89.8	-33	174.44
1937	33.60	109.2	-24	208.04
1938	32.39	105.2	-19	240.43
1939	26.46	86.0	-33	266.89
1940	35.54	115.5	-17	302.43
1941	28.76	93.4	-24	331.19
1942	34.67	112.6	-11	365.86
1943	32.86	106.8	-4	398.72
1944	24.47	79.5	-24	423.19
1945	37.71	122.5	-1	460.90
1946	22.17	72.0	-29	483.07
1947	38.88	126.3	-3	521.95
1948	30.71	99.8	-3	552.66
1949	35.10	114.0	11	587.76
1950	38.02	123.5	35	625.78
1951	32.11	104.3	39	657.89
1952	27.66	89.9	29	685.55
1953	24.92	81.0	10	710.47
1954	33.89	110.1	20	744.36
1955	24.47	89.2	9	771.83
1956	30.66	99.6	9	802.49
1957	34.93	113.5	23	837.42
1958	23.47	76.3	-1	860.89
1959	38.50	125.1	24	899.39
1960	23.87	77.6	2	923.26
1961	28.64	93.0	-7	951.90
1962	24.01	78.0	-29	975.91
1963	20.35	66.1	-63	996.26
1964	26.98	87.7	-75	1023.24

Basic data from USWB.

Table 9. Annual runoff of the Red Cedar study basin expressed as a percent of the 30-year mean (1931-1960), as the cumulative departure from the 30-year mean, and as an accumulated value.

Calendar Year	In Cfs	Percent of 30-year mean	Cumulative departure from mean in % units	Accumulated in cfs
1931	54	27.0	-73	54
1932	192	95.8	-77	246
1933	186	92.8	-84	432
1934	118	58.9	-125	550
1935	133	66.4	-159	683
1936	103	51.4	-208	786
1937	203	101.3	-207	989
1938	189	94.3	-213	1178
1939	122	60.9	-252	1300
1940	145	72.4	-280	1445
1941	127	63.4	-317	1572
1942	212	105.8	-311	1784
1943	318	158.7	-252	2102
1944	158	78.9	-273	2260
1945	208	103.8	-269	2468
1946	151	75.4	-294	2619
1947	350	174.7	-219	2969
1948	316	157.7	-161	3285
1949	207	103.3	-158	3492
1950	369	184.2	-74	3861
1951	272	135.8	-38	4133
1952	252	125.8	-12	4385
1953	135	67.4	-45	4520
1954	219	109.3	-36	4739
1955	156	77.9	-58	4895
1956	270	134.8	-23	5165
1957	217	108.3	-15	5382
1958	106	52.9	-62	5488
1959	289	144.3	-18	5777
1960	233	116.3	-2	6010
1961	118	58.9	-41	6128
1962	142	70.9	-70	6270
1963	93	46.4	-124	6363
1964	47	23.3	-201	6410

Basic data from USGS.

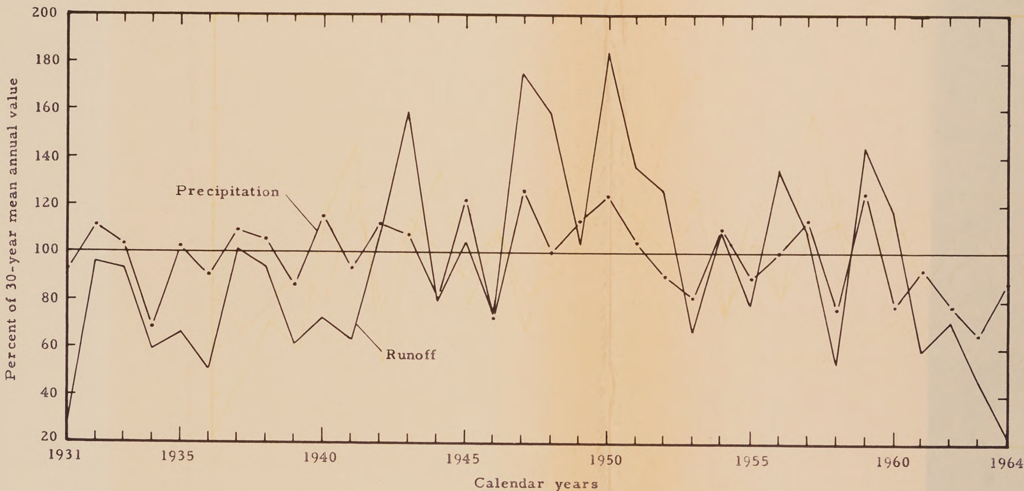

Figure 12. Annual precipitation and annual runoff for the Red Cedar study basin each expressed as a percent of the corresponding 30-year mean annual value. Both means are based on the period 1931-1960. Basic data from USWB and USGS.

which are 17% and 39% respectively. This difference implies that the distribution of the runoff values has a much larger range and less tendency to cluster about the mean.

Tables 8 and 9 and Figure 13 show the precipitation and the runoff of the study basin expressed as the cumulative departure which is given as a percent of the 30-year mean. Each series of values was determined by a series of algebraic summations of the annual percentages of the 30-year mean. The graphs were extended beyond the 1931-1960 base period to show the trend for additional years for which observations were available. Once again, much greater variation is shown for the runoff than for the precipitation. The annual values for runoff ranged from -317% in 1941 to the mean at the end of the base period in 1960. During the same period the precipitation ranged from -33% in both 1936 and 1939 to +39% in 1951.

One of the difficulties in drawing conclusions based on a period of record of a given finite length is illustrated by the precipitation record shown in Figure 13 for the four years after the standard 30-year base period. Of these four years two of them (1963 and 1964) exceeded the previous 30-year minimum for departure from the 30-year mean.

<u>Red Cedar Runoff Compared with Regional Runoff</u>.--Busby (USGS 1963) divided the conterminous United States into nine regions which are geographic areas having stream flow records which exhibit similar patterns of annual runoff. All of

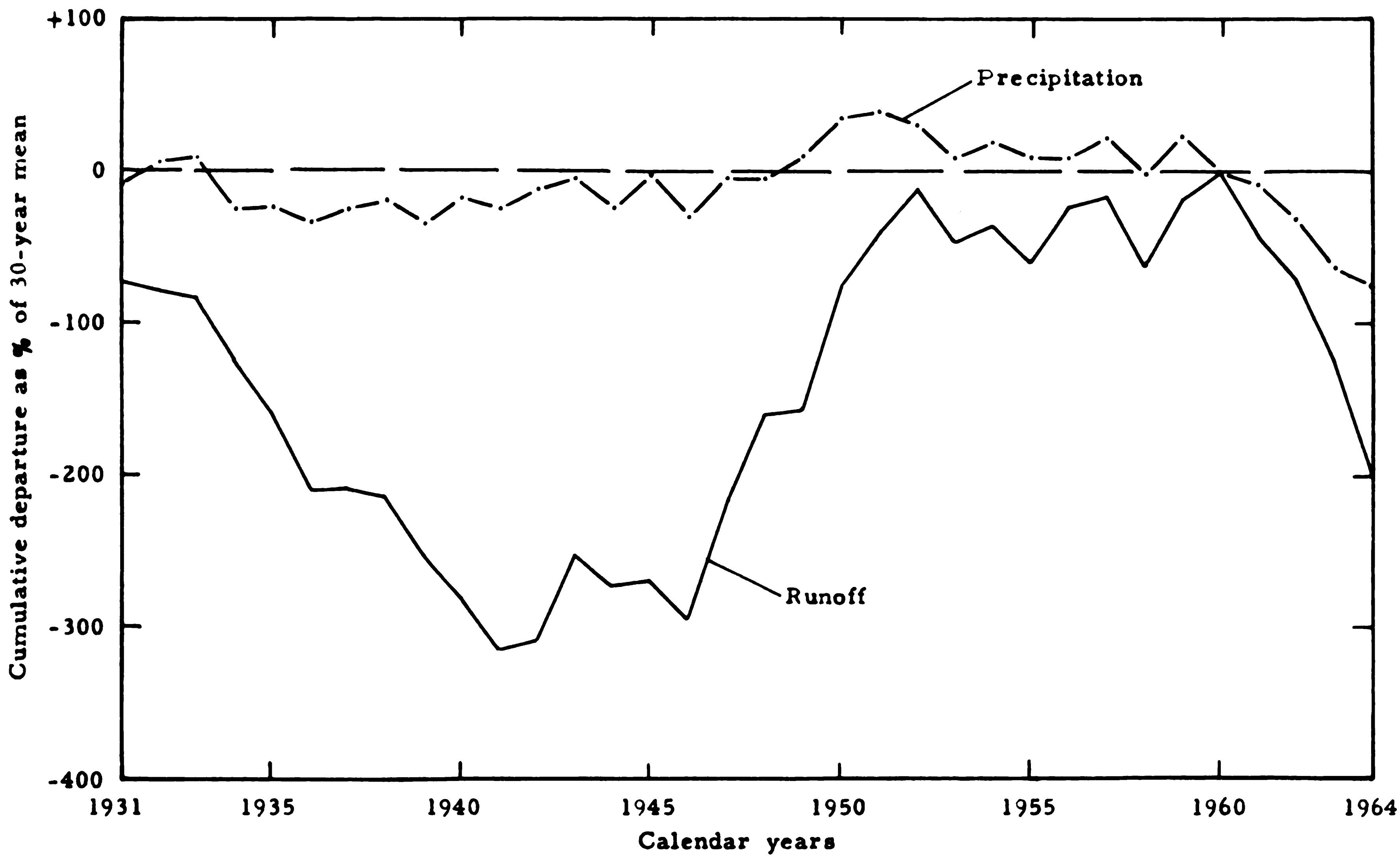

Figure 13. Annual precipitation and annual runoff for the Red Cedar study basin expressed as the cumulative departure from the 30-year mean. The mean is based on the period 1931-1960. Basic data from USWB and USGS.

Michigan falls within the Midwest Region which also includes all of Wisconsin and Indiana and major portions of Minnesota, Iowa, Missouri, Illinois, Kentucky and Ohio.

Figure 14 shows the annual runoff for the Midwest Region expressed as a percent of the 30-year mean (1931-1960). The same information is shown for the Red Cedar study basin for comparison, and in general the study basin curve follows the pattern of the regional runoff curve.* The study basin's maxima and minima are farther from the 30-year mean than the corresponding points for the region. This is expected, and in part is a reflection of the large influence of the occurrence or absence of local rainstorms on the relatively small area of the study basin. The regional curve represents average conditions over a much larger area where the local departures from the norm tend to offset each other.

In 1935, 1943 and 1958 the annual runoff values for the study basin and the region are quite different but the curves peak in the same direction. In 1945, 1948, 1954 and 1956 the annual values for the study basin and the region are quite different but the curves peak in opposite directions.

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*Figures 12 and 14 both express study basin annual runoff as a percent of the 30-year mean. The graphs are slightly different because one is based on water years and the other on calendar years. It was necessary to use calendar years in the one case in order to avoid an excessive number of conversions of meteorlogical data to the water year basis.

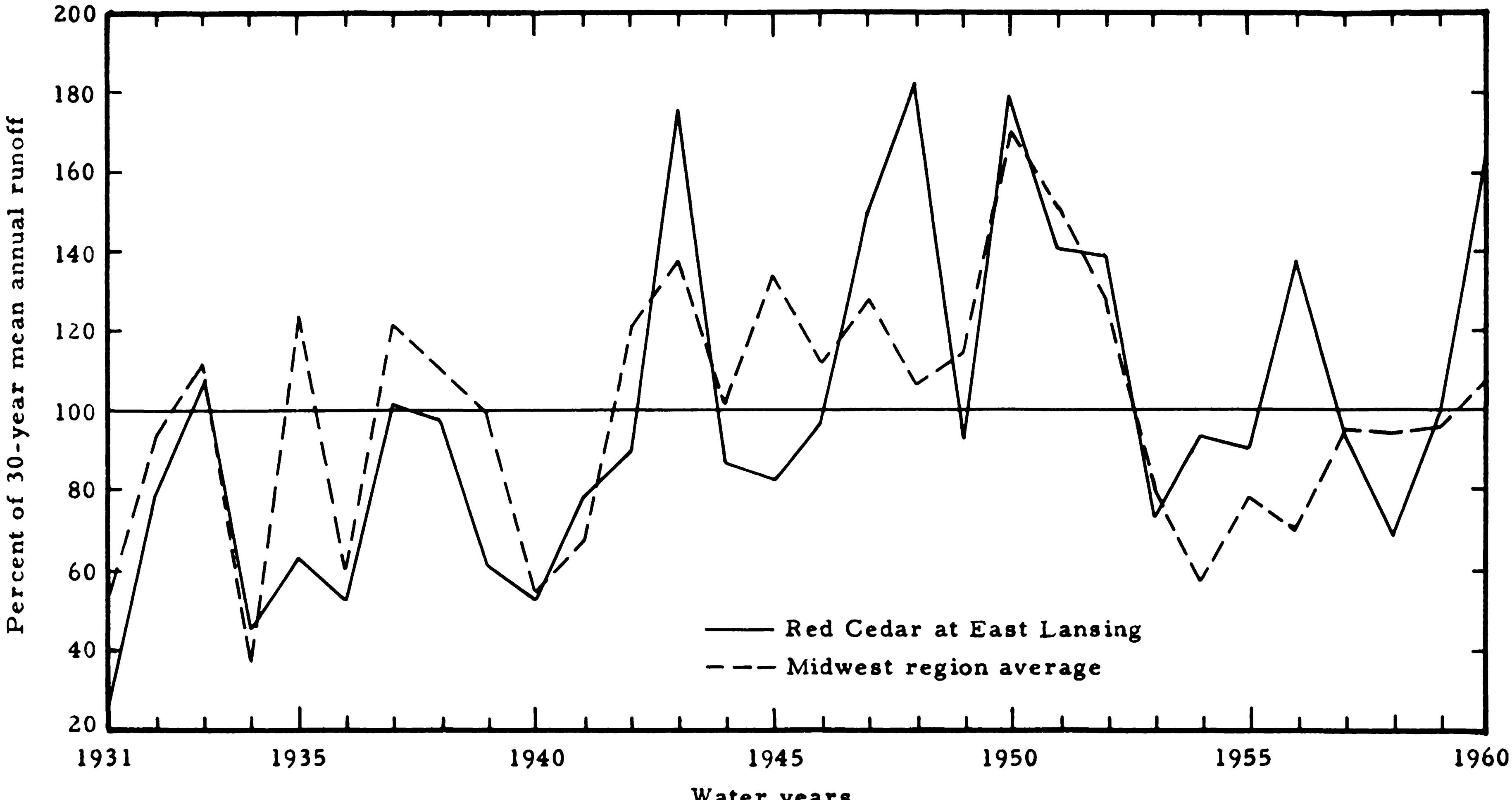

Figure 14. Annual runoff for the Red Cedar study basin and for the Midwest region. Runoff is expressed as a percent of the 30-year mean which is based on the period 1931-1960. Basic data from USGS.

The lowest runoff for the study basin occurred in 1931 at approximately 26% of the 30-year mean while the lowest runoff for the Midwest Region occurred in 1934 at approximately 38% of the 30-year mean. The highest runoff for the study basin occurred in 1948 at approximately 183% of the 30-year mean while the highest runoff for the region occurred in 1950 at approximately 170% of the 30-year mean. Thus the flow of the Red Cedar varied widely from year to year with the maximum annual flow during the 30-year period being seven times greater than the minimum annual flow during the same period.

Since the annual runoff percentage values are approximately normally distributed, about two-thirds of the annual runoff values should lie within one standard deviation of the mean value (USGS 1963). When considered in this way, the least variable region was the humid Northeast Region with a standard deviation of 20% (New York City's recurring water supply problems notwithstanding). The most variable regions were the Southwest and the Lower Plains, each with a standard deviation of 75%. The standard deviation for the Midwest Region is given as 35%, thus two-thirds of the regional average annual discharges lie between 65% and 135% of the 30-year mean. I calculated the standard deviation for the study basin to be 41%, thus two-thirds of the annual discharges of the Red Cedar lie between 59% and

141% of the 30-year mean. Again the greater variation occurs in the study basin.

The Huron River that lies adjacent to and southeast of the Red Cedar basin is the closest watershed which is roughly comparable in size (711 square miles) and also has long-term discharge records (USGS 1964). For the period 1931-1960 the Huron at Ann Arbor had a maximum annual flow of approximately 188% of the 30-year mean discharge and a minimum annual flow of approximately 40% of the 30-year mean. For the Huron River the standard deviation of the annual discharge values for 1931-1960 is 39% which is similar to corresponding value of 41% for the Red Cedar. The Huron's maximum annual flow is within three percentage points of the Red Cedar's maximum, but the Huron's minimum is 14 percentage points above the Red Cedar's minimum. This implies that the Red Cedar has numerous relatively small low flow values even though the distributions of annual flow values for the two basins are basically similar.

Assuming that a 30-year period provides a reasonably long base for quantitative comparisons such as those made above, the question becomes, "Is the 1931-1960 period a typical 30-year period?" Busby (USGS 1963) presents evidence that the 1931-1960 period is a typical period. In the Huron River basin the mean annual runoff at Ann Arbor for the 30-year period 1931-1960 is 8.42 inches; for the 25-year period 1921-1945 it is 6.98 inches; and for the 50-year period 1911-

1960 it is 8.51 inches. These values indicate that the 30-year period 1931-1960 is probably a typical 30-year period. Thus the only 30-year period of record for the Red Cedar, 1931-1960, is probably a more or less typical 30-year period.

Frequency Distribution of Runoff.--Although average runoff values such as the annual and 30-year means used in previous sections are useful to help understand the hydrologic nature of a drainage basin, they do not reveal the range and the distribution of the runoff data. Figure 15 gives the mean monthly runoff values for the study basin for 1931-1960. The nature of the distribution of values is shown in terms of the upper quarter, the middle half and the lower quarter. None of the twelve distributions appear to be a normal distribution; rather, all are skewed toward the high end of the range. The distributions for October and September are so greatly skewed that the mean falls in the upper quarter, not in the middle half as expected. April has the largest range of any month, from 0.20 inches in 1931 to 4.70 inches in 1947, a range of 4.50 inches. August has the smallest range of any month, from 0.03 inches in both 1934 and 1936 to 0.42 inches in 1959, a range of 0.39 inches.

Just as the 30-year monthly mean fails to reveal the extremes among the annual monthly runoff values, in turn the frequency distribution of monthly values does not reveal the nature of either momentary or daily runoff values. For example, the extreme momentary flood value for 1931-1960 of

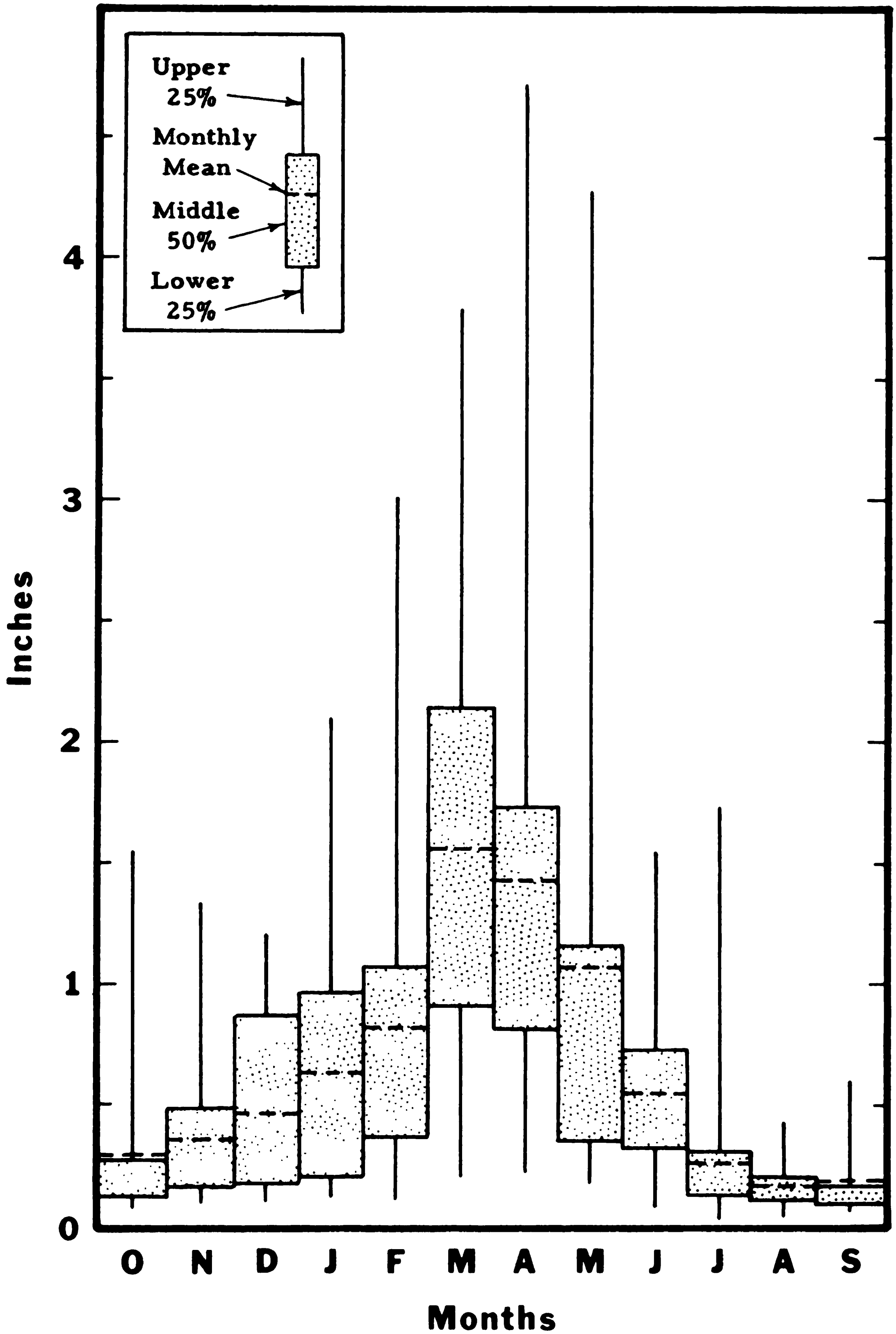

Figure 15. Runoff for the Red Cedar study basin for 1931-1960. The monthly mean, the upper quarter, the middle half and the lower quarter of the distribution of runoff values for each month are shown. Basic data from USGS (1958 and 1964).

5920 cfs (April 7, 1947) is masked in the corresponding monthly mean of 1494 cfs. The extreme momentary low flow of 3 cfs (July 31, 1931) is masked in the corresponding monthly mean of 40.5 cfs.

To illustrate the masking effect of the monthly mean discharge a month with a relatively compact 30-year distribution, June, was selected. The 30-year mean for June is 0.54 inches, so June 1948 with a discharge of 0.55 inches was selected to demonstrate how the "typical" month achieved its close-to-the-mean value (Fig. 16). The 0.55 inches is equivalent to an average discharge of 176 cfs for the month. The first 22 days of the month are moderately below the monthly mean, and the last eight are well above the mean while the mean itself did not occur even once as a daily discharge. June of other years would show even greater variation from the long-term mean since June 1948 was selected because it is so close to the mean.

To more fully understand the nature of runoff several other procedures are commonly used. A thorough graphical statistical analysis of low-flow characteristics is presented by Velz and Gannon (1960) and in a supplement by Gannon (1964). A set of drought duration vs. severity curves, a set of minimum flow curves and a flow duration curve are given for the Red Cedar at East Lansing. In the original paper these plots are based on the 16-year period

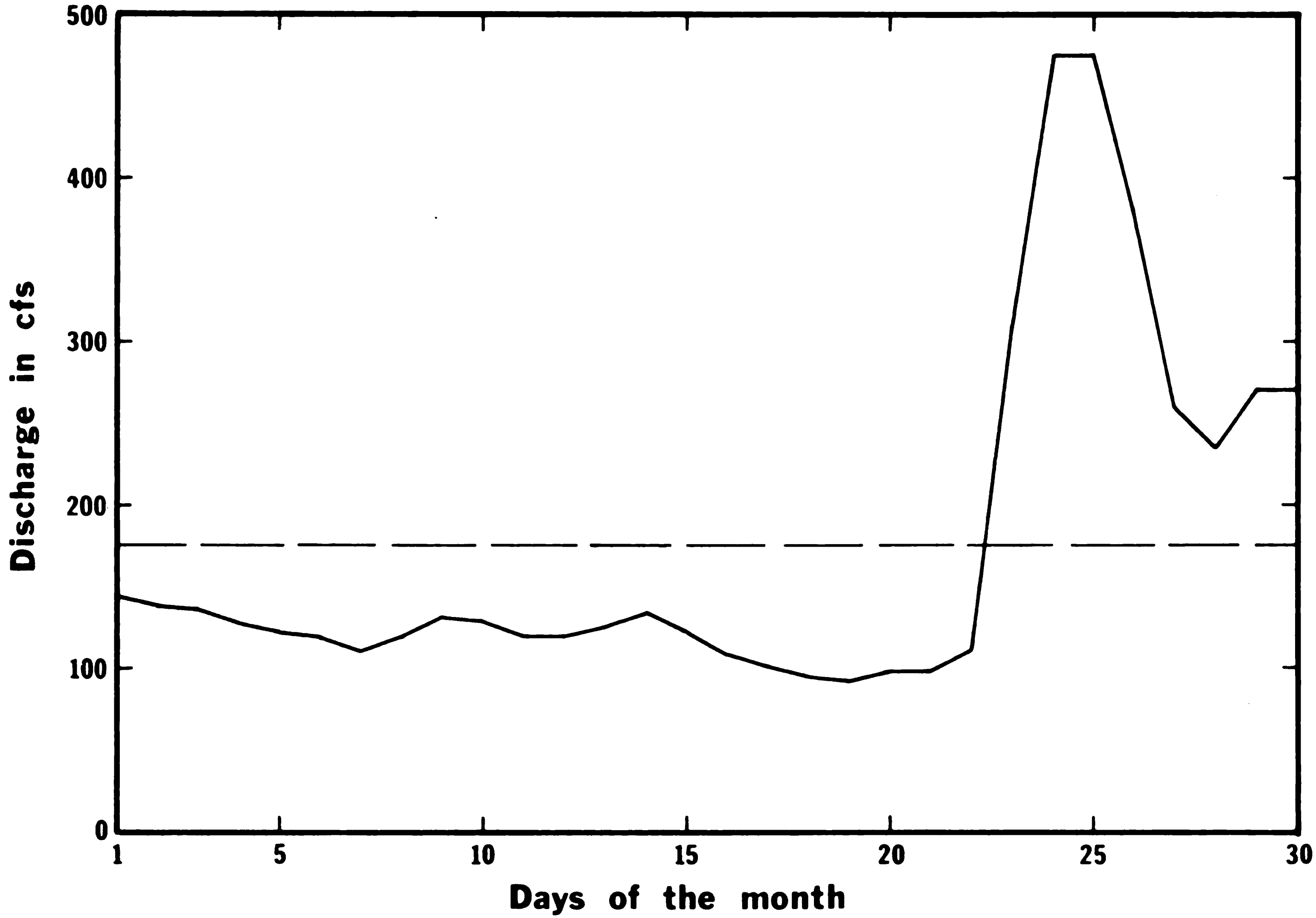

Figure 16. A hydrograph for the Red Cedar River at East Lansing for June 1948. Daily discharge is expressed in cubic feet per second. The monthly mean, 176 cfs, is shown by the broken line. Basic data from USGS (1950).

1939-1954. They were updated by the supplement to cover the years 1955-1960.

The streams of central Lower Michigan are characterized as having extremely poor drought flow discharge per square mile. The Red Cedar has a most probable yield of 0.077 cfs per square mile for a consecutive seven-day drought which ranks among the lowest values for southern Lower Michigan streams of comparable size. The Red Cedar's variability ratio is given as 0.390 which again occurs among the lower values of comparable streams. This ratio for the Red Cedar means that the most severe once-in-ten-year, seven-day low flow is 39% of normally expected low flow which classes the Red Cedar among the " . . . highly unstable streams with great risk of occasional extremely severe drought flows decidedly below normal." (Velz and Gannon 1960).

The flow-duration curve is a plot of discharge against percent of time in the total period being considered. Such a curve for the study basin is shown in Figure 17. Daily discharge in cfs for 1931-1960 is given on the ordinate on a four-cycle logarithmic scale. The raw daily discharge data were grouped by the U. S. Geological Survey (no date) into 29 classes. The number of items per class was calculated and then accumulated in a series from the maximum discharge value to the minimum discharge value. The percent of the total time period was determined for each accumulated value. These values are plotted on the abscissa on a

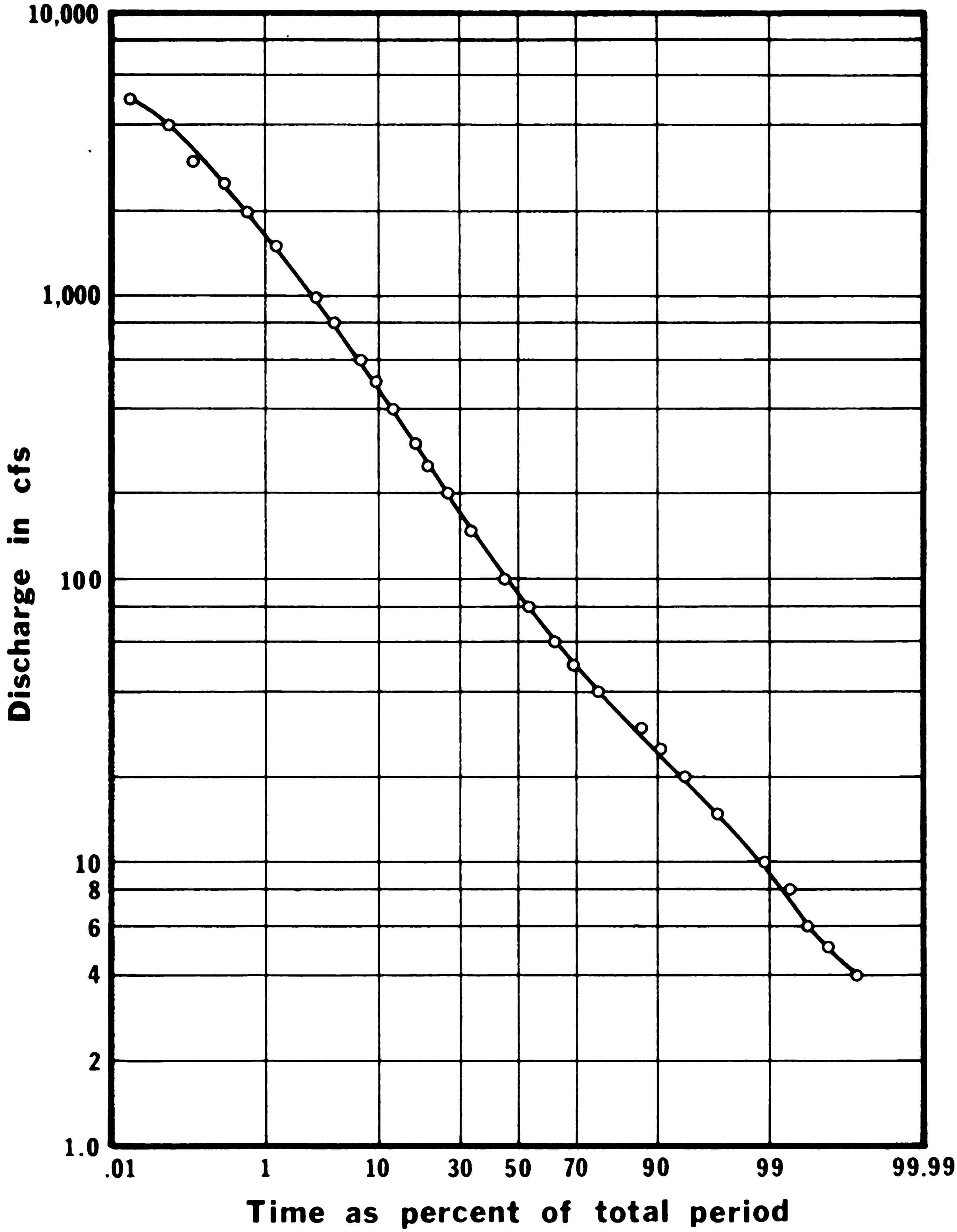

Figure 17. Flow-duration curve for the Red Cedar River at East Lansing, 1931-1960. Daily discharge is given in cubic feet per second. Time is expressed as the percent of the total period for which the corresponding daily discharge was equaled or exceeded. Basic data from USGS (no date).

probability scale. The abscissa thus represents the percent of time that daily discharges either equaled or exceeded the discharge shown.*

Although the flow-duration curve does not provide a probability of occurrence (Velz and Gannon 1960), it does summarize conditions for the 30-year base period. In as much as the next 30-year period will resemble the base period used, the flow-duration data preview what may be expected for the long term. For example, during ten percent of the base period the daily discharge was equal to or greater than 480 cfs.

The discharge which is equaled or exceeded 90% of the time may be used as an index of drought flow which is assumed to be base flow only (Cross 1949). For the Red Cedar this flow is 28 cfs. Thus during the base period the daily discharge underneath the Farm Lane bridge was less than 28 cfs 10% of the time. The discharge was less than 9.6 cfs one percent of the time or for approximately 110 days.

In order to appreciate the nature of the distribution of the discharge values I plotted a regular frequency distribution on linear by linear graph paper using the same

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*If the same values are plotted on standard linear by linear graph paper the resulting plot is similar to an equilateral hyperbola in the first quadrant. Such a curve is extremely inefficient to use to read values from one axis to the other. The logarithmic, extremal probability plot yields a slightly curved line with a sufficient angle to each axis to allow efficient reading of values from one scale to the other.

values that were used for the flow-duration plot. The resulting curve for 1931-1960 is shown in Figure 18. The curve is highly skewed to the right showing that the majority of daily discharges lie below the 30-year mean of 199 cfs.

Considering the various analyses of the runoff from the study basin, the Red Cedar River may be characterized as a small, highly variable stream that has a relatively low yield per square mile during drought conditions. The bulk of the daily discharges are smaller than the mean values which are often quoted.

Long-Term Trends in Runoff.--One way to detect long-range trends in hydrologic variables is by use of the double-mass curve in which the accumulation of one variable is plotted against the accumulation of another. The resultant curve should be a straight line if the variables are directly proportional to each other. The slope of the line is the proportionality constant associated with the two variables.

If the relation between the two variables should change the straight line would reflect the change as a change in direction, that is, a break in slope. Such a break in slope is more readily detected if the array of points is at approximately 45 degrees to both axes which can be achieved by proper selection of the vertical and horizontal scales. Year to year minor variations between the variables cause minor breaks in slope which are usually ignored as insignificant. Only changes in slope that persist

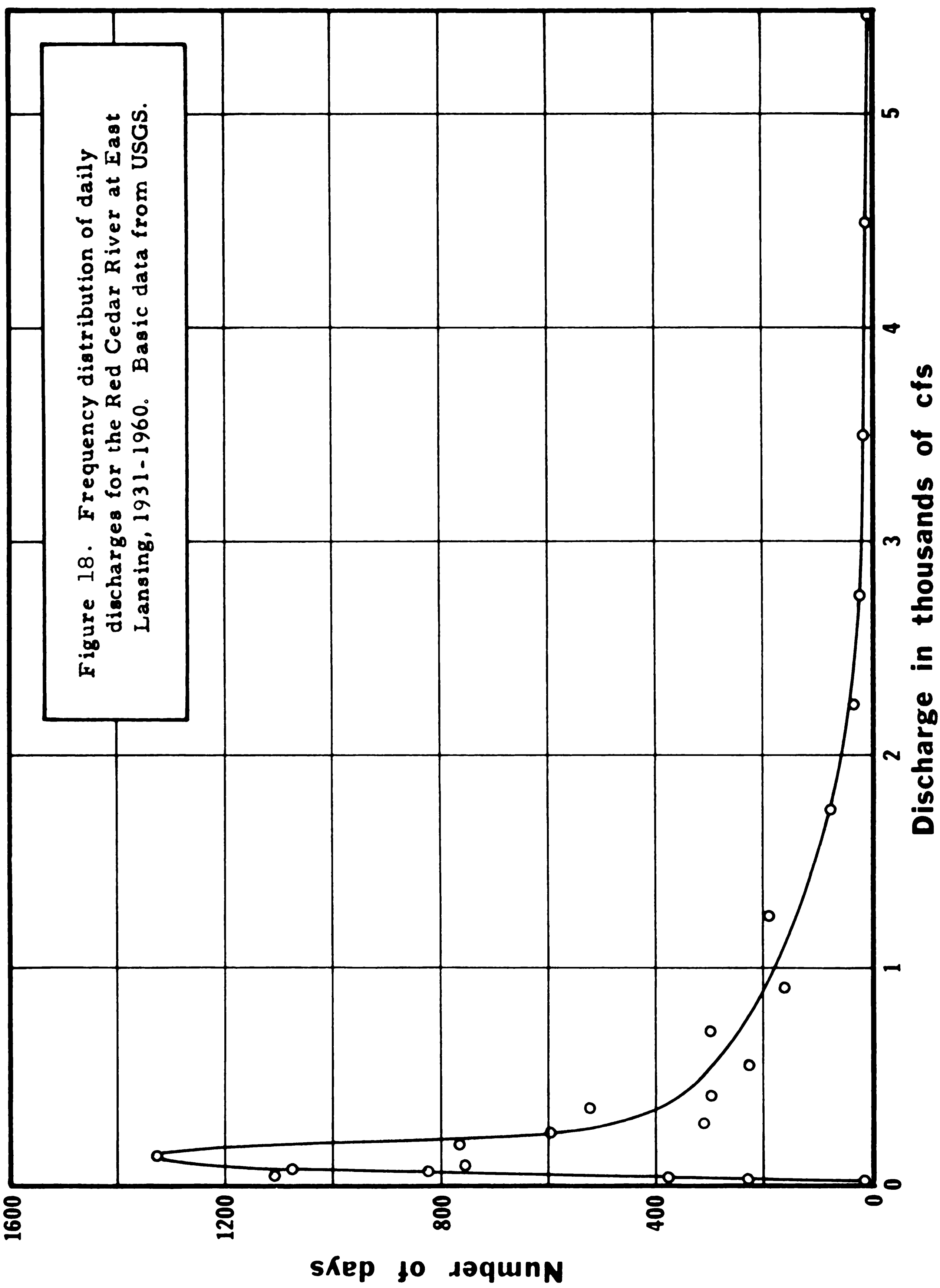

Figure 18. Frequency distribution of daily discharges for the Red Cedar River at East Lansing, 1931-1960. Basic data from USGS.

for more than five years are considered significant (USGS 1960b). However, even then, such a break may not be due to an actual change in the relation between the variables, but rather due to a change in the procedure for collecting the data for one or both of the variables. For example, the change in the location of a rain gage or a stream gage may produce such an effect. An actual change in the relation between the variables may be due to either natural or man-made alteration of the hydrologic variables in the system being considered.

A double-mass curve for the Red Cedar study basin in which the cumulative mean annual runoff is plotted against the cumulative annual precipitation for 1931-1965 (calendar years) is given in Figure 19. The runoff data were obtained from the USGS (1958 & 1964) and from open file reports in the Survey's Lansing office. The precipitation data were obtained from a variety of published and unpublished records of the USWB and the Bureau's Lansing office (see section on climate).

Although the interpretation of such a curve is somewhat arbitrary, I have shown the array of points defining a line with two breaks in slope, one at 1940, and the other at 1960. The annual precipitation values are averages of several stations none of which was relocated in or near the years of 1940 or 1960. Even if one station had been relocated it probably would not have changed the overall average since

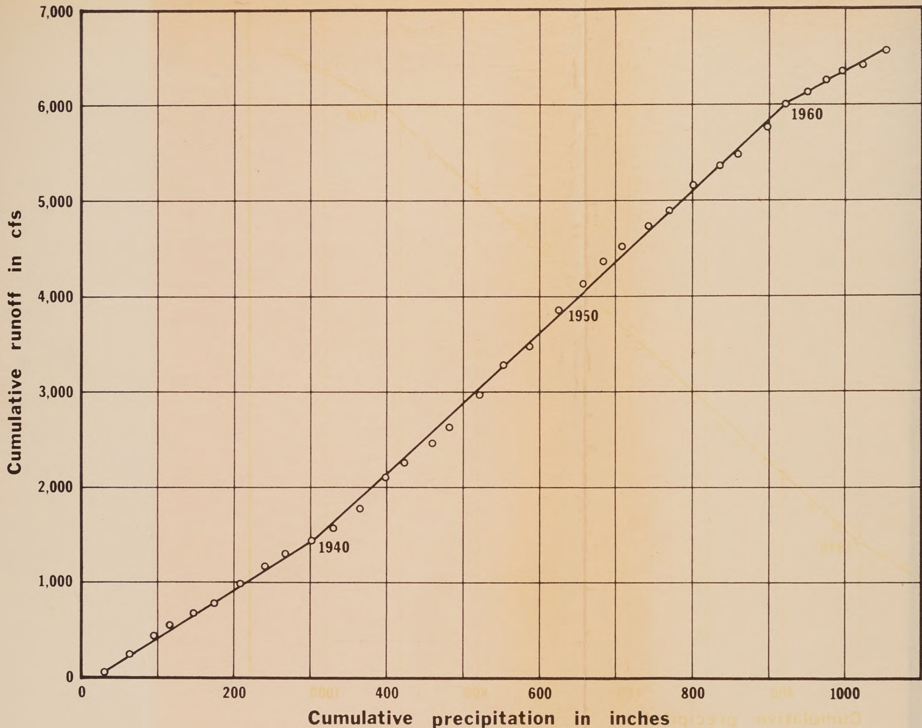

Figure 19. Double-mass curve for the Red Cedar study basin for 1931-1965. Runoff is the accumulated mean annual runoff for the Red Cedar River at East Lansing. Precipitation is the accumulated annual precipitation over the study basin. Breaks in slope are shown at 1940 and 1960. Basic data from USGS and USWB.

individual station relocations did occur at other times but are not reflected as major breaks in slope. The runoff values are based on the record from one stream gage (East Lansing) which was relocated in 1940. However, this change should not be the cause of a major break in slope because the gage was moved about 250 feet downstream remaining in the same pool at the same reference datum (Bent 1966).

These two breaks are probably due to the decrease in runoff as a percent of percipitation that occurs during low-precipitation years. During 1931-1941 runoff as the cumulative departure from the 30-year mean steadily declined in response to the dry-weather decade of the 1930's (Fig. 13). During this time runoff as a percent of precipitation was below normal. In the 1941-1960 period cumulative runoff returned to and remained near the mean while cumulative precipitation was near or above the mean. During 1960-1965 precipitation and runoff declined sharply, again with the resulting effect of runoff becoming a smaller percent of the precipitation.

During the two dry periods included in the record the corresponding portion of the double-mass curve has less than normal slope and the beginning and end of these periods probably account for the breaks in slope. Other changes were not detected by this runoff-precipitation, double-mass curve. If other breaks had occurred further analysis of them would be warranted as outlined in Water-Supply Paper 1541-B (USGS 1960b).

Four other double-mass curves were plotted covering the water years 1931-1965 (Fig. 20, map pocket). Each curve has the cumulative mean annual runoff of the Red Cedar plotted against the cumulative mean annual runoff of a relatively nearby stream with a continuous, long-term gaging record. The other four river gaging stations used are all in southern Lower Michigan: the St. Joseph River at Niles, the River Rouge at Detroit, the Huron River at Ann Arbor and the Grand River at Grand Rapids. The river gaging data were obtained from USGS published records (1958 & 1964) and from open file reports in the Survey's Lansing office.

The curve for the Red Cedar vs. the Rouge showed no major breaks in slope while the other three curves each had one major break. The break in the Red Cedar-St. Joseph curve occurred about 1941. Although the Red Cedar stream gage was relocated during the preceding year, it should not affect the cumulative discharge series as noted above. The St. Joseph did not have a gage relocation during the period of record. This change in slope was probably due to the change from the series of dry years in the 1930's in the Red Cedar basin to the series of normal or wet years as was noted above.

The break in the Red Cedar-Grand curve occurred about 1943. The Grand did not have a gage relocation during the period of record. Thus this break in slope in the same direction at about the same time as the Red Cedar-St. Joseph break, probably can be accounted for in the same way, that is, a change from a dry period to a normal period in the study basin.

Since the Red Cedar-Rouge and the Red Cedar-Huron curves show no breaks during the early 1940's the River Rouge and the Huron River probably had runoff patterns similar to the Red Cedar's during these years.

The Red Cedar-Huron curve does have a break about 1947 that is probably a result of the relocation of the Huron River stream gage in that year.

Each of the curves except the Red Cedar-Rouge has a slight change in slope in the most recent six years of record. These minor changes are probably due to the dry period beginning in 1961 experienced on the Red Cedar but not experienced, at least to the same degree, on the other river basins. Since the trend extends for only the several most recent years of record the conclusion must be tentative, but it does support the similar conclusion based on the Red Cedar's runoff-precipitation, double-mass curve discussed above.

Since all of the major breaks in slope can be accounted for by known phenomena, these four double-mass curves do not indicate any long-range trend in the quantity of the mean annual runoff of the Red Cedar from the study basin. If such a trend does exist it is not apparent from this analysis.

Ground Water

Introduction.--In the study basin ground water occurs in the Pleistocene glacial drift and in the Pennsylvanian bedrock below it. For the most part the drift is a heterogeneous mixture of clay, silt, sand, gravel and boulders, but it contains some interspersed units of sorted materials. It varies in thickness from just a few feet to more than 200 feet (Moore 1959; Vanlier, no date). In general the drift is low in permeability and only provides water for low-yield wells.

For most of the study basin the bedrock lying immediately below the drift is the Saginaw Formation. This early Pennsylvanian formation contains sandstone and shale with some limestone and coal (Mich. Water Res. Comm 1961; Mich. Dept. Conserv. 1964). Some younger bedrock of the Grand River Group (sandstone and shale) occurs in the southern portion of Meridian Township; and some older bedrock, a complex of Mississippian strata, occurs in the eastern townships of the study basin (Mich. Dept. Conserv. 1957; Mich. Water Res. Comm. 1961). The bedrock strata of the study basin are located south and east of the center of the Michigan Basin and generally dip northwestward.

The upper portion of the bedrock provides the main supply of the ground water in the study basin; the deeper bedrock produces mineralized water (Vanlier, no date). For the study basin then, usable ground water occurs in both the unconfined aquifers of the glacial drift and the confined aquifers of the upper bedrock, mainly the Saginaw Formation. The amount of ground water which is available for human utilization in the Lansing area is unknown, but it is estimated to be about three times the recent annual usage of 30 mgd (Tri-Co. Reg. Plan. Comm 1963).

Water Table and Piezometric Surface.--The upper surface of the zone of saturation, the water table, is at a pressure of one atmosphere. The water in the confined bedrock is under pressure of more than one atmosphere and will rise in a well which is cased from the surface down into the consolidated aquifer. This artesian system may or may not produce a flowing well depending on the relative elevations of the land surface and the water level. The surface defined by the static water levels in the deep wells that penetrate the bedrock aquifer is a pressure surface, the piezometric surface.

The piezometric surface was originally probably at or near the land surface in the western portion of the study basin as indicated by flowing wells at various locations which have been reported by several sources. Lane reported flowing wells on what is now the Michigan State University campus (USGS 1899) and at four other locations in the

Lansing-East Lansing area (USGS 1906). Cooper refers to flowing wells in Okemos and Meridian in Meridian Township (Mich. Geol. Surv. 1905). The flowing wells no longer exist in the extreme western end of the study basin which is adjacent to large-scale municipal and industrial pumping, but some flowing wells still exist at locations removed from the metropolitan area. For example, in the town of Williamston (Firouzian 1963) and in section 23 of Iosco Township where the continuous discharge is used to help maintain a swimming pond.

Cone of Depression.--The water table and the piezometric surface fluctuate in response to natural and man-made variations in the hydrologic cycle. For example, a pumping well discharging water to the surface creates a cone of depression in the water table or the piezometric surface depending on whether a confined or an unconfined aquifer is being used.

In the Lansing metropolitan area before municipal wells were installed in the late 1800's, the piezometric surface was probably in a state of dynamic equilibrium and probably more or less flat dipping slightly to the west of north (Stuart 1945). Municipal and industrial deep wells have increased in number as the area has grown with the result that a cone of depression has formed in the piezometric surface. With the increasing pumpage of the metropolitan area the cone of depression has not remained static, but has expanded both vertically and horizontally. The cone is a composite cone reflecting the influence of the several well fields of the cities of Lansing and East Lansing, Michigan State University, Meridian Township and privately owned industries.

For comparison, a profile extending from one of the depressions near the middle of the composite cone in the city of Lansing to a point six miles due east in Meridian Township is given in Figure 21. The profile is shown for 1945 and 1962. The piezometric surface has been significantly lowered under Lansing, East Lansing (including Michigan State University), and the western half of Meridian Township. The greatest lowering to occur in the 17-year period as indicated by the distance between the profiles was about 46 feet. Firouzian (1963) reports a maximum lowering in the composite cone of between 80 and 90 feet on the north side of Lansing. Thus the piezometric surface under the western portion of the study basin is influenced by the adjacent water-demanding urbanized area that lies mainly outside the study basin.

The residents of the study basin who do not use municipal water supplies use their own well supply. This sort of discharge also affects the piezometric surface but apparently only locally and in a minor way (Stuart 1945; Mencenberg 1963; Vanlier 1963).

Mr. Ralph Hudson, a long-time resident of the East Lansing area, reported (1964) that in about 1900 a domestic well was installed on his farm in the northwest quarter of

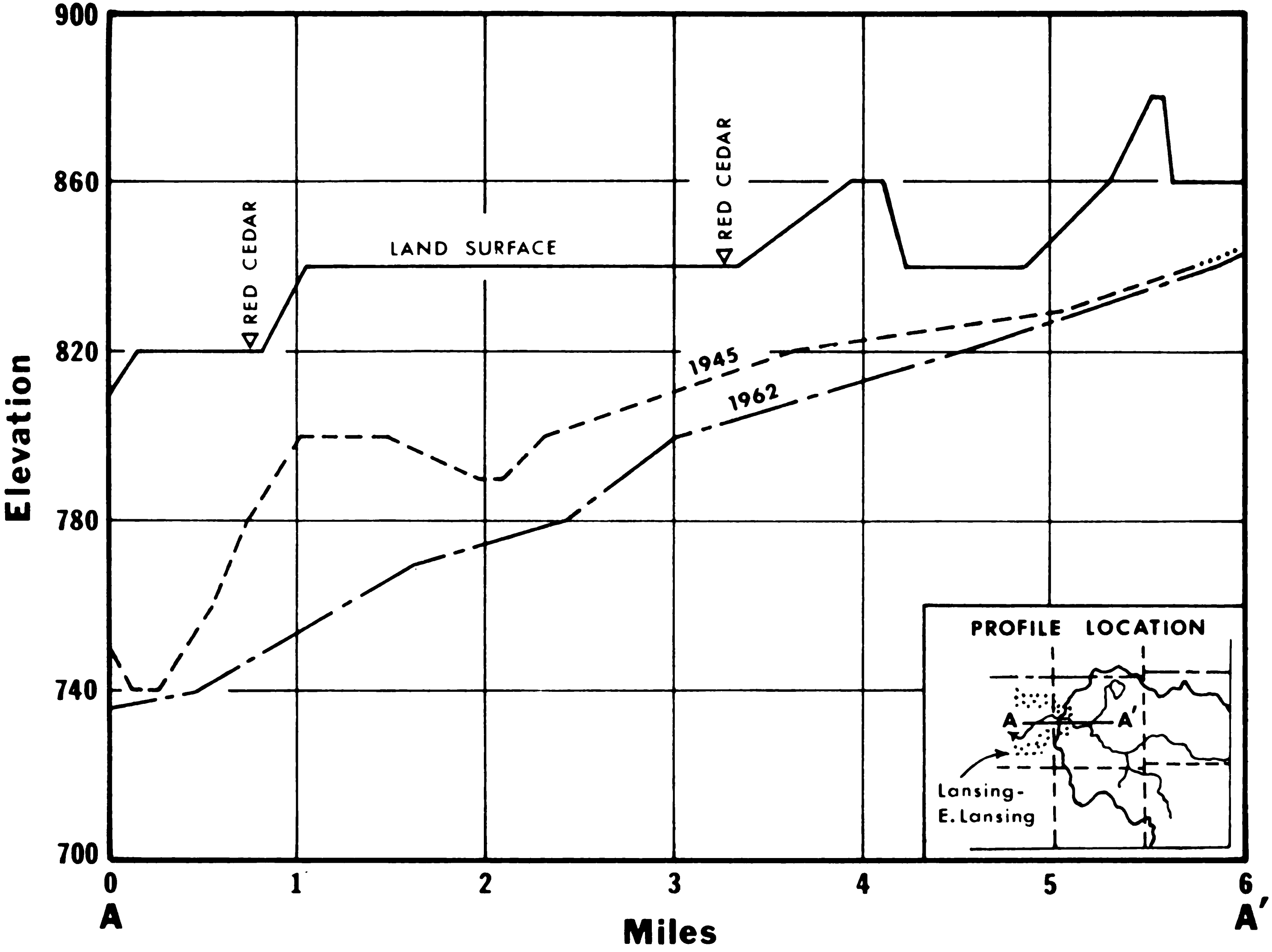

Figure 21. **Profiles of the piezometric surface in the Lansing-E. Lansing-Meridian Twp. area for 1945 and 1962. Elevation is in feet above mean sea level. Distance along the profiles is in miles. Basic data from USGS topographic maps, Stuart (1945) and Firouzian (1963).**

section 29 of Meridian Township. The well was finished in the bedrock at 160 feet below the land surface. In 1964 he measured the water level in this well and found that it had dropped 12 feet from its original elevation. This is the magnitude of change which would be expected assuming that the original piezometric surface was near the land surface prior to the drawdown created by the heavy pumping immediately to the west.

The source of ground water in the study basin is precipitation most of which probably fell onto the land surface of the study basin. All of the study-basin ground water would be derived from study-basin precipitation if the water-table and piezometric-surface divides were to lie directly below the surface divide. Reference to the uncertainty of this situation was made earlier with regard to the determination of the boundary of the study basin. The nature of the surface- and ground-water divides for the study basin is quite complex and not thoroughly known (Vanlier 1963). One major change in the piezometric surface was alluded to above in connection with the development of the metropolitan Lansing cone of depression: its peripheral expansion and concomitant alteration of the divide on the piezometric surface.

Although the exact nature of the exchanges of water between the surface water, water-table ground water and artesian ground water is not fully understood, a few cases are known. Stuart (1945) states that along the Red Cedar River favorable conditions exist for recharge of the sandstone where it lies near the land surface. Originally the Grand River, the Red Cedar River and Sycamore Creek probably discharged ground water where they were lower than the piezometric surface. Firouzian (1963) reports that in the Lansing area the greatest amount of recharge to the bedrock aquifer occurs where the sandstones are in direct contact with saturated portions of the glacial drift. By use of a flow-net analysis he estimated that in the Lansing area 28 mgd (million gallons per day), the equivalent of 4.8 inches of water, pass into the sandstone aquifer mainly by recharging from the overlying drift to the bedrock. He states that the Grand River in the city of Lansing recharges about 3 mgd in this process. The analysis of 2.4 square mile sample area in the southwest portion of Meridian Township gave a value of about 7.6 inches of water per year recharging to the sandstone aquifer from the drift. Thus ground-water recharge now occurs in an area which originally was probably an area of ground-water discharge to surface waters.

CHAPTER VI

HUMAN SETTLEMENT IN THE STUDY BASIN

Overview

Since the retreat of the most recent continental glacier south central Michigan (including the study basin) has had at least three distinct major types of human occupance. (Occupance is defined as the process of living in an area and the transformation of the original landscape which results (James 1951).) During the period immediately prior to the settlement by the white man, the American Indians who inhabited the study basin maintained an economy that was essentially of the good-gathering type. The occupance of the white settlers and their progeny was essentially agricultural, depending on domesticated plants and animals. The third type of occupance has developed as a phase of modern Western culture: urbanization with its concentration of industry, commerce and dwellings and the associated intricate networks of communication and transportation. The present inhabitants of the study basin, representing the third type of occupance, are a mixture of agricultural and urban types and a variety of intermediate forms.

Each of the three recent major cultures to occupy the study basin have used the natural resources of the area in different ways, each interpreting and utilizing the resources in accordance with its own cultural principles. I will consider population density and selected facets of land and water use for each of the three cultures of the study basin.

Indian Occupance

During the period prior to the arrival of the white settler, American Indians of the Potawatomi tribe practiced a way of life based on hunting, fishing and food-gathering with some maize agriculture (Driver 1961). With this pattern of occupance the regional population density was about 0.09 persons per square mile (Driver 1961). Accordingly the entire study basin had a human population of about 30 persons. This estimate may be too low or too high since it is derived from a regional average that is applied to a smaller specific area, i.e , the study basin. It is quite possible that parts of the study basin may have had a much higher density than the regional average. For example, Fuller (1928) refers to the village of Okemos as the "Indian metropolis" of Ingham County, and the population of the county is estimated to have been 500 or less at the time of settlement.

Another complicating factor is that the Indian population did not usually remain in the same location for all four seasons. All things considered it is probable that the population density for the entire study basin was less than one yearlong resident (or equivalent) per square mile.

Considering the kind of occupance and the population density, the lands and waters of the study basin were not intensively used by the Indians. Except for trails, food caches and a few clearings the virgin forest land was unchanged. The waters of the study basin were used without the aid of modern mechanical devices for domestic purposes and for travel, but in all probability they too remained essentially unchanged.

Agricultural Occupance by the White Man

Population.--Although the first white man passed through Central Michigan in the 1700's, it was not until the 1820's that the original land survey was made and the 1830's that land purchase and settlement began. The Livingston County and southern Ingham County portions of the study basin received the earliest settlers. In the early 1840's action was taken by the pioneer residents of the northwest portion of the study basin and the last townships were formally organized.

The early settlers were mainly farmers who viewed the forest as an obstacle to their livelihood. By the time of the 1850 decennial U. S. census, the first following the political organization of all the townships of the study basin, the estimated population of the study basin was 4,647. The corresponding density was about 14 persons per square mile (Table 10).

The population estimates were made by transferring the geographical township boundaries, the village and city limits, and the study basin divide from the study basin base map to tracing paper. Then the areas of each township lying inside and outside the study basin and the areas of villages and cities were determined by cutting and weighing. For purposes of calculation I assumed that in each township the population was evenly distributed except for the villages and cities. Because settlement depends on various physical and cultural characteristics, the assumption is not completely valid; but, I do not know of any locations in the study area where major errors have resulted as a consequence of the assumption.

Thus, in approximately the first ten years of white settlement the human population of the study basin changed from something less than 500 to over 4,600 and the density changed from less than one person per square mile to about 14 persons per square mile.

In Central Michigan as elsewhere prior to the early 1900's energy necessary for the agricultural enterprise was derived mainly from the muscles of man and animal. Nonetheless land was cleared and tilled, drainage was accomplished, wells were dug, and roads were built and maintained.

Table 10. Estimates of population in the Red Cedar study basin for 1850, 1900 and 1960 by minor civil divisions.

Geographic township	Total area, $miles^2$	Segment lying within study basin: % of total	Segment lying within study basin: $Miles^2$	Population in the study-basin segment: Number 1850	Number 1900	Number 1960	Density, no./$mile^2$ 1850	Density 1900	Density 1960
Clinton County									
Bath	37.07	4.08	1.51	9	43	152	6	29	101
Ingham County									
Alaiedon	36.17	34.82	12.59	131	408	721	10	32	57
Bunker Hill	33.57	0.10	0.03	a	a	a	a	a	a
Ingham	33.85	80.96	27.40						
Dansville Village			1.02	b	374	453	b	367	444
Remainder of Twp.			26.38	602	628	714	22	24	27
Leroy	35.12	100.00	35.12						
Webberville Village			0.27	b	346	664	b	1281	2459
Remainder of Twp.			34.85	254	1095	1121	7	31	32
Locke	36.03	61.47	22.15	197	767	720	9	35	33
Meridian	36.49	86.43	31.53	317	1405	19,343[c]	10	45	613[c]
Stockbridge	36.87	8.18	3.02	54	60	115	18	20	38
Vevay	36.08	2.25	0.81	18	23	35	22	29	44
Wheatfield	31.18	97.17	30.29						
Williamston City[d]			0.40	b	b	828	b	b	2069
Remainder of Twp.			29.89	224	857	872	7	28	29
White Oak	36.06	99.44	35.86	505	1020	994	14	28	28
Williamstown	30.12	79.25	23.87						
Williamston City[d]			0.67	b	1113	1386	b	1040	2069
Remainder of Twp.			23.20	311	725	1546	13	31	67

Livingston County									
Cohoctah	38.64	0.38	0.15	2	5	4	14	35	27
Conway	37.61	31.84	11.98	146	384	311	12	32	26
Handy	35.26	100.00	35.26						
Fowlerville Village			1.37	b	946	1674	b	691	1222
Remainder of Twp.			33.89	484	1023	1216	14	30	36
Howell	36.96	31.17	11.52	212	319	524	18	28	45
Iosco	35.39	100.00	35.39	645	908	705	18	26	20
Marion	37.68	50.02	18.85	442	509	870	23	27	46
Putnam	36.47	0.41	0.15	4	3	6	27	19	40
Unadilla	35.24	7.88	2.78	81	73	96	29	26	35
Shiawassee County									
Antrim	36.65	2.50	0.92	7	23	22	8	25	24
Perry	35.09	0.69	0.24	2	6	9	9	24	38

[a]The number of inhabitants in this small corner of Bunker Hill township is probably zero since no dwelling units are located in the segment (Rockford Map Publ. 1957). The land use is similar to the adjacent townships.

[b]Data for this unit are included in the appropriate township values since the unit is not recorded separately in the census for this date.

[c]Taken from the detailed analysis of Meridian township by census tracts.

[d]Partial values given since Williamston City lies in both Williamstown and Wheatfield townships.

Basic population data from U. S. Bureau of the Census (1853, 1901 and 1961).

Considering the existing culture, by 1900 the land was somewhat overpopulated. In the decade or two before and after 1900 most of the rural townships of the study basin reached a population maximum and then began to decline. The use of marginal farm land was reflected in farm abandonment and its eventual return to the state for nonfarm uses such as some of the land included in the Rose Lake Wildlife Experiment Station just north of the study basin in Bath Township.

The year 1900 was the more or less average time of the peak of rural population for the study basin. In 1900 the population of the study basin was mostly rural and is estimated to have been 13,063 with a population density of about 39 persons per square mile (Table 10).

Land and Water Use.--This rural population changed the landscape significantly in a variety of ways. Almost all of the upland forests were removed to allow farming and for the value of the timber. Only the inaccessible wet forests remained little changed (Bryant 1963). Partially unprotected soils and hard surfaces such as roads and roof tops were substituted for the trees and their litter. The soil itself was changed by exposing it to the weather and physically rearranging its structure. Organic matter and some minerals were reduced in quantity by the physical and chemical processes that resulted.

Water use increased for domestic and livestock purposes. Dams were built early at Okemos and Williamston. Some swamps and wetlands were drained. From these generalities it is not possible to determine the hydrologic budget for the study basin at this time, but it was not possible to find records that are needed for such an analysis.

During the early years of settlement of southern Lower Michigan, 1830-1850, there was agitation for a canal from Lake Huron or Lake St. Clair to Lake Michigan. Several preliminary plans and engineering plans were presented for the Clinton and Kalamazoo Canal; even a ground-breaking ceremony and celebration occurred at Mt. Clemens (Ingersoll 1882). However none of the plans was executed, in part, due to serious fiscal difficulties of the young state that caused funds for public works to become very scarce (Ellis 1880). Depending on the particular route proposed the Red Cedar or its tributaries would have become a part of the canal system (Blois 1838; Hunt 1839; E. Hurd 1839; J. Hurd 1839; Crittenden 1911).*

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*A similar proposal has been presented recently by U. S. Representative John C. Mackie of Flint. In the proposed Trans-Michigan Waterway, water would be taken from Lake Huron at Port Huron and channeled to Lake Michigan mainly using streams which are not highly polluted at the present (Baird 1966).

Modern Occupance

Population: Number and Trends.--Beginning about 1900 the nature of the occupance of the study basin changed considerably. During the previous period (1840-1900) the change was mainly quantitative, but since 1900 the change has been qualitative as well as quantitative.

The population growth curves for the state of Michigan, Ingham County and the study basin are given in Figure 22. Michigan was admitted as a state to the Union in 1837. The population has increased continuously since the first decennial census in 1840, and it is expected to continue to do so in the foreseeable future. The rate of increase diminished regularly until the 1910-1920 and 1920-1930 decades which show marked increases again. The Great Depression of the 1930's is reflected in the sharp decrease in the rate of growth during that decade. The 1940-1960 period had, and the 1960-1980 is expected to have, a fairly constant growth rate.

The population growth curve of the entire state is an average of extremely diverse regions. Demographers take this divergence into account by dividing the state into relatively homogeneous regions that reflect the highly urbanized southeast (metropolitan Detroit), the moderately urbanized southern Lower Michigan (mixed agricultural lands and metropolitan areas south of the Muskegon-Bay City line), and

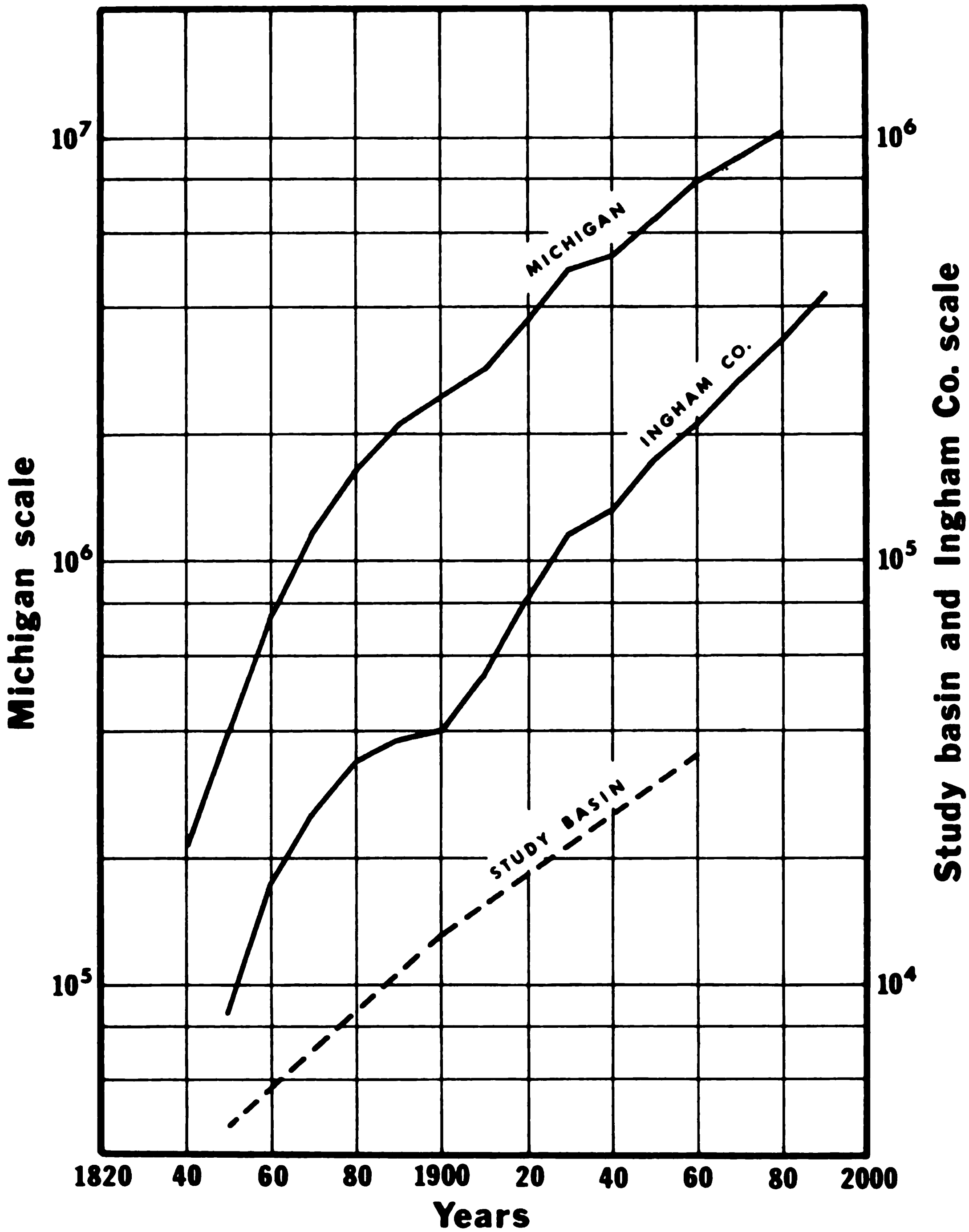

Figure 22. **Population growth curves for the state of Michigan, Ingham County and the study basin. Note the two vertical scales used. Basic data from U.S. Bureau of the Census (1853, 1901 and 1961), Michigan Dept. Public Health (1965) and Tri-County Reg. Plan. Comm. (1966).**

the very slightly urbanized north (northern Lower Michigan and all of the Upper Peninsula).

Because of the highly diverse regions of the state the overall growth curve for the state masks the regional population trends. The southern Lower Peninsula (including the metropolitan Detroit area) has accounted for most of the state's growth since 1900 (Mich. Dept. Pub. Health 1965). Moreover, within this region the metropolitan centers have accounted for most of the growth. Considering the population as either "rural" or "urban," the rural population was the larger from the time of statehood (96% in 1840) until about 1912 when each class contained 50% of the total population (Hawley 1949). Since then the urban population has increased its percentage until in 1965 the rural population was down to 28%, and the trend is expected to continue (Mich. Dept. Pub. Health 1965).

Another trend which is not evident in the overall state curve is the composition of the non-metropolitan population. Although there has been an absolute increase in the size of the rural population since 1900, the relative number of rural-farm residents compared with the rural-nonfarm residents has reversed. Since 1933 the rural-nonfarm has been the larger segment (Beegle and Thaden 1960).

The growth curve for Ingham County indicates more directly the growth pattern of a relatively small land unit. Its pattern is essentially the same as that of the state but with fewer of the masking effects that stem from averaging data from several widely diverse areas.

Although Ingham County was legally organized in 1829, there were few white men in the area until the mid-1830's (Fuller 1928). During the first several decades after settlement began the population growth rate was particularly great (Fig. 22). From 1880 to 1900 there was a marked decrease in the rate of growth. From 1900 through 1990 the increase in rate of growth has been, or is expected to be, moderately high but never at the same level that occurred during the first decades.

Several interrelated factors in the pattern of occupance may account for the variation in this growth curve. From 1850 to 1900 the curve resembles the upper part of the sigmoid portion of a growth curve of a biological population which has been introduced into a new, highly favorable environment. This period of rapid increase in population, the logarithmic phase, is often followed by a phase of dynamic equilibrium in which the population increase approximately equals the population decrease, i.e., the environment is sustaining a maximum number of organisms, the carrying capacity. Such relatively constant population level usually indicates a situation in which there is no basic change in either the environment or the requirements of the population. The Ingham County growth curve gives evidence of approaching a plateau as it tends to level off between 1880 and 1900.

This leveling-off phenomenon is more clearly illustrated if the population of the city of Lansing and the remainder of the county are considered separately. The non-Lansing population reached a maximum about 1880 and then declined slightly until about 1910. Thus the trend of the rural population was masked by the relatively rapid urban growth in the city of Lansing.

The sharp rise in the growth curve beginning in 1900 suggests another logarithmic phase. Essentially the white man's first occupance (before 1900) was self-sufficient, mainly based on the resources and energy available locally. The second form of occupance (after 1900) is not based mainly on the resources of Ingham County only, for both energy and material imports and exports are a vital aspect of this system.

During the late 1800's and the early 1900's in Ingham County, particular cultural changes were initiated which had, and continue to have, a marked effect on the requirements of the local human population. During this time the following innovations came to Ingham County: the municipal distribution of electricity for use in lighting and driving machinery; municipal water supplies dependent on deep wells; the internal combustion engine as the power source for automobiles and farm machines; and electric railways serving both intra- and interurban traffic. In general, these innovations were first used by the metropolitan area

(Lansing) and later were established in the rural parts of the county.

The advances in science and technology have become a part of the culture because of the population's willingness to utilize them. These cultural changes have allowed a corresponding change in the size of the population. In approximately 1904 the Lansing population exceeded the population of the rest of the county for the first time. Since then the population of Ingham County has been predominantly urban and suburban in character.

In summary, it appears that about 1900 Ingham County approached the carrying capacity for its human population considering the existing mode of occupance. About that time technological changes initiated overall changes which gave rise to a new type of occupance. The growth curve from 1900 to 1960, and projected to 1990, gives no indication of approaching an horizontal asymptote which would indicate a new carrying capacity is being approached. However, a decrease in the growth rate is apparent after 1930.

The growth curve for the study basin indicates only the general trend of population growth in the study basin (Fig. 22). Actually the pattern of growth in the study basin probably follows the pattern of growth in Ingham County except that the increased growth rate due to urbanization began at a later date since the study basin remained essentially rural until after World War II. By 1960 the estimated population of the study basin was 35,101 with a corresponding density of about 105 persons per square mile (Table 10).

Now that urbanization is occurring in the study basin its growth rate will assume more and more the nature of the dominant urban influence. Geographic Meridian township (in contradistinction to political Meridian Township) is receiving the major share of the urban-suburban residents migrating into the study basin. It is the only rapidly urbanizing area for which recent detailed population figures are available. What is currently happening there will probably happen in the adjacent townships later, depending on the pattern of urban growth in this portion of Ingham County.

That portion of the city of East Lansing lying within the study basin had a population of 7,276 in 1960 and a population of 8,111 in 1965 (Table 11). (As before these estimates are based on cutting and weighing.) The corresponding densities were 3,519 persons per square mile in 1960 and 3,923 persons per square mile in 1965. That portion of political Meridian Township lying within the study basin had a population of 12,067 in 1960 and a population of 13,604 in 1965 (Table 11). The corresponding densities were 408 and 460, respectively.

Population trends during the 1960-1965 period for the state, for the county and for the most populated segment

Table 11. Population of the Meridian township segment of the Red Cedar study basin for 1960 and 1965 by census tracts.

Census tract	Total area, $miles^2$	Area lying within the study basin		Population in the study basin segment			
				Number		Density (No. per $mile^2$)	
		% of total	$Miles^2$	1960	1965	1960	1965
East Lansing City							
EL 39	1.5248	30.96	0.4732	1048	1381	2215	2918
EL 42	0.4211	20.33	0.0856	1135	1135	13,259	13,259
EL 43	0.7451	90.06	0.6710	3304	3973	4924	5921
EL 44	3.7183	22.53	0.8377	1789	1622	2136	1936
Meridian Charter Twp.							
MT 45	1.5063	2.15	0.0324	28	31	864	957
MT 46	3.9127	84.74	3.3156	1993	2362	601	712
MT 47	3.5124	98.16	3.4478	1858	1922	539	557
MT 48	4.6369	99.40	4.6091	2600	2899	564	629
MT 49	6.1640	100.00	6.1640	4171	4943	677	802
MT 50	13.0546	91.78	11.9815	1417	1447	118	121

Basic data for 1960 and delineation of the census tracts from U. S. Bureau of the Census (1962). Basic data for the 1965 estimates from Tri-County Regional Planning Commission (1966).

of the study basin are given in Table 12. While the state had an increase of 7.2% during 1960-1965, Ingham County had an increase of 15.1%. The East Lansing-Meridian Township segment of the study basin had an increase of about 12% showint that it shared in the relatively large increase of the county. During 1960-1965 the state population increased at an average rate of 1.4% per year. The corresponding values for Ingham County and the East Lansing-Meridian Township study basin segment are 2.8% per year and 2.3% per year, respectively.

These comparisons show that the study basin is located in an area which during the last five years of record has had a growth rate considerably higher than that for the state as a whole. Within the study basin the Meridian Township segment experienced a slightly greater rate of growth than did the East Lansing segment.

By using the census tract data for East Lansing and Meridian Township and applying Ingham County township data (Tri-County Reg. Plan. Comm. 1966) for all other parts of the study basin an estimate of the 1965 population of the study basin was calculated to be 38,454. This gives an average 1960 to 1965 increase for the entire study basin of 9.6%.

Another way to view the population in the study basin is to consider the population density as determined from the most recent complete census data (1960). The pattern shown in Figure 23 is somewhat artificial; the true

Table 12. Population trends in Michigan, Ingham County and the study basin during 1960-1965.

Geographic unit	Population 1960[a]	Population 1965[b]	Percent of increase	Equivalent growth rate (% per year)
Michigan	7,823,000	8,387,000	7.2	1.4
Ingham County	211,296	243,100	15.1	2.8
<u>Study basin</u>				
Segment of political Meridian Township	12,067	13,604	12.7	2.4
Segment of East Lansing City	7,276	8,111	11.5	2.2

[a]U.S. Bureau of the Census (1961 and 1962).

[b]Michigan entry from Michigan Department of Public Health (1965). Others based on data from Tri-County Regional Planning Commission (1966).

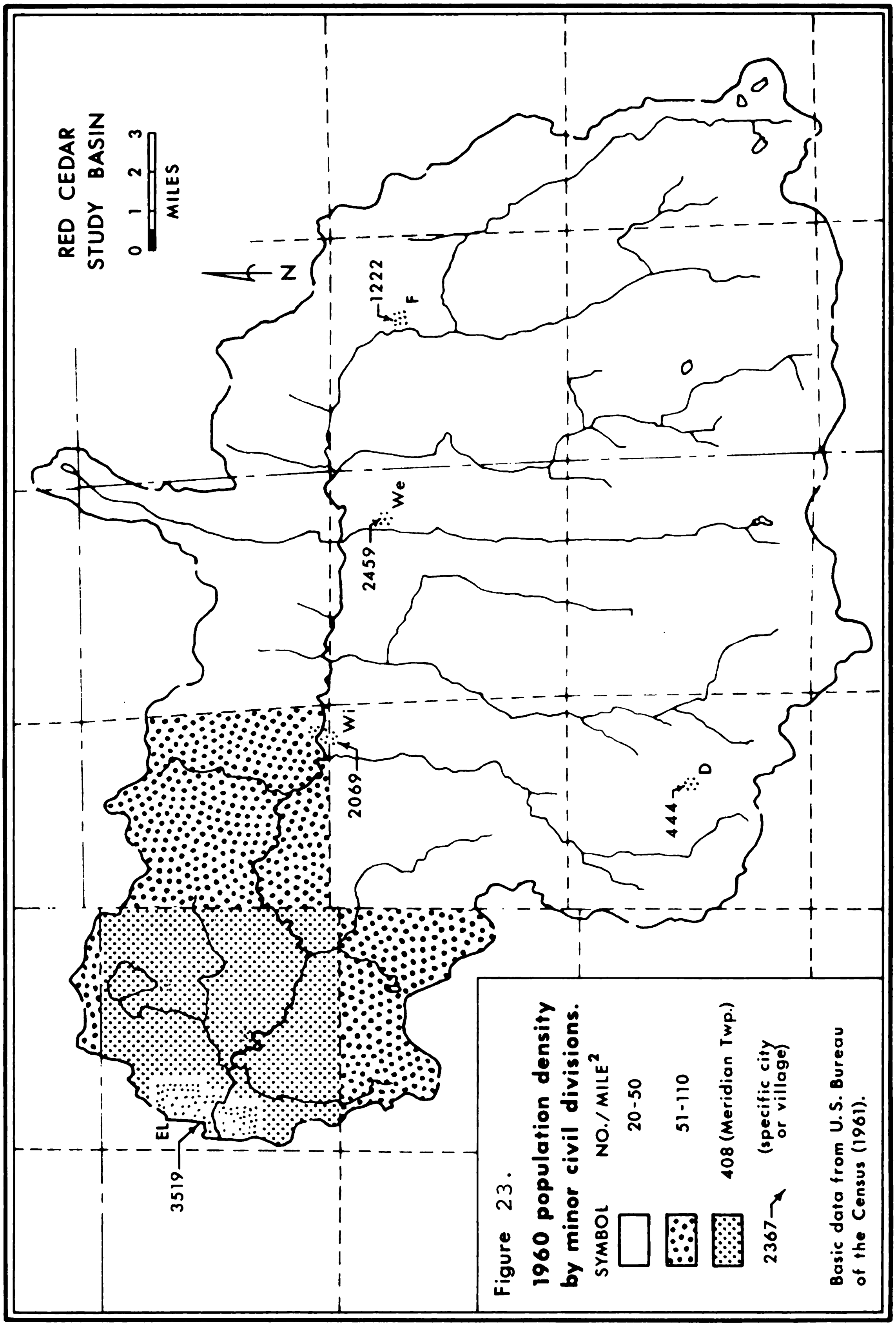

Figure 23.
1960 population density by minor civil divisions.

Basic data from U.S. Bureau of the Census (1961).

pattern would reflect the natural features and cultural features (especially the transportation net) of the land. Nonetheless the pattern shown does provide the overall trend. The East Lansing segment has the highest density with 3,519 persons per square mile. Williamston City and Webberville Village have moderately high values of 2,069 and 2,459, respectively. Fowlerville Village has a value of 1,222 and Dansville Village has a value of 444. With the exception of Webberville the cities and villages of the study basin can be arranged in a series of decreasing size in which the larger the population the greater is the population density.

The townships (exclusive of the villages and cities) that have relatively high proportions of rural farm residents have a population ranging from 20 to 46 persons per square mile (Fig. 23 and Table 10). All the townships of the study basin except those in the northwest quarter are in this class.

Four townships in the study basin had densities that show the result of the influx of rural-nonfarm residents. Three townships show moderately higher densities: Alaiedon with 57; Williamstown with 67; and Bath with 101. Meridian Township constitutes a class by itself with a density of 408 persons per square mile.

The overall pattern is one of high density in the urban area, low density in the rural area, with a gradational change in the zone between the extremes. Density appears to be a function of proximity to the urban center.

In summary, the study basin has experienced a large population increase during the last 150 years. During the Indian occupance the population totaled something less than 500 with a density of less than one person per square mile. During the muscle-powered early agricultural occupance the maximum population was about 13,000 with a density of 39. In the most recent urban and mechanical-powered agricultural occupance, by 1960 the population had grown to over 35,000 with a density of 105. Since 1900 the portion of the basin that has remained predominantly in agricultural production has experienced a nearly stable or slightly decreasing population. Since 1900 the portion of the basin that has had an influx of urban, suburban or rural-nonfarm residents has had, and is still experiencing, a high rate of growth. During 1960-1965 the main area of such change, the Meridian Township segment, experienced a growth of about 12% which is almost twice as large as the rate for the state as a whole. The adjacent townships are experiencing moderately high growth rates, others most likely will later depending on the pattern of population growth.

Water Use.--The amount of water used by humans, as individuals or as groups, is quite variable. For all classes of users the amount available may be limited by either physical or economic factors, or both. For nations and states geographic location, climate, recent weather, level of technology, and tradition help to determine the water use. As part of a state and a nation the individual is influenced, at least indirectly, by these group-influencing factors.

In addition the individual is influenced by several factors that only apply to individuals. In order to satisfy normal physiological needs a human requires somewhat more than two quarts of water per day (Anthony 1959). More than half of this requirement is met by drinking water or beverages. The remainder is derived from "solid foods" or is a product of normal metabolic processes. The minimum water intake required by an individual varies, especially reflecting the temperature and humidity of the environment and the amount of physical activity of the individual.

In considering the water used by units of population the amount used by a family dwelling is the smallest unit generally available. Water used in and around the home is called domestic use and is usually stated on a per capita basis. Domestic use includes all of the water used from the home water system, so in addition to the drinking water it includes cooking, laundering, bathing, lawn sprinkling, consumption by pets, etc. For the conterminous United States MacKichan and Kammerer (1961) estimated the 1960 domestic water use by state to range from 35 gpd (gallons per day) per person for the lowest state to 100 gpd per person for the highest state. Most states were estimated at 50 gpd per person. In the United States domestic water use per family dwelling appears to be positively correlated to several

socioeconomic factors such as education, occupation and income (Hansen and Hudson 1956; Dunn and Larson 1963).

The domestic water use does not truly represent the amount of water used to support the typical urban or suburban resident who is connected to a municipal water supply system. Part of the water produced by the system does not supply dwellings but is lost through leakage or is used by various industrial, commercial and governmental operations that are a part of the community. Considering all users of the municipal water supply the use in the conterminous United States average 151 gpd per person in 1960 (MacKichan and Kammerer 1961).

But even this rate of water use does not truly represent the water necessary to support one person in our present society. In addition to the municipal water, self-supplied business and industry, and rural uses (mainly irrigation) should be considered. For the conterminous United States the 1960 water use of all types except for water power uses was estimated to be about 1,500 gpd per person (MacKichan and Kammerer 1961). This was an increase of 62% over the per capita use in 1940, and an increase of 120% over the actual use in 1940 (Pavelis and Gertel 1963). Thus, not only is the demand for water rising because of the general increase in population, it is also rising because of greater per capita use. No significant change in this trend is projected in the foreseeable future (Picton 1960).

As used above "water use" refers to water which is taken from its natural place in the hydrologic cycle. This diversion of surface water or ground water constitutes the withdrawal uses. Other uses of water that do not require diversion are on-site or nonwithdrawal uses. The demand for nonwithdrawal uses include water-oriented recreation and sewage dilution both of which will probably increase at least as rapidly as the withdrawal uses.

In comparing Michigan with the nation the Michigan averages are near the national averages (MacKichan and Kammerer 1961). For domestic water use Michigan is approximately at the national average of 50 gpd per person. For municipal use Michigan is approximately at the national average of 153 gpd per person. However, in total water used excepting waterpower uses, Michigan used 870 gpd per person compared with the national average of 1,500 gpd per person. Although Michigan as a state is relatively very well endowed with natural waters it uses far less per capita than the nation.

Water use in the study basin in the past has been mainly rural domestic and related agricultural uses. Now in the villages and suburbanizing portion of the study basin water use is mainly domestic with a relatively small use by commerce and industry.

In order to determine the water use in the study basin for 1965, water use in domestic, business and agricultural use categories will be estimated. In the study basin as elsewhere domestic use varies considerably from household to household, season to season, and community to community. Here in southern Lower Michigan the variation is exemplified by comparing Holt using 50 gpd per person with Birmingham using about 150 gpd per person (Richmond 1963). In a river basin study in western New York state Bordne (1960) used 80 gpd per person as an estimate of domestic usage. The same value was suggested by Smith (1967) for use in the study basin. A value of 100 gpd per person is often currently used in planning water systems but this allows for an expected increase in water use during the useful life of the system.

The above estimates of water use are for homes which have running water. In the study basin virtually all of the new houses have running water either supplied by a public water system or private well. Nonetheless about 6% of the rural-farm and rural-nonfarm housing units do not have running water (U. S. Bur. Census 1963) and these on the average use only about 20% as much as the units with running water. Rather than adjust the overall estimate for this reduced use I assumed that the excess water use would be an estimate of the water use of the relatively few business places located in the study basin (Mich. Water Res. Comm. 1961).

The value of 80 gpd per person was used to estimate domestic water use in the study basin. As given in the section on population the 1965 population of the study basin is estimated to be 38,454. Thus the domestic water use for the entire study basin is estimated to be 3,076,320 gpd. This estimate includes urban, suburban, rural-nonfarm and rural-farm domestic water use, and the relatively small business use. The 3,076,320 gpd is equivalent to 4.76 cfs or 0.192 inches of water over the entire study basin per year.

In order to determine the water used for agricultural stock watering I used the 1964 United States Census of Agriculture (U. S. Bur. Census 1966a & 1966b) as the basis to estimate the number and kind of livestock present in the study basin. Since the smallest units reported were counties I assumed that the mean animal population density for the county would apply to that segment of the study basin lying in each county.

The small segments of the study basin lying in Bath Township (Clinton County) and Perry Township (Shiawassee County), totaling less than two square miles, were included as a part of the Ingham County segment of the study basin. This segment equals 220.7 square miles, or 39.5% of Ingham County. The small segment of the study basin lying in Antrim Township (Shiawassee County), equaling less than one square mile, was included as a part of the Livingston County segment of the study basin. This segment equals 115.1 square miles, or 20.2% of Livingston County.

The types of livestock and their water needs are given in Table 13. The total livestock watering use in the Ingham County segment of the study basin is estimated to average 427,338 gpd which is equivalent to 0.041 inches of water per year over this segment. The total livestock watering use in the Livingston County segment of the study basin is estimated to average 166,898 gpd which is equivalent to 0.031 inches of water per year over this segment. The weighted average for the entire study basin is 0.036 inches of water per year.

An accurate estimate of annual water use for irrigation in the study basin is especially difficult to obtain due to the wide year to year variation and the lack of records. Irrigation uses on homesites and business sites (i.e., lawn sprinkling and garden watering) are included in the domestic water use given above.

Irrigation as a user class refers to operations which have an irrigation system mainly for application of water to agricultural crops or golf course turfs. Although the study basin is located in the Humid East, supplemental irrigation of some crops and turf is becoming standard practice to meet demands for high quality products and to avoid the economic disaster of a very dry season. Public records of irrigation water use are meager. The 1964 U. S.

Table 13. Livestock water use in the Red Cedar study basin by county segments.

Livestock	Water use in gpd per head[a]	Ingham County: Number in entire county[b]	Ingham County: Study basin segment: Number in segment	Ingham County: Study basin segment: Water use gpd	Livingston County: Number in entire county[b]	Livingston County: Study basin segment: Number in segment	Livingston County: Study basin segment: Water use gpd
Milk cows	40	15,311	6,045	241,800	12,810	2,581	103,240
Other cattle	12	28,101	11,094	133,128	21,186	4,269	51,228
Hogs	4	23,153	9,141	36,564	5,535	1,115	4,460
Sheep	3	12,246	4,835	14,505	12,240	2,466	7,398
Chickens	0.04	84,267	33,269	1,331	70,816	14,269	571
Turkeys	0.06	415	164	10	41	8	1
TOTAL				427,338			166,898

[a]Gallons per day per head, mainly after Bordne (1960).

[b]From the U.S. Bureau of the Census (1966a & 1966b).

Census of Agriculture (U. S. Bur. Census 1966a & 1966b) reports fewer acres of irrigated farmland for Ingham and Livingston counties combined than the Michigan Water Resources Commission (1961) reported for the Red Cedar basin only.

In order to estimate the irrigation water use in the study basin I assumed that the study basin used an amount proportional to its area (74% of the entire Red Cedar basin) and that a 10% increase had occurred since the Michigan Water Resource Commission's survey taken in 1957-1958 and 1960 that was reported in 1961. The estimate for 1965 is 625 acres of irrigated land in the study basin.

In order to estimate the water used in irrigation it is necessary to estimate the rate of water use on the irrigated land. This is not possible with a high degree of precision since local irrigation is mainly supplemental and has an irregular, inverse relationship to precipitation which itself is not uniform. As a rough approximation, irrigation water may be applied at a rate of one to two inches per week for anywhere from zero to ten or more weeks per season. An estimate of 1.5 inches per week for five weeks was used which leads to an estimate of 4,688 acre-inches of irrigation water used per year in the study basin. This is equivalent to 348,761 gpd or 0.022 inches of water over the entire study basin per year.

Considering all uses the average water use for the study basin is 0.250 inches per year which seems quite small when compared to the average precipitation of 30.78 inches per year. Although these averages are useful to give the overall relationships they obscure some of the details. For example, in residential communities the heaviest water use occurs during the summer when lawn sprinkling and air conditioning may cause daily demands on the local system several times greater than the average daily use. Irrigation demands are concentrated also during the summer months. Since the peak demand for withdrawal uses occurs during the period when natural waters generally are least available even relatively small needs may be impossible to satisfy without conflicting with other needs.

For example, if we assume that one half of the study basin's irrigated acreage uses surface water as a source and that during a long drought it is desirable to apply two inches of water per week on these acres, the daily water use would be 2,424,464 gallons or 3.75 cfs. For comparison, the record minimum daily low flow for the Red Cedar at Farm Lane was 3 cfs (USGS 1964). During the 1931-1960 base period the Farm Lane station recorded less than 9.6 cfs for 1% of the time and less than 28 cfs for 10% of the time (see section on frequency distribution of runoff). Thus several large-scale irrigators using a surface water source could significantly affect the streamflow of the study basin.

The legality of such influence is questionable under the local riparian doctrine and explains, in part, why the trend in irrigation water source is to ground water. When recreational uses, esthetic values, sewage dilution needs, fish and wildlife needs (i.e., the on-site uses) are also considered, the relatively small requirements of each category are in conflict with the others during summer drought periods when demand is at its peak.

Land Use.--Clearly the most dramatic land use change in the Red Cedar study basin was the deforestation by the early agriculturally oriented settlers. Nonetheless, since then the demands of the evolving society in the study basin have continuously modified the land uses of the basin.

As mentioned previously the agricultural land of the study basin was fully settled by about 1900. Since that time there has been no further increase in the amount of farm land, rather there has been a gradual reduction of land used for agriculture. This trend still continues. In 1959, 79% of Ingham County was in farms and in 1964, 72% was in farms; the corresponding values for Livingston County are 63% in 1959 and 58% in 1964 (U. S. Bur. Census 1966a & 1966b).

In the study basin the land that is shifting out of agriculture is becoming idle or is being used for urban sprawl or highway construction. Moore (1953) studied the effects of suburbanization on land use in the Lansing rural-urban fringe. He found that as the rural-nonfarm residents and the part-time farmers increased in number the amount of idle land increased and that the agricultural land use

tended to shift to more small grain and row crops with corresponding decreasing numbers of livestock. Jensen (1958) also noted the increase in idle land in the fringe of the Lansing area, and he estimated that the Lansing area had doubled in size during the 1940-1955 period.

Barlowe (no date) states that in rural Michigan the shift from farm land to urban sprawl, forest, parks and throughways will reduce the amount of farm land by 20% during the period 1964-1980. Philbrick (1961 & 1963) recorded this kind of change in rural areas of southern Lower Michigan by a land use survey that utilized quarter sections of land as the smallest mapping unit. His concept of the Dispersed City of Lansing indicates that significant amounts of the non-farm land uses associated with the metropolitan area extend eastward in the study basin to include Williamstown and Wheatfield Townships. In this way the rural-nonfarm activities are shown to extend far beyond the corporate city limits and beyond the area usually designated as the rural-urban fringe. The Disperse City of Lansing roughly coincides with the population density class 51-110 persons per square mile that was previously noted in the section on study basin population.

About 54% of the land area of the entire state of Michigan is in woodland (Barlowe, no date). Ingham County had about 12% of its total land area in woodland according to the recent land use report of the Tri-County Regional

Planning Commission (1966b). For the rural townships in the Ingham County portion of the study basin (with a population density of 20-50 persons per square mile) the percent in woodland is 10% to 20%. This agrees with the woodland acreage reported by Horton (1908) for Ingham County in about 1900. For the townships in the 51-110 population density class the woodland value is 13% to 14%; for Meridian Township the value is 19%; and for the East Lansing City segment of the study basin the value is 3%. Thus from virtually a 100% forest cover portions of the study basin have shifted to a forest cover of 3% to about 20%.

Highway and street rights of way as a land use class equals about 4% of Ingham County (Tri-County Reg. Plan Comm. 1966b). In the study basin the typical rural townships have about 2.5% of their land in this use. The rural townships that have the Interstate 96, limited access expressway crossing them have about 3% to 4% of their land in the right-of-way land use. The Meridian Township segment of the study basin has about 4.5% in right of way land use reflecting the greater frequency subdivision streets. The East Lansing segment of the study basin has about 17% in right-of-way reflecting the more complete urbanization of this segment.

When the first settlers began to farm the land of the study basin the poorly drained sites were avoided. In time, man-made surface and subsurface drainage (tiling) was used to decrease the moisture in some soils, particularly in order to get into the field in the spring. Horton (1908) reported that by about 1900 the Red Cedar study basin had 20% to 30% of its land area tributary to artificial drains. Many segments of study basin streams have been altered by being extended, straightened or cleaned out, sometimes more than once. Since such drainage work is initiated and paid for by the citizens of the drainage districts, flurries of drainage work coincide with periods of wet years (Graham 1964). Each highway, road and street alters the natural drainage pattern to some extent with its right of way surface drain or storm drain system. Road maps, drain maps and records (in the county drain office), and graphic presentations (e.g., Mich. Water Res. Comm. 1961) indicate a large portion of the study basin is now influenced by artificial surface drainage.

With the demand for more quality and quantity per unit of land in agricultural production, tiling of farm fields has become a wide-spread practice in the study basin. Considering the present circumstances the overall effectiveness of the surface and subsurface man-made drainage is impossible to determine due to lack of records and the continually changing efficiencies of drainage works due to plant growth and siltation in the surface waterways, and siltation, misalignment and deterioration of tile systems. Thus the present state of knowledge regarding the influence of artificial drainage on the hydrology of the study basin prohibits generalizations in terms of the overall effects of drainage on the water budget. The state of the art is exemplified in the study of the Upper Grand River basin by the Michigan Water Resources Commission (1961) which contains this statement: "The effect of artificial drainage upon flooding is obscure."

Land use activities often allow organic and inorganic materials to be washed into waterways by rain and surface runoff. Agricultural land use practices allow mineral solids, fertilizer, pesticides and bacteria to be washed into streams. Construction of buildings and highways allow solid mineral matter to be washed into streams. Keller (1962) reports a six-fold increase in stream sediment load in an urbanizing area in Maryland. Guy and Ferguson (1962) report more than a one-hundred-fold increase in such an area near Washington, D. C. King and Ball (no date) report large increases in stream sedimentation during expressway construction in the study basin during the early 1960's.

Geographic Name of the River

Through time the main stream of the study basin has been referred to by several different terms, but mainly, "Cedar River" and "Red Cedar River." I have tried to trace the origin of the name and the common and official usage.

In addition to the usual vagaries of the usage of place names through time, streams may be called different names at the same time by persons associated with it at different geographic locations. Regarding place names in Ingham County, Foster (1942) reported that he found it not uncommon for a stream at the same point in time to be designated by three different names depending on the place of residence (headwaters, mid-section or mouth) of the user. For the main stream of the study basin I found present usage, both verbal and in print, to be limited to either "Cedar River" or "Red Cedar River."

Early Usage.--In the original land survey notes of 1824, Joseph Wampler, the surveyor, used "Misticen" which may have been an English version of an Indian word (Foster 1942). Ellis (1880) reported that "Iosco" was the Chippewa Indian name used for one of the main branches of the river in what is now Iosco Township, Livingston County. Neither of these names were used widely either officially or unofficially.

Two historical sources state that the name "Red Cedar" originated from red cedar trees which grew in the vicinity of the river (Fuller 1928; Foster 1942). Two other sources refer to a grist mill called the "Red Cedar Mill" that was built in 1842 at the dam site at Okemos (Durant 1880; Adams 1923). According to a local professional forester (Arend 1965) it is possible that clumps of red cedar grew in openings along the banks of the river. Thus the names which have been most widely used, "Cedar" and "Red Cedar," may have originated with early residents and their

recognition of a local tree species. (Pine Lake which is now Lake Lansing probably received its name in the same way.)

A sample of the terminology used in some early references is given in Table 14. Although this sample is not complete it does show the mixed usage during roughly the first half of the white man's occupance of the study basin. The first two entries in Table 14 are nongovernmental and use "Red Cedar." The third entry is governmental (the state topographer's report to the first state geologist, Douglass Houghton), and it uses "Red Cedar." But another report in the same series (C. C. Douglass to Houghton) used "Cedar River." Yet another report in the same series (Hubbard to Houghton) uses "Red Cedar River." As the entries in Table 14 illustrate, through the early years the usage by both governmental and nongovernmental sources is divided between the two terms, but the earliest usage in both sectors was "Red Cedar River."

Recent Usage.--During the more recent half of the white man's occupance I found that the frequency of usage in both governmental and private sectors favor "Red Cedar River." During my ten years of residence in the Lansing-East Lansing area I have found that local laymen use "Red Cedar" almost exclusively. All the public media reflect this use, as do place names such as Red Cedar Road, Red Cedar School, Red Cedar Golf Course and Red Cedar Woodlot. This usage is also that of a local commercial map maker (Dreher's 1961), the

Table 14. Terminology used by some early works referring to the main stream of the study basin.

Date, title and author[a]	Term used: "Cedar River"	Term used: "Red Cedar River"
1835. The tourist's pocket map of Michigan, J. H. Young.		X
1838. Gazetteer of the State of Michigan, John T. Blois.		X
1839. A geological survey report, S. W. Higgins. In G. N. Fuller (1928a), Geological reports of Douglass Houghton. (Higgins was the topographer for the state.)		X
1839. A geological survey report, C. C. Douglass. In G. N. Fuller (1928a), Geological reports of Douglass Houghton. (Douglass was an assistant geologist for the state.)	X	
1839. Report on the Cedar and Grand River branch of the Clinton and Kalamazoo Canal, Jarvis Hurd. In Documents of the House (of Michigan).	X	
1841. A geological survey report, B. Hubbard. In G. N. Fuller (1928a), Geological reports of Douglass Houghton. (Hubbard was an assistant geologist for the state.)		X
1844. Map of the state of Michigan and the surrounding country, John Farmer.		X
1861. First biennial report of the progress of the Geological Survey of Michigan.		X
1874. County atlas of Ingham Michigan, F. W. Beers.	X	
1874. Ingham County News, I. H. Kilbourne. In F. L. Adams, Pioneer history of Ingham County. (Used both in the same article.)	X	X

Table 14. Continued

Date, title and author[a]	Term used: "Cedar River"	Term used: "Red Cedar River"
1880. History of Ingham and Eaton counties, Michigan; Samuel W. Durant. (Used "Red Cedar Mill" for mill at Okemos.)	X	
1880. History of Livingston County, Michigan; Franklin Ellis.	X	
1884. The Cedar River state swampland improvement, Mich. Dept. Conservation.	X	
Late 1800's (?) Map of the drainage basin of Grand River Michigan (no author given). (Map not dated. Received as gift by Grand Rapids Public Library in 1912. Contains the notation "Agrl. College" [now MSU] which was founded in 1855.)		X
1903-1907, 1910 & 1912. Water-Supply Papers, nos. 83, 97, 129, 170, 206, 244 & 284; USGS.		X
1907, 1908, 1910 & 1911. Topographic maps for Howell, Fowlerville, Lansing and Mason: USGS. (These are still used in 1967.)	X	
1923. Pioneer history of Ingham County, (Mrs.) Franc L. Adams. (Used "Red Cedar Mill" for mill at Okemos.)	X	
1928. Historic Michigan, Ingham County; George N. Fuller. (Used both.)	X	X
1931. Michigan lakes and streams directory, Magazine of Mich. Co.		
Ingham Co. entry		X
Livingston Co. entry (Also used "Cedar Creek.")	X	

[a]Full bibliographic citations given in the list of references.

Automobile Club of Michigan (1961), and the 4-H sponsored Ingham County Plat Book (Rockford Map Publ. 1957).

From my contacts with residents of the study basin beyond the metropolitan area, I found that both terms were used, sometimes by the same individual during the same conversation. Also, the Livingston County Plat Book (Rockford Map Publ. 1958) uses "Cedar River."

Local or locally oriented governmental agencies or quasi-governmental agencies use "Red Cedar" for the most part. For example, the Road Map of Ingham County by the Ingham County Road Commission (1958), the Campus Map by Michigan State University (1965), various maps and text by Professor Humphrys (1964) of Michigan State University, and various maps and text by the Tri-County Regional Planning Commission (no date & 1963). However, the Livingston County Road Map by the Livingston County Road Commission (1959) uses "Cedar River."

State-level, governmental agencies have used both terms. The Michigan Department of Conservation publishes a widely used series of county maps that have an approximate scale of 0.4 inches equal to one mile. Both the old series (before about 1960) and the new series (from about 1960 to date) use "Red Cedar" on the Ingham County map and "Cedar River" on the Livingston County map. The Michigan Highway Department uses both terms in the same way in their series of county maps. "Red Cedar" is used in the <u>Outline of</u>

Geologic History of Ingham County (Mich. Dept. Conserv. 1958) and "Cedar River" is used on the map of surface formations of Southern Michigan (Mich. Dept. Conserv. 1955). The Michigan Water Resources Commission (1961) uses both terms in their study of the Upper Grand River Basin.

At the federal, governmental agency level once again the usage is mixed. The U. S. Army Engineers (1963) use "Red Cedar" in its study of the Grand River basin. The U. S. Weather Bureau (1913-1930) used "Red Cedar River" in the first third of the series, Daily River Stages, and "Cedar River" in the last two-thirds. The U. S. Geological Survey used "Cedar River" on the original topographic quadrangle sheets covering the study basin (1907, 1908, 1910 & 1911) which are still the most recent issue. The Survey originally used "Red Cedar River" to report stream gaging in its Water-Supply Paper series (1903-1907, 1910 & 1912), but when the Farm Lane bridge station was reported in the same series "Cedar River" was used (various dates from 1933 through the present). When Mr. Berkeley Johnson submitted his report regarding the establishment of the new station in March 1931 he used "Red Cedar at East Lansing." Later he received a memorandum in the form of a letter from the Washington office of the Survey stating that the official designation would be changed to "Cedar River at East Lansing" since the topographic maps and the base map of Michigan used that term (USGS 1931).

In summary, in both the early and recent history of the study basin the use of terminology has been variable. The fact that the residents of the watershed have used both terms simultaneously is reflected in print from both governmental and private sources. Even within a single source, sometimes within the same series of publications, occasionally within a single publication, and in one case on a single map, both terms have been used at different locations or at different times, or both.

CHAPTER VII

SUMMARY, CONCLUSIONS AND DISCUSSION

Summary.--Selected physical and cultural characteristics of a small drainage basin, the Red Cedar study basin, were studied. This watershed is the major portion of one of the tributary basins of the Grand River basin of south central Lower Michigan. The topography of the study basin is typical of many other small watersheds of the glaciated North Central States. A detailed attempt was made to delineate the watershed divide which bounds the study basin and subsequently the drainage area was determined to be 335.8 square miles.

Only a few lakes occur in the study basin. The pattern of the stream drainage net is a combination of the rectangular and dendritic types reflecting the most recent continental glaciation of the area. By using the modified version of Horton's stream order system the study basin was determined to be a fourth order basin. The long profile of the main stream, the Red Cedar River, was of the usual concave-up type with the lower nine-tenths of the river having an average gradient of only 1.8 feet per river mile.

The history of stream gaging in the study basin on the main stream and on the tributaries was followed. The main records are found in the Water-Supply Paper series of the U. S. Geological Survey, but minor additions are found in U. S. Weather Bureau publications, in Michigan State University theses, and in open-file reports of the Lansing office of the U. S. Geological Survey.

By using a soil type-forest type correlation method the presettlement vegetation was determined to be essentially one of complete forest cover. Approximately 76% of the study basin was in upland forest types (mainly the climatic climax, beech-maple) and approximately 23% was in the lowland forest types with less than 1% covered with water or otherwise treeless.

The hydrologic cycle was presented in general terms and then the main variables were quantified as they are found in the study basin. The study basin lies in the humid mesothermal climate type. The long-term temperature and precipitation norms were considered and the base period, 1931-1960, was selected to allow comparisons with other hydrologic variables. All available precipitation records for the base period were inspected. After several methods were considered, annual precipitation for the study basin was calculated by taking the arithmetic mean of all pertinent weather station records. The average annual precipitation for the base period was 30.78 inches. By using the inflow-outflow method and the Thornthwaite method, evapotranspiration during the base period was determined to be approximately 23 inches of water per year or about 73% of the annual precipitation. From June through September evapotranspiration exceeds precipitation and a moisture deficit occurs.

Runoff from the study basin during the base period was analyzed in several ways: 1) hydrograph comparisons; 2) comparison to study basin precipitation; 3) comparison to regional runoff; 4) frequency distribution analysis; 5) flow-duration curve; and, 6) double-mass curves with four other drainage basins. The Red Cedar is a highly variable stream with occasional very low flows. No evidence was detected to indicate that the known variables in mean annual runoff cannot be accounted for as the consequence of natural variation in the other hydrologic variables, particularly precipitation.

The piezometric surface of the bedrock aquifer of the northwestern portion of the study basin is part of the composite cone of depression created by the metropolitan area adjacent to and encroaching into the study basin.

The presettlement Potawatomi-Indian occupance was based on hunting, fishing, and food-gathering and a little maize agriculture. The population density was probably less than one person per square mile. This culture altered the natural ecosystem of the study basin only slightly.

From the mid-1830's to about 1900 the agriculturally oriented occupance of the early white settlers was dominant. Population increased rapidly so that by 1850 the study basin had a population density of approximately 14 persons per square mile. By 1900 the density was approximately 39 persons per square mile. Dramatic changes occurred in both land and water use. Most of the forest was cut except for the inaccessible swamp type and drainage projects were begun. Lack of records prevents precise understanding of the affect on the waters of the study basin.

Modern occupance of the study basin is a mixture of urban, suburban and agricultural types. Population continued to increase until in 1960 the overall population density of the study basin was 105 persons per square mile. In the urban segment the density was 3,519 and in the most suburban township it was 408. In the more rural townships the density was between 20 and 50 persons per square mile.

All water uses combined are estimated to be equivalent to 0.25 inches of water over the entire study basin per year. Highest water demands occur during the summer months when the water supply is at its seasonal low. Drainage projects are widespread since they are associated with roads, streets and agricultural land use.

The origin and usage of the geographic name of the main stream of the study basin were traced from the notes of the original land survey to the present. "Red Cedar River" is the most common term.

Conclusions and Discussion.--Considering the history of man, in only a short time a slowly evolving ecosystem, the study basin, has become a relatively rapidly changing, man-dominated system that has been altered in a variety of both obvious and subtle ways. Historically, few official or unofficial records have been made of the water resource of the study basin, yet the study basin has more records than most other similar drainage basins of southern Lower Michigan. The lack of records prevents a thorough understanding of the nature of the changes among the variables of the hydrologic cycle which have accompanied the changes in land and water use. This inability to quantify the nature of the changes does not diminish their importance in terms of the utility of the waters of the study basin.

This study has several implications regarding water use in the study basin. More basic data needs to be collected for both physical and cultural phenomena to allow a better understanding of the complex man-resource relationship. These data should be continuous through time. They should be recorded and stored in the smallest, feasible units in order to allow the greatest flexibility attainable for various kinds of analyses both at the present and in the future. Rapid, accurate, flexible retrieval is essential to allow articulation in the design and execution of interdisciplinary studies. The problem of information retrieval is critical when studying a natural unit such as the study

basin which is only 336 square miles in size but lies in parts of 32 governmental units below the state and federal level.

Even at the present population density the natural waters of the study basin are not sufficient to supply all needs at all times. Water-use decisions should be purposefully made with long-range goals in mind, not simply ignored until a crisis-level problem demands a sudden, short-range solution. Water-use decisions for a small watershed should be made with an awareness of their implications for regional river basin planning and in the context of other natural resource decisions.

Water-use decisions should include both cultural and physical considerations. If a human community does in fact operate according to general ecological principles (as assumed at the outset), the environment sets the overall limitations within which cultural principles are necessarily limited even though they may be by their nature more easily quantified. Thus, physical explanations and esthetic considerations should not be less influential in water-use decisions than more quantified economic and other social factors. Recognition of the evolving nature of physical explanations, cultural theories, and human desires warrants attempting to make water-use plans as flexible as short-range necessities will allow.

Since tax-paying citizens are directly or indirectly influential in resource-use decisions in our society, they should be aware of the resource situation. Lack of understanding and interest are reflected in our past use of natural waters as expressed by Stewart Udall, Secretary of the Interior (1965): "Water is the conservation scandal of our generation. . . . From the Hudson to the Great Lakes to the Colorado most of our water crises are man-caused. It is not that existing, finite supplies aren't, in most areas, adequate. It's rather a case of infinitely poor management of these supplies." Formal and informal teaching for environmental awareness is particularly necessary now that most of the population are urban and have little opportunity to understand the nature of their place in the ecosystem.

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RED CEDAR RIVER WATERSHED

FROM FARM LANE BRIDGE UPSTREAM

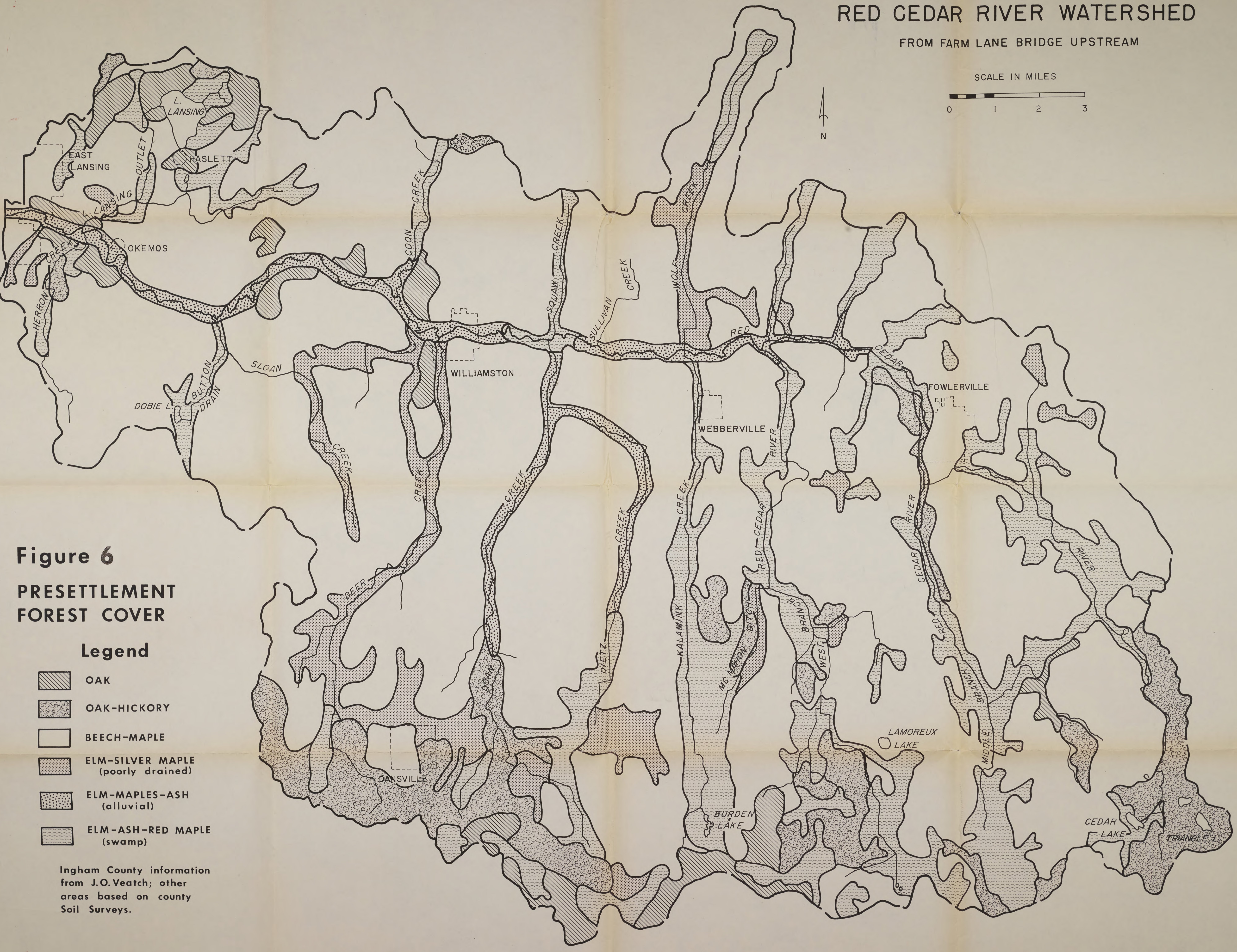

Figure 6

PRESETTLEMENT FOREST COVER

Legend

- OAK
- OAK-HICKORY
- BEECH-MAPLE
- ELM-SILVER MAPLE (poorly drained)
- ELM-MAPLES-ASH (alluvial)
- ELM-ASH-RED MAPLE (swamp)

Ingham County information from J.O. Veatch; other areas based on county Soil Surveys.

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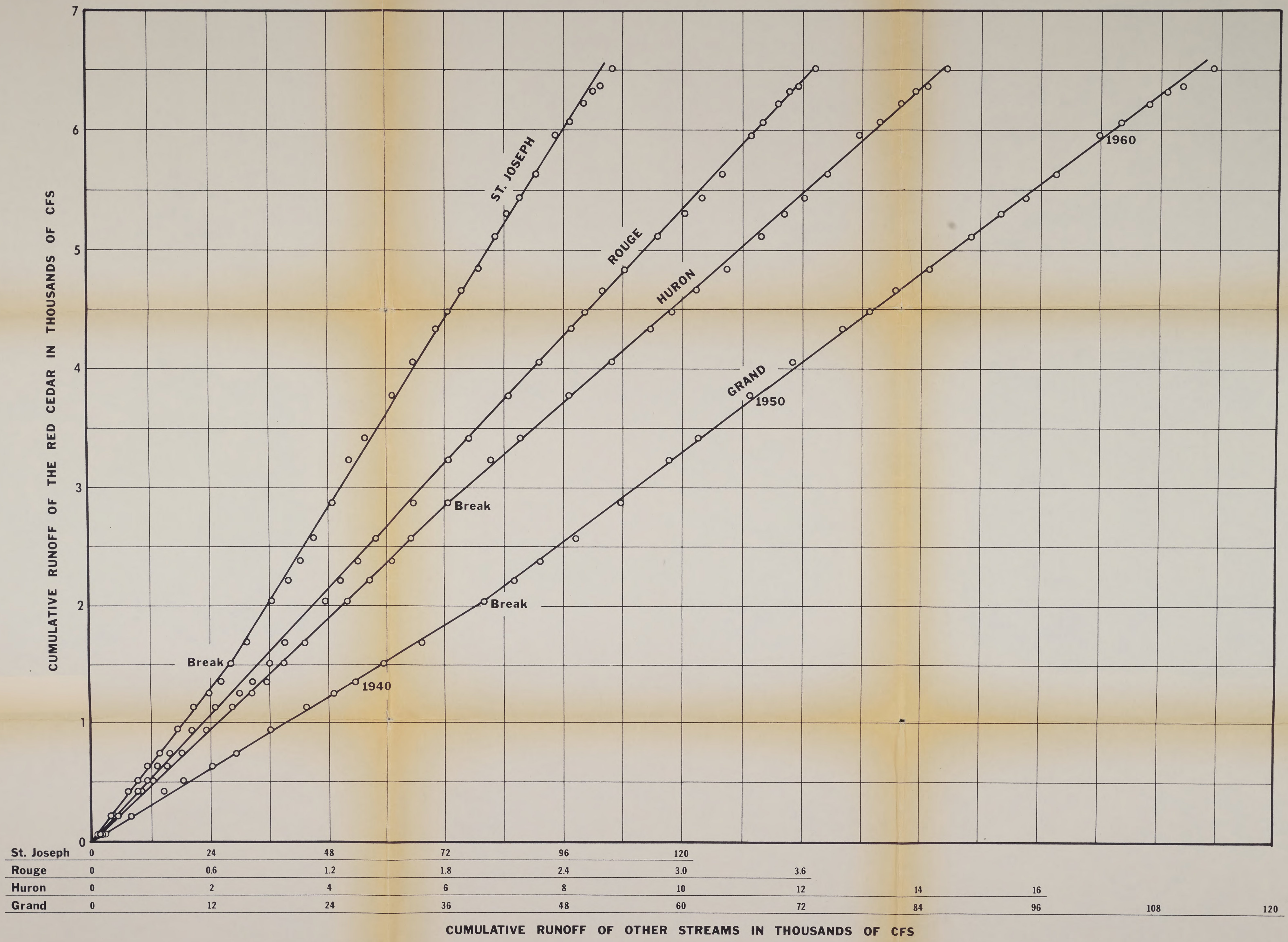

Figure 20. DOUBLE-MASS CURVES.
Basic data from USGS.

H. K. STEVENS

Pocket has: Fig. 2, Fig. 6, Fig. 20

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Legend

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CITY OR TOWN LIMITS, OR VILLAGE CENTER

STUDY BASIN DIVIDE

MODIFICATION OF DIVID

DIVIDES OF SLOAN AND DEER CREEKS

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