A RIVER LOW FLOW PROJECTION METHOD USING THE UPPER GRAND RIVER BASIN AS AN ANALYTICAL MODEL

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ABSTRACT

A RIVER LOW FLOW PROJECTION METHOD
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by Eckhart Dersch

The purpose of this study was to determine the compatibility of future Upper Grand River water supply with anticipated demand. Certain of the primary forces that influence supply and demand were discussed and projections concerning their probable future condition were made. Of greatest concern were the agricultural land use changes and soil conditioning measures and the urban land use trends which essentially accelerated the runoff cycle in such a way that the coefficient of runoff increased and the summer low flows became even more critical. The projections revealed that 4 percent of the land would go out of cropland, forest and woodland, and pasture and range use, that 5 percent of the land should experience drainage project action, and that 11 percent of the land above Lansing would become urbanized.

Low flow requirements were expressed in terms of minimum flow requirements at Jackson and Lansing to properly meet the demands imposed by sewage plant effluent. Both cities are in need of additional flow. In 15 years Jackson will require an additional 19.8 cfs during low flow and Lansing will require 408 cfs during this critical period if the oxidizable nitrogen content of effluent remains at the present high level. The future supply was expressed in terms of percentage change in flow re-

sulting from agricultural and urban land use change. The dichotomous result, that flow requirement or demand will increase as minimum flow decreases, was made apparent.

The study revealed that the government agencies responsible for or in some way in control of these flow modification forces, are not totally aware of the influence their works will have on runoff and the consequential minimum flow of the Grand River. The Michigan Water Resources Commission on the one hand operates to improve the water quality, while the local governments and the SCS are altering flow in such a way that low flows will become even more critical. Although this trend is the major finding, certain methods are still available for increasing flow or decreasing the present flow requirement. These take the form of flow augmentation reservoirs or the inclusion of tertiary sewage treatment.

The study revealed furthermore that the projected agricultural land use change, based upon information from the Soil Conservation Service's Soil and Water Conservation Needs Inventory, and its 2 percent sample, induced an inaccuracy variable of greater magnitude than that which a land use change could possibly induce. This reflects the importance of and the need for more accurate information upon which to base water supply projections and the resultant change in runoff and river flow. Further research is required for determining the quantitative runoff result of agricultural land use change, particularly that of artificial drainage, and for designing an economically operative tertiary sewage treatment method.

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CHAPTER I

INTRODUCTION

Need for the Study

The present concern over water supply represents the contemporary manifestation in our economy of water's growing role as an essential and critical basic resource. Water of the desired quality and quantity is not available in unlimited amounts at all times and places. Consequently, the need arises for planning within this vast realm of water availability and use. A water supply projection method provides one basis upon which to design an overall approach to the problem of integrating future water supply with anticipated demand for water.

The Select Committee on National Water Resources, under the chairmanship of Senator Robert S. Kerr, released a report in 1960, which uses the basic projections and information furnished by Federal agencies to develop tentative balance sheets on water supply and demand for each of the twenty-two regions into which the contiguous parts of the United States were divided.[1] This report makes clear the relationship of time to the growing quality and quantity of water problems. General, but nevertheless realistic, statements such as these serve to stimulate an awareness of the need for water supply studies.

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[1]Select Committee on National Water Resources, Water Resources Activities in the United States, Water Supply and Demand, Pursuant to Senate Resolution 48, Committee Print No. 32 (Washington: U. S. Government Printing Office, August 1960).

A knowledge of the physical supply or availability of water is necessarily a primary ingredient in the detailed watershed analyses which will soon be of prominant importance in our economy. A quantitative water supply figure based on the absolute yield of water possible from the hydrologic cycle as it operates within a watershed, defines the limit of water available under prevailing and anticipated conditions. It is within this limit that water-related planning must proceed.

The need for a study of this nature, therefore, becomes apparent. A knowledge of absolute water supply is essential for anticipating water planning requirements for the increased productivity and growth of the region. This is particularly important in light of the fact that both per capita demand for water and the population itself are increasing. In effect, this yields a double geometric water demand progression that must be satisfied by rain, the static original source of water supply and diversion into the region. At the same time pollution can actually decrease this static water supply by rendering portions of it economically unsalvageable.

A further need for the study and application of water supply and water supply projection methods is that imposed by the forces, both natural and cultural, which modify the actual water supply. The water supply variation is a function of both seasonality and land use. The resultant flow must then be shared by both upstream uses such as conservational water retention measures and downstream demands such as industrial and municipal supply and waste disposal.

In order to modify the restraining effects that could be imposed by an unexpected limit in water supply and to encourage long-range planning that will take into consideration the interrelationships of natural land conditions, weather variability, land use, population change, and industrial demands, this method is advanced for establishing a water supply projection. The practical application of this method is then illustrated, using the Upper Grand River Basin as an analytical model.

Objectives of the Study

The aim of this study is to establish a method for systematically relating and projecting naturally and culturally caused variations in water supply to water demands imposed by the changing water consuming elements of our economy. An effort was made to select significantly meaningful criteria for indicating water supply conditions and then to apply projective techniques to establish the balance or imbalance of water supply and demand in the selected year of 1975. A motivating force in this research was to determine the validity and limits of accuracy displayed by several standard sources of information, particularly the Soil Conservation Service's "Soil and Water Conservation Needs Inventory," the Michigan Water Resources Commission's Upper Grand River Basin report, the Battelle Memorial Institute's study for the Tri-County Regional Planning Commission, and various Bureau of Census reports. The final water supply and demand projections, as applied to the Upper Grand River Basin, establish a dependence factor of Grand River communities upon surface water supply for purposes of sewage disposal.

Approach to the Problem

A systematic approach was used in the design of this water supply projection method. First, the present water supply was determined, making an effort to define the limits of variation and the sources of supply. Then the water requirement was established, using primarily published sources of information, and translating these figures where necessary into a form useful to this study. Using both the present supply and demand as foundation information, projections were made. Future supply was determined by expressing the cumulative effect of both natural change including drought flow, evapotranspiration, and precipitation, and cultural changes including primarily land use change and change that could be affected by flow augmentation measures. Future demand was determined on the basis of per capita use projections. The degree of coincidence of these two projections was then noted and implications of the deviation discussed.

This method was applied to the Upper Grand River Basin, indicating the cumulative effect of water supply factors as they progressively influenced the selected Grand River communities from Jackson down to Ionia. The resultant compilation of the water supply-demand conditions was used as a basis for initial water supply planning recommendations.

CHAPTER II

THE ELEMENTS OF RIVER BASIN WATER SUPPLY ANALYSIS

The Water Supply

The water supply in any given area is necessarily the result of a direct functional relationship with several variable factors. The underlying assumption is here made that the analysis of a water supply is best structured on the basis of land use influence upon the precipitation to streamflow process. This assumption is made because land use change is increasingly within man's realm of influence, and man is thereby able to modify, sometimes quite unintentionally, that part of stream flow beyond the influence of purely natural forces. These purely natural forces will also be mentioned, but only insofar as their variability modified man's influence.

It can generally be said that precipitation is the primary source of a drainage basin's basic water supply upon which the additional influences of land use and climatic, geologic, and topographic conditions exert a combined modifying influence. The quantitative study of water supply is consequently an inventory problem. "It is a problem of determining and keeping on record the amount of water that can be obtained from a given surface basin for whatever development is contemplated."[1] The

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[1]Edgar E. Foster, Rainfall and Runoff (New York: Macmillan and Co., 1948), p. 441.

quantitative value for water supply will here be expressed as the sum of stream flow and sustained yield ground water withdrawal. It is not a difficult matter to measure stream flow or to establish a rainfall-runoff equation, such as that developed by Foster,[1] but in order to translate these phenomena into an equation whose form permits the projection of stream flow or runoff, requires the inclusion of factors that reflect directly the potential influence of changes in each of the variables that affect final streamflow or runoff.

In developing a projection method it is essential that the dynamic forces in a watershed are given full quantitative consideration. The simplified form of the equation upon which this projection method will be constructed is the following:

$$R + G = P + D - L$$

where:

R = Runoff available for use
G = Ground water available on a sustained yield basis
P = Precipitation
D = Diversion into basin
L = Losses, both natural and cultural

Within any given drainage basin several variable factors act upon this equation to cause the final yield. An absolutely stable basin could produce a yield easily calculatable from a rainfall-runoff relationship determined simply from previous records, however, one rarely finds such a stable basin due to the modifying influence of both men and nature.

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[1] Ibid., p. 445.

Therefore, it is necessary, in making a water supply analysis easily convertible to projective techniques, to include functions that reflect the various specific entities that can influence yield with time and change. These specific entities must be included in the basic equation whose functions reflect the various specific parameters that can influence yield.

A complete watershed analysis should include these critical and variable parameters and should furthermore be expressed in terms compatible with those necessary for making projections. The basic unit for such an analysis is understandably the drainage or river basin. Within these bounds usable expressions of past, prevailing, and future conditions must be represented. These expressions must clearly indicate the sources of water for the basin and the water losses from the basin as well as the physical, economic, and cultural characteristics which may in time cause change.

A detailed consideration of the parameters suggested in equation 1, for the purpose of investigating the full continuum of forces requiring consideration in a river basin water supply study, would include an understanding of the following factors relating directly to those parameters. The water supply condition must be considered in relation to that quantity required for present and future sewage dilution, municipal needs, industrial needs, irrigation, and downstream uses. In conjunction with ground and surface waters, intensive surveys must be made of the minimum flow threat, augmented flow, surface and ground water storage changes, and the resultant stream recession curve. Precipitation must be considered in light of its seasonality, variability, intensity, duration, and drought probability. Finally, water losses from a basin resulting from transpiration, interception, evaporation, diversion from the basin, and watershed leakage must be estimated. The sum total of these factors, as applied in equation 1, would represent a fairly accurate indication of the water supply condition.

Sources of Water for a Drainage Basin

There are commonly only two major sources of water for a drainage basin. These are precipitation and diversion from other basins. Minor sources such as cosmic water and volcanic (magmatic) water provide no appreciable amounts for inclusion in the projection period and location here considered. Of the two major sources, diversion is the most easily measured, and where this source is dominant, primary supply can easily be determined. Precipitation is the other primary source and requires greater consideration in establishing a useful watershed analysis upon which a projection technique can be developed.

Precipitation

Precipitation records avail themselves quite readily for use in river basin water supply analysis and projection. Emphasis will be placed here on precipitation records prior to and in times of low flow, for it is this critical period that determines to a large extent the limit of water-using development in the area. Of greatest value are precipitation records that indicate mean rainfall on the basin during this period, variation in rainfall intensity, the frequency of rainfall, and the runoff relationship.

The mean rainfall can be expressed by 1) the arithmetic mean, 2) the Thiessen mean, or 3) the isohyetal method. These methods are suitable for use in determining the mean depth of rainfall on an area either during a single storm or for any longer period such as a month, year, or longer period of record.

The arithmetic mean is obtained by dividing the sum of the depths recorded at all the stations on the basin by the number of stations. The results of this method will not differ appreciably from those obtained from either of the other methods if the stations are uniformly distributed over the basin and the rainfall varies in a regular manner.

The Thiessen mean[1] incorporates a method which compensates for unevenly spaced recording stations. Adjacent stations are joined by straight lines, thus dividing the entire area into a series of triangles. Perpendicular bisectors are constructed on these lines, thereby forming a series of polygons, each containing one rainfall station. Any point within the polygon is closer to the enclosed rainfall station than to any other station and therefore would seem to be more indicative of the rainfall in that location. If the mean rainfall on the basin is P and the total

[1] C. O. Wisler and E. F. Brater, Hydrology (New York: John Wiley & Sons, Inc., 1949), p. 86.

area is A, and $P_1 P_2 \ldots P_n$ represent the rainfall records at the individual stations whose surrounding polygons have areas of $A_1, A_2, \ldots A_n$, then:

$$P = \frac{A_1P_1 + A_2P_2 + ---A_nP_n.}{A}$$

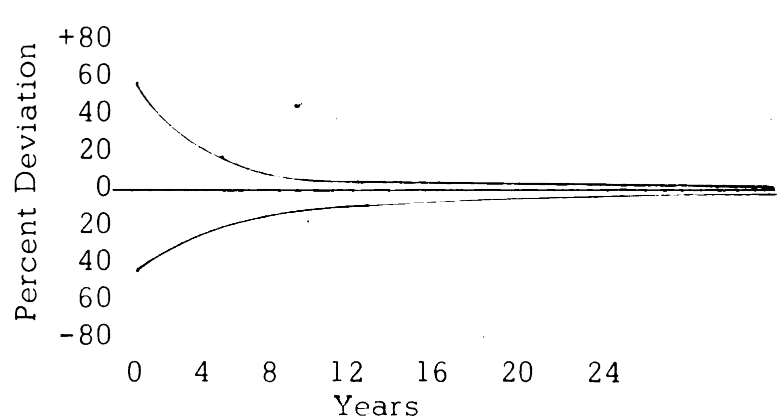
Equation II

The Isohyetal method consists simply of drawing contours having equal rainfall. The areas between adjacent isohyetals is found by planimetering and then Equation II can be used. Special judgment is required for this method in that the drawing of the isohyetals to conform with the local situation directly and significantly influences the results.

Variations in Rainfall

It is necessary in establishing the frequency and degree of variation of rainfall in a basin for use in determining potential supply, to also understand what the average percentage deviation is from the true mean for any given number of recorded years. A study made by A. Binnie[1] indicates this variation.

Figure 1. Deviation of Rainfall from the True Mean



[1] Ibid., p. 91.

It is important to emphasize here that an annual deficit will not necessarily diminish the summer low flow unless the deficit occurred during or just prior to the critical period and the deficit rainfall was not sufficient to recharge the ground water storage to normal levels. In some instances a deficit rainfall may only yield diminished runoff in a time of adequate stream flow.

Several types of measurement are used to express the characteristics of rainfall. The best measure, according to Baker and Conkling,[1] of seasonal variation which takes into account not only the relationship between absolute maxima and minima, but also the variations in all years is based upon the theory of least squares; the formula is:

$$\text{Coefficient of Variation or C.V.} = \sqrt{\frac{\Sigma V^2}{n - 1}}$$

where:

V = variation of any single year from the mean of the record
ΣV^2 = summation of the squares of all variations
n = number of years of record

A good treatment of the various other methods for calculating the precipitation variations, frequencies, fluctuations, and probabilities can be found in Foster.[2] The actual use of these methods is of greater value in determining basic precipitation characteristics of a basin than in establishing a water supply projection based on changes of land use.

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[1] *Ibid*., p. 66.

[2] Foster, *op. cit*., pp. 106-234.

The basic precipitation information can then be applied to the hydrograph or runoff characteristics in terms of probable natural variations. The hydrograph of any stream is the basic unit upon which surface supply can be calculated. It is determined by two entirely different sets of factors, the one depending on the nature of the precipitation and the other upon the physical characteristics of the basin that regulate water losses. The precipitational influence, then, depends on:

1. Type of precipitation - rain vs. snow
2. Rainfall intensity
3. Duration of rainfall
4. Distribution of rainfall on the basin
5. Direction of storm movement

For projective purposes, precipitation represents a basic source of potential water supply which will under ordinary circumstances remain constant, at least within the probable occurrence of natural variations. The probability of variation can be calculated if records of sufficient length exist. Then, upon the relatively constant basic sources - precipitation and diversion - the water consuming factors operate. Man does have an influence on these factors and can, in effect, alter the runoff from a particular area. The next section considers these various forces and also considers to what extent a given change induced by man can alter runoff.

Upon these basic considerations and assumptions it is possible to construct a projection of future water supply, using primarily information relating to the anticipated changes man plans in a given basin. It should be mentioned here, that in constructing an analysis of a basin such as this, more accurate results would be obtained by using the cumulative effect of change in each individual watershed instead of making gross generalizations about the basin as a whole.

Losses

Acting on the basic sources of water are the components that affect water losses. These components include 1) interception, 2) evaporation, 3) transpiration, and 4) watershed leakage. Water loss is here defined as the difference between the total precipitation and the total runoff from any given area. Water loss could also be defined, particularly by the agriculturalist, as the difference between precipitation and transpiration. According to Wisler[1] "...the interrelationship between these losses which makes separate measurement difficult tends to make their total more nearly constant for any region and climate and, therefore, reduces the importance and the necessity for their separate measurements." He goes on to say "...the presence of vegetation affects and reduces the rate of evaporation from the ground surface and, in turn, the evaporation from the ground surface reduces the moisture available for transpiration thereby making their sum more nearly uniform over any given basin regardless of the

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[1] Wisler, op. cit., p. 142.

variation in vegetal cover." His conclusion is that the actual amount of loss on any drainage basin depends on the following factors:

1) The nature of the precipitation

2) The type and development of the vegetation

3) The area covered by buildings, pavements, and other objects

4) The climatological, such as temperature, humidity, and wind velocity.

The implication one easily makes from the two preceding quotations is that change in vegetal cover, when considered in relation to the sum of water consuming forces, automatically negates the change of significant runoff alterations when vegetal land use change, particularly in agriculture can significantly influence water loss and indirectly the final water supply. Furthermore, it is believed that several of the recommended conservation measures also directly influence final water supply. The effect of these measures will be mentioned in a later section dealing specifically with conservational recommendations proposed for the Upper Grand River Basin.

The following is a brief description of the forces effecting water loss and which are believed to change with change in land use.

<u>Interception</u>

Interception accounts for a small, but nevertheless measurable amount of water loss from a basin. Both the vegetative type and precipitation duration and intensity determine the percentage of the total precipitation lost. For illustration, a 0.25 inch rainfall in a dense forest may lose 80 percent to interception and only 30 percent in a one inch rainfall. Coniferous trees intercept greater amounts of precipitation than deciduous trees even in full leaf. Dense grasses, shrubs, and grains approaching full growth can also intercept nearly as much precipitation as deciduous trees in full leaf.

For any given area and condition of vegetation, the equation for interception is of the form:[1]

$$X = a + bt$$

where X represents the total interception in inches depth on the basin, a is the interception storage capacity in inches depth on the basin, b is the evaporation rate in inches per hour, and t is the duration of the shower in hours. This equation is applicable only to storms exceeding the interception storage capacity a.

For projective purposes, then, consideration must be made of both interception storage capacity change in relation to land use change, and the associated effect on the more constant precipitation and intensity characteristics of the basin.

Evaporation

Natural evaporation from a basin occurs primarily as soil or land evaporation and evaporation from free water surfaces. On free water surfaces the rate of evaporation depends on the difference between vapor

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[1] Ibid., p. 143.

pressure of air and water or in other words, upon the pressure gradient. This principle is known as Dalton's law and is expressed by the formula $E = C(p_w - p_u)$, in which E is the rate of evaporation in inches per day, p_w is the vapor pressure in the film of water next to the water surface, p_u is the vapor pressure in the air above, and C is a coefficient that is dependent upon barometric pressure, wind velocity, and any other acting variables.[1] Depth of the water body further influences evaporation rate, primarily through the influence of temperature.

Evaporation from soil, according to Foster,[2] can be obtained only by observation. It is mentioned, however, that evaporation from soil can equal and even exceed evaporation from a water surface under the proper conditions. Invariably the discussion about evaporation by Foster, Baker[3] and Wisler,[4] were based on experiments using water and land evaporation pans. Under carefully controlled conditions these results can reflect those in nature, but only in that location. Consequently, these evaporation determinations, although of value in studies of small plots, would not reflect the conditions in a basin or even a watershed due to the extreme variation in soil type, moisture availability, vegetation,

[1] Ibid., p. 152.

[2] Foster, op. cit., p. 285.

[3] Donald M. Baker and Harold Conkling, Water Supply and Utilization (New York: John Wiley & Sons, Inc., 1930), p. 91.

[4] Wisler, op. cit., p. 147.

temperature, wind, and humidity. Therefore, although evaporation may admittedly play a significant role in a basin's water consumption regimen, this quantity will necessarily be an assumed and inherent factor in the rainfall-runoff ratio. For projective purposes it will further be assumed that evaporation rate in any given location will remain constant unless an extreme change occurs in land use such as might be experienced when forested lands change to inter-state highway lands.

Sublimation is also an evaporative force which can, under proper conditions, consume up to 4 inches of winter precipitation. This loss occurs primarily where snow and ice are exposed to constant winds and where coniferous vegetation helps to expose great quantities of branch accumulated snows to sublimational processes. Thus, locational climatic, micro-climatic, and vegetational characteristics determine the sublimation rate and water loss due to sublimation.

Transpiration

Transpiration in a river basin represents a loss whose quantity and significance is still subject to disagreement. One source expressed the opinion that change in water losses due to change in vegetal type would represent a very minor if not insignificant difference.[1] This opinion appears to be in disagreement with the results one would obtain from applying the transpiration ratio and runoff alterations characteristic of

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[1] Personal correspondence from Dr. A. Earl Erickson of the Michigan State University Department of Soil Science.

different plants. The runoff changes will be discussed in a later section, but transpiration ratios will be discussed here. Foster expresses the opinion that the use of water by plants is best shown by stating the quantity of water consumed to produce a unit weight of dry plant matter.[1] This quantity is commonly designated as the transpiration ratio. A few representative ratios, as determined by Lee,[2] Wisler,[3] and Baker[4] are as follows:

Plant	Ratio: lbs. of water per lb. of dry matter	
corn	345	Lee
wheat	375	Lee
potato	426	Lee
alfalfa	829	Lee
oats	500	Wisler
rye	500	Wisler
barley	450	Wisler
red clover	800	Wisler
sugar beets	400	Wisler
weeds	600	Wisler
grasses	861	Baker
beech	1,043	Lee
elm	738	Lee

These ratios can be used to advantage in calculating the change in water consumption by transpiration due to change in vegetal type. This

[1] Foster, op. cit., p. 147.

[2] Ibid., reference is made by Foster to an unavailable publication by Lee.

[3] Briggs and Shantz, "The Relative Water Requirements of Plants," Journal of Agricultural Research, Vol. III, No. 1, October 1914, pp. 58-59.

[4] Baker, op. cit., p. 131.

would be done by calculating the dry matter change per acre or square mile and then multiplying that by the transpiration ratio and converting to inches of water loss. This quantity combined with the associated change in runoff is of significant value in projecting changes in water supply due to trends in changed vegetal land use. The projection is made possible by using Census of Agriculture information to estimate future vegetal land use figures. Transpiration during a given period is equal to:[1]

$$T = I + S_1 - S_2 - E - D$$

where:

T = transpiration during period
I = water received by precipitation or irrigation
S_1 = water in root zone at start of period
S_2 = water in root zone at end of period
E = evaporation from surface of soil
D = deep percolation

Infiltration

Infiltration represents still another significant measure that can be directly influenced by land use change. Wisler[2] and other hydrologists recognize this fact and have mentioned several methods for determining infiltration capacities with change in land use, however, these measures are only locally meaningful and it remains for the hydrograph analysis to illustrate indirectly the infiltration change in a large drainage basin.

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[1] Ibid., p. 133.

[2] Wisler, op. cit., p. 177.

Even this can be difficult to accomplish and misleading because delay or lag periods between rainfall beginning and the appearance of surface runoff at a measuring point make average infiltration capacity the only usable measure.

When infiltration characteristics are considered in relation to land use change, particularly in the critical low flow periods of the summer, most regions would experience what approaches complete infiltration. This would mean that although infiltration capacity is of prime importance in flood studies, it would have only minimal importance in runoff studies during low flow periods. The implication is made here that the other forces acting on the infiltrated rainfall such as evaporation and transpiration significantly influence runoff due to their control of the amount of water that reaches the subsurface flow in the summer months.

The Combined Effect

The most obvious conclusion to be made from the aforementioned considerations is that although each factor, whether it be interception, evaporation, transpiration, or infiltration, is influenced measurably by land use change, the result on a basin wide scale is inevitably extremely conditional. To equate land use change with these measures of water transfer and consumption to arrive at a final stream flow relationship would obviously be made infinitely long by the extremely numerous conditional factors. This makes it necessary to formulate the relationship of land use change to runoff or water supply in terms of the composit end result. Therefore, until it becomes possible to integrate the continuum of variable factors in a river basin that influence final stream flow, it becomes necessary to measure the naturally occurring cumulative effects of these variable forces. The cumulative effect is found in runoff and hydrograph records. These cumulative effects are discussed next in relation to the influence land use change exerts upon them.

Runoff

Runoff is that water remaining from precipitation after the losses from interception, evaporation, and transpiration have occurred. In effect, runoff constitutes the last phase of the hydrologic cycle. This runoff may be divided into three types: 1) the residual water from rainfall, 2) residual snowfall and, 3) ground water runoff that comes from subterranean storage. The latter of these types is the predominant factor of consideration in seasons of low flow. The formulation of a rainfall-runoff relationship is a commonly used method for representing runoff from a large watershed, however, in the summer the consumptive forces reign. The accuracy and proper placement of streamflow and precipitation gages determines the effectiveness of this method. Understandably this relationship depends to a great extent on infiltration and water consumption in low flow periods, and infiltration is in turn made a variable factor due to changes in land use. Many published reports are available concerning rainfall-runoff relationships, but very few of these reports include quantitatively the influence that land use change exerts on runoff. For approximative purposes, certain studies have been selected that measured runoff change with land use change. The results were reduced to percentage change figures. These percentage figures are then used in a later chapter to predict what influence certain anticipated land use changes on a specific area could have on runoff, assuming that the percentage relationship remains fairly constant between similar regions even if the quantitative values may differ.

Runoff and Land Use Change

Among the several types of land use change that can occur in a drainage basin, the most common are the agricultural and urban types. The agricultural types include crop change, cropping method, and cultivation method. The urban types range from highway caused drainage modifications to the vast assortment of urban features that block, divert, and prevent precipitation from infiltrating.

Runoff has been shown to be least controllable from crop lands.[1] Crops have as a major disadvantage over forest and grasslands, the extreme exposure of soils which can be the result of the crop type, such as corn, or the cropping method which allows soil to be exposed in times

[1] E. A. Colman, Vegetation and Watershed Management, (New York: Ronald Press, 1953), p. 216.

of the greatest rainfall. Terracing, contour cultivation, stubble mulching, minimum tillage, sod strips, and shifts between clean cultivated and close growing plant covers offers some additional resistance to immediate runoff. Contour cultivation can reduce runoff from 12 to 99 percent. One series of experiments has shown that in fifteen of twenty-one tests, runoff was reduced more than 30 percent.[1] Of the two runoff-decreasing cropping methods strip cropping provides a more constant influence than rotation cropping, but the long term average remains the same. Strip cropping did have the advantage of reducing soil erosion by nearly 50 percent, however. One crop rotation experiment in LaCrosse, Wisconsin, had the following surface flow result:[2]

Crop (3 year rotation)	Runoff (percent of rainfall)
Continuous corn	29.2
Corn rotation	20.6
Grain in rotation	18.9
Hay in rotation (Clover, Timothy)	11.5
Rotation average	17.0

In a glacial till area of Bethany, Missouri:[3]

Crop (4 year rotation)	Runoff (percent of rainfall)
Continuous corn	27.1
Corn in rotation	20.7
Wheat in rotation	23.3
Meadow in rotation	11.8
Rotation average	16.2

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[1] Ibid., p. 217.

[2] Ibid., p. 221.

[3] Ibid., p. 227.

Percentage figures such as these preferably obtained directly from the location being analyzed, rather than from a similar area, could be used to indicate in a projection the expected percentage increase or decrease in runoff that one could anticipate from an area if an agricultural land use change occurs. Additional percentage runoff change could be predicted if it were known exactly what influence a changed cultivation method would impose.

The extent of grazing also influences runoff. Lysimeter experiments showed that in storms of low intensity and long duration there was no difference in runoff between grazed and ungrazed lands.[1] However, intense summer storms yielded the following runoff change:[2]

	Runoff (percent of rainfall)
Ungrazed	1.8%
Moderately grazed	5.5%
Heavily grazed	10.8%

In LaCrosse, Wisconsin, the runoff increased from 0 in ungrazed woodlots to 1.2 percent in grazed woodlots.

These experiments indicate in a general way the relative magnitudes of the various changes possible in a watershed. Additional changes of course would be created by the changed evapotranspiration ratio as previously mentioned.

Urbanization is responsible for yet another change in the rainfall-

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[1] Ibid., p. 243.

[2] Ibid., p. 290.

runoff relationship. Studies in both the Delaware River Basin[1] and the Detroit area of Michigan[2] have revealed that urban development has no marked effect upon total volume of storm runoff. However, a change does definitely occur in the time of peak flow resulting from a storm. The Detroit study found that the time of concentration or lag time[3] for the urban basin was about three hours, while in the natural basin concentration of flow did not occur until twelve hours after the "center of mass of precipitation excess."

Although the above mentioned study near Detroit would be most representative, of the available studies at least, of the conditions that one might expect in the Upper Grand River Basin, this is not to say that the runoff lag times could not be more or less divergent under other land conditions.

Lynch has made one of the few available statements with actual urban coefficient of runoff figures.[4] He states that the fraction of total

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[1] R. L. Hobba, Memorandum No. 2009 from U. S. Department of Agriculture, Forest Service, Washington, D. C., March 13, 1959, p. 4.

[2] S. W. Wiitala, Some Aspects of the Effect of Urban and Suburban Development upon Runoff, United States Geological Survey open file report, August 1961, p. 11.

[3] Concentration of lag time is defined as the "time between the center of mass of precipitation excess and the center of mass of the resulting storm runoff."

[4] Kevin Lynch, Site Planning (Cambridge: Massachusetts Institute of Technology Press, 1962), p. 197.

rainfall which runs off on the surface may be estimated for any area from the following approximate values:[1]

Surface Type	C. or Coefficient of Runoff
Roofs, asphalt, concrete pavements and other waterproof surfaces	0.9
Macadam, compact earth and gravel without plant growth	0.7
Lawns and parks	0.3
Unpaved yards and lots and overgrown areas	0.2
Woods	0.1-0.2

The coefficient of runoff may also be more quickly estimated from the following, using density of development as a criteria:

Density of Development	C. or Coefficient of Runoff
Development at 10 families/acre	0.3-0.5
Development at 40 families/acre	0.5-0.7
Dense urban area	0.7-0.9

In making projections about runoff, and the consequential downstream flow and surface supply resulting from urban development, these figures could be used for making rough estimates of the quantities of water involved in the concentration or time lag change resulting from urbanization.

Several of the commonly used expressions for stream flow conditions can be modified to also represent projections. These basic expressions include base flow regression curves which form the basis of the drought

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[1] These values are not based upon rigorous scientific experimentation.

or minimum flow curve, and flow summation curves. If streamflow records are available, these curves can be plotted, including the desired limits of deviation. These curves can then be projected, using as much as possible the anticipated influence of land use change. Then the resultant curve can be superimposed with a curve that expresses projected water supply requirement. The variation of these two curves would indicate the magnitude of corrective measures necessary to match water supply with demand.

Minimum Flow

Because summer minimum flow is of more importance in the Great Lakes States than excess flow, this value for stream flow should be emphasized. As previously mentioned, land use change can influence infiltration capacity transpiration, evaporation, and runoff. There being a direct relationship between these quantities and final stream flow would necessarily reflect the need to seriously consider anticipated land use change in watersheds when one analyzes the seriousness of the present and future low flow. The low flow threat can conceivably be increased or decreased depending on long range forethought when conservational measures and urban developments are expanded.

In areas such as the one which will presently be discussed, low water flow is derived primarily from ground water instead of other possible sources such as snow melt waters, and areas that contain a large amount of surface storage. It was shown by Horton that that portion of the hydrograph that represents only ground water flow is an exhaustive curve, and may be expressed by an equation of the form:[1]

$$Q = Q_o \, e^{-cd^n}$$

where:
Q = discharge in cubic feet per second at the end of d days after termination of surface runoff.
Q_o = discharge when d equals o.
e = Napierian base 2.718
c and d = constants

A composite ground water depletion curve should be constructed from the recession graphs of the drainage basin for a number of storms in order to evaluate Q_o, c, and n. This is accomplished by shifting, with respect to the time axis, the various segments of the recession curves until they appear to match and then an average or composite curve is drawn through them. The time when d = o is arbitrarily selected at or before the time of occurrence of the highest point on any of the recession curves that is thought to be free of any surface runoff. The longest period that is likely to elapse between rains of sufficient magnitude to produce ground water accretion may be determined by studying long-term records of rainfall in the region.

Yield in low flow periods is determined not by basin size as is the procedure for determining surface runoff, but rather by climate. In humid regions the yield of a stream for any year as for any month is dependent upon the elevation of the water table at the beginning of the period. The

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[1] Wisler, op. cit., p. 315.

change in ground water storage is obviously important. According to Wisler, "...if the long-term mean annual rainfall and the corresponding average annual water loss are known, the average yield may be taken as the difference between the two. However, the determination of yield, month by month or even year by year, cannot be made with the same degree of accuracy (as from 10-year records) because of the increasing importance of ΔS (change in storage) as the time interval decreased and because of the relatively greater influence of the various factors that influence evaporation opportunity."[1]

The conclusion by Wisler is that there is a lack of correlation between water loss, rainfall, and temperature for short periods. This would indicate among other things, the importance of including in these considerations the influence of ΔS and specifically the influence of land use change on ΔS.

As any study of total water losses from a drainage basin indicates, it is difficult to measure loss from interception, evaporation, transpiration and ground water out flow. But collectively losses can be more accurately and easily estimated by considering the rainfall, runoff, and storage, as in the equation:[2]

$$L = P - Q + \Delta S$$

where:
L is the total losses for the period

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[1] Ibid., p. 319.

[2] Ibid., p. 171.

P the total precipitation for the period
Q the total runoff for the period
ΔS the increment in surface and subsurface storage during the period

the three factors of ΔS are:

1) the increment in surface storage in lakes, ponds, swamps and streams
2) the change in ground water storage below the water table, which for any given area and period is equal to the product of the average change in level and the average porosity of the soil
3) the change in field moisture above the water table

Acting on this relationship are the rather well defined cyclic characteristics of rainfall. For example, in southern Michigan, 18 percent of the annual precipitation occurs in winter, 27 percent in spring, 29 percent in summer, and 26 percent in fall.[1] In response to the cyclic nature of a basin's water regimen, ground water level usually reaches its maximum stage in the first of May and then experiences a more or less general decline until late September or early October. Although there may be fluctuations amounting to several feet or even more in any one year, the observed level on October 1, of any year does not ordinarily differ greatly from the long term elevation for that date except as a result of unnatural changes or developments made within the basin. Surface storage and soil moisture deficiency do not vary considerably from year to year at this season of the year. Consequently, the average annual loss for any period of five years or longer, beginning and ending on the first of October may be determined from the previous equation,

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[1] Ibid.

ignoring ΔS. The accuracy, according to Wisler, would be within one or two inches.

However, if only one year is considered in determining the loss, the error will be considerably greater depending then on the value of ΔS for that year. This error can be detected and at least a partial correction made because all the stream flow is derived from ground water and from surface storage with the exception of surface runoff immediately following a storm. Surface storage and soil moisture content vary more or less in parallel with the ground water storage, and except when surface runoff is occurring at the end of the water year, the streamflow at that time provides a good index of ΔS for that year. A change in this value from one year to another would indicate ground water levels and surface storage should be checked, and with complete information could reflect a correlation factor and possibly a relationship with land use change.

Another method for determining ΔS in the above equation ($L=P-Q+\Delta S$) would be from the normal depletion curve which represents the rate of depletion of ground water storage, and at the same time, the area beneath the portion of the curve bounded by the discharge rates occurring at the beginning and end of the period for which ΔS is being determined is actually equal to ΔS.

Thus it is possible to determine average annual water losses from any drainage basin quite accurately for a long period of time from only precipitation and runoff records. Annual water losses can be determined with reasonable accuracy if ΔS is taken into account using hydrograph and ground water level information. Seasonal and monthly losses are naturally slightly less accurate.

Another method for determining change in storage is proposed by Foster.[1] First the average change in ground water level is determined in the basin area. (The Thiessen method can be used here, using wells instead of rain gages as before mentioned.) "The change in stage for any given well is expressed in terms of specific yield."[2] Then in an area A with n wells, the change in volume V_s can be expressed as follows:

$$V_s = A/a_1(W_sS_y)_1 + a_2(W_sS_y)_2 + a_3(W_sS_y)_3 + \ldots a_n(W_sS_y)_n$$

S_y = specific yield

W_s = increase in elevation of water table or $\frac{P_w}{S_y}$

Where P_w = portion of precipitation reaching free ground water.

This equation naturally applies only to unconfined aquifers. The ground water equation according to Conkling is as follows:[3]

Surface outflow + Underflow out + Consumptive use + Change in storage + Exportation	=	Surface inflow + Underflow in + Precipitation

[1]Foster, op. cit., p. 433.

[2]Ibid.

[3]Harold Conkling, "Utilization of Ground Water Storage in Stream System Development," Proceedings of the American Society of Civil Engineers, Vol. 33, January 1945.

Drought Flow

Drought flow, a term usually used synonymously with minimum flow, is defined as the minimum stream discharge occurring during the summer-fall warm weather season from May 1 through October 31. The discharge can be measured in any one of several ways. These include minimum daily average discharge, minimum consecutive 7, 15, or 30 day averages, or even minimum monthly average. The fundamental approach to the statistical evaluation of low flow characteristics of streams stems from the theory of extreme values (Gumbel Theory).[1] An extremal probability grid initially developed for flood flows was adopted to droughts by the simple technique of dealing with values in their order of severity rather than in order of magnitude. Yield is usually expressed as cfs per square mile of tributary or cfs at the gaging station. The variability ratio which is sometimes expressed as the standard deviation, is better expressed as a simple ratio because drought flow is an asymmetrical distribution. Flow duration curves do not provide the probability of occurrence, but reflect entire distribution of discharge. Another common method for estimating flow at a specific location other than by gaging station record, is to assume that flow is proportional to the size of the drainage area tributary to that location, using the yield at the nearest gage.

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[1] Clarence J. Velz and J. J. Gannon, "Drought Flow Characteristics of Michigan Streams." University of Michigan for the Michigan Water Resources Commission, 1960.

Physical and Economic Characteristics of the Basin

Physical

Certain physical conditions of a basin will under ordinary conditions remain constant for years and probably for times longer than those used in most projections. These conditions would include area, shape, elevation, slope, directional orientation, drainage net, indirect drainage, and artificial drainage. Although the last factor, artificial drainage, could easily change within a projection period, the end flow result would be constant, but not the same in quantity as before. Artificial drains can lower the water table in portions of a drainage basin and thereby influence peak flood flows and minimum flows depending upon the drain's relative location in the basin and the permeability of the soils involved. The lowered water table in drained regions can also bring about the paradoxical condition where water yield is increased because evaporation and transpiration losses are decreased while low flow can be even further decreased because a large amount of potential ground water supply has been released. The quantitative expression for the influence of artificial drainage can best be made by direct measurement of flow changes, but for projective purposes can be roughly estimated by calculating the runoff as a function of ΔS for the drained area, as previously described for the drainage basin as a whole. Often times estimates of anticipated drain construction can be obtained from county drain commissions and an estimate of drainage needs can be obtained from surveys such as the

Soil and Water Conservation Needs Inventory, made by the Soil Conservation Service and cooperating agencies.

Economic Characteristics

Economic considerations must be made in water supply projections in so far as it is necessary to know what amount of water will be required to meet the demands imposed by expanding water use and the price the public will bear for such a supply of water. The water demand or requirement is commonly expressed on the basis of per capita use. Because the combined increase in population and increased per capita demand for water usually remains generally geometrically constant within a projection period, with the exception of a sudden change in the industrial condition, population projections ordinarily serve as the best indicator of future water supply requirements. This study concerns itself primarily with water supplies available under natural conditions or under the influence of land use change but will not delve deeply into the economics and feasibility of developing extensive water supply systems per se. This is a subject in itself and is of course extremely important in regions of chronic water shortages, but is not as yet of chief concern in the humid east where the Upper Grand River Basin is located. But for reference purposes, Heady presents a model mathematical analysis for specifying the optimum allocation of a given investment between alternatives within a watershed.[1] In addition, a rather valuable treatment of the economics

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[1] G. S. Tolley, Economics of Watershed Planning (Ames: Iowa State University Press, 1961), p. 197.

of utilization of existing water supplies, municipal rates, investment in additional water supplies, practical logic of investment efficiency calculations, and technology and costs of water supplies can be found in Hirshleifer, DeHaven, and Milliman.[1]

The Balance of Future Water Supply with Future Demand

In addition to understanding the forces that influence the essentially natural progression of water supply, it is necessary to understand the probable activity of man in a watershed, both as he influences the supply related forces and as he influences the demands for which the supply is used. This probable activity can best be expressed in terms of two basic projections. One projection being that of anticipated change in the watershed that will influence supply, and the other projection being that of anticipating future water demand. The primary analysis of a watershed would treat these two projections independently and merely compare the end result to establish the degree of balance. These independent projections would then serve as the basis for designing a program that would most effectively balance supply influencing measures with demand or demand-reduction measures.

Projecting the Physical Availability of Water Supply

The projection of a water supply is accomplished by quantitatively

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[1] J. Hirshleifer, J. C. DeHaven, and J. W. Milliman, Water Supply, Economics, Technology, and Policy (Chicago: University of Chicago, 1960).

evaluating the change rate of forces that influence the supply. One category of these forces is man-influenced urban or vegetal land use change and the other is upstream man-influenced losses such as consumptive use through irrigation, diversion, and industrial consumption. The relative magnitude of these forces would naturally depend on the particular watershed, and would range from the rather stable influence of a wilderness area, through that of an agricultural area and on to the influences exerted by urban and highly industrialized places.

The basic availability of a surface water supply can be determined in terms of average flow and limits of variation on a time scale. Then, upon this record of known conditions, a projection is made incorporating both the previously experienced natural variations and the culturally influenced supply modifying influences such as those exerted by land use change and new upstream consumptive uses. A complete supply projection includes also ground water supplies. Since there is an interrelationship between surface and ground waters, in that some upstream measures can decrease surface supply and at the same time increase ground water recharge, these two sources are here considered together. They should be considered separately, however, in areas where there is a distinct economic difference between the two supplies. Specific methods for the presentation of this projection are illustrated in Chapter IV.

Projecting Water Requirements

The subject of projecting water requirements is a distinct topic in itself. For this reason the reader is referred to the methodology used by the Select Committee on National Water Resources[1] and the specific study of the Upper Grand River Basin area by the Tri County Planning Commission[2] and the Michigan Water Resources Commission.[3]

Generally speaking, the projection of water requirements can be expressed either as a simple projection of the combined result of increased per capita demand and increasing population or this projection could be further sophisticated by considering the economic incentives that would, with increasing water costs, encourage the installation of water saving systems, and by considering the array of water quality classifications required by a water demanding area.

The Value of Balancing Supply and Demand Projections

As a result of the above considerations, a comprehensive program can be initiated to deal with the water condition of an area before make-shift emergency measures are required. Water supply planning should be an integral part of the overall planning operation in any area. The capacity of an area to deal effectively in the preparation of measures for preventing future emergencies, whether they be flood, low flow, or pollution threats, could well determine the future economic well being of that area.

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[1]"Water Resources Activities in the United States," op. cit.

[2]D. A. Crane, et al., "Long-Range Water Use Planning for the Tri County Region," Preliminary Draft for the Lansing Area Water Advisory Council, Battelle Memorial Institute, Columbus, Ohio, April 8, 1963.

[3]"Water Resource Conditions and Uses in the Upper Grand River Basin," Michigan Water Resources Commission, Lansing, Michigan, 1961.

CHAPTER III

THE ANALYTICAL MODEL

Considering now a specific area and its condition in relation to the several water supply modification factors upon which the area depends for future economic stability and productivity, it becomes apparent that planned water control measures must be included as an integral and dynamic function of the overall development design. The Upper Grand River Basin does have an ample potential supply of water, however, the cultural and economic condition of the basin area necessitates a serious consideration of the water regimen for assuring an adequate supply of water, particularly in times of naturally low flow. Man's activity and his relative locational placement of water dependent communities in the basin have automatically made the time of summer low flow the critical period and the period for which planning efforts are most essential.

The Upper Grand River Basin, as indicated on Map 1, is located in south central Michigan, where Lansing and Jackson are the two major cities. The drainage area extends from the City of Ionia at the western extreme of the basin to the headwaters of the Grand River above Jackson. The basin covers about 2,840 square miles and the main stream length between these two points is approximately 172 miles. The basin boundaries were established by the Michigan Water Resources Commission on the basis of natural surface drainage characteristics. These boundaries obviously do not follow county lines, and even interpolations using township data do not accurately define the condition of individual watersheds. Therefore, basin information is expressed in terms of watershed units. These watershed units are also indicated on Map 1. Their relative position of cumulative impact in relation to the selected Grand River communities are listed on Table 1.

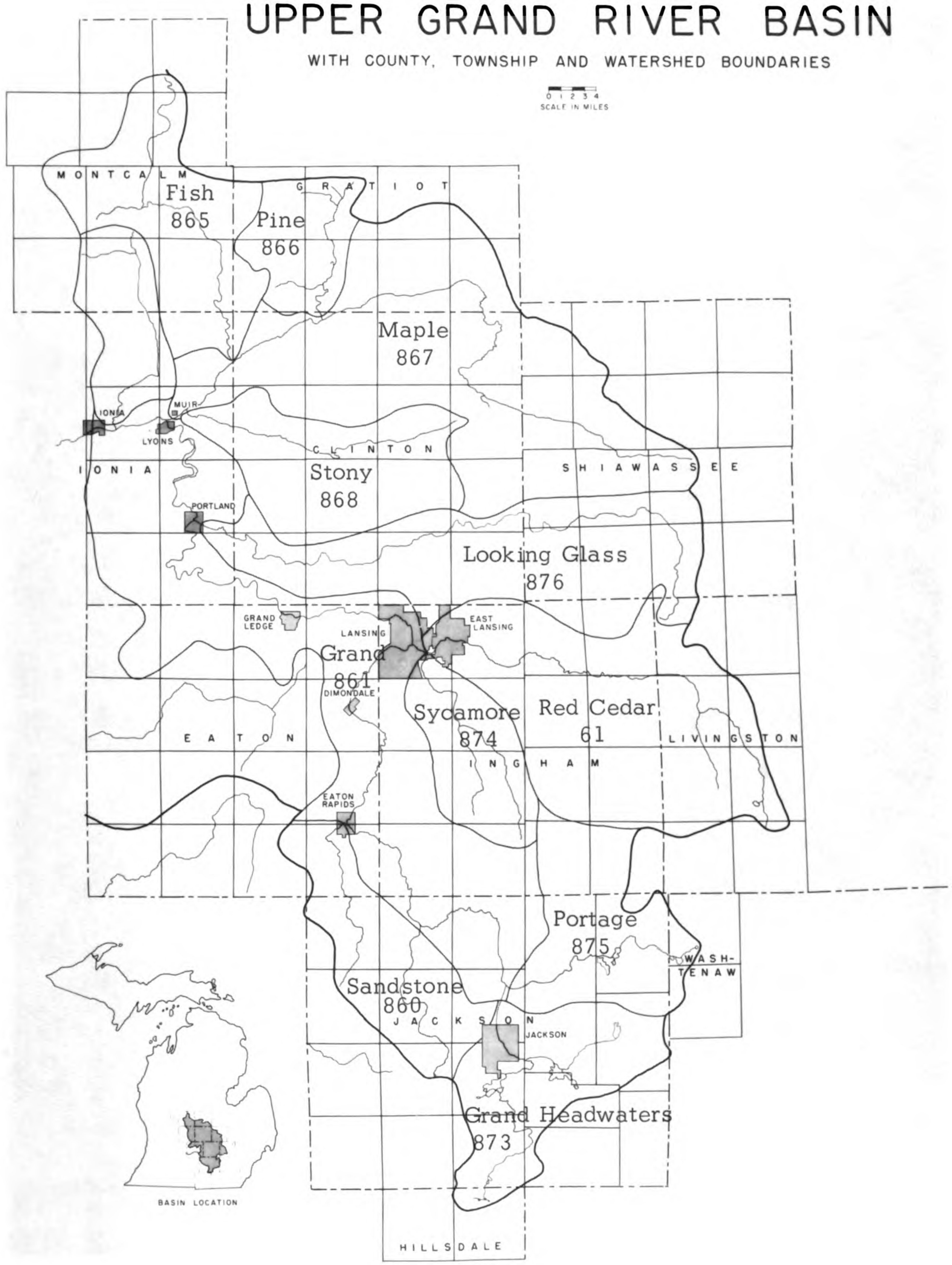
TABLE 1. Cumulative Watershed Impact on Selected Grand River Communities

Watershed Communities	Acreage	Square Miles	Percent of Total Area
873	122,560	191.5	
Total at Jackson	122,560	191.5	6.7
61	236,600	369.7	
860	111,080	173.6	
861	140,864*	220.1*	
874	68,000	106.3	
875	108,000	168.8	
Total at Lansing	787,104	1,230.	43.3
861	196,224*	306.6*	
865	127,720	199.6	
866	55,000	85.9	
867	307,000	479.7	
868	115,000	179.7	
869	58,000	90.6	
876	171,440	267.9	
Total at Ionia (River Basin Total)	1,817,488	2,840.	100.0

*Interpolated value

UPPER GRAND RIVER BASIN

WITH COUNTY, TOWNSHIP AND WATERSHED BOUNDARIES



Map 1

This basic cumulative impact table will also be used later to express other parameters significant to this study. The watershed numbers used in this table correspond with those indicated on Map 1. These numbers were established by the Soil Conservation Service, but do not include the original prefix MICH-GL-SL, used to designate the Great Lakes and St. Lawrence major drainage area.

The Present and Projected Water Requirement

Presently the water requirement or demand considerations initiate most of the concern about water supply, although at first an abundant water supply may have influenced the region's original development. This occurs as water consuming forces, particularly those of irrigation, sewage disposal, and industrial use increase to the limit of water availability. At this point decisions and modifications must be made to assure a favorable and continuing water supply.

Critical Regions

The present water requirement can be measured if sufficient investigation is possible. This is primarily an inventory procedure that measures the total water use of an area by water source and season of use. A complete account of water use in the Upper Grand River Basin is, of course, far beyond the scope of this study. Consequently, three Grand River communities appearing to display the most critical need for water were selected. These communities are Jackson, Lansing, and Ionia.

Jackson was considered to be a critical region because during summer low flows, the effluent from its sewage disposal plant occasionally exceeds the Grand River flow itself. Lansing was selected on the basis of its summer flow threat in relation to power plant requirements and high volume sewage effluent. Ionia, although not itself threatened by low flow, is a convenient measuring point representing the sum total Upper Grand River surface flow product. This becomes an important measure in that the next downstream metropolitan area, Grand Rapids, depends on the Grand River for not only sewage disposal processing, but also for about 50 percent of its water supply at peak demand periods.

Measures of Water Requirement

The water requirement in the Upper Grand River Basin during low flow can best be measured in terms of irrigation needs and sewage disposal needs. These are the two primary purposes for which Grand River surface flow is used. A short discussion of the local condition follows.

An irrigation survey was completed late in 1958 by the Michigan Water Resources Commission[1] which revealed that during years of average precipitation, 4.28 inches of irrigation water are applied per irrigated acre, of which the Upper Grand has 2,470 acres (1959 Census of Agriculture interpolation). Typical irrigation practices in the area indicate the following usages:

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[1] Water Use for Irrigation, Michigan Water Resources Commission, Lansing, Michigan, 1959.

Crops Irrigated	Inches of Water Applied Per Year
Potatoes	5
Field Crops	3-1/2
Hay, Pasture, Silage	4-1/2

It was also found that agricultural irrigation was increasing at a greater rate than municipal irrigation and that a trend to ground water and storage water as sources could be detected. Although this trend to non-surface sources does essentially make more water available for sewage needs, great quantities of water are being used nonetheless for irrigation, and in most cases the water used would indirectly have contributed to surface flow. This would have occurred primarily through base flow. In terms of economic return, irrigation also suffers a handicap, since agriculture in the region contributes only 2 percent to the economy although it occupies 86 percent of the land.[1] This and the fact that the Tri-County area imports more agricultural items than it exports, indicates the relative insignificance of water in agriculture as a result of the insignificance of agriculture itself. A later section will show, however, that agricultural land use can influence river flow.

The primary water requirement problem in the Upper Grand River Basin is that of providing sufficient quantities of water for sewage disposal purposes. During summer low flow periods, the BOD (Biochemical Oxygen Demand) becomes dangerously high relative to flow, and threatens

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[1] O'Donnel, John L., et al., Economic and Population Base Study of the Lansing Tri-County Area, Bureau of Business and Economic Research, Michigan State University, 1960.

both fish life, recreation, and aesthetic value. In order to determine exactly how critical the problem is and exactly how much flow augmentation must be considered for future water requirements, some figures will be cited that indicate the flow requirement per population unit. This flow-to-population relationship is made possible due to the fact that nitrogenous and other organic content of sewage is fairly constant per unit of population, and consequently it is possible to roughly approximate the cubic feet per second (cfs) of stream flow required per 1,000 people to effect natural purification. For the treatment of raw sewage, Blackett considered 3 cfs/1,000 persons sufficient to preserve fish life if not complicated by industrial chemical wastes.[1] However, in a Resources For the Future, Inc. publication, the suggested flow was 4 cfs/1,000 population.[2] In areas where treatment occurs, Blackett assumes that primary treatment reduces oxygen demand by 35 percent and complete treatment reduces oxygen demand by 90 to 95 percent. These figures are particularly important in the Upper Grand River Basin because this region is the most heavily populated portion of the State outside of Detroit. The basin population is approximately 760,000 of which 520,000 are urban.[3]

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[1]Blackett, Olin W., Water Resources and Plant Location in Michigan, University of Michigan, School of Business Administration, 1957, p. 25.

[2]Jarrett, Henry, ed., Comparisons in Resource Management (Baltimore: Johns Hopkins Press, 1961), p. 162.

[3]Blackett, op. cit., p. 37.

Many of the growing urban areas are being pressured into the construction of sewage disposal facilities and the costs must be considered in their planning program. Blackett mentioned, as an average figure, for total sewage treatment expansion, including lateral and interceptor sewer and pumping equipment, $127/capita.

Condition at Critical Period

Jackson

In Jackson the problem is primarily that of creating sufficient river flow for handling sewage plant operations and effluent dilution. The present municipal water supply system, serving nearly 51,000 people and several industries with 11,758,000 GPD from well sources amounts to approximately 232 GPD/capita.[1] But indirectly, river flow influences this water supply by way of infiltration through the river bed. Jackson has already acquired rights to this river bottom land as far upstream as Center Lake to protect the area from practices harmful to natural recharge. Sewage plant expansion has kept pace with increasing demands and provides complete treatment except under heavy storm drainage conditions. Assuming that 93 percent[2] of the oxygen demand is eliminated at this treatment facility, only 7 percent of the 4 cfs required per 1,000 population would be necessary. This means that 0.28 cfs are required per 1,000

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[1] Water Resource Conditions and Uses in the Upper Grand River Basin, Michigan Water Resources Commission, Lansing, Michigan, 1961, p. 105.

[2] A figure given by Mr. Greene, superintendent of the Jackson sewage disposal plant.

population, or assuming an equal number of persons have municipal sewage drainage service as receive municipal water supplies, 14.3 cfs would be the required flow of the Grand River at Jackson.

Figure 2 is a typical hydrograph of the Grand River at Jackson, and serves to show that the low flow threat does not appear to be extremely critical. However, the minimum discharge has fallen below this figure twice (in 1936 and 1941) in the last twenty-eight years in terms of daily average, and once in terms of the seven-day average.[1]

This apparently rare incidence of critical low flow is deceptive, however. According to the sewage plant superintendent, the entire river flow is frequently diverted through the sewage plant during low flow periods. Obviously the resultant effluent then has no river flow with which to be diluted, and consequently additional river flow at Jackson can be deemed desirable. In view of this discrepancy, it would seem reasonable to increase low flow at Jackson at least by 14.3 cfs, or by an amount equal to that required to properly dilute the effluent at times of essentially no flow due to the complete diversion into the sewage treatment plant.

Projecting now, to determine the Grand River flow requirement during low flow periods, on the basis of 1975 population sewage treatment needs, non-city population seems to be the determinant factor. Jackson itself will probably not experience a population change of a greater order than

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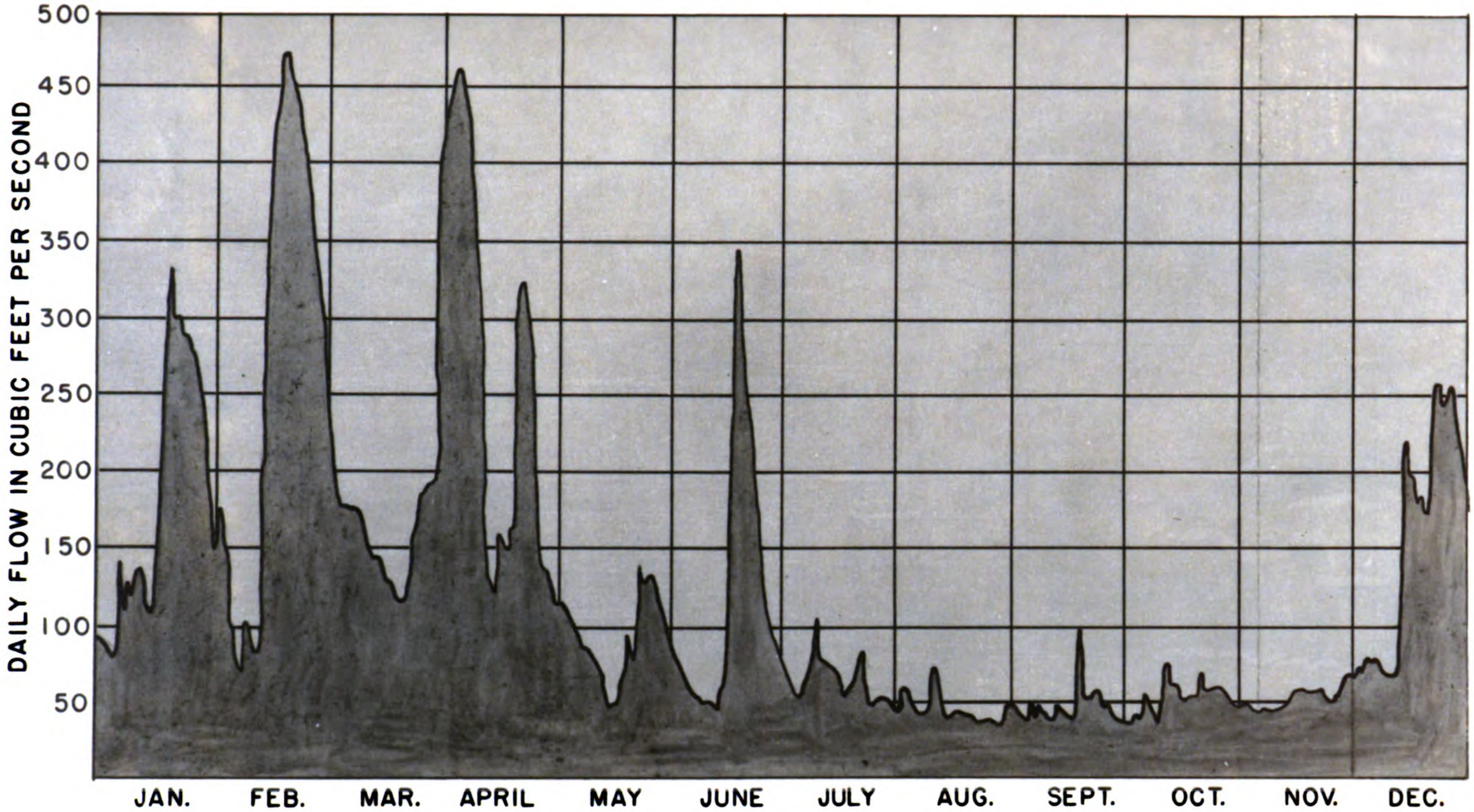
[1] C. J. Velz and J. J. Gannon, op. cit., p. 296.

ANNUAL HYDROGRAPHIC FLOW DURING 1949

GRAND RIVER AT JACKSON, MICH.
174 SQ. MILES



FLOW DURATION STUDIES OF 14 YRS. OF RECORD INDICATE RIVER FLOW EQUAL OR EXCEEDS 20 c.f.s. 95 % OF THE TIME.

Figure 2

1,000, judging by the 368 decline between 1950 and 1960, or representing a change of -0.7 percent. However, a two to three MGD increase in sewage is expected from the anticipated sewage connections with peripheral communities. This would result in a 31.5 percent increase over the present 9.52 MGD average sewage flow. This, in turn, would increase the required minimum flow to 14.3 cfs + 4.5 cfs or 19.8 cfs. This additional flow must be produced in the 174 square miles of watershed above Jackson, which is already responsible for a ten-year variability ratio of .440, .488, .475, and .464 for one-day, seven-day, fifteen-day, and thirty-day periods respectively.[1] The following chapter discusses the present and future water supply, and will describe the influence that anticipated land use change will have on this flow requirement at Jackson for proper sewage dilution.

Lansing

The primary reason for which Lansing is dependent upon Grand River flow is again for sewage plant effluent dilution. The Lansing sewage treatment facility serves a population of 113,379.[2] The average resultant treated sewage was 18.34 MGD or 153 GPD/capita in 1961. The facility presently has a 30 MGD capacity, well over that required for

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[1] Ibid., p. 293.

[2] The superintendent of the Lansing sewage disposal plant provided the sewage operation statistics.

the city's present population, but none the less, in three years, construction will be completed that will increase the capacity to 50 MGD or sufficiently to serve the anticipated 1980 population of 178,000.

The present plant operation removes 90.2 percent of the BOD. This leaves 9.8 percent of the 4 cfs/1,000 population as the required flow of the Grand River to properly dilute the sewage plant effluent of 0.392 cfs/1,000 population. This means that required flow at Lansing should be 44.44 cfs. However, if the oxidizable nitrogen continues to be released at the present high level, a flow of 300 cfs would be required at Lansing.[1]

Minimum flow of the Grand River at Lansing has fallen below this minimum 44.44 cfs rate three times in the last 28 years, and falls below the 300 cfs mark every summer, even when calculated as a 30-day average. This does indicate a serious condition, and in order to properly handle the effluent load for 178,000 people in 1980, some modifications must occur in the 1,385 square mile drainage system upstream of Lansing to increase the flow to 0.392 cfs x 178 or to 69.78 cfs. Possibly even 408 cfs will be required if the extreme nitrification continues. This represents a minimum flow increase of 36 percent or 25.34 cfs without the nitrification problem and 108 cfs with continued nitrification.

It must be kept in mind when considering these values that these are representative only of the residential sewage treatment requirements

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[1] Water Resources Conditions and Uses in the Upper Grand River Basin, op. cit., p. 121.

and not those of the industrial requirements. According to the Battelle Memorial Institute,[1] BOD generation from manufacturing in the Tri-County region in 1960 was 21 percent greater than residential BOD generation, and in 1980 it will be 39 percent greater. Also, as determined from Battelle figures, commercial, manufacturing, and municipal BOD generation was 42 percent that of residential BOD generation in 1960, and in 1980 will be 54 percent that of residential BOD generation. Translated into the terms previously used to show the required cfs of river flow necessary to handle residential sewage effluent, an approximate figure for total minimum river flow required at Lansing to handle total sewage effluent without nitrification would be 63.1 cfs in 1960 and 107.46 cfs in 1980. With nitrification the requirement was 116.7 in 1960 and 198.8 cfs in 1980. The seven-day average minimum flow at Lansing has already fallen below this 1980 non-nitrification requirement seven times in the last 28 years and sixteen times if only one-day averages are considered. Combined with this more apparent low flow threat is the additional uncertainty induced by the ten-year river flow variability ratio, which at Lansing amounts to .268, .390, .398, and .420 for one-day, seven-day, fifteen-day, and thirty-day periods respectively.[2]

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[1] D. A. Crane, et al., Long-Range Water Use Planning for the Tri-County Region (preliminary report), Battelle Memorial Institute, Columbus, Ohio, April 8, 1963, p. V9.

[2] C. J. Velz and J. J. Gannon, op. cit., p. 293.

The following chapter will make clear the relationship between the above mentioned flow requirements and the future flow that can be expected as a result of anticipated land use change.

Ionia

Ionia serves as a convenient measuring point for indicating the sum total result of the water regimen in the Upper Grand River Basin. Although the city itself does not suffer from inadequate low flow during the summer and fall months, the actual and projected total flow at this point serves to indicate what the downstream city of Grand Rapids might expect in terms of flow from the Upper Grand River Basin. The Grand Rapids dependence factor on Grand River flow should be expressed in terms of sewage treatment plant effluent dilution requirements rather than in terms of supply due to the fact that supply expansion would cost the same whether it is by way of a Lake Michigan pipe supply or more intensive treatment of Grand River water.[1] And the additional expense of making upstream modifications solely for supplying Grand Rapids sufficient quantities of water during low flow periods would add to the expense and thereby make the river source a less feasible alternative.

The sewage BOD reduction at Grand Rapids is 80 percent to 85 percent efficient and the population served in 1961 was 225,000. Then, 20 percent of 4 cfs is 0.8 cfs/1,000 population or the required flow for

[1]Personal correspondence with Mr. Elmer Bauhahn, of the Grand Rapids Water Works, Grand Rapids, Michigan.

treated sewage effluent dilution is 180 cfs. Minimum flow has never fallen below this level, even for a one-day average, but it has fallen as low as 381 cfs in 1936. The superintendent of the sewage treatment works, Huntley DeLano, and the superintendent of the water works provided data that indicated they did not consider the need for additional Lake Michigan water as urgent as did various consulting firms.[1] Thus, Grand Rapids is actually not in the desperate situation that various consulting firms would like to have one believe existed. Consequently, Grand River flow at Ionia will be expressed in the following chapter only as a statement of conditions at the lower end of the Upper Grand River Basin.

Overall Indicators of Grand River Flow Requirements

A general idea of the sewage treatment condition can be obtained from Figure 3. In Jackson and Lansing the circled area designated as "untreated equivalent" is due primarily to the inherent inefficiency of the treatment facility. Eaton Rapids, Dimondale, Grand Ledge, and Portland show relatively large percentages of "untreated equivalent." This is not serious, however, because the effluent rate in comparison to river flow at those points is sufficiently small.

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[1]a) Report on Water Supply for Kent-Ottawa Metropolitan Water District and Grand Rapids, Michigan, Black, Veatch Consulting Engineering, Kansas City, Missouri, 1956.

b) City of Grand Rapids, Michigan, Report on Water Supply Improvements, 1954, Revised February 1955, Consoer, Townsend and Associates, Consulting Engineers, Chicago, Illinois.

SEWAGE TREATMENT

UPPER GRAND RIVER

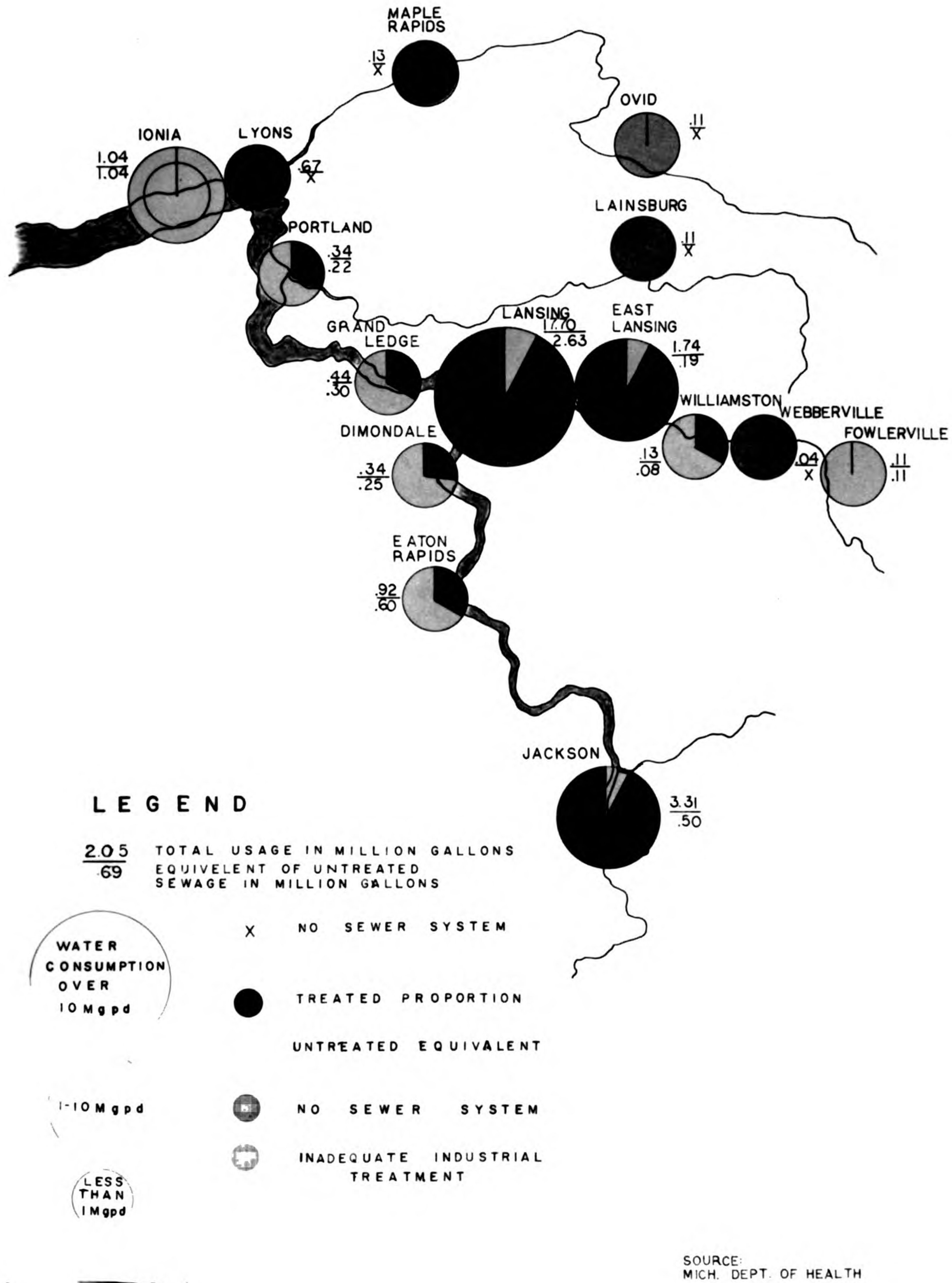


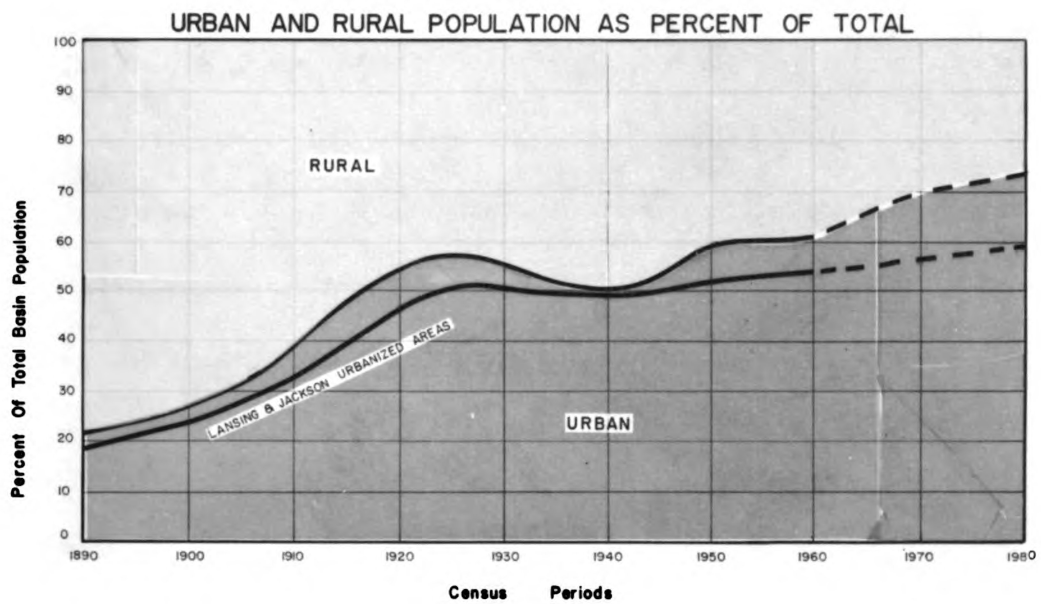
Figure 3

At Ionia, the only city on the Upper Grand River with no treatment facilities, but with a sewer system, plans are being completed to provide at least primary treatment. This will be accomplished by way of thirty-year 5 percent bonds for a lagoon system costing $58,838.

Population growth values, as indicated on Figure 4, also serve as indicators of water requirement. The percentage chart readily reflects the highly urbanized nature of the basin. The Lansing and Jackson urbanized areas could experience a 38 percent population increase from 1960 to 1975, according to this Figure, or an additional flow requirement of 680 cfs for residential needs alone. The graph designating actual population values serves well to show that both rural and urban population might increase at a rate of 100,000 each ten years. This rapid population increase, particularly that in urban regions will also influence the runoff from the resultant expanded urban regions, as will be discussed in the following chapter.

POPULATION GROWTH

Upper Grand River Basin



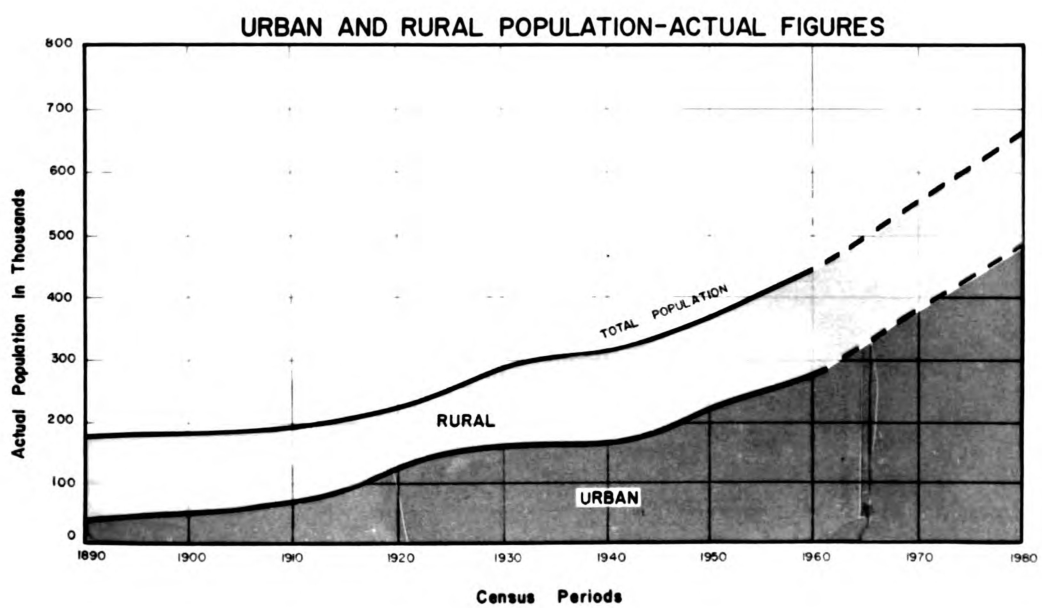


Figure 4

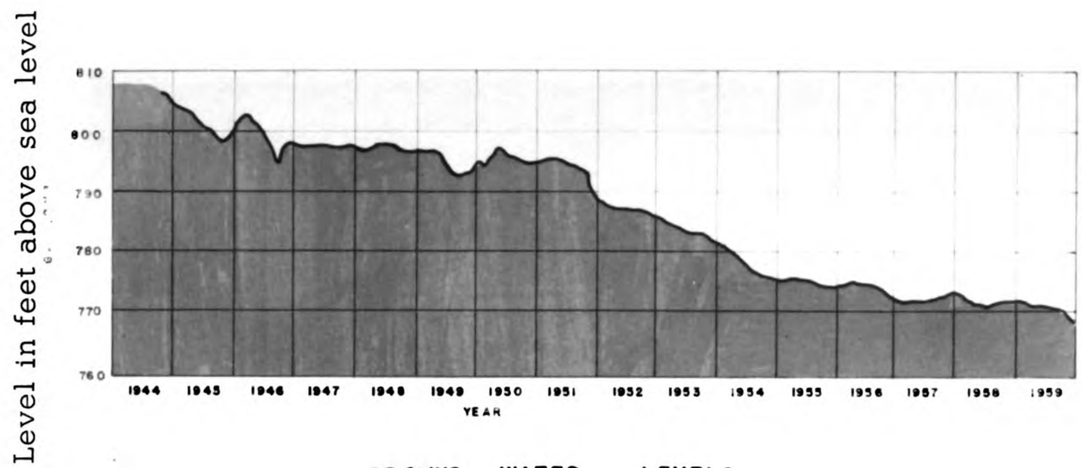
Present and Projected Water Supply

Present Supply in Critical Regions

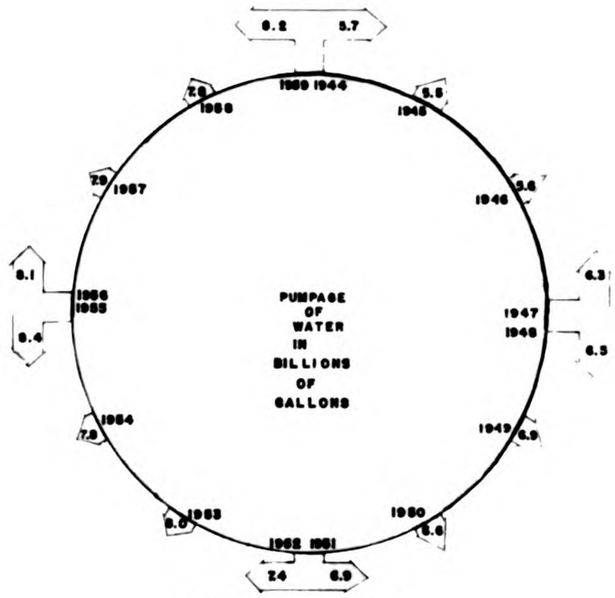
In this discussion water supply will be referred to as that water flowing in the Grand River. Other supplies such as those from well sources will not be considered in detail because well sources in this region are not generally in immediate danger of depletion. In Jackson, for instance, the city has acquired rights to the well field recharge area. There, the recharge is so obvious that a direct correlation had been made between river level and recharge rate. The lag time between infiltration through the river bed and the appearance of that water in the wells is two to three days. There seems to be little danger that Jackson will suffer from an immediate well water shortage.

Lansing has experienced a steady decline in its water table due to increased pumpage as illustrated in Figure 5. However, according to Mr. David Johnson of the United States Geological Survey in Lansing, the falling water table is fairly well stabilized now due to better well spreading and regulated pumping, although climatic changes still cause two to four foot changes in level. Precipitation is still responsible for the greatest amount of recharge water, but the Grand River has become influent in the Lansing area and consequently contributes substantially to the ground water reservoir.

The river water supply for purposes of proper sewage dilution does represent a pressing contemporary situation. To illustrate this condition



GROUND WATER LEVELS



WATER PUMPAGE

DATA FOR LANSING AREA

Figure 5

the following table indicates the daily and seven-day average minimum flow in Jackson and Lansing from 1935 to 1959.[1]

TABLE 2. Minimum Flow at Jackson and Lansing in cfs

	Jackson		Lansing	
	Daily Average	Seven-Day Average	Daily Average	Seven-Day Average
1935	20	22.7	72	102.
1936	12	14.0	25	44.4
1937	39	43.9	160	189.
1938	36	39.0	94	121.
1939	26	30.3	48	75.4
1940	28	30.0	50	92.1
1941	14	19.0	20	69.9
1942	29	34.0	92	152.
1943	50	56.0	187	281.
1944	29	37.7	76	127.
1945	33	35.6	145	176.
1946	20	24.1	43	78.4
1947	38	49.9	214	232.
1948	22	27.9	70	133.
1949	31	35.1	97	168.
1950	39	42.9	154	191.
1951	44	46.9	156	194.
1952	30	35.9	123	162.
1953	15	21.0	76	127.
1954	20	30.0	89	157.
1955	19	29.6	84	114.
1956	30	32.1	101	146.
1957	25	33.3	123	176.
1958	23	25.0	116	167.
1959	28	29.3	140	108.
25 Year Average	28	33.0	102.2	143.3
Deviation	+22 -16	+23 -29	+112 -82	+138 -99

[1] Velz and Gannon, op. cit., pp. 296 and 313.

These flows are the direct product of surface runoff and base flow, the latter being the most important during summer low flow periods. For the purpose of illustrating the variation between these low flows and the annual mean flow, Jackson's twenty-five year mean annual flow was 119.2 cfs, with a high of 203 cfs in 1943, and a low of 70.7 cfs in 1936, and Lansing's 31 year mean annual flow was 845 cfs, with a high of 1,410 in 1943 and a low of 431 cfs in 1935. Various forces, primarily those resulting from land use change, will act on the critical summer low flow. Some deliberate agricultural measures such as irrigation and soil conservation techniques act on the base flow characteristics of a region. Other changes effect less obvious influences on the low flow. Included in this category are the changes caused by urbanization. These land use changes, particularly those which will specifically have the greatest influence on the Upper Grand River flow will be discussed in the following section.

Forces That Will Act on the Grand River Flow

Certain land use changes are predicted or recommended for the Upper Grand River Basin. The anticipated agricultural land use changes were obtained primarily from a recent study by the Soil Conservation Service concerning soil and water conservation needs.[1] As applied to

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[1]Soil Conservation Service, An Inventory of Michigan Soil and Water Conservation Needs, published by Michigan State University Agricultural Experiment Station (no date, but probably 1962). (Unpublished original data was also used extensively.)

the Upper Grand River Basin, the anticipated changes were determined by using both individual watershed data and the county percentage conversion factors, found in Appendix A, for translating the county information into watershed data. A straight percentage conversion of this nature did not seem inaccurate considering the fact that the SCS information was based on a 2 percent sample. The difference between Census information and expanded SCS estimates of land use ranged from +24.2 percent to -10.1 percent according to Heneberry.[1] This range of inherent inaccuracy in the basic agricultural land use data makes it impossible to project runoff and infiltration changes because the magnitude of the hydrologic changes due to changed agricultural land use is far less than that displayed by the variability in the original land use data. The runoff change resulting from changed crop type is less than 15 percent and usually less than 10 percent, as indicated by the runoff figures in Chapter II. Thus, the basic information available concerning anticipated crop type and acreage were not considered accurate enough to make a valid projection on this basis.

This is not a serious limitation, however, according to the available SCS information, as illustrated on Figure 6. Only 76,000 acres will be eliminated from cropland, forest and woodland, and pasture and range use in the next fifteen years. This is only 4 percent of the total area

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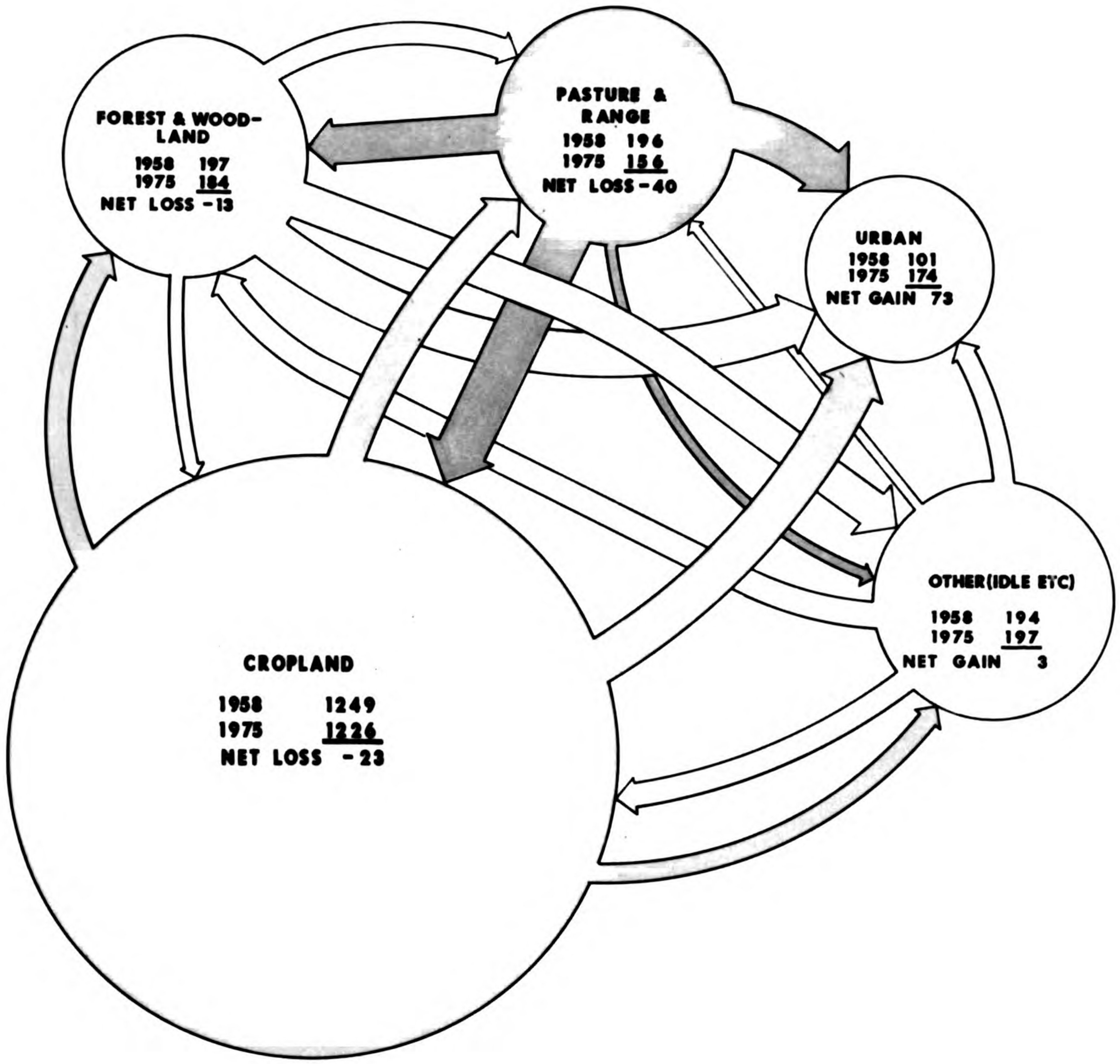
[1]William H. Heneberry, Differences Between 1954 Census and Expanded Soil Survey Estimates of Land Use in Michigan, unpublished, undated.



EXPECTED LAND USE CHANGES 1958 - 1975
(THOUSANDS OF ACRES)
UPPER GRAND RIVER BASIN

SOURCE: MICHIGAN SOIL AND WATER CONSERVATION NEEDS INVENTORY

Figure 6

and 3,000 acres of this is only idle land which usually restricts runoff even more than cropland. The urban net gain of 73,000 acres is significant and will be discussed in the urban section that follows the next section about agricultural water management.

Of greatest significance in the SCS report is the section about agricultural water management. In this section the opinion is expressed that more drainage problems exist needing project action than any other type problem such as flood water and sediment damage reduction, erosion damage reduction, and irrigation. Acreage requiring project action is said to be 85,000 acres or 5 percent of the Upper Grand River Basin area. The cumulative impact is illustrated in Table 3. This 5 percent increase in drained area could have an extremely significant influence on low flow, due to the effect drainage has on speeding the runoff cycle. It could safely be assumed that the resultant runoff would occur before low flow periods and thus decrease summer low flow even more. This assumption is made because drainage would lower the water table considerably and it is this water which contributes to base flow during summer low flow. A discussion with Mr. Arlington Ash of the United States Geological Survey and Mr. Dale Granger of the Michigan Water Resources Commission revealed that apparently no published information is available concerning quantitative agricultural drainage-runoff relationships.

TABLE 3. Cumulative Impact of Proposed Drainage Projects in the Upper Grand River Basin

Watershed Communities	Total Acreage	Acreage Needing Project Activities	Percent of Upstream Area
873	122,560	0	
Total at Jackson	122,560	0	0
61	236,600	4,000	
860	111,080	2,000	
861	140,864	2,190	
874	68,000	1,000	
875	108,000	3,000	
Total at Lansing	787,104	12,190	1.5
861	196,224	3,050	
865	127,720	0	
866	55,000	0	
867	307,000	30,200	
868	115,000	18,000	
869	58,000	0	
876	171,440	22,400	
Total at Ionia	1,817,488	85,840	4.7

In terms of quantitative figures it is unfortunately not possible to express the exact cfs change that agricultural land use change will have on Grand River flow. However, it is possible to make the inference from available information that agricultural land use change and conservation measures will essentially diminish the base flow rate. The exact amount of change is difficult to estimate, but an assumption on the basis of the percentage of land expected to experience drainage installation and the percentage of land expected to go out of agriculture, as will be described in the next section shows that roughly a 5 percent decrease could be expected in low flow assuming present trends continue.

The Influence of Urban Land Use Change

Having discovered that agricultural land use change, as determined by the SCS, is not sufficiently accurate to be used in deriving the resultant change in stream-flow and runoff relationships, another approach must be considered. This approach also involves agricultural data, but the enumeration used is that of acreage in farms as a percent of total area in acres. The assumption was made by Steinmueller, Hostetler, and Jensen that the non-agricultural remainder of farm acreage is representative of the urban land.[1] Because a major part of the urbanization that would influence runoff would occur in the peripheral regions of metropolitan areas, the townships surrounding metropolitan areas were designated by total acreage, farm acreage and percent for 1930, 1940, 1950, and 1960. This information, taken from the Steinmueller, Hostetler, and Jensen study, for the two large Upper Grand River metropolitan areas of Jackson and Lansing, reveal the information found in Table 4.

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[1]Milton H. Steinmueller, John E. Hostetler, and Clarence W. Jensen, "Urbanization and Its Effects in the Rural Areas." Unpublished research, June 1963.

TABLE 4. Peripheral Urbanization

	1930	1940	1950	1960	Interpolated 15 Year Project Percent	1975
Metropolitan Area -- Jackson						
Total Area	451,008	-------	-------	-------		
Farm Acreage	362,083	378,239	349,089	303,392		
% in Farms	80.28	83.86	77.40	67.26		
% Non-Farm (urbanized)	19.72	16.14	22.60	32.74		
Non-Farm Acreage (urban)	88,925	72,769	101,919	157,616	+44.57	227,861
Population	37,117	43,452	56,837	81,274	+38.30	112,403
Metropolitan Area -- Lansing						
Total Area	528,896	-------	-------	-------		
Farm Acreage	453,964	450,321	426,060	433,954		
% in Farms	85.83	85.14	80.55	82.04		
% Non-Farm (urbanized)	14.17	14.86	19.45	17.96		
Non-Farm Acreage (urban)	74,932	78,575	102,836	94,942	+4.46	99,178
Population	41,414	55,601	72,354	93,564	+31.62	123,150

The 1975 projection was made on a percentage basis. The 1975 Jackson urban area increase would be to the order of 44.57 percent.

This corresponds roughly to the population increase and can be considered a reasonable percentage indicator of the urban land area that can be anticipated in fifteen years. However, the small percentage increase that appears to be Lansing's fifteen year rate of urban growth could well be misleading. It appears to the writer that a greater number of peripheral townships should have been included in the study by Steinmueller, Hostetler, and Jensen. On the one hand the acreages considered for the Lansing area could well have already experienced the initial surge of urbanization and that over-urbanization may even have occurred. Urbanization may also be occurring farther from the central city area than originally anticipated, and is probably occurring in the so-called bedroom communities surrounding Lansing.

However, for making a rough estimate of runoff increase resulting from urbanization, the Lansing value was modified to correspond relative to population with Jackson's percentage figure. This results in a 37 percent value for Lansing, or an acreage increase of 35,129 acres.

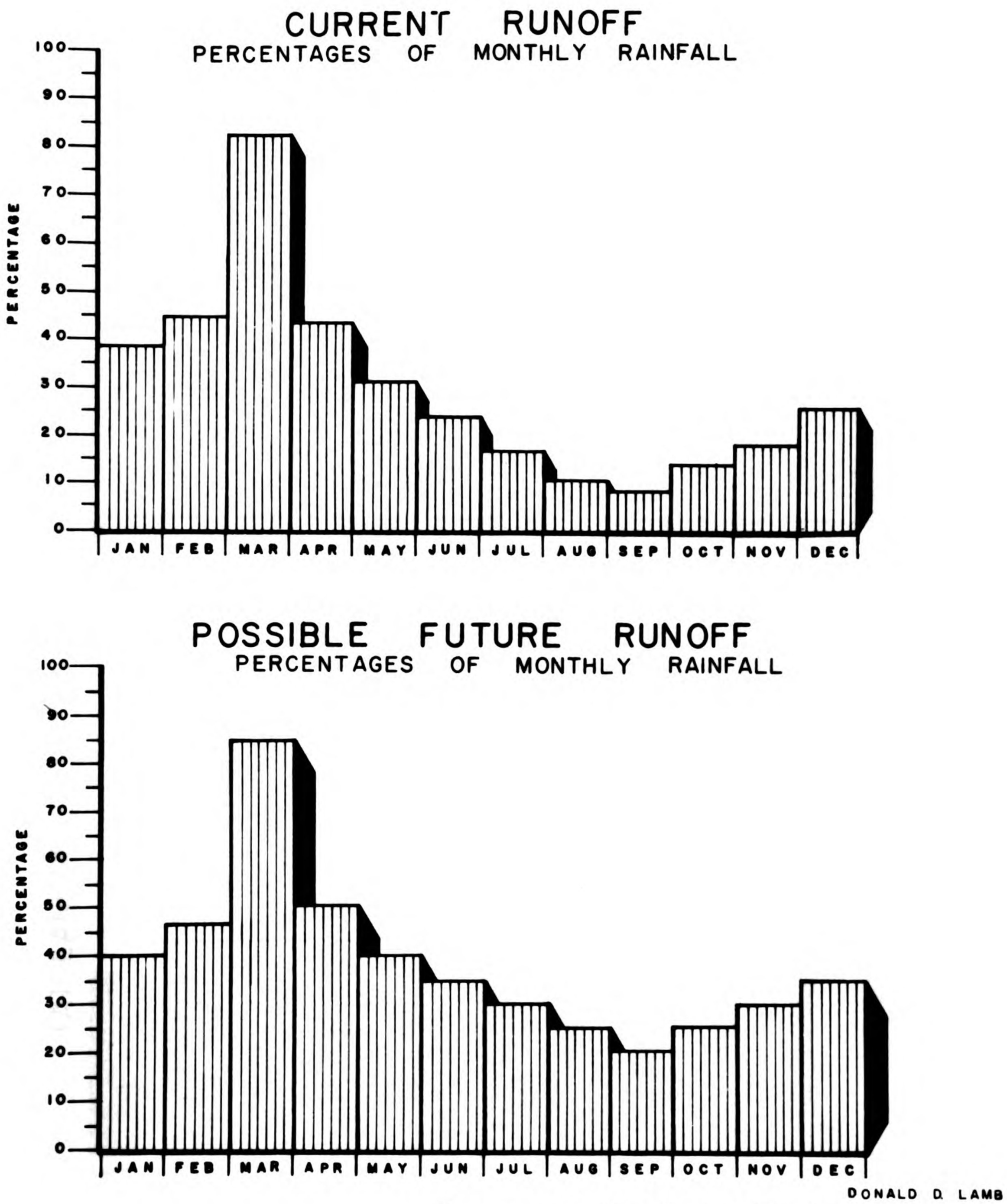
Using this information in combination with the previously mentioned urban runoff information and a knowledge of the runoff conditions in the basin, a rough approximation can be made of the influence urbanization will have on streamflow. First, urbanization of the nature expected in the Upper Grand River Basin would result in an approximate coefficient of runoff amounting to 0.5. Since average runoff at Lansing is 9.40 inches and the total average rainfall is 31.30 inches, 15.65 inches may become the runoff instead of 9.40 inches. This is an increase of 6.25 inches.

The combined acreage affected in this way near Jackson and Lansing alone is 85,374 acres. This is 11 percent of the area above Lansing. If the 20 percent runoff increase from the 11 percent of the land is considered in relation to the rainfall and runoff data on Figures 7 and 8, then it becomes obvious that any decrease in runoff in the summer months could seriously affect the already existent low runoff. The bottom graph of Figure 7 indicates the possible future runoff using augmented reservoir flow. (The temperature graph is included in Figure 8 to illustrate the additional temperature created evaporation potential during the summer period.)

This potential runoff increase from urbanization is essentially a subtraction from Grand River low flow, because a great percentage of the increase would occur in the high rainfall seasons when low flow is not a problem. In other words, the cfs increase occurs as rapid runoff instead of contributing to the ground water reservoir which had previously provided a base flow to the river. (The critical state of this base flow at Jackson can be seen from the flow duration curve at Jackson, included in Appendix B.)

Thus it is evident that a change in Grand River flow can be expected in the next fifteen years. Unfortunately, all the important forces that are operating to modify low flow are exerting a diminishing influence.

UPPER GRAND BASIN



Source: United States Geological Survey

Figure 7

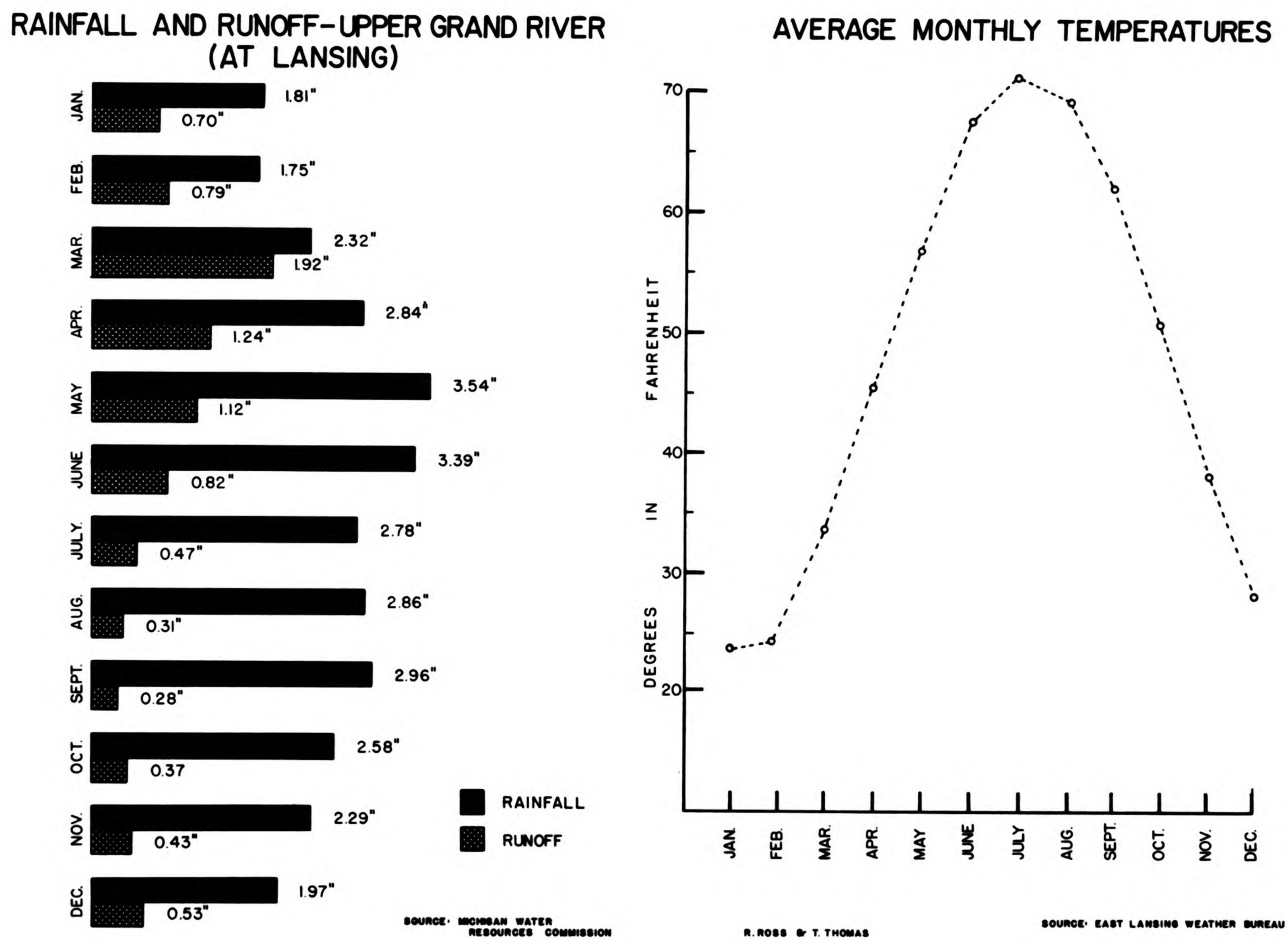

RAINFALL AND RUNOFF-UPPER GRAND RIVER
(AT LANSING)
JAN. 1.81" 0.70"
FEB. 1.75" 0.79"
MAR. 2.32" 1.92"
APR. 2.84" 1.24"
MAY 3.54" 1.12"
JUNE 3.39" 0.82"
JULY. 2.78" 0.47"
AUG. 2.86" 0.31"
SEPT. 2.96" 0.28"
OCT. 2.58" 0.37
NOV. 2.29" 0.43"
DEC. 1.97" 0.53"
RAINFALL
RUNOFF
SOURCE: MICHIGAN WATER RESOURCES COMMISSION
AVERAGE MONTHLY TEMPERATURES
DEGREES IN FAHRENHEIT
70
60
50
40
30
20
JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.
R. ROSS & T. THOMAS
SOURCE: EAST LANSING WEATHER BUREAU

Figure 8

Although the inherent error in land use data is of a greater magnitude than the actual change in flow that could result, it can nevertheless be safely assumed that the minimum flow will be a function of the combined effect of variability from the natural runoff influencing forces and the modifications in runoff imposed by man's land use change.

Augmented Flow

When the low flow threat becomes sufficiently serious as a result of the above mentioned forces, certain measures will remain for increasing low flow. Of primary importance is the potential value of low flow augmentation reservoirs. The Michigan Water Resources Commission has determined that an upriver reservoir storage of 60,000 acre feet would be required to maintain a 300 cfs minimum flow at Lansing.[1] Figure 9 indicates the reservoir capacities for various other minimum flows at Lansing, which have been appraised by the Water Resources Commission and are capable of storage in excess of the amount required to maintain minimum flow at Jackson and Lansing.[2] These sites will, however, probably not be developed until the economic impact of summer low flow is great enough to encourage development. Until that time two dangers exist. One is that the sites may be developed for other purposes and the other is that the river quality will degenerate to even greater lows.

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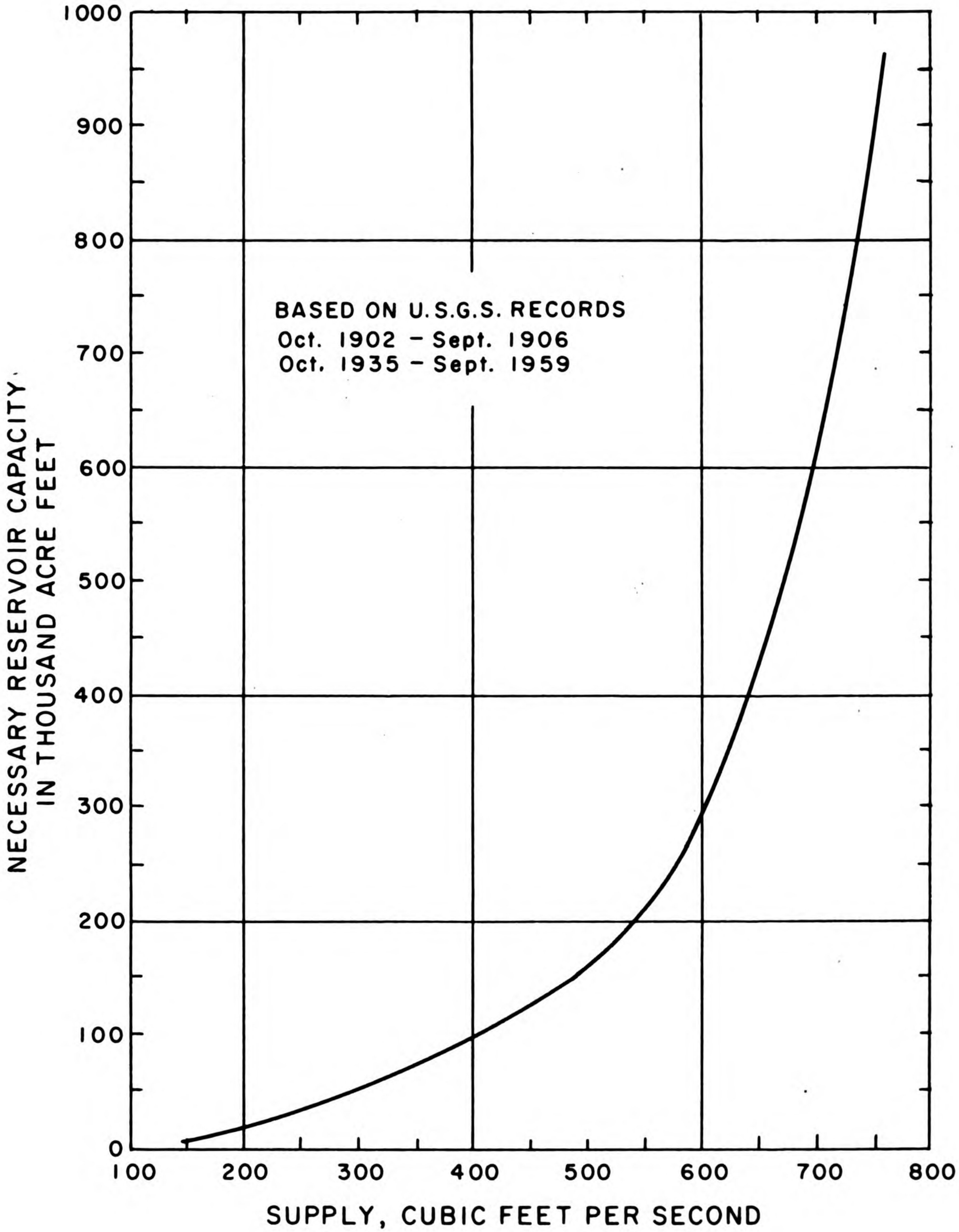
[1] Water Resources Conditions and Uses in the Upper Grand River Basin, op. cit., p. 121.

[2] Ibid., pp. 122-128.

STORAGE DRAFT CURVE FOR GRAND RIVER AT LANSING



SOURCE :
Michigan Water Resources Comm.

Figure 9

CHAPTER IV

SUMMARY AND CONCLUSIONS

The Upper Grand River summer low flow, according to the results obtained from this study will experience a slow but steady decline. Although total annual runoff will probably remain the same, the forces expected to act in this basin will essentially accelerate the runoff cycle. Thus flows will probably increase during the wet seasons and will diminish during the dry seasons or in times of lowest flow.

The various forces that control runoff and river flow were reviewed, and from these, those forces having the greatest influence on Upper Grand River flow were selected and studied more closely. These forces included agricultural land use change, agricultural soil conditioning measures, and urbanization. Grand River flow was found to be used primarily for sewage treatment plant effluent dilution. At Jackson, the flow requirement for this purpose must presently be increased by 14.3 cfs, and to meet the 1975 demand, a 19.8 cfs increase must occur. These demands were established on the basis of fixed demand per unit of population. The future demand was established on the basis of a percentage population change projection. At Lansing, the present flow must be increased to 300 cfs and by 1975, if the oxidizable nitrogen content of the effluent remains at the present high level, the flow must increase to 408 cfs.

Acting on these flow requirements are the flow-decreasing forces of present and anticipated land use change. Agricultural land use change is one such force. However, the inherent inaccuracy of projected agricultural land use for 1975, based on a 2 percent sample and a resultant error ranging from +24.2 percent to -10.1 percent, makes a projected runoff change impossible to make because the magnitude of the runoff change could only be to the order of 10 percent. But, even if the SCS projected land use change values were acceptable, only 4 percent of the land would go out of cropland, forest and woodland, and pasture and range use. If information of greater accuracy were available for surrounding river basins, interpolative procedures could have been used to reflect the condition in the Upper Grand River Basin. The other significant agricultural land use force that would influence runoff is drainage, and the SCS considers 5 percent of the Upper Grand River Basin to be in need of drainage project action. This could have great runoff acceleration potential, but no quantitative estimates can be made at this time.

Urbanization will also cause an additional runoff acceleration to the order of 20 percent in 11 percent of the area above Lansing. This could cause a 2 percent flow decrease during summer low flow due to urbanization.

There remains one important method for counteracting these flow diminishing forces, and that is the construction of flow augmentation reservoirs. Several sites capable of producing the needed flow augmentation are still available for this purpose. However, in time, these sites will become less available as development, particularly urban development, proceeds in these locations. Unfortunately, the Grand River condition in times of low flow will probably continue to degenerate until the economic benefit of increased flow exceeds the construction costs of storage reservoirs.

Another somewhat novel approach is available for improving the Grand River condition without the extensive use of augmented flow. The idea itself is based partially upon an experiment conducted in the Ruhr Valley of Germany. This involves attacking the water demand problem at the source. It is true that secondary sewage treatment now reduces oxygen demand by about 90 percent, but if tertiary treatment were performed, oxygen demand might be decreased nearly 100 percent. This might seem easier said than done, but a change in the river-use concept may be all that is involved. Today rivers are considered primarily as free drainage systems for nearly anything. However, if a river were considered in terms of a working and controlled unit, the river itself could perform additional and accelerated water quality improvement functions.

The condition of the Upper Grand River in particular would make this an ideal experimental location. The river should be divided into two channels, beginning at each large municipal area and extending a short distance downstream. The entrances to the channels would be controlled and sewage effluent would enter only one of the channels. In this sewage effluent channel flow rate, oxygen introduction, and bacterial population would be held at an optimum for decreasing BOD. Fish would be prevented from entering this channel. All additional relatively pure river flow would be diverted down the second channel, and here fish life and boating could continue. During flood periods, of course, both channels would be used to accommodate the additional water because adequate dilution would not be a problem. This is a particularly important possibility for the Lansing area, where a 9°F. river temperature increase, resulting from power plant cooling operations, significantly increases the oxidizable nitrogen potential. Thus, it seems that a fairly unique experimental solution is also available for the improvement of the steadily degenerating quality of the Grand River.

Although this study concerned itself only with those forces which control the physically possible quantities of river flow, this was not to imply that other forces such as economic, political, and legal do not also wield considerable influence.

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