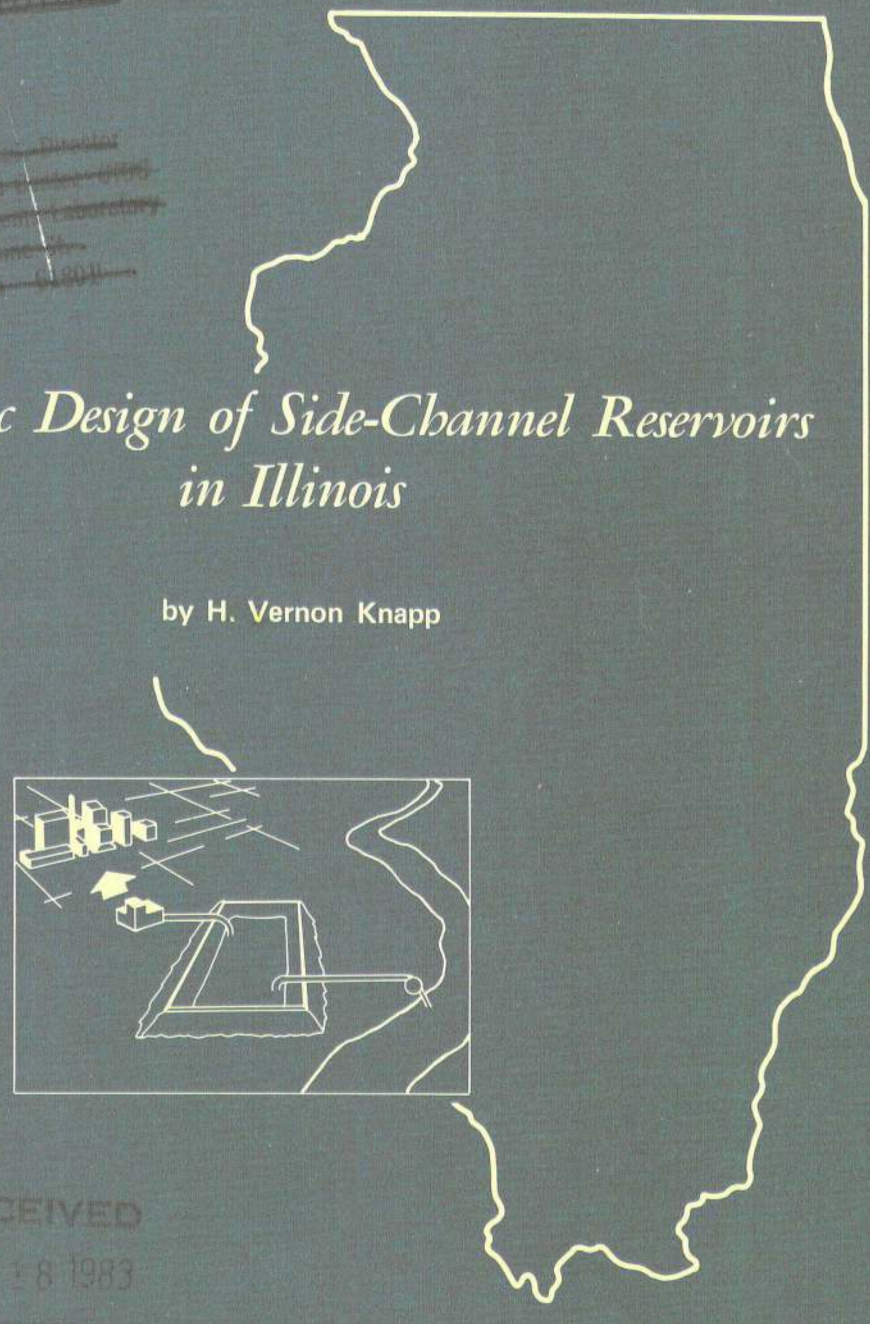
ISWS/BUL–66/82
BULLETIN 66
STATE OF ILLINOIS
DEPARTMENT OF ENERGY AND NATURAL RESOURCES

Hydrologic Design of Side-Channel Reservoirs in Illinois

by H. Vernon Knapp



Prepared for
DIVISION OF WATER RESOURCES
ILLINOIS DEPARTMENT OF TRANSPORTATION

ILLINOIS STATE WATER SURVEY
CHAMPAIGN
1982

BULLETIN 66

Hydrologic Design of Side-Channel Reservoirs in Illinois

by H. VERNON KNAPP

Title: Hydrologic Design of Side-Channel Reservoirs in Illinois.

Abstract: This report provides data and methodologies for use in the hydrologic design and evaluation of side-channel reservoirs in Illinois. A side-channel reservoir is an off-stream storage impoundment into which water is pumped from a nearby stream. These types of reservoirs are seen as a viable alternative to conventional impounding reservoirs when the amount of storage required for water supply is relatively small. The data in this report include demand-storage-recurrence design graphs for 87 stream gaging stations in Illinois. These graphs are based on conceptual conditions at these stations, involving a mass analysis of the water pumped into the reservoir, withdrawals, and reservoir evaporation. The amount of water pumped into the reservoir, and hence the storage analysis, is dependent not only upon the variability of the stream low flows, but upon both the design of the pumping station and the imposition of instream flow restrictions. Procedures are presented which allow the engineer to estimate the effect of these two latter factors on the storage analysis of the reservoir.

Reference: Knapp, H. Vernon. Hydrologic Design of Side-Channel Reservoirs in Illinois. Illinois State Water Survey, Champaign, Bulletin 66, 1982.

Indexing Terms: Instream flow, pumping systems, side-channel reservoirs, storage analysis, water supply storage.

STATE WATER SURVEY DIVISION
STANLEY A. CHANGNON, JR., M.S., Chief

CHAMPAIGN
1982

Printed by authority of the State of Illinois
(SWS-6-82-200)

CONTENTS

Hydrologic Design of Side-Channel Reservoirs in Illinois

by H. Vernon Knapp

INTRODUCTION

Whenever the demand for water supplied by a stream exceeds the stream's minimum flow level, a storage of water must be developed in order to satisfy the demand. The conventional method of creating storage is to build a dam on the stream, allowing excess streamflow to be retained in an on-stream reservoir upstream of the dam. The hydrologic design of these conventional reservoirs in Illinois is most recently covered in Terstriep et al. (1982). Such reservoirs typically store from 10% to over 100% of the average annual flow of the stream.

Frequently the amount of storage required for a small water supply system is a small percentage of the amount of water which flows in the stream during a normal year. However, many economic and environmental disadvantages are associated with small reservoirs. For example, even the smallest on-stream reservoirs are required to allow the passage of large floods. This necessitates the construction of a large, usually expensive, spillway. Furthermore, small on-stream reservoirs are subject to great rates of sedimentation, and on-stream reservoirs of any size seriously affect the ecology of the stream. For these reasons, another type of storage facility, the side-channel reservoir, is viewed as a serious alternative to on-stream reservoirs in many cases.

A side-channel storage reservoir is an impoundment into which water is pumped from a relatively large stream during those periods when the streamflow is sufficient. Streamflow sufficiency is defined in each individual case with the consideration of instream flow needs, to be discussed later.

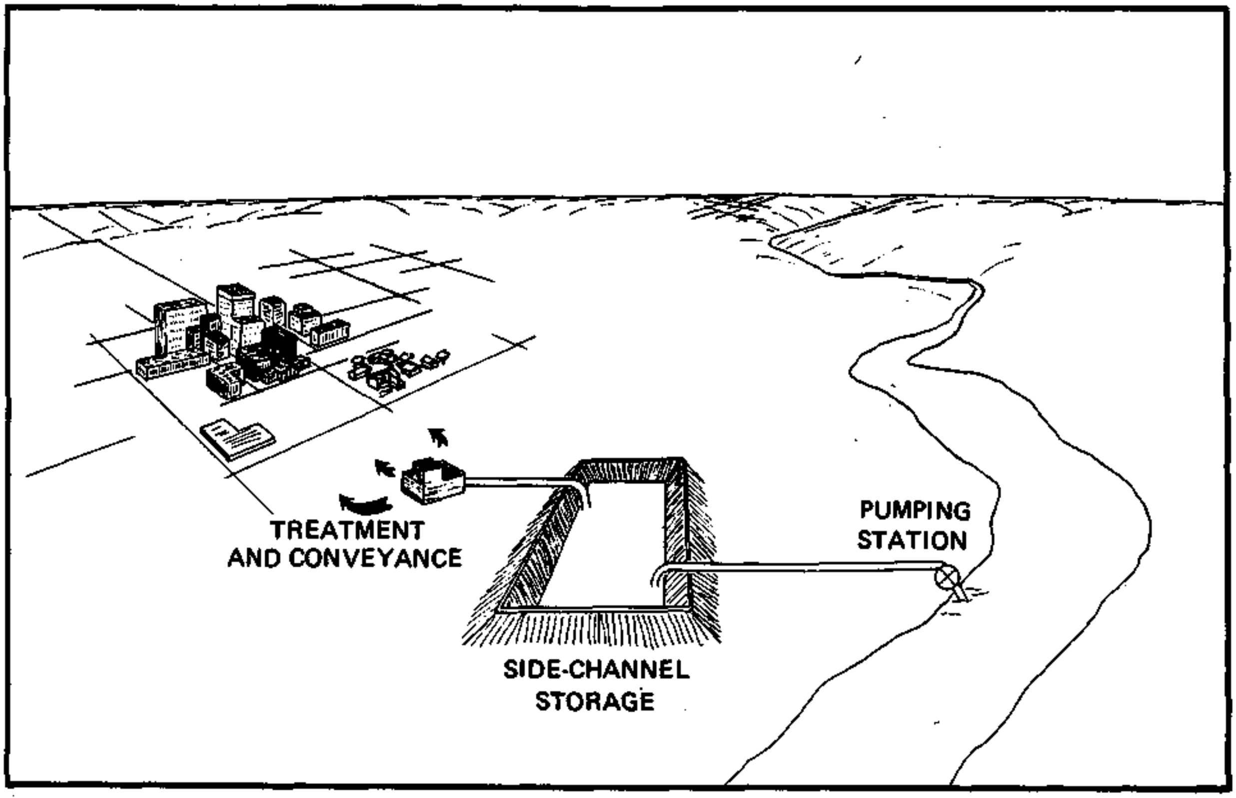


Figure 1. Illustration of a Side-Channel Reservoir System Used for Municipal Water Supply

An example of a side-channel reservoir is shown in Figure 1. The reservoir shown is of a cut and fill design, which is considered the standard side-channel reservoir design. Side-channel reservoirs can also be located in other topographic depressions, such as an impounded small stream valley or an abandoned quarry. In most of these cases, the side-channel reservoir will be isolated from surrounding drainage patterns such that the pumped inflow and precipitation are the only sources of water entering the reservoir.

The design of the amount of side-channel storage necessary to meet a particular demand requires a study of all of the factors that affect the amount of pumped water which enters the reservoir. These factors include not only the volume of the demand and the variability of the streamflow, but also aspects of the design and use of the pumping system which delivers the water to the reservoir. The purpose of this report is to provide compiled data that directly address these factors. In addition, a procedure is recommended concerning the use of these data, which will provide the professional engineer with the information necessary for sound side-channel reservoir storage design.

This report is presented in two parts. Part 1 describes the development of the methodologies used to describe not only the standard design-storage-recurrence relationships for individual streamflow records, but also the relationships between required design storage and aspects concerning the design and operation of the side-channel reservoir pumping system. Part 2 includes the storage design curves as developed for 87 streamflow records and arranged into regions of relatively homogeneous character. In addition, a step-by-step procedure is recommended for use in developing a reservoir storage and pumping system design at both gaged and ungaged sites in Illinois.

Acknowledgments

This study was funded by the Illinois Department of Transportation, Division of Water Resources, and was prepared under the direction of Michael L. Terstriep, Head, Surface Water Section, and Stanley A. Changnon, Jr., Chief, Illinois State Water Survey. Dr. Krishan P. Singh contributed helpful comments throughout the study. Mrs. J. Loreena Ivens provided the technical editing; John Brother, William Motherway, Jr., and Vicki Stewart prepared the illustrations; and Lynn Weiss typed the final report.

PART 1. Analytical Methods for Side-Channel Reservoir Storage Design

CONSIDERATIONS IN THE DESIGN OF SIDE-CHANNEL RESERVOIRS

Side-channel reservoirs are usually designed for one purpose, that being municipal or industrial water supply. By not being located on the stream, the side-channel reservoir is not subject to flood control objectives. Furthermore, because side-channel reservoirs are usually small and have fluctuating water levels, they are not favorable for recreational or fishery interests. With the absence of alternate objectives, the design and maintenance of the reservoir may be directed more efficiently toward the purpose of water supply, and the design of the reservoir storage becomes a much simpler process.

Numerous other differences exist between standard on-stream and side-channel reservoirs. An obvious and major distinction is the impact of the reservoir on the stream. The modification of the stream environment by the standard on-stream reservoir is both complete and well documented, and it is one of these modifications, i.e., reservoir sedimentation, that is directly responsible for the obsolescence of many on-stream reservoirs. In addition, although the on-stream reservoir provides a favorable habitat for certain forms of aquatic life, it disrupts the habitat of much of the natural biota.

The modification of the stream environment caused by a side-channel reservoir is associated with the pumping system located on the stream. The degree of environmental modification caused by the pumping system is primarily a function of the amount of water withdrawn from the stream, and hence is dependent on the gross demand of the reservoir. Whenever the gross demand of the reservoir is as much as 10% of the mean annual flow of the stream, the removal of streamwater through pumping will greatly affect the downstream distribution of flow. However, frequently the pumping system can be operated in a manner that minimizes the detrimental effects to instream flow needs. When the gross demand of the side-channel water supply system is less than 1% or 2% of the mean annual flow, there is no reason to believe that the associated pumping will have any detrimental effects on the stream environment, other than to the immediate locale of the pumping.

Side-Channel Reservoir Sedimentation

Whenever water is pumped from the stream to the side-channel reservoir, the sediment suspended in that water will be deposited in the side-channel reservoir. An investigation of the rate of the deposition of suspended sediment into side-channel reservoirs is not included in this study; however, the sedimentation rate is expected to be relatively low for the following reasons: 1) the volume of water which passes through the pumping system and into the reservoir is essentially equal to the gross demand and as such is generally a small portion of the total streamflow; and 2) the pumping system will be able to pump only a small percentage of the large floodwaters that carry a great proportion of the stream's annual sediment load. In many situations, the side-channel reservoir pumping system does not need to be in operation when the streamflow is especially turbid.

Storage Design Hydrology

The major difference in the water supply hydrology between a side-channel reservoir and a standard on-stream reservoir is that the amount of water entering the side-channel reservoir is the discharge pumped out of the stream, and is not the actual streamflow volume. The pumped discharge is not only dependent on the variability of the streamflow, but also upon 1) the discharge capacities available with the pumping system, and 2) the amount of streamflow which is allowed to pass the pumping system for instream flow considerations. Because the mass of water entering the reservoir is dependent on factors other than the variability of streamflow, the ordinary mass analysis for storage design (using the Rippl diagram) is not appropriate for determining the amount of storage needed to meet a specific demand. For this reason a modified mass analysis technique, described in a later section, was developed which determines the side-channel reservoir storage necessary for meeting certain demand levels.

The factors affecting storage design that are associated with the side-channel reservoir pumping system are not constant for a given site and demand rate. For this reason, alternate choices exist for the joint design of the reservoir storage capacity and the pumping system. For example, pumping systems which offer a wide and more continuous range of discharge capacities are more efficient in supplying the side-channel reservoir with water during low flow periods than are elementary pumping systems. Use of more efficient (and generally more expensive) pumping systems reduces the amount of storage needed in the side-channel reservoir. Ultimately the engineer must judge the various options with criteria such as 1) the operational reliability of the system, 2) maintenance and repair requirements, 3) flexibility of the system for growth, and most importantly, 4) the total costs involved in implementing each option.

Side-Channel Reservoir Costs

The costs unique to a side-channel reservoir system are those costs involved with the construction of the reservoir and with supplying the reservoir with streamwater. Beyond these costs exist treatment and conveyance costs which are associated with any water supply system and for this reason are not discussed. The costs associated with the construction of the reservoir include land costs, expenses for earthmoving and land clearing, and the costs of riprap, stone bedding, and reservoir lining. The average composite cost of side-channel reservoir construction, C_{RES}, can be expressed as a function of the storage capacity of the reservoir, S, and is estimated as:

$$C_{RES} = 15{,}000\ S^{.6} \tag{1}$$

in which C_{RES} is expressed in 1982 dollars and S is in acre-feet (adapted from Camp Dresser & McKee, 1980). The addition of a synthetic reservoir lining may double the reservoir cost given by Equation 1.

Additional costs involved in the installation of a side-channel reservoir system are those associated with supplying the reservoir with streamwater, i.e., costs for 1) the intake station, 2) pipes leading to the reservoir, 3) the pumps, and 4) accumulated energy costs used in pumping. The composite of these costs generally ranges from 15% to 50% of the reservoir construction costs, being comparatively lower for large reservoirs. Most of these costs are closely related to the total volume of water passing through the pumping system (essentially the gross demand of the reservoir) as well as the distance of the reservoir from the stream. Hence, for a given demand level and reservoir location most of the costs are not highly variable. However, the number and the size of the pumps used in the pumping system can be varied, which affects the expenditures for pumps and to a lesser extent the costs of the intake station.

The differentiation in costs associated with the variability in the pumping system design is not significant in itself. However, as mentioned previously, a change in the size and number of the pumps employed can greatly alter the hydrology of the side-channel reservoir and in so doing may modify the storage required in the reservoir to meet the given demand level and recurrence interval. The magnitude of the effect on storage requirements caused by the variation in pumping system design is investigated in a forthcoming section of this report. The results of this study indicate that in many situations a comparatively inexpensive addition to a planned pumping system can greatly reduce the required design storage, and thus the cost of the reservoir construction. For this reason, the design of the pumping system is a consideration of primary importance in the planning process of a side-channel reservoir.

AVAILABLE STREAMFLOW AND NET EVAPORATION DATA

Streamflow Data

The basic streamflow data used in this study are daily flows recorded at 87 USGS gaging stations on Illinois streams between the years 1914 and 1978. The streamflow stations considered for use in this report include the 121 stations within the boundaries of Illinois possessing at least 25 years of daily flow records. Twenty-six of these stations, including 24 in the urban area of northeastern Illinois, were eliminated because the streamflow at these stations is subject to modifications that would alter the results of the analyses. In addition, 15 gaging records for streams having drainage areas exceeding 2000 mi^2 were not used for the analysis because these locations have minimum flows capable of supporting most water supply systems. Seven stations with records of from 20 to 25 years were included in the analyses to supplement the records in areas that otherwise lack proper coverage. The location and identification of the 87 streamflow gaging stations used are shown in Figure 2. Watershed and streamflow characteristics for each of these locations are presented in Part 2 of this report.

Net Evaporation Data

The net evaporation of a reservoir is defined as the reservoir evaporation minus the precipitation over the reservoir. Monthly lake evaporation estimates and precipitation measurements were available for the nine locations, in an around Illinois, identified in Figure 2. The lake evaporation for these locations was determined by use of the methodology presented by Roberts and Stall (1967). The precipitation measurements and the data used to develop the lake evaporation estimates were supplied primarily from the National Weather Service Climatological Data.

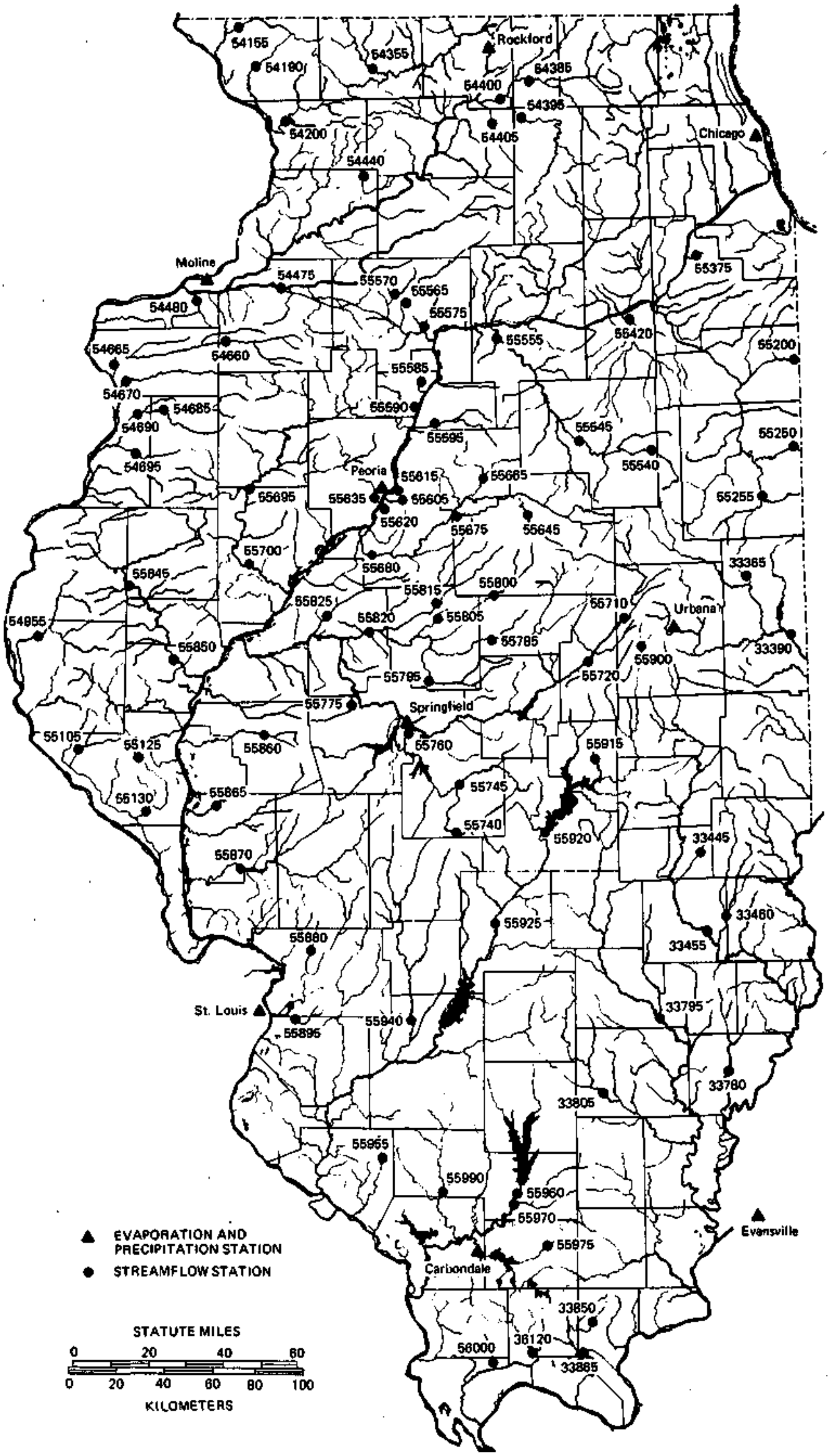


Figure 2. Location of Streamflow Gaging Stations used in Analyses

STORAGE ANALYSES FOR SIDE-CHANNEL RESERVOIRS

In standard reservoir design, the required storage is defined as a function of the gross demand on the reservoir (D) and the recurrence interval (T). An unstated component in this relationship is the cumulative streamflow (Q), which for any gaging station is a constant. This demand-storage-recurrence relationship is therefore given by the function:

$$S = f\ (D,\ T,\ \Sigma Q) \qquad (2)$$

The solution of this relationship involves fixing the demand as a constant for individual solutions. The storage requirement is then solved by a mass analysis of the streamflow, as the storage relates to the frequency of occurrence with which it is required (i.e., the inverse of the recurrence interval). The storage-recurrence relationships for several values of demand are usually presented in the form of curves on a graph.

However, in the storage design of side-channel reservoirs, Equation 2 takes the form:

$$S = f(D,\ T,\ \Sigma Qp) \qquad (3)$$

in which ΣQp is the cumulative streamflow available for pumping. ΣQp is dependent not only upon the streamflow variability, but also upon the design of the reservoir's pumping system and the minimum flow for which pumping is allowed (i.e., the instream flow policy). For example, assume that the reservoir storage is obtained from one pump located on the stream which has a fixed capacity of 500 gpm, and that no pumping will occur unless the streamflow (Q) equals or exceeds 900 gpm (2.0 cfs). Then:

$$Qp = 0 \text{ gpm, when } Q < 900 \text{ gpm}$$

$$= 500 \text{ gpm, when } Q \geq 900 \text{ gpm}$$

For every combination of pumping system and instream flow policy there exists a unique demand-storage-recurrence relationship. Rather than present numerous demand-storage-recurrence curves for each station of interest, a single demand-storage-recurrence relationship is presented from which storage values related to alternate pumping systems can be computed. This single storage relationship, hereafter described as the primary relationship, was developed with the use of a selected pumping system and instream flow policy. The pumping system chosen for determining this primary relationship is one in which a continuous range of pumping discharges is available up to 8 times the gross demand on the reservoir. The primary instream flow policy allows the pumping of any flow above that which occurs in the stream 75% of the time (Q_{75}). In addition, in the flow range between the 7-day, 10-year low flow ($Q_{7,10}$) and the Q_{75}, half of the flow above the $Q_{7,10}$ is available for pumping. The sensitivity of the demand-storage-recurrence primary relationship to 1) changes in the selected pumping system, and 2) alternate instream flow policies is investigated in forthcoming sections. Use of these sensitivity analyses allows for a wide range of pumping system designs and operation.

Modified Mass Analysis Technique

The water budget for any reservoir for a time period, t, is given by:

$$I_t = Dw + Dg + E_t + O_t - \Delta S_t \qquad (4)$$

in which I_t is the inflow into the reservoir, O_t is the reservoir outflow, Dw is the withdrawal demand, Dg is seepage into groundwater, E_t is the net evaporation (evaporation minus precipitation) over the reservoir, and is the change in reservoir storage, and is defined to be positive for <u>decreases</u> in storage volume. For side-channel reservoirs, the outflow is inherently equal to zero, and the reservoir inflow is equal to Qp, the streamflow available for pumping. Dg is usually taken as a constant, and is added to Dw to determine the gross demand, D.

Mass analysis is a method used to define the cumulative storage ($\Sigma\Delta S_t$) required to produce a given gross demand for each year of record. Because those low flows that necessitate storage occur most often in the late summer and fall, and do not occur in spring, the water year defined for mass analysis is taken to begin April 1 and end March 31 of the following year. The reservoir capacity needed to meet the gross demand during any given water year is the maximum accumulated change in storage (as defined in Equation 4) occurring for any time period ending in that water year. This maximum accumulated change is storage, S, is defined as:

$$S = \max \sum_{j=0}^{k} \Delta S_{t-j} \tag{5}$$

and is subject to the constraint:

$$\sum_{j=0}^{k} \Delta S_{t-j} \geq 0 \qquad j=0,\ 1,\ 2,\ 3,\ldots,k \tag{6}$$

The length of time over which the cumulative storage is maximized, is defined as the "critical period." The terminal date of the critical period, t, can occur any time within the water year of interest. Equation 5 is defined to allow carryover storage in the storage computation, should it be needed. Carryover storage is that storage needed in the second or third year of a drought when the reservoir inflow (pumped water) that occurs during the wet seasons of the drought is not able to refill the reservoir. The constraint, Equation 6, limits the computation of carryover storage to only those years which are applicable.

Treatment Of Evaporation

The implementation of the mass analysis described by Equations 4, 5, and 6 requires not only streamflow data, but also an estimate of the net evaporation of the reservoir. The total volume of net evaporation occurring over a reservoir is dependent upon the surface area of the reservoir, but the surface area is generally not known until after the design of the storage volume, i.e., after the completion of the mass analysis. In order to provide an estimate of the net evaporation for use in the mass analysis the following measures are used:

1) It is assumed that the relationship between the reservoir surface area, A, and the storage capacity, S, follows the empirical relation:

$$A = .2\, S^{.85} \tag{7}$$

in which A is expressed in acres, and S is expressed in acre-feet. The surface area is not expected to decrease significantly during periods of drawdown. With Equation 7, net evaporation can be expressed in terms of the storage capacity.

2) An iterative process is used in association with Equation 5, such that whenever Equation 5 computes a need for greater reservoir capacity, the net evaporation cumulated over the critical period is increased to allow for the greater reservoir surface area. Therefore, if we assume that the standard surface area-storage function is true, the amount of net evaporation is always correct.

By including the net evaporation in the mass analysis, the critical duration is no longer important in the analysis of storage. The advantage associated with not needing the critical duration is realized when the demand-storage-recurrence relationship must be adjusted owing to alterations in the pumping system design and instream flow policy. Some error is introduced in the estimation of the net evaporation through the use of the standard reservoir design function, Equation 7. However, the effect of this error on the overall storage design of the side-channel reservoir is relatively small.

Recurrence Interval

Use of the above methodology produces an annual series of storage values needed to meet the given gross demand. The values in the annual series are then ranked in order of decreasing magnitude, with the largest storage value being of rank 1. The mean recurrence interval for each of these storage values is computed as follows:

$$MRI = \frac{N + 1}{m} \qquad (8)$$

in which MRI is the mean recurrence interval in years, N is the number of elements in the annual series, m is the the rank of the storage required. For an annual series of length 42 years, the event with the greatest storage requirement has a recurrence interval of 43 years; the second greatest storage value has a recurrence interval of 21.5 years, and so forth. When this relationship between the storage values and the recurrence interval is developed for numerous values of the gross demand, the result is the demand-storage-recurrence relationship.

Demand-Storage-Recurrence Primary Relationship

Estimates of the reservoir storage necessary to meet various gross demands for various return intervals were computed for the stations shown in Figure 2 by means of the mass analysis represented by Equations 3, 4, and 5 and using the recurrence relationships previously described. The analysis was performed for gross demand values which range from less than 0.1% of the mean annual flow of the stream up to 20% of the mean annual flow. Recurrence intervals are dependent upon the length of the streamflow records, and range from 2 to 65 years.

The demand-storage-recurrence relationships developed are based upon the initial design of the reservoir's pumping system and instream flow requirements, which were described earlier in this chapter. Because the storage requirements of a reservoir vary with alternative pumping system designs, the demand-storage-recurrence relationships herein described are defined as primary relationships. These primary relationships are presented in graphical form in the second part of this report. An example of these demand-storage-recurrence curves is given in Figure 3. These curves are presented on a probability-logarithmic scale, a type of scale that is commonly available on graph paper. The ordinate (logarithmic scale) describes the storage requirement as a multiple of the daily gross demand. The abscissa of the graph is the recurrence interval, plotted using a scale associated with the normal distribution variate, z. The z value is the solution of the normal distribution cumulative density function such that:

$$P\ (Z < z) = 1 - \frac{1}{MRI} \tag{9}$$

in which Z represents the population of all possible normal distribution variates. The z values can be obtained from almost any reference dealing with probability.

Interpretation of the Recurrence Interval for Long Duration Droughts

A cursory examination of Figure 3 and the graphs in Part 2 of this report indicates that the required storage for a certain recurrence interval, expressed as a scalar of the daily gross demand, increases as the gross demand increases. As the demand for water supplied by the stream continues to increase, there comes a level at which there is not enough streamflow available in some years to refill the reservoir, and extra water

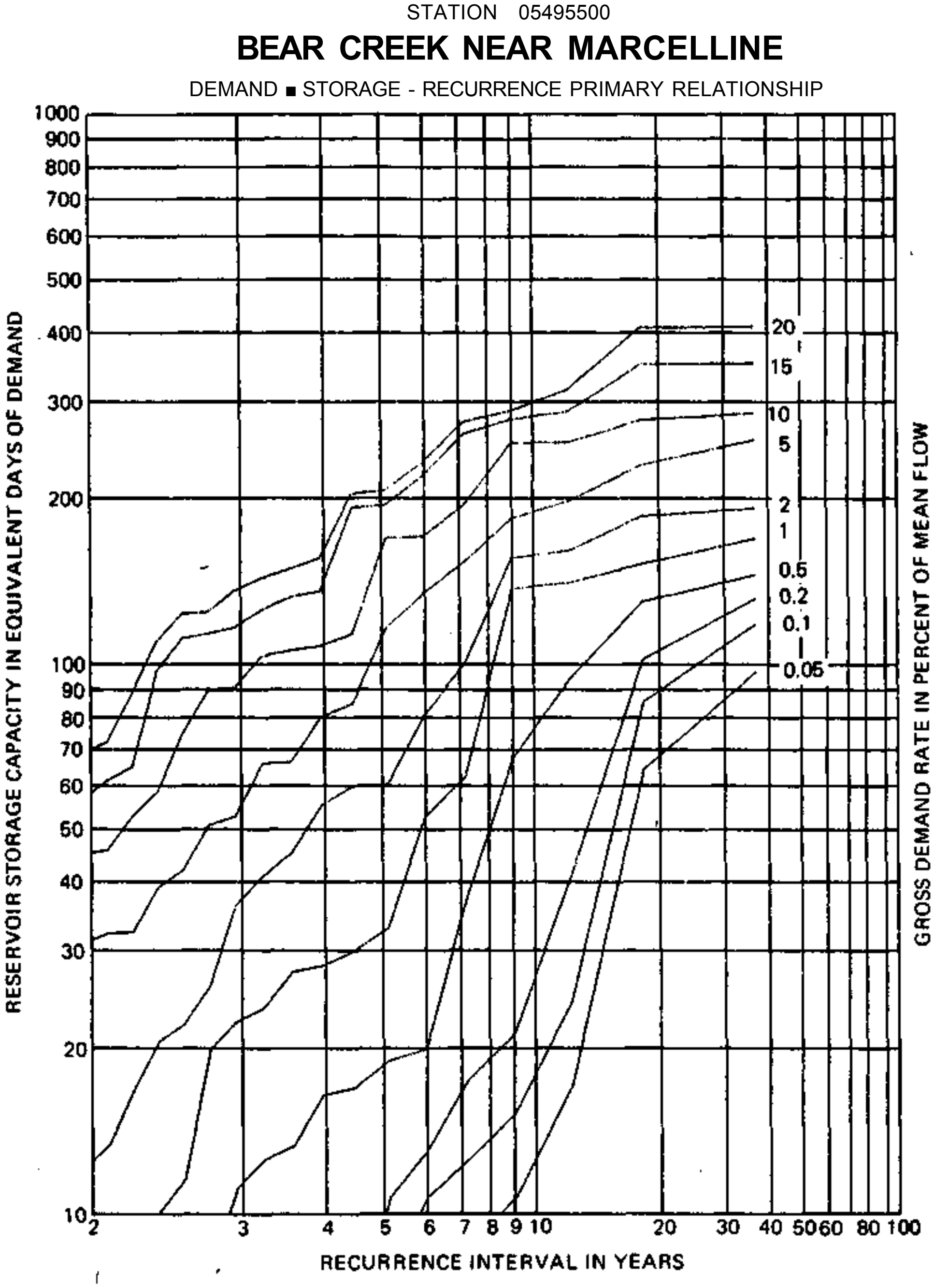


Figure 3. Demand-Storage-Recurrence Relationship for Bear Creek near Marcelline

must be stored during wetter years for release during these dry years. This extra storage is termed carryover storage. The level of demand at which carryover storage becomes necessary varies geographically across the state. Northern areas of the state have the most consistent annual supply of water in the state, and for reservoirs in these regions the gross demand can approach 15% of the average annual flow before carryover storage is required. On the other hand, side-channel reservoirs in southern Illinois may require carryover storage when the gross demand is only 2% to 5% of the average annual flow. Areas in central and western Illinois generally require carryover storage at a demand of about 10% of the average annual flow.

For the demand levels which are low enough that carryover storage is not required, the series of annual storage values can be interpreted as completely independent values, and the probability of a certain storage being needed in any given year is the inverse of the recurrence interval associated with that storage. However, when carryover storage is required, the recurrence interval associated with a given storage is given a slightly different interpretation. This situation exists because the total storage needed to endure the second or third year of a drought period is dependent upon the storage conditions present at the end of the previous water year. It is also likely that the recurrence interval associated with the storage needed in each of the years of the drought will be high. Thus, for demand levels in which carryover storage is required, the inverse of the recurrence interval describes the percentages of years for which the associated storage is required, but does not accurately describe the probability with which that storage might be needed for any given year.

For many cases involving reservoir storage design, this difference in the interpretation of the recurrence interval may be of little importance.

REGIONAL SIMILARITIES IN DESIGN STORAGE

The graphs of the demand-storage-recurrence primary relationships, shown in Part 2, indicate substantial variation in the magnitude of storage required for side-channel reservoirs in the state. Much of the variation in the storage relationships can be directly attributed to regional differences in the temporal distribution of low flows. The regional factors that most affect low flows include topography, soil permeability, and shallow groundwater (Singh, 1971). For example, those areas with the lowest soil permeability generally have the most extensive and severe periods of low flow. These areas, in turn, also require the greatest amount of storage for a given demand, relative to other areas of the state.

Through an examination of the demand-storage-recurrence relationships, the state was divided into ten regions of relatively homogeneous side-channel storage needs. These regions are shown in Figure 4. Because these regions were patterned after side-channel storage needs, and not physiographic regions, the regional boundaries do not closely resemble previously defined state hydrologic or physiographic regions. A few boundaries, however, are similar to those used with the hydrologic regions developed by Singh (1971). Within each region there still remains variation in reservoir storage needs. Much of this variation can be ascribed to differences in the drainage area of the basins.

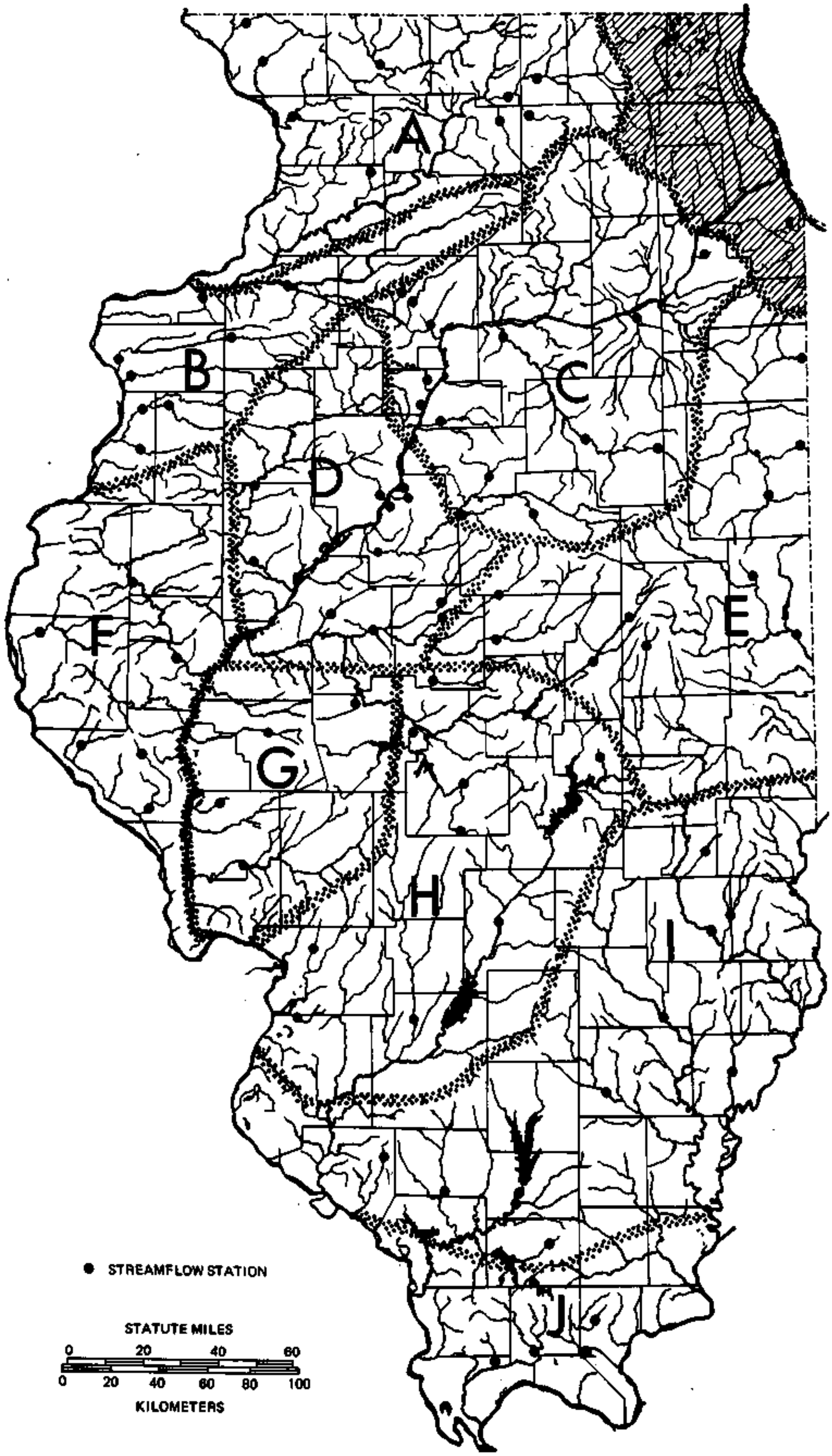


Figure 4. Regions of Similar Storage Design Characteristics

Drainage Area-Storage Relationships

Within each region identified above, a variation in drainage area size causes a change in the amount of storage needed for each given demand and recurrence interval. These differences in storage are a result of the relationship between drainage area and the distribution of low flows. As the watershed size of a stream increases, the probability that some part of the watershed will receive precipitation increases, thus enhancing the chance that new runoff will amplify or sustain the existing streamflow; In addition, streams with larger watershed generally are more entrenched, resulting in greater groundwater sustenance of streamflow. The consequence is that streams with large drainage areas generally have greater and more reliable low flows, and a reservoir associated with a large stream will need less storage than one associated with a smaller stream.

This drainage area-storage relationship can be identified for any region and for a given demand and recurrence interval, by plotting the storage requirements and drainage area for the stations within that region on semi-logarithmic paper, as shown in Figure 5. The development of graphs such as Figure 5 can be extremely useful in determining the amount of storage required for a side-channel reservoir design at ungaged sites. The amount of scatter present in the storage values in Figure 5 is not unusual. This scatter is the result of a lack of total homogeneity within each design region as well as the differences in the length and period of record of the streamflow gages used. For this reason it is advisable to use those stations with the longest periods of record and those stations nearest the design site for the drainage area-storage analysis.

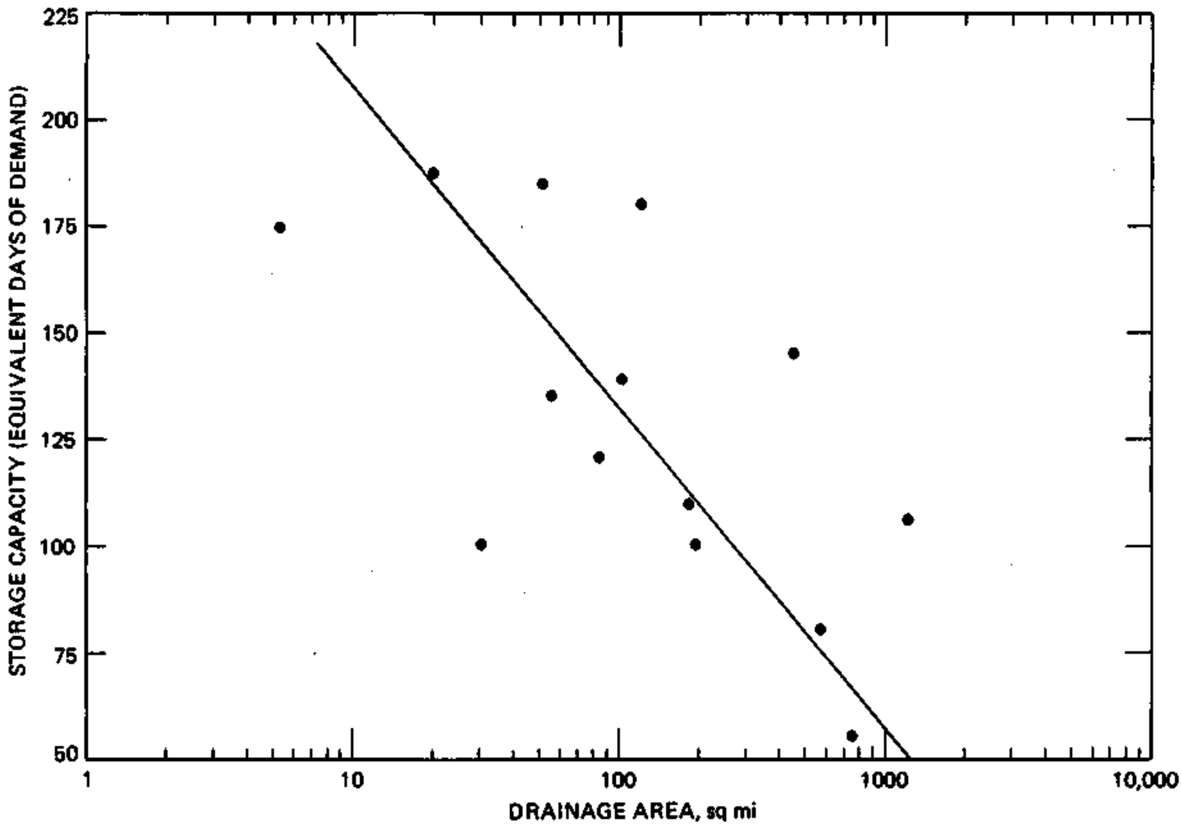


Figure 5. Drainage Area-Storage Relationship for Region C;
Demand = 1% of Mean Annual Flow, Recurrence Interval = 20 Years

MODIFICATIONS TO THE PRIMARY STORAGE REQUIREMENTS

The storage required by a reservoir is directly associated with the variability of inflow into the reservoir. For a side-channel reservoir this variability of inflow is dependent not only upon the flow of the stream, but also upon limitations related to the pumping system design and operation (instream flow decisions). The effects of each of these limitations on the side-channel reservoir storage design are treated in this section in the order described.

Effects of the Pumping System Design on Storage Requirements

The pumping system used to develop the demand-storage-recurrence primary relationships involves the use of two variable-speed pumps which can pump continuously over a range of from 0.25 to 8 times the water supply gross demand. This pumping system provides a practical lower limit for the amount of storage needed at the reservoir for the given level of demand. Even if all of the streamwater available for pumping (above the minimum pumping level) were pumped into the reservoir, the required storage would not decrease by more than 5%.

For many reasons, the design engineer may choose to install a pumping system different from that used to develop the demand-storage-recurrence curves. Foremost among these reasons is the questionable reliability of current variable-speed pump systems and of automatic control-sensor systems. It is therefore imperative to know how possible changes in the design of the pumping system will affect the amount of storage required to meet the water supply demand for a certain drought. This first requires a more comprehensive understanding of the variety of pumping systems which could be used in association with a side-channel reservoir.

The only characteristic of a pump or set of pumps that is significant in the design of side-channel reservoir storage is the number and magnitude of the allowable discharge capacities. To this end, all pumps can be classified into two groups: 1) pumps with fixed-speed motors, which pump only one set discharge, and 2) pumps with variable-speed motors, which can pump a continuous range of discharges. The use of each of these pump types in selected pumping systems is described below.

Variable-Speed Pumping Systems. These systems employ one or two pumps with variable-speed motors. The variable-speed systems are dependent on an automatic control which governs the speed of the pump motors and hence the discharge of the pumps. The pump speed is related to the amount of water available in the stream as measured by a "bubbler" sensor (see Figure 6). Variable-speed systems offer both the high and low discharge variability necessary for efficient reservoir storage design. There are distinct advantages associated with a continuous range of pumping discharges. However, the current use of variable-speed pumping for water supply is very limited; this situation exists because variable-speed motors require greater maintenance and are not as reliable as the fixed-speed motors. It is assumed, though, that in the future variable-speed pumping systems will be more reliable and more desirable.

Fixed-Speed Pumping Systems — 3 to 6 Pumps. A multi-pump fixed-speed pumping system is essentially a fixed-speed equivalent to a variable-speed pumping system. The pumps may be used separately or in conjunction and are sized to offer a wide variety of discharge capacities. The complexity associated with the operation of these systems requires that an automatic control-sensor also be used to govern the use of the pumps. The advantage

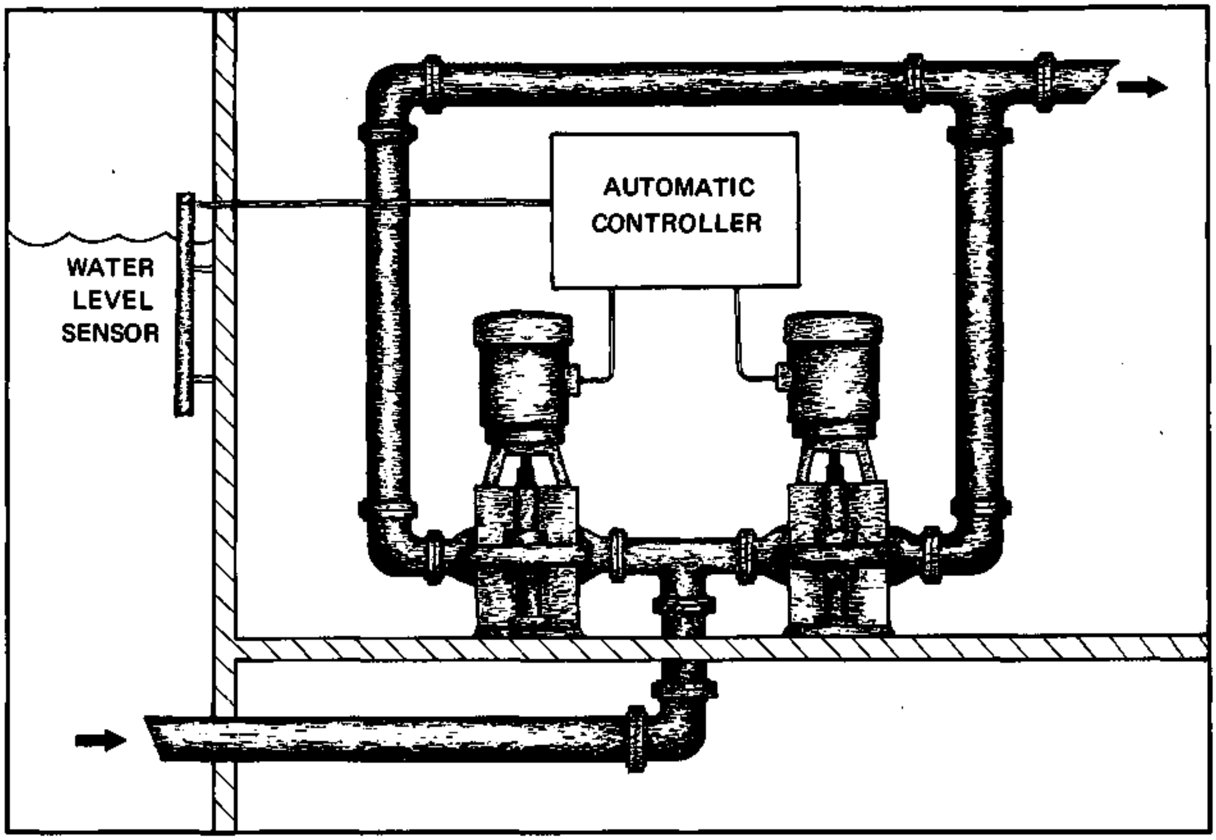


Figure 6. Illustration of a Pumping System with an Automatic Control and Sensor

in using a multi-pump fixed-speed system compared to a variable-speed pumping system is that the fixed-speed motors are more reliable than their variable-speed counterparts.

Fixed-Speed Pumping Systems — 1 or 2 Pumps. This type of pumping is the simplest and most commonly used. These pumping systems generally do not require a complicated controlling system, although automatic shut-off mechamisms should be included in the pumping system design. Because neither a controller nor a variable-speed motor is used, these pumping systems are the most reliable of those systems herein described. However, the one or two pump systems also are the least efficient and least flexible in conveying streamwater to the reservoir. For this reason, a reservoir with this type of pumping system will require much greater amounts of storage to meet a given demand and recurrence interval. Because the construction of the reservoir represents by far the largest cost associated with a side-channel reservoir, the adoption of a one or two pump system in the long run is much more expensive than is using a more elaborate pumping system.

Combination Fixed-Speed and Variable-Speed Systems. The simulation of pumping conditions shows that during an average year, the side-channel reservoir will maintain its maximum storage level a majority of the time. For this reason during most of the year the amount of water which should be pumped into the reservoir is equal to the amount withdrawn, i.e., the gross demand. This means that an isolated fixed-speed pump could be working alone for most of the year while the rest of the pumping system need not be in use except during periods of reservoir deficit. For all but the largest demands in the southern and central parts of the state, a combination system involving one isolated fixed pump ($Q = D$), and one variable speed pump provides as efficient pumping as does a two pump variable-speed system. The variable-speed system need be used only during that time when the reservoir is not full, therefore there will be less of a chance of breakdown.

Pumping System Adjustment Ratios

For every variation in the available discharge capacities of a pumping system there exists a unique demand-storage-recurrence relationship. The storage required for a given demand and recurrence with these unique pumping systems can be described as a multiple of the respective storage provided by the demand-storage-recurrence primary relationship. This multiple is termed an "adjustment ratio" in this report. A set of adjustment ratios, covering a wide range of demands and recurrence intervals, was computed for 30 locations across the state using 30 different pumping system designs. The adjustment ratios for each of the pumping designs were then averaged over three sections of the state to provide the average pumping system adjustment ratios presented in Tables 1, 2, and 3.

The three sections of the state defined in the adjustment ratio tables are associated with the design regions presented earlier. The table for northern Illinois references design regions A and B. Similarly, the central Illinois section-is associated with design regions C through H, and the southern Illinois storage ratios are for design regions I and J (see Figure 4).

There are no discernible changes in the values of the pumping system adjustment ratios due to differences in stream basin size, although the ratios for smaller streams tend to fluctuate from the average ratio to a greater extent. Additionally, there does not appear to be any variation in the adjustment ratios due to differences in the recurrence interval.

The ratios given in Tables 1, 2, and 3 help to indicate the demand levels and pumping system types for which certain pump sizes are useful. In general, as the demand level increases, the need for large pumping capacities increases. This need for greater pumping capacities occurs because the time duration for which pumping can occur decreases with increased demand levels. This desired maximum pumping level is from 4 to 7 times the gross demand for demand levels exceeding 10% of the mean annual flow, dependent upon regional location, and is as low as 1 3/4 to 2 1/2 times the demand for very small demand levels. Once the ability to pump this maximum pumping level is reached, further increases in the maximum

Table 1. Pumping System Adjustment Ratios for the Northern Section of Illinois (design regions A and B)

Pumping System*	Ratios for Gross Demand (% of the mean annual flow) 20.0	15.0	10.0	5.0	2.0	1.0	0.5	0.2	0.1
1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
3	1.55	1.45	1.30	1.25	1.15	1.10	1.05	1.03	1.02
4	1.75	1.60	1.35	1.25	1.15	1.10	1.05	1.03	1.02
5	1.60	1.50	1.25	1.15	1.05	1.04	1.02	1.00	1.00
6	2.10	1.90	1.55	1.20	1.10	1.08	1.07	1.05	1.05
7	1.30	1.25	1.20	1.20	1.15	1.12	1.10	1.10	1.10
8	1.75	1.65	1.35	1.30	1.20	1.15	1.10	1.10	1.10
9	1.60	1.45	1.40	1.35	1.25	1.20	1.15	1.15	1.15
10	2.00	1.80	1.65	1.50	1.30	1.20	1.15	1.15	1.15
11	2.20	2.00	1.70	1.50	1.30	1.20	1.15	1.15	1.15
12	2.10	1.95	1.80	1.75	1.60	1.30	1.25	1.25	1.20
13	3.25	2.80	2.20	1.50	1.30	1.25	1.15	1.10	1.10
14	--	5.90	3.60	2.25	1.60	1.40	1.30	1.20	1.15
15	--	4.60	3.85	2.35	1.90	1.50	1.25	1.25	1.20
16	3.10	2.80	2.55	1.80	1.70	1.60	1.35	1.25	1.20
17	3.00	2.60	2.25	1.80	1.70	1.60	1.35	1.25	1.20
18	3.10	2.75	2.35	2.00	1.85	1.60	1.35	1.30	1.25
19	3.10	2.75	2.35	2.00	1.85	1.60	1.35	1.30	1.25
21	3.90	3.65	3.35	2.85	2.60	1.75	1.50	1.40	1.40
22	3.00	2.85	2.75	2.70	2.45	1.75	1.50	1.40	1.40
23	--	--	--	4.55	2.95	1.85	1.65	1.45	1.35
24	--	--	5.40	3.75	2.70	2.60	1.90	1.50	1.40
25	--	5.30	4.75	4.00	3.50	3.30	2.55	1.65	1.50
26	--	4.75	4.25	4.20	4.00	3.60	3.20	1.90	1.65
27	--	--	--	5.15	4.40	3.90	3.45	2.20	2.00

* description of the pumping systems is given in Table 4.

Table 2. Pumping System Adjustment Ratios for the Central Section of Illinois (design regions C, D, E, F, G, and H)

Pumping System*	Ratios for Gross Demand (% of the mean annual flow) 20.0	15.0	10.0	5.0	2.0	1.0	0.5	0.2	0.1
1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33
3	1.35	1.30	1.28	1.25	1.22	1.20	1.15	1.11	1.08
4	1.45	1.40	1.35	1.30	1.25	1.20	1.15	1.11	1.08
5	1.60	1.52	1.45	1.40	1.20	1.10	1.08	1.05	1.05
7	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
8	1.36	1.32	1.26	1.20	1.16	1.14	1.13	1.13	1.13
9	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22
10	1.54	1.48	1.40	1.35	1.32	1.29	1.27	1.25	1.24
11	1.63	1.56	1.48	1.39	1.32	1.29	1.27	1.25	1.24
12	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41
16	2.15	2.00	1.90	1.80	1.70	1.60	1.52	1.45	1.40
17	1.90	1.80	1.70	1.65	1.60	1.55	1.50	1.45	1.40
18	1.90	1.80	1.70	1.65	1.60	1.57	1.54	1.50	1.45
19	1.90	1.80	1.70	1.65	1.60	1.60	1.58	1.55	1.50
20	2.05	1.90	1.75	1.68	1.66	1.64	1.63	1.62	1.60
21	2.25	2.10	2.00	1.90	1.85	1.87	1.90	2.00	2.10
22	1.80	1.70	1.60	1.60	1.65	1.75	1.85	2.00	2.10
24	--	6.50	4.50	3.10	2.60	2.45	2.40	2.35	2.35
25	4.80	2.70	2.90	2.40	2.25	2.30	2.40	2.70	3.00
26	4.00	3.25	2.70	2.20	2.15	2.35	2.70	3.40	4.00
27	3.70	3.00	2.50	2.15	2.15	2.45	2.90	3.90	4.75
28	3.70	3.00	2.50	2.15	2.15	2.50	3.00	4.20	5.20
29	3.70	3.00	2.50	2.15	2.15	2.55	3.30	5.00	6.40
30	4.00	3.25	2.70	2.30	2.30	2.70	3.60	5.60	7.50

* description of the pumping systems is given in Table 4.

Table 3. Pumping System Adjustment Ratios for the Southern Section of Illinois (design regions I and J)

Pumping System*	Ratios for Gross Demand (% of the mean annual flow) 20.0	15.0	10.0	5.0	2.0	1.0	0.5	0.2	0.1
1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21
3	1.36	1.26	1.24	1.20	1.18	1.17	1.15	1.14	1.14
4	1.55	1.40	1.30	1.25	1.20	1.17	1.15	1.14	1.14
5	1.90	1.70	1.50	1.30	1.20	1.15	1.12	1.10	1.08
7	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
8	1.55	1.44	1.33	1.24	1.18	1.15	1.13	1.11	1.10
9	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18
10	1.40	1.25	1.20	1.20	1.20	1.20	1.20	1.20	1.20
11	1.88	1.67	1.50	1.38	1.32	1.28	1.25	1.22	1.20
12	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
16	2.70	2.20	1.70	1.38	1.35	1.35	1.35	1.35	1.35
17	2.00	1.65	1.48	1.38	1.35	1.35	1.35	1.35	1.35
18	1.80	1.50	1.40	1.35	1.35	1.35	1.35	1.35	1.35
19	1.75	1.50	1.45	1.40	1.40	1.40	1.40	1.40	1.40
20	1.75	1.50	1.45	1.40	1.40	1.40	1.40	1.40	1.40
21	2.40	1.90	1.55	1.45	1.45	1.50	1.60	1.70	1.80
22	1.70	1.45	1.40	1.40	1.40	1.45	1.60	1.70	1.80
24	--	--	5.60	3.10	2.00	1.80	1.80	1.90	2.05
25	5.30	3.80	2.70	1.85	1.60	1.65	1.80	2.00	2.20
26	3.50	2.60	2.00	1.60	1.55	1.70	1.90	2.15	2.40
27	3.00	2.35	1.85	1.55	1.60	1.75	2.00	2.30	2.50
28	2.90	2.30	1.80	1.55	1.60	1.80	2.05	2.40	2.60
29	2.85	2.20	1.75	1.60	1.70	1.90	2.15	2.50	2.80
30	2.85	2.20	1.75	1.60	1.70	1.90	2.20	2.60	2.90

* description of the pumping systems is given in Table 4.

Table 4. Description of the Pumping System Designs used for Tables 1, 2, and 3

Pumping System	Description
Variable-Speed and Combination Systems	
1	Two variable-speed pumps with maximum capacities of 1 and 8 times the demand; effective pumping range: .1-8.0 D. (Primary Relationship System)
2	One variable-speed pump with maximum capacity of 8 times the demand; effective pumping range: 1-8D
3	One variable speed pump with maximum capacity of 4 times the demand and one fixed speed pump with a capacity equal to the demand; effective pumping range: .5-5.0 D
4	One variable-speed pump with maximum capacity of 4 times the demand; effective pumping range: .5-4.0 D
5	One variable-speed pump with maximum capacity of 2 times the demand and one fixed speed pump with a capacity equal to the demand; effective pumping range: .2-3. D
6	One variable-speed pump with maximum capacity of 2 times the demand; effective pumping range: .2-2.0 D
Multi-Pump Fixed-Speed Systems	
7	Five fixed-speed pumps with capacities of 4D, 2D, 1D, .5D, & .25D. Can pump in denominations of .25D up to 7.75 D
8	Four fixed-speed pumps with capacities of 2D, 1D, .5D & .25D. Can pump in denominations of .25D up to 3.75D
9	Four fixed-speed pumps with capacities of 4D, 2D, 1D, & .5D. Can pump in denominations of .5D up to 7.5D
10	Three fixed-speed pumps with capacities of 4D, 1D, & .5D. Can pump at .5D, 1D, 1.5D, 4D, 4.5D, 5D, & 5.5D
11	Three fixed-speed pumps with capacities of 2D, 1D, & .5D. Can pump in denominations of .5D up to 3.5D
12	Three fixed-speed pumps with capacities of 4D, 2D, & 1D. Can pump at 1D, 2D, 3D, 4D, 5D, 6D, & 7D

Table 4. (continued)

13	Three fixed-speed pumps with capacities of 1D, .5D & .25D. Can pump in denominations of .25D up to 1.75D
Two Fixed-Speed Pump Systems	
14	Two pumps with capacities of 1D and .5D. Can pump at .5D, 1D, and 1.5D
15	Two pumps each with a capacity of 1D. Can pump at 1D or 2D
16	Capacities of 1D and 2D. Combined can pump at 3D
17	Capacities of 1D and 3D. Combined can pump at 4D
18	Capacities of 1D and 4d. Combined can pump at 5D
19	Capacities of 1D and 5D. Combined can pump at 6D
20	Capacities of 1D and 8D. Combined can pump at 9D
21	Capacities of 2D and 2D. Combined can pump at 4D
22	Capacities of 2D and 4D. Combined can pump at 6D
One Fixed-Speed Pump Systems	
23	Capacity = 1.5D
24	" = 2.0D
25	" = 3.0D
26	" = 4.0D
27	" = 5.0D
28	" = 6.0D
29	" = 8.0D
30	" = 10.0D

available pumping rate do nothing to increase pumping efficiency. As a rule, the pumping characteristics that allow the required storage to decrease are supplied by increasing the number and range of discharge capacities that are available for use at discharges below the maximum pumping rate. This is why variable-speed pumping systems are the most efficient in reducing required reservoir storage. The ability to pump at discharges at or below the demand level is particularly important for efficient pumping for locations in northern Illinois.

EFFECT OF INSTREAM FLOW REQUIREMENTS

The withdrawal of large quantities of water from a stream has the potential of greatly disturbing the natural stream environment, as well as potentially limiting many instream uses of the streamflow. For this reason, water supply facilities may be required to practice a pumping policy which restricts the amount of low volume flow which may be taken from the stream.

The quantity of flow which must be present to meet specific instream flow needs is not well defined. Because definitive traits of desirable instream flows do not exist, the minimum flow policies must usually be defined in terms of an abstract flow quantity. For example, minimum flow levels may be defined as a percentage of the mean flow such as with the Montana Method (Bayha, 1976), or in terms of the frequency with which that flow occurs. In all of these cases, the selected abstract flow is used as an index to a certain instream flow need as a substitute to a scientific evaluation of the individual stream environment.

Seven levels of minimum flow policies based on flow frequency were evaluated as to their effect on the side-channel reservoir storage design at selected locations. These policies are illustrated in Figure 7 and defined in the following equations:

$$\textbf{Policy}\quad \text{A)}\quad QA = Q$$

$$\text{B)}\quad QA = Q-Q7,\ 10$$

$$\text{C)}\quad QA = Q-Q90$$

$$\text{D)}\quad QA = Q-Q75$$

$$\text{E)}\quad QA = Q-Q60$$

$$\text{F)}\quad QA = \max\begin{cases} Q-Q60 \\ \dfrac{Q-Q70}{2} \end{cases}$$

$$\text{*G)}\quad QA = \max\begin{cases} Q-Q75 \\ \dfrac{Q-Q7,10}{2} \end{cases}$$

in which Q is the streamflow, QA is the flow available above the minimum pumping level, and Q7,10, Q90, Q75, and Q60, are the 7-day, 10-year low flow, the 90% duration flow, the 75% duration flow, and the 60% duration flow, respectively. The minimum flow policy G is that policy used to establish the demand-storage-recurrence primary relationships presented in Part 2 of this report, and for this reason is marked by an asterisk. Policy G was used because of its suitability in the presentation of the storage relationships. The policy is not intended to be representative of current instream flow restrictions.

The change in storage design caused by the imposition of the minimum flow policies varies greatly across the state. The greatest relative variation in storage requirement exists for locations in the northern part of the state; the reason for this greater variability is best explained by example. Figure 8 illustrates a portion of the flow duration curves for

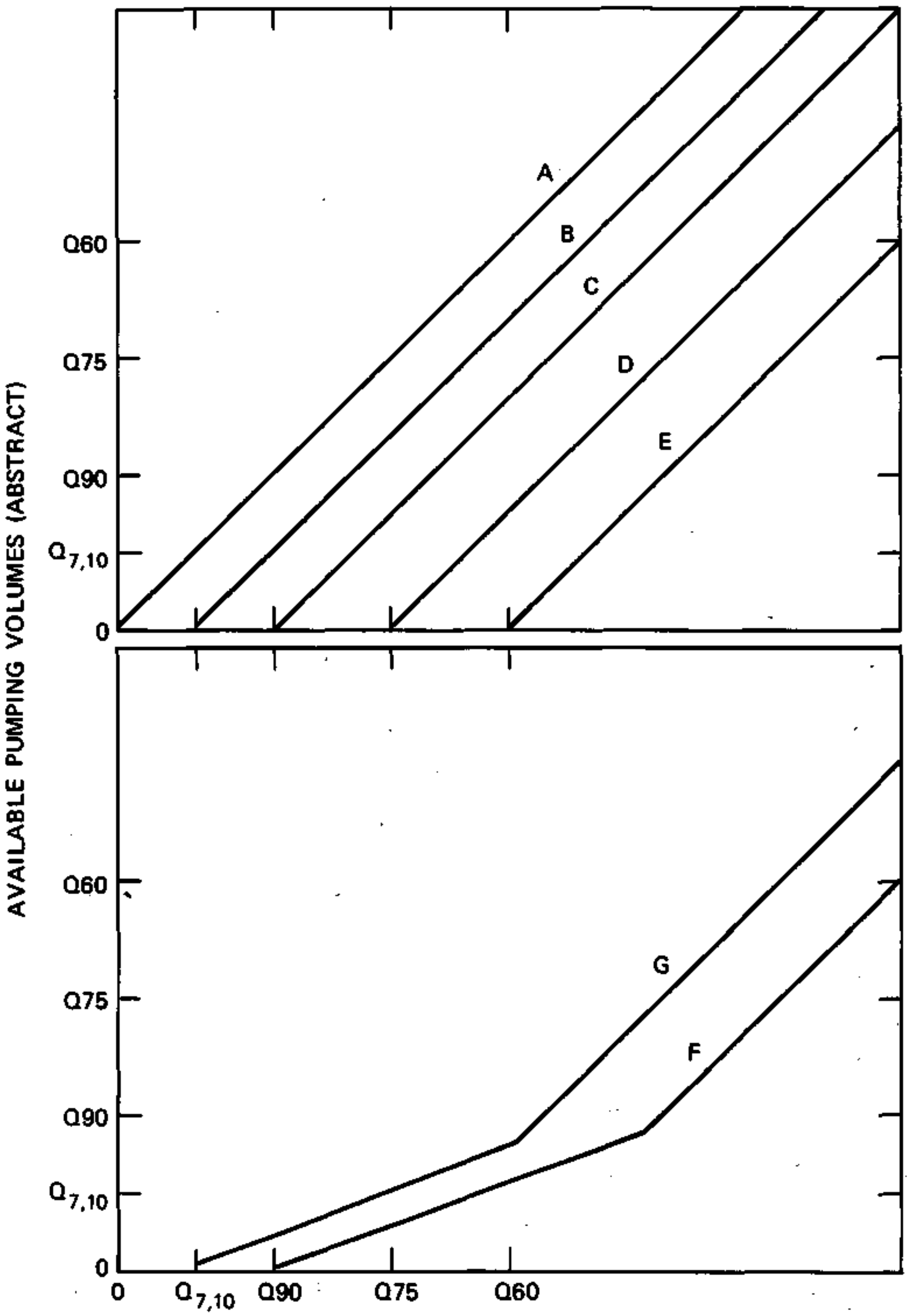


Figure 7. Comparison of the Effects of the Minimum Flow Policies on the Quantity of Flow Available for Pumping

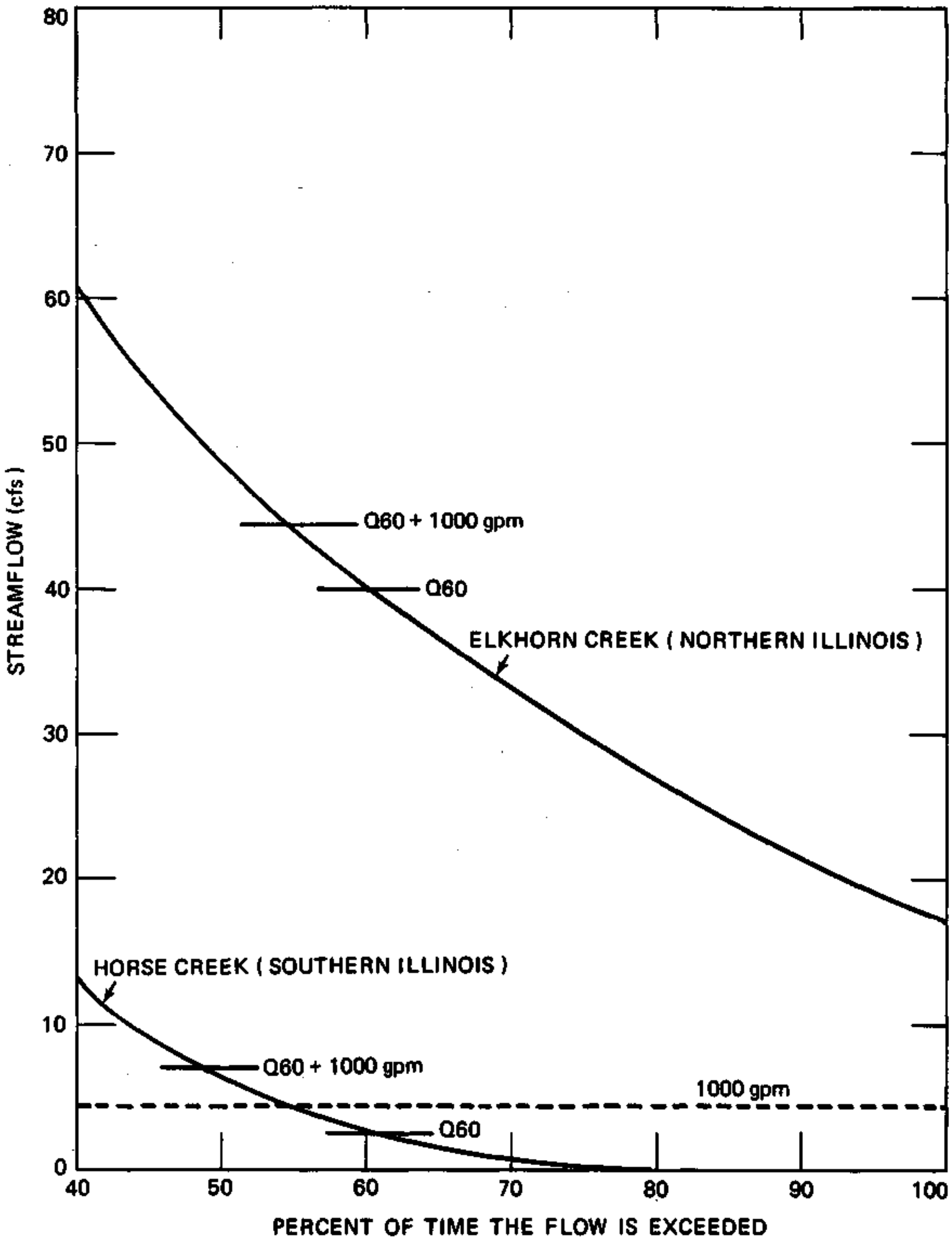


Figure 8. Effect of the Q60 Minimum Plow Policy on the Amount of Time Pumping is Allowed; Elkhorn Creek and Horse Creek

Elkhorn Creek at Penrose and Horse Creek near Keenes, which are representative of the northern and southern parts of the state, respectively. The mean annual flow at each of these locations is approximately 95 cfs. However, the flow duration distribution of the two streams is quite dissimilar. Horse Creek by nature experiences long and frequent periods when streamflow is at or near zero flow, such that the median flow is less than 7% of the mean annual flow. For pumping systems with large flow capacities, the physical restrictions created by the lack of consistent streamflow on Horse Creek are much greater than are the restrictions which are likely to be associated with instream flow policies. For example, a pump with a capacity of 1000 gpm (2.4% mean annual flow) is capable of pumping only 54% of the time, even with no flow restrictions. The imposition of a Q60 minimum flow policy would only reduce the maximum pumping time to 48% (see Figure 8). In both cases, the amount of storage required for a side-channel reservoir associated with this pump would be large, and the sensitivity of the required storage to the instream flow restriction would be small.

In contrast to Horse Creek, Elkhorn Creek never experiences extremely low flow. In fact, a 1000 gpm pump used without minimum flow restrictions could pump all of the time. The use of a Q60 minimum flow policy would restrict the use of the pump to 55% of the time. For Elkhorn Creek this restriction would require that as much as 200 days of storage be available in order to maintain the 1000 gpm pumping level for most years. Therefore the storage values that the engineer might have to evaluate could conceivably range from a very large storage down to no storage at all.

Examples of the dependency of the storage-recurrence relationship to changes in the minimum flow policy are shown for 12 locations across the state in Figures 9-20. The increased sensitivity of the required storage to instream flow needs associated with stations in the northern part of the state is evident. Less apparent but present is a similar tendency for greater sensitivity of storage among larger watersheds. This tendency occurs because larger watersheds have relatively larger low flows than do smaller watersheds, such that the imposition of instream flow restrictions (designed in terms of flow duration) has a comparatively greater effect on larger watersheds.

The instream flow limitations which are based on an abstract flow quantity, such as the seven policies described above, do not produce a uniform effect across the state. In some cases the instream flow limitations associated with the use of the minimum flow policy G* may be construed as too restrictive. This is especially likely with streams in northern Illinois where the magnitude of the minimum flow may be much greater than the withdrawal rate of the water supply system. The converse is true for many streams in southern Illinois, for which a minimum flow policy such as policy E might be required in order to maintain the stream's low flow environment. For reasons such as these, it is suggested that rational instream flow limitations either be judged for individual cases or be established for separate regions of the state.

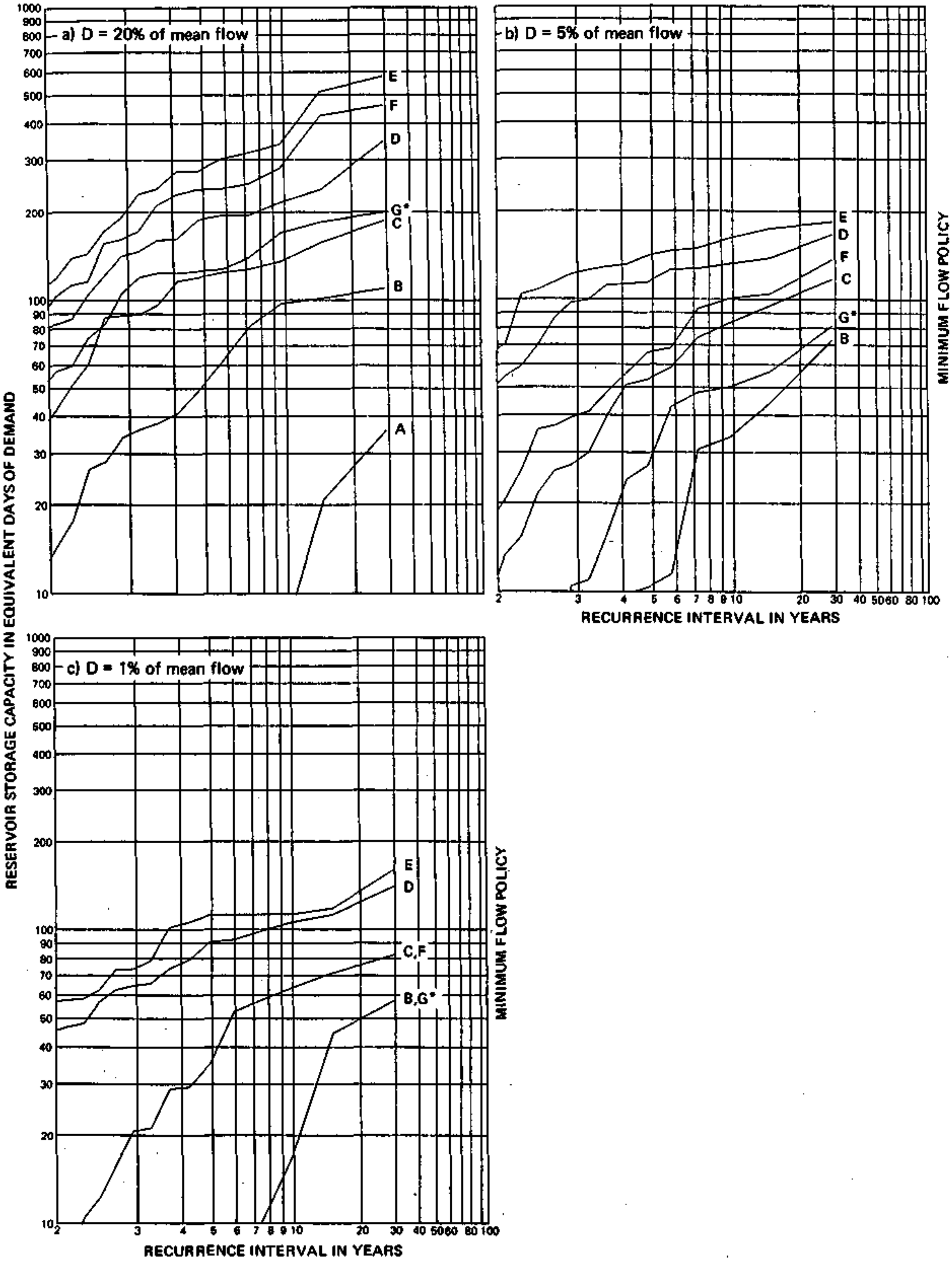


Figure 9. Comparison of Storage Requirements Using Varying Policies of Minimum Flow Needs; East Fork Galena River at Council Hill, d.a. = 20.1 mi^2

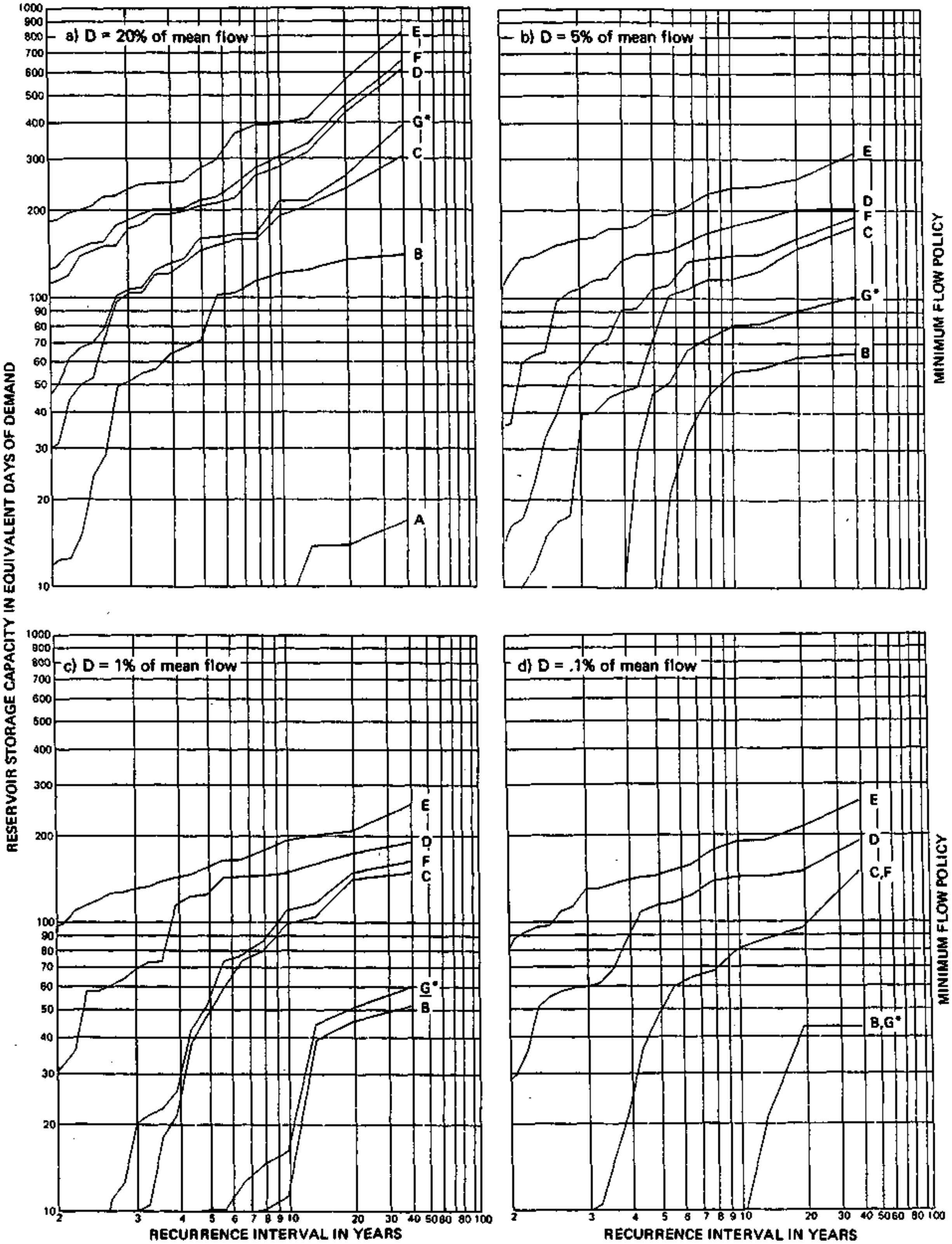


Figure 10. Comparison of Storage Requirements Using Varying Policies of Minimum Plow Needs; Elkhorn Creek near Penrose, d.a. = 146 mi^2

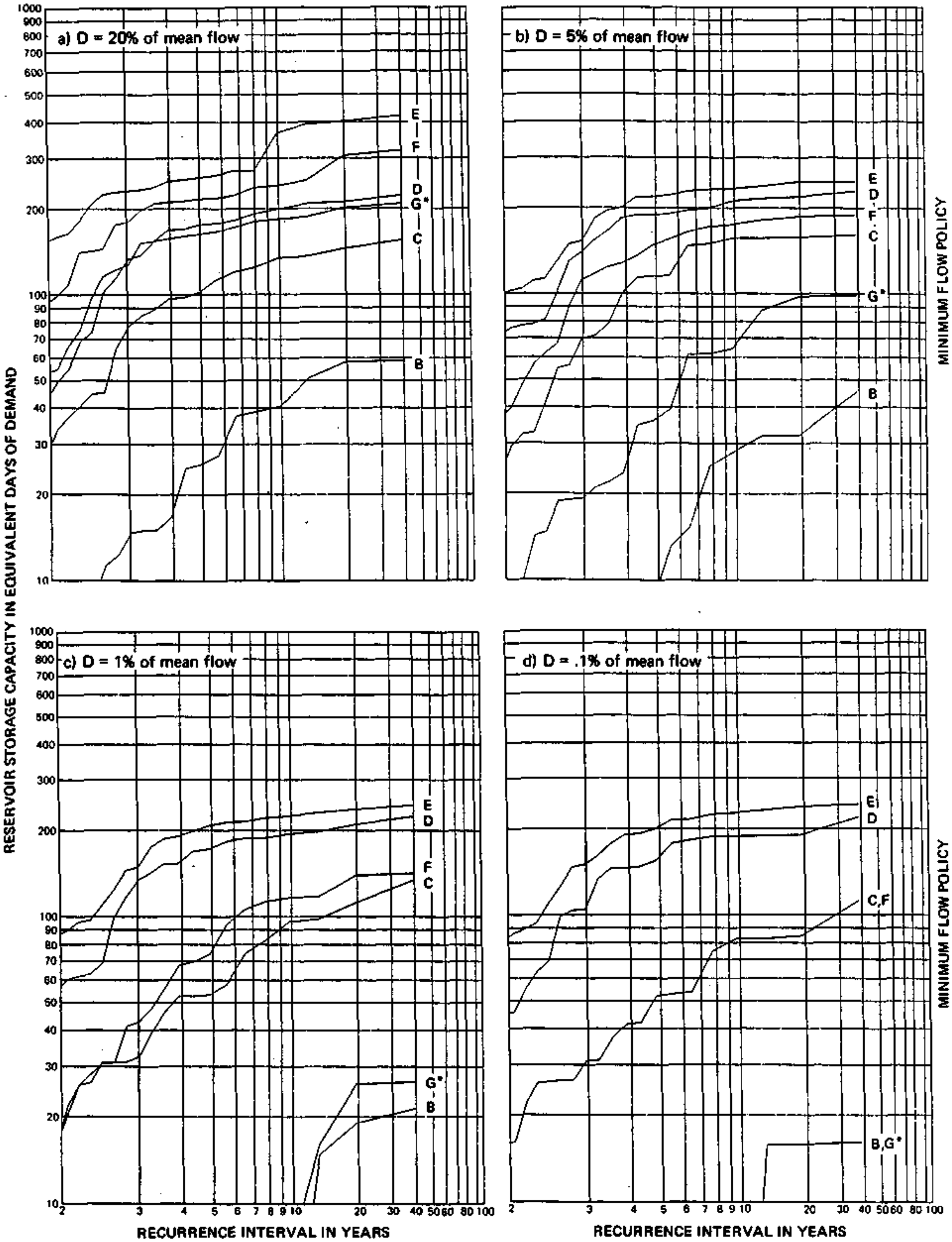


Figure 11. Comparison of Storage Requirements Using Varying Policies of Minimum Flow Needs; Kishwaukee River near Perryville, d.a. = 1099 mi^2

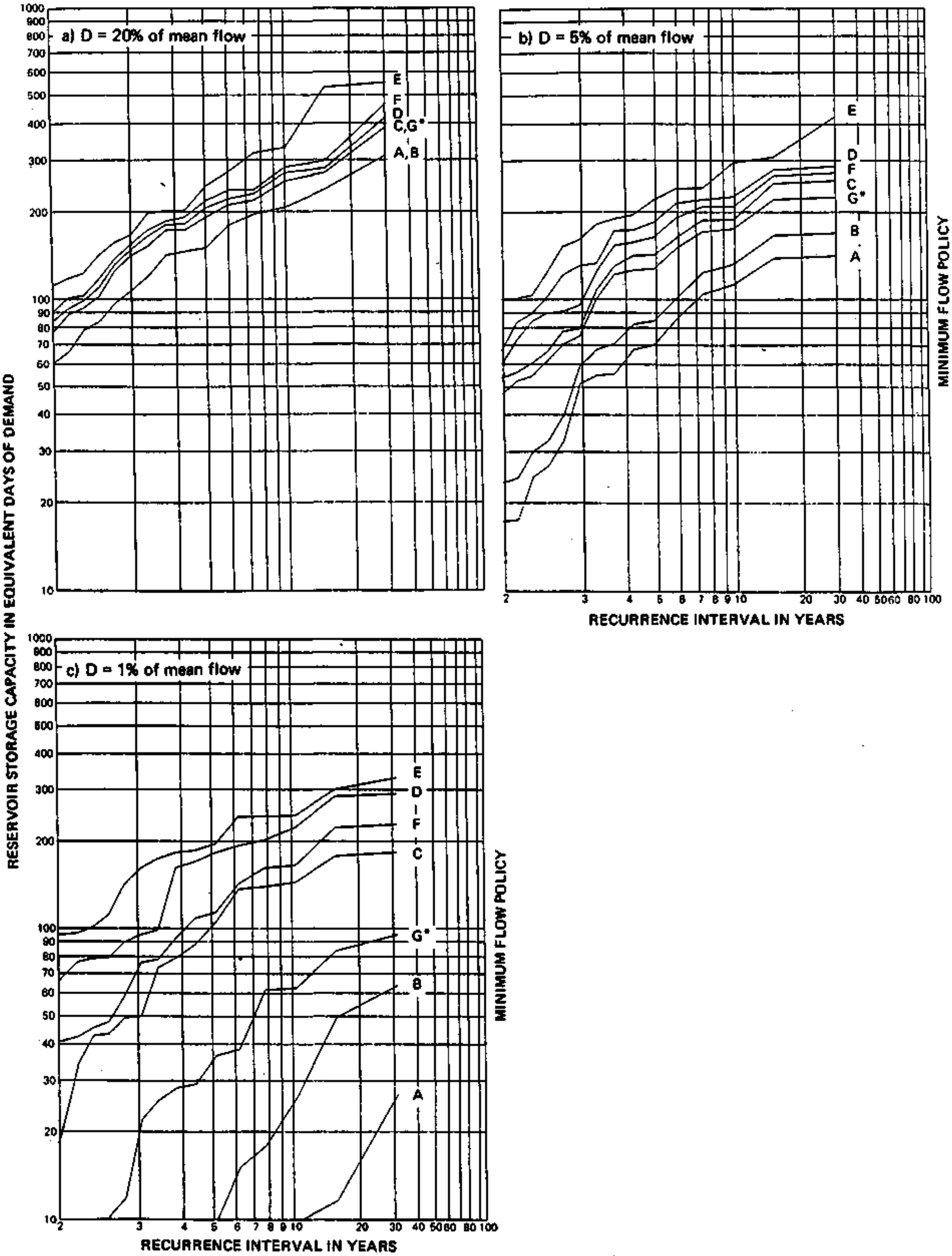


Figure 12. Comparison of Storage Requirements Using Varying Policies of Minimum Flow Needs; Kaskaskia Ditch at Bondville, d.a. = 12.4 mi^2

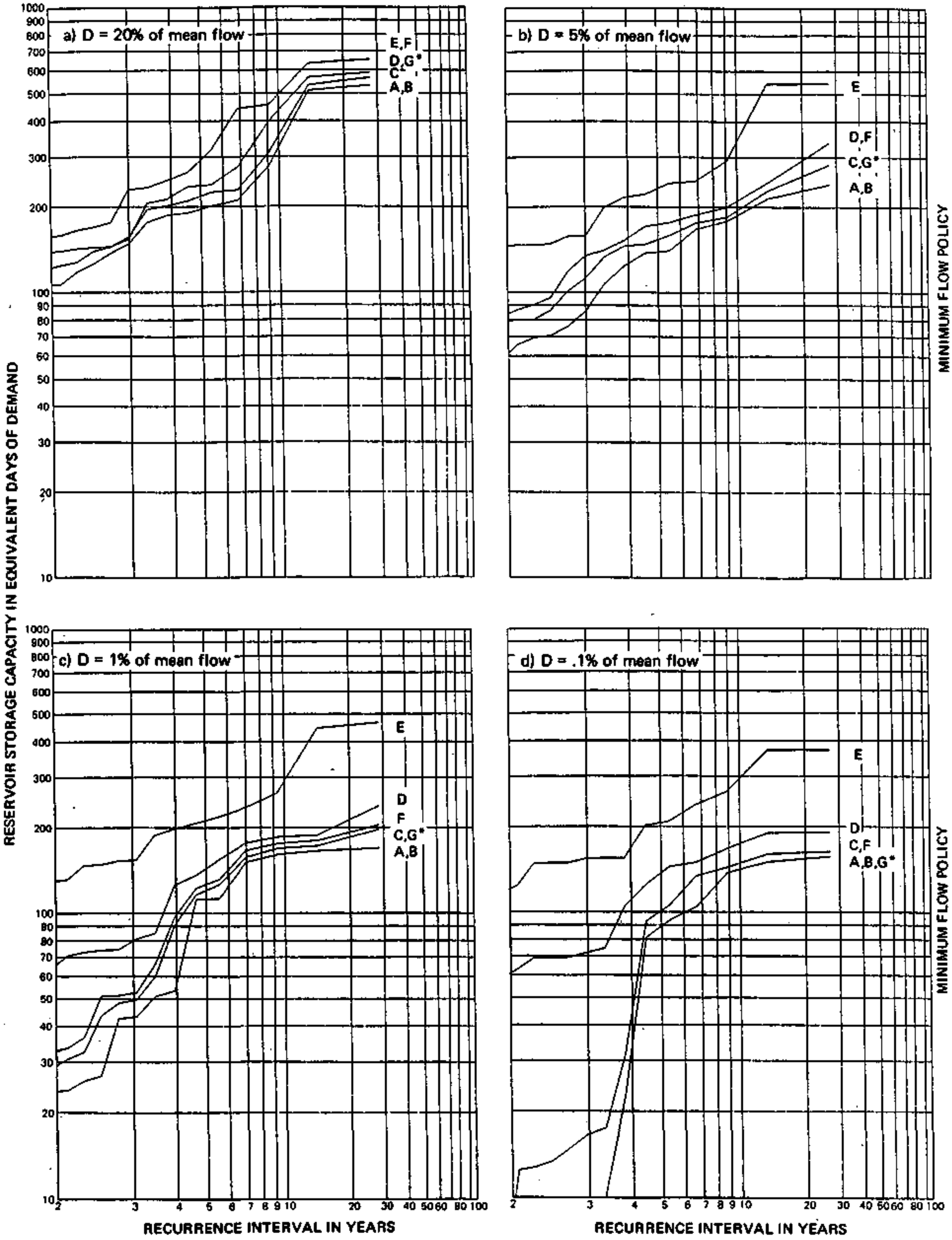


Figure 13. Comparison of Storage Requirements Using Varying Policies of Minimum Flow Needs; Crow Creek near Washburn, d.a. = 115 mi^2

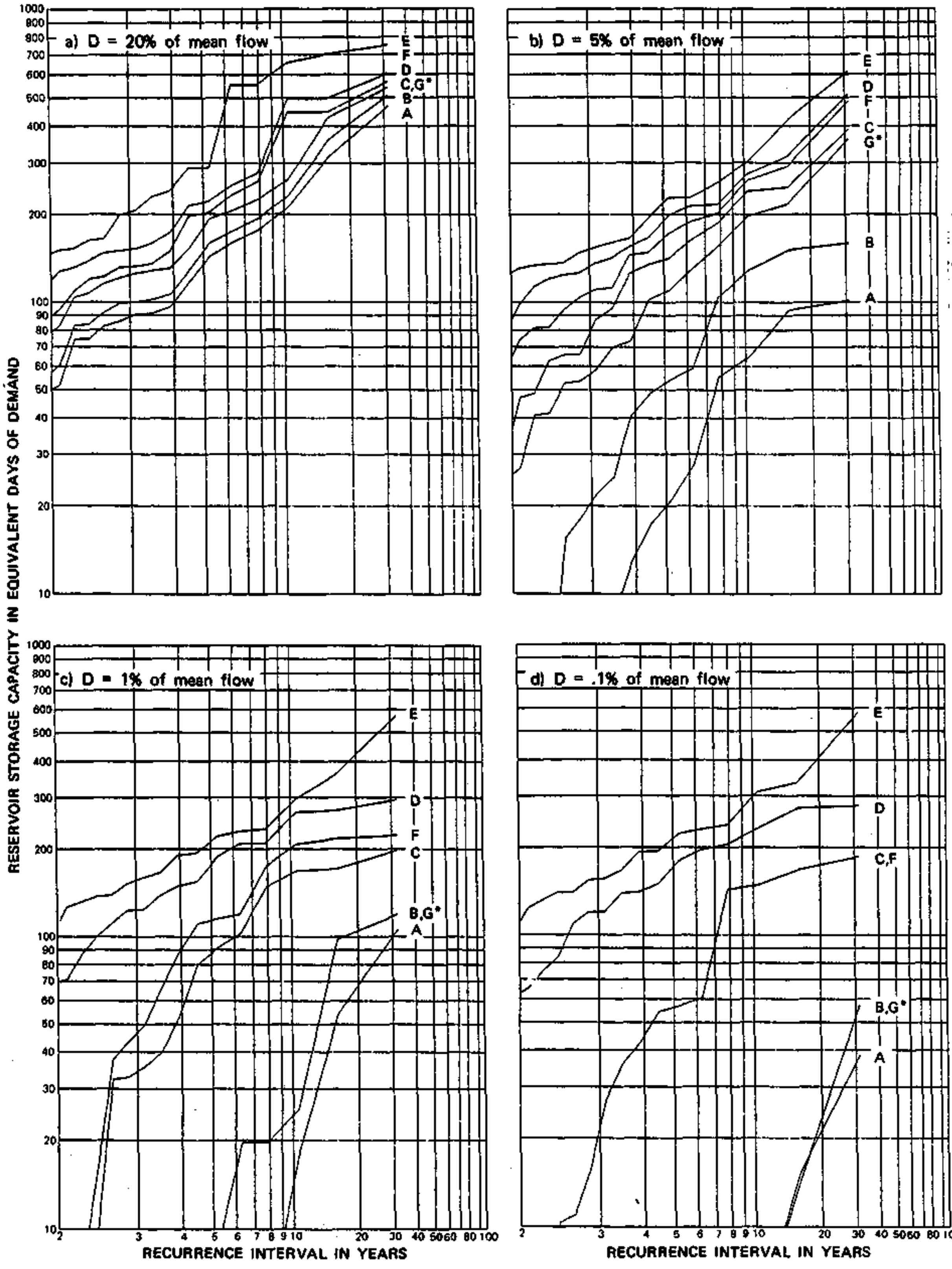


Figure 14. Comparison of Storage Requirements Using Varying Policies of Minimum Flow Needs; Lake Fork near Cornland, d.a. = 214 mi^2

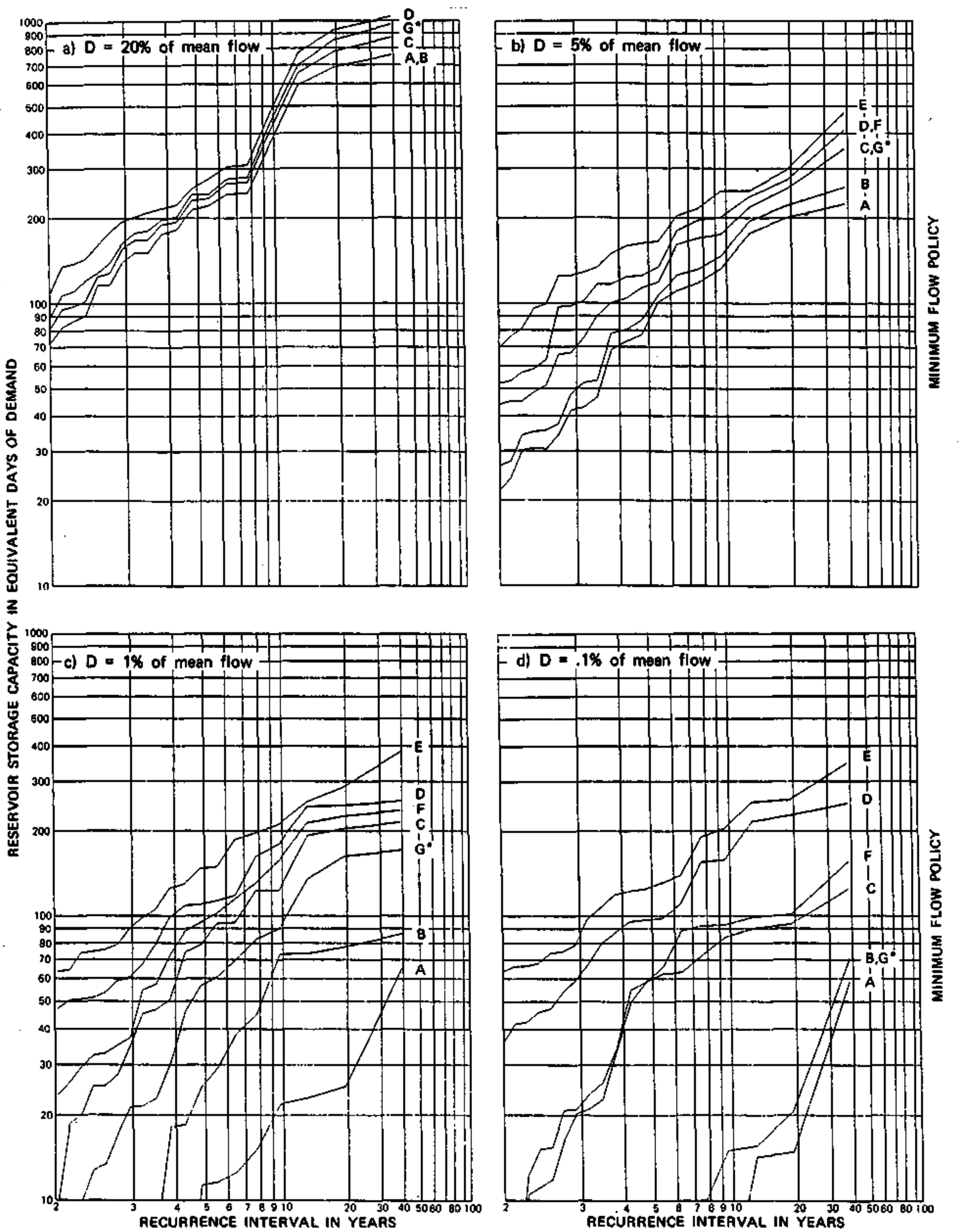


Figure 15. Comparison of Storage Requirements Using Varying Policies of Minimum Flow Needs; Macoupin Creek near Kane, d.a. = 868 mi^2

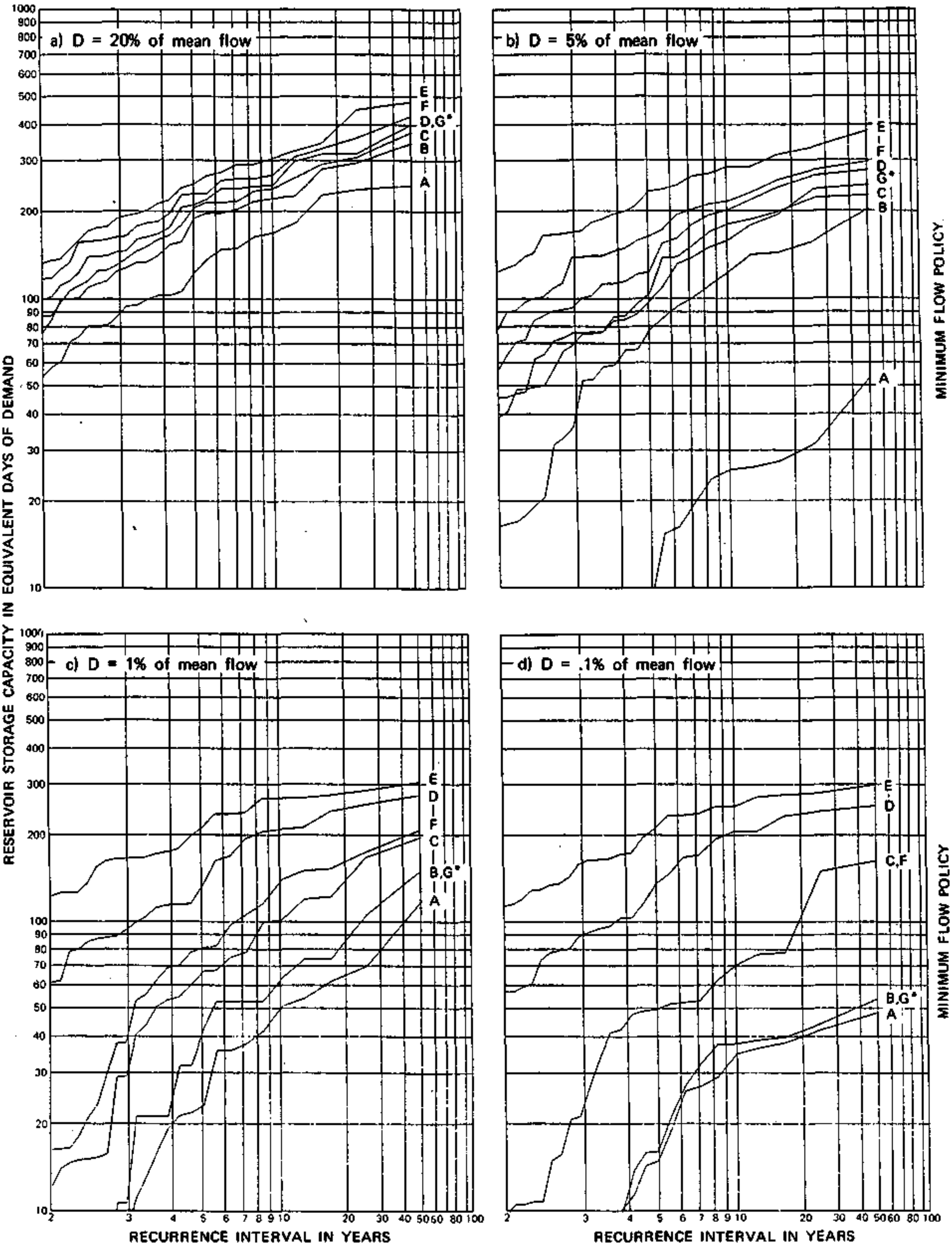


Figure 16. Comparison of Storage Requirements Using Varying Policies of Minimum Flow Needs; Vermilion River near Danville, d.a. = 1290 mi^2

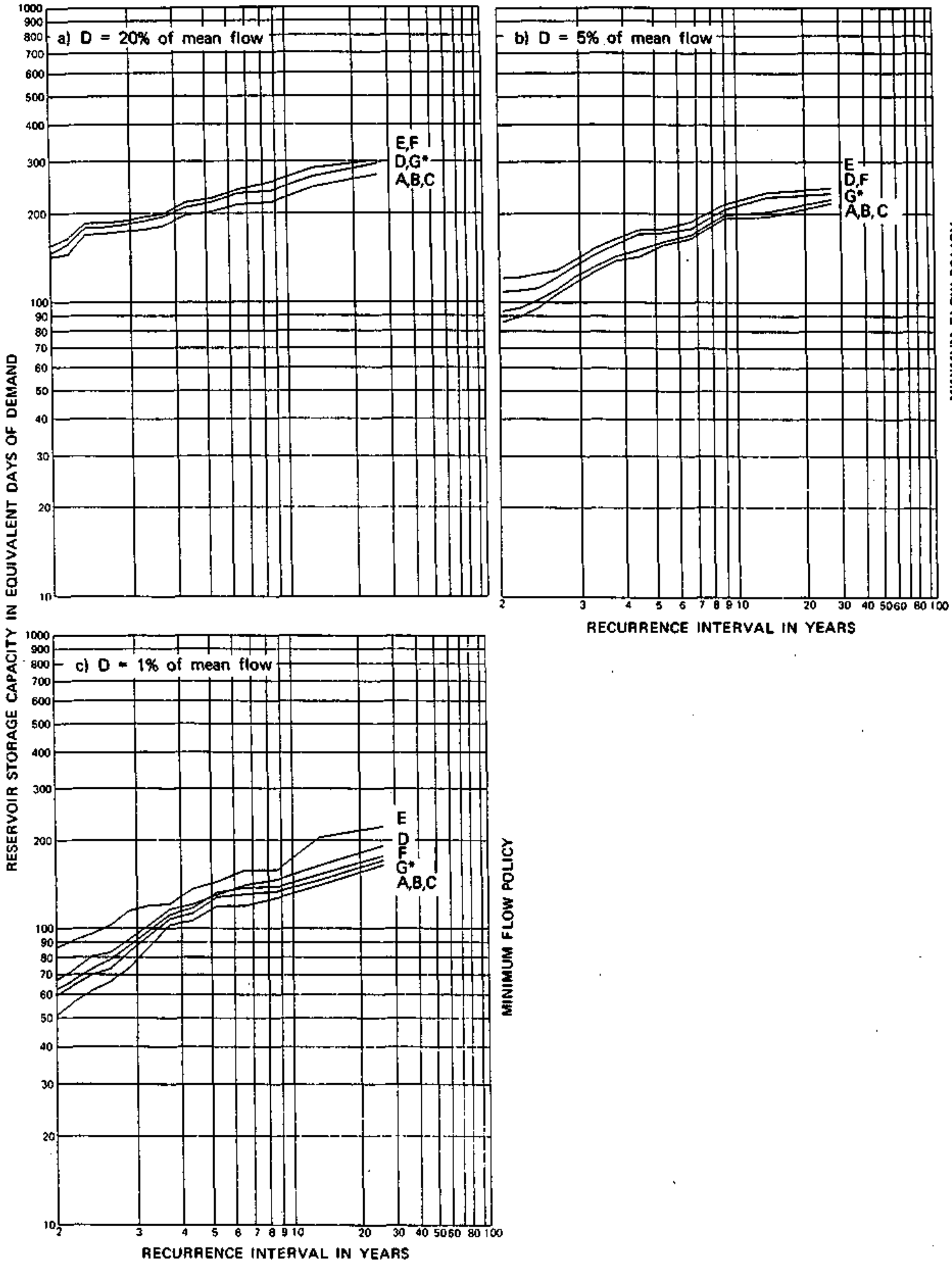


Figure 17. Comparison of Storage Requirements Using Varying Policies of Minimum Flow Needs; Hayes Creek at Glendale, d.a. = 19.1 mi^2

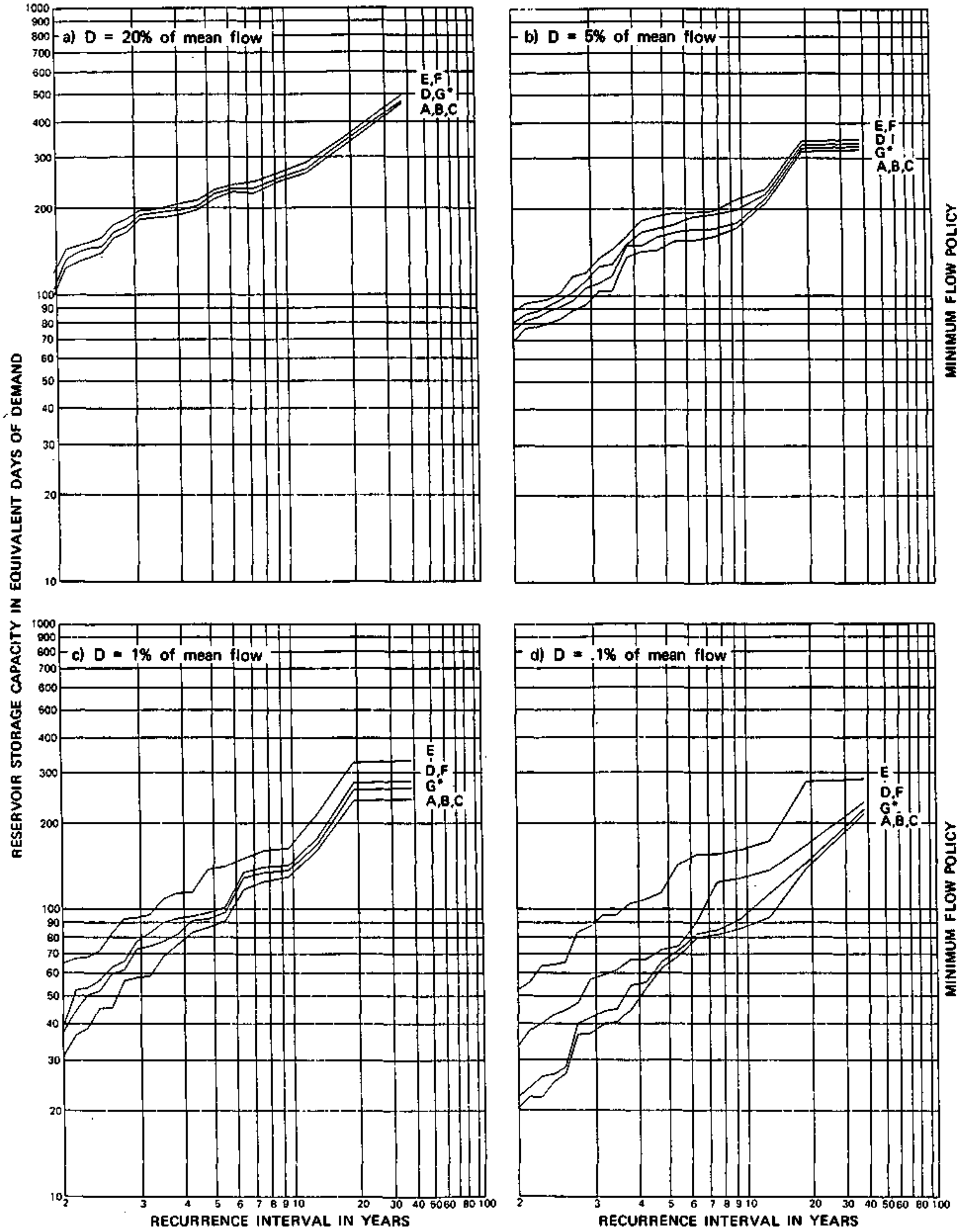


Figure 18. Comparison of Storage Requirements Using Varying Policies of Minimum Flow Needs; Bonpas Creek at Browns, d.a. = 228 mi^2

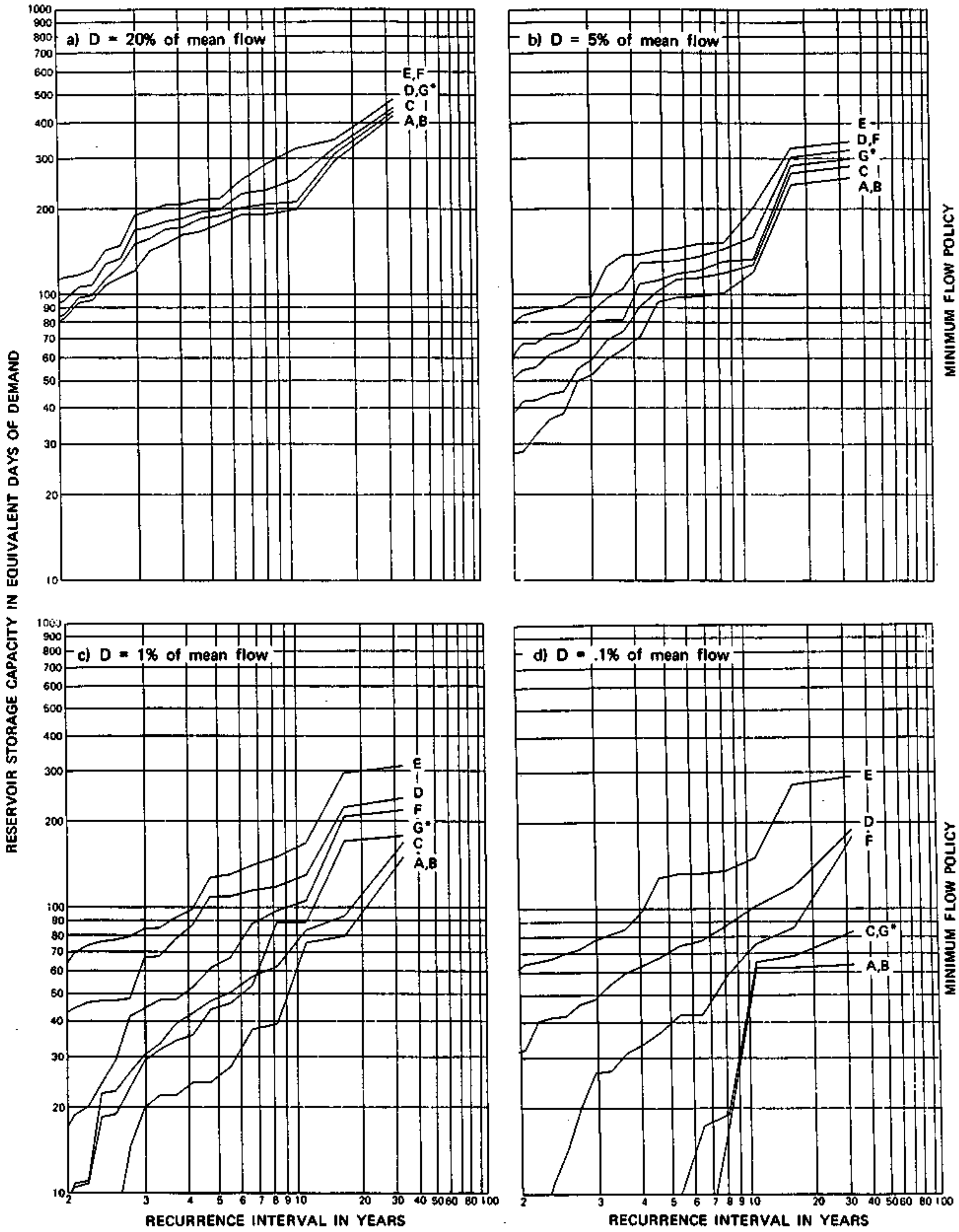


Figure 19. Comparison of Storage Requirements Using Varying Policies of Minimum Flow Needs; Beaucoup Creek near Matthews, d.a. = 292 mi^2

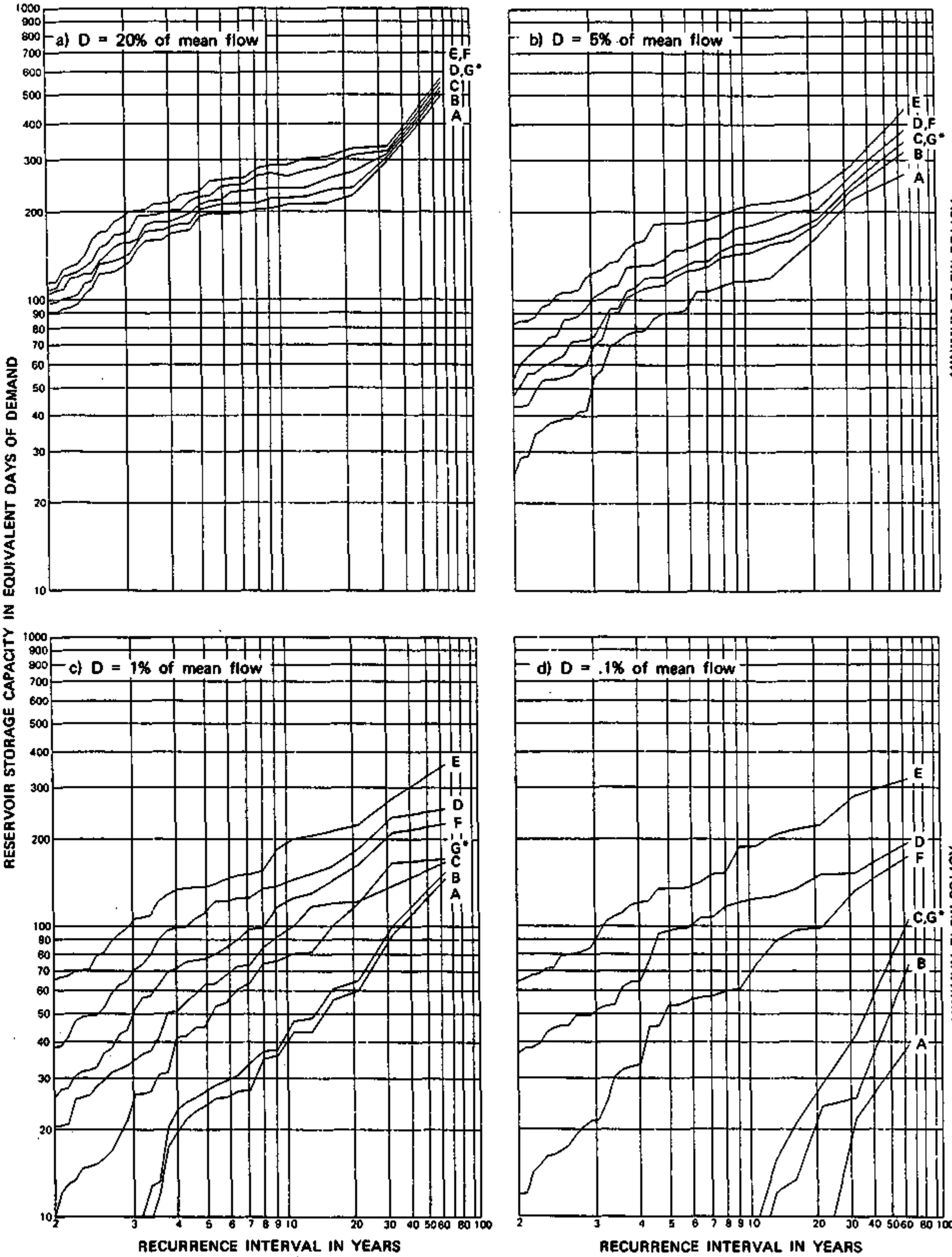


Figure 20. Comparison of Storage Requirements Using Varying Policies of Minimum Flow Needs; Little Wabash River below Clay City, d.a. =1131 mi^2

REFERENCES

Bayha, Keith. 1976. Instream Flows—The Big Picture. Proceedings of the Symposium and Specialty Conference on Instream Flow Needs, Boise, ID, May 1976, American Fisheries Society, Bethesda, MD.

Camp Dresser & McKee, Inc. 1980. Guidelines for Water Reuse. Camp Dresser and McKee, Boston.

Roberts, W.J., and J.B. Stall. 1967. Lake Evaporation in Illinois. Illinois State Water Survey Report of Investigation 57, 44 pp.

Singh, Krishan P. 1971. Model Flow Duration and Streamflow Variability. Water Resources Research, V. 7(4):1031-1036.

Terstriep, M.L. et al. 1982. Hydrologic Design of Impounding Reservoirs in Illinois. Illinois State Water Survey Bulletin 67.

PART 2. Procedures for Storage Design Evaluation

This portion of the study presents processed data for use in the design and the evaluation of side-channel reservoir storage for 87 stream gaging stations in Illinois. The stations have been grouped into geographical regions, shown in Figures 4 and 22, which display relatively homogeneous demand-storage-recurrence relationships. This regionalization allows that the data presented for the 87 stations may be used for the design and evaluation of side-channel reservoir storage at ungaged sites. Enlarged regional maps, which include the locations of the gaging stations, are presented with the processed data. Stations on these maps are identified by the 2nd through 6th digits of the complete station numbers (e.g., the number 55975 locates station 05597500).

Major Data Items

For each stream gaging station, two major sets of data are presented: 1) a summary of watershed and streamflow duration data, and 2) graphs of the demand-storage-recurrence primary relationship. The demand-storage-recurrence graphs are termed primary relationships because they were developed using an initial (primary) estimate of both the design of the side-channel reservoir's pumping system and the instream flow limitations which partially govern the pumping system's operation. In the design or evaluation of side-channel reservoir storage, each storage value obtained from the primary relationships must be adjusted to meet planned or existing pumping conditions. The adjustment factors used to describe the effect of the pumping system design on side-channel reservoir storage are provided in Tables 1, 2, and 3 of this report. Furthermore, an examination of the effects of varying instream flow limitations on the magnitude of the required storage is provided in pages 33-50.

Procedure for Estimating Storage Design

The determination of the side-channel reservoir storage required to meet a given rate of withdrawal is generally a lengthy process. This occurs because the gross demand on the reservoir, upon which the storage is dependent, is a function not only of the withdrawal rate but also of the groundwater seepage from the reservoir. The seepage, in turn, is dependent on the storage capacity of the reservoir. Several steps in an iterative design process must generally be completed before the relationship between the storage, gross demand, and reservoir seepage becomes approximately correct. With each iteration, the estimates of the gross demand and storage are modified. In addition, if the pumping system design necessitates an adjustment to the primary storage, that measure must be addressed in each iteration. The following procedure describes those steps which must be included in the storage design. For this procedure it is assumed that a demand-storage-recurrence relationship is available for the location of interest. A description of the changes needed in this procedure for ungaged sites, and an example of the use of the procedure are provided later.

1) Identify the demand-storage-recurrence graph and the pumping system adjustment ratio table to be used. If a demand-storage-recurrence graph does not exist for a station on the same stream as the proposed side-channel reservoir, such a graph must be computed using the suggestions immediately following step 8.

2) Determine the withdrawal demand of the water supply system and express it as a multiple of the average annual flow of the stream. If withdrawals are expected to fluctuate by season, use the average withdrawal rate for the season of high use for design purposes. The withdrawal demand is the initial estimate of the gross demand.

3) If the instream flow policy to be used is not similar to the policy associated with the primary relationship (see page 34), study the instream flow graphs (Figures 9-20) to determine how the demand-storage-recurrence curves should be adjusted. The adjustment may be expressed as a ratio, which is multiplied by the primary relationship storage in step 6.

4) Express the discharge capacity of the pumps in the pumping system in terms of a multiple of the current estimate of the gross demand. Advance to the pumping system adjustment ratio table and estimate the adjustment ratio that should be associated with the designed pumping system.

5) With the current estimate of the gross demand and the desired recurrence interval, use the demand-storage-recurrence graph to determine required storage.

6) Multiply the storage determined in step 5 by the adjustment ratios found in steps 3 and 4. This is the storage needed to meet the current gross demand, using the described pumping system and minimum flow policy. Proper use of the adjustment ratios described above is essential for the determination of an accurate storage.

7) Design the reservoir at the location of interest giving it the storage capacity calculated in step 6. Estimate the seepage rate of

this reservoir. Add the seepage rate to the withdrawal demand to produce a new estimate of the gross demand.

8) If the gross demand estimated in step 7 is significantly greater than the previous estimate of the gross demand, repeat steps 3 through 7. If the current and previous estimates of the gross demand are essentially equal, the storage estimation process is complete.

When the location of a proposed side-channel reservoir is not at one of the 87 stations presented in this report, an estimate of the demand-storage-recurrence relationship at the design site must be calculated. The estimation of the demand-storage-recurrence relationship at an ungaged site is achieved by generalizing that relationship from nearby stations in the methodology described below. Once this estimate is made, one may continue with the 8-point procedure presented above to determine storage needs at the design location.

The low flow characteristics which determine side-channel reservoir storage needs are most closely associated with 1) the regional character of the watershed, described by the design regions defined in Figures 4 and 22, and 2) the drainage area. From these two variables, estimates of the mean flow and minimum flow statistics can commonly be made. In a similar manner, the drainage area can be related to the side-channel storage requirements of an ungaged site by plotting the storage requirements and drainage areas of nearby stations and assuming a graphical relationship between the two variables (see Figure 5). The streamflow stations chosen for this analysis should represent a variety of drainage basin sizes and should be those stations nearest the location of interest. Preference should be given to those stations with lengthy streamflow records. This drainage area-storage estimation technique is further clarified in the following example of side-channel reservoir storage design.

Example of Storage Design

Assume, for example, that a side-channel reservoir is planned for the Fox River, a tributary of the Little Wabash River, at Olney for the purpose of supplementing that city's water supply. The drainage area of the Fox River at the site of the proposed reservoir is 83 mi^2, and the estimated mean annual flow is 60.5 cfs. The projected withdrawal demand from the side-channel water supply system is 175,000 gallons per day (.175 mgd) which is equivalent to .45% of the mean annual flow. The side-channel storage is expected to meet the stated withdrawal demand for droughts up to a recurrence interval of 40 years.

There are no gaging stations in the immediate vicinity of Olney which have storage graphs that can be used to directly determine the amount of storage needed for the side-channel reservoir. For this reason a relationship between the drainage area and the storage design requirements for surrounding gaging stations must be computed. Six streamflow stations in the vicinity of Olney were chosen for the analysis of the drainage area-storage relationship, those being Range Creek near Casey, Embarras River at Ste. Marie, North Fork Embarras River near Oblong, Bonpas Creek at Browns, Little Wabash River below Clay City, and Skillet Fork at Wayne City. The drainage areas of these six stations were plotted with the respective values of storage needed at each station for gross demands of .2%, .5%, and 1.0% of the mean annual flow and for a recurrence interval of 40 years. All of the stations have streamflow records approaching or exceeding 40 years in length except for the station on Range Creek; for this station a 40-year recurrence storage was extrapolated from the station's demand-storage-recurrence graph. The drainage area-storage relationship subsequently developed from the six stations is shown in Figure 21. The estimated storage needs for gross demands of .2%, .5%, and 1.0% of the mean annual flow are 186, 210, and 250 days of demand, respectively.

The pumping system planned for use with this reservoir is designed to incorporate two fixed-speed pumps with discharge capacities of 1 and 3 times the estimated gross demand. Associated with this pumping system is an adjustment ratio which must be used to modify all estimates of the required side-channel reservoir storage (see step 4, page 54). This adjustment ratio, equal to 1.35, is found in Table 3 associated with pumping system #17 for demands less than 2% of the mean flow. The pumping system will be operated under the guidelines set forth by the minimum flow policy used to establish the primary demand-storage-recurrence relationships, therefore there is no adjustment for instream flow differences.

The initial estimate of the gross demand, for use in the storage design procedure, is the withdrawal demand of .45% of the mean annual flow. The storage calculated in Figure 21 for this demand is approximately 205 days of demand (step 5). This expression of storage may be converted to acre-feet by multiplying the storage (given in number of days of demand) by the daily gross demand (in mgd) and then converting this volume (million gallons) to acre-feet by multiplying by 3.07; producing:

$$\text{205 days} \times \text{.175 mgd} \times 3.07\ \frac{\text{a-ft}}{\text{mg}} = \text{110 acre-feet}$$

This storage amount is then modified by the pumping system adjustment ratio, 1.32, to produce the storage of 145 acre-feet (step 6). This is the

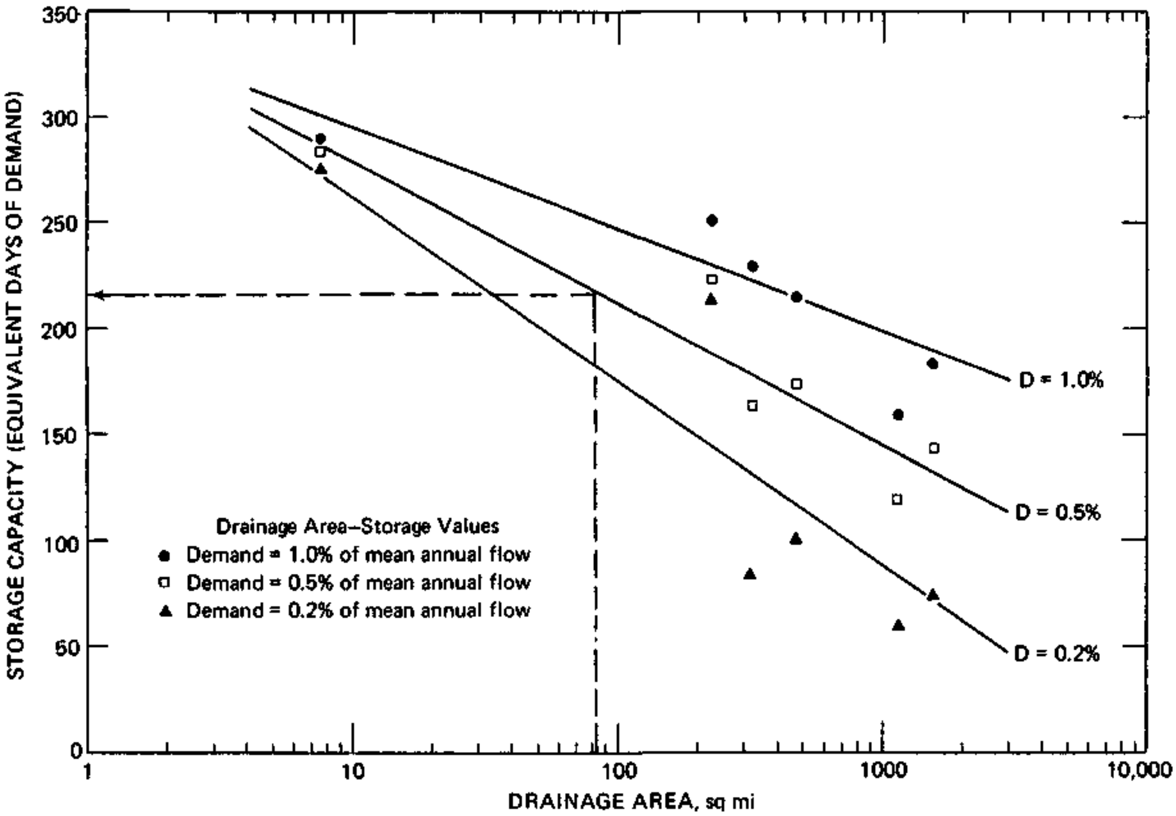


Figure 21. Drainage Area-Storage Relationship for the Vicinity of Olney, Illinois; Recurrence Interval = 40 years

initial estimate of the storage, which in reality is the storage required if the gross demand were equal to the withdrawal demand.

The estimate of the gross demand needed to find the actual design storage is the sum of the withdrawal demand and the demand due to groundwater seepage. The average rate of seepage, in turn, must be computed from a reservoir design that uses an existing estimate of the reservoir storage. By alternately revising the estimates of the seepage demand and the required storage, starting with the initial storage estimate shown above, these two parameters will approach their correct values.

Let us assume that after several iterations of steps 3-7, the estimated gross demand of the designed reservoir stabilizes at .23 mgd (.59% of the mean annual flow). The storage in Figure 21 associated with this demand level is approximately 225 days of demand, which converts to 159 acre-feet. Again the adjustment ratio is used to modify the primary relationship storage, producing a final estimate of the required storage of 210 acre-feet.

Use of Design Data for Evaluating Existing Facilities

The evaluation of existing side-channel reservoirs involves a reversed use of the demand-storage recurrence graphs and the pumping system adjustment ratios, perhaps best explained by the following example. Computations associated with this example are shown in Table 5.

Assume that a side-channel reservoir exists near Jacksonville immediately downstream of the USGS gage along the North Fork of Mauvaise Terre Creek. The demand-storage-recurrence primary relationship for this gage is shown on page 139. The capacity of the reservoir is 180 acre-feet and the gross demand on the reservoir is .13 mgd, which is equal to 1.0% of

Table 5. Example of the Evaluation of an Existing or Potential Side-Channel Reservoir

Location North Fork Mauvaise Terre Creek near Jacksonville

Design Region G

1) Drainage Area = 29.1 mi^2

2) a. Estimated Mean Flow = 9.43 inches per year

b. .0738 x line 1 x line 2a = 20.25 cfs

3) a. Gross Demand = .13 mgd

b. line 3a x 694.4 = 90.27 gpm

c. line 3a x 1.55 = .2015 cfs

d. line 3c ÷ line 2 x 100% = 1.00 % of the mean annual flow

4) a. Reservoir Storage = 180 acre-feet

b. line 4a ÷ 3.07 = 58.6 million gallons

c. line 4b ÷ line 3a = 451 days of demand

5) Instream Flow Adjustment Ratio = .85 .

6) Pump Sizes

270 gpm ÷ line 3b = 3.0 x Demand

________ gpm ÷ line 3b = ________ x Demand

________ gpm ÷ line 3b = ________ x Demand

7) Pumping System Adjustment Ratio (Tables 1, 2, or 3)

= 2.30

8) Equivalent Primary Storage (line 4c ÷ line 5 + line 7)

= 231 days of demand

9) Recurrence Interval (lines 3d and 8 used with the design-storage-recurrence primary relationship) = 12 years

the mean annual flow of the stream. The pumping system currently in use employs one pump of capacity 270 gpm (equivalent to 3 times the gross demand). The pumps are used whenever the streamflow volume allows their use and when the reservoir storage is not at capacity. There is no allowance for instream flow.

Adjustment due to Instream Flow Differences. Because instream flow limitations are not applied with the described side-channel pumping system, the amount of storage needed at the reservoir will be less than would be the case if the primary relationship's minimum flow policy were used. An evaluation of the effect that this may have on required storage may be obtained through the examination of Figures 9-20. Of these figures, Figure 13, which represents Crow Creek at Washburn, seems to best represent the possible effect that the instream flow policies may have on the North Fork of Mauvaise Terre Creek. An interpretation of Figure 13 suggests that the use of a zero minimum flow policy will on average reduce the required storage to 80-90% of that shown in the demand-storage-recurrence graphs. Therefore, an adjustment ratio of approximately .85 should account for the differing instream flow policy (line 5 in Table 5).

Pumping System Adjustment Ratio. The one-pump pumping system described earlier is essentially the same as pumping system #25 presented in Table 4. The pumping system adjustment ratio needed for evaluating the reservoir storage is found from Table 2 (central Illinois) by matching pumping system 25 with the gross demand of 1.0%. This ratio (2.30) is shown on line 7 of Table 5.

Equivalent Primary Storage. The side-channel reservoir storage of 180 acre-feet at the described site is equal to 451 days of the gross demand. However, this storage is not equivalent to that used in the primary relationship demand-storage-recurrence graphs because the pumping and instream flow conditions are not the same. When the storage value (451 days) is divided by the instream flow adjustment ratio (.85) and the pumping system adjustment ratio (2.30), the resulting storage value is 231 days of demand. This latter value is defined as the equivalent primary storage of this reservoir. This means that the storage in the existing reservoir has the same drought recurrence interval as does a reservoir which has the same gross demand, but has 231 days of storage, and which uses the pumping system and instream flow policy used to define the primary relationship.

The equivalent primary storage is used with the gross demand and the demand-storage-recurrence graph (page 139) to determine the recurrence interval for which the side-channel reservoir becomes deficient. This recurrence interval for this example is estimated to be approximately 12 years (see Table 5).

Evaluation of the Pumping System. The large adjustment ratio associated with the pumping system in this example, 2.30, suggests that much more efficient use could be made of the reservoir storage. For instance, by adding to the system a pump of capacity 90 gpm (equivalent to the gross demand), the adjustment ratio could be reduced to 1.55. The equivalent primary storage would then be estimated at 345 days of demand. Use of the demand-storage-recurrence graph indicates that an equivalent primary storage of 345 days is sufficient for recurrence intervals exceeding 30 years. Consequently, by suggesting improvements in the pumping systems of existing reservoirs, the methodologies in this report may be used to increase the reliability, and in many cases the safe yield, of many side-channel reservoirs.

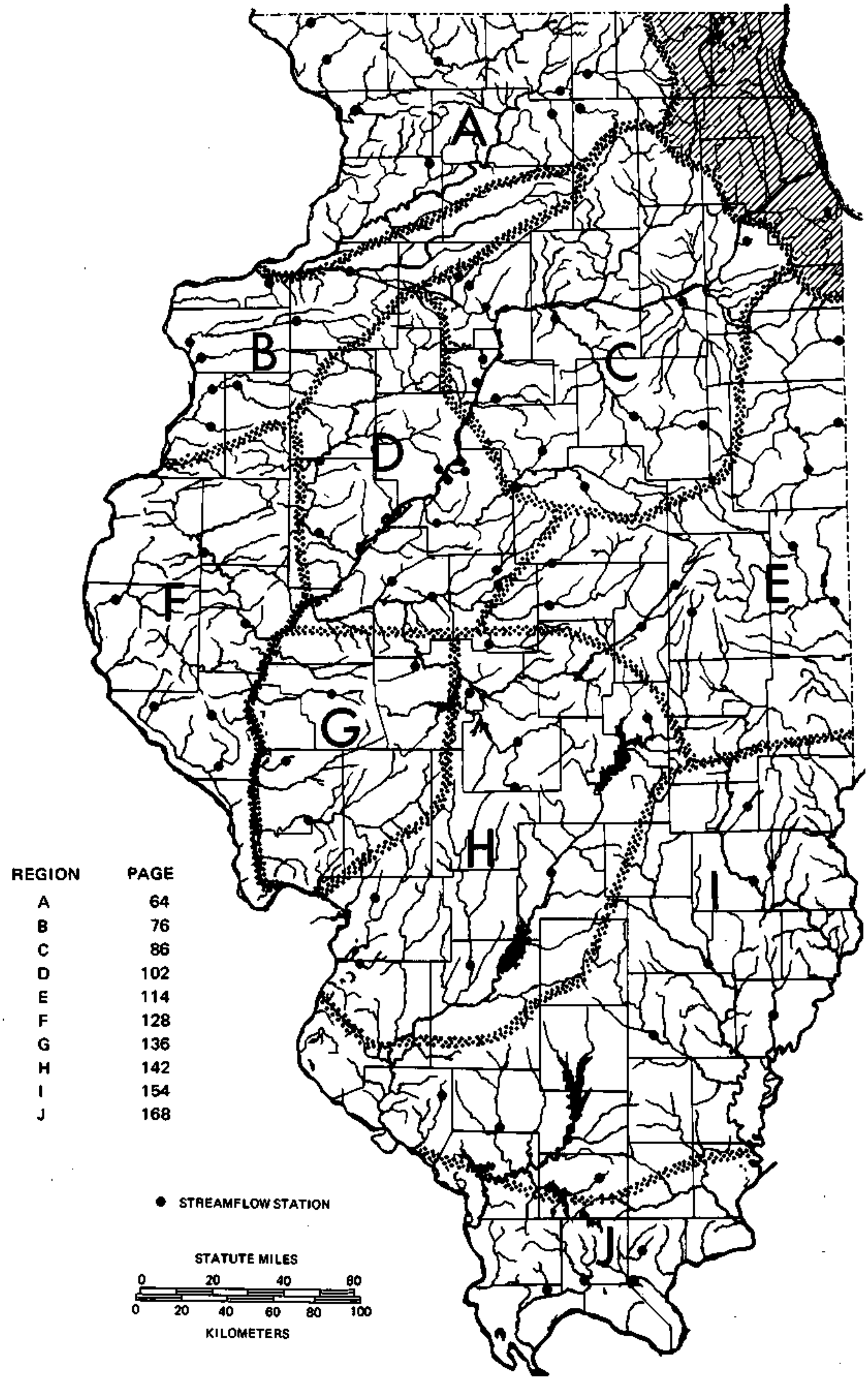
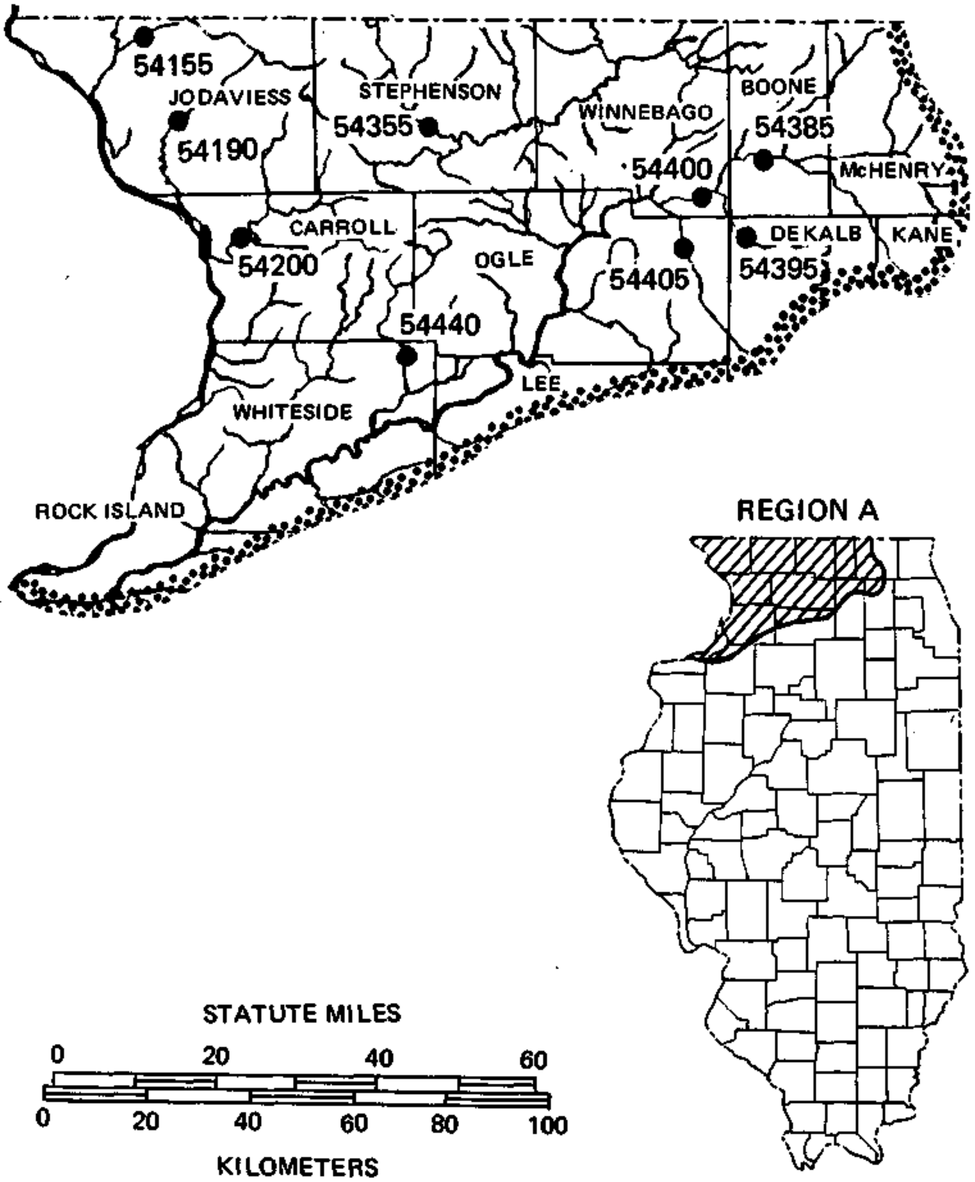


Figure 22. Storage Design Regions


54155
JODAVIESS
54190
STEPHENSON
54355
WINNEBAGO
BOONE
54385
54400
McHENRY
CARROLL
54200
OGLE
54405
DEKALB
KANE
54395
54440
LEE
WHITESIDE
ROCK ISLAND
REGION A
STATUTE MILES
0 20 40 60
0 20 40 60 80 100
KILOMETERS

REGION A

USGS Gage No.	Name of Station	Period of Record	Number of Years
54155	East Fork Galena River at Council Hill	1940-1968	28
54190	Apple River near Hanover	1935-1978	43
54200	Plum River below Carroll Creek nr Savanna	1941-1976	35
54355	Pecatonica River at Freeport	1915-1978	63
54385	Kishwaukee River at Belvidere	1940-1978	38
54395	South Br. Kishwaukee River near Fairdale	1940-1978	38
54400	Kishwaukee River near Perryville	1940-1978	38
54405	Killbuck Creek near Monroe Center	1940-1971	31
54440	Elkhorn Creek near Penrose	1940-1978	38

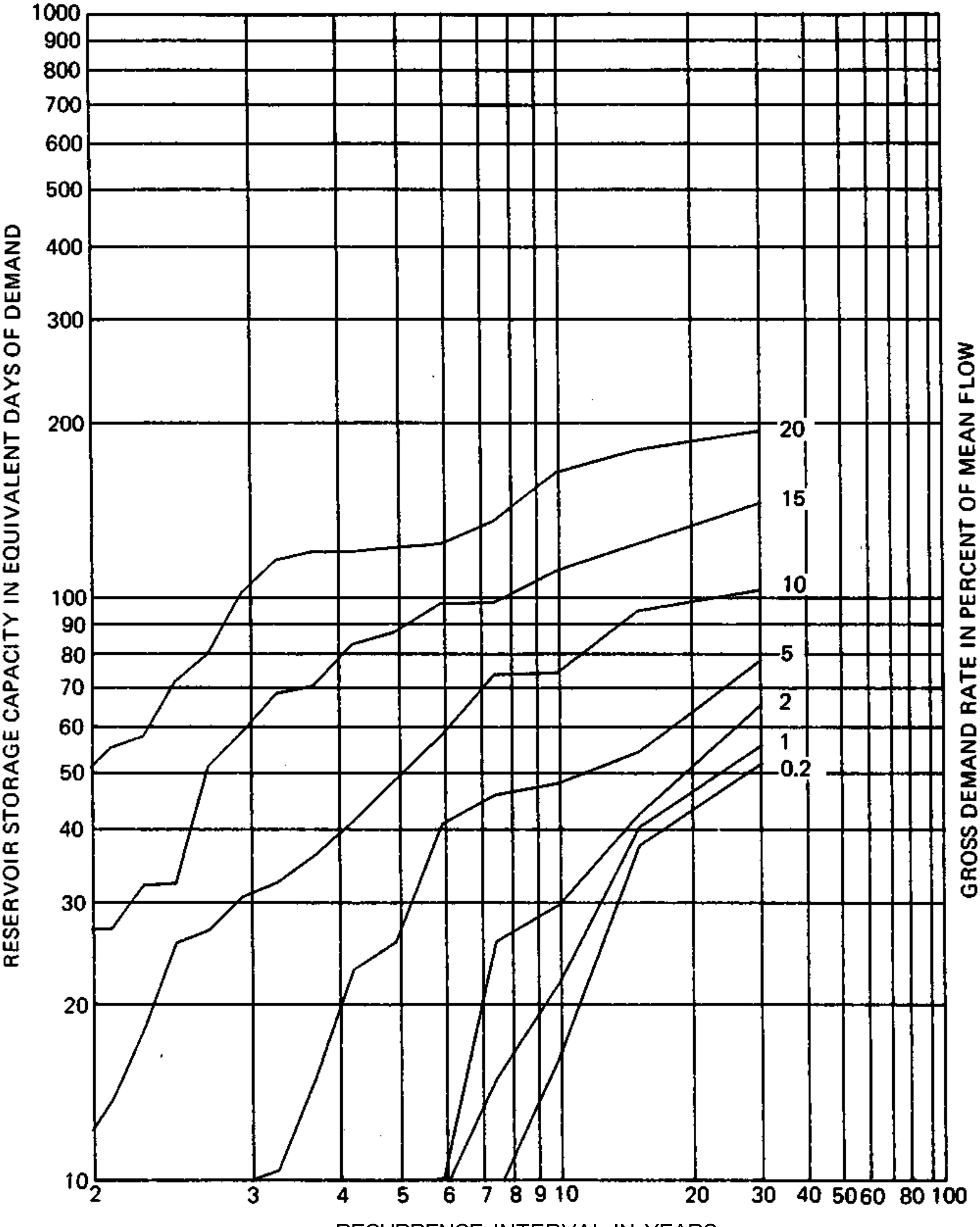
Drainage Area and Streamflow Characteristics

Gage No.	Drainage Area (mi^2)	Mean Flow (cfs)	Mean Flow (in./year)	$Q_{7,10}$ (cfs)	Q90 (cfs)	Q75 (cfs)	Q60 (cfs)
54155	20.1	12.3	8.29	2.3	3.3	4.9	5.6
54190	247.	166.0	9.13	20.1	29.0	45.0	62.0
54200	230.	150.0	8.86	10.7	21.0	32.0	50.0
54355	1326.	887.0	9.08	181.0	300.0	400.0	500.0
54385	538.	330.0	8.33	34.3	60.0	96.0	140.0
54395	387.	245.0	8.60	9.9	17.0	32.0	66.0
54400	1099.	673.0	8.32	62.3	110.0	180.0	270.0
54405	114.	59.7	7.10	3.1	6.1	10.6	18.0
54440	146.	94.2	8.76	15.5	23.0	33.0	43.0

STATION 05415500

EAST FORK GALENA RIVER AT COUNCIL HILL

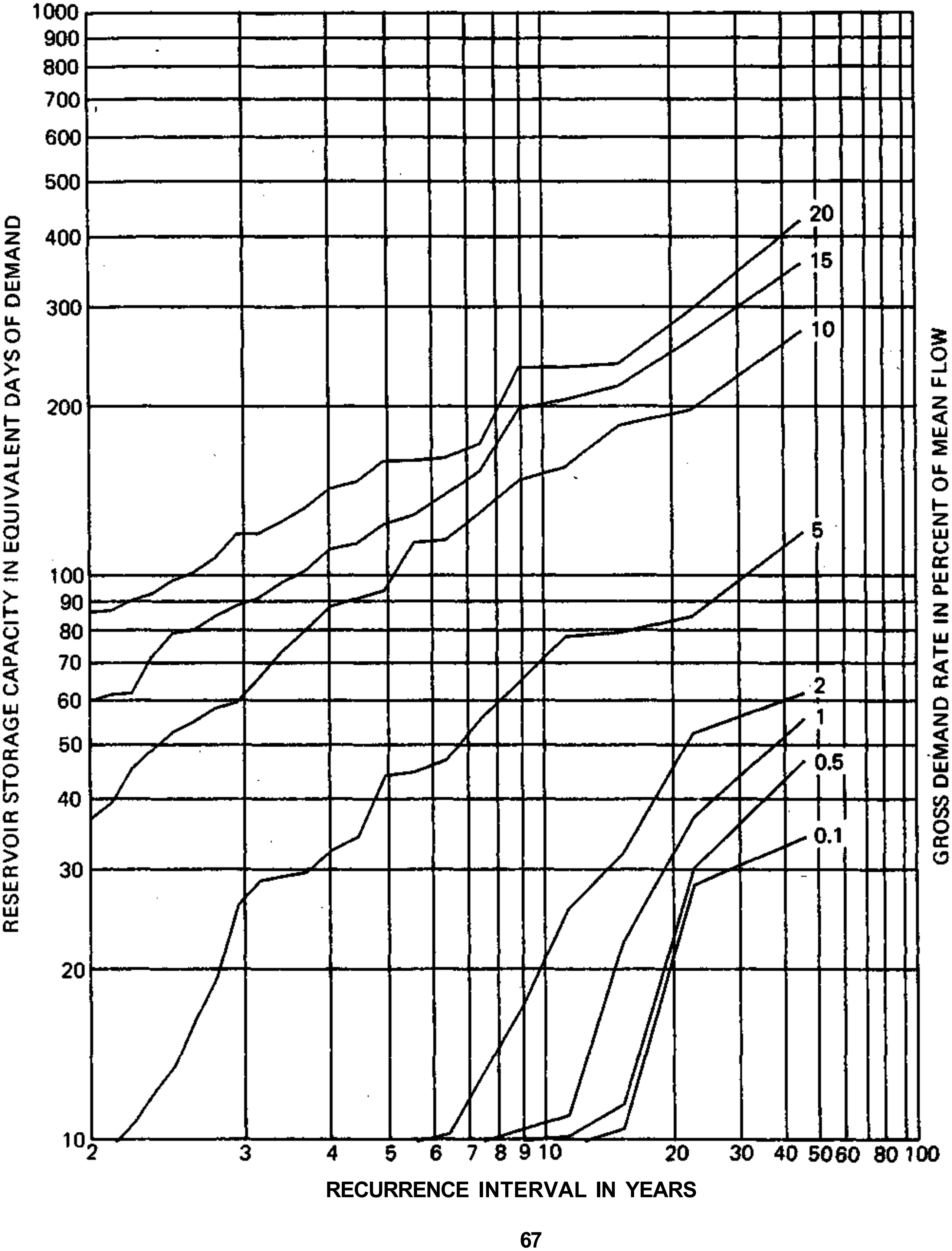
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05419000

APPLE RIVER NEAR HANOVER

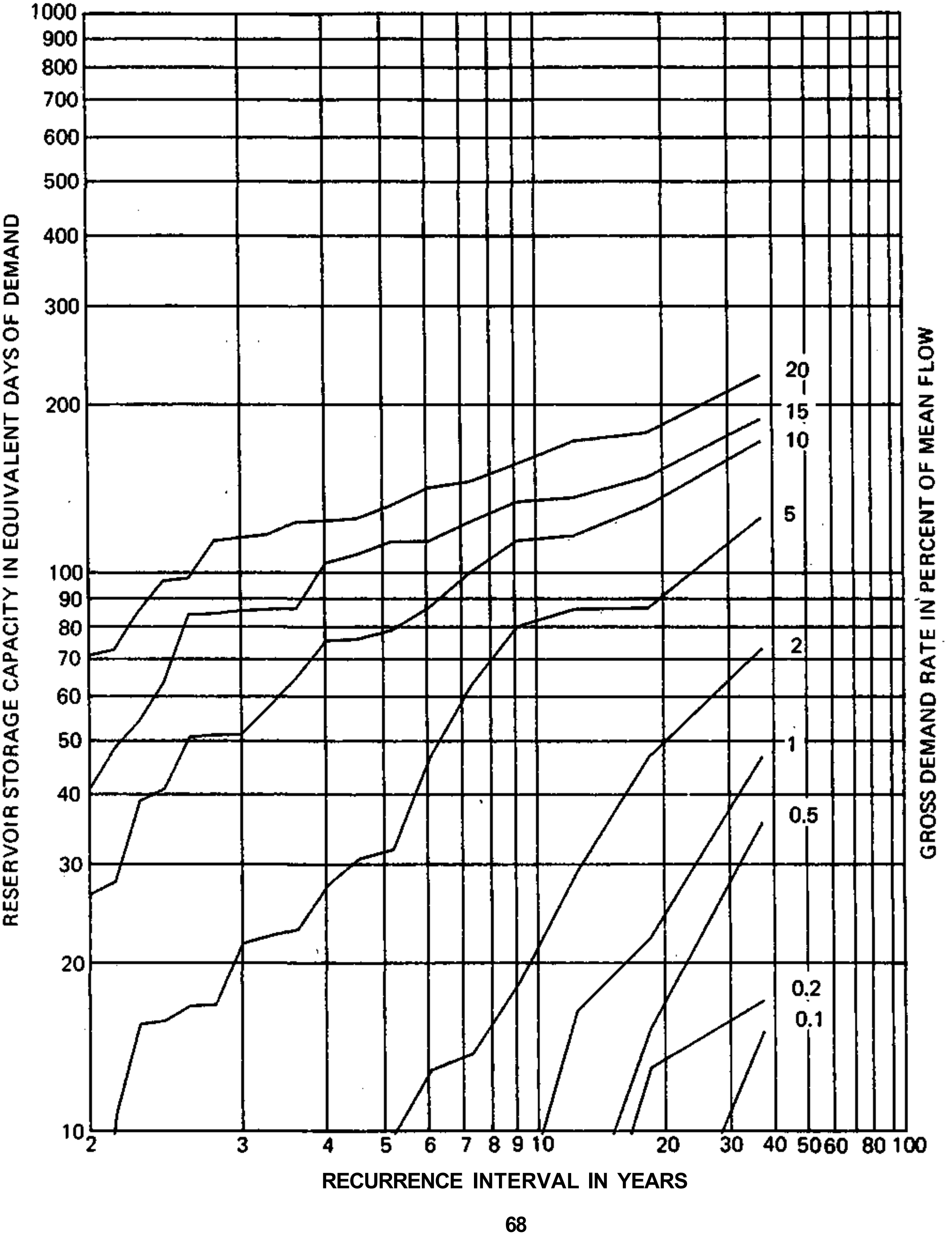
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05420000

PLUM RIVER BELOW CARROLL CREEK, NEAR SAVANNA

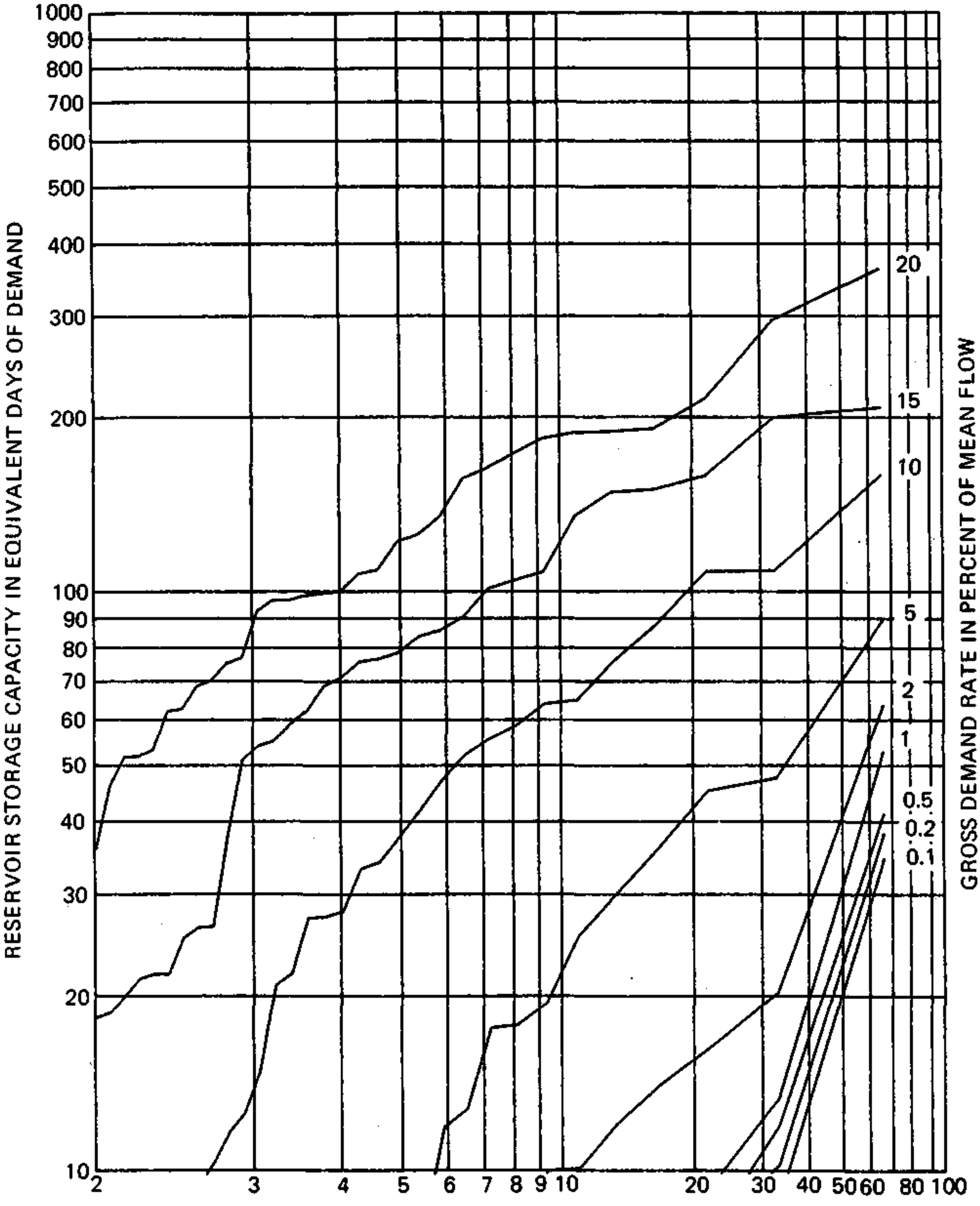
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05435500

PECATONICA RIVER AT FREEPORT

DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP

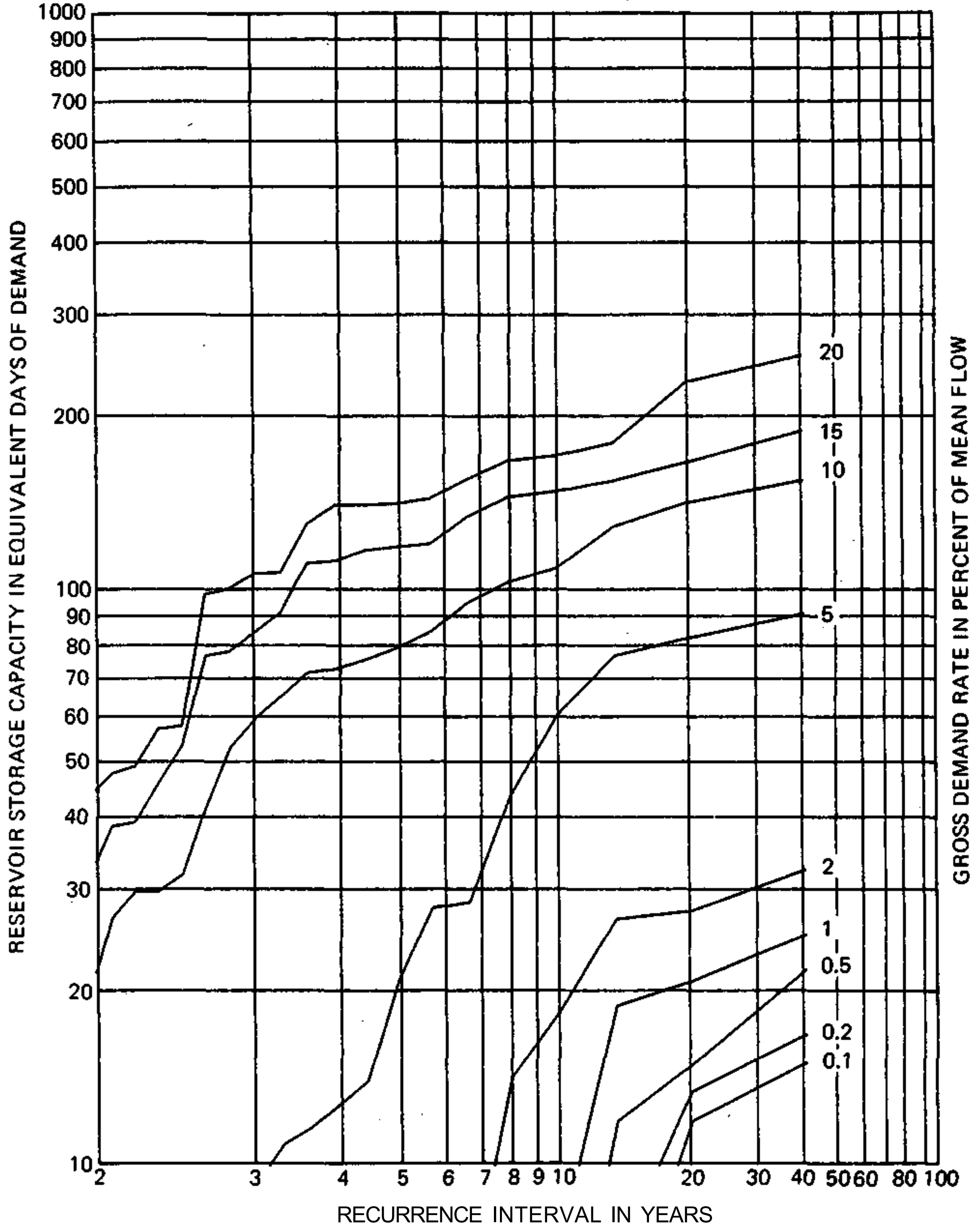


RECURRENCE INTERVAL IN YEARS

STATION 05438500

KISHWAUKEE RIVER AT BELVIDERE

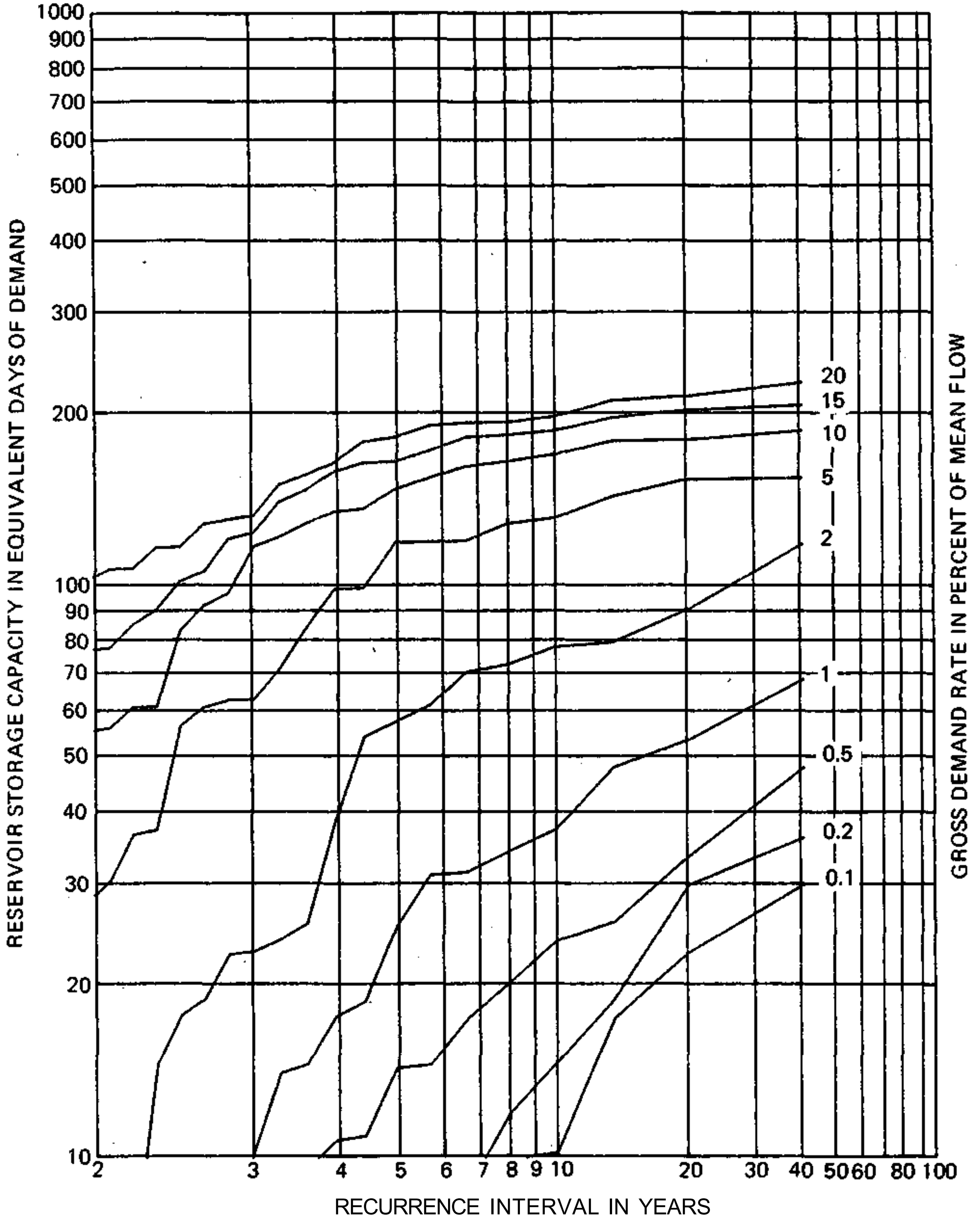
DEMAND-STORAGE-RECURRENCE PRIMARY RELATIONSHIP



STATION 05439500

SOUTH BRANCH KISHWAUKEE RIVER NEAR FAIRDALE

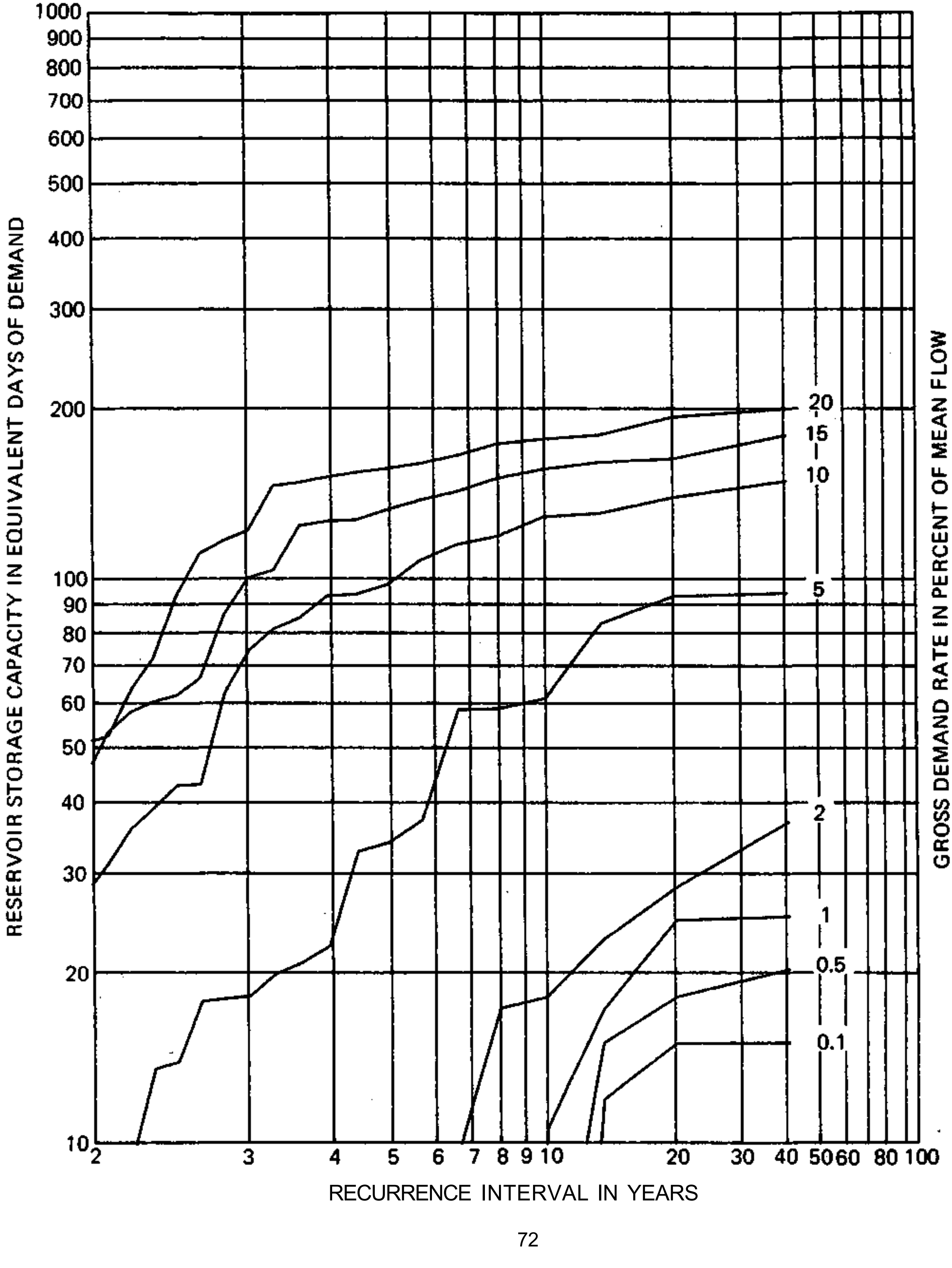
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05440000

KISHWAUKEE RIVER NEAR PERRYVILLE

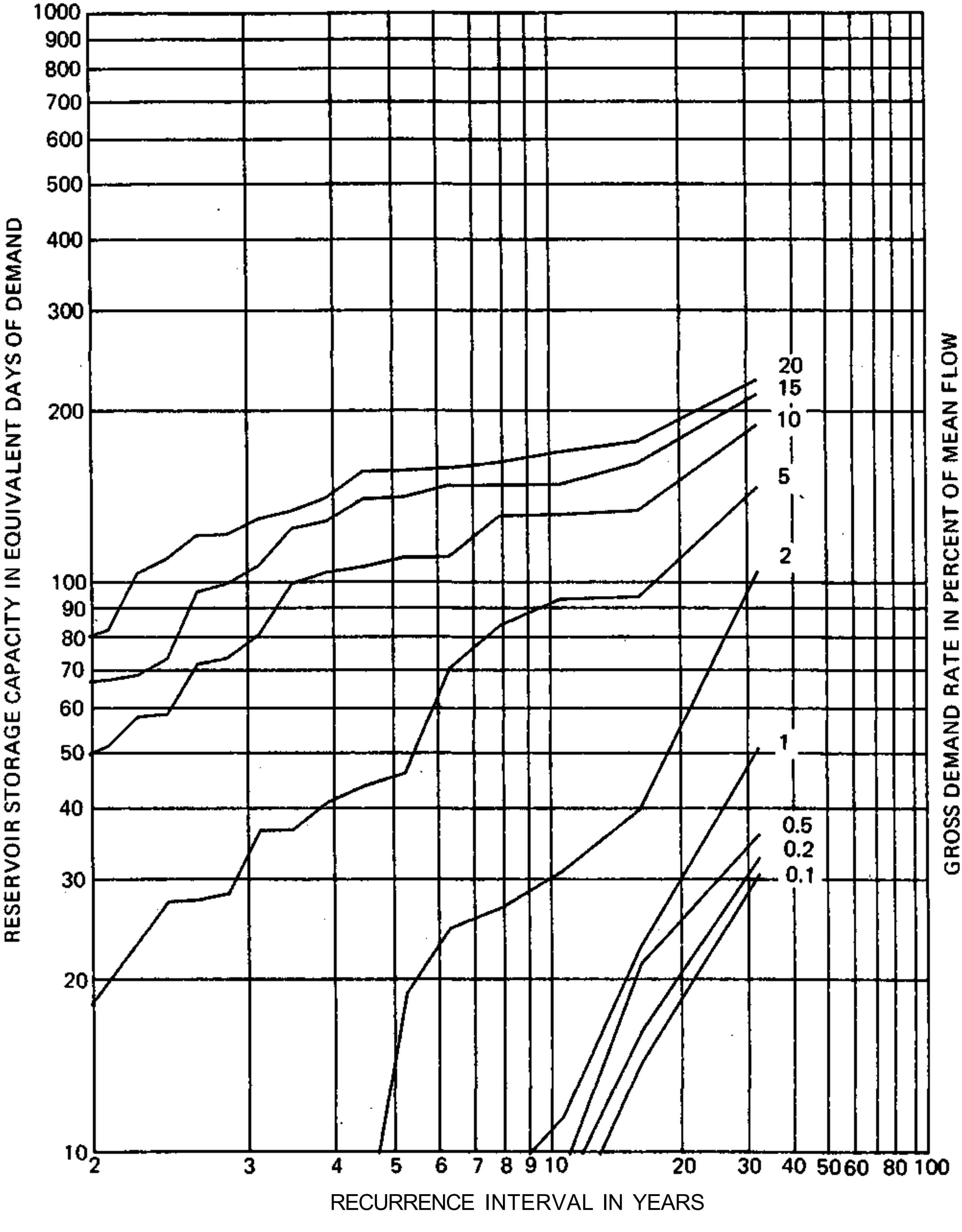
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05440500

KILLBUCK CREEK NEAR MONROE CENTER

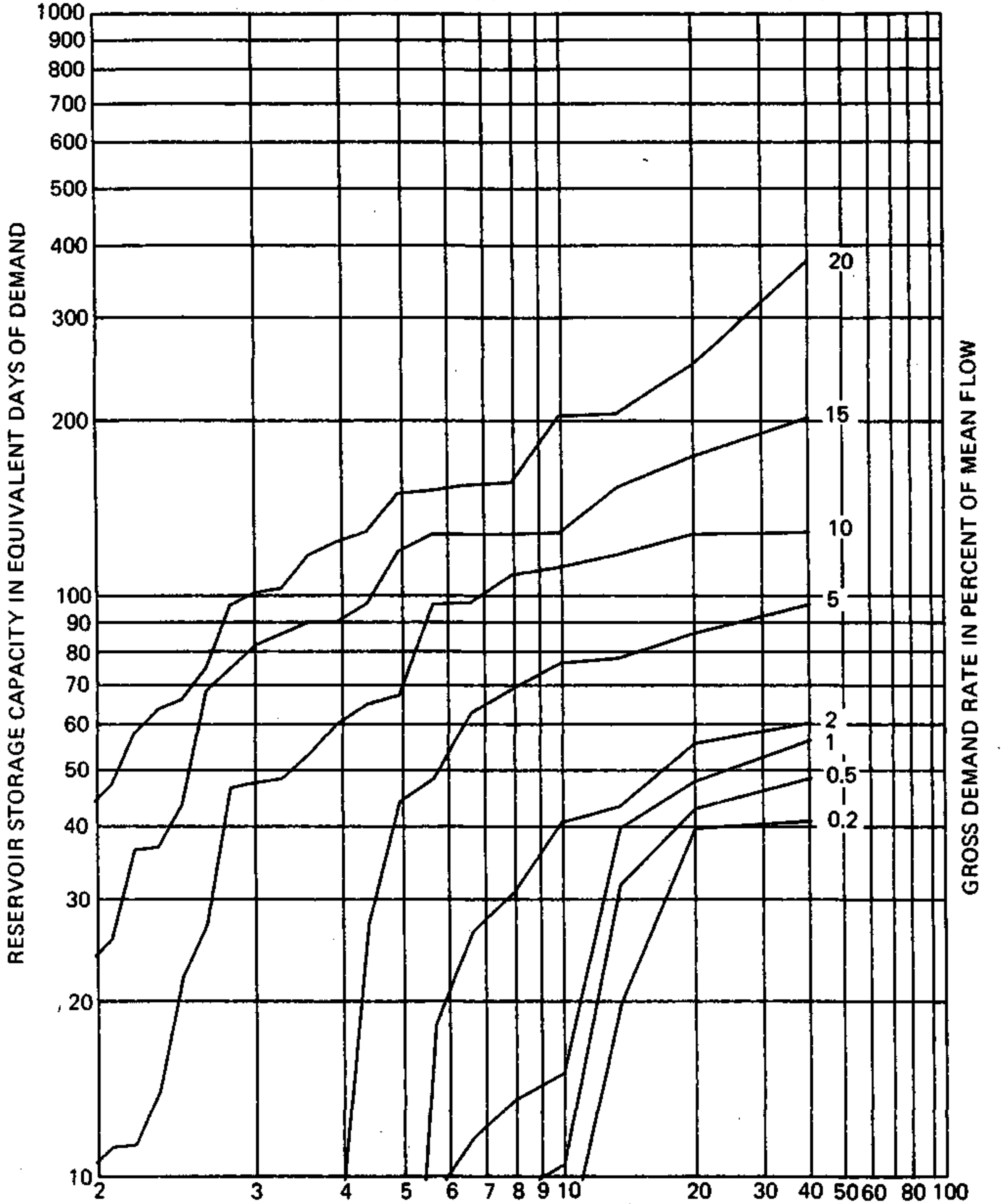
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



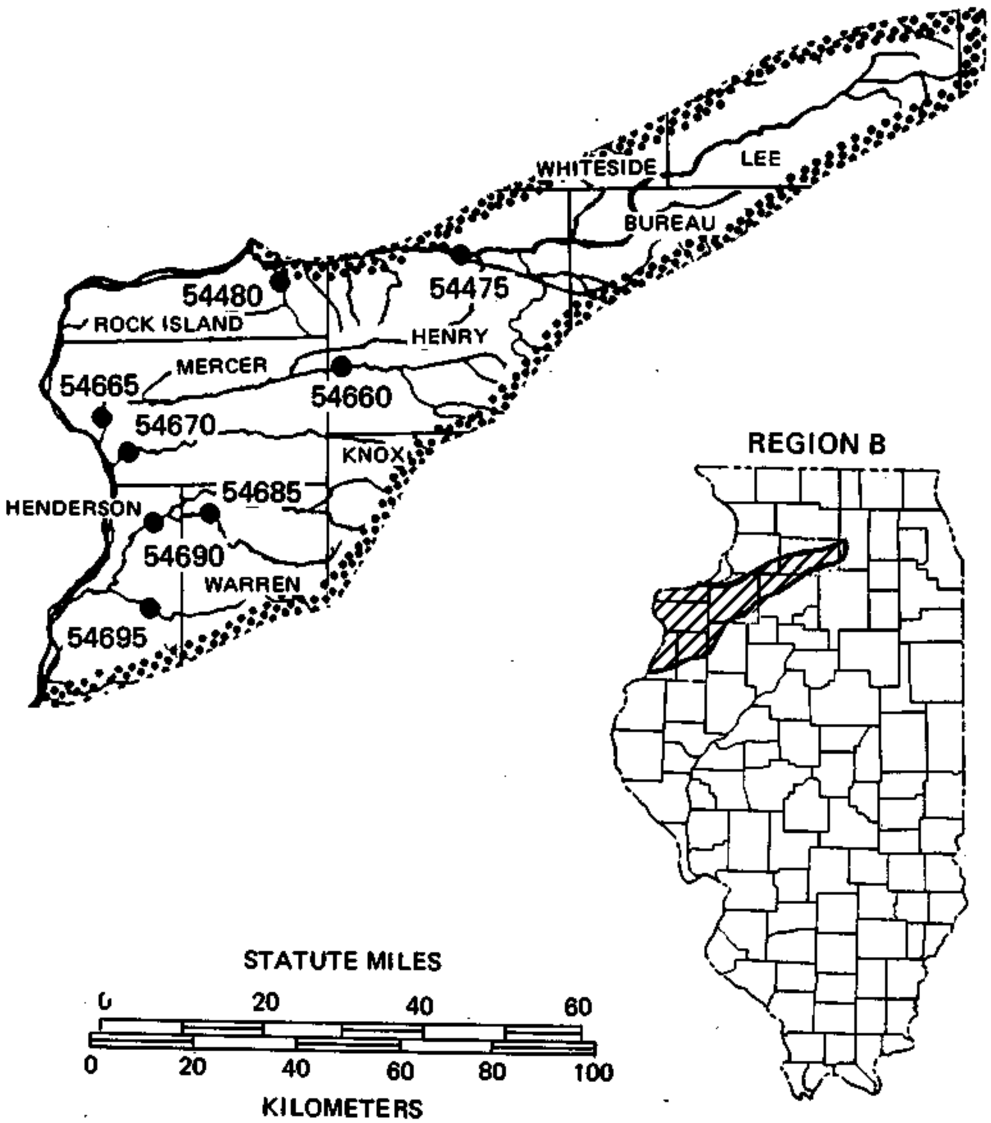
STATION 05444000

ELKHORN CREEK NEAR PENROSE

DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



RECURRENCE INTERVAL IN YEARS



WHITESIDE
LEE
BUREAU
54480
54475
ROCK ISLAND
HENRY
MERCER
54665
54660
54670
KNOX
REGION B
54685
HENDERSON
54690
WARREN
54695
STATUTE MILES
0
20
40
60
0
20
40
60
80
100
KILOMETERS

REGION B

USGS Gage No.	Name of Station	Period of Record	Number of Years
54475	Green River near Geneseo	1936-1978	42
54480	Mill Creek at Milan	1942-1978	36
54660	Edwards River near Orion	1941-1978	37
54665	Edwards River near New Boston	1935-1978	43
54670	Pope Creek near Keithsburg	1935-1978	43
54685	Cedar Creek at Little York	1941-1971	30
54690	Henderson Creek near Oquawka	1935-1978	43
54695	South Henderson Creek at Biggsville	1940-1971	31

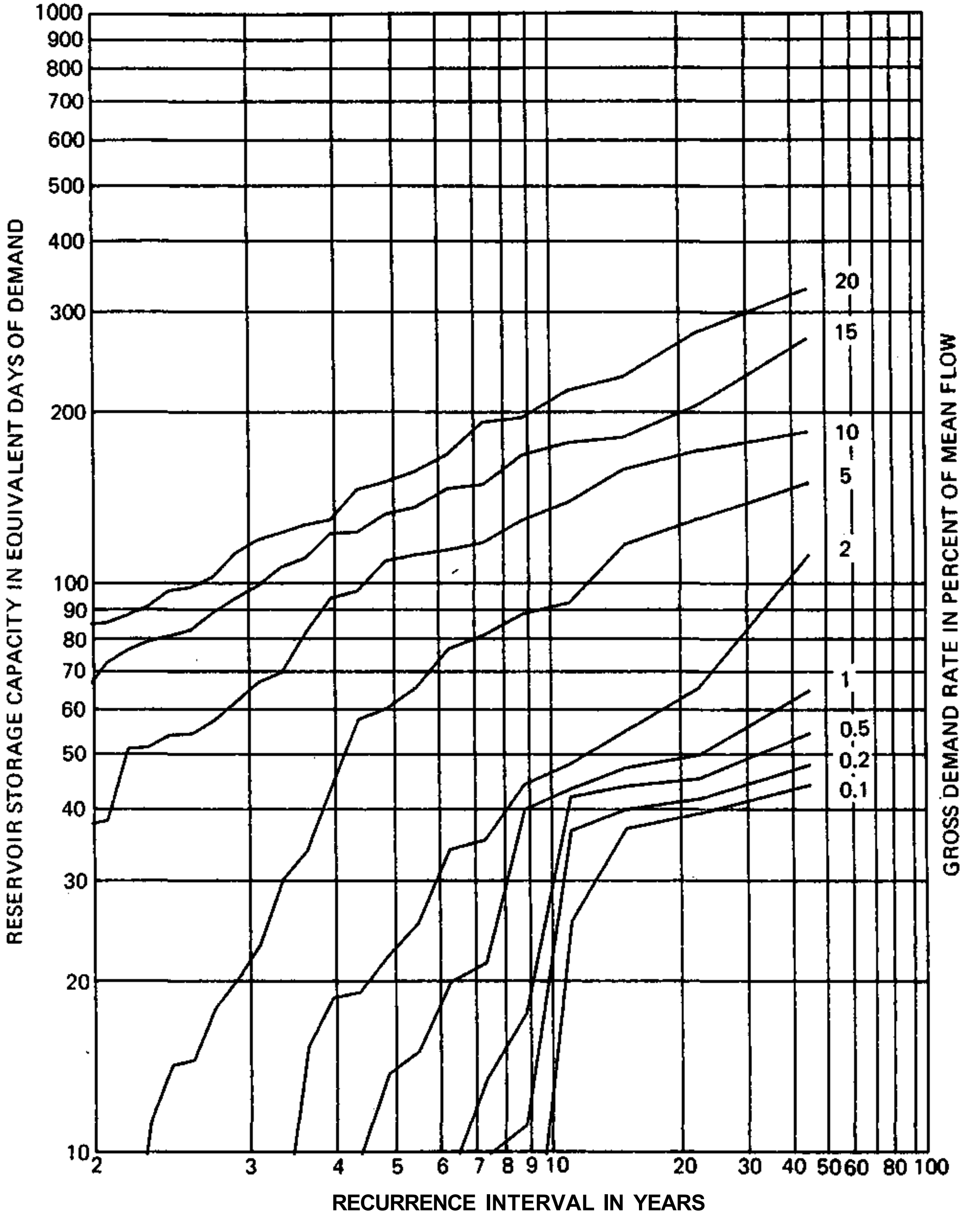
Drainage Area and Streamflow Characteristics

Gage No.	Drainage Area (mi^2)	Mean Flow (cfs)	Mean Flow (in./year)	$Q_{7,10}$ (cfs)	Q90 (cfs)	Q75 (cfs)	Q60 (cfs)
54475	1003.	586.0	7.93	49.2	87.0	140.0	240.0
54480	62.4	42.0	9.14	.1	1.3	3.9	9.0
54660	155.	103.0	9.02	1.7	4.9	12.3	26.0
54665	445.	271.0	8.27	6.8	19.0	39.0	72.0
54670	183.	102.0	7.57	1.9	5.6	13.0	25.0
54685	128.	87.3	9.24	7.4	14.3	20.0	33.0
54690	432.	277.0	8.71	7.8	17.0	36.0	70.0
54695	81.4	46.4	7.72	0.0	.3	2.8	9.0

STATION 05447500

GREEN RIVER NEAR GENESEO

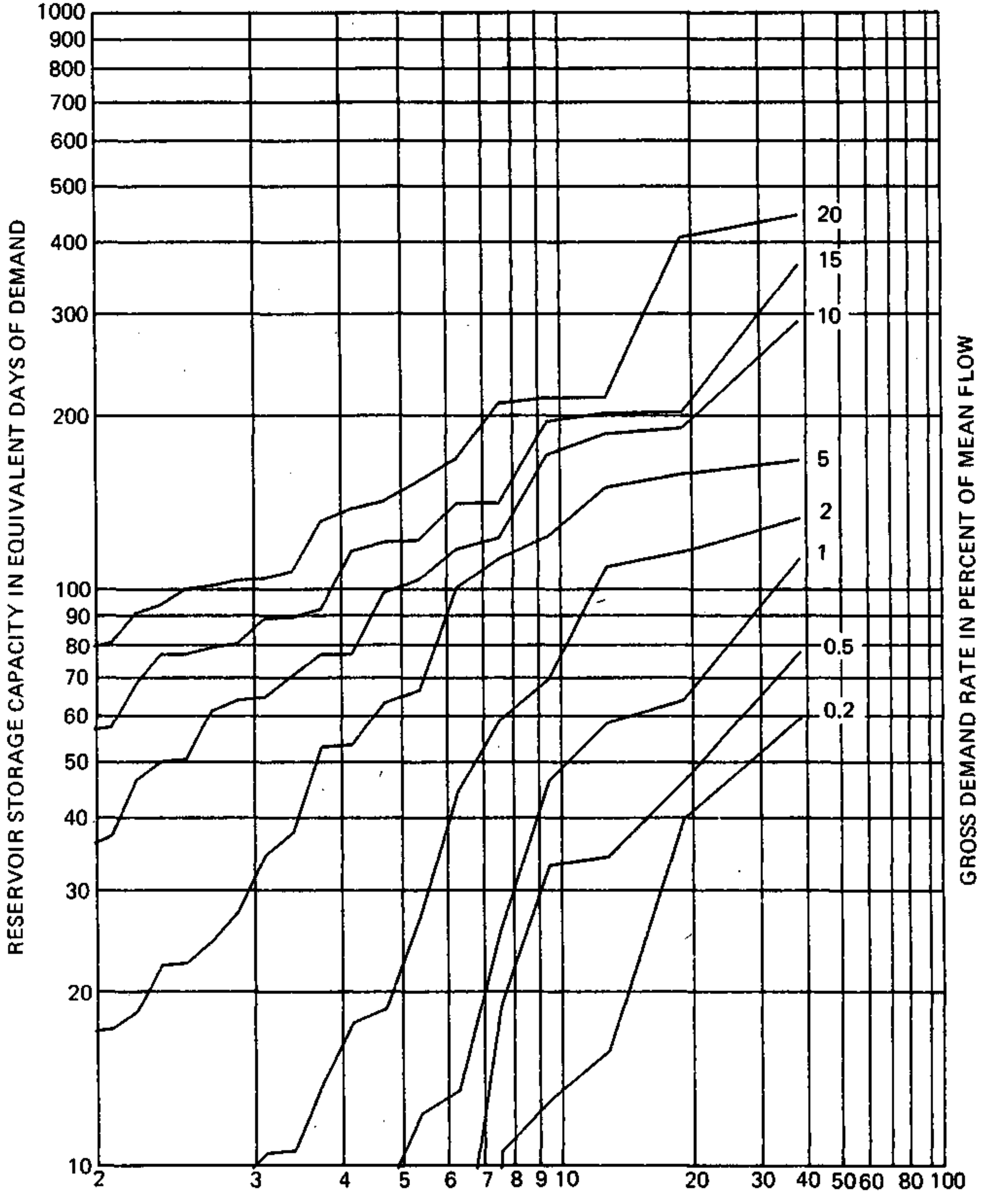
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05448000

MILL CREEK AT MILAN

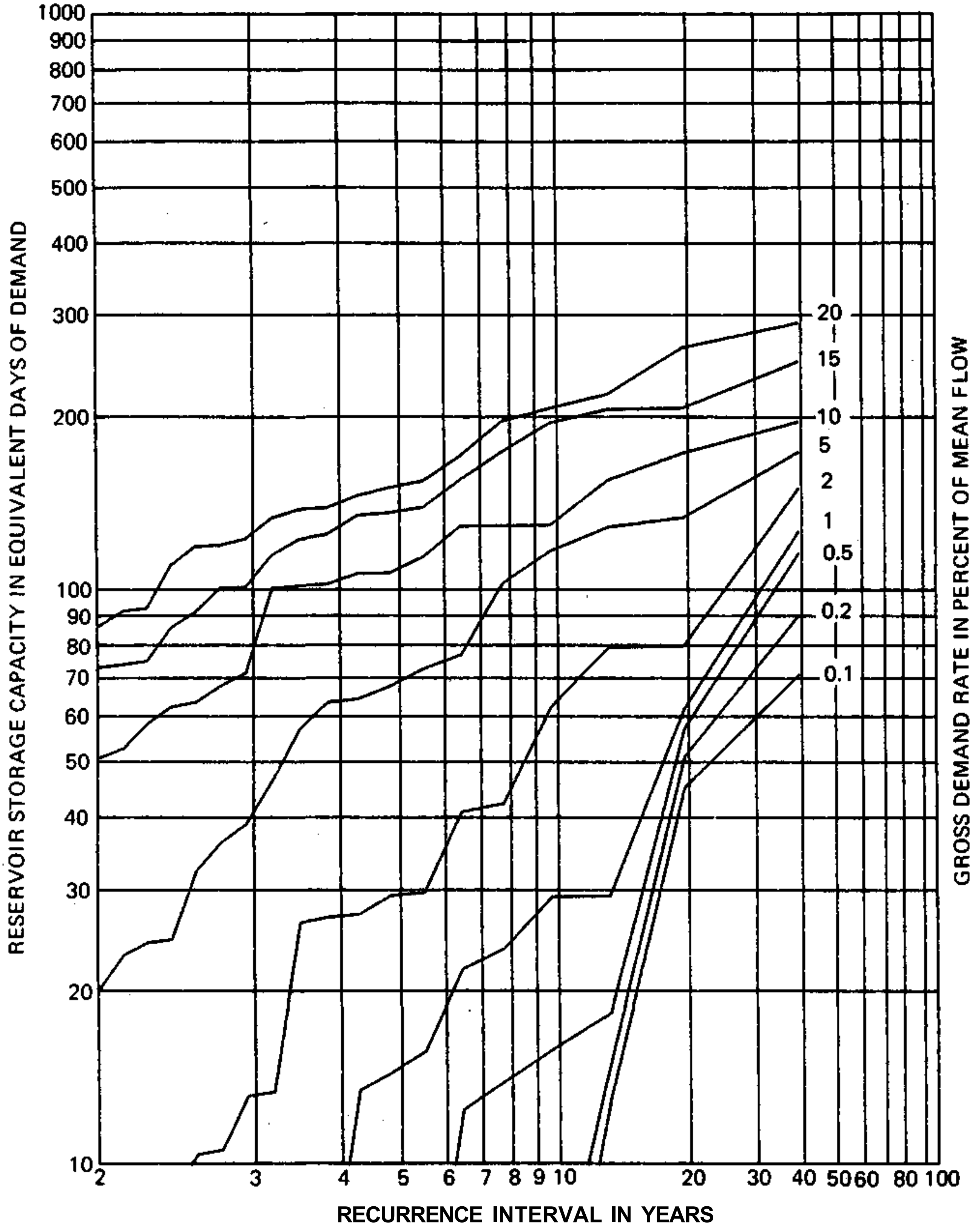
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05466000

EDWARDS RIVER NEAR ORION

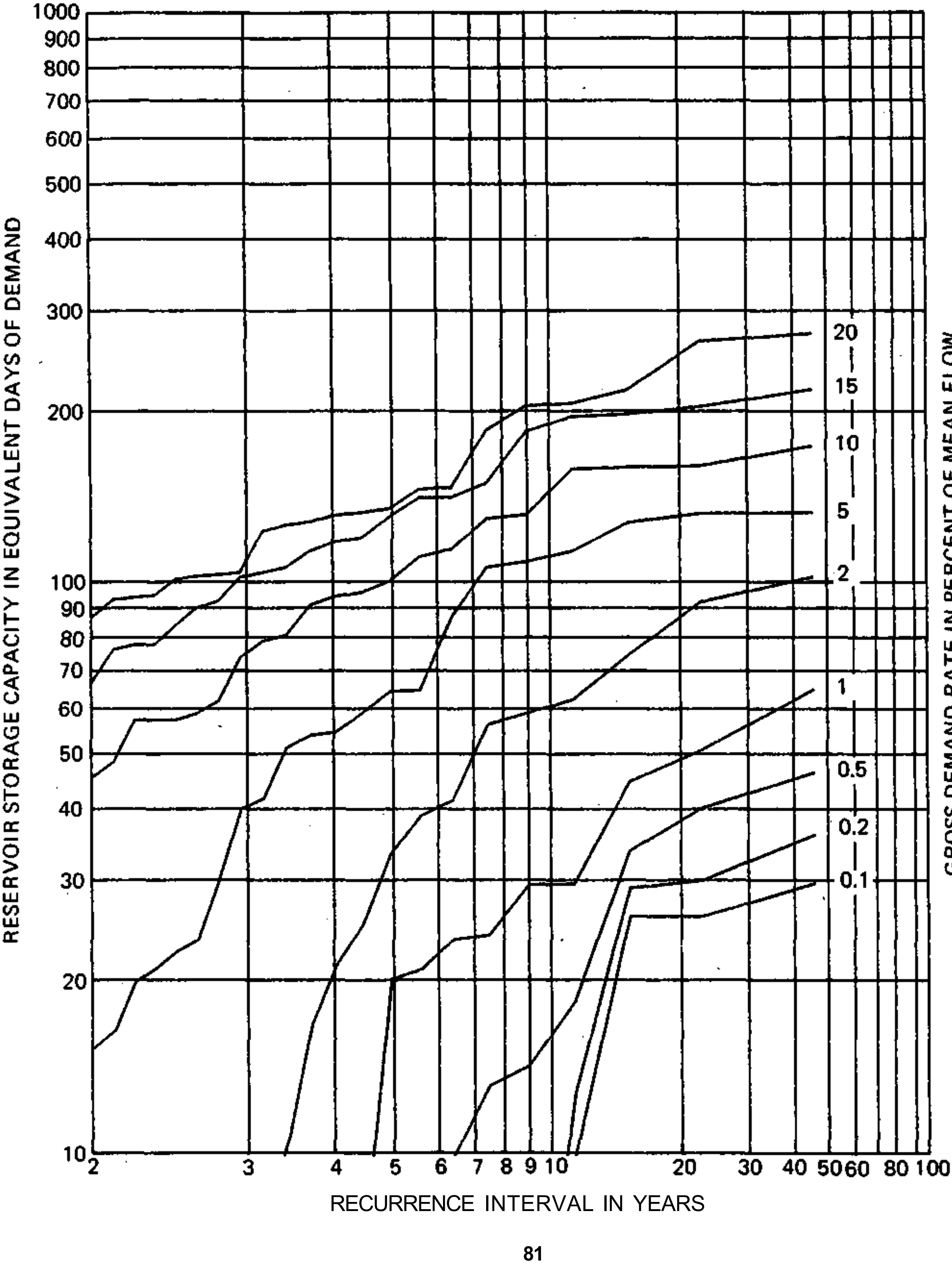
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05466500

EDWARDS RIVER NEAR NEW BOSTON

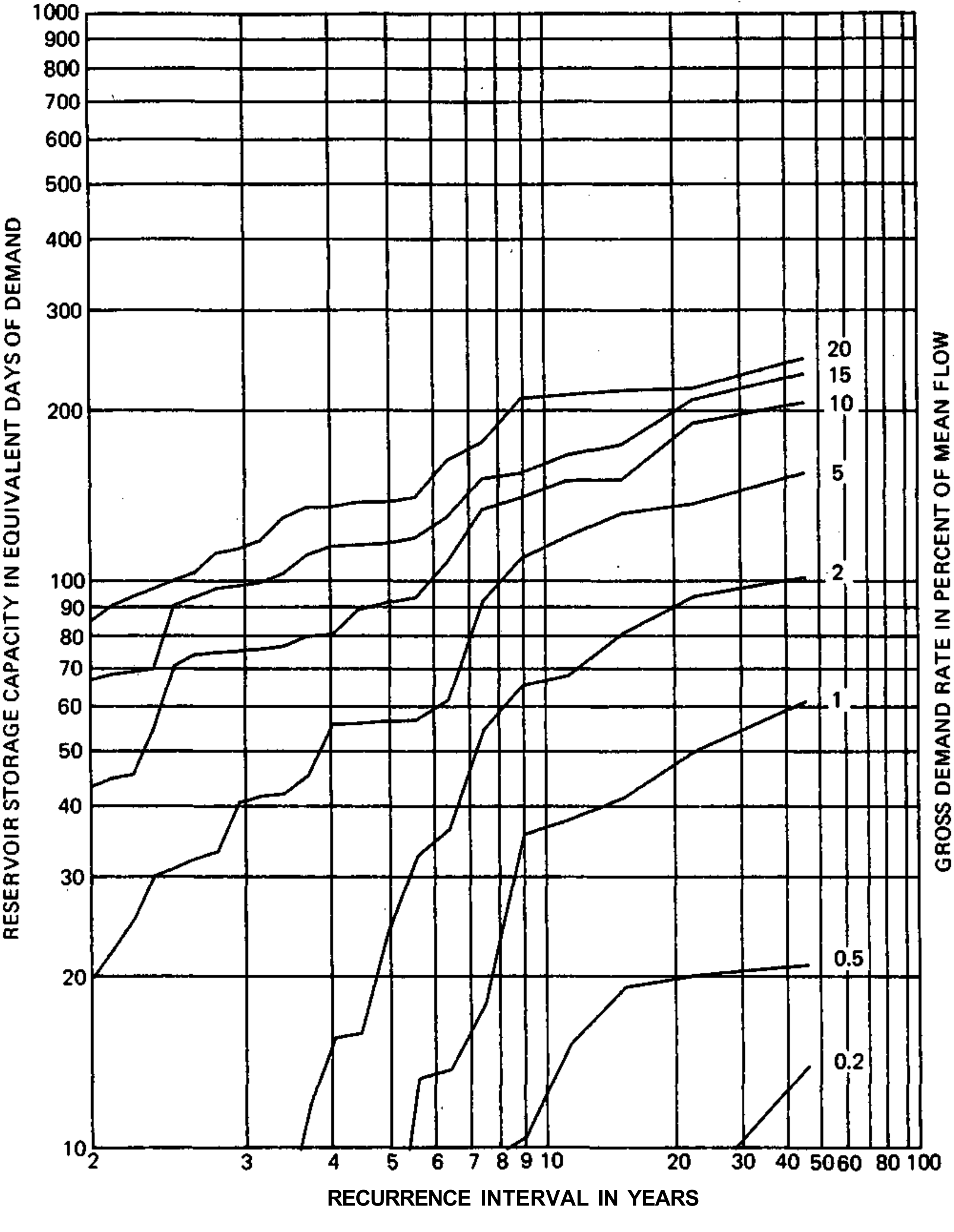
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05467000

POPE CREEK NEAR KEITHSBURG

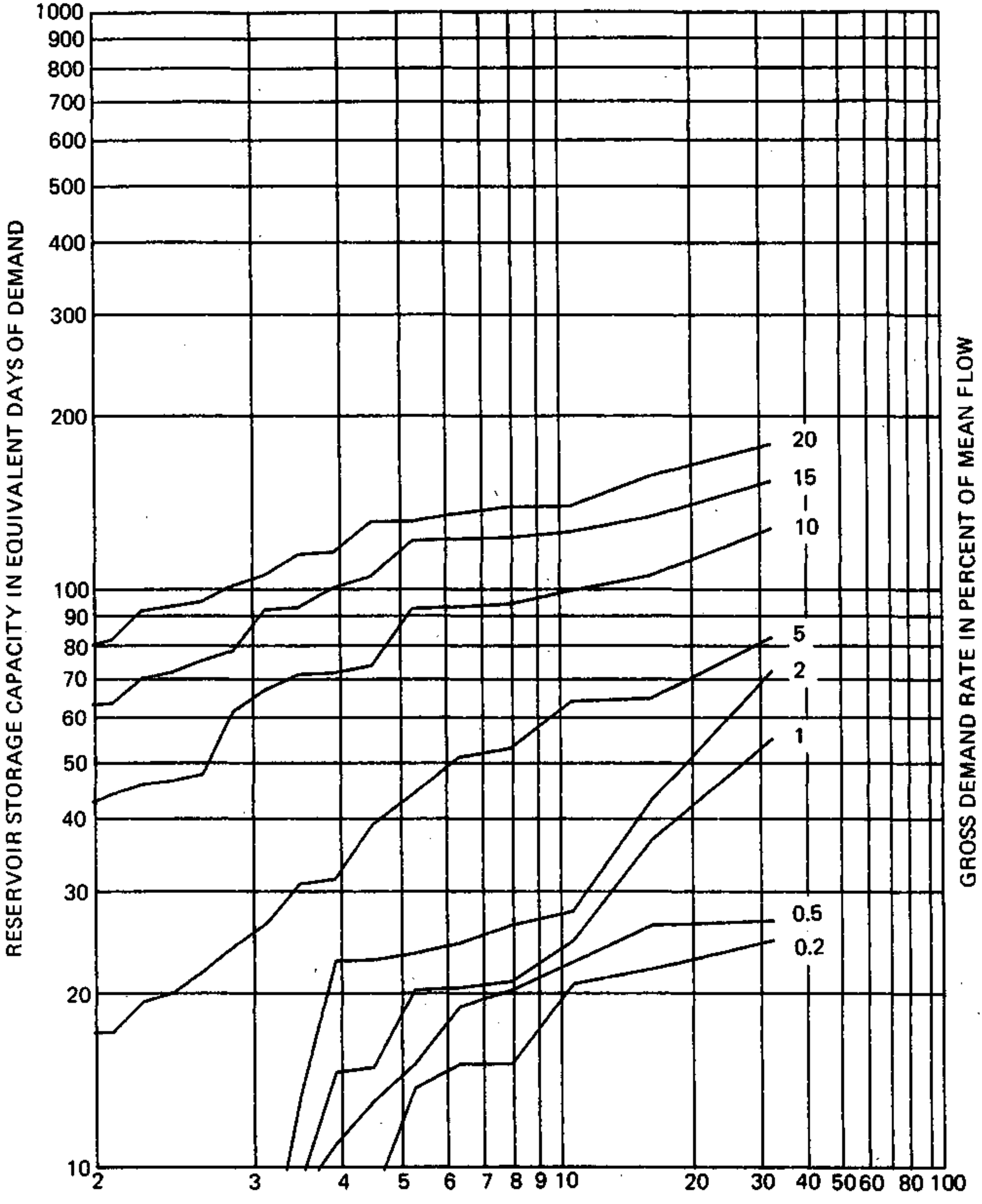
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05468500

CEDAR CREEK AT LITTLE YORK

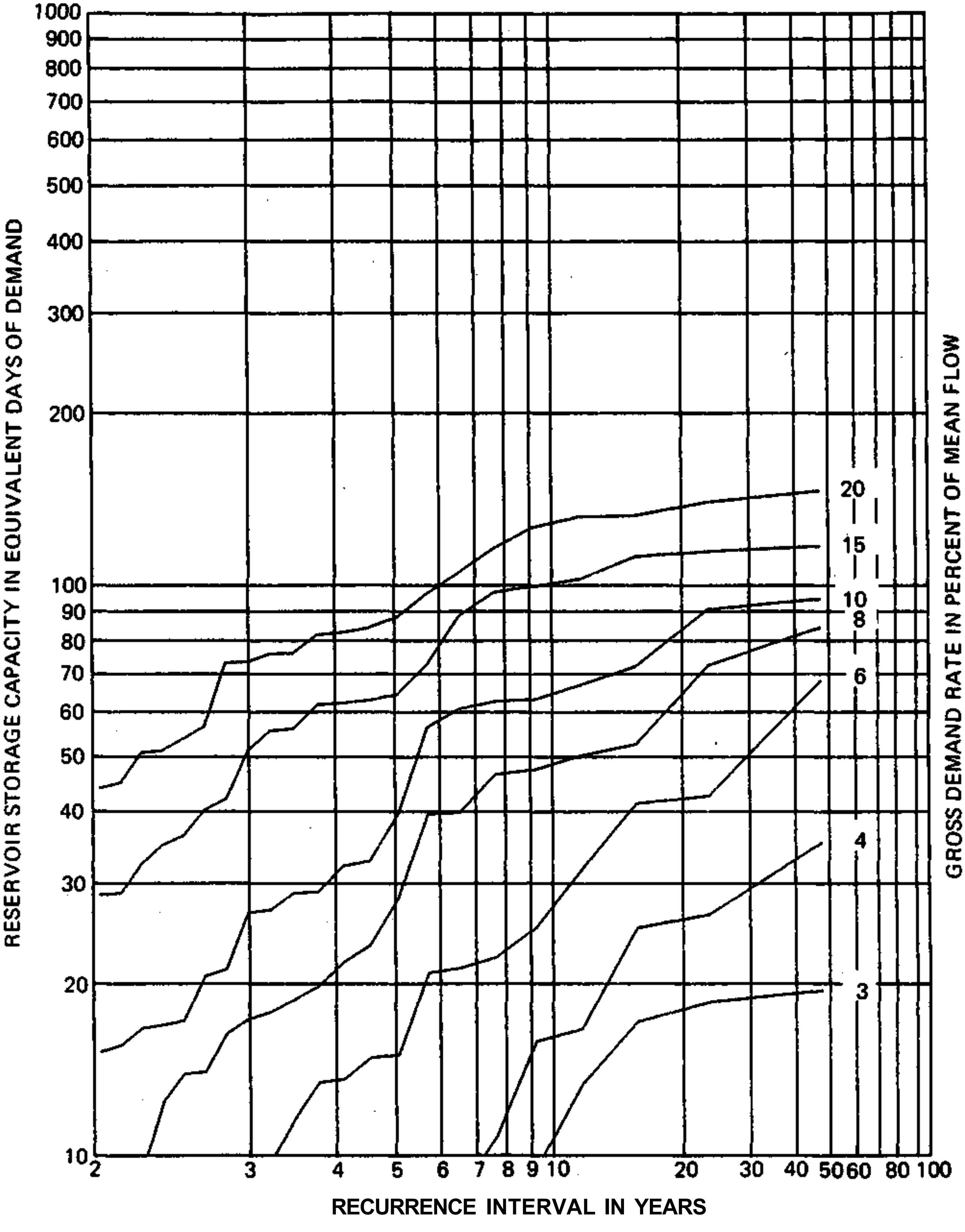
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05469000

HENDERSON CREEK NEAR OQUAWKA

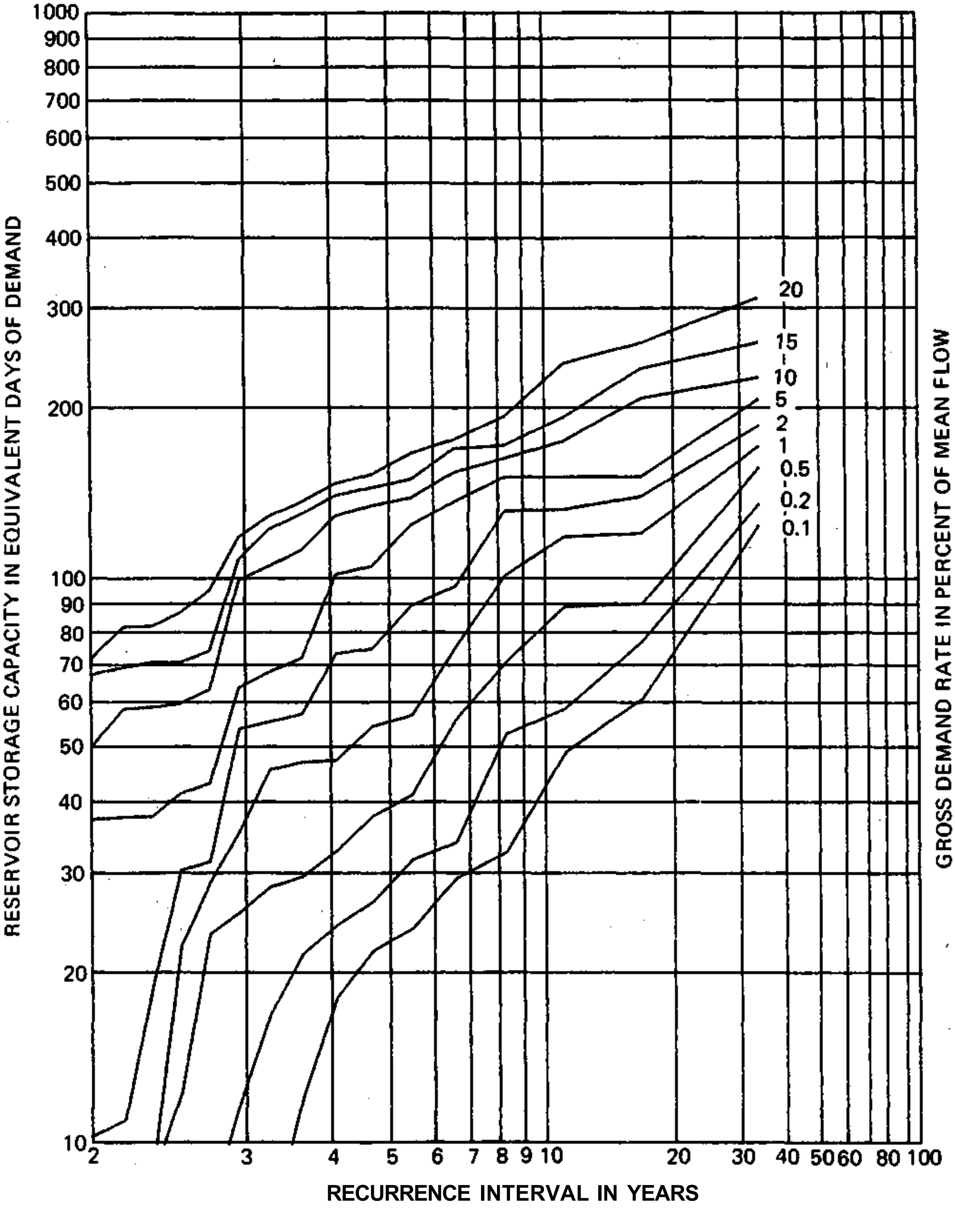
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP

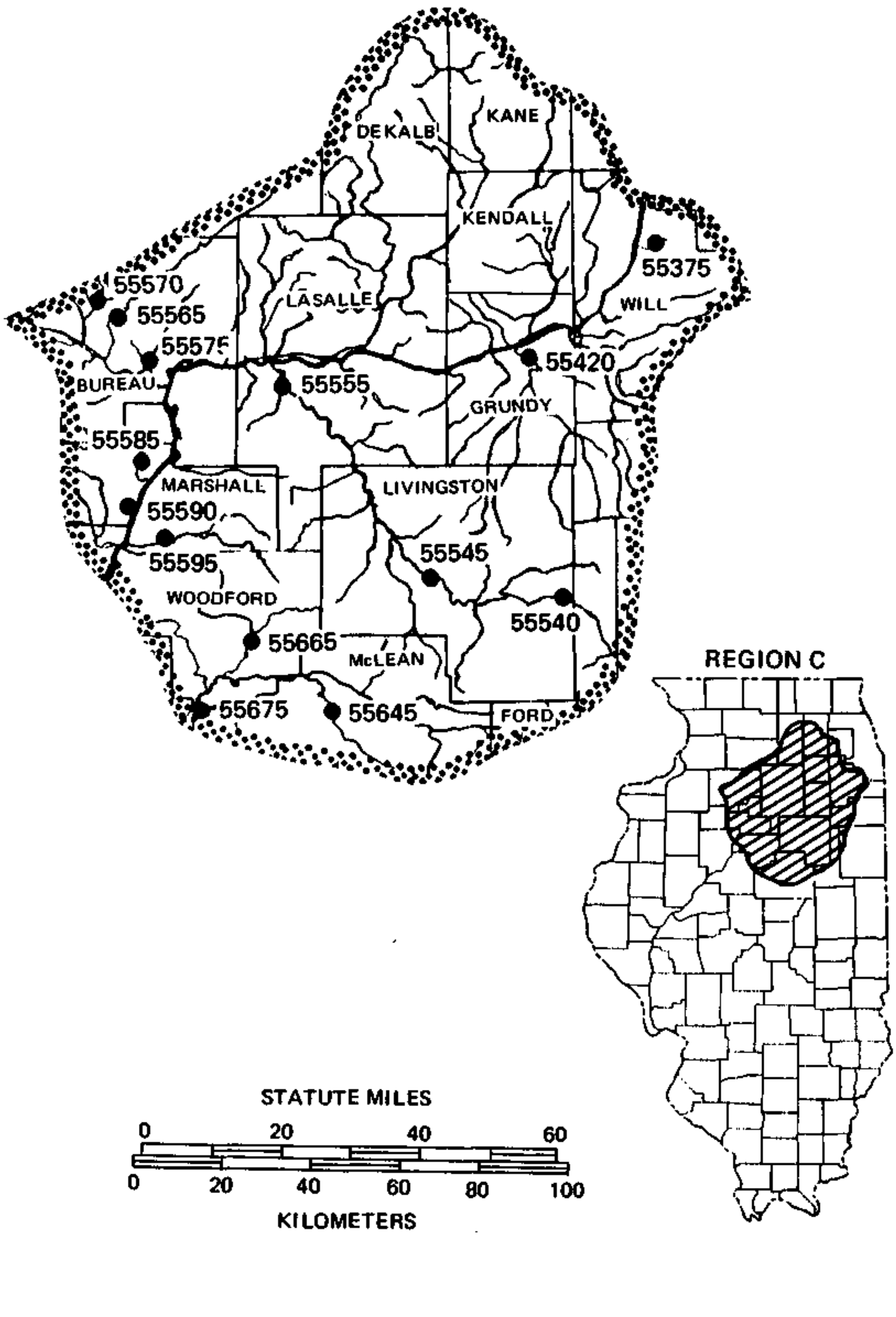


STATION 05469500

SOUTH HENDERSON CREEK AT BIGGSVILLE

DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP




DEKALB
KANE
KENDALL
55375
WILL
55570
55565
55575
LASALLE
55420
BUREAU
55555
GRUNDY
55585
MARSHALL
LIVINGSTON
55590
55545
55595
WOODFORD
55540
55665
McLEAN
REGION C
55675
55645
FORD
STATUTE MILES
0 20 40 60
0 20 40 60 80 100
KILOMETERS

REGION C

USGS Gage No.	Name of Station	Period of Record	Number of Years
55375	Long Run near Lemont	1952-1978	26
55420	Mazon River near Coal City	1940-1978	38
55540	North Fk. Vermilion River near Charlotte	1943-1962	19
55545	Vermilion River at Pontiac	1943-1978	35
55555	Vermilion River at Lowell	1932-1971	39
55565	Bureau Creek at Princeton	1936-1978	42
55570	West Bureau Creek at Wyanet	1936-1966	30
55575	East Bureau Creek near Bureau	1936-1966	30
55585	Crow Creek (west) near Henry	1950-1971	21
55590	Gimlet Creek near Sparland	1950-1971	21
55595	Crow Creek near Washburn	1945-1971	26
55645	Money Creek above Lake Bloomington	1934-1957	23
55665	East Branch Panther Creek at El Paso	1950-1978	28
55675	Mackinaw River near Congerville	1945-1978	33

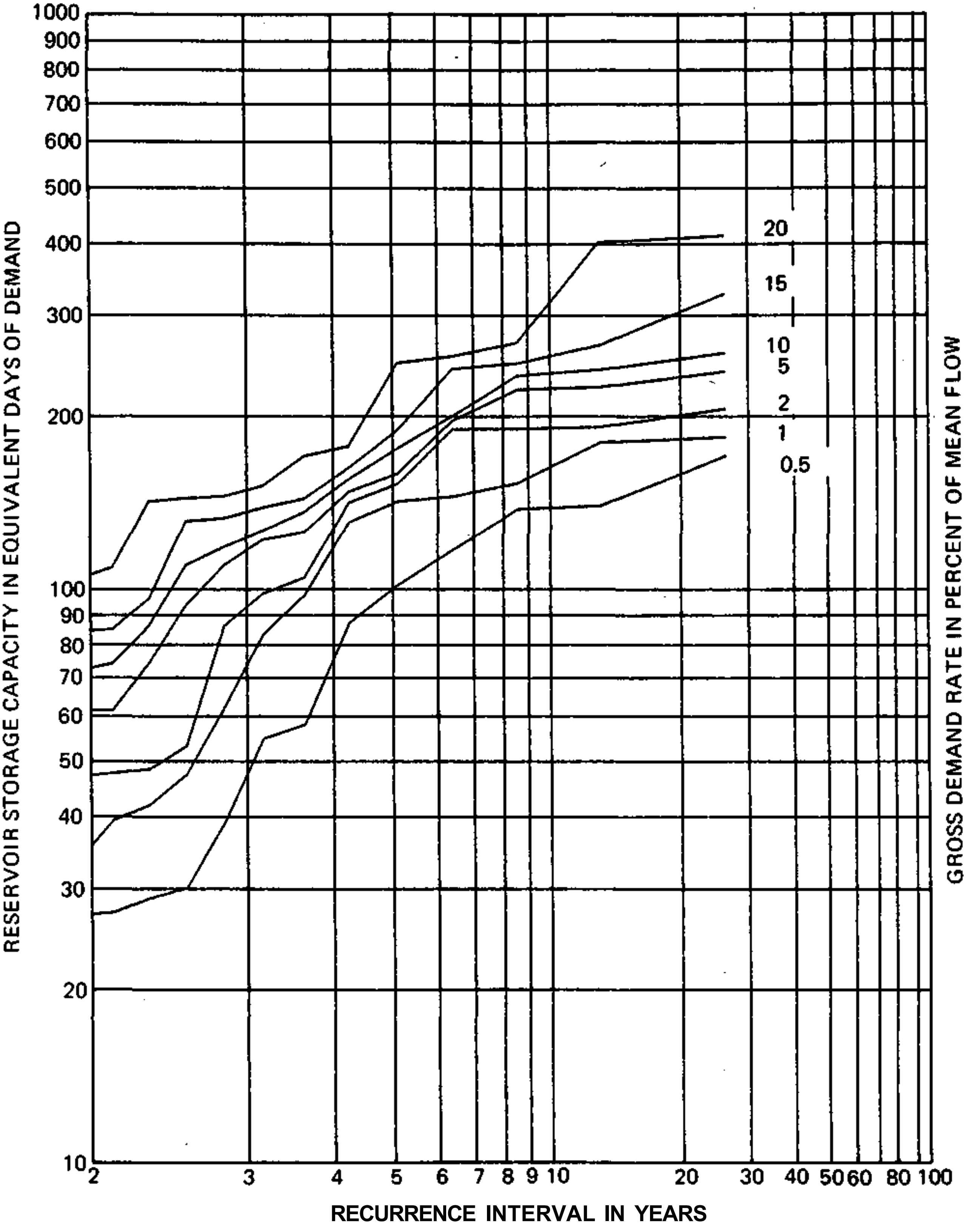
Drainage Area and Streamflow Characteristics

Gage No.	Drainage Area (mi^2)	Mean Flow (cfs)	Mean Flow (in./year)	$Q_{7,10}$ (cfs)	Q90 (cfs)	Q75 (cfs)	Q60 (cfs)
55375	20.8	15.8	10.20	0.0	0.0	.3	1.6
55420	455.	313.0	9.33	0.0	1.2	6.5	31.5
55540	184.	124.0	9.10	0.0	.7	3.2	12.0
55545	579.	373.0	8.75	.2	6.0	19.0	55.0
55555	1230.	734.0	8.09	7.3	15.0	42.0	125.0
55565	196.	128.0	8.87	.9	2.6	7.6	21.0
55570	83.3	45.0	7.32	0.0	.2	1.7	5.5
55575	101.	47.8	6.42	0.0	0.0	1.0	4.6
55585	55.3	36.0	8.84	0.0	.4	2.0	6.4
55590	5.42	3.7	9.17	0.0	0.0	0.0	.4
55595	123.	60.3	6.66	0.0	.1	1.4	9.3
55645	51.9	33.0	8.62	0.0	0.0	.4	2.9
55665	28.8	19.0	8.94	0.0	.1	.5	2.0
55675	764.	485.0	8.60	1.5	12.0	41.0	100.0

STATION 05537500

LONG RUN NEAR LEMONT

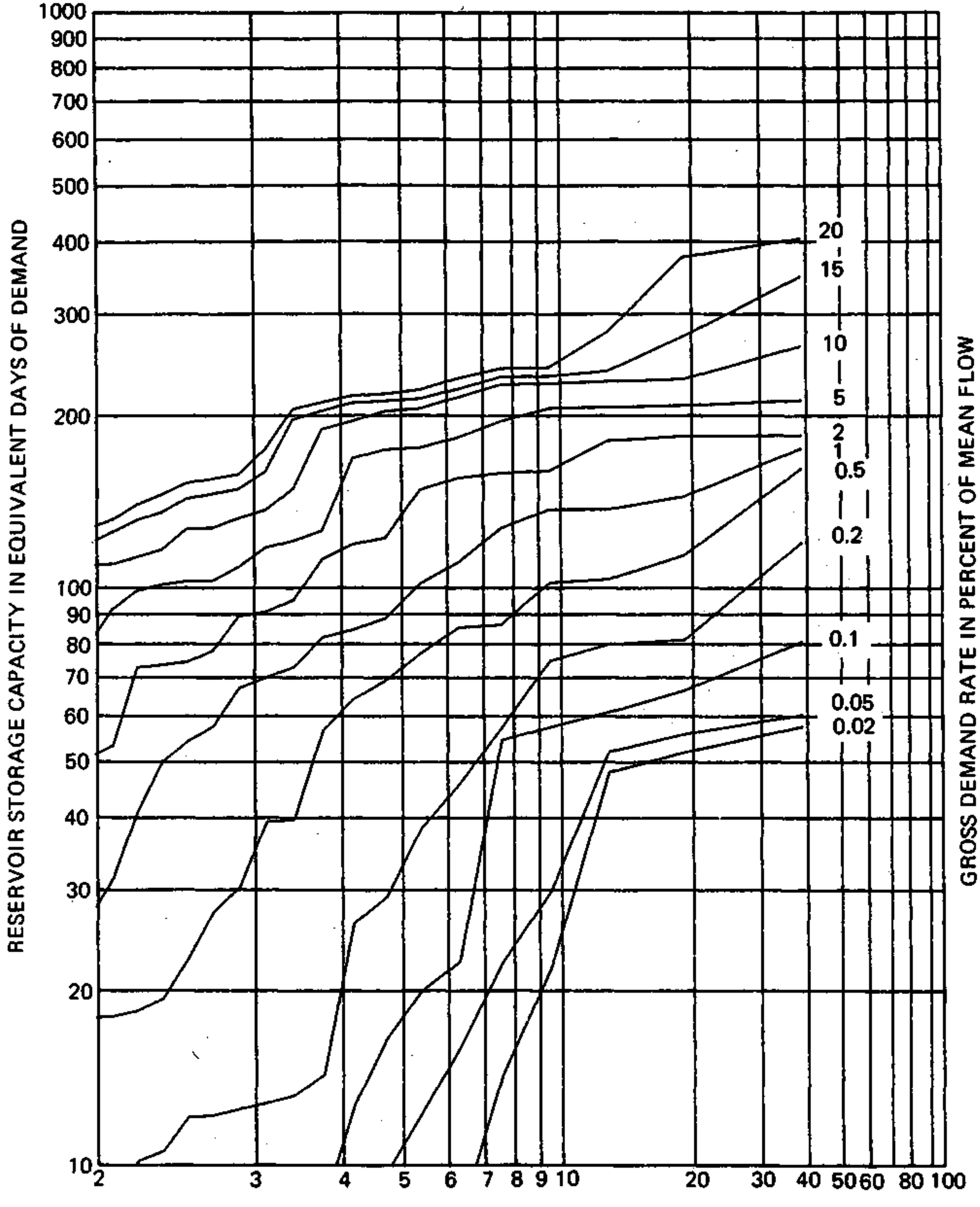
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05542000

MAZON RIVER NEAR COAL CITY

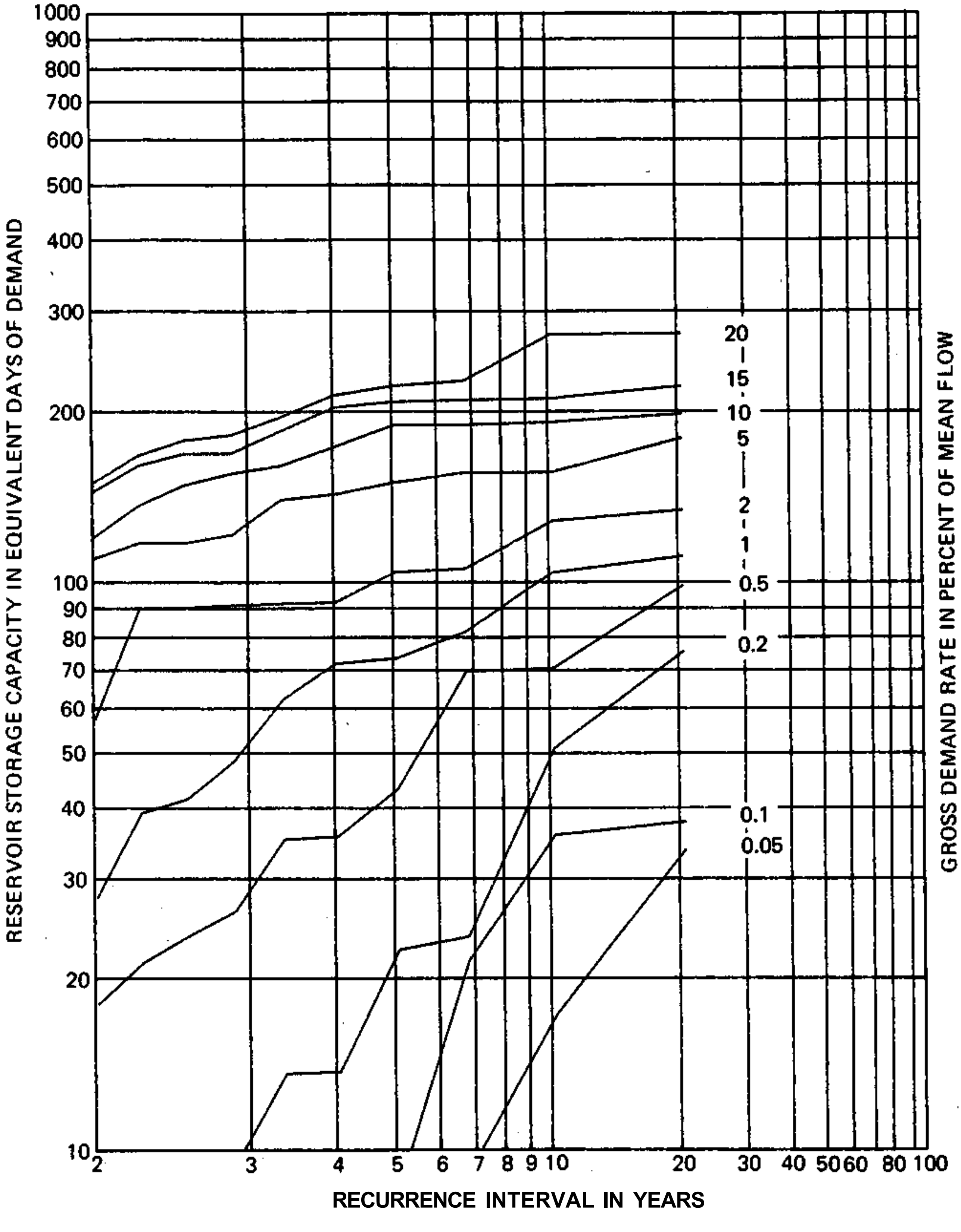
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05554000

NORTH FORK VERMILION RIVER NEAR CHARLOTTE

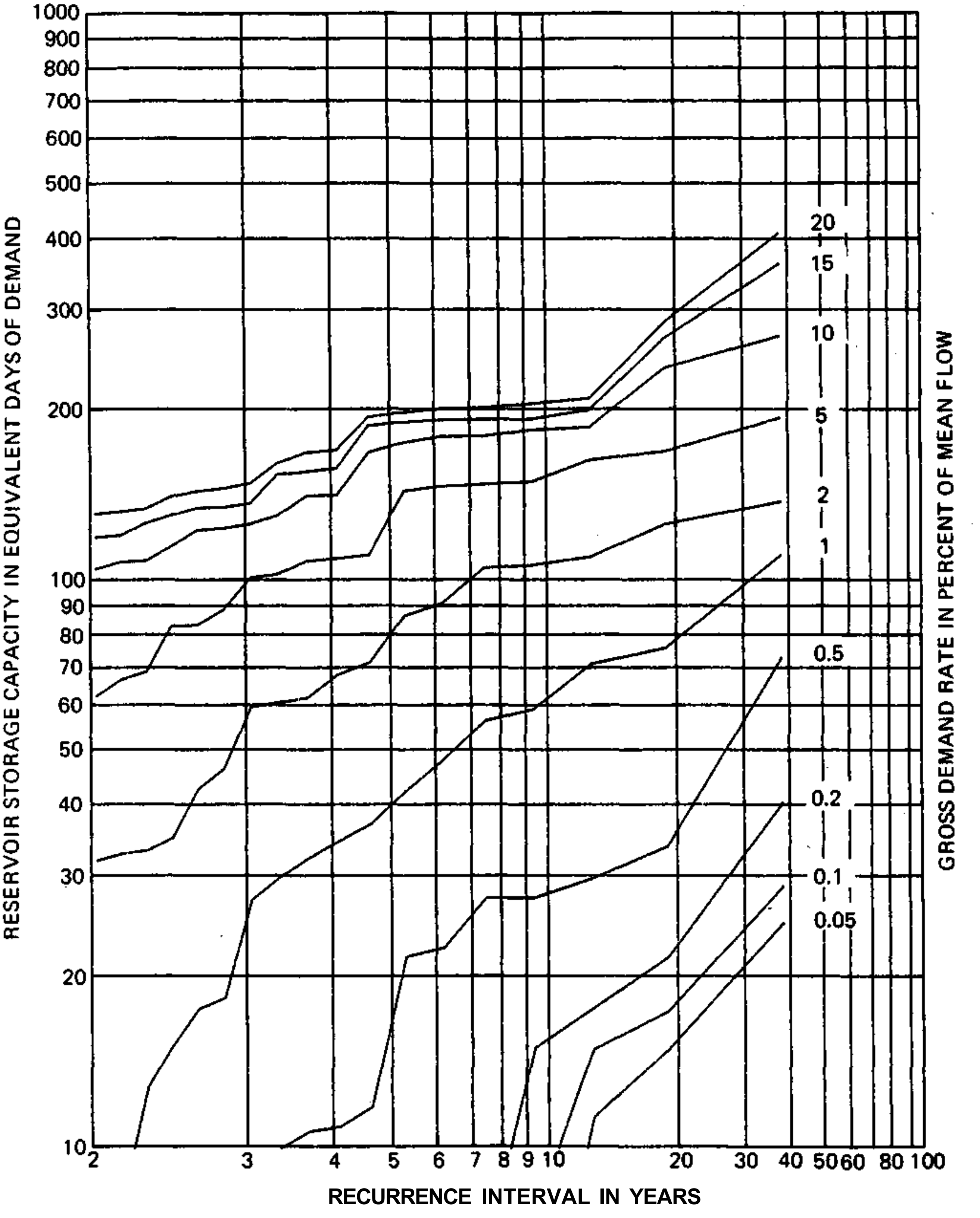
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05554500

VERMILION RIVER AT PONTIAC

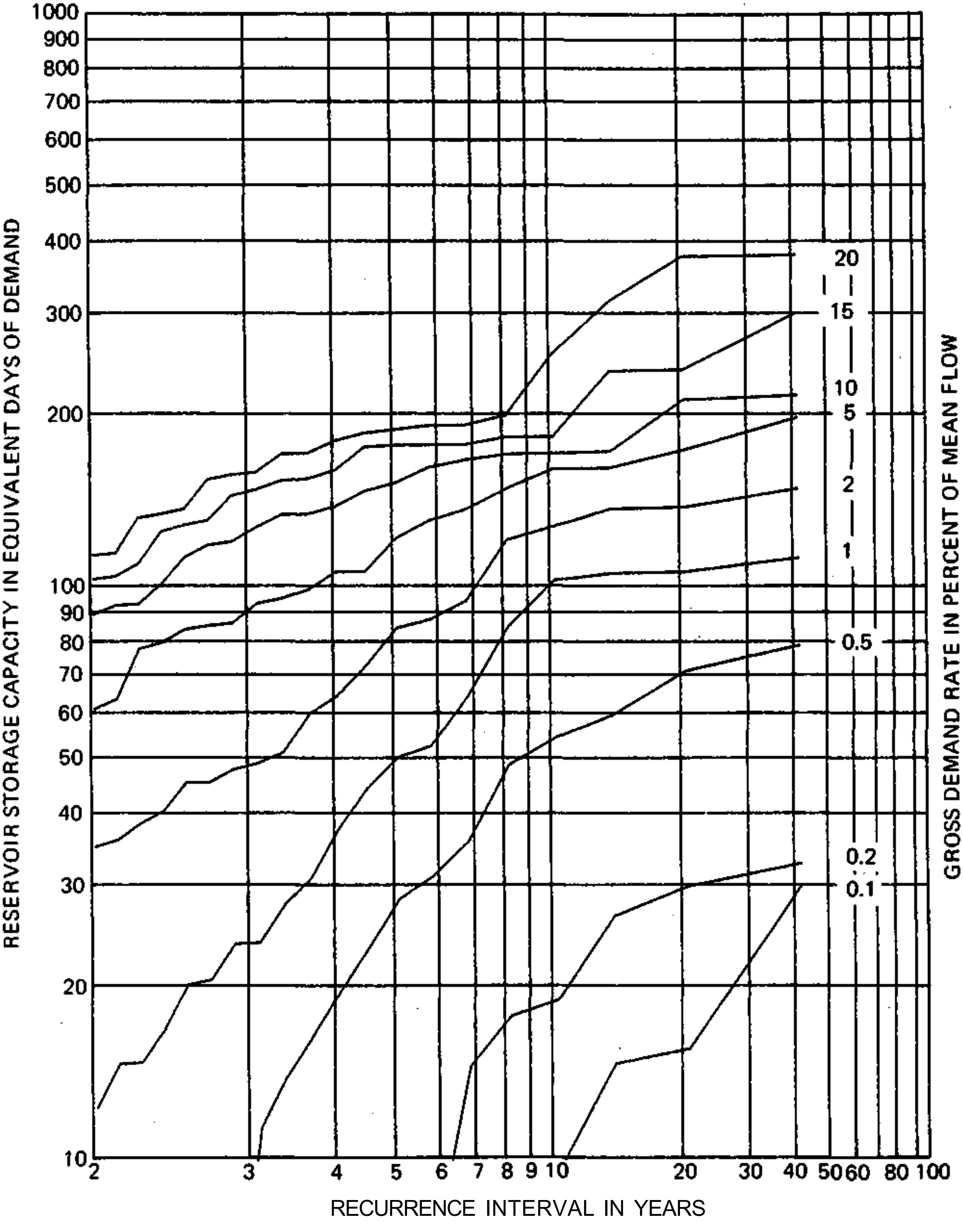
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05555500

VERMILION RIVER AT LOWELL

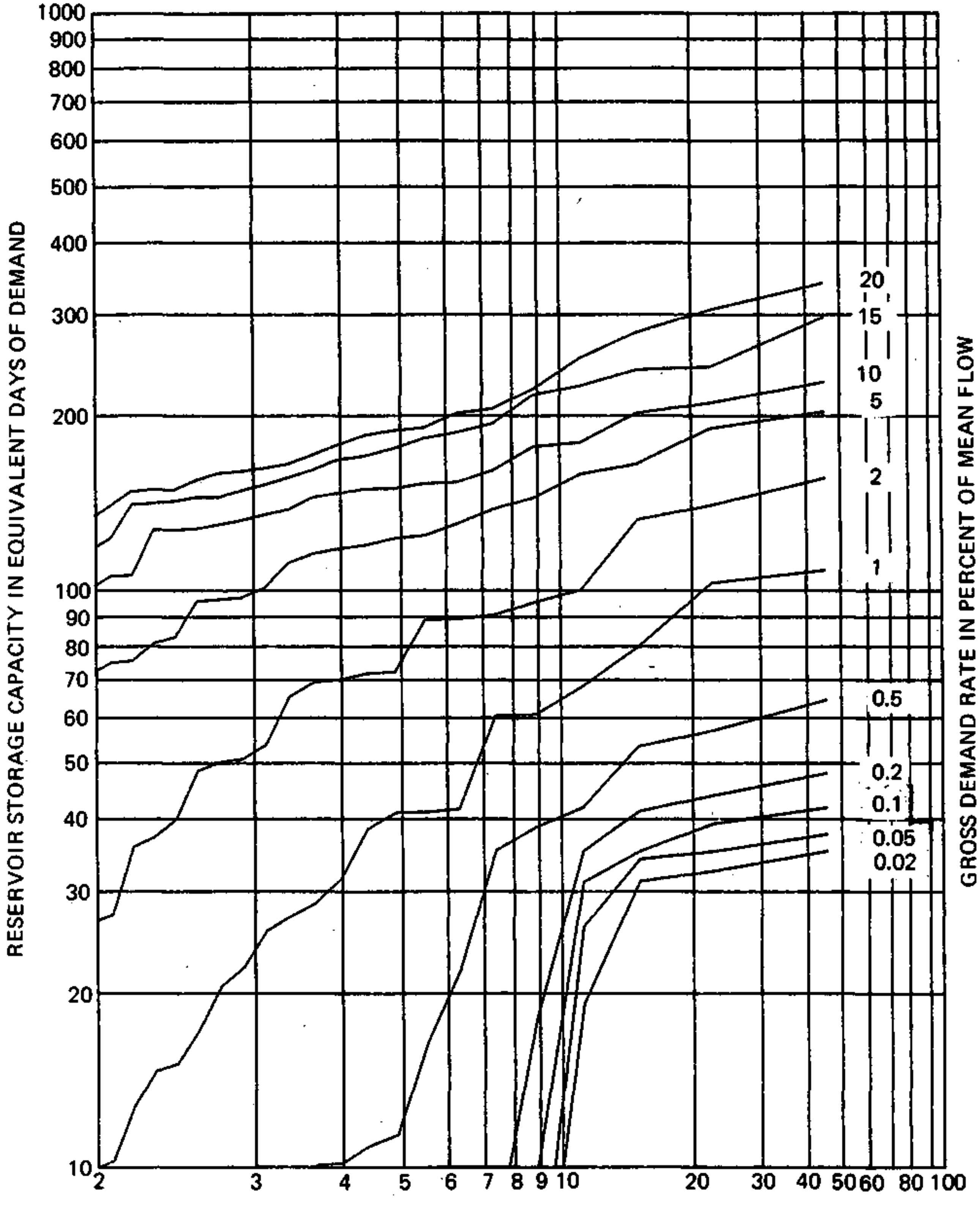
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05556500

BUREAU CREEK AT PRINCETON

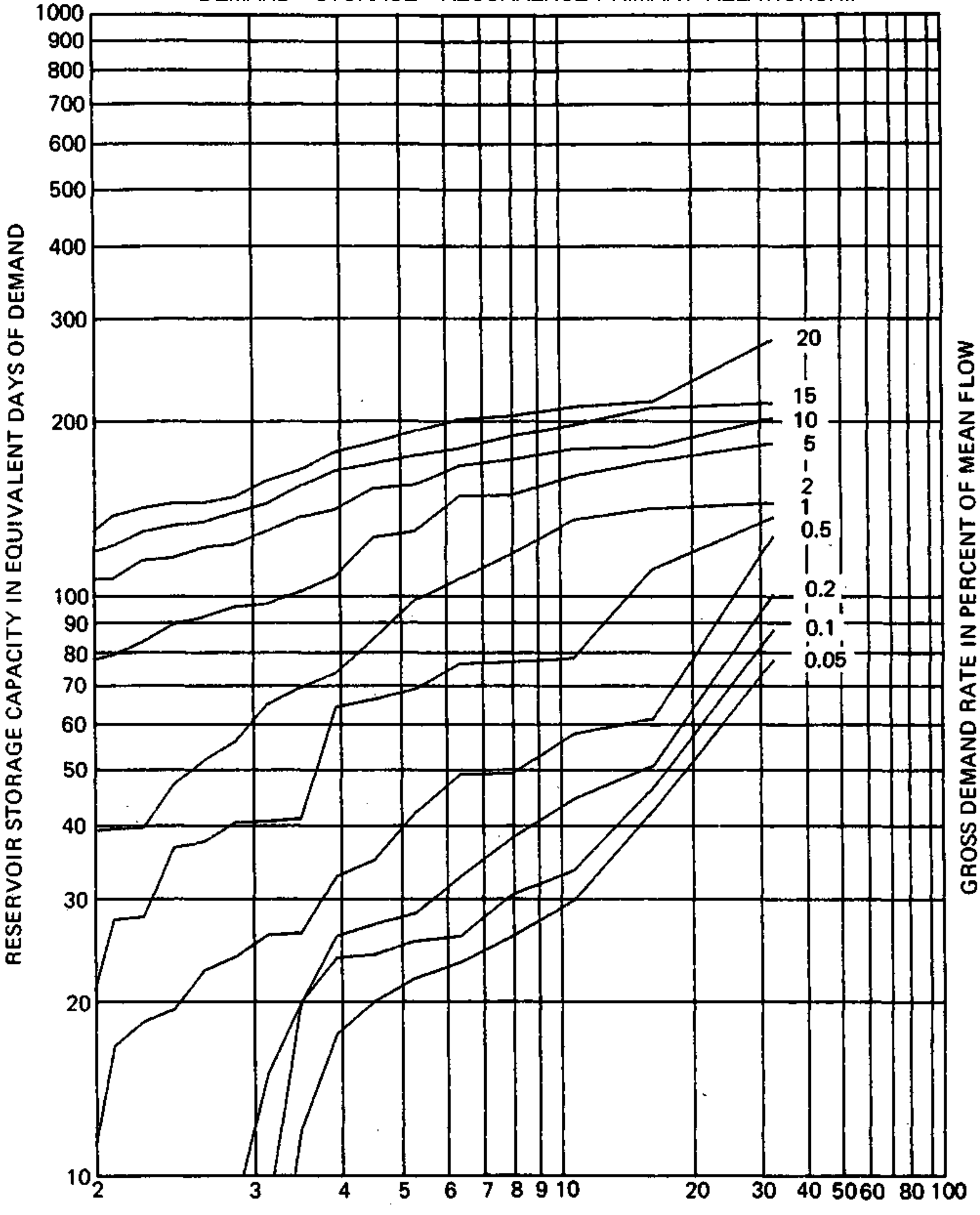
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05557000

WEST BUREAU CREEK AT WYANET

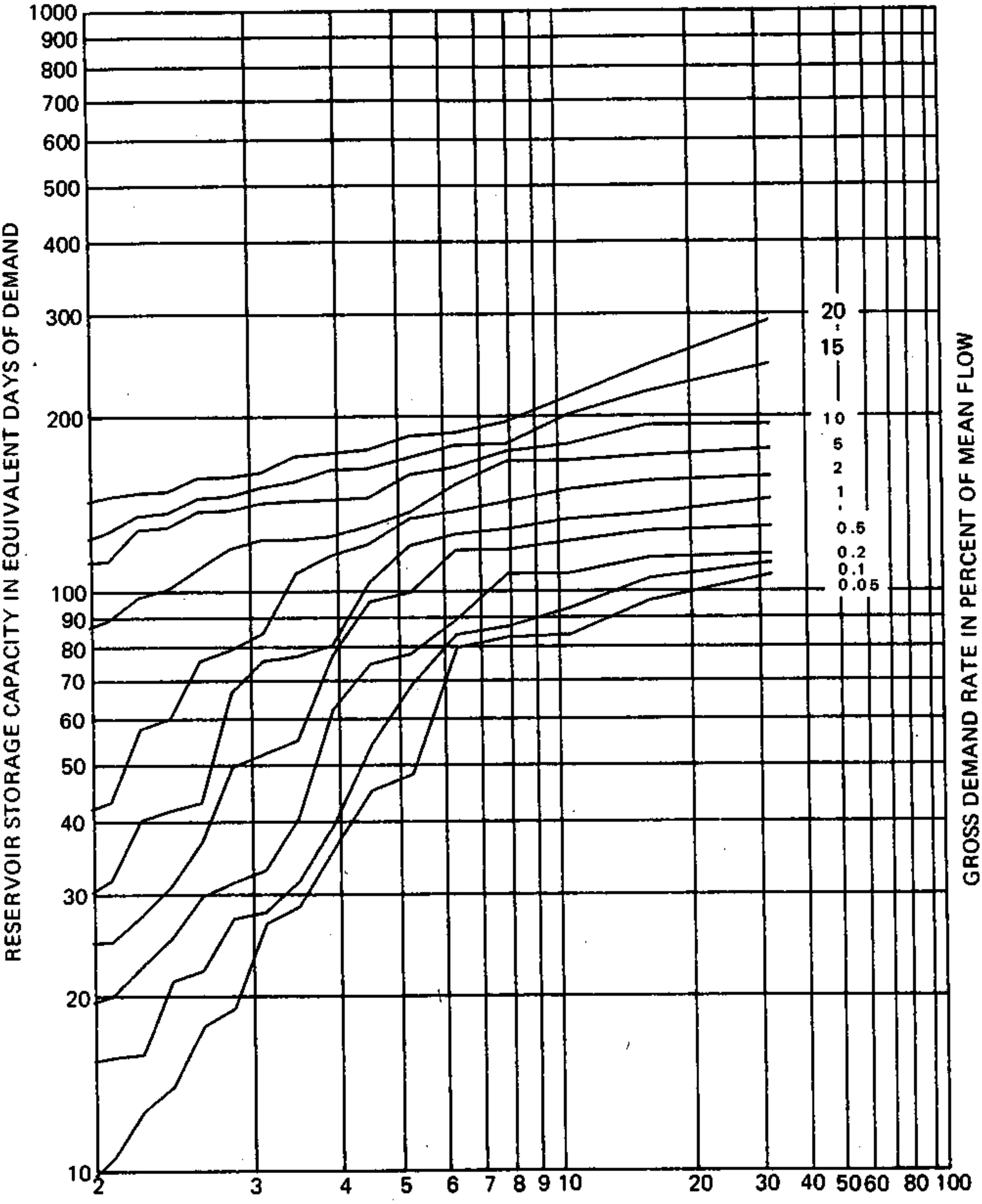
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05557500

EAST BUREAU CREEK NEAR BUREAU

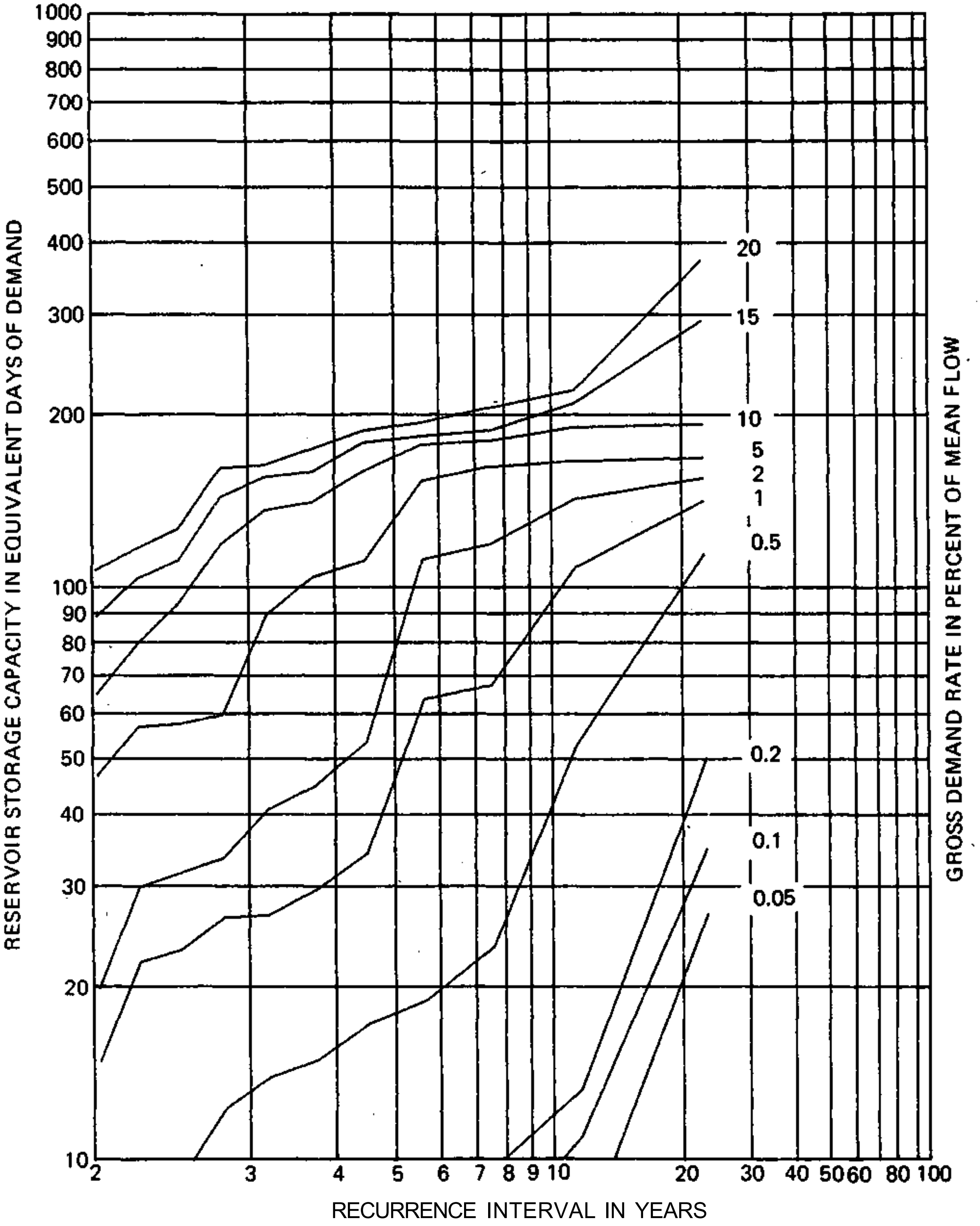
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05558500

CROW CREEK (WEST) NEAR HENRY

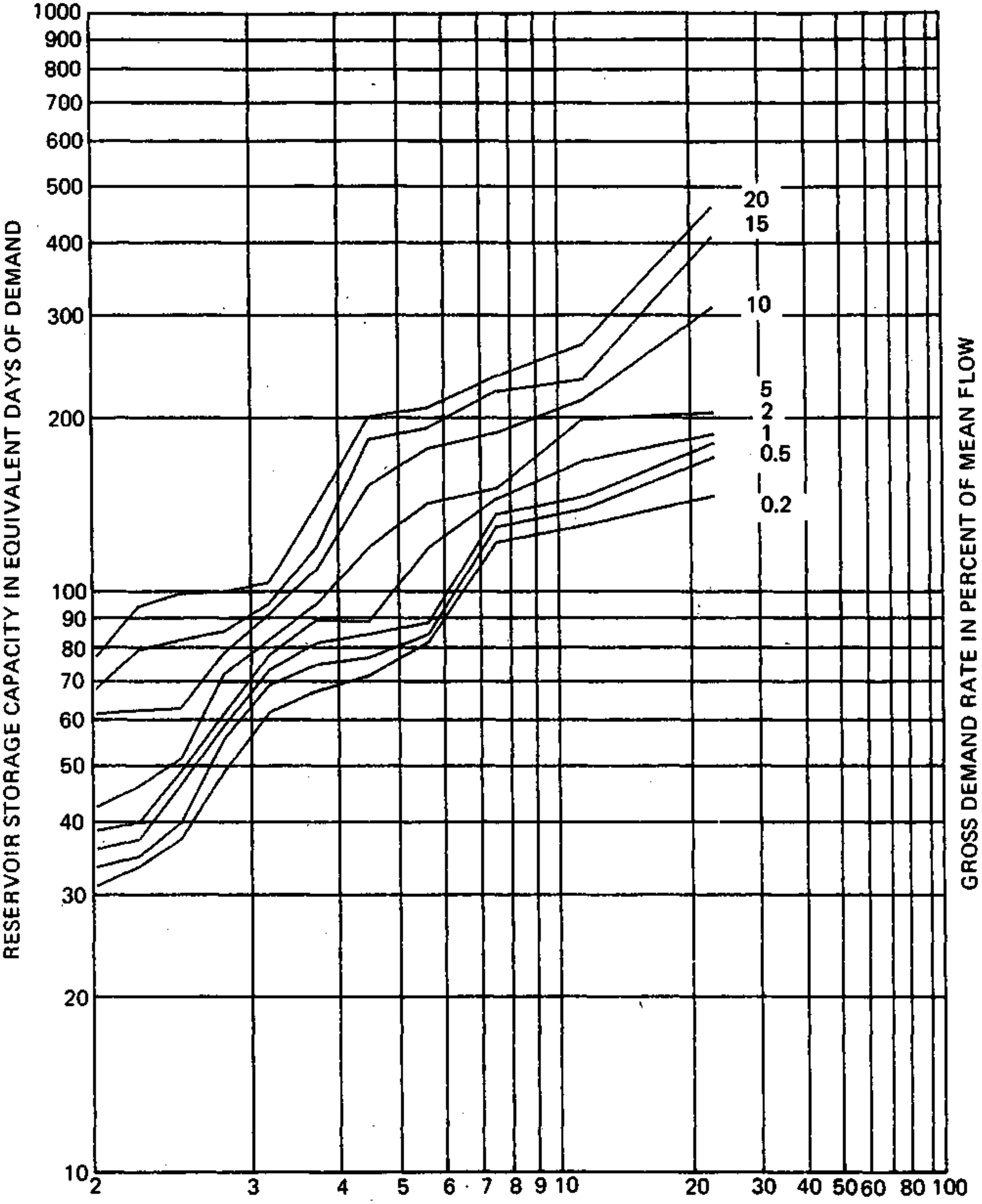
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05559000

GIMLET CREEK AT SPARLAND

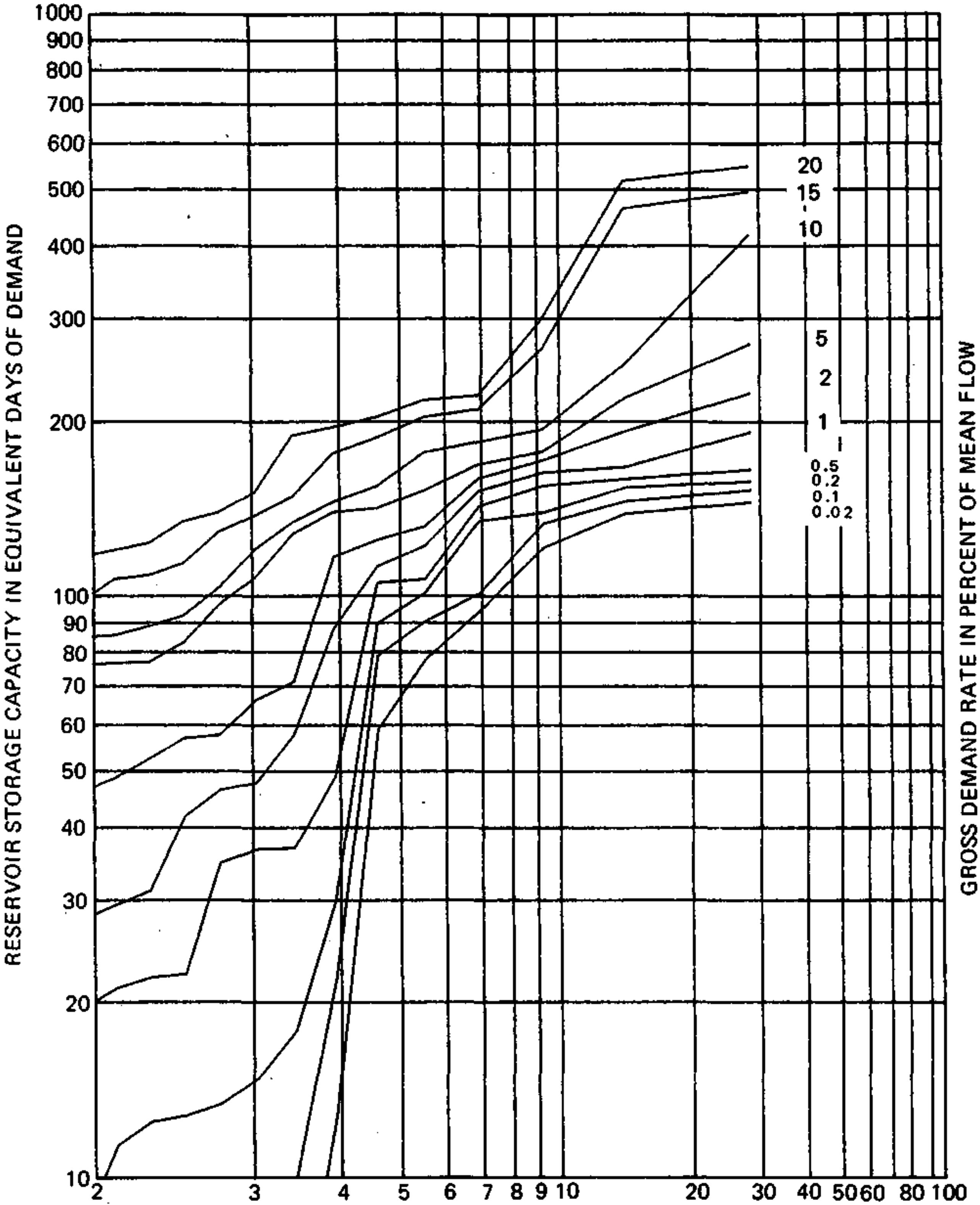
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05559500

CROW CREEK NEAR WASHBURN

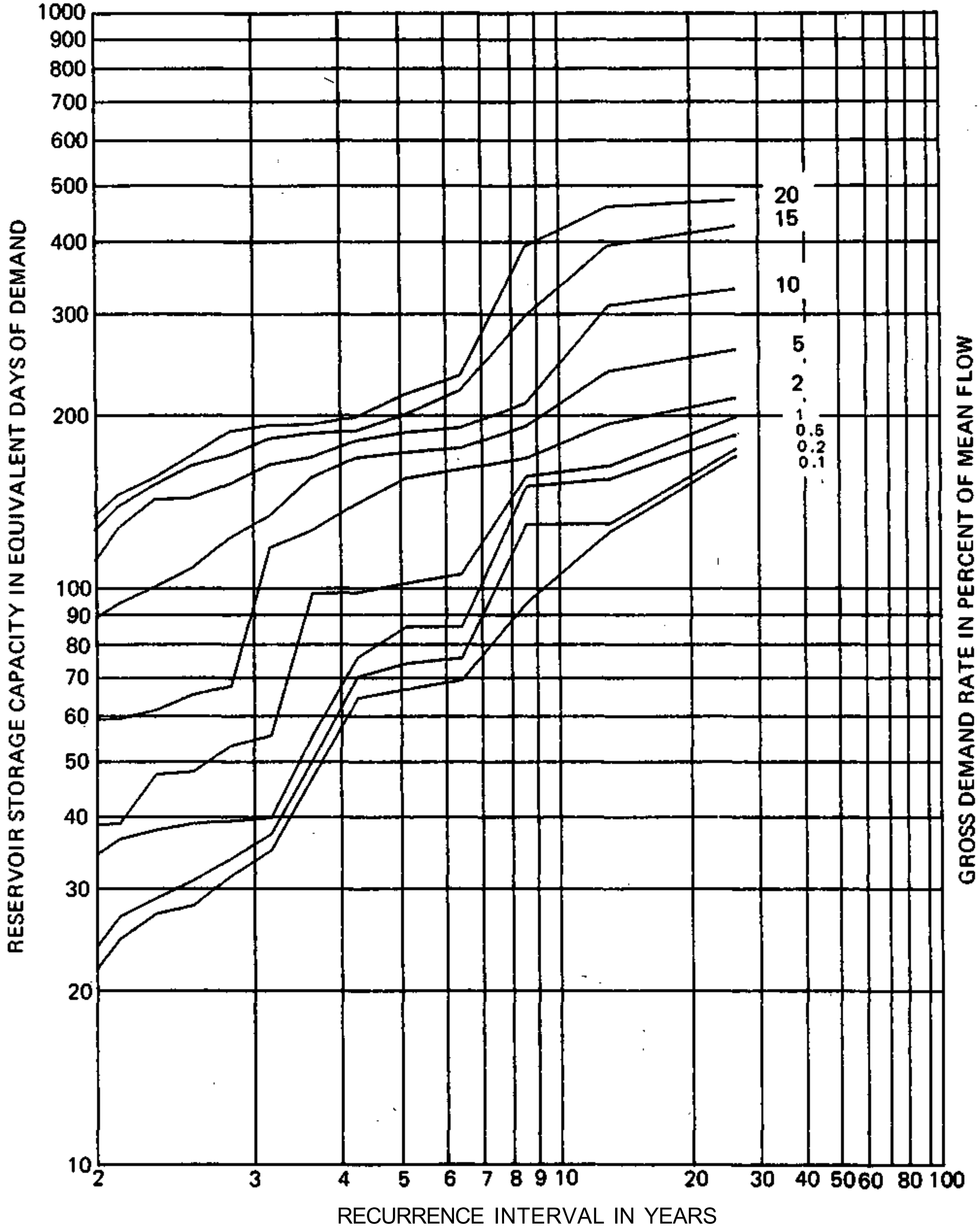
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05564500

MONEY CREEK ABOVE LAKE BLOOMINGTON

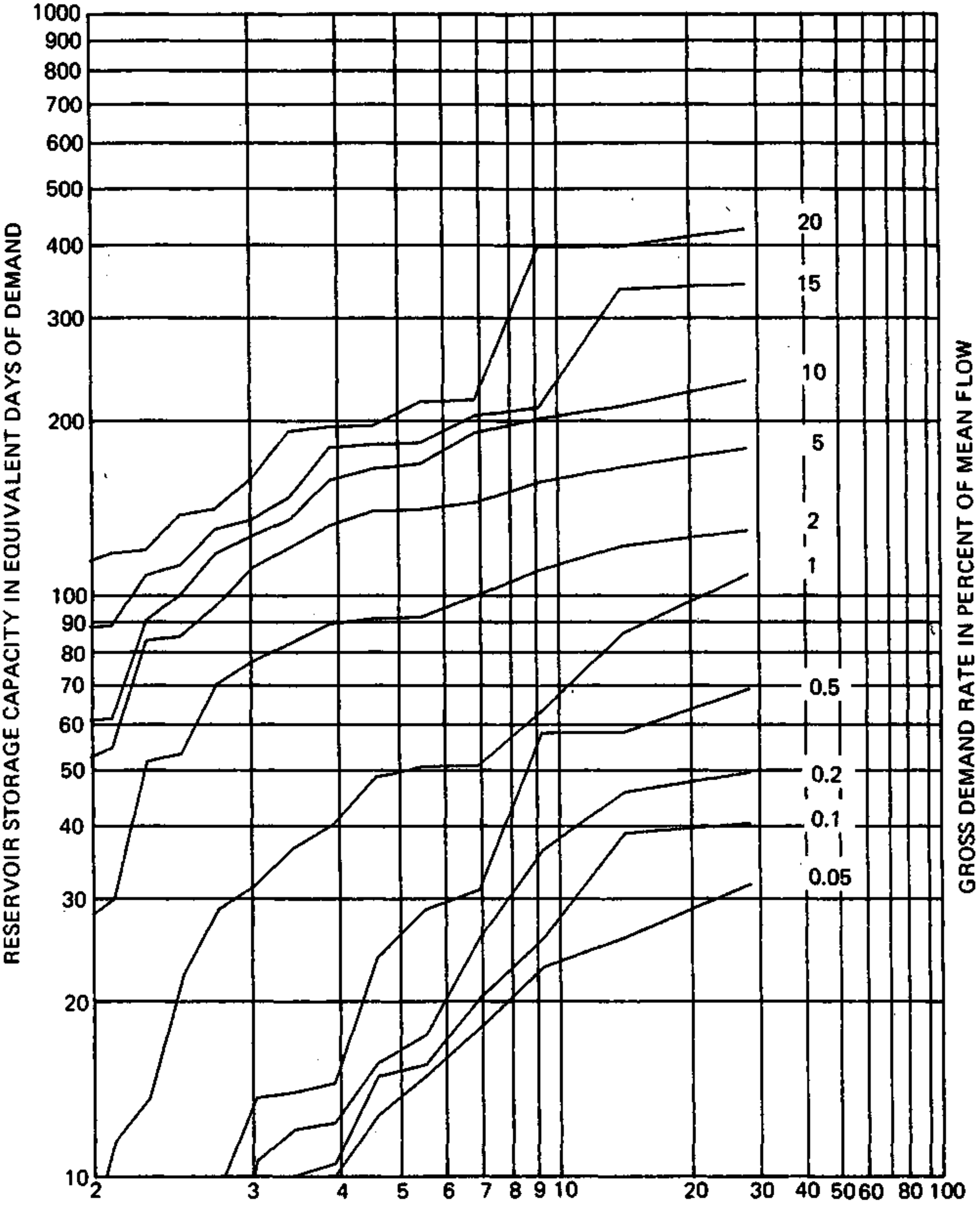
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05566500

EAST BRANCH PANTHER CREEK AT EL PASO

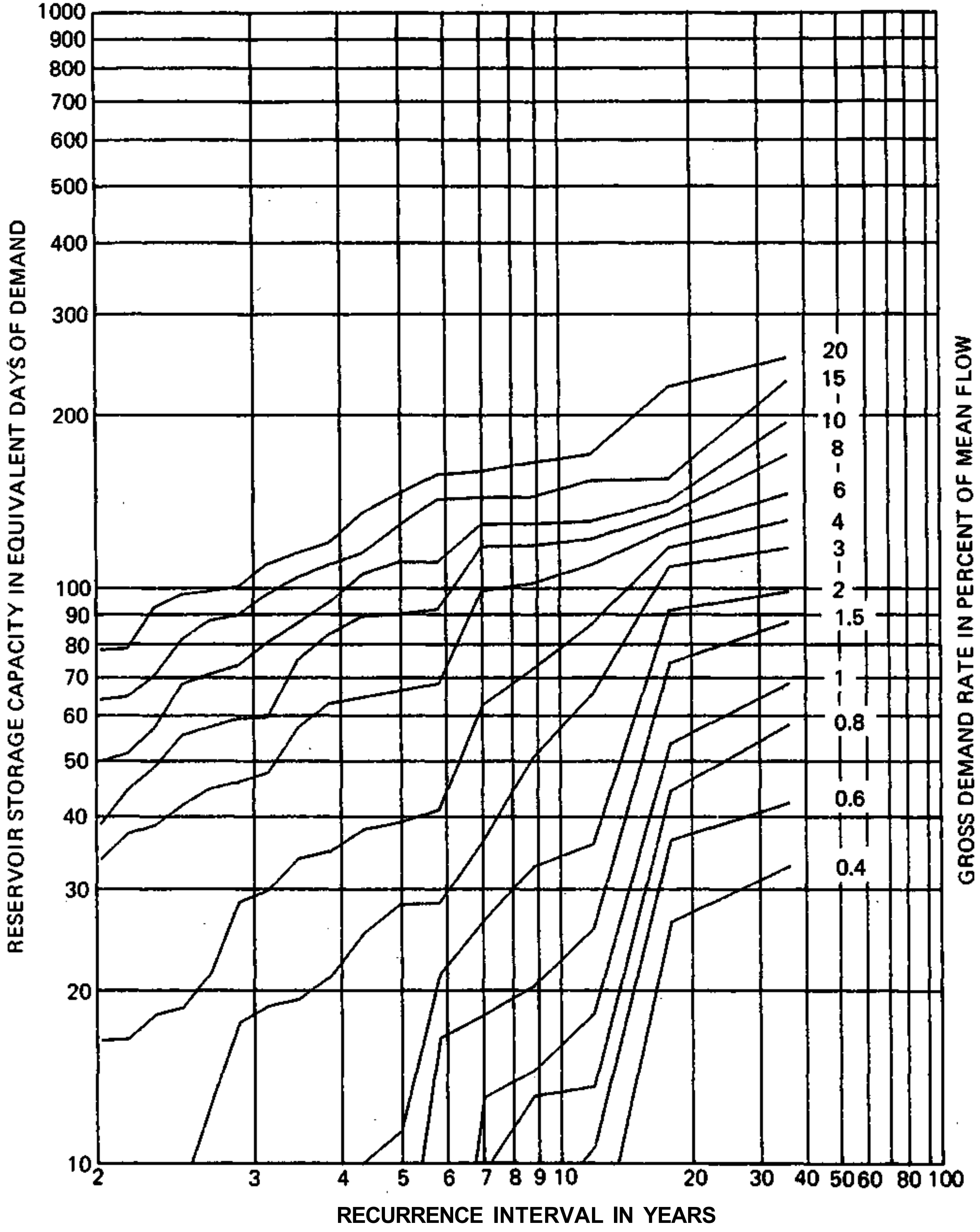
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP

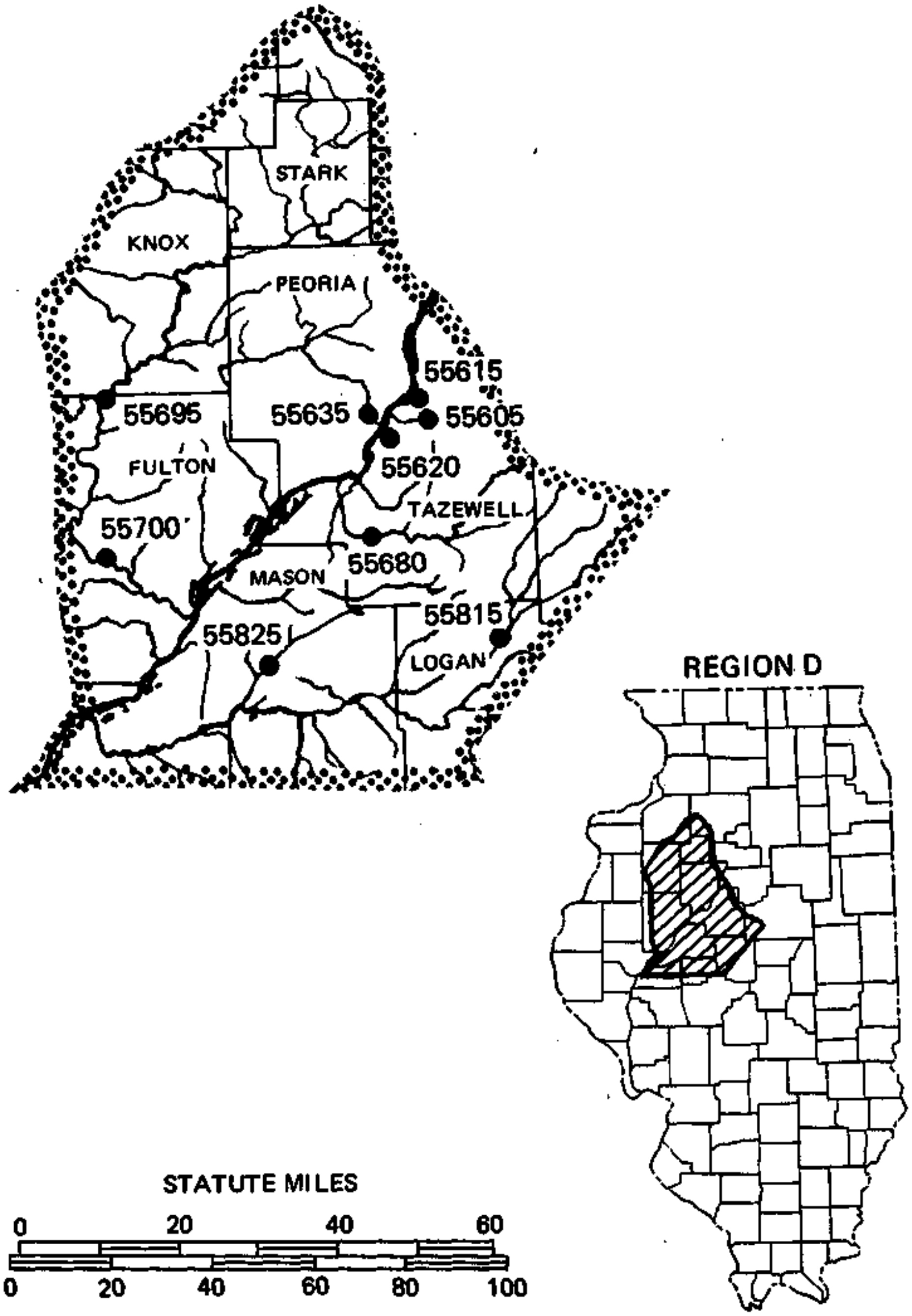


STATION 05567500

MACKINAW RIVER NEAR CONGERVILLE

DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP




STARK
KNOX
PEORIA
55615
55695
55635
55605
FULTON
55620
TAZEWELL
55700
55680
MASON
55815
55825
LOGAN
REGION D
STATUTE MILES
0
20
40
60
0
20
40
60
80
100
KILOMETERS

REGION D

USGS Gage No.	Name of Station	Period of Record	Number of Years
55605	Farm Creek near Farmdale	1949-1978	29
55615	Fondulac Creek near East Peoria	1948-1978	30
55620	Farm Creek at East Peoria	1944-1978	34
55635	Kickapoo Creek at Peoria	1942-1971	29
55680	Mackinaw River near Green Valley	1921-1956	36
55695	Spoon River at London Mills	1943-1978	35
55700	Spoon River at Seville	1915-1978	63
55815	Sugar Creek near Hartsburg	1945-1971	26
55825	Crane Creek near Easton	1949-1974	25

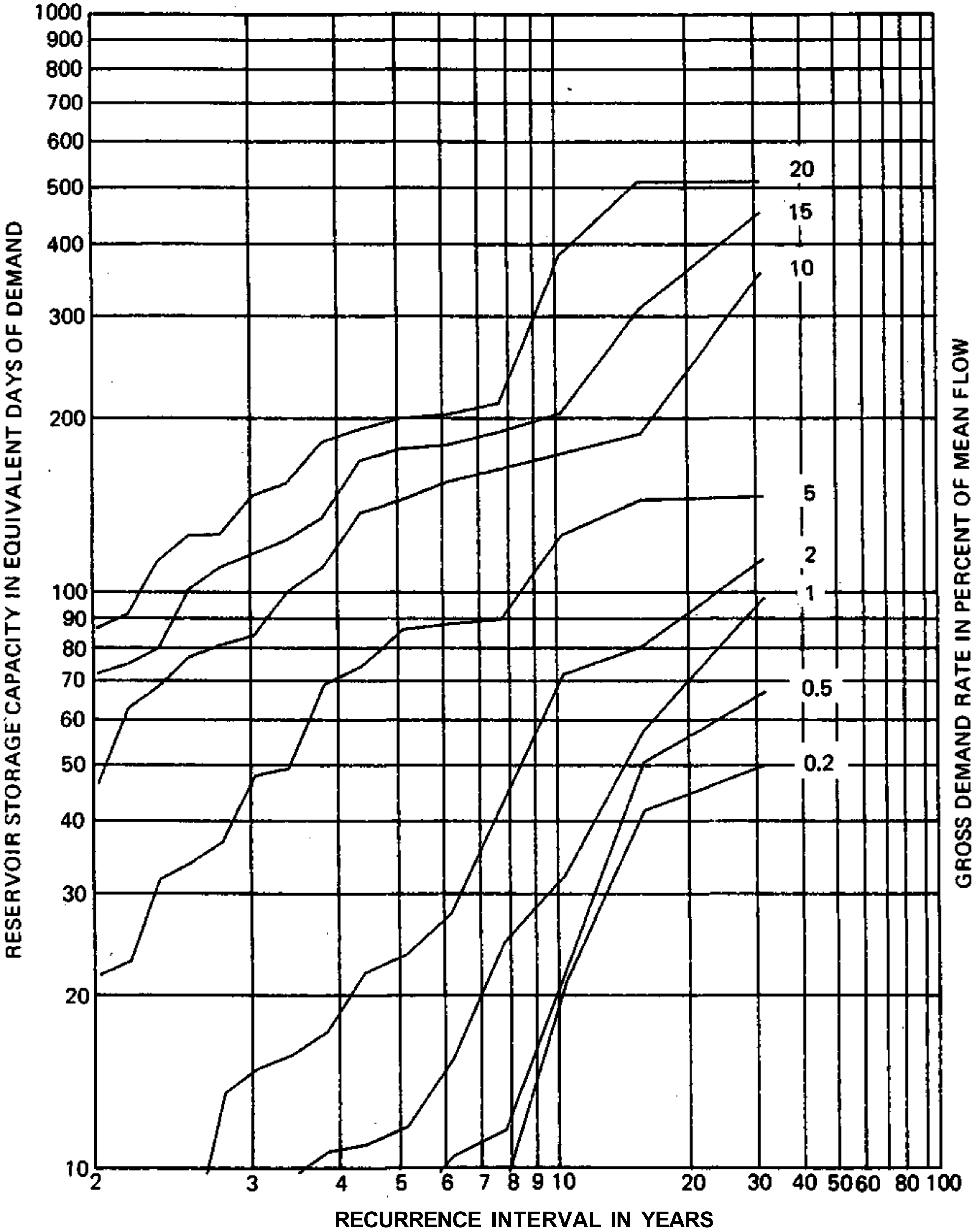
Drainage Area and Streamflow Characteristics

Gage No.	Drainage Area (mi^2)	Mean Flow (cfs)	Mean Flow (in./year)	$Q_{7,10}$ (cfs)	Q90 (cfs)	Q75 (cfs)	Q60 (cfs)
55605	27.4	17.9	8.87	0.0	0.5	1.4	3.2
55615	5.54	4.3	10.46	0.0	0.0	0.0	0.1
55620	61.2	43.3	9.62	0.0	1.6	3.2	5.8
55635	296.	168.0	7.69	1.0	7.5	16.2	34.0
55680	1100.	688.0	8.47	25.5	45.0	79.0	160.0
55695	1062.	687.0	8.78	9.8	38.0	81.0	180.0
55700	1636.	1036.0	8.52	19.0	59.0	140.0	285.0
55815	333.	197.0	8.02	11.9	16.5	30.0	55.0
55825	28.7	16.3	7.70	0.9	3.5	6.0	8.6

STATION 05560500

FARM CREEK AT FARMDALE

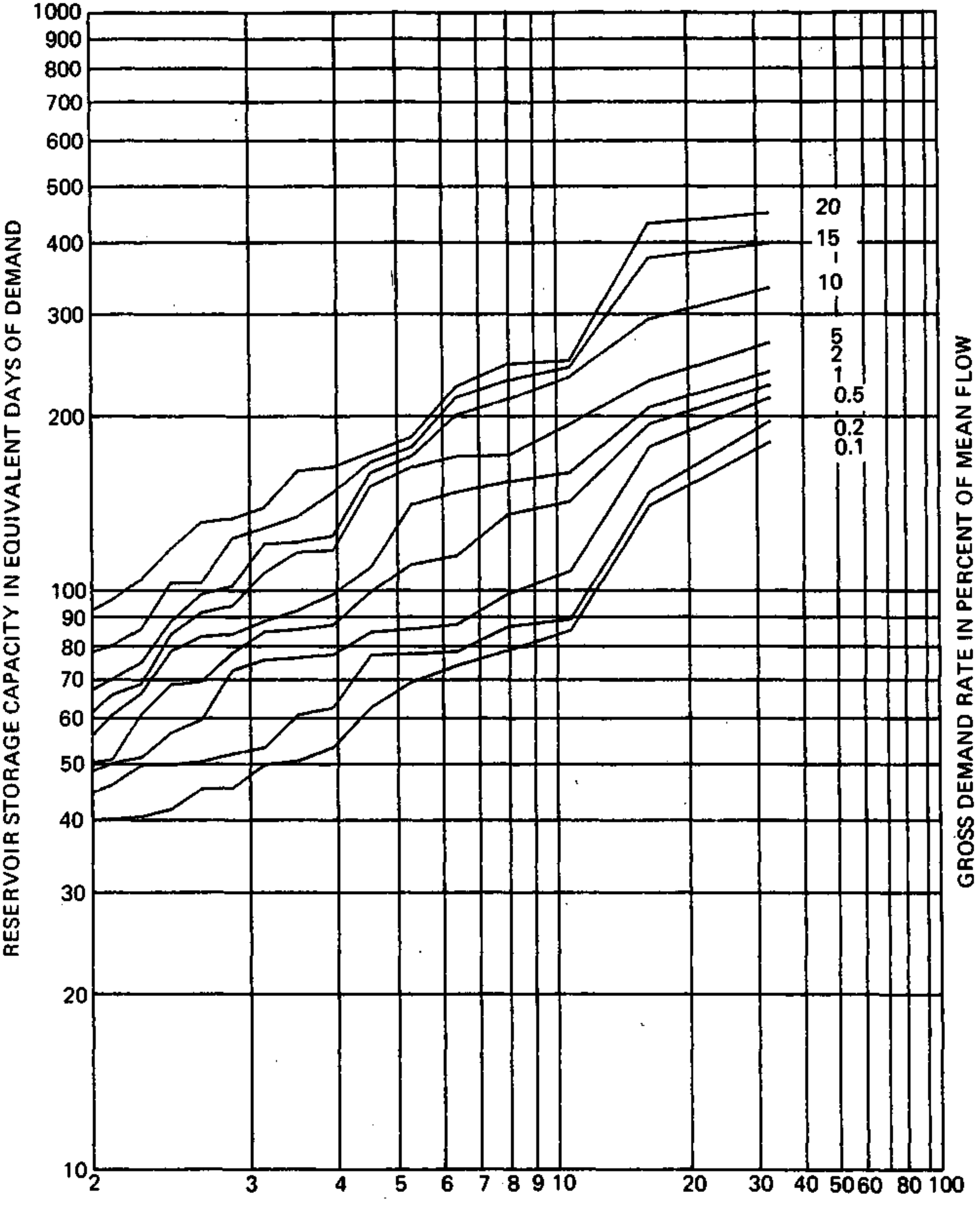
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05561500

FONDULAC CREEK NEAR EAST PEORIA

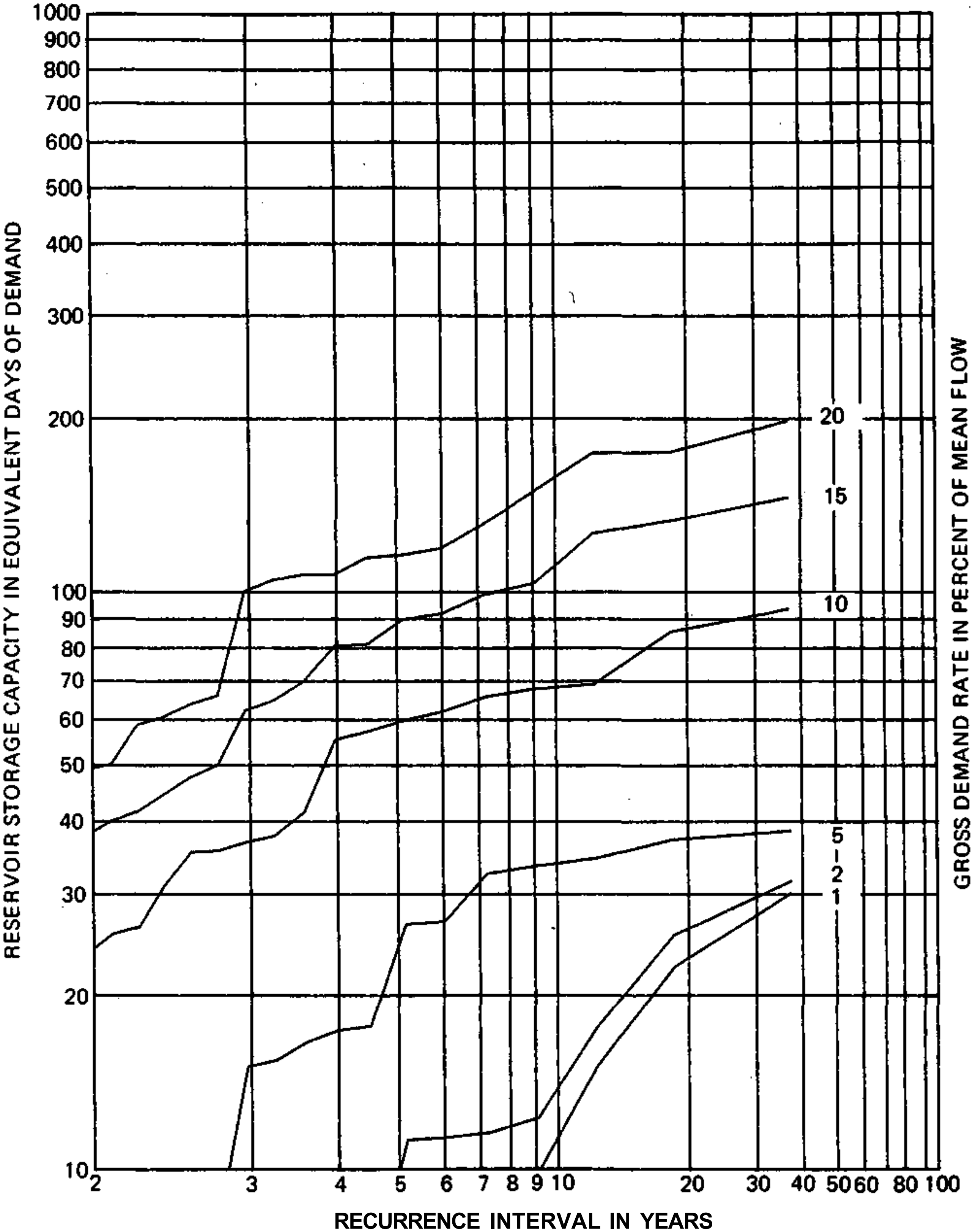
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05562000

FARM CREEK AT EAST PEORIA

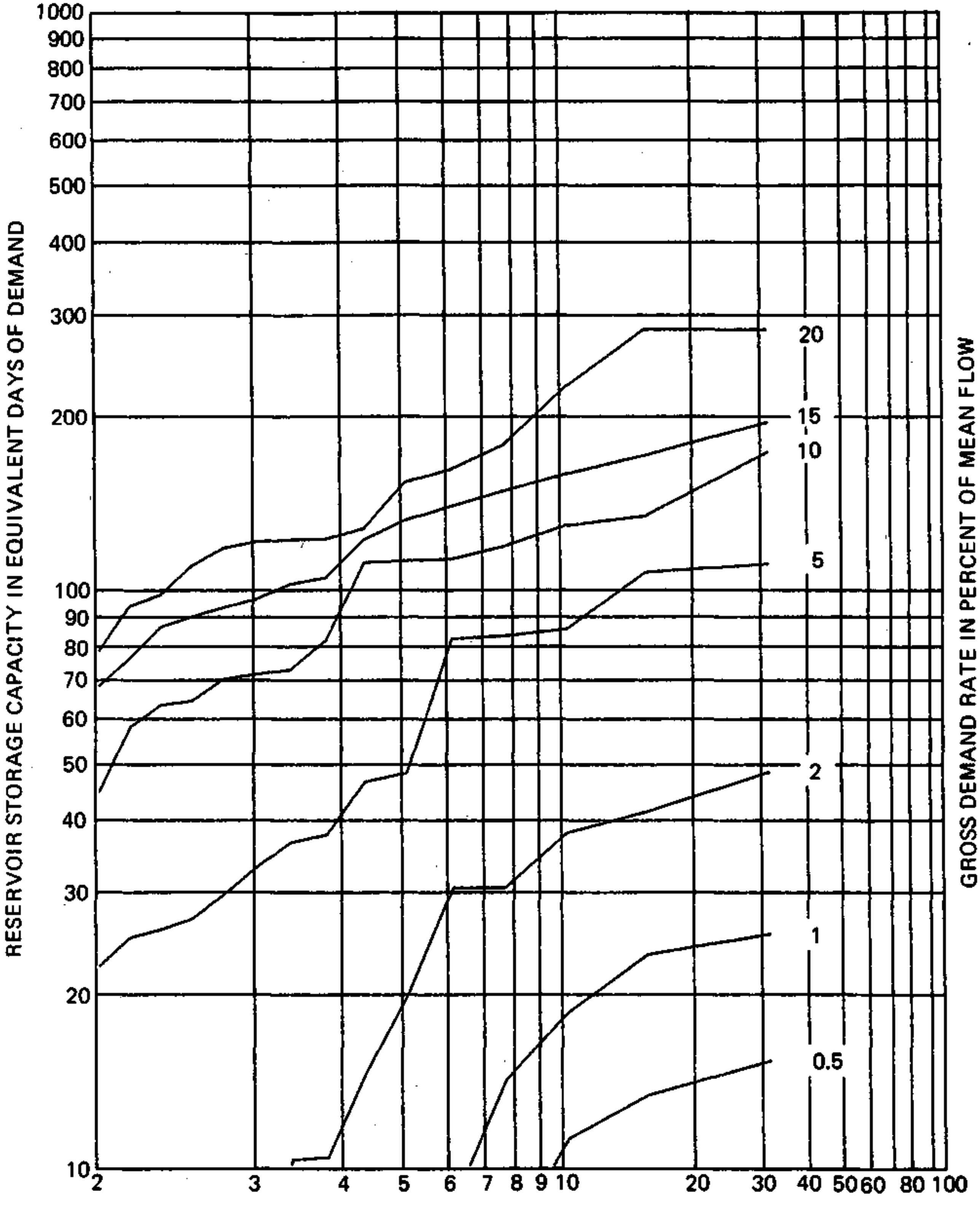
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05563500

KICKAPOO CREEK AT PEORIA

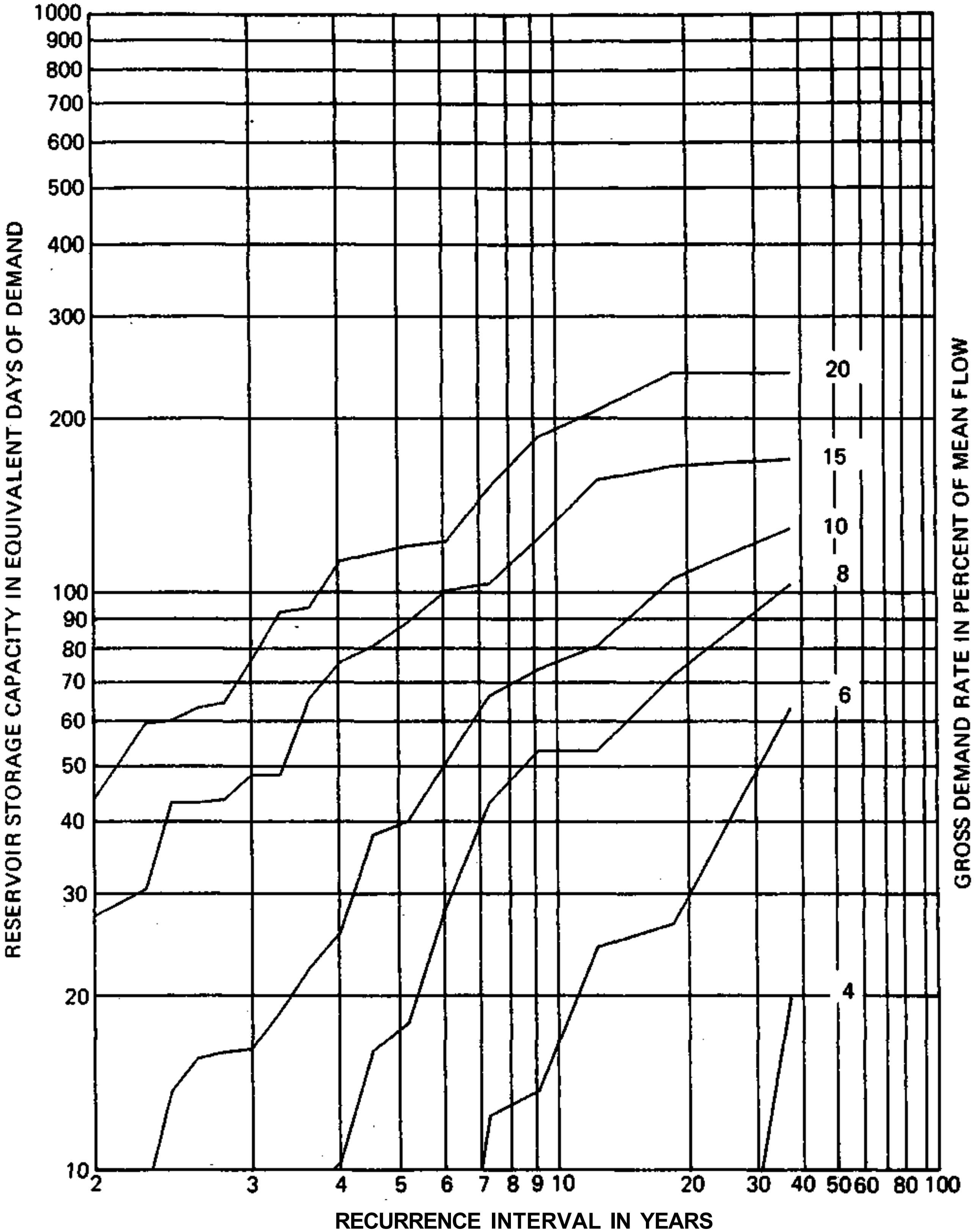
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05568000

MACKINAW RIVER NEAR GREEN VALLEY

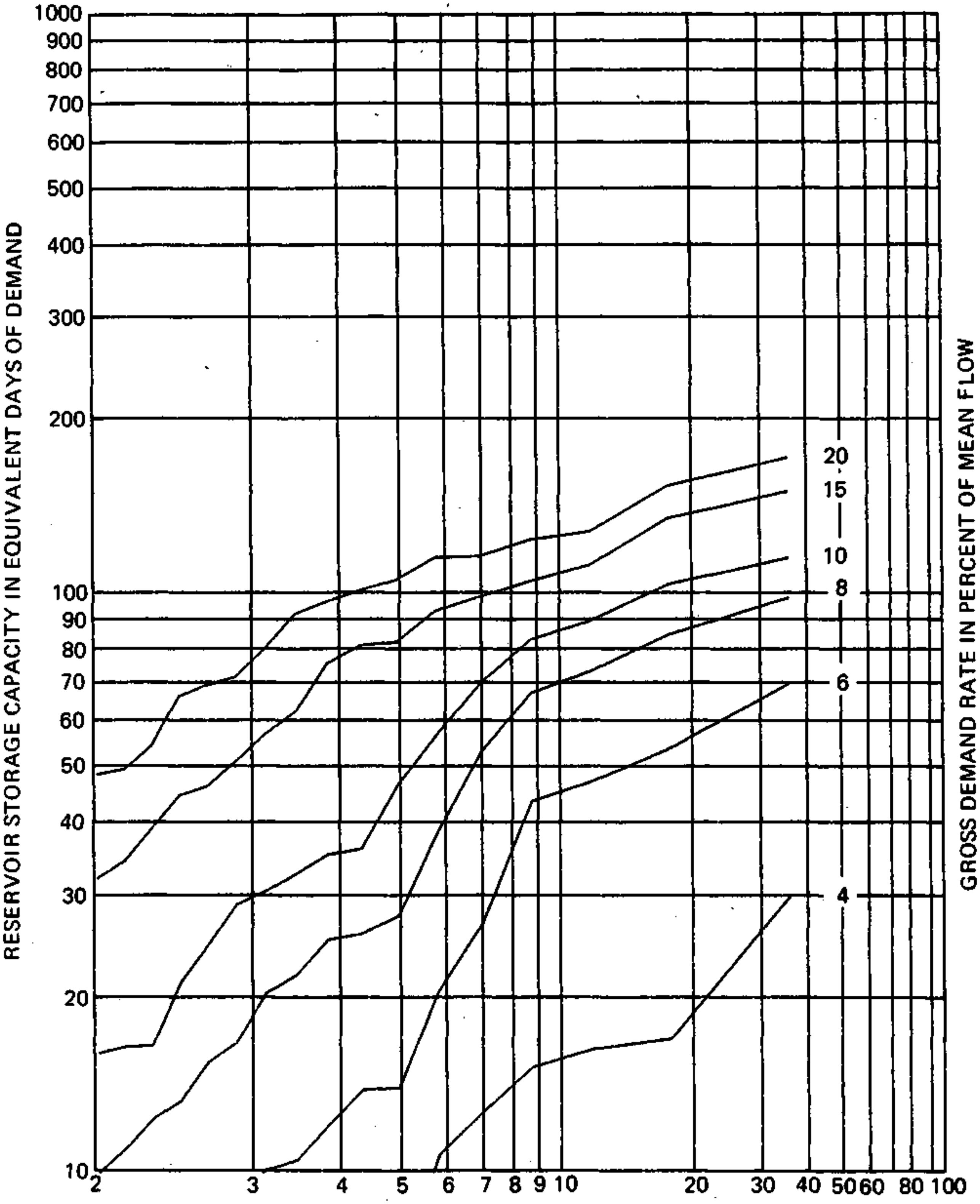
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05569500

SPOON RIVER AT LONDON MILLS

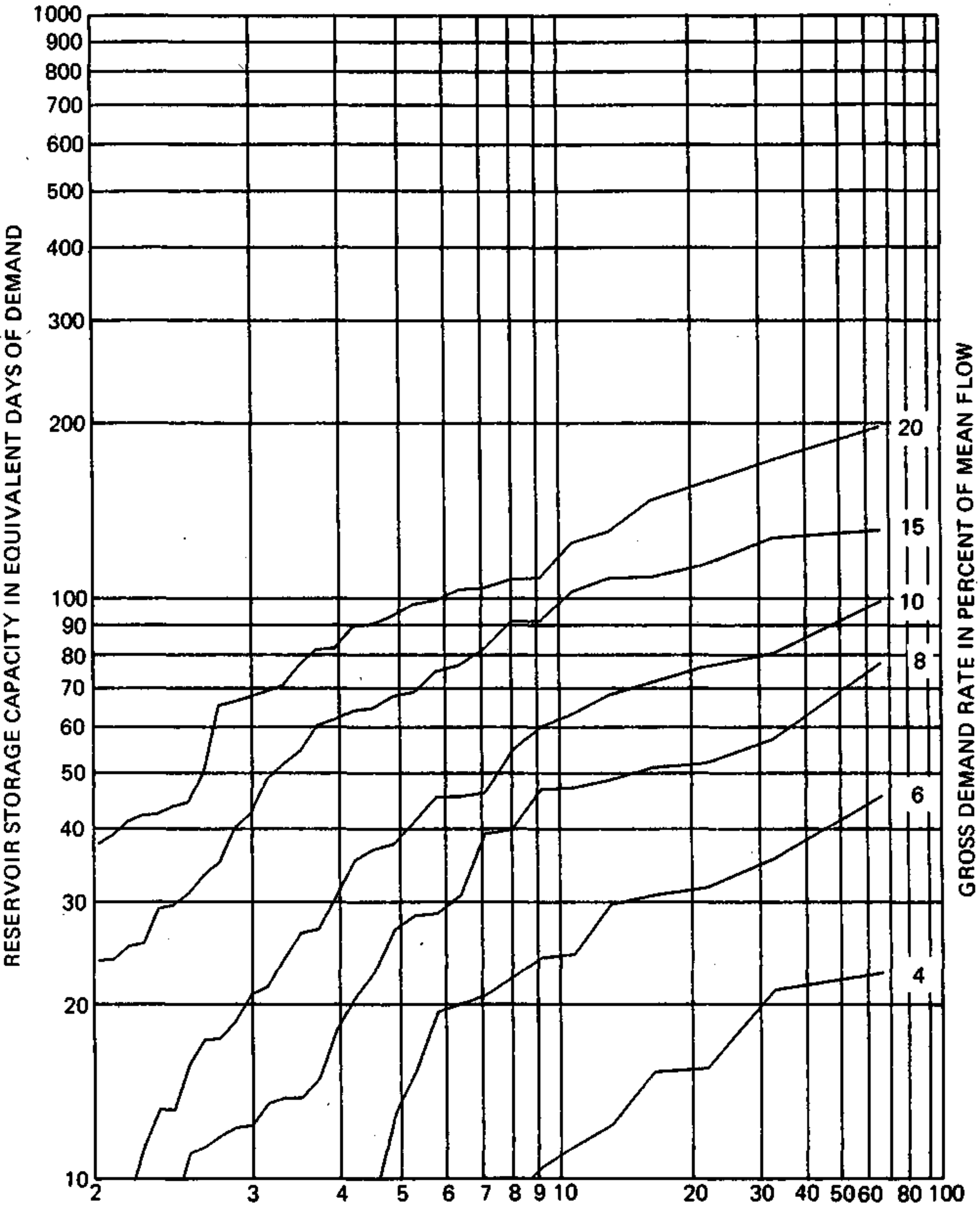
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05570000

SPOON RIVER AT SEVILLE

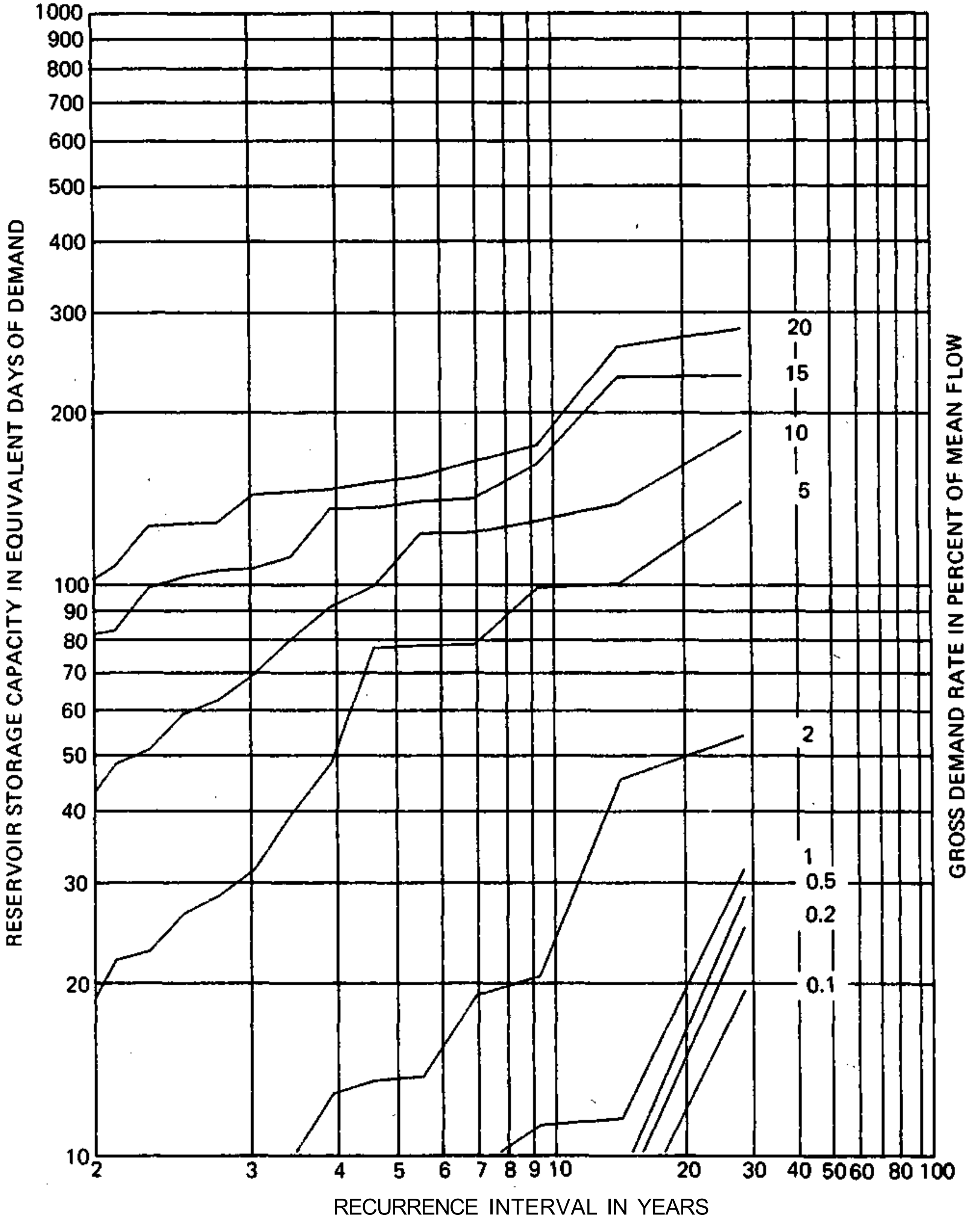
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05581500

SUGAR CREEK NEAR HARTSBURG

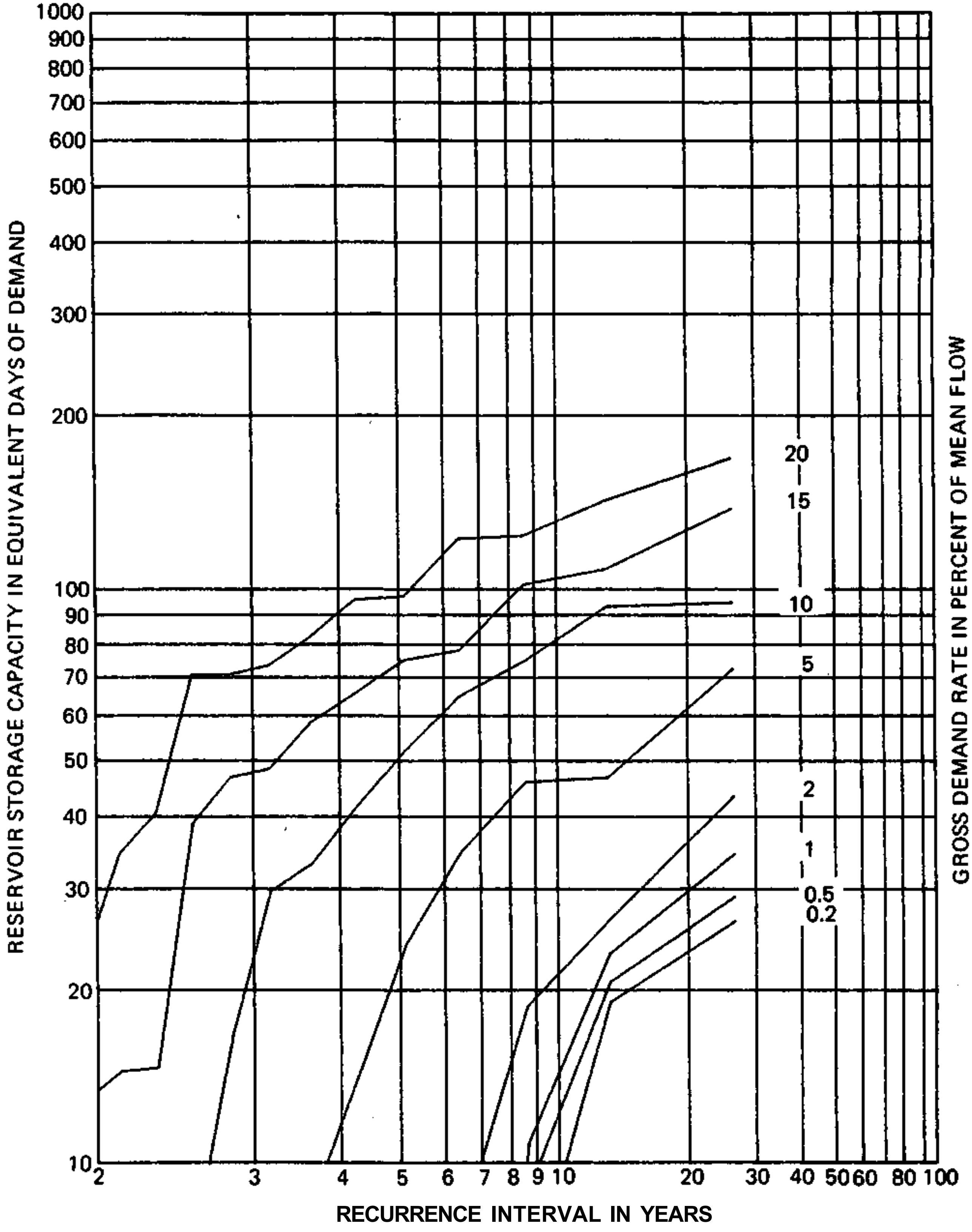
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP

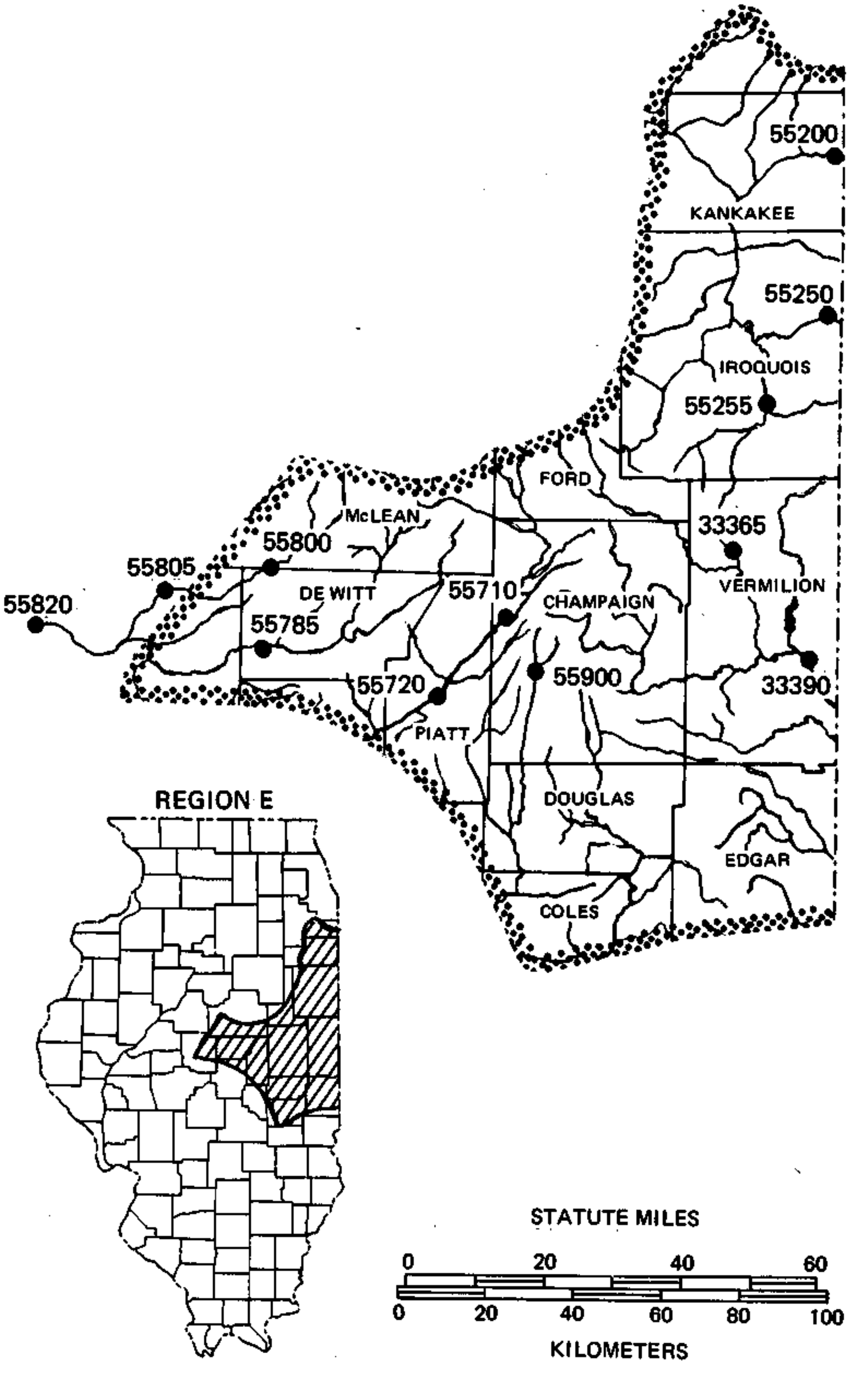


STATION 05582500

CRANE CREEK NEAR EASTON

DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP





55200
KANKAKEE
55250
IROQUOIS
55255
FORD
McLEAN
55800
55805
55820
DE WITT
55785
55710
CHAMPAIGN
33365
VERMILION
55720
55900
33390
PIATT
REGION E
DOUGLAS
EDGAR
COLES
STATUTE MILES
0
20
40
60
0
20
40
60
80
100
KILOMETERS

REGION E

USGS Gage No.	Name of Station	Period of Record	Number of Years
33365	Bluegrass Creek at Potomac	1950-1971	21
33390	Vermilion River near Danville	1929-1978	49
55200	Singleton Ditch at Illinoi	1945-1976	31
55250	Iroquois River at Iroquois	1945-1978	33
55255	Sugar Creek at Milford	1949-1978	29
55710	Sangamon River at Mahomet	1948-1978	30
55720	Sangamon River at Monticello	1915-1978	63
55785	Salt Creek near Rowell	1943-1977	34
55800	Kickapoo Creek at Waynesville	1948-1978	30
55805	Kickapoo Creek near Lincoln	1945-1971	26
55820	Salt Creek near Greenview	1942-1978	36
55900	Kaskaskia Ditch at Bondville	1949-1978	29

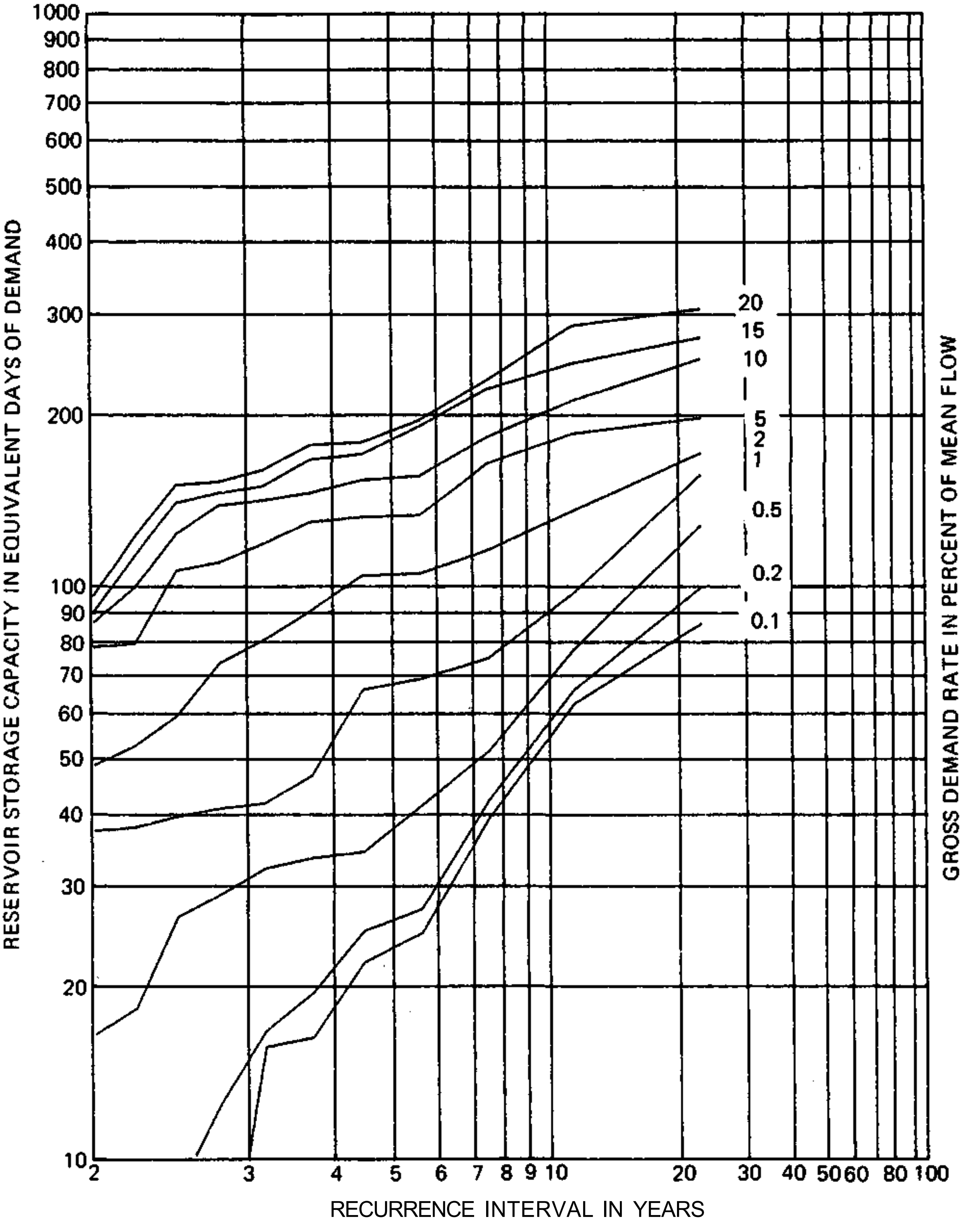
Drainage Area and Streamflow Characteristics

Gage No.	Drainage Area (mi^2)	Mean Flow (cfs)	Mean Flow (in./year)	$Q_{7,10}$ (cfs)	Q90 (cfs)	Q75 (cfs)	Q60 (cfs)
33365	34.8	28.4	11.08	0.0	0.1	0.5	3.3
33390	1290.	930.0	9.79	33.0	47.0	100.0	220.0
55200	220.	178.0	10.96	12.7	28.0	47.0	73.0
55250	686.	535.0	10.19	9.1	29.0	69.0	150.0
55255	446.	347.0	10.57	3.5	10.0	25.0	64.0
55710	362.	261.0	9.79	0.3	5.8	18.2	50.0
55720	550.	398.0	9.83	2.1	12.0	33.0	86.0
55785	335.	237.0	9.61	2.2	11.0	25.0	58.0
55800	227.	149.0	8.91	0.5	4.2	13.0	32.0
55805	306.	187.0	8.30	2.5	8.0	18.5	44.0
55900	12.4	9.9	10.87	0.1	0.3	0.8	2.4

STATION 03336500

BLUEGRASS CREEK AT POTOMAC

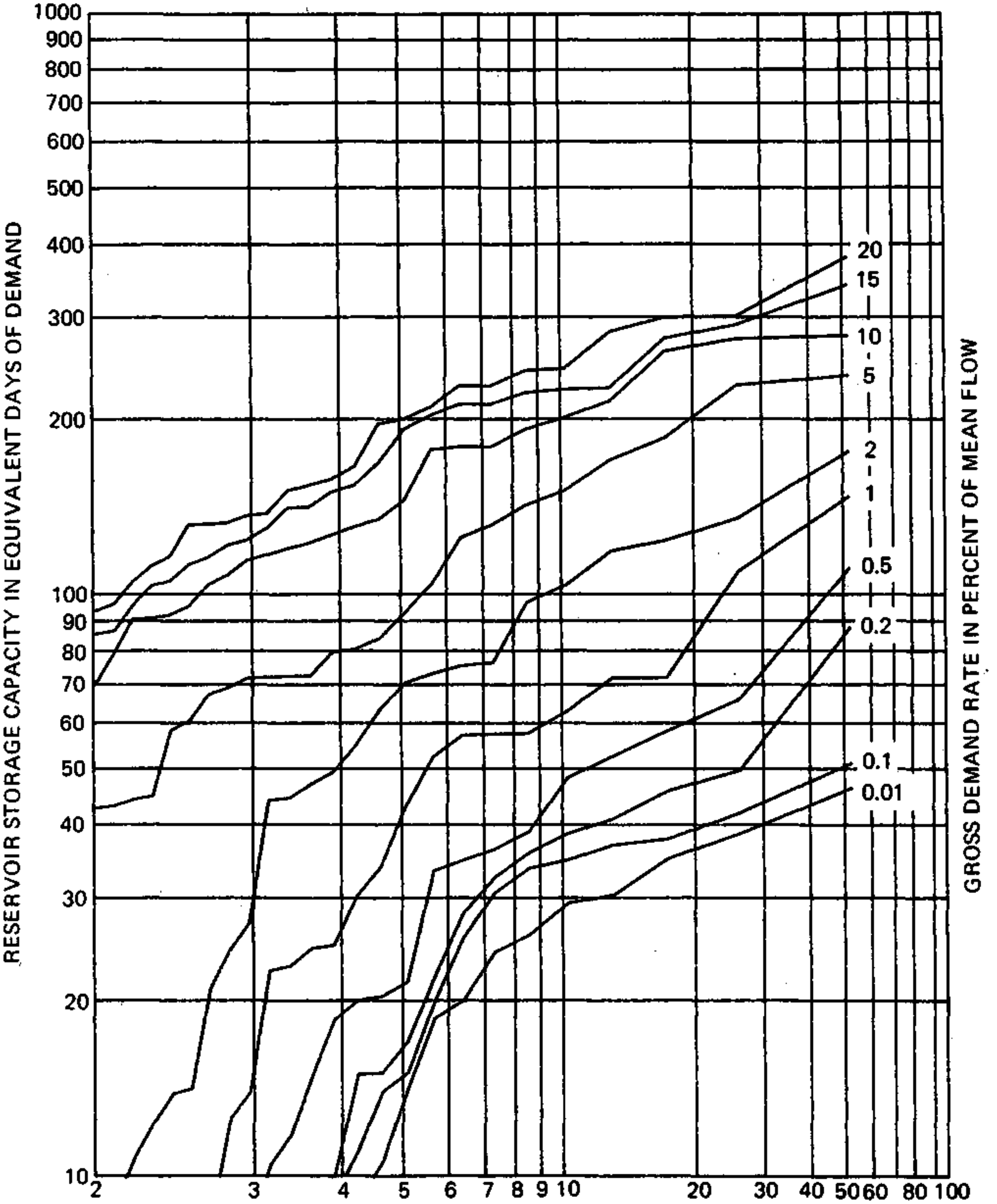
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 03339000

VERMILION RIVER NEAR DANVILLE

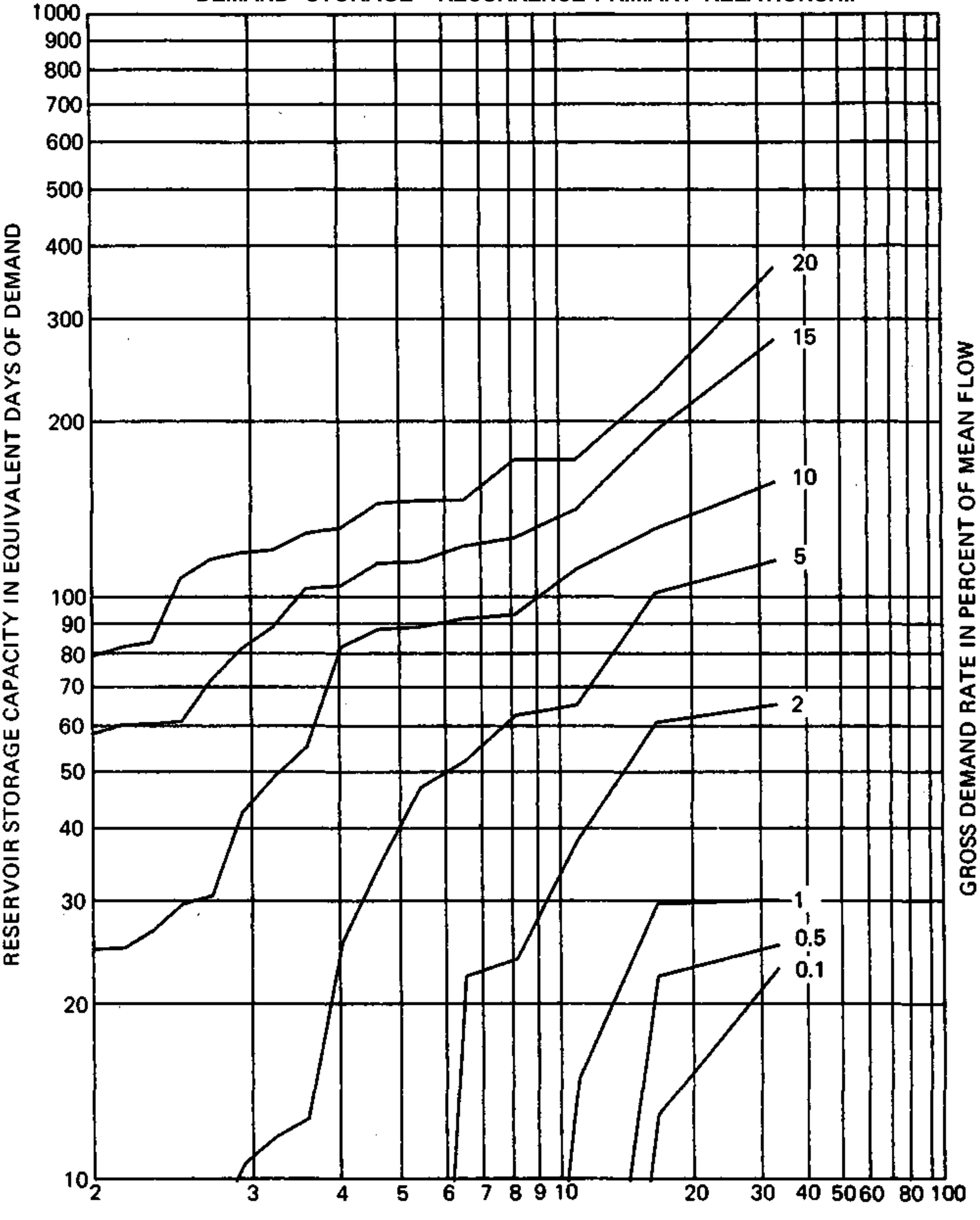
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05520000

SINGLETON DITCH AT ILLINOI

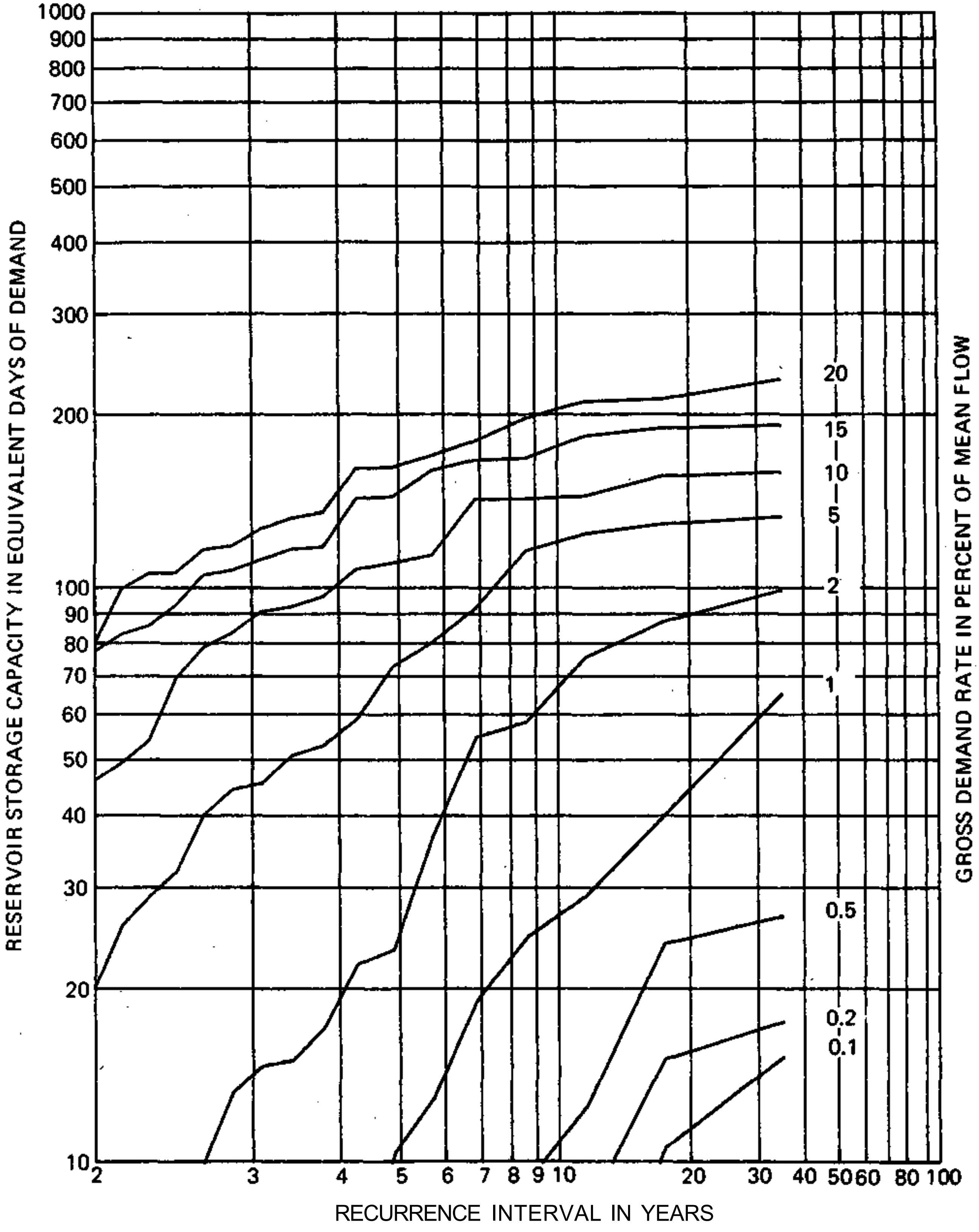
DEMAND -STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05525000

IROQUOIS RIVER AT IROQUOIS

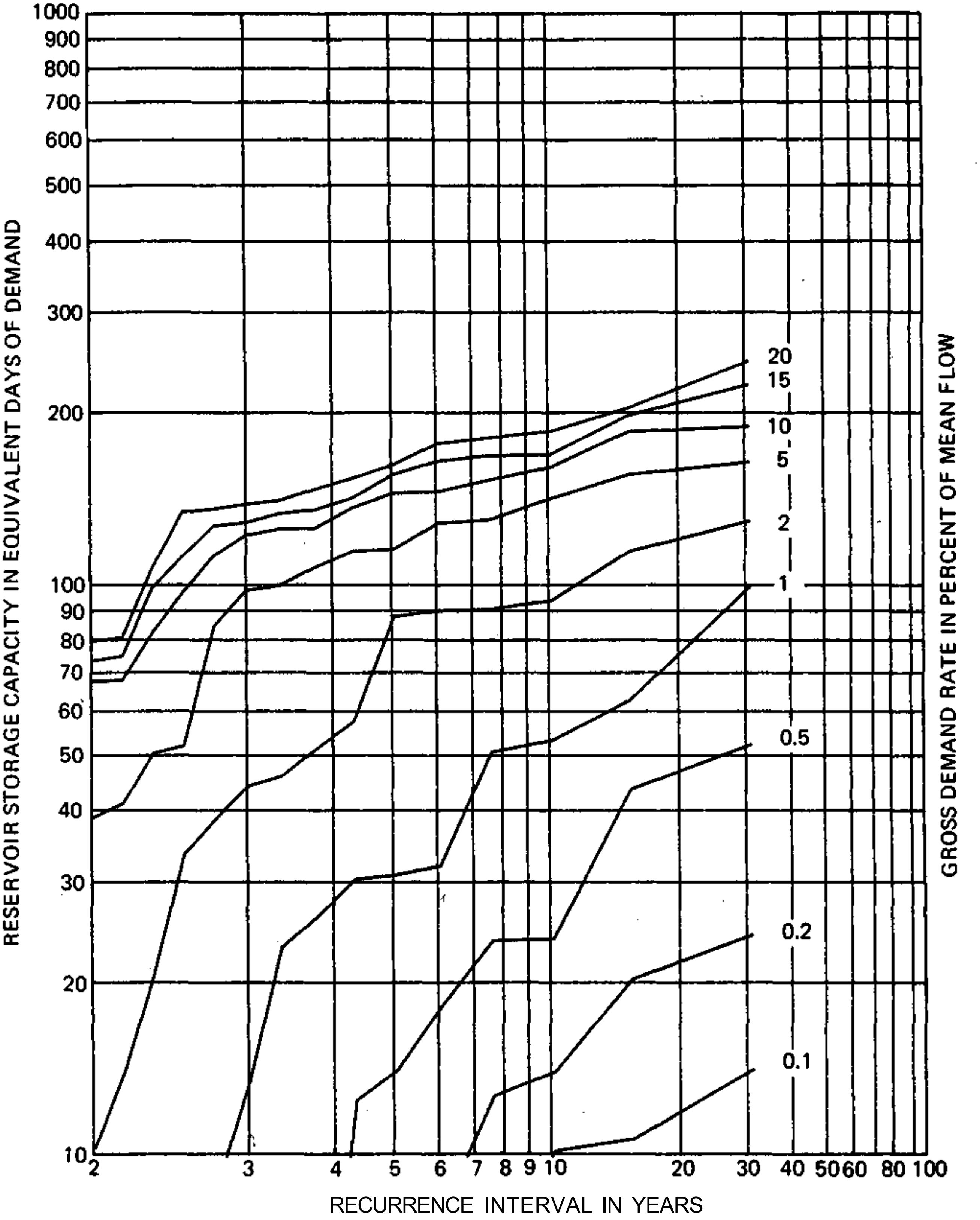
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05525500

SUGAR CREEK AT MILFORD

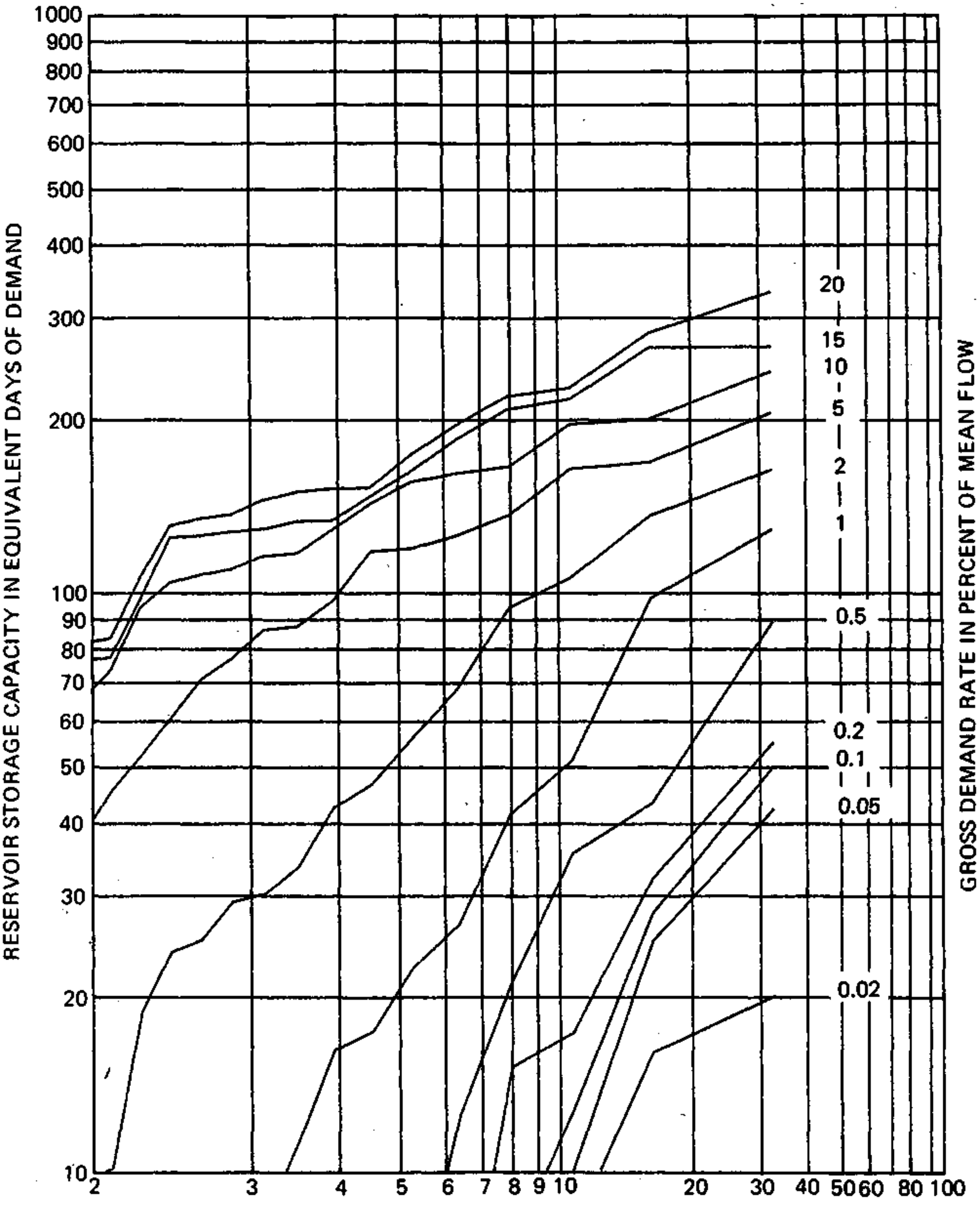
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05571000

SANGAMON RIVER AT MAHOMET

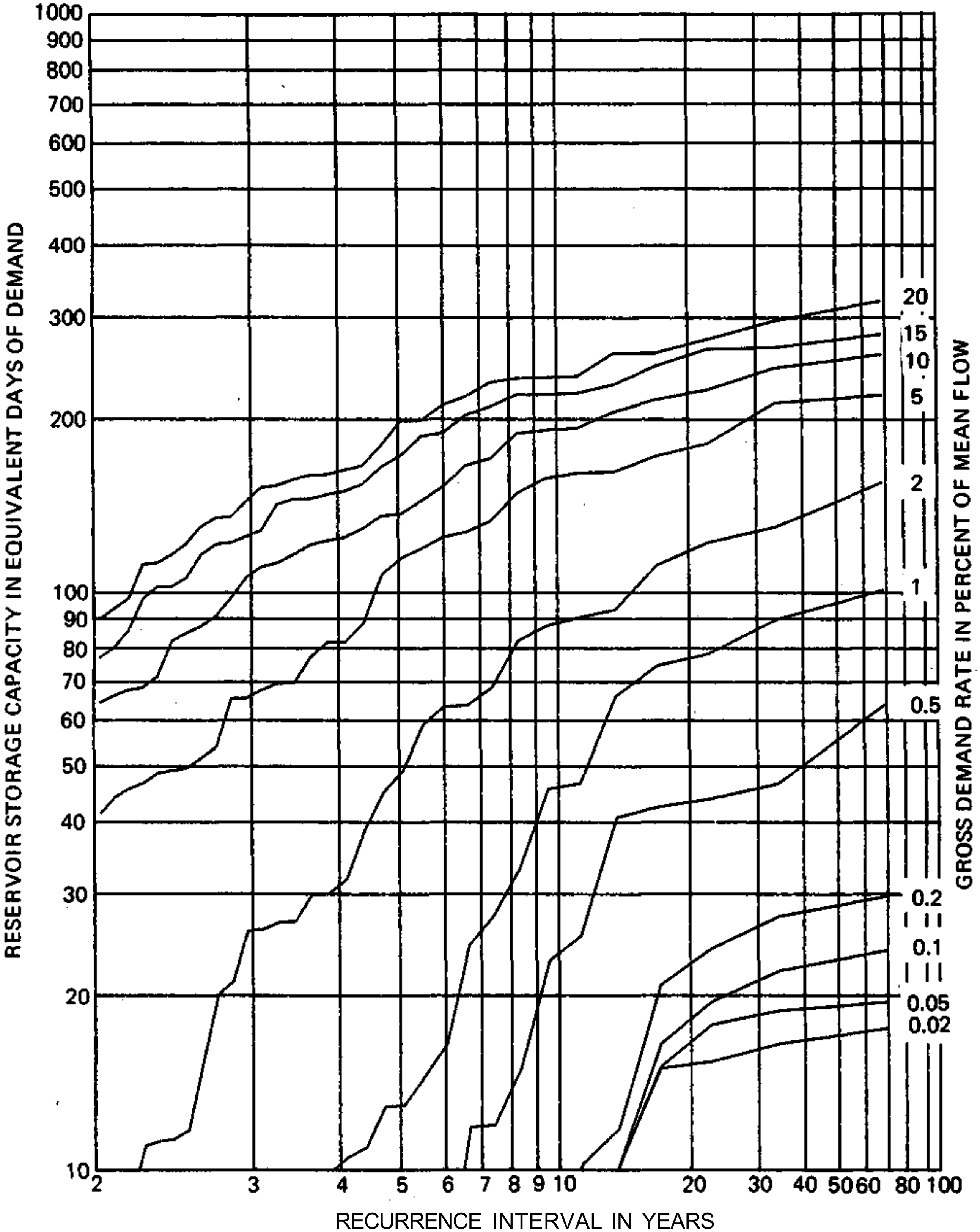
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05572000

SANGAMON RIVER AT MONTICELLO

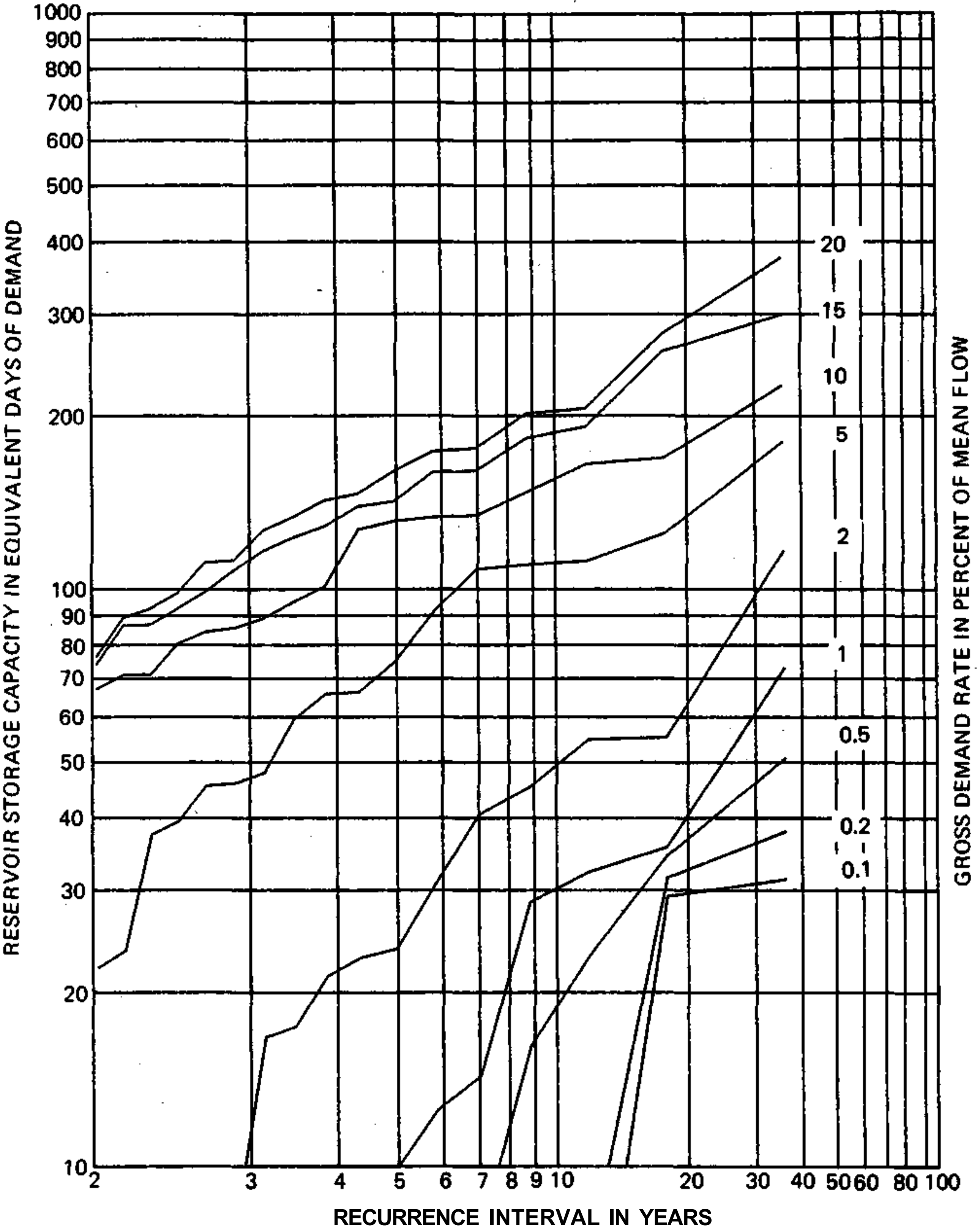
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05578500

SALT CREEK NEAR ROWELL

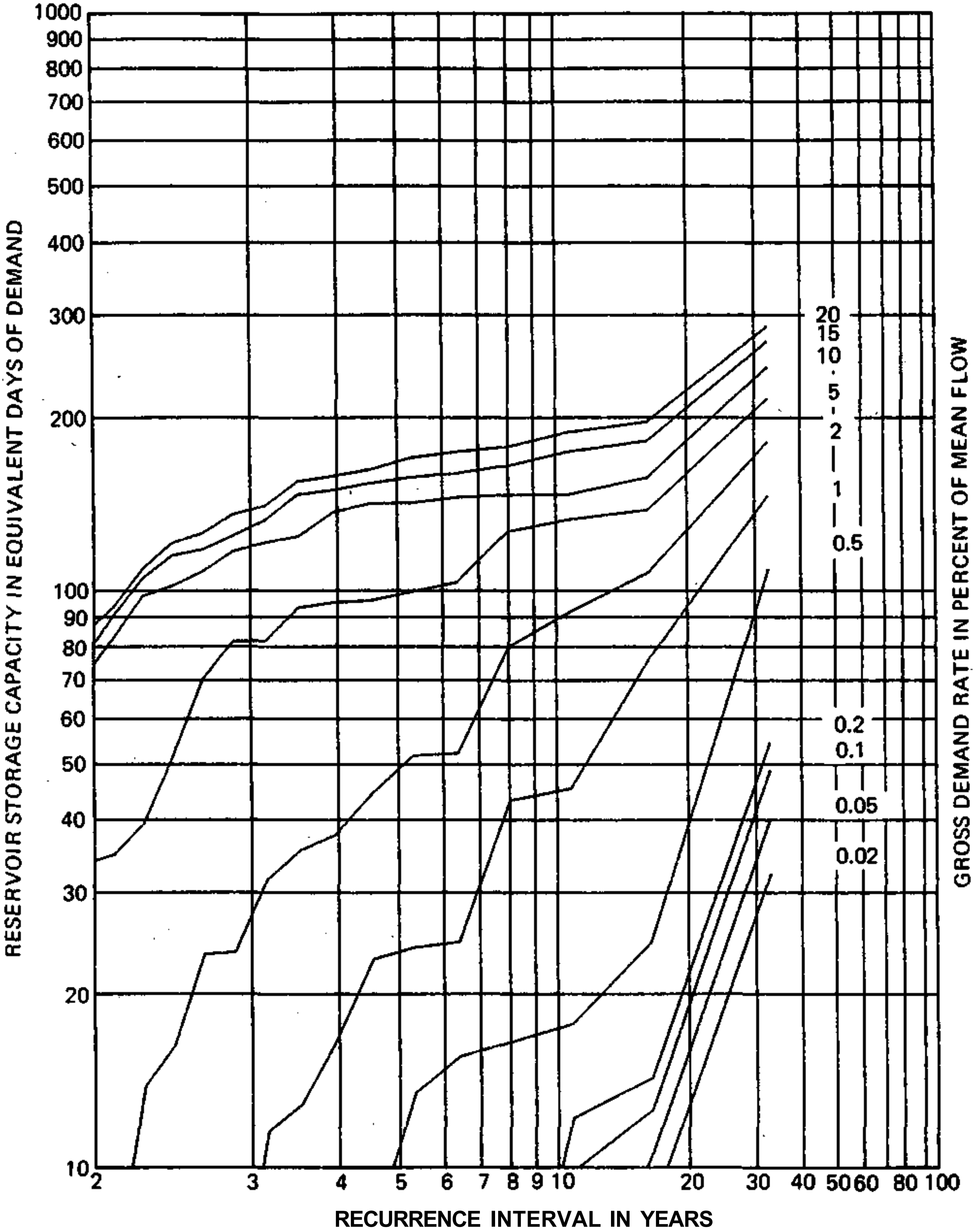
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05580000

KICKAPOO CREEK AT WAYNESVILLE

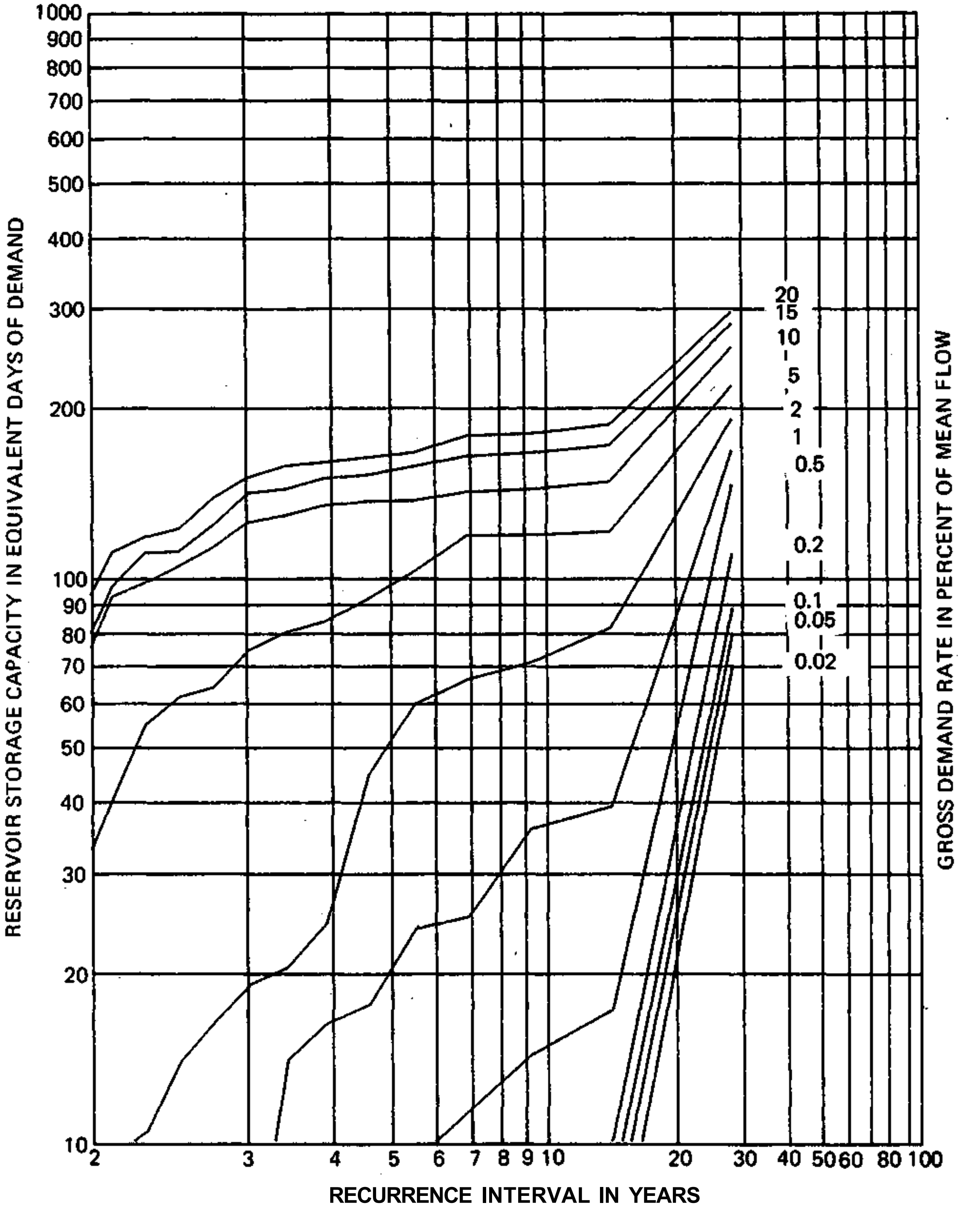
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05580500

KICKAPOO CREEK NEAR LINCOLN

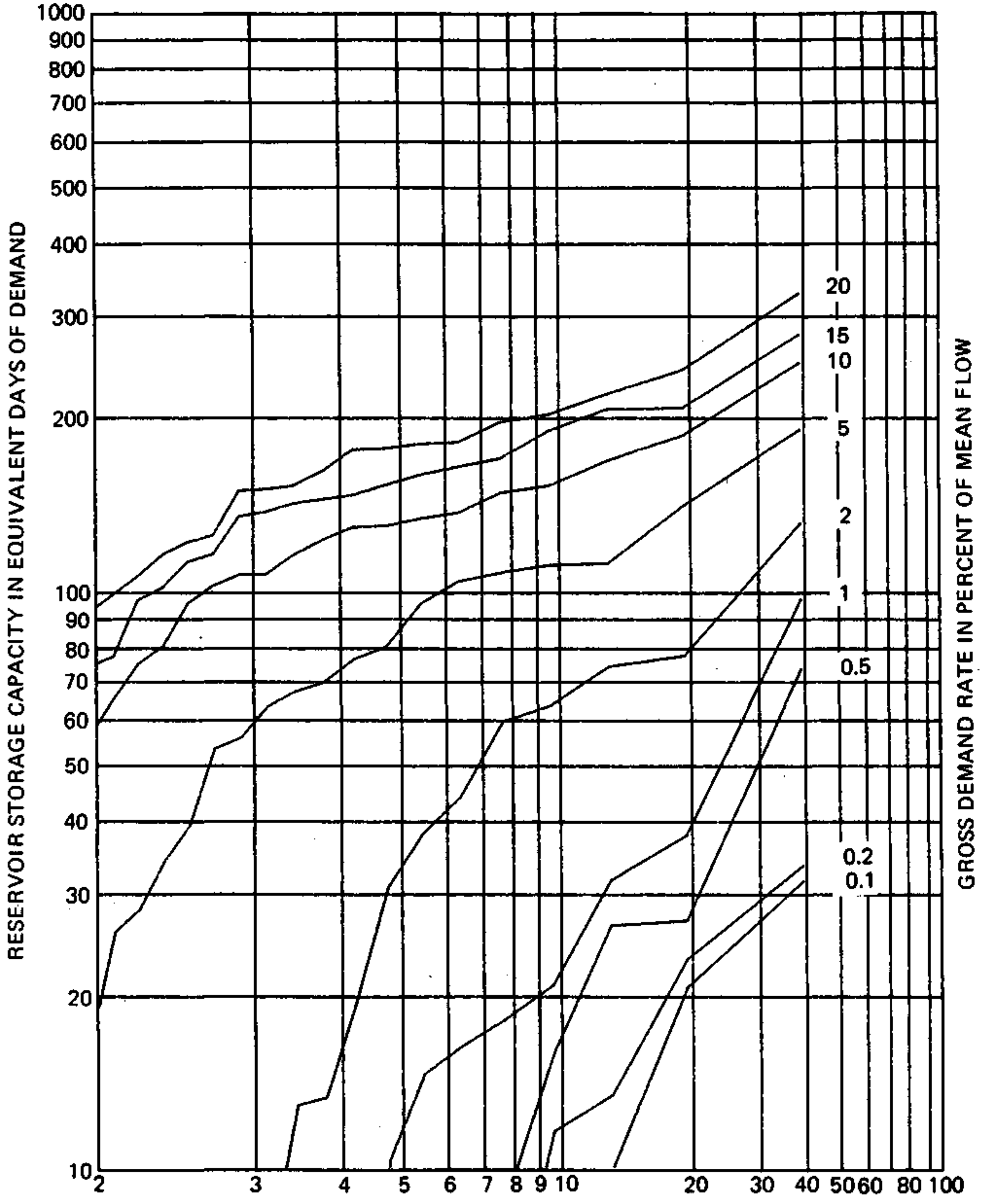
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05582000

SALT CREEK NEAR GREENVIEW

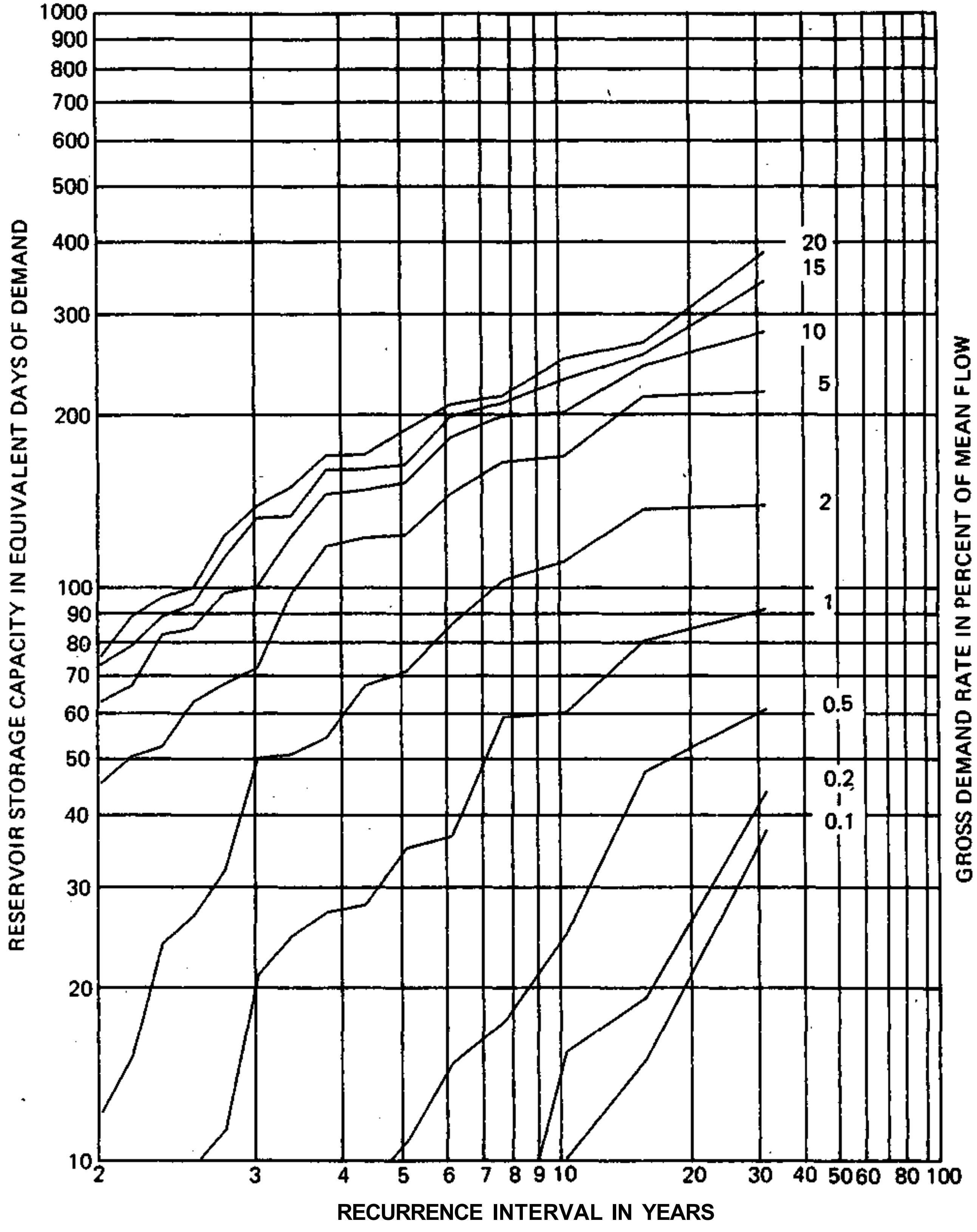
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP

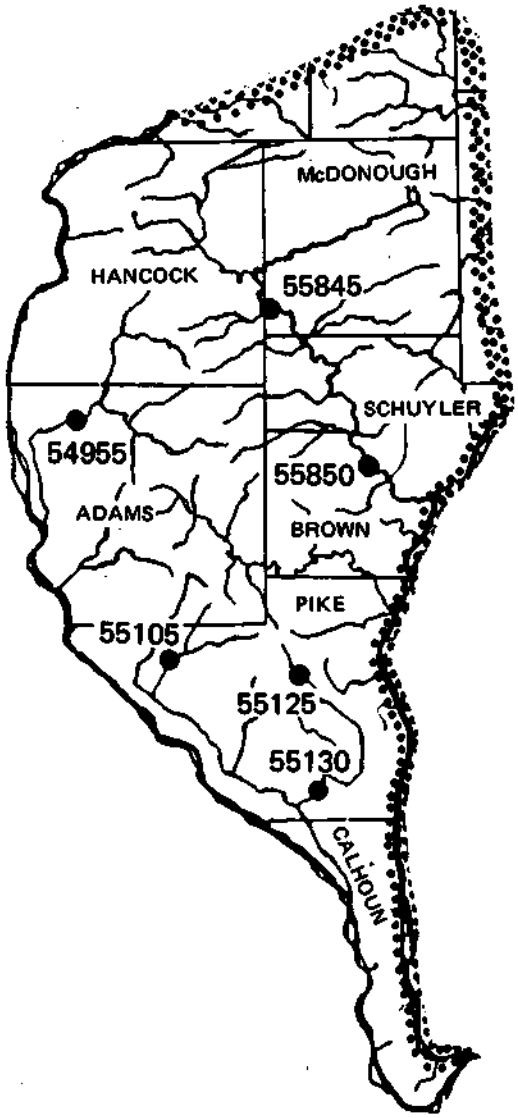


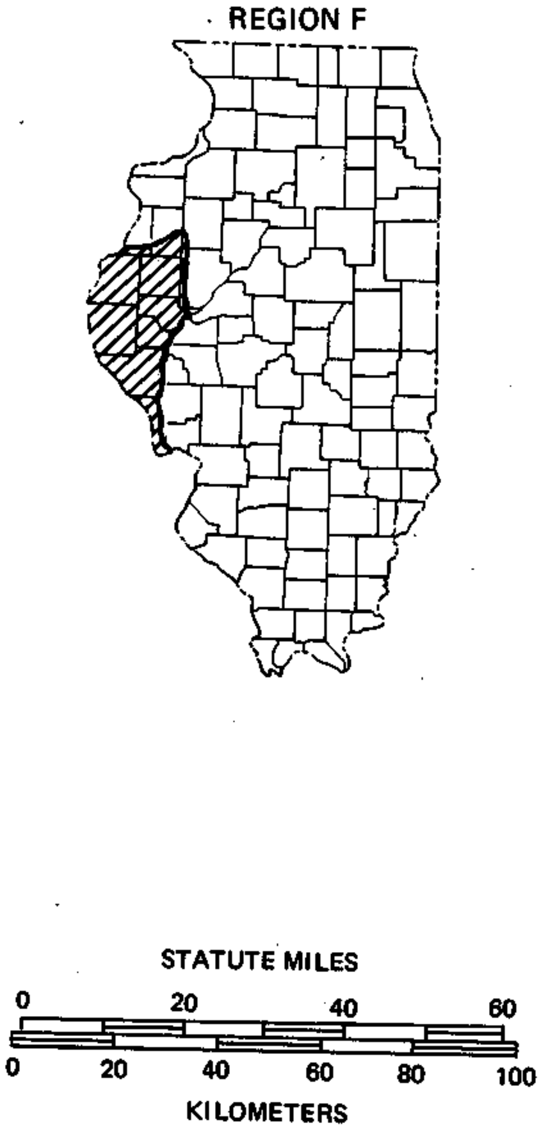
STATION 05590000

KASKASKIA DITCH AT BONDVILLE

DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP




McDONOUGH
HANCOCK
55845
SCHUYLER
54955
55850
ADAMS
BROWN
PIKE
55105
55125
55130
CALHOUN


REGION F
STATUTE MILES
0
20
40
60
0
20
40
60
80
100
KILOMETERS

REGION F

USGS Gage No.	Name of Station	Period of Record	Number of Years
54955	Bear Creek near Marcelline	1944-1978	34
55105	Hadley Creek at Kinderhook	1940-1973	33
55125	Bay Creek at Pittsfield	1940-1978	38
55130	Bay Creek at Nebo	1940-1978	38
55845	LaMoine River at Colmar	1945-1978	33
55850	LaMoine River at Ripley	1921-1978	57

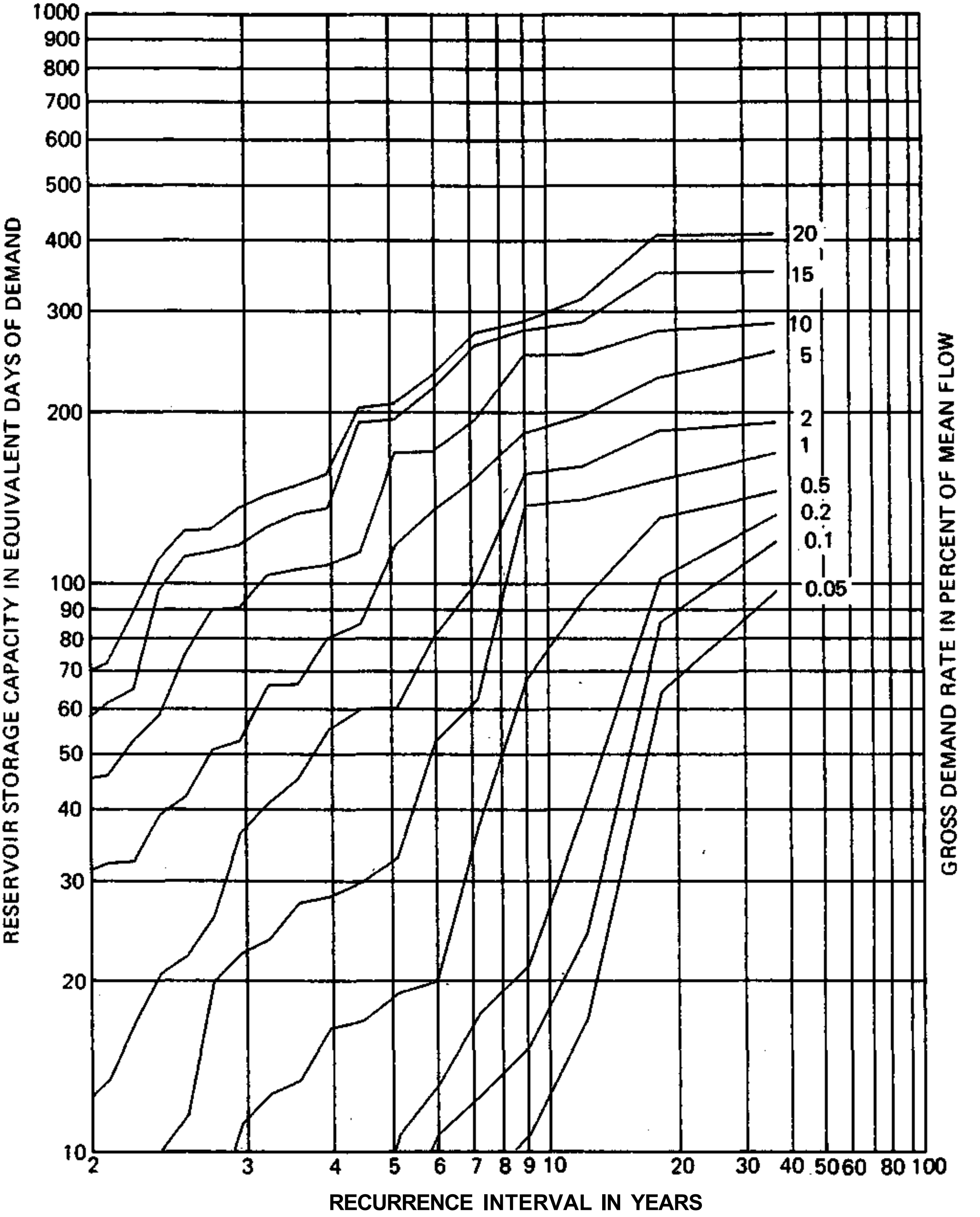
Drainage Area and Streamflow Characteristics

Gage No.	Drainage Area (mi^2)	Mean Flow (cfs)	Mean Flow (in./year)	$Q_{7,10}$ (cfs)	Q90 (cfs)	Q75 (cfs)	Q60 (cfs)
54955	349.	199.0	7.74	0.0	0.9	3.7	10.0
55105	72.7	53.5	9.99	0.0	0.6	2.7	5.5
55125	39.4	26.6	9.17	0.0	0.2	0.5	1.5
55130	161.	96.1	8.11	0.0	1.3	5.2	12.0
55845	655.	435.0	9.02	0.8	10.0	30.0	68.0
55850	1293.	781.0	8.20	9.0	28.0	67.0	140.0

STATION 05495500

BEAR CREEK NEAR MARCELLINE

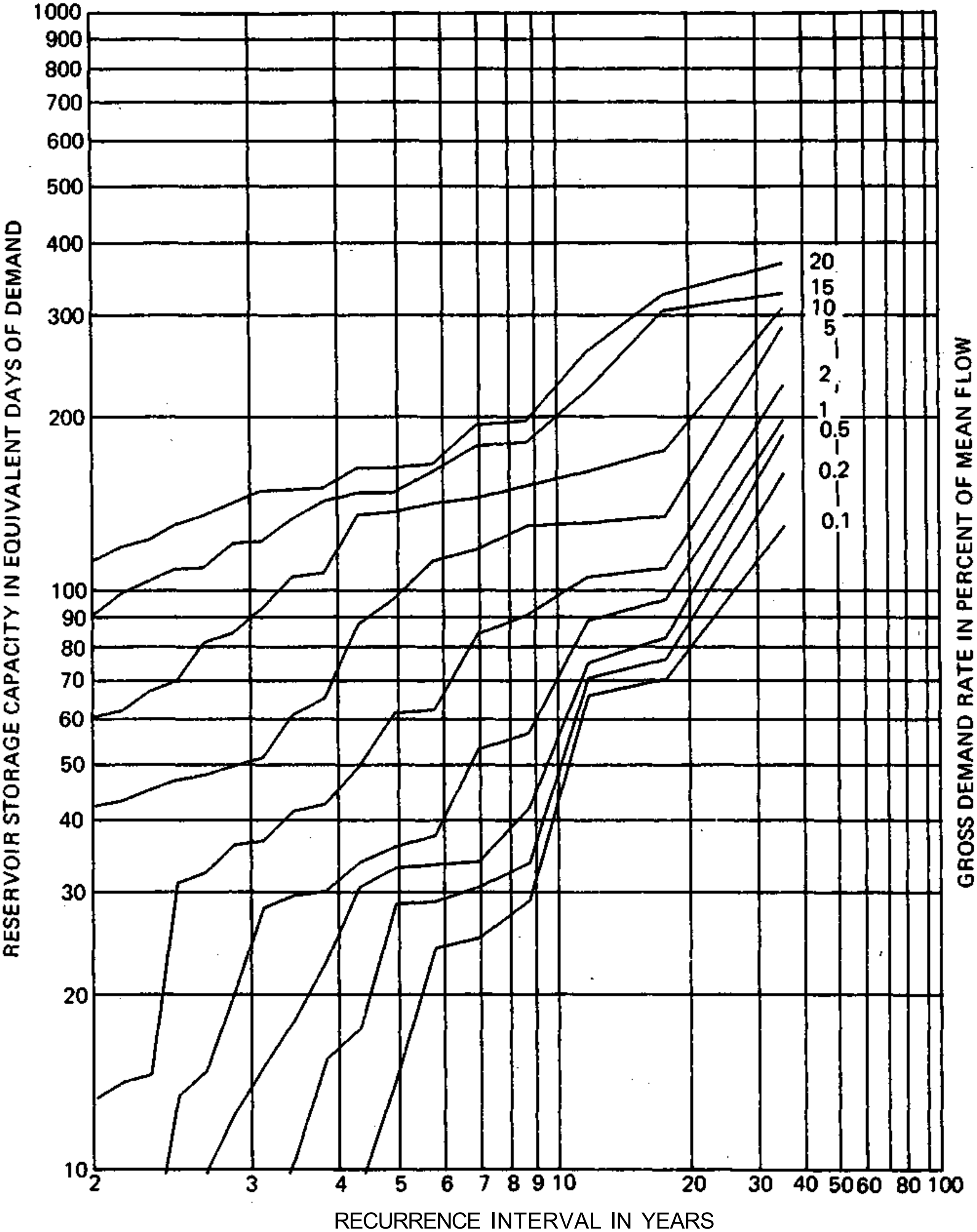
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05510500

HADLEY CREEK AT KINDERHOOK

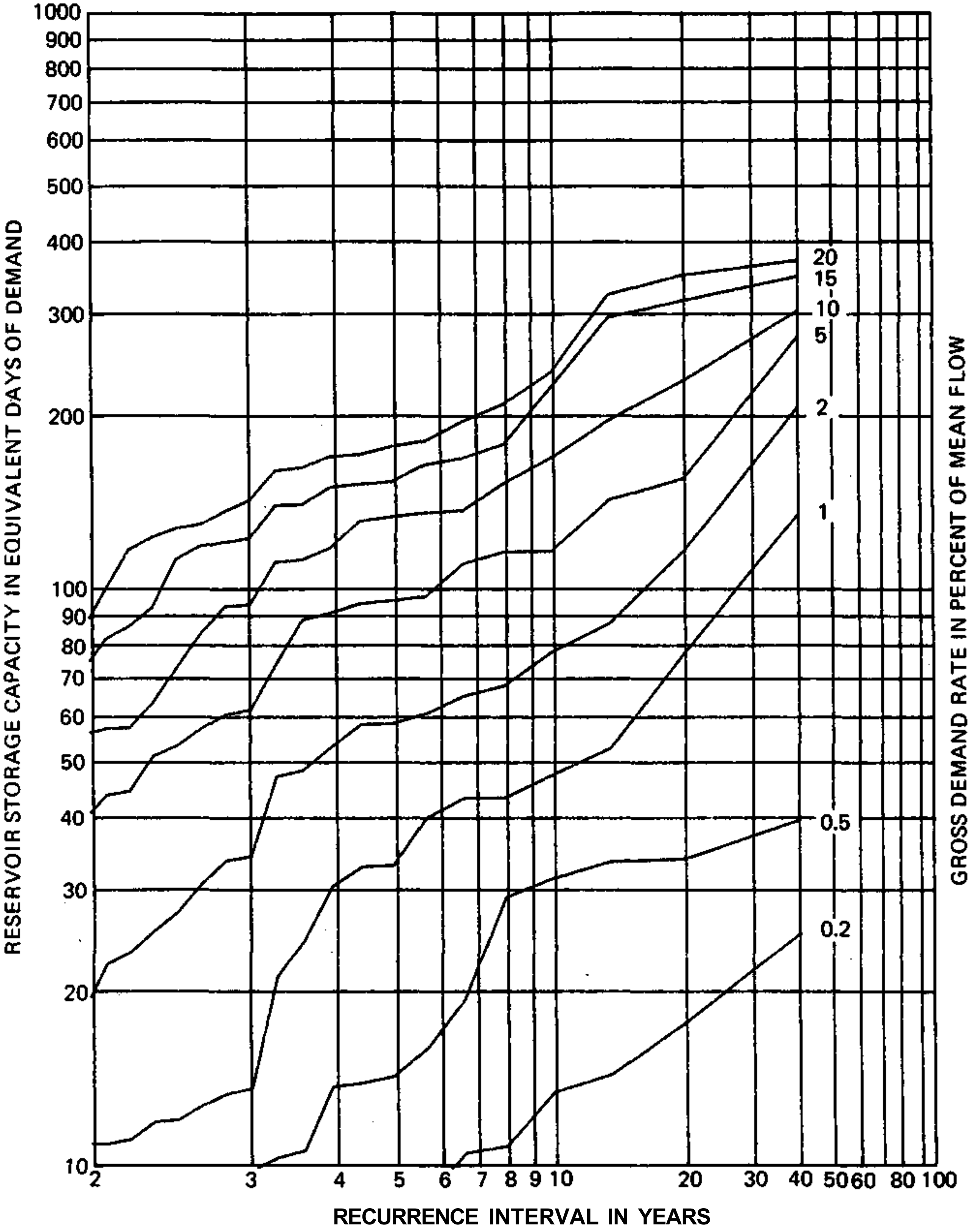
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05512500

BAY CREEK AT PITTSFIELD

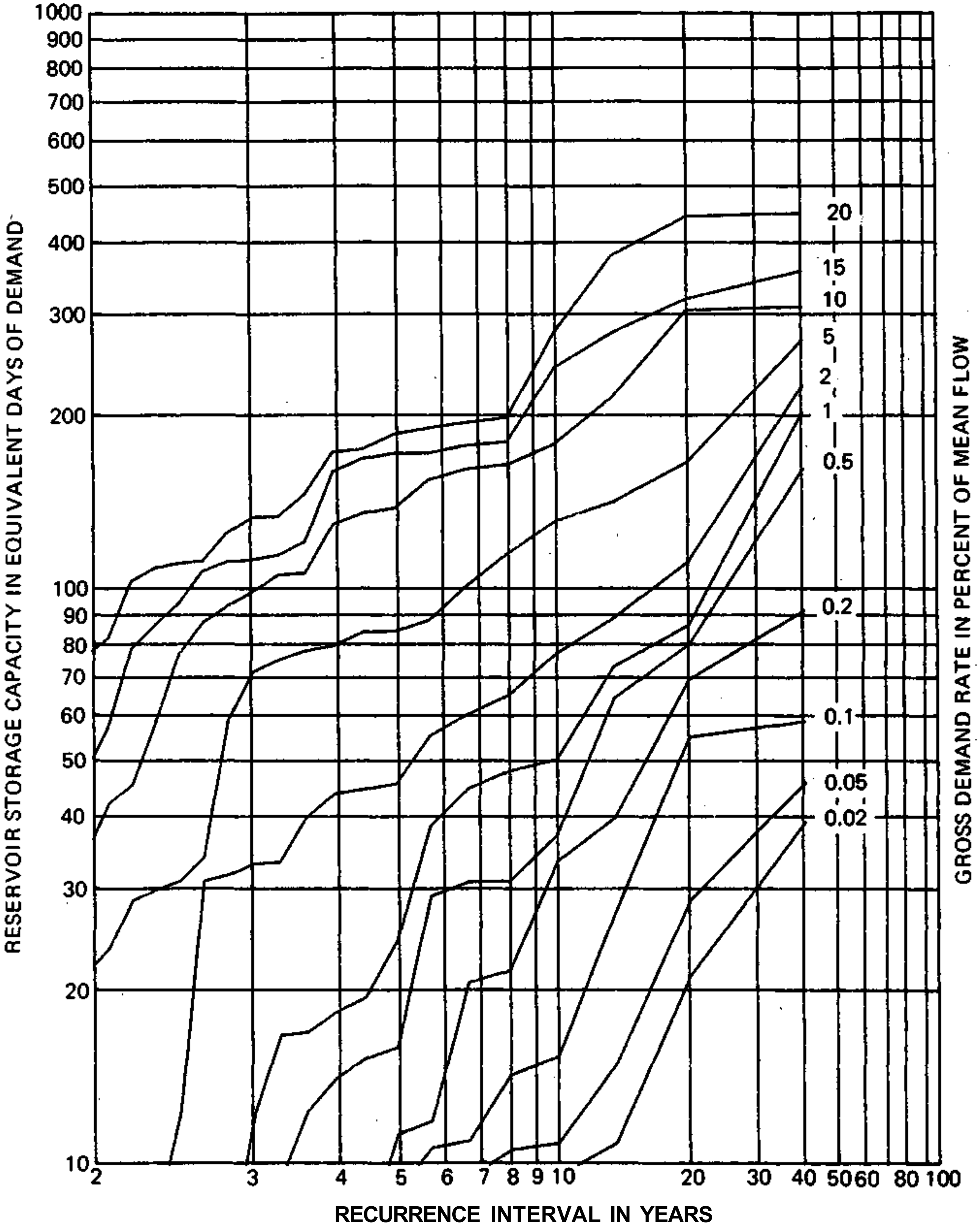
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05513000

BAY CREEK AT NEBO

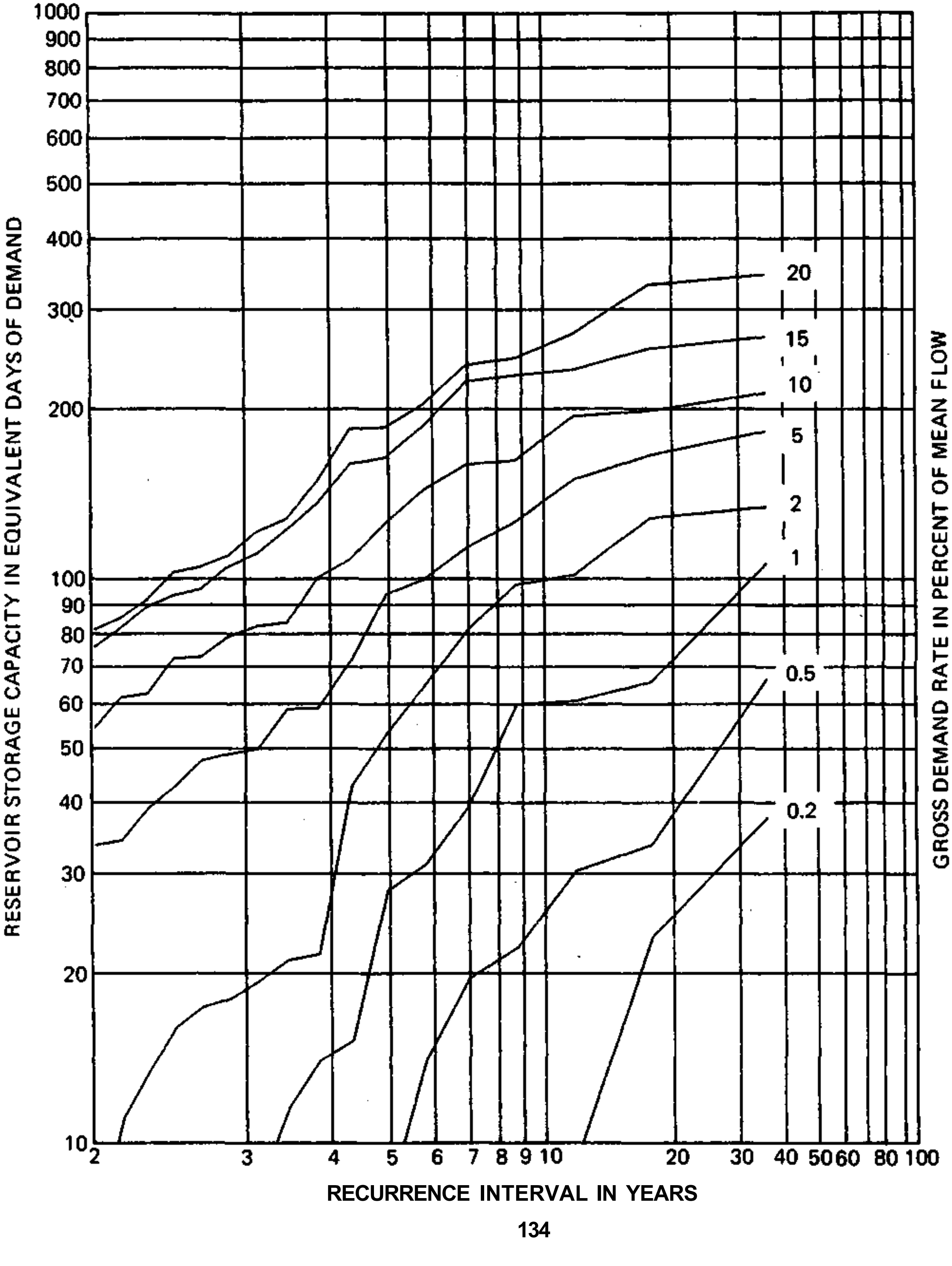
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05584500

LA MOINE RIVER AT COLMAR

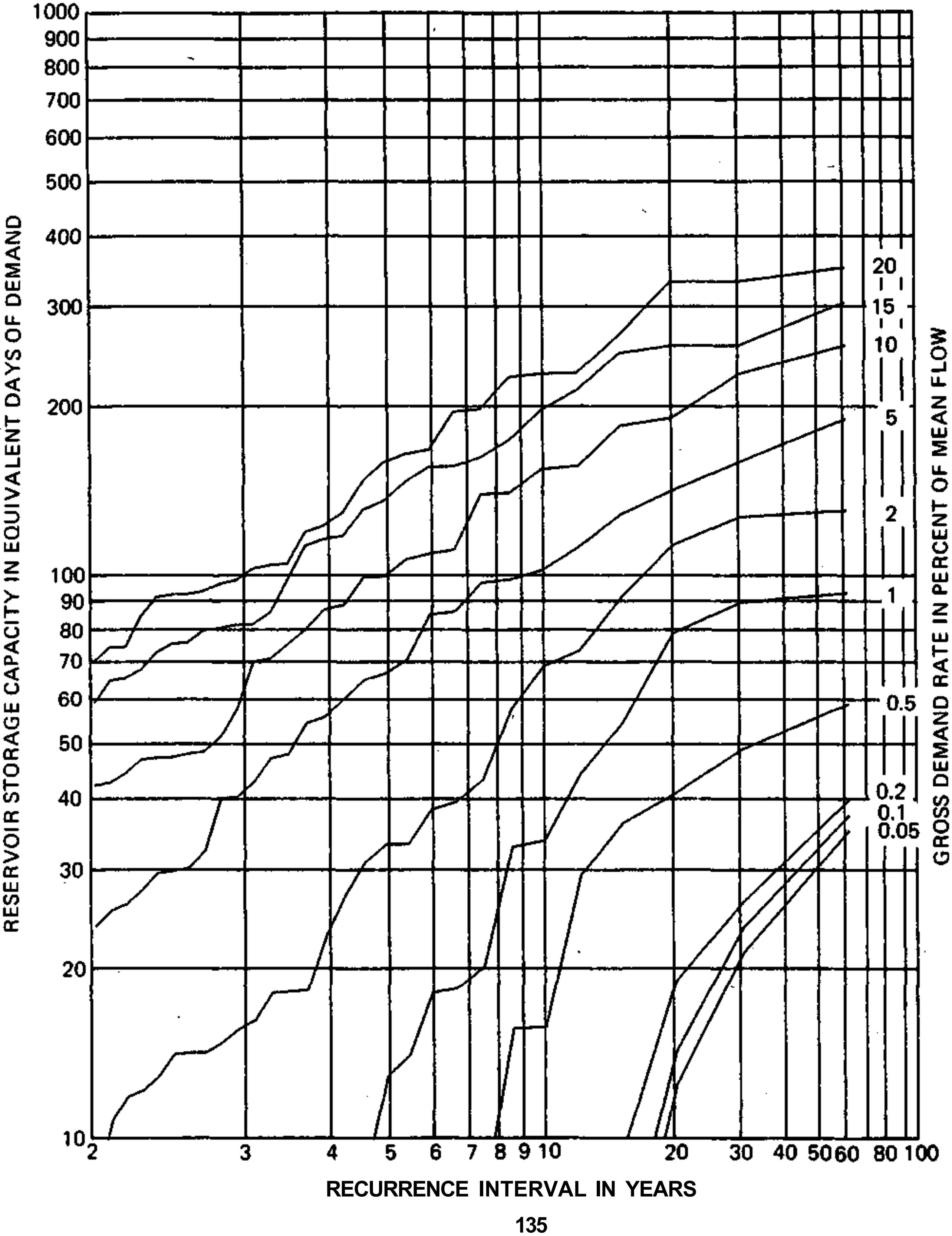
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP

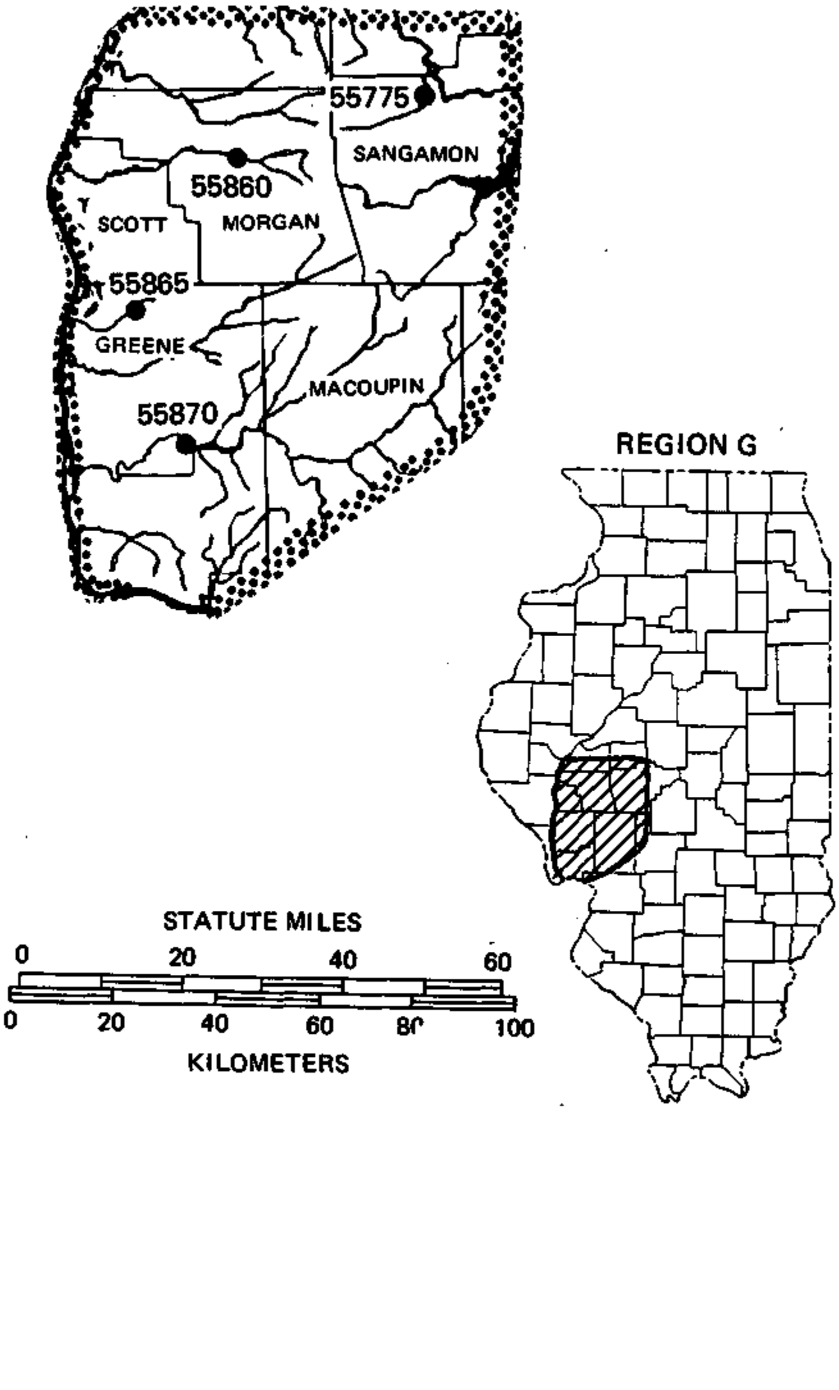


STATION 05585000

LA MOINE RIVER AT RIPLEY

DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP




55775
SANGAMON
55860
SCOTT
MORGAN
55865
GREENE
MACOUPIN
55870
REGION G
STATUTE MILES
0
20
40
60
0
20
40
60
80
100
KILOMETERS

REGION G

USGS Gage No.	Name of Station	Period of Record	Number of Years
55775	Spring Creek near Springfield	1949-1978	29
55860	North Fk. Mauvaise Terre Creek, near Jacksonville	1950-1975	25
55865	Hurricane Creek near Roodhouse	1951-1975	24
55870	Macoupin Creek near Kane	1941-1978	37

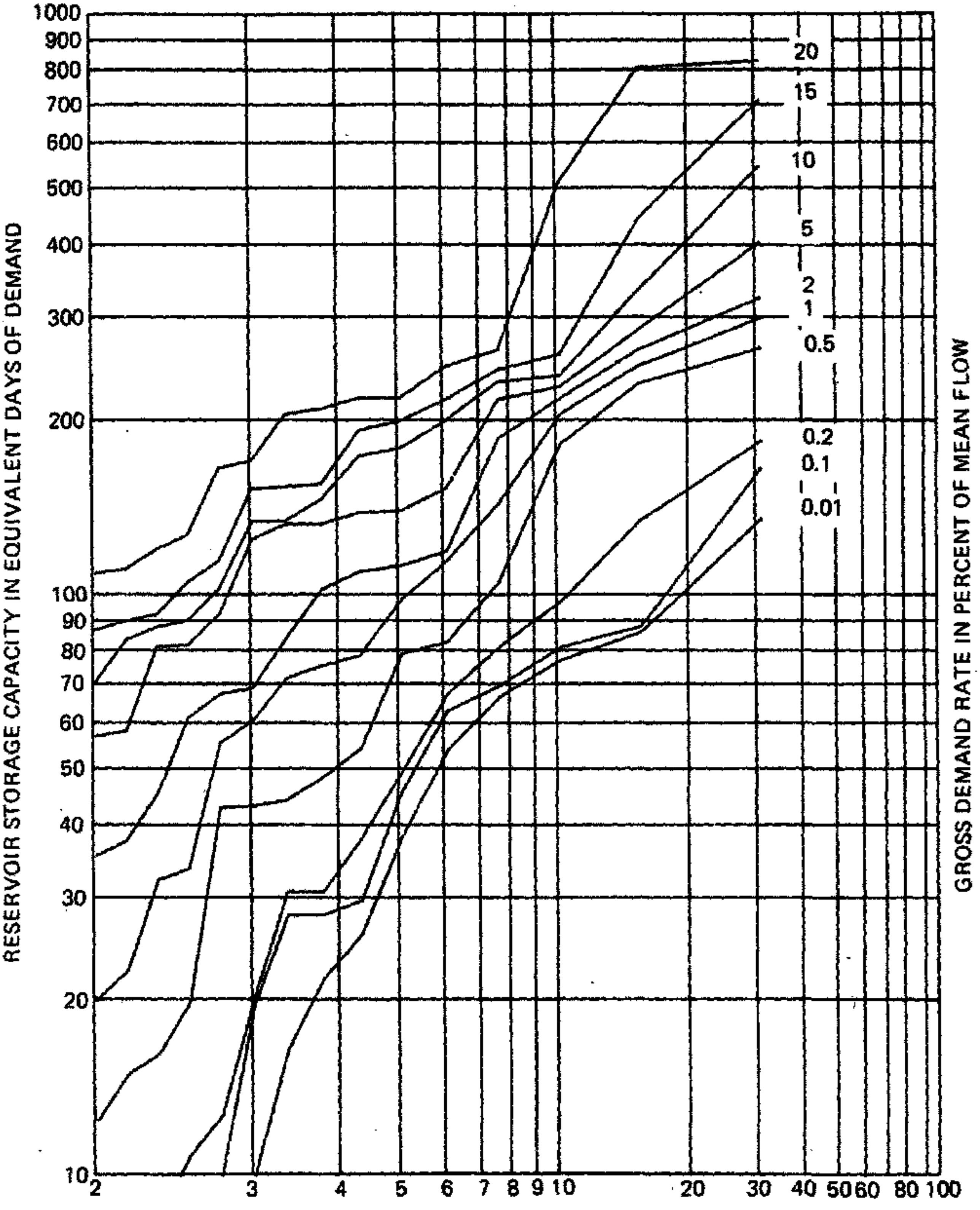
Drainage Area and Streamflow Characteristics

Gage No.	Drainage Area (mi^2)	Mean Flow (cfs)	Mean Flow (in./year)	$Q_{7,10}$ (cfs)	Q90 (cfs)	Q75 (cfs)	Q60 (cfs)
55755	107.	64.1	8.14	0.0	0.0	2.0	9.0
55860	29.1	20.2	9.43	0.0	0.0	0.6	3.5
55865	2.3	1.5	8.80	0.0	0.0	0.0	0.1
55870	868.	531.0	8.31	2.0	7.7	24.0	56.0

STATION 05577500

SPRING CREEK AT SPRINGFIELD

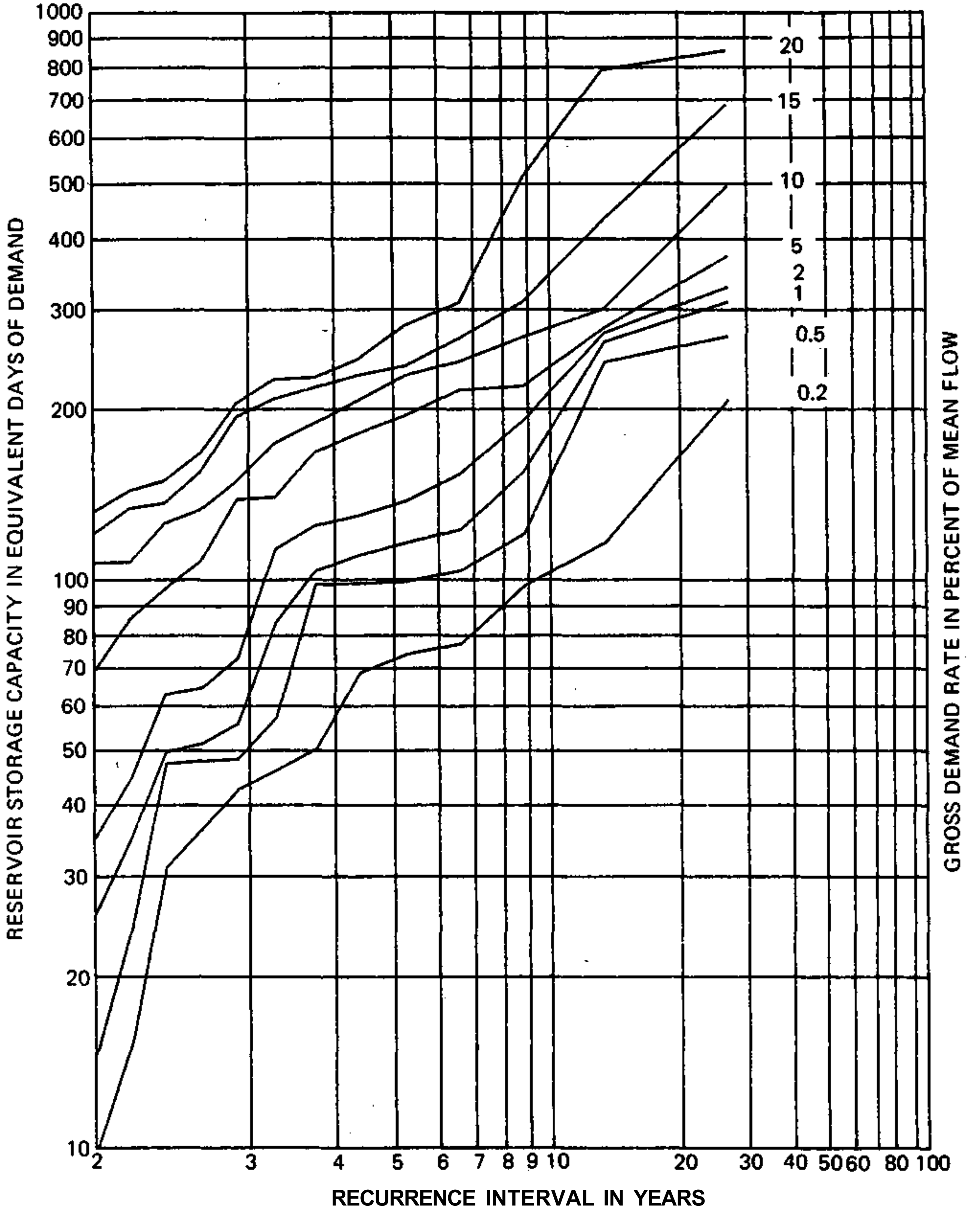
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05586000

NORTH FORK MAUVAISE TERRE CREEK NEAR JACKSONVILLE

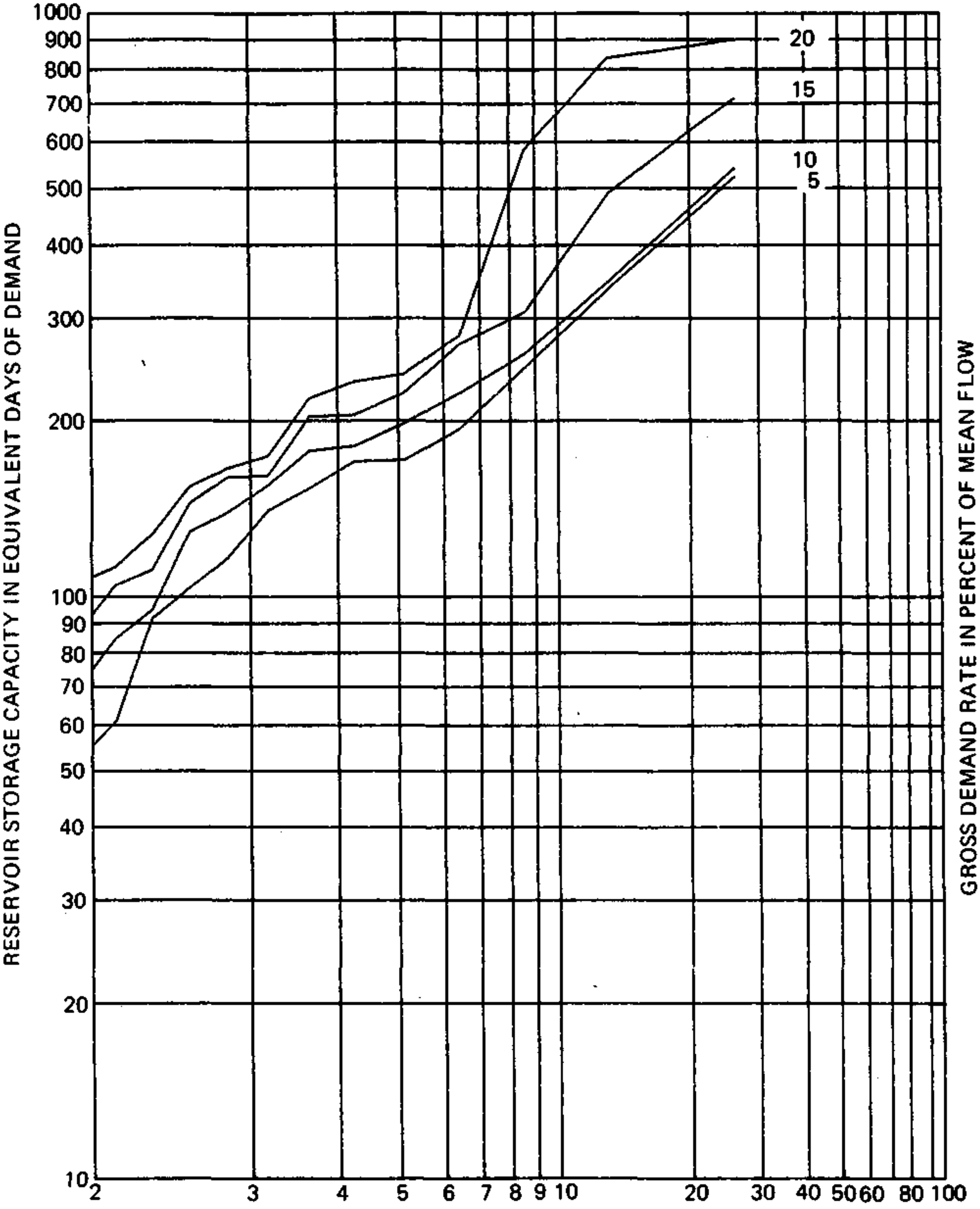
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05586500

HURRICANE CREEK NEAR ROODHOUSE

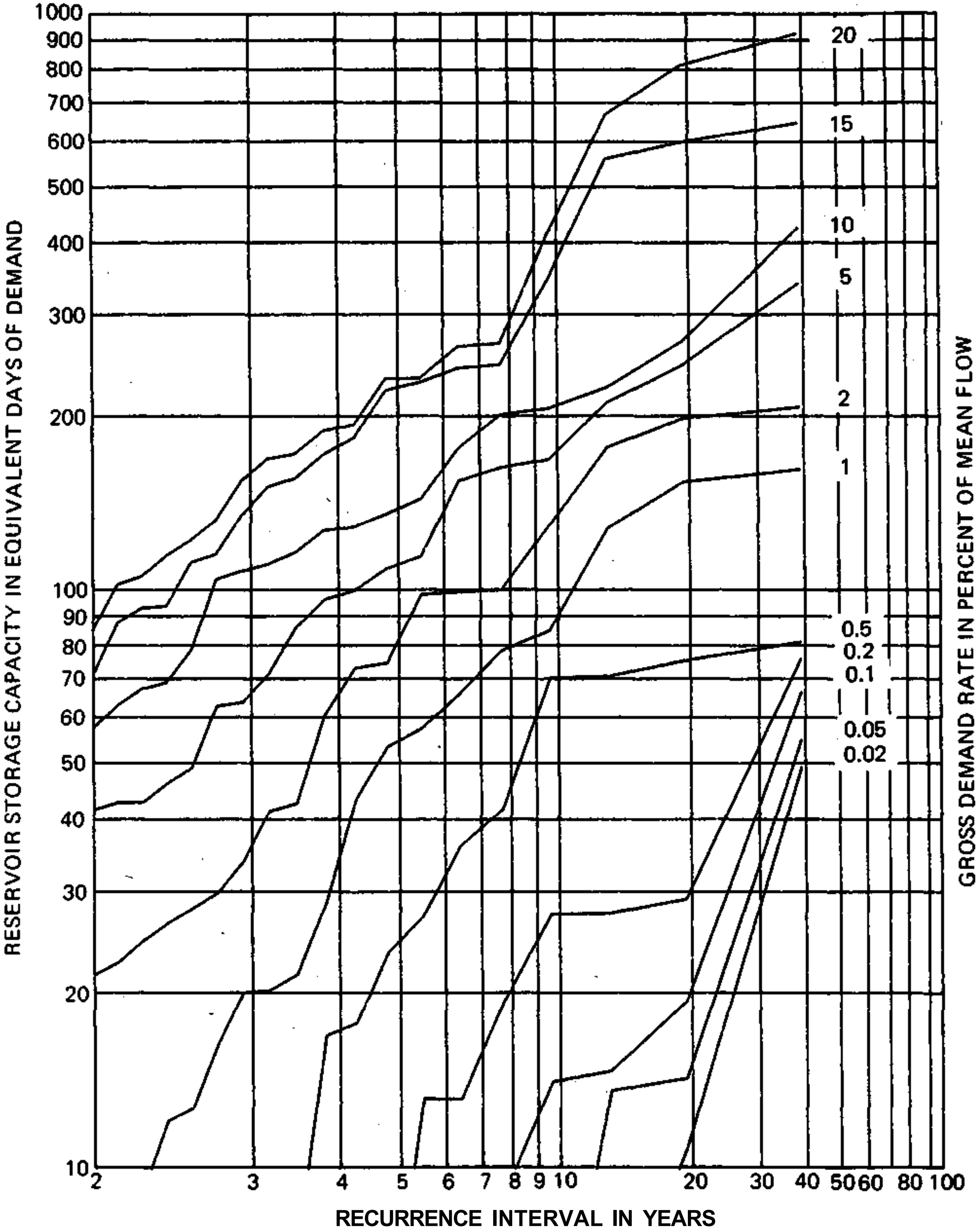
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP

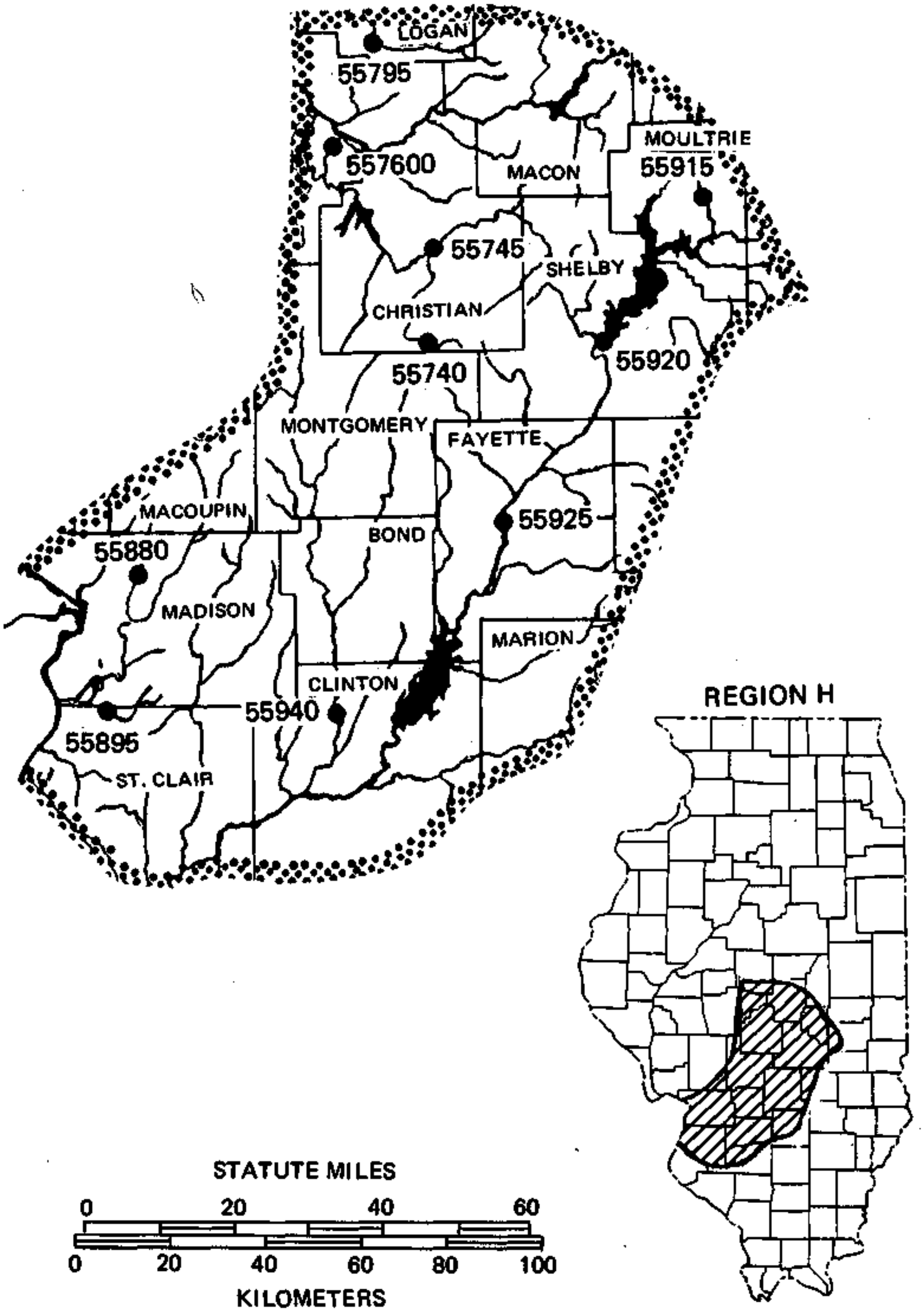


STATION 05587000

MACOUPIN CREEK NEAR KANE

DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP




LOGAN
55795
557600
MACON
MOULTRIE
55915
55745
SHELBY
CHRISTIAN
55740
55920
MONTGOMERY
FAYETTE
MACOUPIN
55925
55880
BOND
MADISON
MARION
CLINTON
55940
55895
ST. CLAIR
REGION H
STATUTE MILES
0
20
40
60
0
20
40
60
80
100
KILOMETERS

REGION H

USGS Gage No.	Name of Station	Period of Record	Number of Years
55740	South Fk. Sangamon River near Nokomis	1951-1975	24
55745	Flat Branch near Taylorville	1950-1978	28
55760	South Fk. Sangamon River near Rochester	1950-1978	28
55795	Lake Fork near Cornland	1948-1978	30
55880	Indian Creek near Wanda	1940-1978	38
55895	Canteen Creek at Caseyville	1939-1978	39
55915	Asa Creek at Sullivan	1951-1978	27
55920	Kaskaskia River at Shelbyville	1941-1969	28
55925	Kaskaskia River at Vandalia	1915-1969	54
55940	Shoal Creek near Breese	1946-1978	32

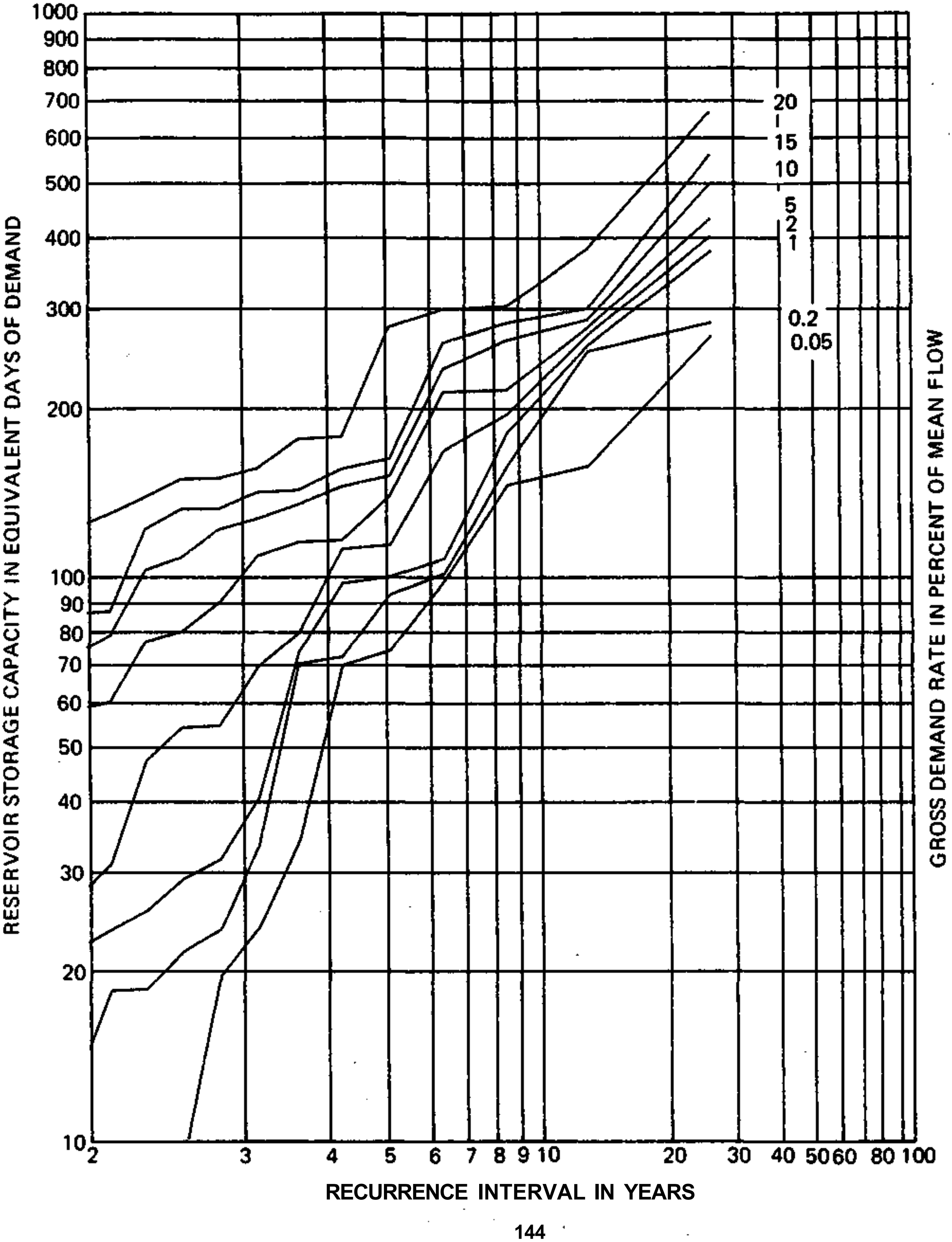
Drainage Area and Streamflow Characteristics

Gage No.	Drainage Area (mi^2)	Mean Flow (cfs)	Mean Flow (in./year)	$Q_{7,10}$ (cfs)	Q90 (cfs)	Q75 (cfs)	Q60 (cfs)
55740	11.0	7.3	8.95	0.0	0.0	0.0	0.3
55745	276.	198.0	9.74	0.0	2.1	11.0	31.0
55760	867.	565.0	8.85	0.9	9.4	37.0	100.0
55795	214.	143.0	9.07	2.0	6.7	14.0	31.0
55880	36.7	25.0	9.25	0.0	0.0	0.3	1.4
55895	22.6	16.9	10.16	0.0	0.4	1.1	2.7
55915	8.05	5.9	9.95	0.0	0.0	0.1	0.6
55920	1030.	788.0	10.39	0.4	9.1	35.0	155.0
55925	1980.	1412.0	9.68	16.0	45.0	120.0	305.0
55940	735.	511.0	9.44	0.2	13.0	31.0	64.0

STATION 05574000

SOUTH FORK SANGAMON RIVER NEAR NOKOMIS

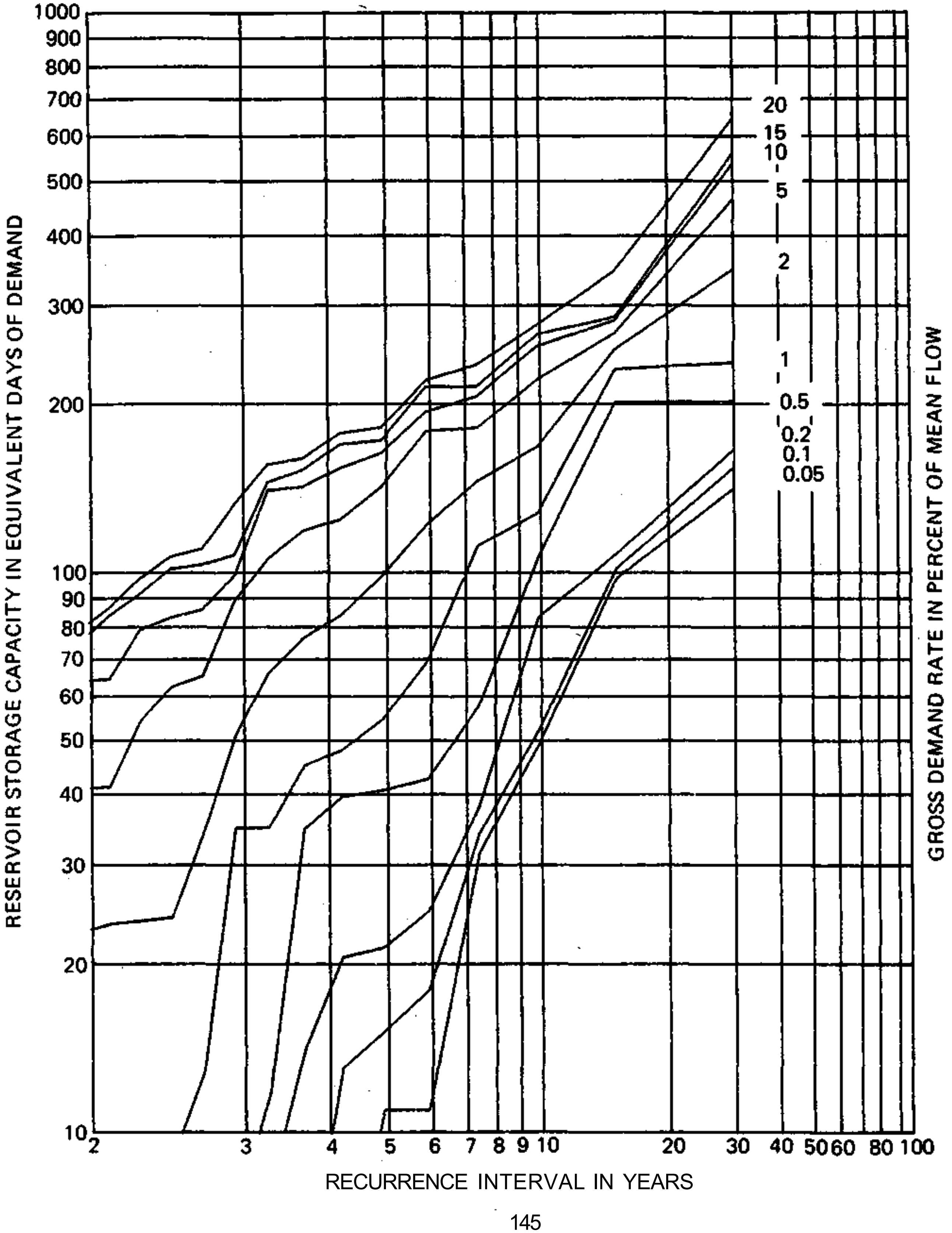
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05574500

FLAT BRANCH NEAR TAYLORVILLE

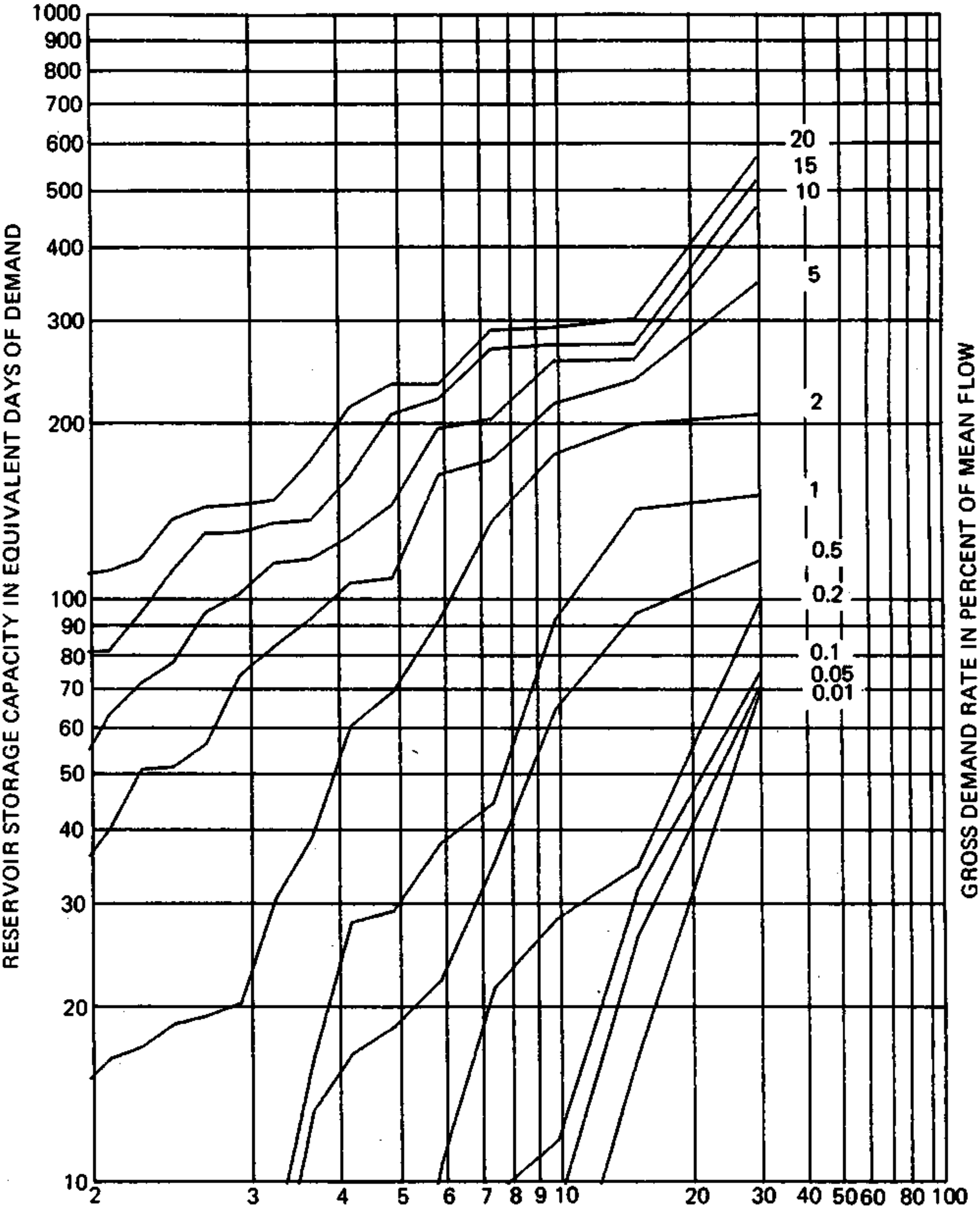
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05576000

SOUTH FORK SANGAMON RIVER NEAR ROCHESTER

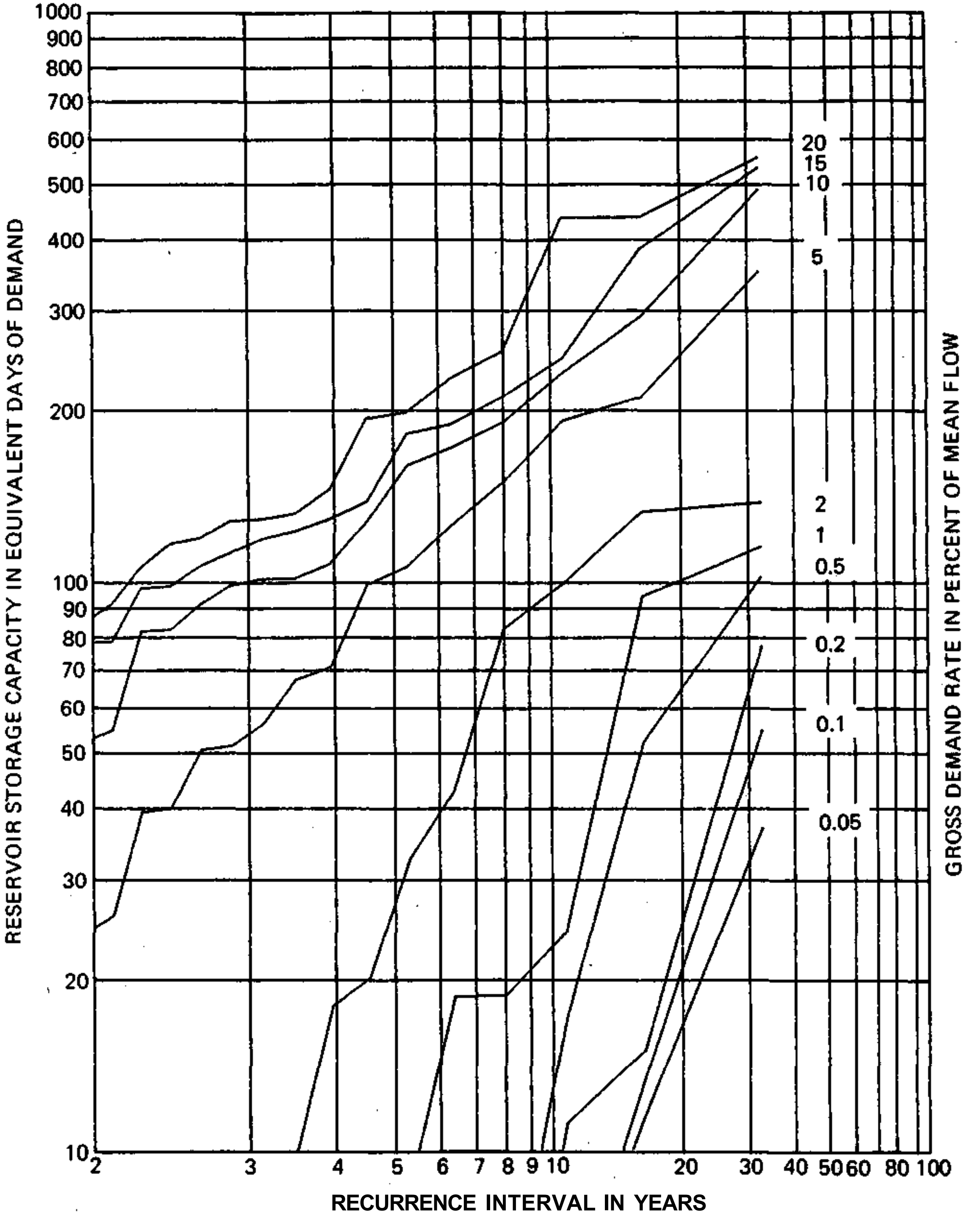
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05579500

LAKE FORK NEAR CORNLAND

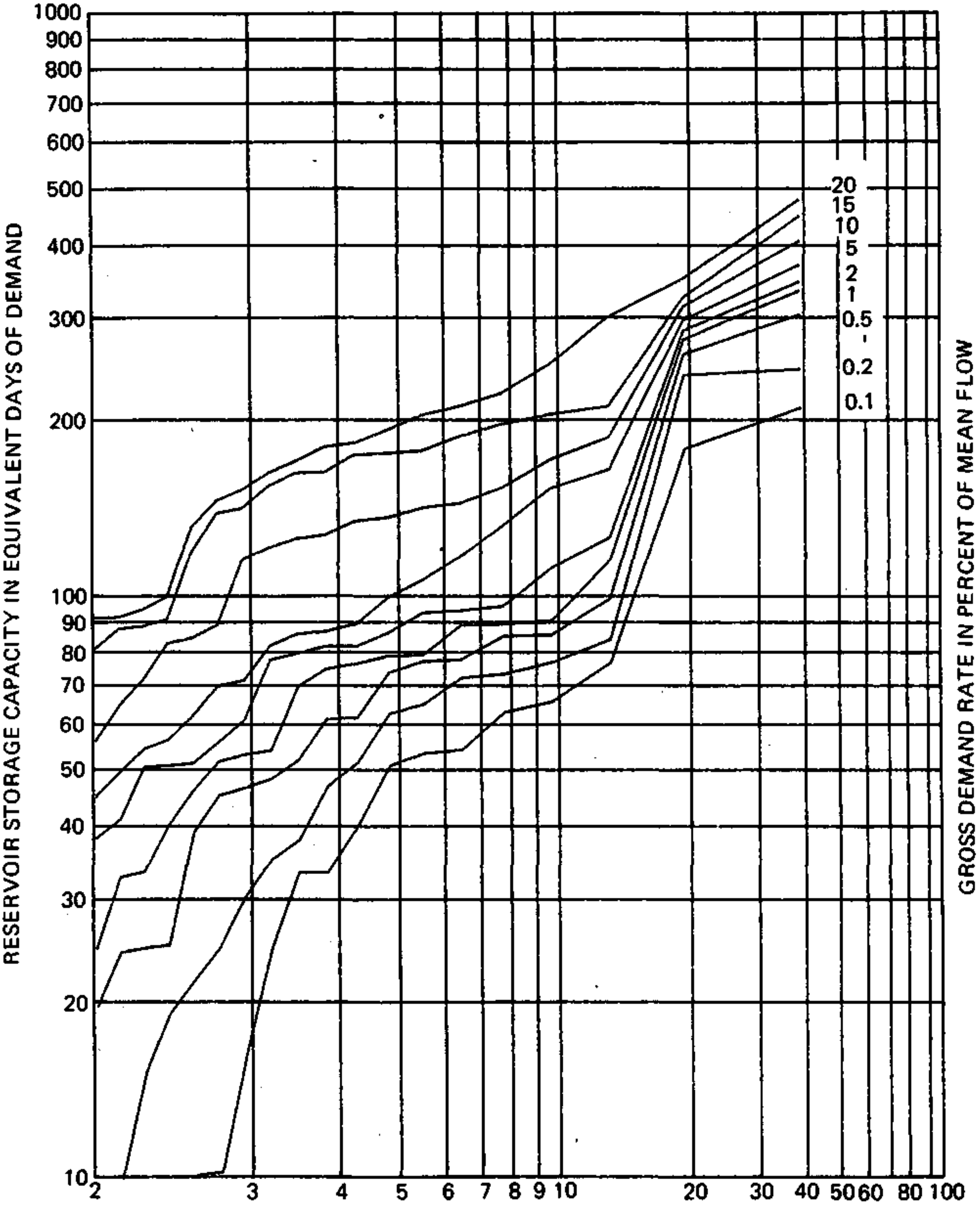
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05588000

INDIAN CREEK AT WANDA

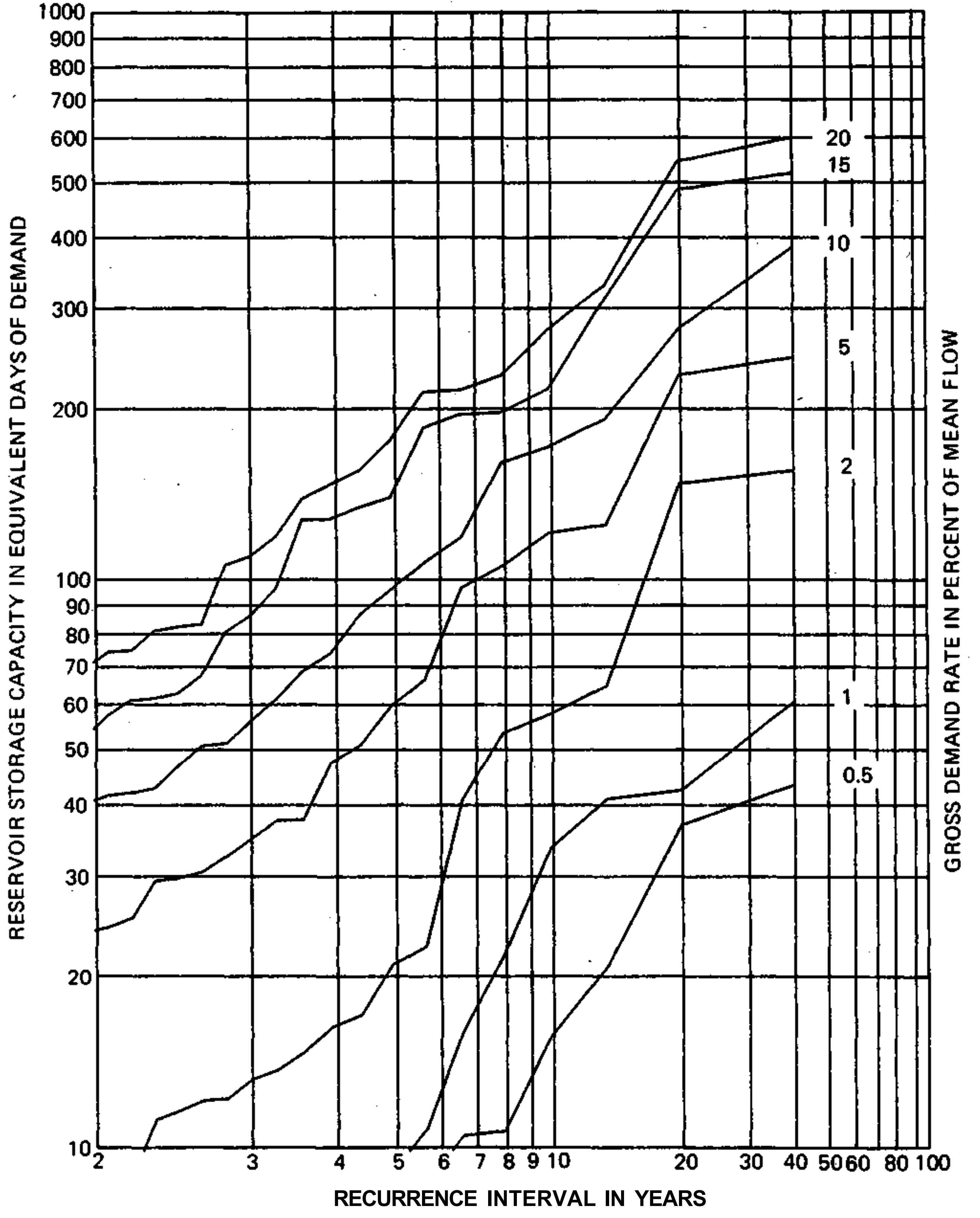
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05589500

CANTEEN CREEK AT CASEYVILLE

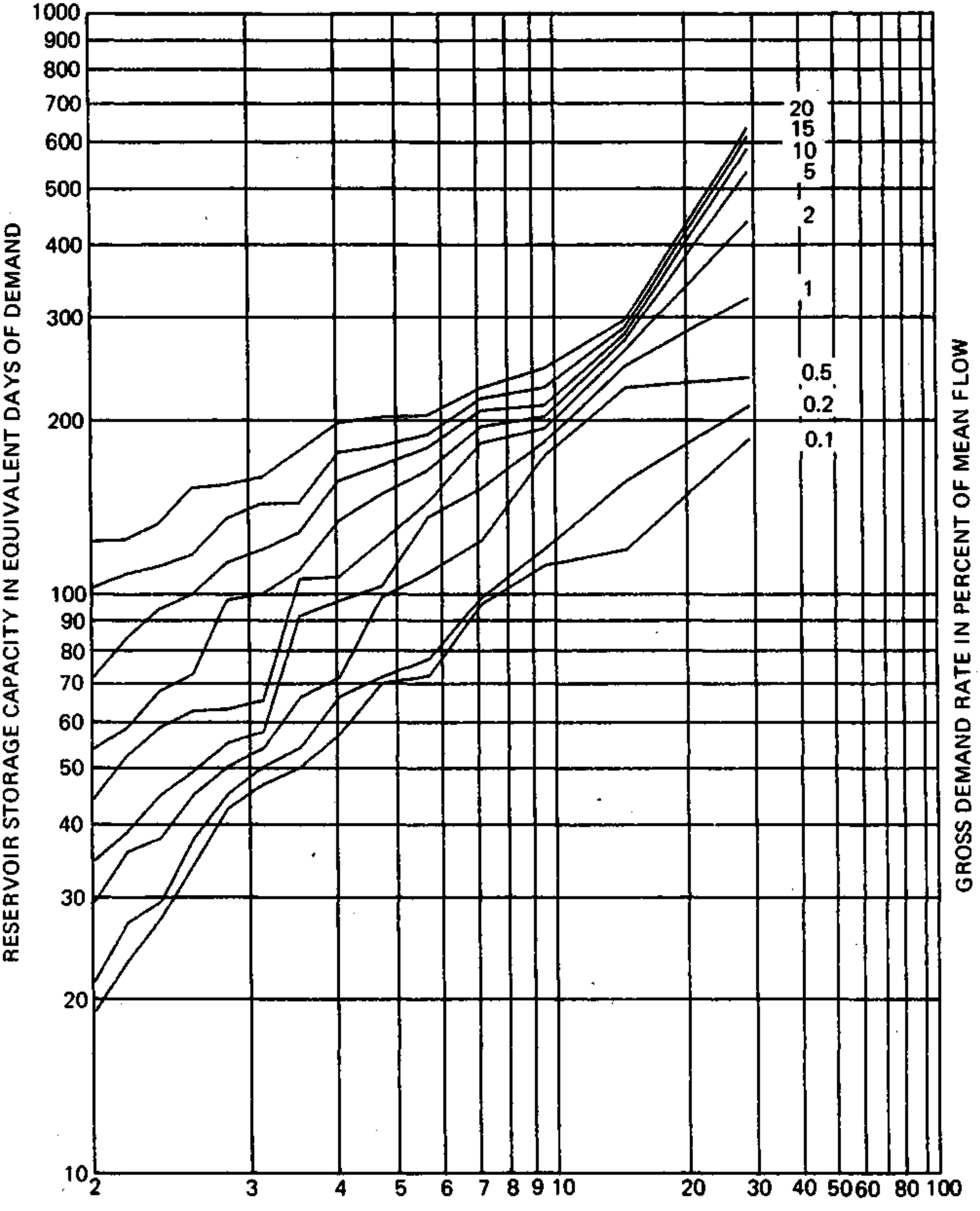
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05591500

ASA CREEK AT SULLIVAN

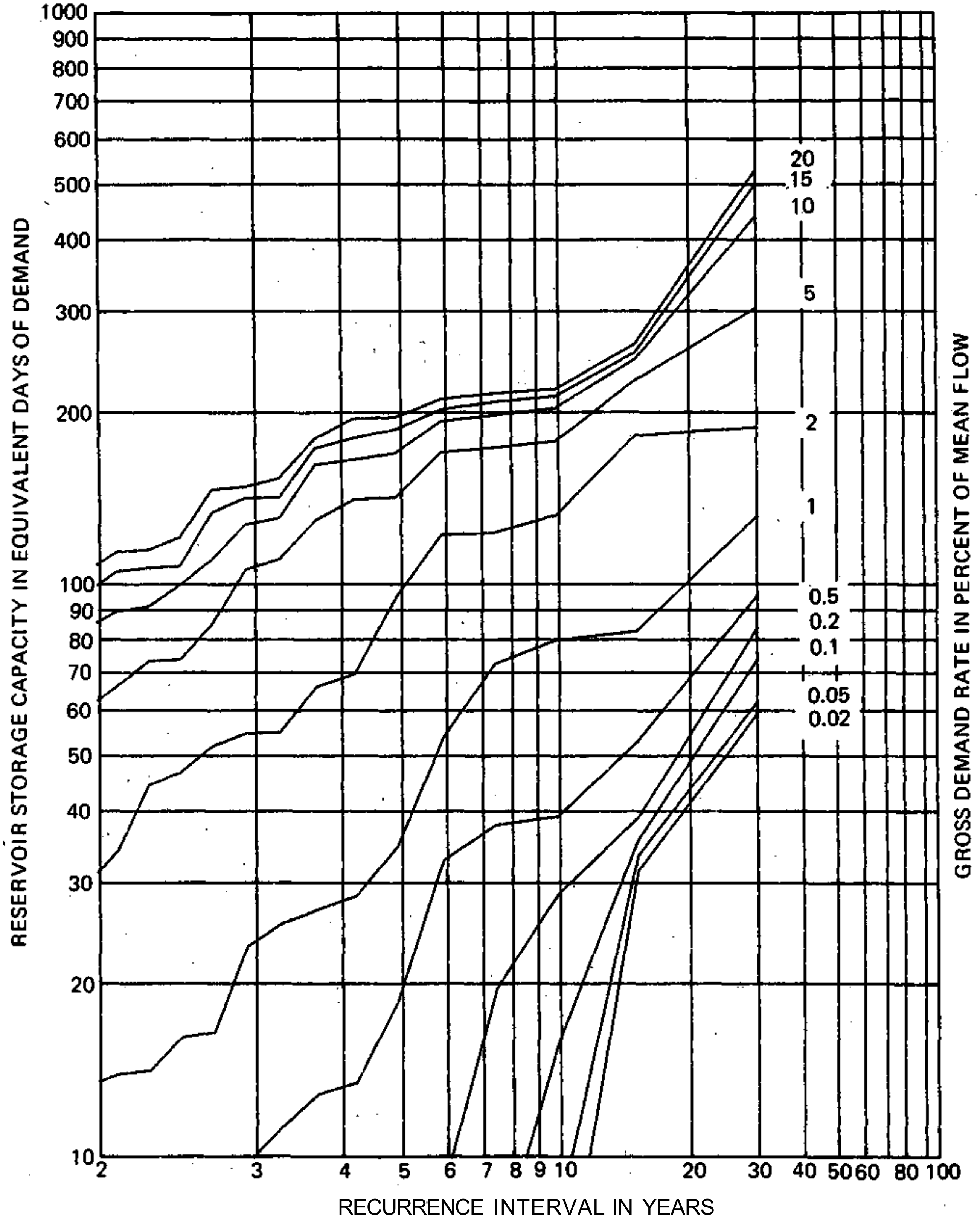
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05592000

KASKASKIA RIVER AT SHELBYVILLE

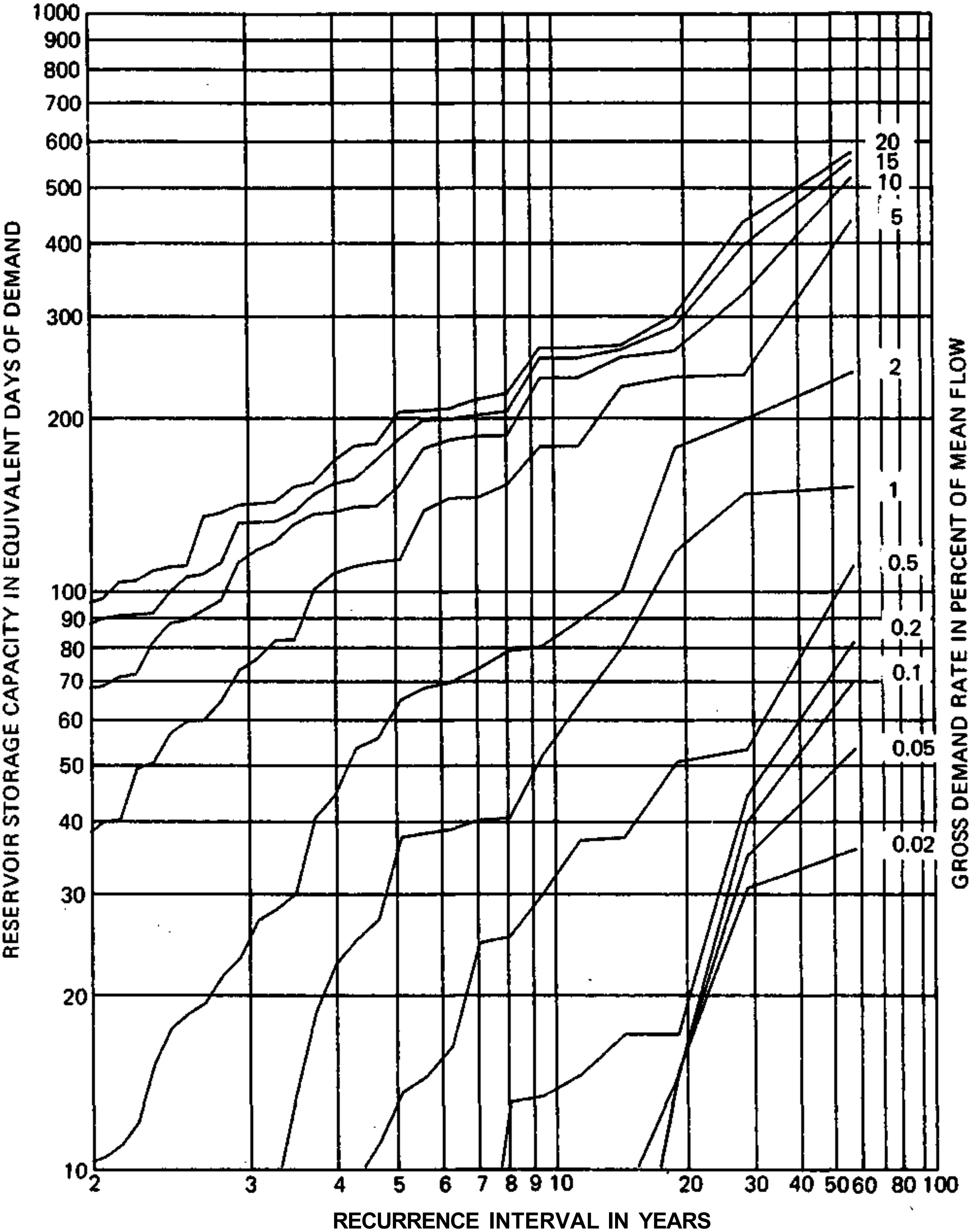
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05592500

KASKASKIA RIVER AT VANDALIA

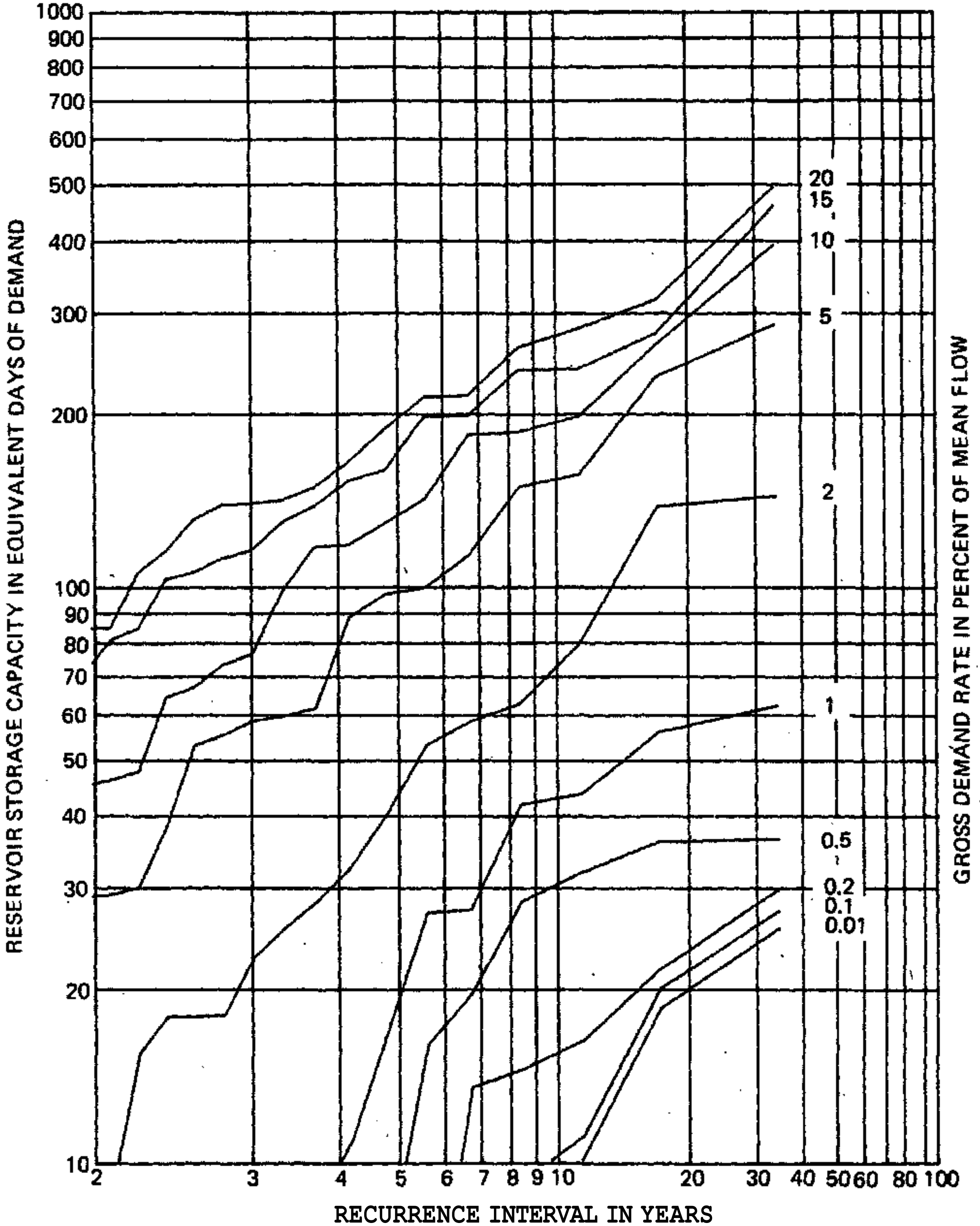
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP

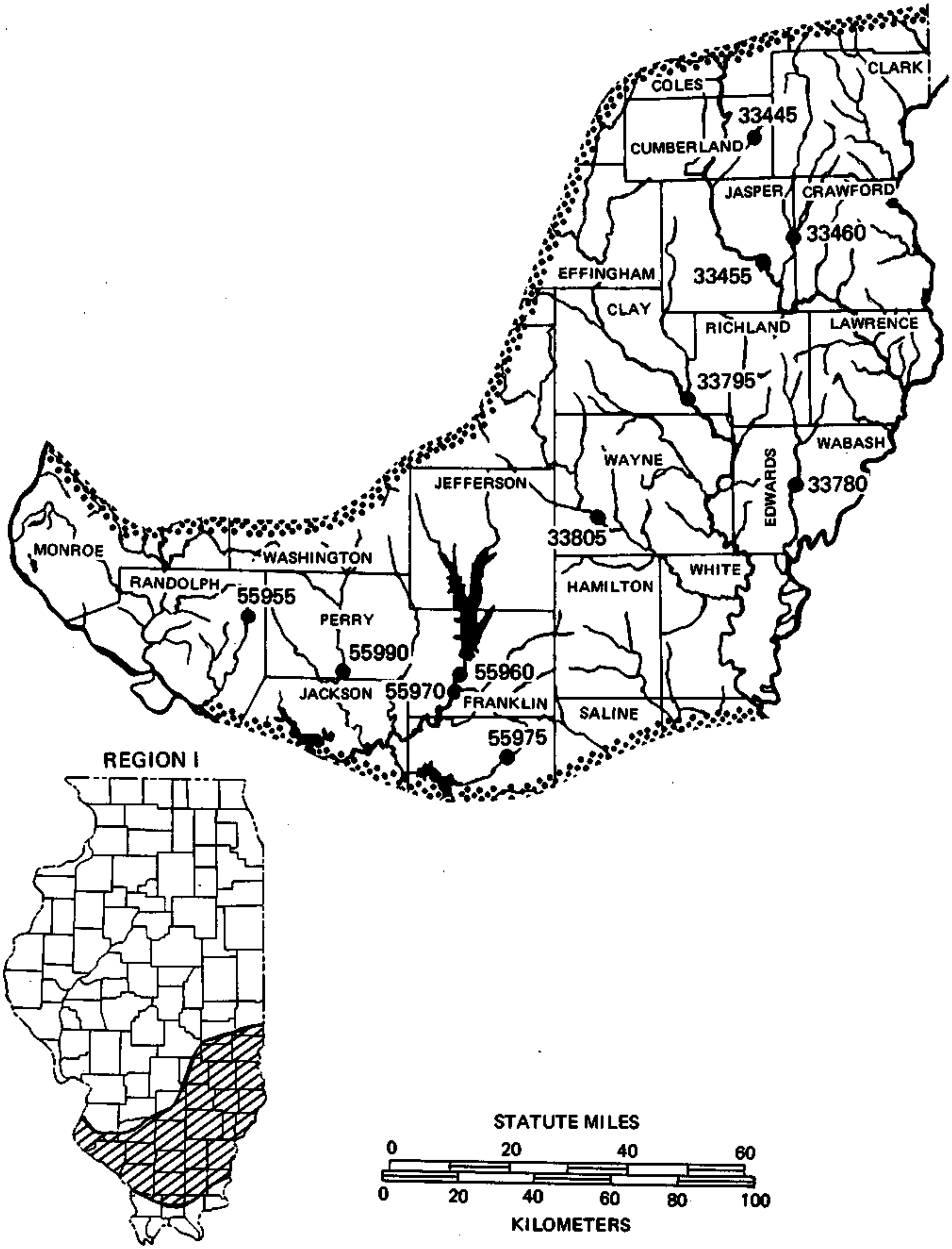


STATION 05594000

SHOAL CREEK NEAR BREESE

DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP




COLES
CLARK
CUMBERLAND
33445
JASPER
CRAWFORD
33460
EFFINGHAM
33455
CLAY
RICHLAND
LAWRENCE
33795
WABASH
WAYNE
JEFFERSON
EDWARDS
33780
33805
MONROE
WASHINGTON
WHITE
RANDOLPH
55955
HAMILTON
PERRY
55990
55960
JACKSON
55970
FRANKLIN
SALINE
55975
REGION I
STATUTE MILES
0
20
40
60
0
20
40
60
80
100
KILOMETERS

REGION I

USGS Gage No.	Name of Station	Period of Record	Number of Years
33445	Range Creek near Casey	1951-1978	28
33455	Embarrass River at Ste. Marie	1915-1978	63
33460	North Fk. Embarrass River near Oblong	1941-1978	37
33780	Bonpas Creek at Browns	1941-1978	37
33795	Little Wabash River below Clay City	1915-1978	63
33805	Skillet Fork at Wayne City	1929-1978	49
55955	Mary's Creek near Sparta	1949-1971	22
55960	Big Muddy River near Benton	1946-1970	24
55970	Big Muddy River near Plumfield	1915-1970	55
55975	Crab Orchard Creek near Marion	1952-1978	26
55990	Beaucoup Creek near Matthews	1946-1978	32

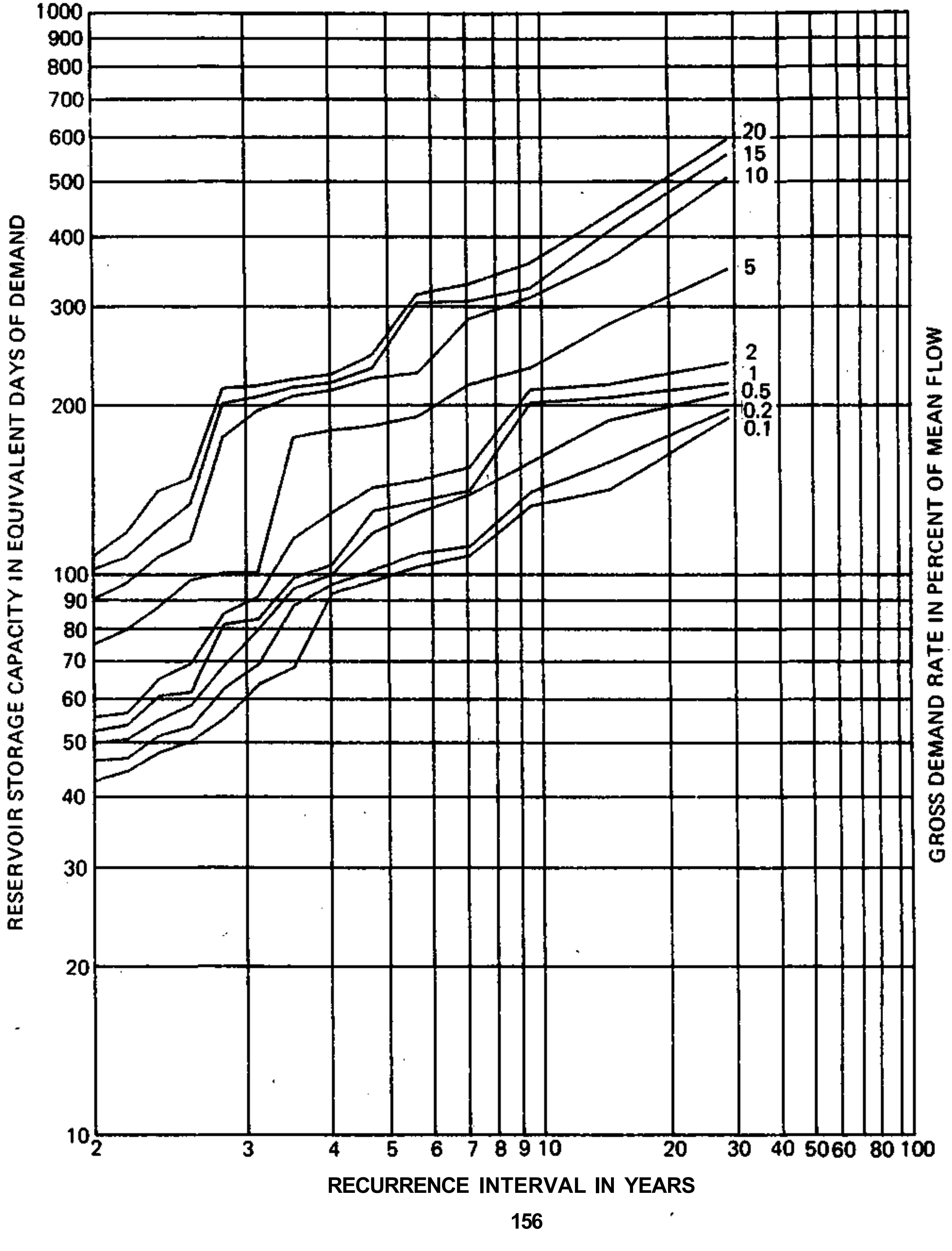
Drainage Area and Streamflow Characteristics

Gage No.	Drainage Area (mi^2)	Mean Flow (cfs)	Mean Flow (in./year)	$Q_{7,10}$ (cfs)	Q90 (cfs)	Q75 (cfs)	Q60 (cfs)
33445	7.61	5.4	9.71	0.0	0.0	0.0	0.1
33455	1516.	1204.0	10.79	16.6	41.0	120.0	270.0
33460	319.	250.0	10.64	0.0	2.4	9.6	25.0
33780	228.	222.0	12.92	0.0	0.0	1.5	7.0
33795	1131.	871.0	10.46	0.5	9.8	33.0	80.0
33805	464.	388.0	11.36	0.0	1.5	5.9	18.0
55955	17.8	12.6	9.61	0.0	0.0	0.0	0.1
55960	498.	452.0	12.32	0.2	2.5	9.0	24.5
55970	785.	699.0	12.09	0.2	3.8	13.0	36.0
55975	31.7	22.6	9.68	0.0	0.0	0.2	0.7
55990	292.	218.0	10.14	0.0	1.4	6.6	16.0

STATION 03344500

RANGE CREEK NEAR CASEY

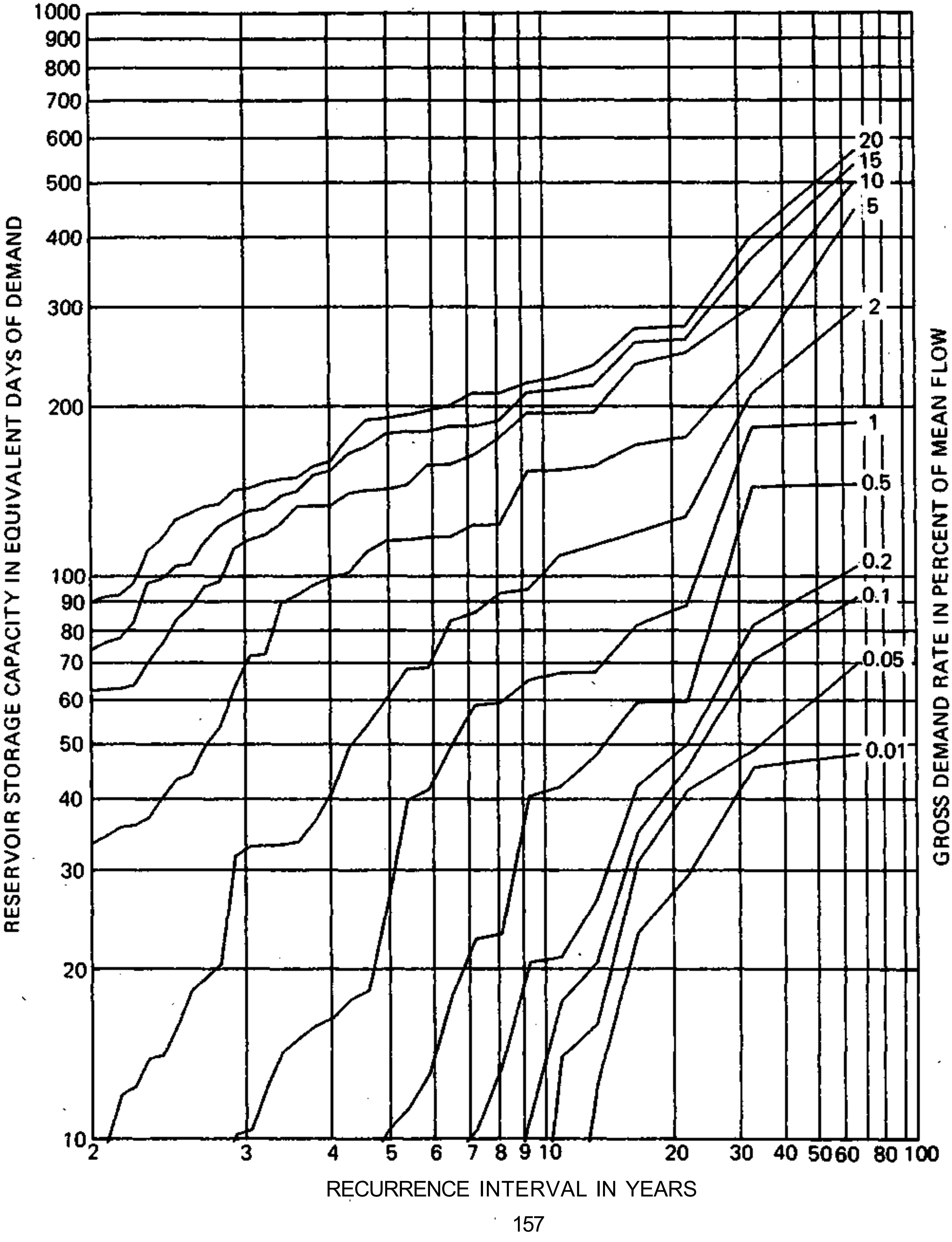
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 03345500

EMBARRAS RIVER AT STE. MARIE

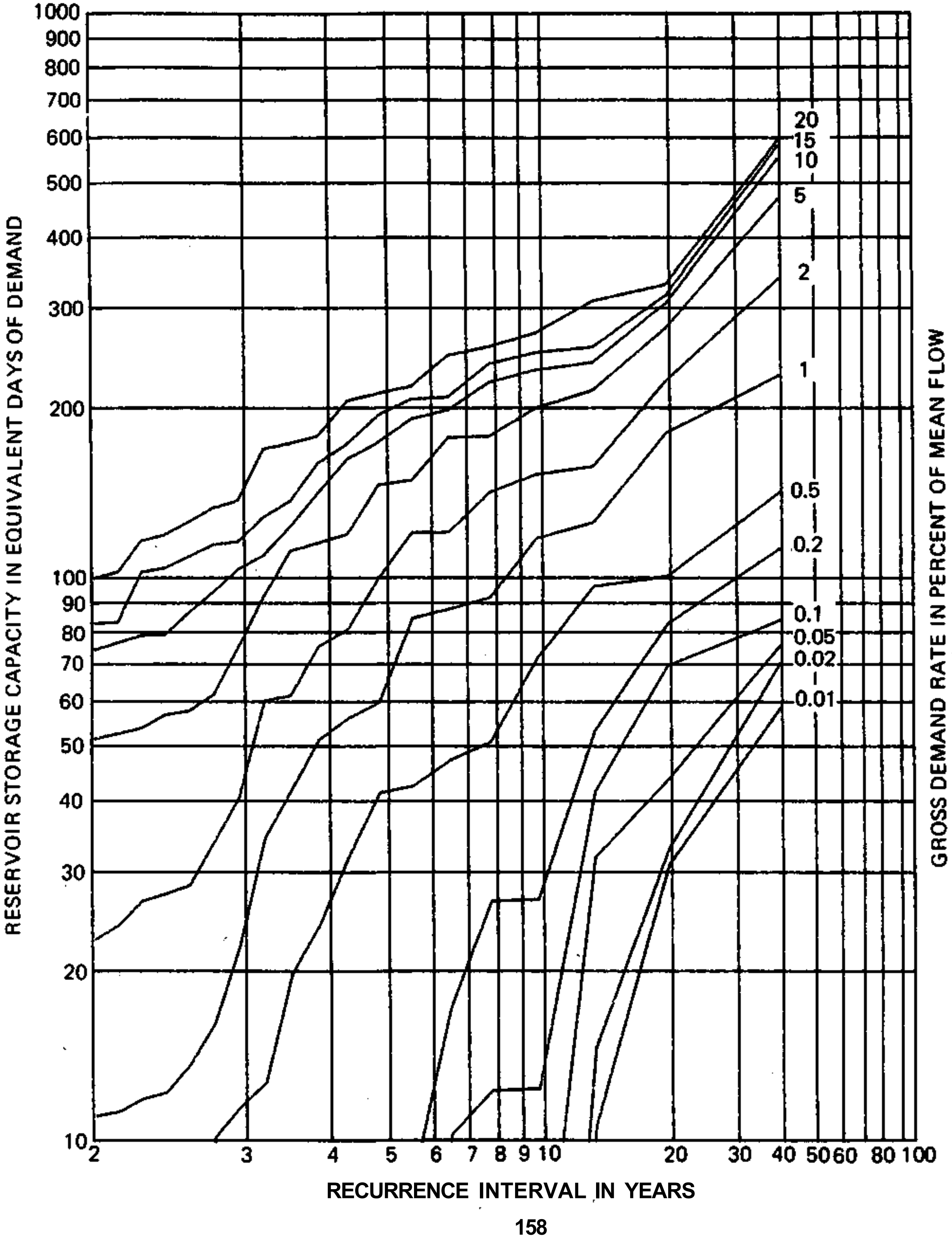
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 03346000

NORTH FORK EMBARRAS RIVER NEAR OBLONG

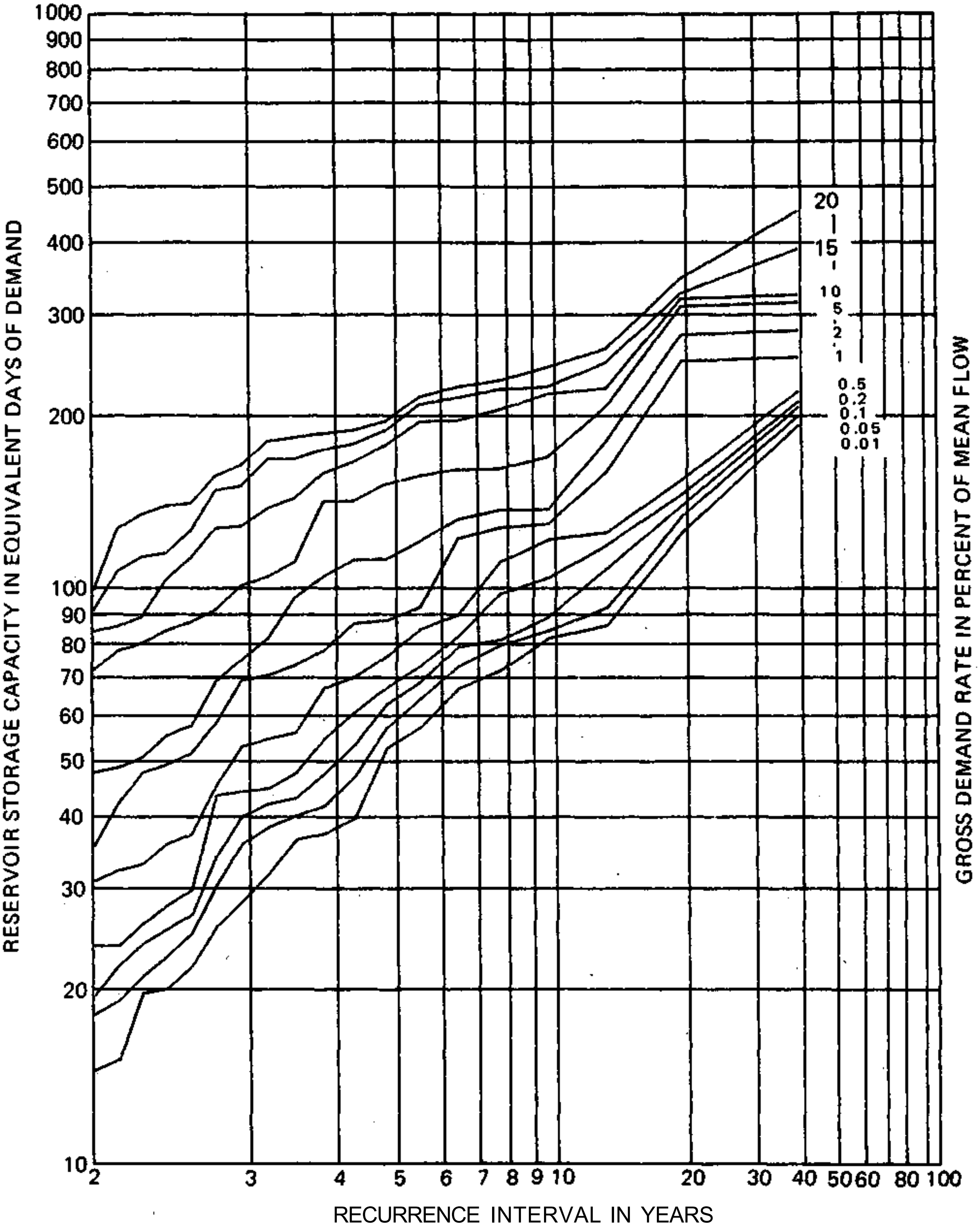
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 03378000

BONPAS CREEK AT BROWNS

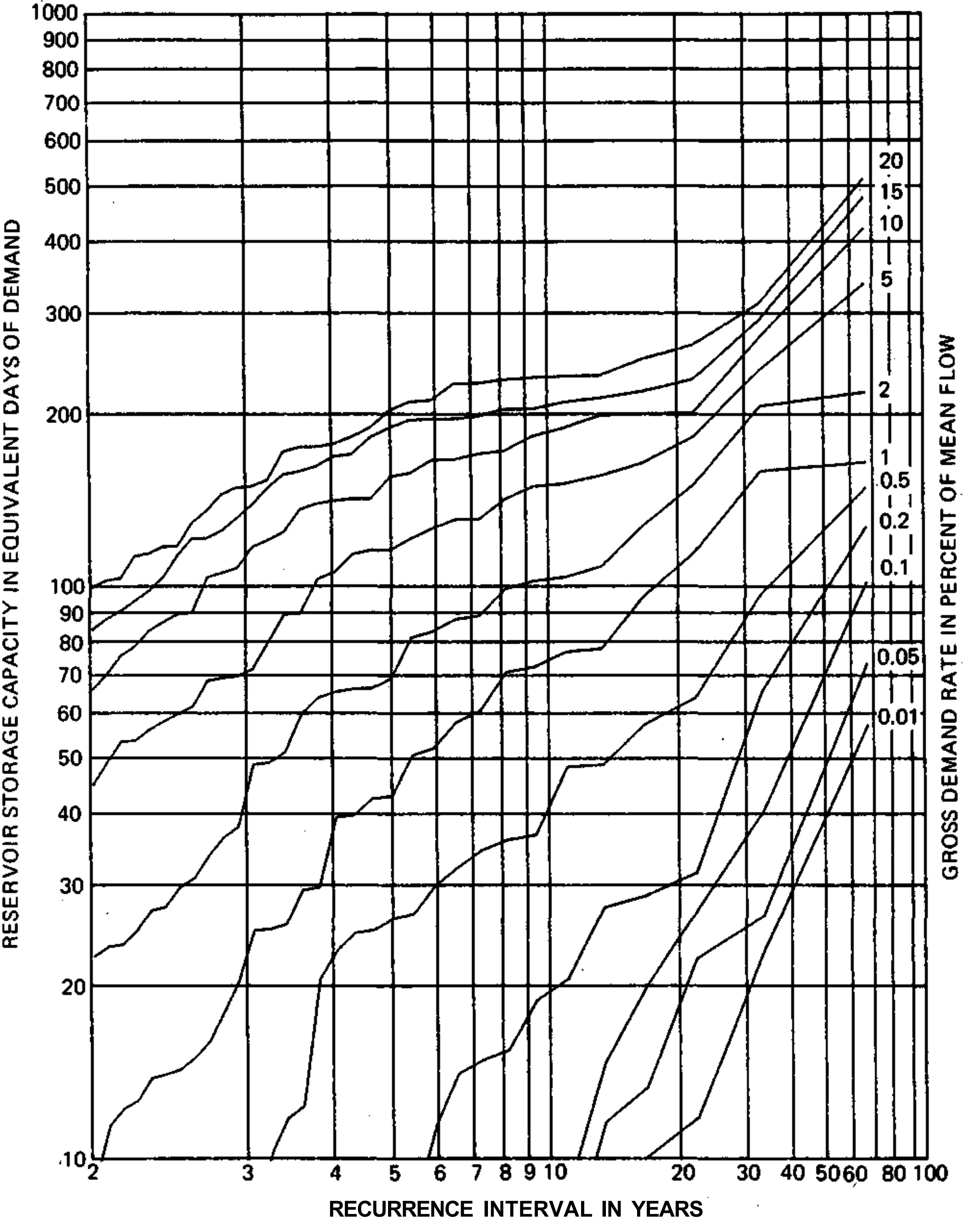
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 03379500

LITTLE WABASH RIVER BELOW CLAY CITY

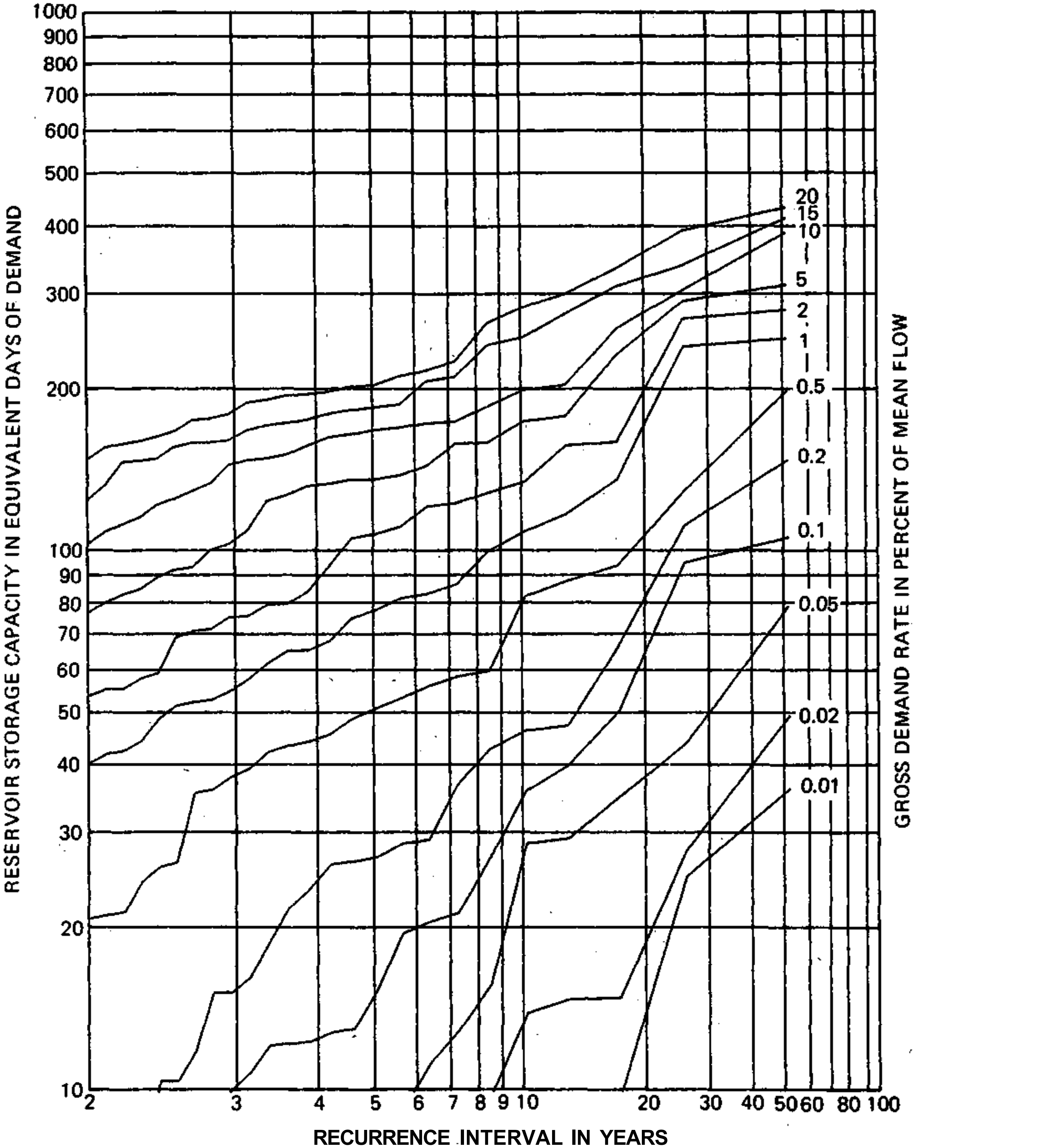
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 03380500

SKILLET FORK AT WAYNE CITY

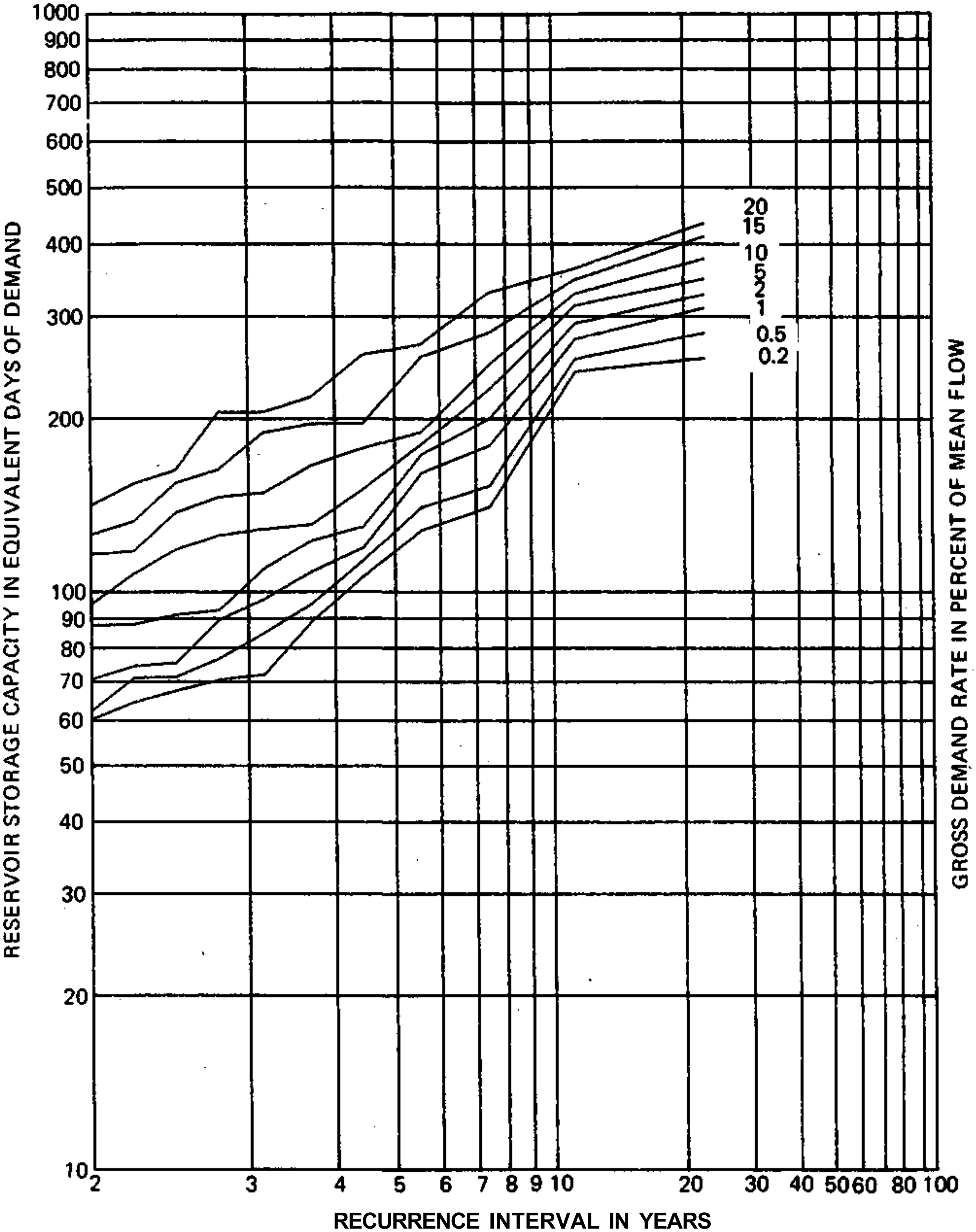
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05595500

MARYS RIVER NEAR SPARTA

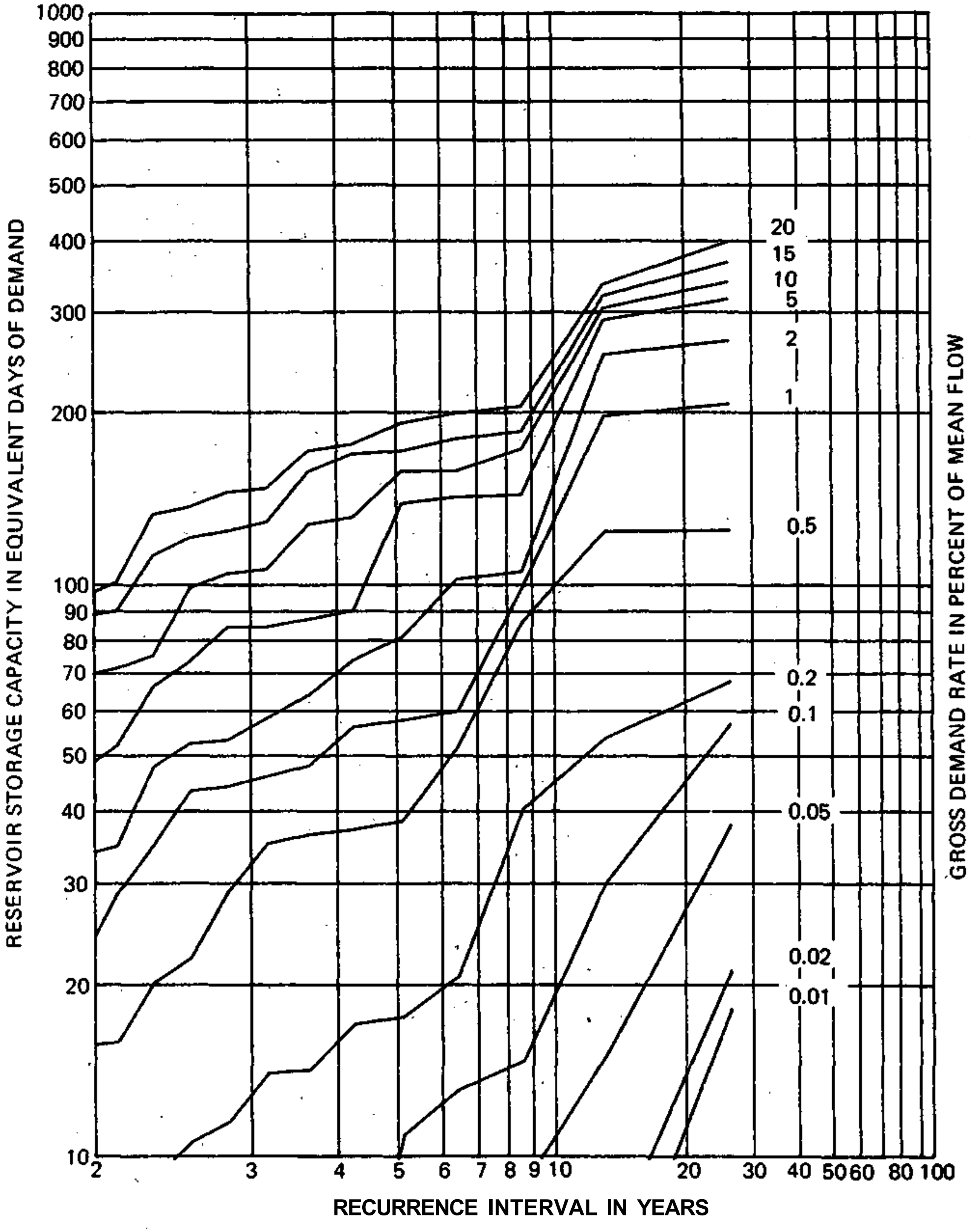
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05596000

BIG MUDDY RIVER NEAR BENTON

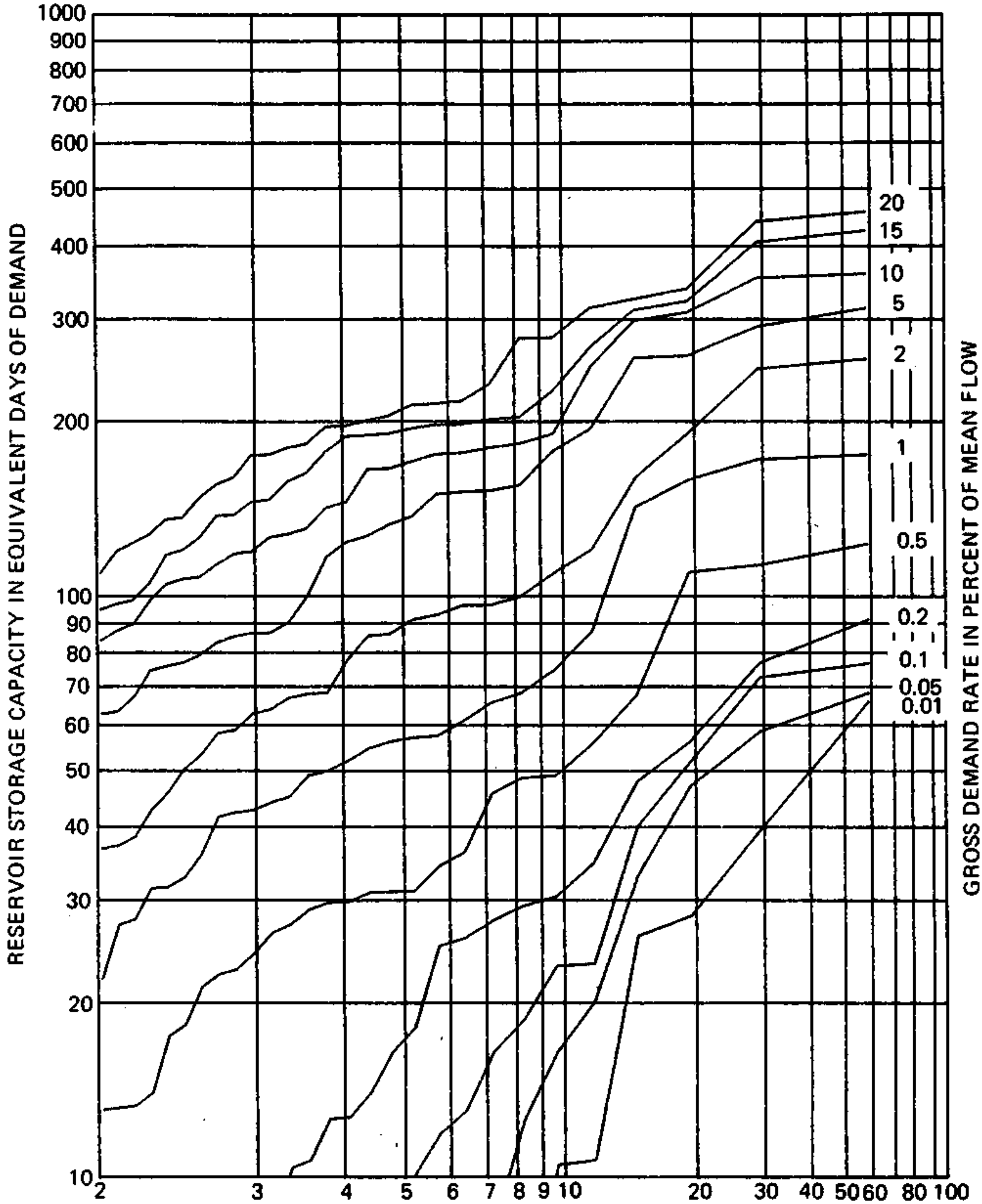
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05597000

BIG MUDDY RIVER AT PLUMFIELD

DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP

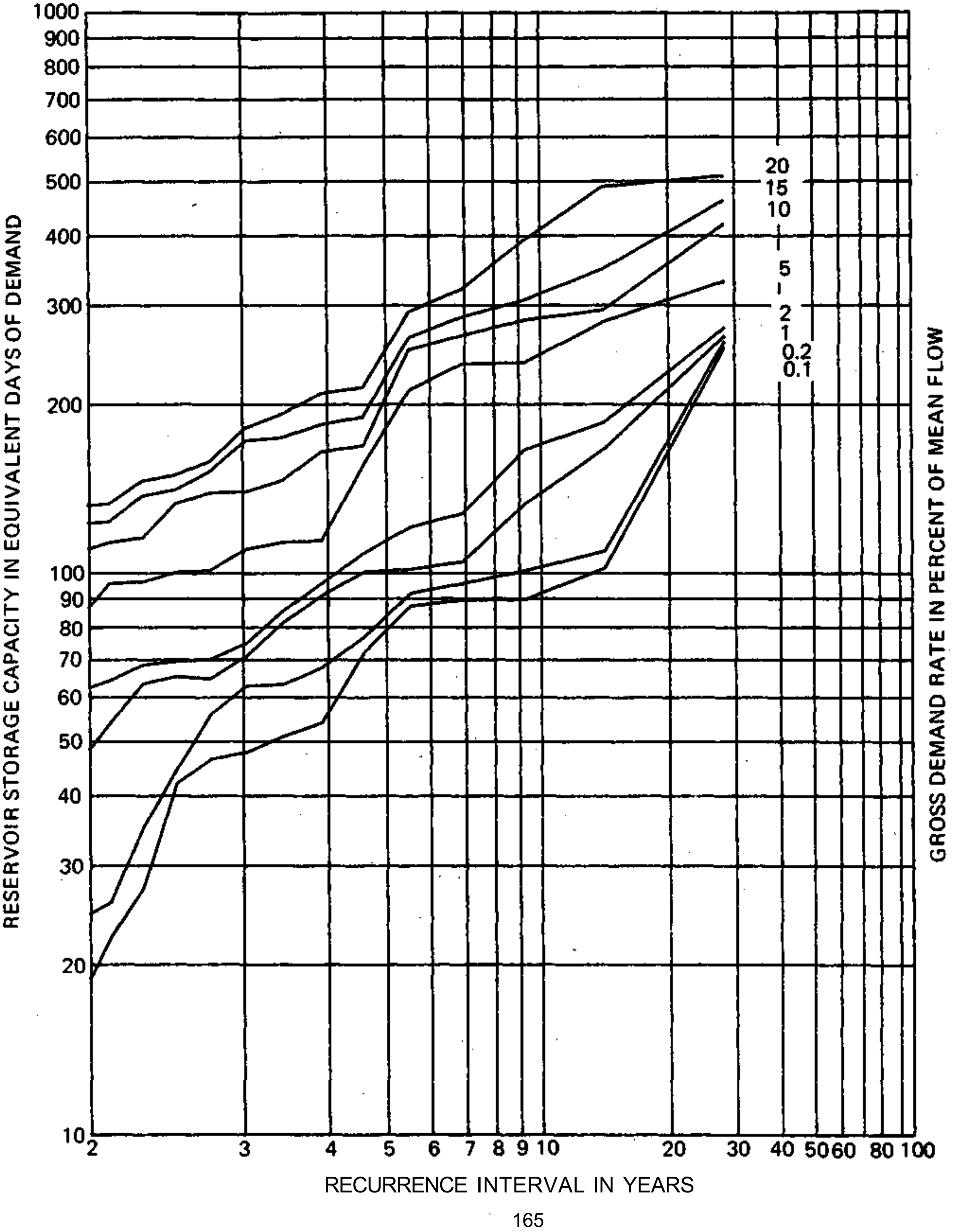


RECURRENCE INTERVAL IN YEARS

STATION 05597500

CRAB ORCHARD CREEK NEAR MARION

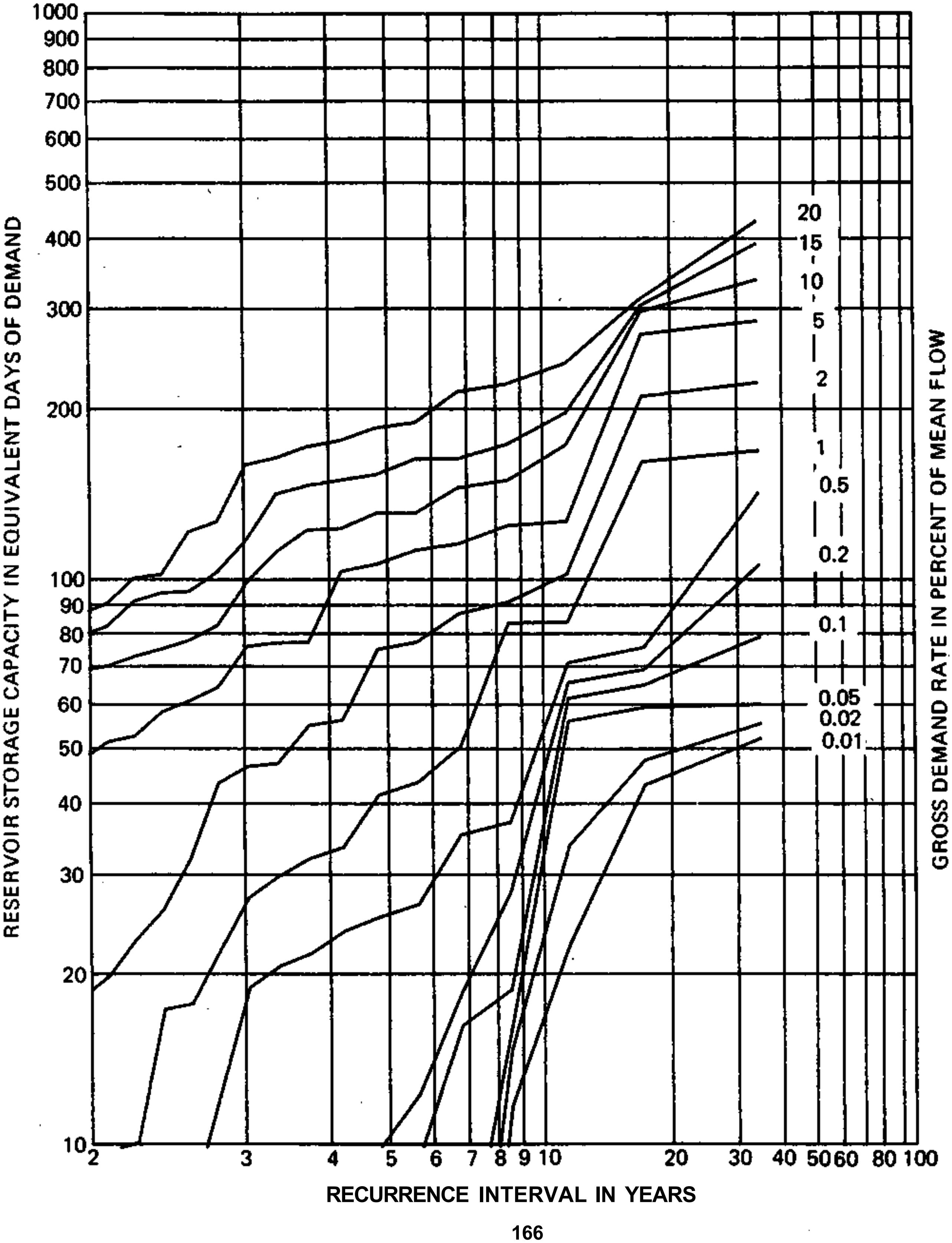
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP

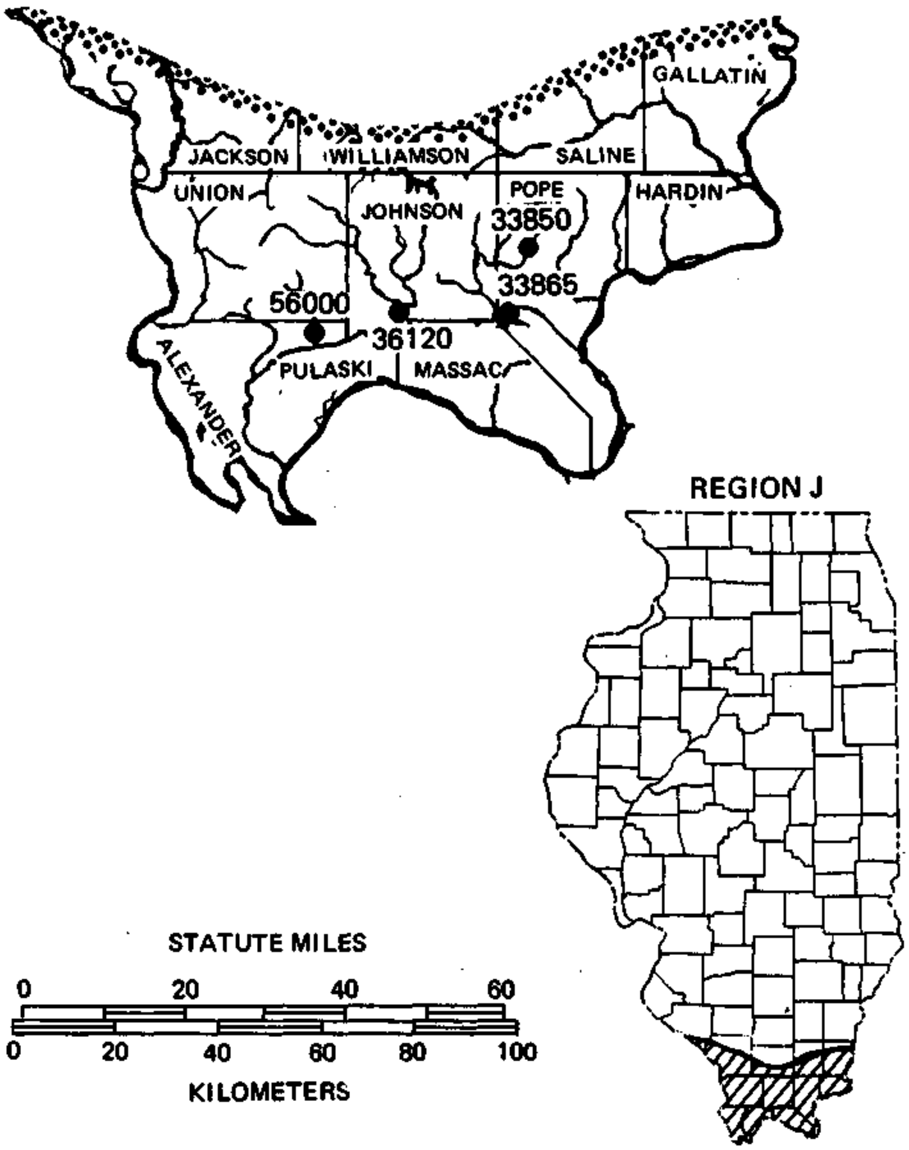


STATION 05599000

BEAUCOUP CREEK NEAR MATTHEWS

DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP




GALLATIN
JACKSON
WILLIAMSON
SALINE
UNION
JOHNSON
POPE
HARDIN
33850
33865
56000
36120
ALEXANDER
PULASKI
MASSAC
REGION J
STATUTE MILES
0
20
40
60
0
20
40
60
80
100
KILOMETERS

REGION J

USGS Gage No.	Name of Station	Period of Record	Number of Years
33850	Hayes Creek at Glendale	1950-1975	25
33865	Sugar Creek near Dixon Springs	1950-1971	21
36120	Cache River at Forman	1925-1978	53
56000	Big Creek near Wetaug	1941-1971	30

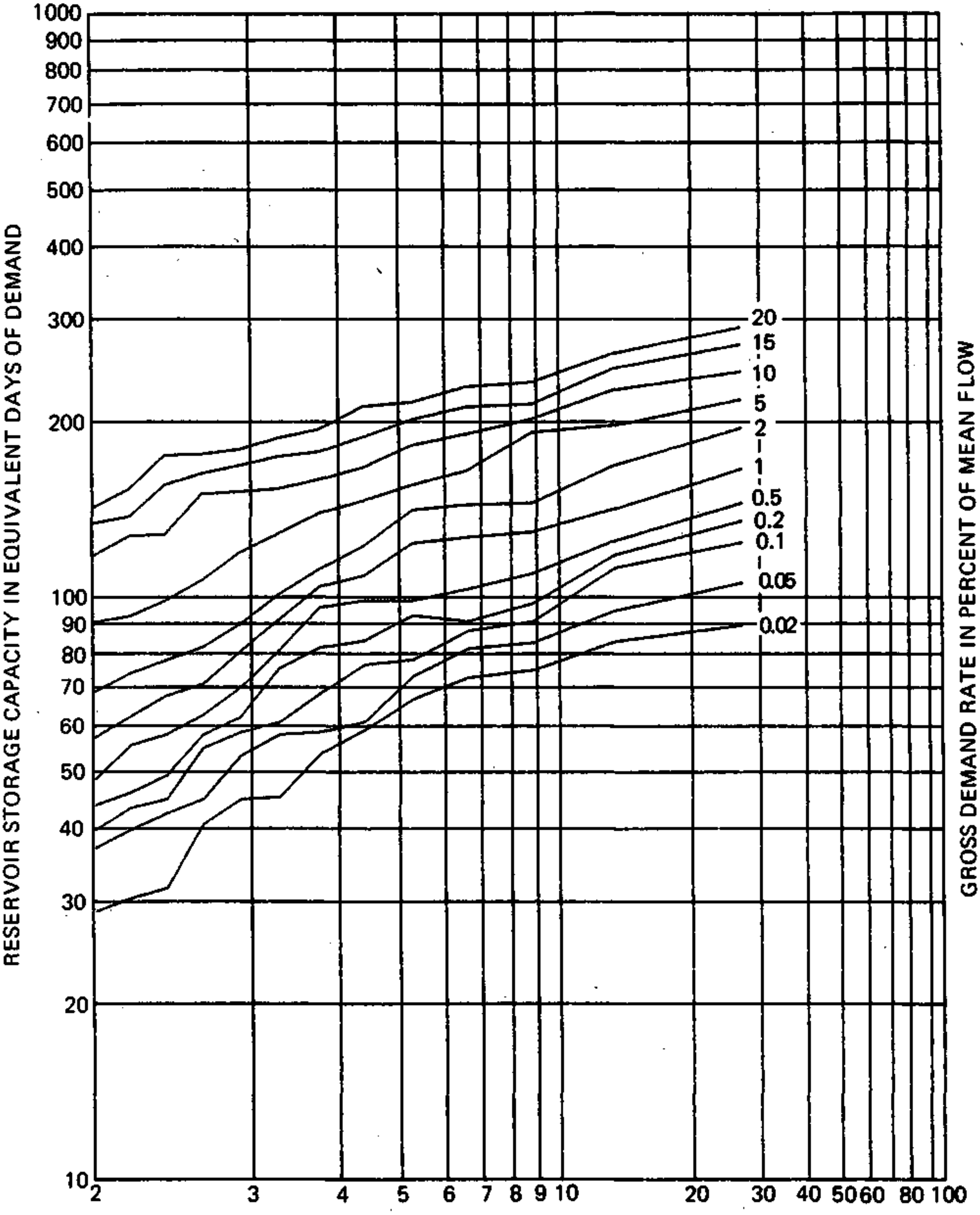
Drainage Area and Streamflow Characteristics

Gage No.	Drainage Area (mi^2)	Mean Flow (cfs)	Mean Flow (in./year)	$Q_{7,10}$ (cfs)	Q90 (cfs)	Q75 (cfs)	Q60 (cfs)
33850	19.1	26.1	18.56	0.0	0.0	0.1	0.8
33865	9.7	10.8	15.12	0.0	0.0	0.0	0.2
36120	244.	295.0	16.42	0.0	1.5	7.2	25.0
56000	32.2	36.4	15.35	0.0	0.7	2.1	4.0

STATION 03385000

HAYES CREEK AT GLENDALE

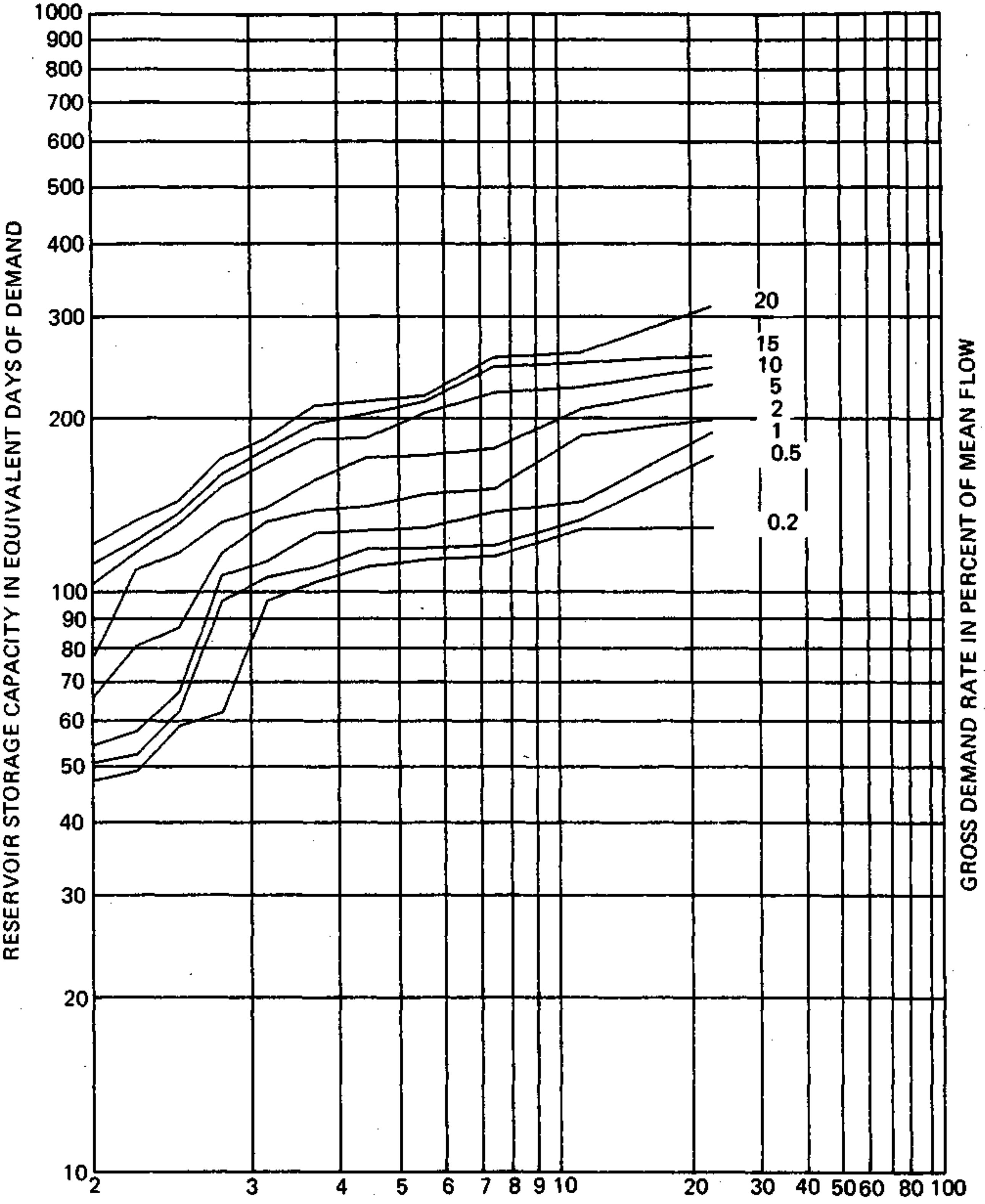
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 03386500

SUGAR CREEK NEAR DIXON SPRINGS

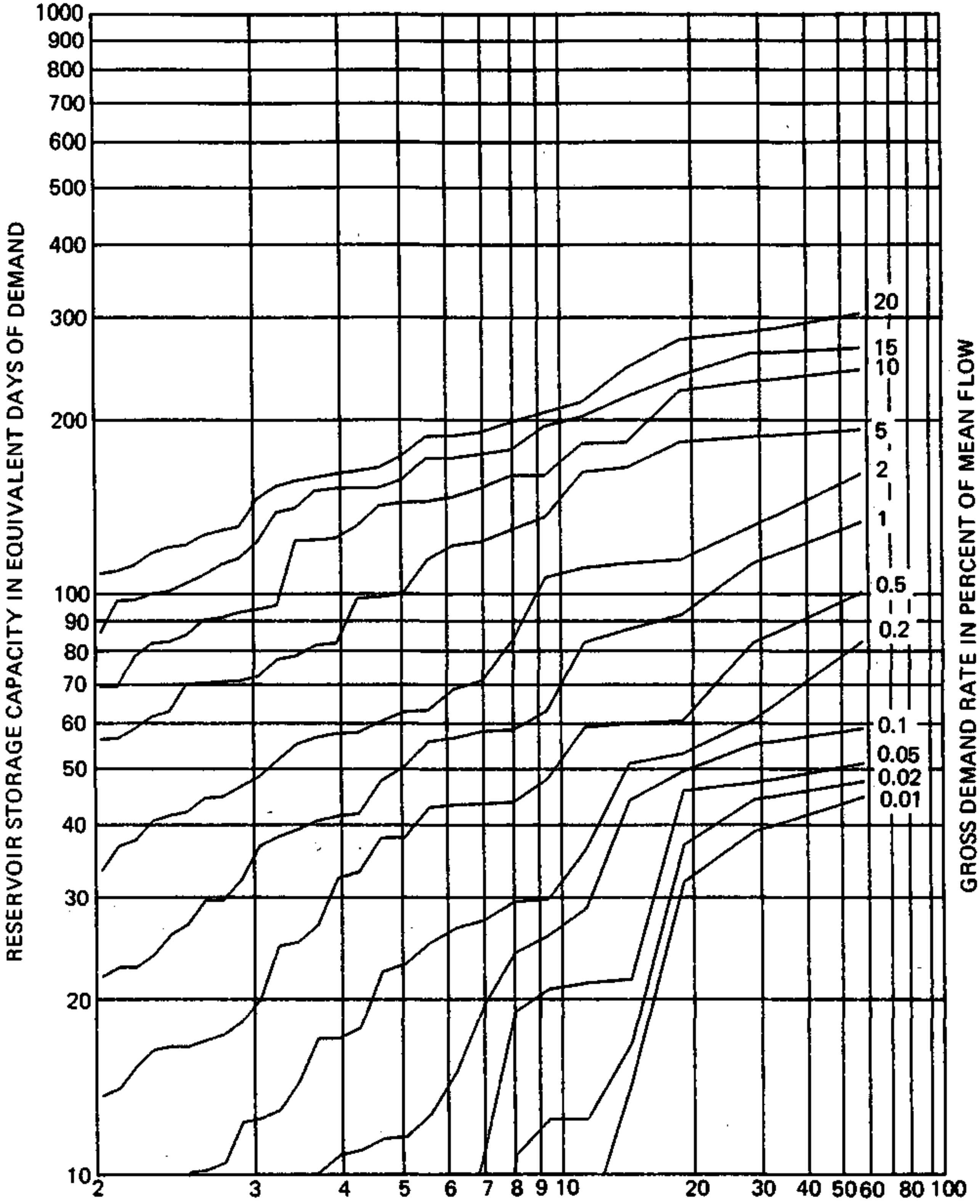
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 03612000

CACHE RIVER AT FORMAN

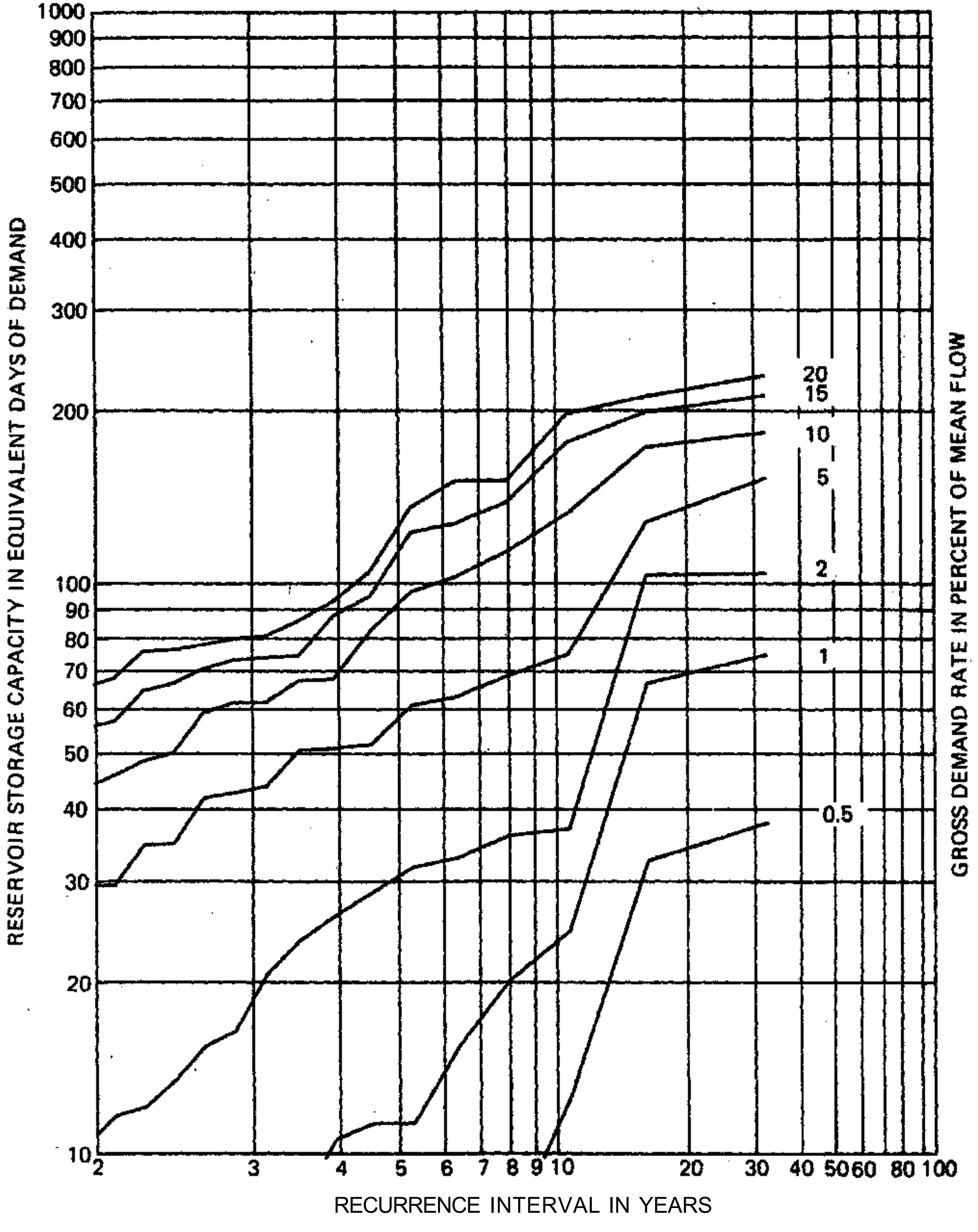
DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



STATION 05600000

BIG CREEK NEAR WETAUG

DEMAND - STORAGE - RECURRENCE PRIMARY RELATIONSHIP



RECURRENCE INTERVAL IN YEARS

Date of request: 7/6/89
Not needed after:
Requester's order no.

A REQUEST

Call No.
SWS
B-67
B-66

LENC. ENGINEERING IN.
1017 OLIVE, SUITE 3008, ST. LOUIS
MISSOURI 63101
attn. Hallen or Allen?

For use of | Status | Dept.

Book author: OR: *periodical title, vol. and date*

Hydrologic design of impounding reservoirs in Illinois
by Michael L. Terstriep and so on.Published in 1982

Book, *title, edition, place, year, series; OR: periodical article author, title, pages.* ☐ This edition only.

Hydrologic design of side-channel reservoirs in Illinois
by H. Vernon Knapp Published in 1982

Verified in: OR: item cited in

ISBN, or ISSN, or LC card, or OCLC, or other number if known________

If non-circulating, & cost does not exceed $________, please supply ☐ Microfilm ☐ Hard copy

ILLINOIS STATE WATER SURVEY LIBRARY
2204 GRIFFITH DR. CHAMPAIGN, IL 61820

Request complies with
☐ 108 (g) (2) guidelines (CCG)
☐ other provisions of copyright law (CCL)

AUTHORIZED BY: Head Librarian
(FULL NAME) Title ~~Ibtsam Dessouky~~

Request for ☒ LOAN or ☐ PHOTOCOPY
According to the A.L.A. Interlibrary Loan Code

REPORTS: Checked by

SENT BY: ☒ Library rate ☐
Charges $ Insured for $
Date sent 7/7/89
DUE 8/7/89

RESTRICTIONS: ☐ For use in library only
☐ Copying not permitted ☐

NOT SENT BECAUSE: ☐ In use ☐ Not Owned
☐ Non Circulating
☐ Request of

Estimated Cost of: ☐ Microfilm ☐ Hard copy

BORROWING LIBRARY RECORD:

Date received
Date returned
By ☐ Library rate ☐
Postage enclosed $ Insured for $

RENEWALS: ☐ No renewals

Requested on
Renewed to
(or period of renewal)

Note: the receiving library assumes responsibility for notification of non-receipt.