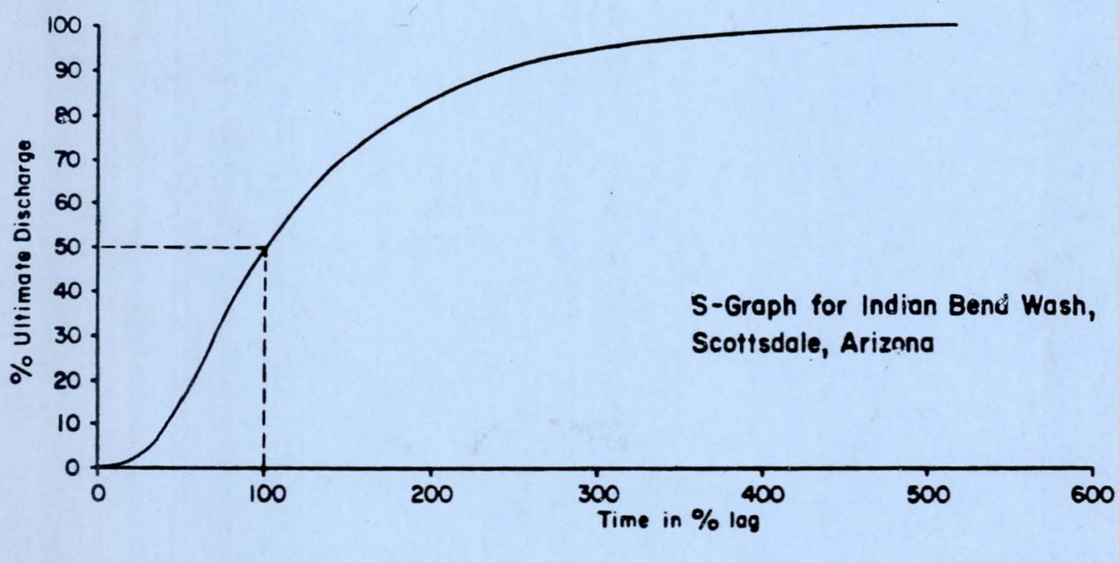
FLOOD CONTROL DISTRICT
OF MARICOPA COUNTY
ARIZONA

S-GRAPH STUDY

CONTRACT FCD 86-36



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Brighton, Colorado

November 1987

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EXECUTIVE SUMMARY

An S-graph is a form of unit-hydrograph and is often used in performing flood studies. S-graphs are usually defined by the reconstitution of recorded flood events and numerous S-graphs are available from such reconstitutions. Existing S-graphs for the southwestern United States have been compiled and have been presented in this report. The purpose of this was to attempt to identify S-graphs for use in Maricopa County.

Fifty-five S-graphs for individual watersheds, and eighteen S-graphs that are classified for regional use have been identified. Twenty-two S-graphs have been identified that were developed or defined for use in Maricopa County. These S-graphs are from reconstitutions of flood events from nine natural watersheds that are predominantly mountainous areas and one urbanized watershed. The majority of the S-graphs are from data for Southern California and have been developed for use in that geographical region. S-graphs are a function of watershed characteristics and the shape of S-graphs appears to be significantly affected by storm characteristics, particularly the maximum intensity of the rainfall. The characteristics of severe flood causing storms in Maricopa County may be different than those in Southern California. Therefore, it may not be advisable to adopt S-graphs that have been developed for Southern California and to apply these to watersheds in Maricopa County because of possible diffferences in rainfall characteristics in these two areas that may affect the shape of the S-graph.

Presently, there is not a large enough data base of individual S-graphs from a variety of physiographic areas or regional S-graphs that have been developed for Maricopa County to make recommendations for the selection of S-graphs for watershed types that exist in Maricopa County. A separate Unit-Hydrograph Study is presently being performed. That study will result in the preparation of S-graphs from reconstitution of flood events for numerous small urban watersheds in Arizona, New Mexico, and Colorado, and some small natural watersheds in Arizona, New Mexico, and Wyoming. The results of the Unit-Hydrograph Study and this S-Graph Study will be used to make a decision on the use of S-graphs for flood analysis in Maricopa County. The S-graphs from these two studies would provide the data base for the selection of appropriate S-graphs for use in Maricopa

County if the decision is made to use S-graphs.

The use of S-graphs requires a procedure to estimate basin lag for ungaged watersheds. Preliminary prediction equations for lag are presented that are based on readily obtainable watershed characteristics.

It is possible to synthesize S-graphs using the Clark unit-hydrograph procedure. These synthesized S-graphs are similar in shape to the S-graphs that have been compiled in this report. It may be possible to develop empirical methods for the estimation of Clark unit-hydrograph parameters for ungaged watersheds in Maricopa County. Such a procedure may provide greater flexibility in fitting unit-hydrographs to the different physiographic types of watersheds in Maricopa County than could be achieved by the selection of a limited number of S-graphs. The development of Clark unit-hydrograph parameters from flood reconstitutions is being performed in the Unit-Hydrograph Study.

SECTION 1
INTRODUCTION

Purpose

This report provides a compilation of S-graphs for Maricopa County, Arizona, and the southwestern United States. These S-graphs were developed by either the U.S. Army Corps of Engineers or the U.S. Bureau of Reclamation in the performance of flood studies by those agencies. The purpose of this S-Graph Study was to compile existing S-graphs for possible use in performing flood studies in Maricopa County.

A preliminary draft of the S-Graph Study report was submitted to the Flood Control District of Maricopa County in March 1987. Several recommendations were provided in that report to expand the base of S-graphs and also to investigate the development of unit-hydrographs by the method of Clark. A subsequent data study (11 May 1987) indicated that there is a large base of rainfall-runoff data that is available for flood reconstitution studies to develop S-graphs and Clark unit-hydrographs for urbanized and natural watersheds in Arizona, New Mexico, Colorado, and Wyoming.

A Unit-Hydrograph Study was authorized by the Flood Control District of Maricopa County to compile additional, unpublished S-graphs for Maricopa County from the files of the U.S. Army Corps of Engineers, Los Angeles District, and to perform flood reconstitutions of the rainfall-runoff data that had been identified in the data study. This report presents the results of the S-Graph Study plus the addition of the 22 unpublished S-graphs for Maricopa County from the Unit-Hydrograph Study.

General

An S-graph is a dimensionless form of a unit-hydrograph and it can be used in the place of a unit-hydrograph in performing flood hydrology studies. The concept of the S-graph dates back to the development of the unit-hydrograph itself, although the application of S-graphs has not been as widely practiced as that of the unit-hydrograph. The use of S-graphs has been practiced mainly by the Department of the Army, Los Angeles District, Corps of Engineers (referred to as the Los Angeles District), and the U.S. Bureau of Reclamation (USBR). Recently the S-graph has been adopted as the unit-hydrograph procedure by Orange and San Bernardino

Counties in California and selected S-graphs are presented in their hydrology manuals. The S-graphs in those hydrology manuals have been selected primarily from S-graphs that had been previously defined by the Los Angeles District from a rather long and extensive history of analyses of floods in California.

S-graphs have been developed for use in Arizona. S-graphs have been developed for the Phoenix vicinity, for Indian Bend Wash, and the Gila River Basin. The availability of S-graphs for adoption by the Flood Control District of Maricopa County (referred to as the Flood Control District) has been investigated and is presented in this report.

A major consideration for the selection of the S-graph technique by the Flood Control District for use in flood hydrology should be computational ease. An S-graph can be converted to a unit-hydrograph by relatively simple hand calculations, or computer programs can be coded to perform this conversion. The resulting unit-hydrograph can then be used to transform rainfall excess into a flood hydrograph, or it can be used as input to a rainfall-runoff model such as HEC-1. A program is available to preprocess an input file containing S-graph data and to convert that file into an input file for HEC-1. This program, LAPRE-1 coded by the U.S. Army Corps of Engineers, Hydrologic Engineering Center, is available to the Los Angeles District, and this program greatly facilitates the use of S-graphs.

Existing S-graphs for the southwestern United States have been compiled and are presented in this report (Appendices A and B). Although an effort has been made to compile all such S-graphs for this geographic area it is anticipated that some S-graphs have not been located. The major emphasis has been to compile S-graphs for Arizona, and the secondary emphasis was to compile S-graphs for physiographically and hydrologically similar watersheds for the possible application of those S-graphs for use in Maricopa County.

The physical characteristics of the watersheds for the compiled S-graphs have been documented. However, watershed characteristics have not been readily available for some S-graphs. Since many of the S-graphs were developed some time ago (into the late 1930's and 1940's) it is not possible to obtain complete documentation of all watershed conditions. More importantly, these watershed conditions are only of value to the Flood Control District if there is potential for the transposition of those S-graphs from the watershed of development to a watershed in Maricopa County. If such transposition is possible then watershed characteristics are needed so that S-graphs can be applied to physiographically similar watersheds. It has not been ascertained at this time that such S-graph transposition is possible between Southern California and Maricopa County.

The application of an S-graph requires the estimation of basin lag. The traditional equation for estimating basin lag has been investigated. This equation is not dimensionally homogeneous, and a modified form of this equation has been provided that is dimensionally homogeneous. Application of the traditional equation for lag requires the selection of a basin average resistance factor that is very subjective resulting in uncertainty in lag estimation. The modified form of the lag equation requires the estimation of a coefficient, and two preliminary equations are presented for evaluating the coefficient. One equation is for natural (undeveloped) watersheds in the southwestern United States, and the other equation is for urbanized watersheds. These equations should be evaluated and modified as necessary by use of data specifically for Maricopa County and small urban watersheds before these equations are generally accepted for use in Maricopa County. Such an expanded data base will be available at the completion of the Unit-Hydrograph Study that is currently underway. A decision will be made during the Unit-Hydrograph Study on adoption of S-graphs for use in the Maricopa County Hydrology Manual. If the decision is made to adopt S-graphs as the criteria then it is planned to develop lag prediction equations and procedures. These preliminary equations can be used as a starting basis for the development of such equations.

Indirect methods to develop synthetic S-graphs have been investigated. It has been determined that S-graphs can be synthesized from the Clark unit-hydrograph and that such S-graphs are similar to S-graphs that have been developed from flood reconstitutions. Therefore, it may be preferable to adopt a unit-hydrograph procedure rather than select a limited number of S-graphs for application throughout Maricopa County. The Clark unit-hydrograph is particularly attractive for such a purpose because the use of a time-area relation allows the unit-hydrograph to be tailored for the specific watershed. In essence, the Clark unit-hydrograph has an infinite variety of shapes depending upon parameter selection including the time-area relation. It may be possible to develop empirical methods to estimate Clark unit-hydrograph parameters for use in Maricopa County. The Clark unit-hydrograph is an option in the HEC-1 flood hydrology model and is generally available for use by the engineering community.

In the preliminary report of this study (March 1987), only a few S-graphs were identified for Maricopa County. Data was identified in the preliminary report that could be used to define additional S-graphs for Maricopa County. It was reported that the Los Angeles District had unpublished file data containing S-graphs from the reconstitution of 22 flood events in Maricopa County. This file data has been obtained in conducting the Unit-Hydrograph Study and these S-graphs have been incorporated in this report.

SECTION 2
COMPILATION OF EXISTING S-GRAPHS

Definitions

S-Graph- An S-graph is a dimensionless form of a unit-hydrograph in which discharge is expressed in percent of ultimate discharge and time is expressed in percent of lag.

Lag- Basin lag is the elapsed time, usually in hours, from the beginning of an assumed continuous series of unit rainfall excess increments over the entire basin to the instant when the rate of resulting runoff equals 50 percent of the basin ultimate discharge. The intensity of rainfall excess is 1 inch per duration of computation interval (D). An equivalent definition of lag is the time for 50 percent of the total volume of runoff of a unit-hydrograph to occur.

Ultimate Discharge- Ultimate discharge is the maximum discharge that will be achieved from a particular watershed when subjected to a continuous intensity of rainfall excess of 1 inch per duration (D) uniformly over the basin. Ultimate discharge (Q_{ult}), in cubic feet per second (cfs), can be calculated from Equation 1

$$Q_{ult} = \frac{645.33\ A}{D} \qquad (1)$$

where A is drainage area, in square miles, and D is duration of the 1 inch of rainfall excess, in hours.

Rainfall Excess- Rainfall excess is that portion of applied rainfall after all rainfall losses have been satisfied. Rainfall excess is equal to the equivalent uniform depth of surface runoff.

Unit-Hydrograph- A unit-hydrograph is a time distribution of the rates of runoff that would result at a particular location in a watershed from 1 inch of rainfall excess of specified duration occurring uniformly over the entire watershed.

Development of S-Graphs

S-graphs are developed by summing a continuous series of unit-hydrographs, each lagged behind the previous unit-hydrograph by a time interval that is equal to the duration of rainfall excess for the unit-hydrograph. The resulting summation is a graphical distribution that resembles an S-graph except that the discharge scale is accumulated discharge and the time scale is in units of measured time. This graph is terminated when the accumulated discharge equals Q_{ult} which occurs at a time equal to the base time of the unit-hydrograph less one duration interval. The basin lag can be determined from this graph at the time at which the accumulated discharge equals 50 percent of Q_{ult}. This summation graph is then converted to a dimensionless S-graph by dividing the discharge scale by Q_{ult} and the time scale by lag, the scales of the resulting S-graph are expressed as percent Q_{ult} and percent lag, respectively.

In practice, S-graphs have generally been developed by reconstituting observed floods to define a representative unit-hydrograph and then converting this to an S-graph. Prior to the advent of computerized models, such as HEC-1, flood reconstitution was a laborious task of rainfall and hydrograph separation along with numerous hand-cranked simulations to define the representative unit-hydrograph. Modern S-graph development generally relies on use of optimization techniques, such as coded into HEC-1, to identify unit-hydrograph parameters that best reproduce the observed flood.

Although the S-graph is completely dimensionless and does not have a duration of rainfall excess associated with it as does a unit-hydrograph, its general shape and the magnitude of lag is influenced by the distribution of rainfall over the watershed and the time distribution of the rainfall. Therefore, the transposition of an S-graph from a gaged watershed to application in another watershed must be done with consideration of both the physioographic characteristics of the watersheds and the hydrologic characteristics of the rainfalls for the two areas. This will be discussed in more detail and illustrated with examples in a later section.

Sources of Data

The source of S-graphs and associated data has been reports and file data of the Los Angeles District, and the USBR. Other sources of S-graphs and data have been pursued but these have been rejected either because the basic data was considered unreliable or the S-graphs and data were considered as not being hydrologically and geographically representative of Maricopa County, Arizona. No screening has been performed of S-graphs; that is, no checks have been made concerning the adequacy or accuracy of the S-graphs. The digitized values of 30 S-graphs have been taken directly from the listing of the LAPRE-1 model code with the exception that an obvious error was detected in LAPRE-1 for SGRH(29). This error was reported to personnel of the Los Angeles District and an assumed correction to the data was made. The only criteria for the reporting of an S-graph in this study was that the S-graph was previously prepared and readily available, and that the S-graph be considered as potentially applicable in Maricopa County.

Presentation of S-Graphs

The S-graphs that have been compiled and presented in this report have been separated into three groups; (1) individual S-graphs, (2) regional S-graphs, and (3) theoretical or synthetic S-graphs. A listing of the compiled S-graphs according to each grouping are shown in TTables 1, 2, and 3, respectively. Each S-graph has been assigned a reference number and will be referred to by that number. Two graphs, at different percent lag scales, of each of the S-graphs is contained in Appendix A, and listings of the digitization of each of the S-graphs are contained in Appendix B. Each S-graph has been digitized at 2 percent increments of percent Q_{ult} so that this data is compatible with the LAPRE-1 format.

Individual S-graphs- Individual S-graphs are those that can be identified with the watershed from which data was used to develop the S-graph. It should be noted that an individual S-graph is often a graphical average of several S-graphs that have been developed from the reconstitution of several flood events for the same watershed. Alternately, when several S-graphs are available for a watershed, one of the S-graphs can be selected as being representative of the watershed. For example three S-graphs are available that were derived from reconstitutions of three different floods on Indian Bend Wash, December 1967 (#16), September 1970 (#17), and June 1972 (#18). The Los Angeles District selected S-graph #17 as being representative of the watershed and #17 is referred to as the Indian Bend Wash S-graph by the Los Angeles District.

The 55 individual S-graphs are identified in Table 1. Column (3) of Table 1 indicates the source of the S-graph, and is cross-referenced in Table 4. Twenty-four individual S-graphs have been identified for Arizona, and 22 of these are for events from 10 watersheds in Maricopa County. As can be seen in Table 1 many of the S-graphs are for Southern California.

It should be noted that two individual S-graphs have been identified that have apparently been derived for different types of storm events on the same watershed. S-graphs #39 is for Santa Anita Creek at Santa Anita Dam for a general storm, and #40 for the same location for a local storm (thunderstorm). These two S-graphs are graphically compared in Figure 1, and it is suspected that these two S-graphs would result in significantly different flood hydrology for the watershed. S-graph #38 is also for the Santa Anita watershed and this is essentially the same as #39. This seems to indicate that the representative S-graph for Santa Anita Creek that has been selected by the Los Angeles District is for a general storm.

The USBR in preparing the Third Edition of <u>Design of Small Dams</u> has identified six S-graphs for applicatioon in generalized regional and physiographic watersheds. Two of these S-graphs are for the Rocky Mountains; one is for a general storm (#54) and the other is for a thunderstorm (#53). These two S-graphs are graphically compared in Figure 2. S-graphs can be classified according to both watershed and storm characteristics.

<u>Regional S-graphs</u>- Regional S-graphs are those that are graphical averages or modifications of individual S-graphs to result in an S-graph that is representative of a specified type of physiographic watershed. Table 2 lists the regional S-graphs that have been identified and compiled. These S-graphs are shown in Appendix A and the digitized tabulations are in Appendix B.

Brief descriptions of each of the regional S-graphs follows:

Phoenix Valley, Arizona (#56)- This S-graph was derived from flood reconstitutions for the streamgages and storm events shown in Table 5. The S-graph from the reconstitution of the September 1970 flood event for Skunk Creek near Phoenix was selected by the Los Angeles District as being representative of S-graphs #1 through #11. S-graph #56 is identical to #4. This S-graph is for general use in valley and urbanized areas in and around Phoenix. This S-graph may be applicable to other areas in Arizona.

Phoenix Mountain, Arizona (#57)- This S-graph was derived from flood reconstitutions for the streamgages and storm events shown in Table 6. The S-graph from the reconstitution of the September 1970 flood event for New River near Rock Springs was selected by the Los Angeles District as being representative of S-graphs #12 through #15. S-graph #57 is identical to #13. This S-graph is for general use in mountainous, non-urbanized areas around Phoenix. This S-graph may be applicable to other areas in Arizona.

Gila River Basin, Arizona, basins less than 1500 square miles (#58)- This S-graph is based on S-graphs for:

1. Blue River near Clifton, Arizona
2. Temecula Creek at Pauba Canyon, California (#28)
3. Murrieta Creek at Temecula, California (#25)
4. Santa Margarita Creek near Fallbrook, California (#27).

The Phoenix Mountain S-graph (#57) is used by the Los Angeles District in place of #58.

Gila River Basin, Arizona, basins greater than 1500 square miles (#59)- This S-graph is based on S-graphs for:

1. Gila River near Clifton, Arizona
2. Gila River at Connor No. 4 Dam Site, Arizona
3. San Francisco River at junction with Blue River, Arizona
4. Santa Ana River at Prado Dam, California.

Average Salt River, Tonto Creek, Verde River, Arizona (#60)- This S-graph is to be provided in the USBR Third Edition of Design of Small Dams as representative of the Southwest Desert, Great Basin, and Colorado Plateau. It is an average of individual S-graphs for the three watersheds.

Average for Arizona, from 10 basins (#61)- This S-graph was developed for use in the Little Colorado River basin of Arizona and New Mexico.

Average Mountain, AZ, CO, NM, UT,WY (#62)- This S-graph was developed by the USBR, and may be used for watersheds in the Rocky Mountains when a more specific S-graph cannot be identified.

Coastal San Diego County, California (#63)- A single representative S-graph was developed from a comparison of several S-graphs that had been derived from flood reconstitutions, and no distinction could be found between mountain and valley S-graphs. This S-graph was apparently first reported in a study of the San Diego River (Los Angeles District, 1975). A reconstitution of 10 floods from five gaging locations for the San Luis Rey River study (Los Angeles District, 1977) indicated that eight of the 10 derived S-graphs were of the same configuration as #63. The two S-graph exceptions were considered to be a consequence of insufficient data. A third study of this area (Los Angeles District, 1981) also states that "no distinction could be clearly made among valley, mountain, or urban S-graphs; hence the decision to select a single representative S-graph."

Average of Santa Ynez River, California (#64)- This is an S-graph that was developed for use in the Santa Ynez basin.

Southern Calfiornia (#65)- This is an average of #22 and #23 foothill watersheds, and has been recommended in the San Bernardino County and County of Orange Hydrology Manuals for use in foothill areas.

Santa Clara River, California (#66)- This is an average of #25, #26, #27, #28, and #36, and was developed for use in the Santa Clara basin.

Whitewater River, California (#67)- This is an average of #25, #26, #27, #28, #29, #32, #36, #44, and #47. This S-graph has been recommended in the San Bernardino County and County of Orange Hydrology Manuals for desert areas.

Los Angeles County, Valley (#68)- This is an average of #34, and #35, and is intended for use in valley drainage areas. This S-graph has been recommended in the San Bernardino County and County of Orange Hydrology Manuals for undeveloped valley areas.

Los Angeles County, Mountain (#69)- This is an average of #30, #31, #38, and #45, and is intended for use in mountain drainage areas. This S-graph has been recommended in the San Bernardino County and County of Orange Hydrology Manuals for mountain areas. This 1944 S-graph has been restudied (Los Angeles District, 1986) and has been found to be still valid for mountain watersheds in the Los Angeles drainage area.

Los Angeles County, Intermediate (#70)- This is a modification of #43 in which the tail of the S-graph has been shortened.

Los Angeles County Drainage Area, Urban (#71)- This S-graph is an average from the reconstitution of three flood events (1978-1980) at each of four streamgages (Los Angelos District, 1986). It is used in place of #68 and represents a higher degree of urbanization since S-graph #68 was defined. This S-graph has been recommended in the San Bernardino County and County of Orange Hydrology Manuals for developed valley areas.

Los Angeles County Drainage Area, Foothill (#72)- This S-graph is an average of the new San Jose Creek S-graph (#49) and the Verdugo Wash S-graph (#50).

Urban, USBR(#73)- This S-graph is being presented in the USBR Third Edition of Design of Small Dams for use in urban watersheds.

Theoretical and Synthetic S-Graphs- Three S-graphs are listed in Table 3 that are based on theoretical considerations or synthetic unit-hydrographs. S-graph #74 is a theoretical graph for overland flow, and represents a rectangular unit-hydrograph. This theoretical S-graph is listed in LAPRE-1. S-graphs #75 and #76 are for the SCS Dimensionless and Triangular unit-hydrographs, respectively. These have been developed for comparison to S-graphs from flood reconstitutions. For example, Figure 3 shows the superposition of the LACDA, Urban (#71) with both of the SCS unit-hydrographs (#75 and #76).

Adoption of Representative S-Graphs for Use in Maricopa County

Only two regional S-graphs (#56 and #57) have been identified that may have direct application in Maricopa County. The 22 individual S-graphs for Maricopa County represent floods on nine natural watersheds and one urban watershed. Eight of these watersheds are larger than 60 square miles. These S-graphs do not provide an adequate base for the selection of regional S-graphs for all types of physiographic watersheds in Maricopa County. In addition, all the flood reconstitutions for Maricopa County and vicinity need to be analyzed in regard to effects of storm characteristics on shape of the S-graph and on magnitude of lag.

The transposition of individual or regional S-graphs that were developed from other areas (particularly Southern California) to Maricopa County may not be directly applicable. There is adequate reason to believe that watersheds in Maricopa County and Southern California have similar physiographic characteristics; however, there is also reason to believe that storm characteristics, particularly the intensity of rainfall, may have a major influence on the shape of the S-graph and the magnitude of lag. Many of the S-graphs from Southern California may be dominated by flood reconstitutions of coastal storms that differ significantly from the predominant flood producing storms in Maricopa County. By comparison, the annual mean number of thunderstorm days (1951-1975) in Phoenix, Arizona is 23.2 and in Los Angeles, California is 3.4 (Court and Griffiths, 1982). A report on flooding in the Phoenix area states, "the short time precipitation intensity for the local summer thunderstorm is the more critical flood peak producing factor for drainage areas smaller than about 700 to 800 square miles" (Los Angeles District, 1974, pg. 12). Whereas general storms may be responsible for major floods and constitute the design condition for large watersheds, the thunderstorm may be more critical for smaller watersheds in Maricopa County. It may be necessary to consider S-graphs for both general storm and thunderstorm conditions for use in Maricopa County.

SECTION 3

WATERSHED CHARACTERISTICS

General

Watershed characteristics are quantitative measures and qualitative descriptors of the watershed's physical properties that may influence the hydraulics of runoff from the drainage basin. Examples of qualitative measures are length of longest watercourse and watercourse slope. Examples of qualitative descriptors are geographic location, such as San Gabriel Mountains, and land-use, such as urbanized. There are three major purposes for documenting watershed characteristics for S-graphs:

1. For establishing watershed classes, such as mountain, foothill, and urban, so that representative watershed class S-graphs can be developed by graphically averaging a composite of individual S-graphs for that class.
2. For use in selecting S-graphs that have been developed from recorded data in one watershed, or watershed class, for adoption in another (probably ungaged) watershed.
3. For developing prediction equations for the S-graph parameter, lag.

As previously discussed, several watershed class S-graphs have been developed by the Los Angeles District. Examples of such watershed class S-graphs are the Los Angeles County Drainage Area, Urban (# 71), the Coastal San Diego County (# 63), the Phoenix Valley (# 56), and the Phoenix Mountain (# 57). Most of the regional S-graphs shown in Table 2 have been developed from S-graphs for Southern California for application to ungaged watersheds in Southern California. The major use of watershed characteristics for the purposes of this study is for establishing a data base to be used to develop prediction equations for the S-graph parameter, lag.

Available Data for Compiled S-graphs

Watershed characteristics for the individual S-graphs are shown in Table 7. The most complete documentation on watershed characteristics is for the Maricopa County S-graphs. Documentation of watershed characteristics for some of the other S-graphs is incomplete due to lack of this data in the files of the agency that developed the S-graph.

Channel profiles of many of the watersheds in the Los Angeles area are shown in the Los Angeles County Drainage Area, Hydrology Report (Los Angeles District, 1986).

The 22 S-graphs for Maricopa County were developed by the reconstitution of flood events on 10 watersheds. Information on the streamgage location, watershed rainfalls, isohyetals maps, and descriptions of the storm and flood events are presented in Appendix C.

Lag Predicition Equation

A general relationship for basin lag as a function of watershed characteristics is given by Equation 2.

$$\text{Lag} = C \left(\frac{L\, L_{ca}}{S^{.5}} \right)^{m} \qquad (2)$$

where Lag is basin lag, in hours,

L is length of longest watercourse, in miles,

L_{ca} is length along the watercourse to a point opposite the centroid, in miles,

S is watercourse slope in feet/mile,

C is a coefficient, and

m is an exponent.

The Los Angeles District often uses $C = 20n$, where n is the estimated mean Manning's n for all the channels within an area, and $m = 0.38$. The USBR (1987) has recommended that $C = 26n$ and $m = 0.33$. Both sets of values in Equation 2 will often result in similar estimates for Lag.

A major disadvantage of Equation 2 is that n must be selected which is very subjective and introduces significant uncertainty into the lag prediction. Also, Equation 2 is not dimensionally homogeneous and does not have a strong theoretical justification. A modified basin lag equation has been developed based on dimensional similitude (Sabol, 1987), Equation 3

$$\text{Lag} = C_{l} \left(\frac{L\, L_{ca}}{S^{2}} \right)^{.25} \qquad (3)$$

where C_l is a coefficient and all other parameters are as previously defined.

Documentation on S-graph characteristics for a wide variety of watershed types was obtained from the files of the Flood Hydrology Section of the USBR in Denver, Colorado. This data was compiled and catagorized by the USBR in preparation for the Third Edition of Design of Small Dams. The data is divided into five geographical catagories plus a catagory for urban drainages. Maricopa County, Arizona would be in the Southwest Desert, Great Basin, and Colorado Plateau category. This data was used to develop prediction equations for C_l of Equation 3 for each of the watershed catagories. The coefficient C_l for natural watersheds in the Southwest Desert, Great Basin, and Colorado Plateau is

$$C_l = -21.72 + 1.79 \log A + 4.90 \log S \qquad (4)$$

and for urban drainages is

$$C_l = -1.14 + 0.31 \log A + 0.91 \log S \qquad (5)$$

where A is drainage area in square miles, S is watercourse slope in feet per mile, and log indicates natural logarithm.

Equation 3 has a better theoretical justification than Equation 2. Lag is much more sensitive to watershed slope in Equation 3 than Equation 2, and this may result in better estimates of lag for watersheds with flat slopes. Although Equation 3 has theoretical and practical improvements as compared with Equation 2, it should not be adopted for use in Maricopa County or elsewhere until it is adequately tested and verified.

Equations 4 and 5 provide a means to estimate the coefficient C_l of Equation 3 from readily available data without the subjective selection of a parameter such as n. Equation 4 is applicable for undeveloped watersheds and Equation 5 is applicable for fully urbanized watersheds. A procedure or adjustment factor would need to be developed for watersheds that are partially urbanized. These equations were derived from data for large regional areas. These equations would need to be reexamined using the best available data that would be representative of conditions in Maricopa County before they are adopted.

SECTION 4
SYNTHETIC S-GRAPHS

General

It may not be possible to identify or select existing S-graphs for use in Maricopa County that adequately define unit-hydrographs for all watershed hydrologic and physiographic conditions. It may be necessary, or even desirable, to generate synthetic S-graphs or other forms of unit-hydrographs by indirect methods rather than adopt S-graphs from flood reconstitution studies. Furthermore, a regionalized procedure of synthetic unit-hydrograph development may be preferable to the selection of a limited number of S-graphs.

An investigation has been performed in which S-graphs were synthesized from Clark unit-hydrographs. The Clark unit-hydrograph was selected because; (1) it is a routing procedure which means that unit-hydrographs can be completely defined by a simple mathematical process, (2) it is an option in HEC-1 and is readily available and economically implemented on microcomputers, and (3) it is a three parameter model that incorporates effects of hydraulic efficiency as measured by time of concentration (T_c), watershed detention effects (R), and the shape of the watershed as represented by the time-area relation. The Clark unit-hydrograph is very flexible and the shape can be adjusted by these three parameters, therefore it may be possible to reproduce S-graphs with the Clark unit-hydrograph.

A unit-hydrograph is a function of size of drainage area (A), and duration of rainfall excess (D). Therefore, the effects of five variables were considered in the investigation of synthesizing S-graphs from Clark unit-hydrographs. These variables being;

1. size of drainage area (A),
2. time of concentration (T_c),
3. storage coefficient (R),
4. time-area relation, and
5. duration of rainfall excess (D).

The S-graph is a completely dimensionless form of unit-hydrograph that is independent of size of drainage area, and it should be possible to eliminate size of drainage area from consideration when synthesizing S-graphs. The results of the investigations indicate that identical S-graphs are obtained for any size drainage area when the ratios of T_c/R and D/T_c are held constant, and the same time-area relation is used.

Effect of T_c and R

The magnitude of T_c and R will vary with the size of drainage area, however the effects of the magnitudes of T_c and R can be eliminated if the ratio of T_c/R is held constant. That is, watersheds of any size and with any values of T_c and R will result in identical S-graphs if the ratio of T_c/R is the same. Therefore, a family of S-graphs can be developed with each S-graph being identified by a ratio of T_c/R. The duration of rainfall excess (D) was set equal to 20 percent of T_c, and the HEC-1 default time-area relation was used to isolate the effects of these variables. The results of the synthesized S-graphs are shown in Table 8 and Figure 4 for a range of T_c/R from 0.25 to 4.0.

In Table 8, column (1) indicates the T_c/R ratio and column (3) indicates D as 20 percent of T_c. The lag as a percent of T_c is shown in column (2), and D as a percent of lag is shown in column (4); these will be discussed subsequently. Columns (5) through (9) show percent lag at various values of percent Q_{ult}. The S-graph is lengthened indicating delayed runoff for smaller ratios of T_c/R. This is appropriate since smaller ratios of T_c/R indicate a greater influence of detention in the watershed with respect to travel time and the S-graph should be lengthened. Column (10) shows a statistic that is called mid-range slope, and this is the average slope of the S-graph between 40 and 60 percent of Q_{ult}. A larger mid-range slope will indicate a larger peak discharge as will a larger T_c/R ratio.

The synthesized S-graphs are shown in Figure 4 with the exception that S-graphs for the T_c/R ratios of 1.25, 1.5, and 1.75 are not shown for reasons of clarity of the figure. The S-graphs have been divided into two portions to facilitate the graphical comparison of the S-graphs. One portion is for the range 0 to 100 percent lag and the other portion for greater than 100 percent lag. As shown in Figure 4, the synthesized S-graphs are very similar to the S-graphs that have been compiled in this report.

Effect of D

The duration of rainfall excess (D) is often taken as about 20 percent of lag in the application of S-graphs. This general rule agrees well with the investigation of unit-hydrograph relations by Snyder (1938) indicating that D should be about 18 percent of lag, and the guidelines for application of the SCS dimensionless unit-hydrograph where D should be about 22 percent of lag. It must be noted that the definition of lag used by both Snyder and the SCS is the time between the mid-point of rainfall excess duration and peak discharge which is different than the S-graph definition of lag. However, from a practical consideration, both definitions of lag will result in similar magnitudes and therefore the application of these criteria for the selection of D with S-graphs seems justified.

In the development of S-graphs from T_c/R ratios the duration was set equal to 20 percent of T_c. As shown in Table 8 column (4) this resulted in a duration that was from 6 to 24 percent of the lag. This indicates that there is not a linear relation between D as a percent of lag and the T_c/R ratio. This relation is shown in Figure 5, and indicates that D equals approximately 20 percent of T_c for the range of T_c/R from 1.5 to 3.0. For T_c/R greater than 3.0, D should be less than 20 percent T_c; and for T_c/R less than 1.5, D should be greater than 20 percent T_c. More extensive investigations are needed to define the relation between D and T_c or lag.

The Clark unit-hydrograph and resulting synthetic S-graphs may not be particularly sensitive to D. As shown in Table 9 the synthetic S-graphs (all for $T_c/R = 1.0$) are all very similar to each other even though they are for a range of D from 10 to 25 percent of T_c. Whether this low sensitivity exists for other ratios of T_c/R has not been investigated.

Effect of Time-Area Relation

The shape of a watershed should have an affect on the shape of the corresponding unit-hydrograph and S-graph; for example a watershed with a small length to width ratio would have a short time to peak on the unit-hydrograph and a relatively short recession limb, whereas a watershed with a large length to width ratio would have a longer time to peak and longer recession limb.

The effect of watershed shape on S-graphs was investigated by synthesizing S-graphs by the Clark unit-hydrograph for three different time-area relations. The time-area relations and corresponding watershed shapes are shown in Figure 6. The first time-area relation is the default relation used in HEC-1, and is for a symmetric watershed of elliptic shape. The second relation is for a triangular shape with the largest contributing area being most removed from the watershed outfall location. This is a common general shape for many watersheds. The third relation is for an inverted diamond shape with the largest contributing area being closest to the watershed outfall location. This may be representative of some alluvial fans where runoff has been restricted or channelized to a common outfall point. The three watershed shapes and assumed time-area relations represent a reasonable range for virtually all time-area relations; that is, most watersheds will have a time-area relation that deviates from that for the idealized elliptic shape but it is unlikely that the shape would be more radical than either the triangular or inverted diamond shapes.

The results of S-graph synthesis using the time-area relations are shown in Table 10 and Figure 7. The three examples are for watersheds with T_c/R equal to 1.0 and for D equal to 20 percent of T_c. As shown in Figure 7 the S-graph is most affected in the range from 0 to 100 percent lag, and the magnitude of this affect is about the same as the effect of a change in T_c/R over the range from 0.25 to 4.0 as illustrated in Figure 4. Also, the mid-range slope shown in column (10) oof Table 10 indicates a rather large variation that will be reflected in hydrograph peak discharges. The lag shown in column (2) of Table 10 varies from 115 to 151 percent of T_c for the inverted diamond shaped and triangular shaped watersheds, respectively. The tail of the S-graph is only moderately affected by watershed shape.

Conclusive results are not available from this limited investigation of effects of watershed shape on S-graphs. However the results do indicate that watershed shape probably significantly affects the S-graph in the range from 0 to 100 percent lag and the mid-range slope of the S-graph. The lag is also significantly affected by watershed shape.

Additional investigations regarding watershed shape would need to be conducted to ascertain the effects for T_c/R ratios other than 1.0. The effects may be more or less pronounced at large or small ratios of T_c/R.

Conclusions Regarding S-graph Synthesis

This investigation has demonstrated that S-graphs can be synthesized. It has been demonstrated that synthetic S-graphs can be developed from synthetic unit-hydrograph procedures and the effect of size of drainage area can be eliminated. Synthetic S-graphs can be developed that are a function of watershed travel time (as measured by some characteristic time such as T_c), storage or detention of rainfall excess on the watershed (such as represented by the Clark R parameter), duration of rainfall excess, and the shape of the watershed (as represented by a time-area relations).

Using the Clark unit-hydrograph it has been shown that S-graphs can be characterized by the ratio of T_c/R, and that the shape of the S-graph is sensitive to the T_c/R ratio. Several analytic techniques are available to estimate T_c, and recently a method has been developed to conveniently estimate R from recorded flood hydrographs, (Sabol, 1988). Additionally the HEC-1 model provides an optimization technique to fit the T_c and R parameters to reconstitute recorded flood events. Such techniques can be used to determine T_c and R for recorded floods in the Maricopa County area. The T_c and R parameters can then be related to watershed physical characteristics and these relations used to predict T_c and R for ungaged watershed in Maricopa County.

A synthetic S-graph is not particularly sensitive to the selection of duration of rainfall excess (D). In general, a D equal to 20 percent T_c will provide a reasonable computation duration for watersheds with a T_c/R ratio between 1.5 and 3.0. Additional investigations on the effect of D are necessary before definative conclusions can be made.

Of particular interest is the result that synthetic S-graphs are relatively sensitive to watershed shape. The watershed shape can be defined by topographic maps and this information is usually available for flood studies. Improvements in estimation of flood hydrographs can probably be made by incorporating the watershed shape into development of the unit-hydrograph.

In summary, synthetic S-graphs can be developed as a function of T_c/R and the watershed time-area relation. It is likely that many of the S-graphs that have been compiled (Appendix A) could be reproduced by a T_c/R ratio and an appropriate time-area relation. Deviations between such synthetic S-graphs and S-graphs that have been developed from flood reconstitutions may be a result of nonuniformity of rainfall on the watershed and the time distribution of rainfall whereas synthetic S-graphs are for uniform rainfall over the entire watershed and uniform intensity of rainfall.

SECTION 5
DATA FOR MARICOPA COUNTY

General

Sources of data for watersheds in and near Maricopa County have been investigated for the purpose of developing S-graphs, performing flood reconstitutions, and developing other forms of unit-hydrographs. Data of potential interest includes rainfall records, streamgaging station records, and unpublished file data including flood analyses and flood reconstitutions.

Raingage Data

Extensive historic rainfall data for Maricopa County does not exist, however in the past 10 or so years there has been a proliferation of raingage installations in Maricopa County. Presently, a rather dense network of raingages exists in and around Maricopa County. These have been installed and are maintained by the Flood Control District, the City of Phoenix, the Salt River Project, the U.S. Geological Survey, and the National Weather Service. A recent evaluation of raingage networks in the Phoenix area has been completed (Tipton and Kalmbach, Inc., 1986), and a listing of National Weather Service and U.S. Geological Survey raingages in Maricopa County is shown in another report (Los Angeles District, 1974, Table 1). That information is not reproduced in this report. It is likely that basic rainfall data for flood reconstitution would not need to be obtained from data collecting agencies because post-storm analyses have already been performed on most, if not all, major storms in the Maricopa County area. These post-storm analyses and isohyetal maps are probably available in previous reports by the Los Angeles District (1973, 1974, and 1982) or are available as file data from the Los Angeles District or other agencies.

Streamgage Data

Numerous severe storms and resulting flood discharges have occurred in Maricopa County. Seven major storms have occurred in or near Maricopa County in the past 20 years for which there should be very reliable records of rainfall and flood discharges. These major events are:

1. 12-21 December 1967,

2. 4-6 September 1970,
3. 21-22 June 1972,
4. 27 February - 6 March 1978,
5. 16-20 December 1978,
6. 13-22 February 1980, and
7. October 1983.

Only one of these storms (21-22 June 1972) has been classified as a thunderstorm (Los Angeles District, 1974), however it is likely that many of the other storm events were general storms with imbedded thunderstorm cells and that the resulting peak flooding was a result of the high intensity rainfall.

USGS streamgage data is available for these storms from as many as 14 gaging stations. Some of this data has already been analyzed by the Los Angeles District in performing flood studies for Maricopa County (Los Angeles District, 1973, 1974, and 1982). However the floods of 1978, 1980, and 1983 have not been analyzed in regard to flood reconstitutions and development of S-graphs, and this newer data could be used to expand the data base for Maricopa County.

SECTION 6
CONCLUSIONS

1. Fifty-five individual S-graphs have been compiled. Each of these was developed from flood reconstitutioons for specified watersheds. Most of these S-graphs are for watersheds in Southern California. Twenty-two individual S-graphs (#1 through #22) have been identified for Maricopa County.
2. Eighteen regional S-graphs have been compiled. Each of these was developed by graphically averaging several individual S-graphs that are representative of particular physiographic areas, or by modifying an individual S-graph. Seven of these regional S-graphs (#56 through #62) have been developed for use in Arizona, and only two of these (#56 and #57) have been developed for Maricopa County.
3. There is not a large enough data base of individual S-graphs or regional S-graphs that have been developed for Maricopa County to make recommendations for the selection of S-graphs for watershed types that exist in Maricopa County.
4. The physiographic characteristics of watersheds in Maricopa County may be comparable with those in Southern California, and it may be possible to extend the S-graph data base for Maricopa County by transposing the application of certain S-graphs from Southern California to Maricopa County.
5. Rainfall characteristics, particularly the maximum rainfall intensity, may have a major influence on the shape of the S-graph and the magnitude of lag. The characteristics of severe flood causing storms in Southern California may be different than those in Maricopa County. If this is true, then S-graphs from Southern California should not be transposed for application in Maricopa County.
6. A preliminary prediction equation for lag that is based on readily obtainable watershed characteristics has been presented.
7. It is possible to synthesize S-graphs that reproduce the general shape of S-graphs that have been developed from flood reconstitutions. Using the Clark unit-hydrograph it has been determined that S-graphs are a function of the ratio of T_c/R and watershed shape. Synthetic S-graphs do not appear to be particularly sensitive to the selection of duration of rainfall excess, measured

as a percent of T_c or lag. The effect of watershed size in S-graph synthesis is eliminated for watersheds of equivalent T_c/R ratios and equivalent time-area relations.

8. S-graphs can be synthesized by unit-hydrograph procedures, and therefore an appropriatee unit-hydrograph procedure may be preferable to the selection of a limited number of S-graphs. It may be possible to develop empirical methods for the estimation of Clark unit-hydrograph parameters for ungaged watersheds in Maricopa County. Such a procedure may provide greater flexibility in fitting unit-hydrographs to the different physiographic types of watersheds in Maricopa County. The Clark unit-hydrograph procedure is an option in HEC-1 and is readily available to the engineering community.

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TABLES

Table 1.- Listing of individual S-graphs that were developed from flood reconstitutions for specified watersheds.

S-graph No. (1)	Name of S-graph according to watershed name and location. Date of flood used in reconstitution is given if known. (2)	Source of S-graph See Table 4 (3)
1	New River at Bell Road (December 1967)	8
2	New River at Bell Raod (September 1970)	8
3	Skunk Creek near Phoenix (December 1967)	8
4	Skunk Creek near Phoenix (September 1970)	8
5	Cave Creek at Phoenix (December 1967)	8
6	Cave Creek at Phoenix (September 1970)	8
7	Queen Creek trib. at Apache Junct., Part 1 (December 1967)	8
8	Queen Creek trib. at Apache Junct., Part 1 (September 1970)	8
9	Queen Creek trib. at Apache Junct., Part 2 (September 1970)	8
10	Agua Fria trib. at Youngtown, Part 1 (September 1970)	8
11	Agua Fria trib. at Youngtown, Part 2 (September 1970)	8
12	New River near Rock Springs (December 1967)	8
13	New River near Rock Springs (September 1970)	8
14	New River at New River (December 1967)	8
15	New River at New River (September 1970)	8
16	Indian Bend Wash near Scottsdale (December 1967)	8
17	Indian Bend Wash near Scottsdale (September 1970)	8,1,7(17)
18	Indian Bend Wash near Scottsdale (June 1972)	8
19	New River near Glendale (December 1967)	8
20	New River near Glendale (September 1970)	8
21	Agua Fria at Avondale (December 1967)	8
22	Agua Fria at Avondale (September 1970)	8
23	Moencopi Wash near Tuba City, Arizona	2
24	Clear Creek near Winslow, Arizona	2,3
25	Murrieta Creek at Temecula, California	5
26	Santa Margarita River at Ysidora, California	5,7(6)
27	Santa Margarita River near Fallbrook, California	5
28	Temecula Creek at Pauba Canyon, California	5

Table 1.- Continued

S-graph No.	Name of S-graph according to watershed name and location. Date of flood used in reconstitution is given if known.	Source of S-graph See Table 4
(1)	(2)	(3)
29	Tujunga Creek at Tujunga Dam No. 1, California	5,7(19)
30	San Dimas Creek at San Dimas Dam, California	5,7(28)
31	Eaton Wash at Eaton Wash Dam, California	5,7(27)
32	East Fullerton Creek at Fullerton Dam, California	5
33	San Jose Creek at Workman Mill Road Bridge, California	5,7(3)
34	Alhambra Wash above Short Street Bridge, California	5
35	Broadway Drain above Raymond Dike, California	5
36	Santa Clara River near Saugus, California	5
37	Colma Creek Basin, California	2
38	Santa Anita Creek at Santa Anita Dam, California	5,7(30)
39	Santa Anita Creek at Santa Anita Dam, California (from general storm)	6
40	Santa Anita Creek at Santa Anita Dam, California (from local storm)	6
41	San Dieguito River, California	7(12)
42	Santa Barbara (Mission Creek) at Los Olivos Street, California	7(13)
43	Live Oak Creek at Live Oak Dam, California	14,7(32)
44	San Gabriel River at San Gabriel Dam No. 1, California	5
45	San Gabriel River at San Gabriel Dam, California	7(29)
46	West Fork of San Gabriel River at Cogswell Dam (No. 2), California	11
47	West Fork of San Gabriel River at Cogswell Dam (No. 2), California	10,11,7(10),7(31)
48	West Fork of San Gabriel River at Cogswell Dam (No. 2), California	11
49	San Jose Creek, California (LACDA)	7(25)
50	Verdugo Wash, California (LACDA)	7(26)
51	Trinity River near Louiston, California	9
52	Animas River at Farmington, New Mexico	6
53	Buckhorn Creek near Masonville, Colorado	9
54	Uinta River near Neola, Utah	9
55	Arbuckle Creek and Dam, Oklahoma	9

Table 2.- Listing of regional S-graphs that are representative averages for particular physiographic areas.

S-graph No. (1)	Name of S-graph (2)	Source of S-graph See Table 4 (3)
56	Phoenix Valley, Arizona	12,7(15)
57	Phoenix Mountain, Arizona	12,7(16)
58	Gila River Basin, Arizona, basins less than 1500 square miles	13,7(4)
59	Gila River Basin, Arizona, basins greater than 1500 square miles	13
60	Average Salt River, Tonto Creek, Verde River, Arizona	9
61	Average for Arizona, from 10 basins	3
62	Average Mountain, AZ, CO, NM, UT, WY	2,7(18)
63	Coastal San Diego County, California	7(22)
64	Average of Santa Ynez River, California	7(14)
65	Southern California (Average of #32 and #33)	7(11)
66	Santa Clara River, California (Average of #25, #26, #27, #28, and #36)	8,7(5)
67	Whitewater River, California (Average of #25, #26, #27, #28, #29, #32, #36, #44, and #47)	8,7(9)
68	Los Angeles County, Valley (Average of #34 and #35)	8,7(2)
69	Los Angeles County, Mountain (Average of #30, #31, #38, and #45)	8,7(1)
70	Los Angeles County, Intermediate (Modification of #43)	7(8)
71	Los Angeles County Drainage Area, Urban	7(23)
72	Los Angeles County Drainage Area, Foothill	7(24)
73	Urban, USBR	9

Table 3.- Listing of theoretical or synthetic S-graphs that are developed from unit-hydrographs.

S-graph No.	Name of S-graph	Source of S-graph See Table 4
(1)	(2)	(3)
74	Overland flow (rectangular unit-hydrograph)	7(21)
75	SCS dimensionless unit-hydrograph	----
76	SCS triangular unit-hydrograph	----

Table 4.- Sources of S-graphs. See References in report for title of references in parentheses.

Number (1)	Reference (2)
1	(Los Angeles District, 1973)
2	U.S. Bureau of Reclamation, undated file data.
3	(Los Angeles District, 1961b)
4	(Los Angeles District, 1975)
5	S-graphs Streams in Southern California, Los Angeles District, U.S. Army Corps of Engineers, undated file data.
6	Los Angeles District, undated file data.
7	LAPRE-1 Program Listing; program S-graph number is shown in ().
8	File data of Los Angeles District, U.S. Army Corps of Engineers. contained in records on reconstitutions of floods in Maricopa County, Arizona.
9	(U.S. Bureau of Reclamation, 1987)
10	(Los Angeles District, 1959)
11	Comparison of S-Graphs, Los Angeles District, U.S. Army Corps of Engineers, undated file data.
12	(Los Angeles District, 1974)
13	(Los Angeles District, 1963)
14	(Los Angeles District, 1961a)

Table 5.- Streamgages and storm events used in flood reconstitutions for the development of the Phoenix Valley, Arizona S-graph (#56) (Los Angeles District, 1974).

Stream Gage (1)	USGS Gage No. (2)	Drainage area sq. mi. (3)	Peak Discharge from Storm, in cfs Dec 1967 (4)	Sept 1970 (5)
New River at Bell Road	09513835	187.0	14,600	11,900
Skunk Creek near Phoenix	09513860	64.6	6,800	9,650
Cave Creek at Phoenix	09512400	70.0[1]	4,080	780
Queen Creek Trib. at Apache Junct.	09492200	.51		
Part 1			28	138
Part 2				84.5
Agua Fria Trib. at Youngtown	09513700	.13		
Part 1				15.8
Part 2				40.5

Note:

1. USGS Water Resources Data for Arizona indicates drainage area of 252 square miles. The contributing drainage area is 70.0 square miles because of the noncontributing area controlled by Cave Creek Dam.

Table 6.- Streamgages and storm events used in flood reconstitution for the development of the Phoenix Mountain, Arizona S-graph (#57) (Los Angeles District, 1974).

Stream Gage	USGS Gage No.	Drainage area sq. mi.	Peak Discharge from Storm, in cfs: Dec 1967	Peak Discharge from Storm, in cfs: Sept 1970
(1)	(2)	(3)	(4)	(5)
New River near Rock Springs	09513780	67.3	10,500	18,600
New River at New River	09513800	85.7	12,500	19,500

Table 7.- Watershed characteristics for the individual S-graphs that were developed from flood reconstitutions and have been compiled in this report.

S-graph No.	A	L	L_{ca}	S	n^1	Lag	RIMP	Watershed Elevation Min	Watershed Elevation Max	Type of Watershed or Geographical Name
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1	187.0	47.6	20.7	83.4	.062	8.85	5	1,190	5,160	New River Mtns. and alluvial fan
2	187.0	47.6	20.7	83.4	.038	5.38	5	1,190	5,160	New River Mtns. and alluvial fan
3	64.6	17.6	9.9	101.9	.042	2.95	5	1,460	3,250	Tonto National Forest and alluvial fan
4	64.6	17.6	9.9	101.9	.031	2.19	5	1,460	3,250	Tonto National Forest and alluvial fan
5	70.0[2]	26.0	11.8	75.9	.054	4.99	5	1,243	3,220	Union Hills and alluvial fan
6	70.0[2]	26.0	11.8	75.9	.063	5.88	5	1,243	3,220	Union Hills and alluvial fan
7	0.51	1.5	.75	67.0	.076	.86	5	1,720	1,820	Alluvial fan
8	0.51	1.5	.75	67.0	.084	.95	5	1,720	1,820	Alluvial fan
9	0.51	1.5	.75	67.0	.070	.79	5	1,720	1,820	Alluvial fan
10	0.13	.77	.39	16.0	.107	.96	25	----	----	Fully urbanized, residential
11	0.13	.77	.39	16.0	.111	1.00	25	----	----	Fully urbanized, residential
12	67.3	20.2	9.7	141.4	.037	2.59	5	2,310	5,170	New River Mountains
13	67.3	20.2	9.7	141.4	.036	2.50	5	2,310	5,170	New River Mountains
14	85.7	26.2	12.4	121.6	.049	4.25	5	1,973	5,160	New River Mountains
15	85.7	26.2	12.4	121.6	.031	2.72	5	1,973	5,160	New River Mountains
16	142.0	27.7	13.6	64.2	.077	8.02	5	1,280	3,060	Phoenix Mountain and alluvial fan
17	142.0	27.7	13.6	64.2	.070	7.31	5	1,280	3,060	Phoenix Mountain and alluvial fan
18	142.0	27.7	13.6	64.2	.030	3.10	5	1,280	3,060	Phoenix Mountain and alluvial fan
19	323.0	55.5	20.6	73.6	.069	10.59	5	1,046	4,080	New River Mtns. and alluvial fan
20	323.0	55.5	20.6	73.6	.045	6.90	5	1,046	4,080	New River Mtns. and alluvial fan
21	718.0[3]	61.0	27.2	68.9	.059	10.68	5	950	5,150	New River Mtns. and alluvial fan
22	718.0[3]	61.0	27.2	68.9	.043	7.80	5	950	5,150	New River Mtns. and alluvial fan

Table 7.- Continued

S-graph No.	A	L	L_{ca}	S	n^1	Lag	RIMP	Watershed Elevation Min	Watershed Elevation Max	Type of Watershed or Geographical Name
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
23	2,490.0	84.5	36.3	42.1	.046	9.2	----	----	----	------------
24	607.0	78.0	46.8	41.0	.053	11.2	----	----	----	------------
25	220.0	27.2	10.3	95.0	.051	4.0	----	----	----	------------
26	740.0	61.2	34.3	85.0	.061	9.5	----	----	----	San Diego Mountains
27	645.0	46.0	22.0	105.0	.062	7.3	----	----	----	San Diego Mountains
28	168.0	26.0	11.3	150.0	.050	3.7	----	----	----	-----------
29	81.4	15.1	7.3	290.0	.052	2.5	0	2,200	5,000	San Gabriel Mountains
30	16.2	8.6	4.8	440.0	.046	1.5	0	----	----	San Gabriel Mountains
31	9.5	7.3	4.4	600.0	.046	1.3	----	900	4,700	San Gabriel Mountains
32	3.1	3.2	1.7	140.0	.029	0.6	----	----	----	San Gabriel Mountains
33	81.3	23.7	9.1	75.0	.032	2.4	18	----	----	San Gabriel Mountains
34	14.0	9.5	4.6	85.0	.011	.6	60	200	700	Fully urbanized
35	2.5	3.4	1.7	100.0	.014	.3	45	----	----	Fully urbanized
36	355.0	36.0	15.8	140.0	.060	5.6	----	----	----	San Diego Mountains
37	-----	----	----	-----	----	---	----	----	----	-----------
38	10.8	5.1	2.1	898.0	.050	1.1	0	----	----	San Gabriel Mountains
39	10.8	5.1	2.1	898.0	----	---	0	----	----	San Gabriel Mountains
40	10.8	5.1	2.1	898.0	----	---	0	----	----	San Gabriel Mountains
41	-----	----	----	-----	----	---	----	----	----	----------
42	7.7	----	----	-----	.050	---	----	----	----	Santa Ynez Mountains

Table 7.- Continued

S-graph No.	A	L	L_{ca}	S	n[1]	Lag	RIMP	Watershed Elevation Min	Watershed Elevation Max	Type of Watershed or Geographical Name
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
43	2.3	2.9	1.5	700.0	.052	0.8	0	100	3,000	San Gabriel Mountains
44	162.0	23.2	11.6	350.0	----	---	0	1,500	2,500	San Gabriel Mountains
45	162.0	23.2	11.6	350.0	.053	3.3	0	1,500	6,700	San Gabriel Mountains
46	40.4	11.4	3.9	400.0	----	---	0	1,500	6,700	San Gabriel Mountains
47	40.4	11.4	3.9	400.0	.051	1.6	0	2,500	5,000	San Gabriel Mountains
48	40.4	11.4	3.9	400.0	----	---	0	2,500	5,000	San Gabriel Mountains
49	-----	----	----	-----	----	---	---	----	----	San Gabriel Mountains
50	26.8	11.4	5.7	310.0	.016	0.64	25	450	1,500	San Gabriel Mountains
51	-----	----	----	-----	----	---	---	----	----	-----------
52	1,360.0	106.3	55.2	72.4	.057	12.9	---	----	----	Rocky Mountains
53	6.9	6.4	3.4	312.0	.036	1.0	---	----	----	Rocky Mtns., foothills
54	-----	----	----	-----	----	---	---	----	----	-----------
55	-----	----	----	-----	----	---	---	----	----	-----------

A - Drainage area, in sq. miles
L - Length of longest watercourse, in miles
L_{ca} - Length of watercourse to point opposite basin centroid, in miles
S - Watercourse slope, in feet/mile
n - Manning's coefficient
Lag - Basin lag, in hours
RIMP - Impervious area of watershed, in percent of total area

Notes: 1. This is the n required to satisfy the lag equation $\text{Lag} = 26n\left(\frac{LL_{ca}}{S^{.5}}\right)^{.33}$

2. Contributing drainage area; total drainage area is 252 sq. miles.
3. Contributing drainage area; total drainage area is 2,013 sq. miles.

Table 8.- Comparison of synthetic S-graphs that are generated from Clark unit-hydrographs.
Time-area relation = HEC-1 default relation
Duration of rainfall excess = 20 percent time of concentration

T_c/R	Lag	Duration of rainfall excess		% Lag at indicated % Q_{ult}					Mid-range Slope in
	% of T_c	% of T_c	% of Lag	20%	40%	60%	80%	100%	% Q/% Lag
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
4.0	83	20	24	64	89	111	137	313	.91
3.0	89	20	22	65	89	111	140	358	.91
2.0	101	20	20	64	88	111	147	457	.87
1.75	105	20	19	64	88	112	150	473	.83
1.5	112	20	18	63	88	114	155	518	.77
1.25	120	20	17	63	88	115	161	566	.74
1.0	133	20	15	61	86	116	166	629	.67
.75	156	20	13	58	84	118	180	695	.59
.5	200	20	10	53	82	122	190	798	.50
.25	333	20	6	45	78	126	208	922	.42

Table 9.- Effect of duration of rainfall excess on synthetic S-graphs that are generated from Clark unit-hydrographs.
Time-area relation = HEC-1 default relation

T_c/R	Lag	Duration of rainfall excess		% Lag at indicated % Q_{ult}					Mid-range Slope in
	% of T_c	% of T_c	% of Lag	20%	40%	60%	80%	100%	% Q/% Lag
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1.0	128	10	8	60	85	117	172	674	.62
1.0	133	75	77	61	86	117	169	620	.65
1.0	133	20	15	61	86	117	168	629	.65
1.0	137	25	18	61	86	116	166	640	.67

Table 10.- Effect of watershed shape as represented by the time-area relation on synthetic S-graphs that are generated from Clark unit-hydrographs.
Duration of rainfall excess = 20 percent time of concentration

T_c/R	Lag % of T_c	Duration of rainfall excess % of T_c	Duration of rainfall excess % of Lag	% Lag at indicated % Q_{ult} 20%	40%	60%	80%	100%	Mid-range Slope in % Q/% Lag
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Elliptic shaped watershed (HEC-1 default equation)									
1.0	133	20	15	61	86	116	166	629	.67
Inverted diamond shaped watershed									
1.0	115	20	17	54	84	119	179	711	.57
Triangular shaped watershed									
1.0	151	20	13	67	88	115	160	556	.74

FIGURES

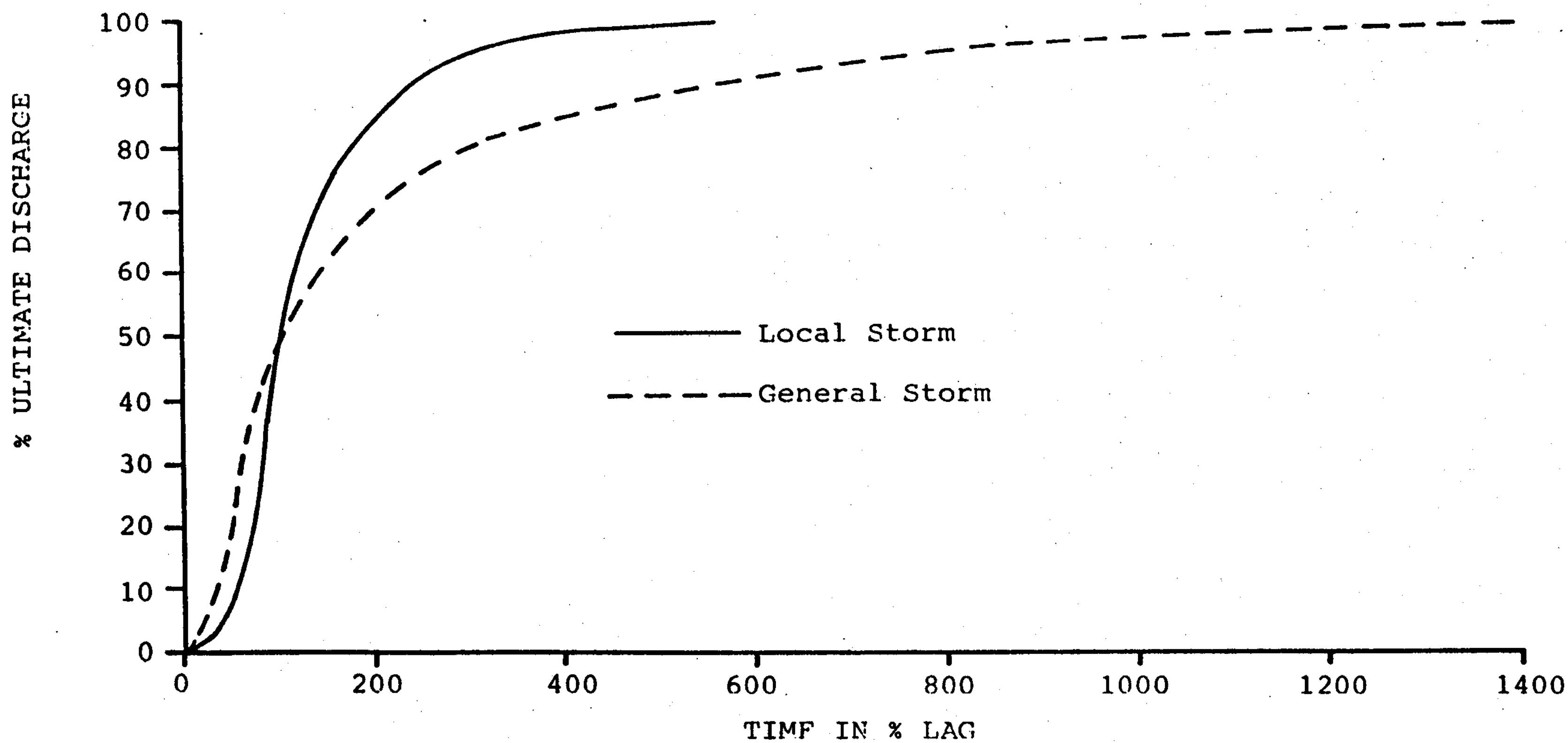


Figure 1.- Comparison of S-graphs that have been defined from reconstitutions of a local storm (#20) and a general storm (#19), respectively, for Santa Anita Creek.

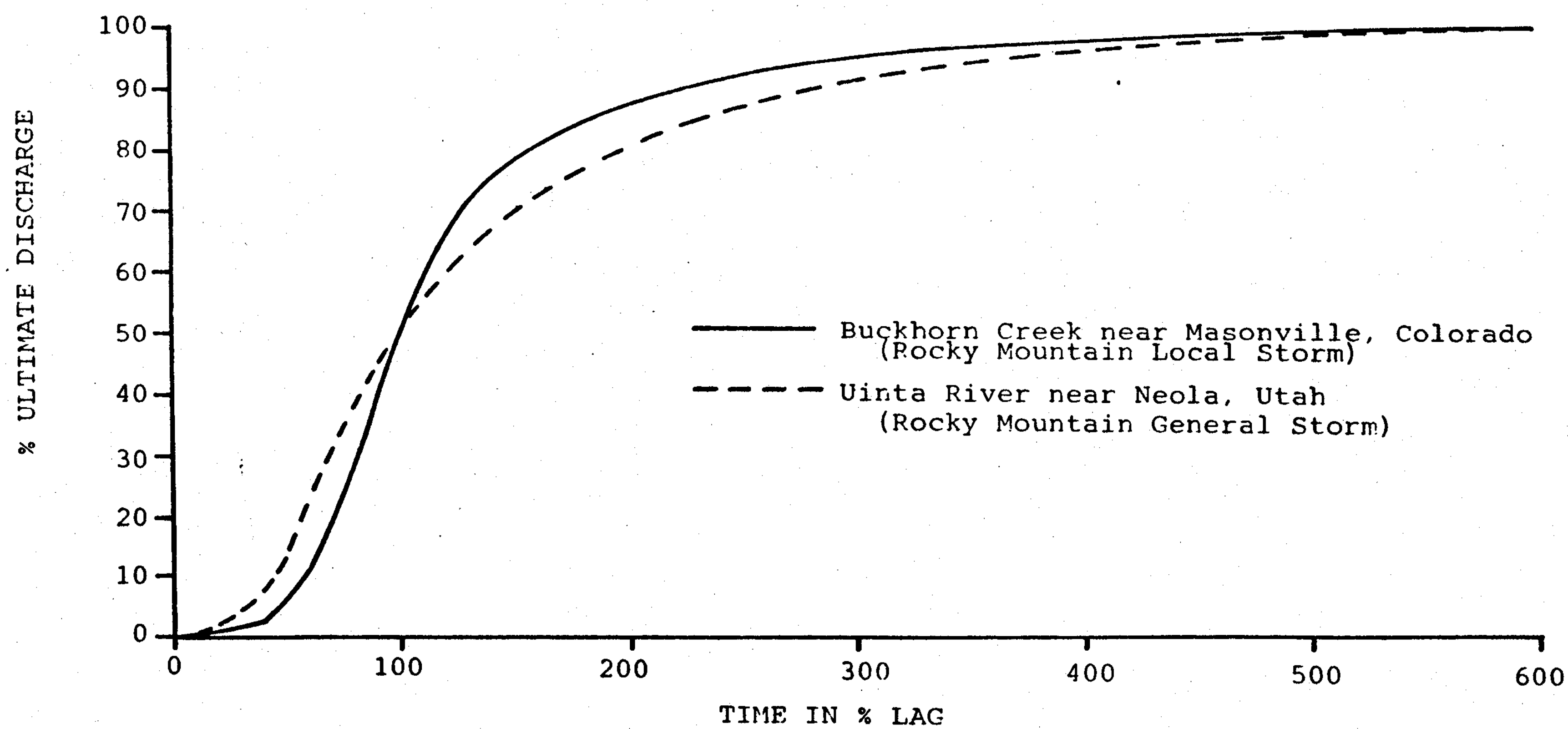


Figure 2.- Comparison of S-graphs that are recommended for use with local storms (#33) and general storms (#34) in the Rocky Mountains.

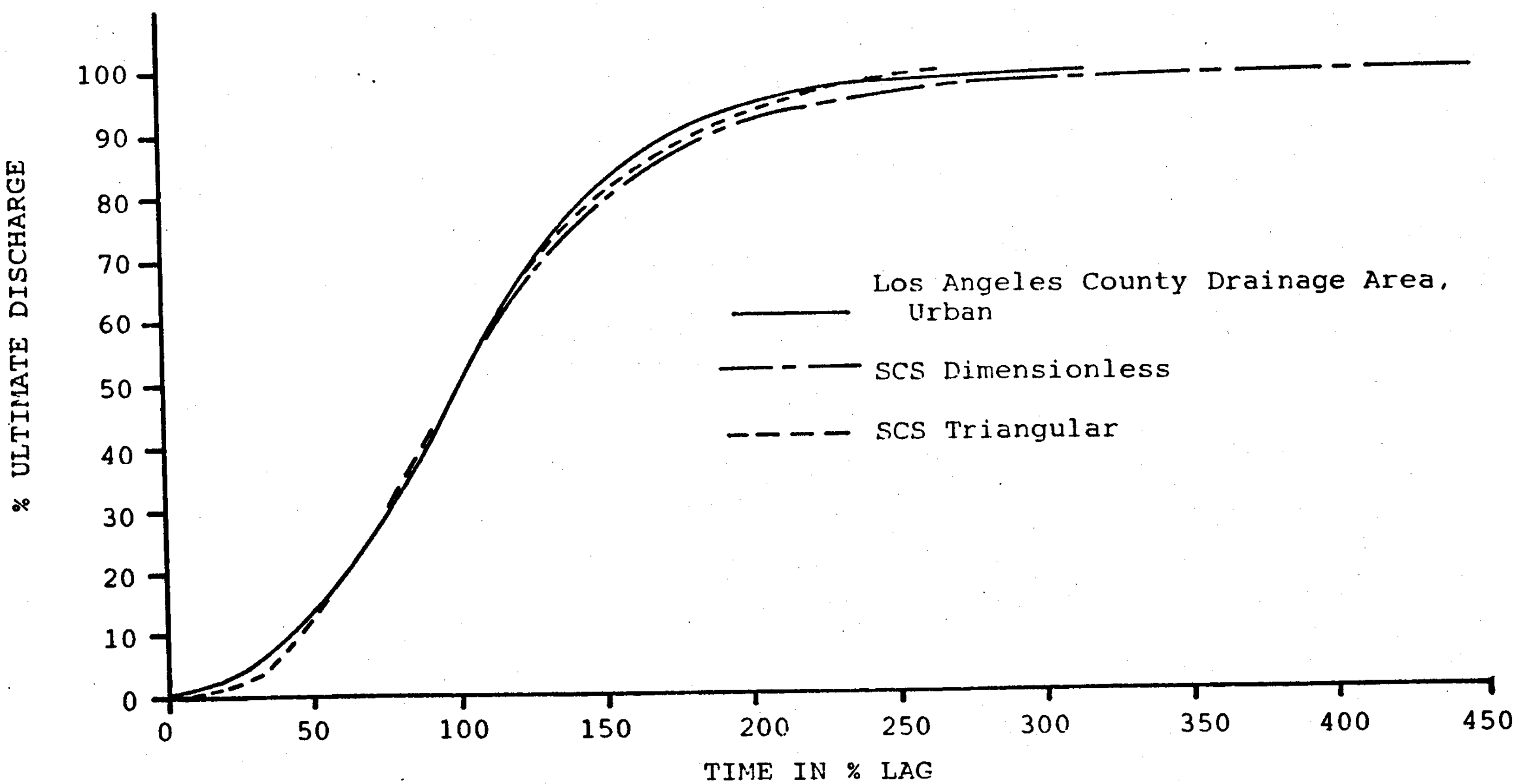


Figure 3.- Comparison of the Los Angeles County Drainage Area Urban S-graph (#51) to the S-graphs that have been developed from the SCS Dimensionless unit-hydrograph (#55) and the SCS Triangular unit-hydrograph (#56).

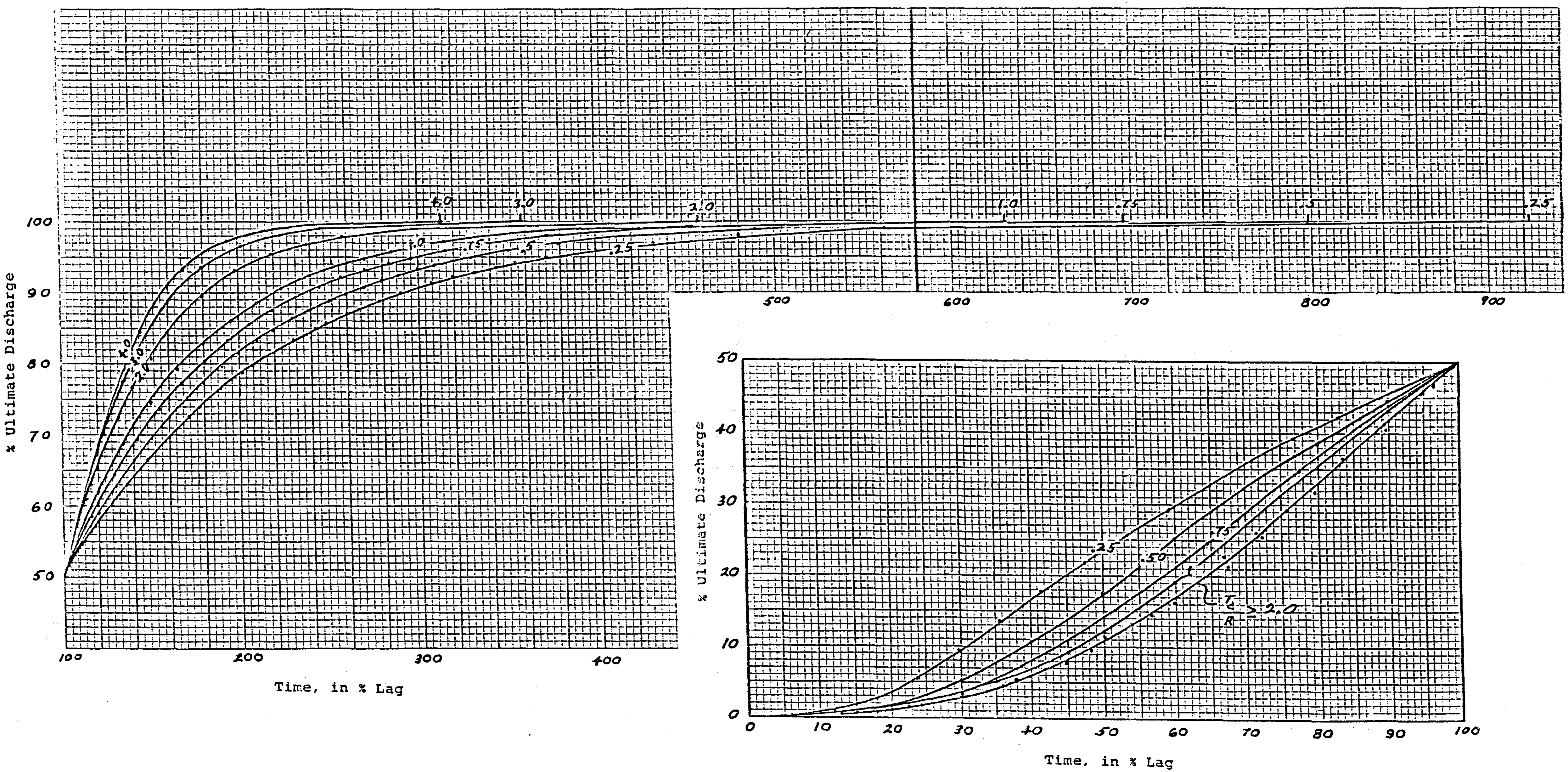


Figure 4.- S-graphs that have been synthesized from Clark unit-hydrographs. The time-area relation is according to the HEC-1 default equation, and the duration of rainfall excess is 20 percent of T_c.

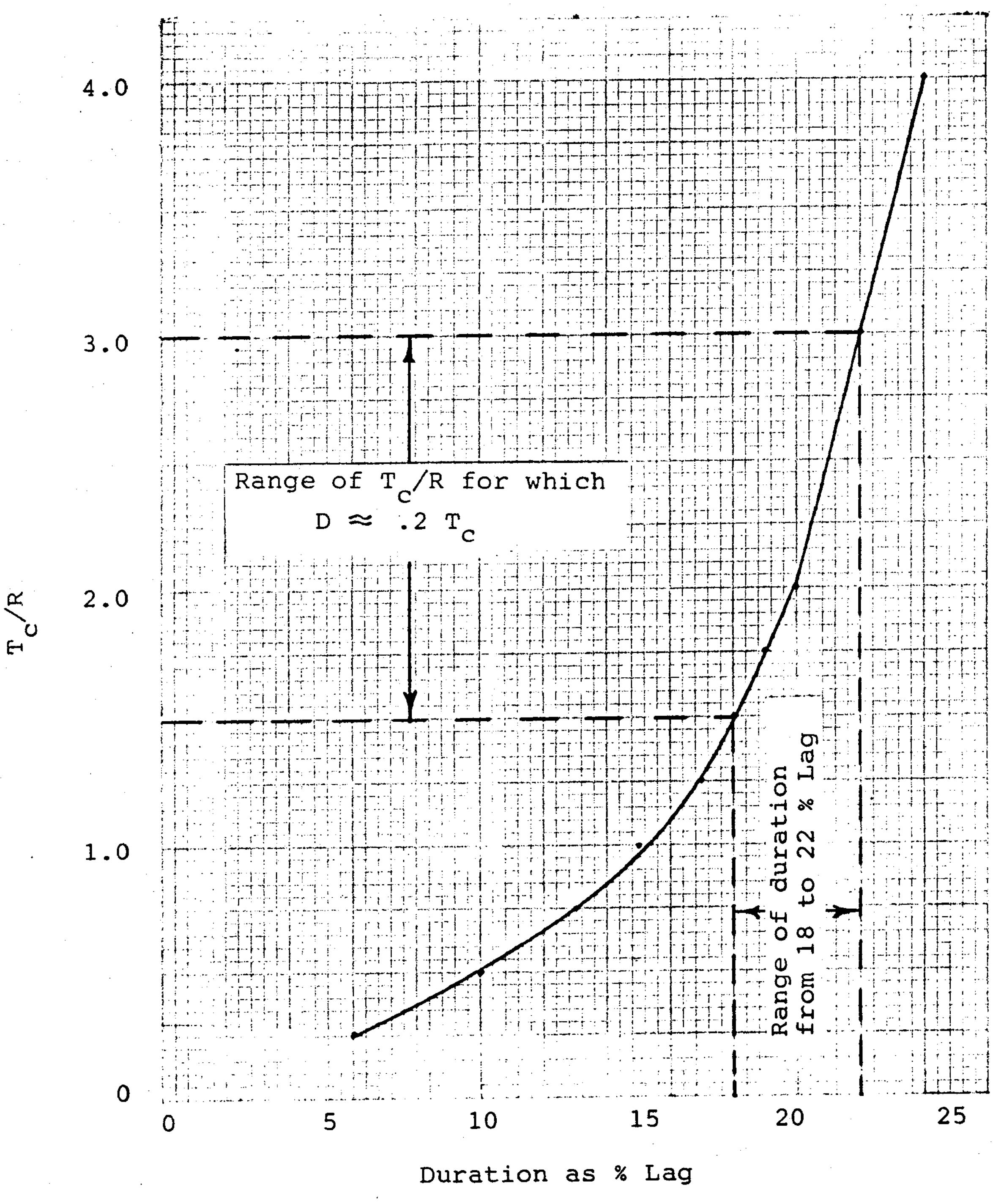


Figure 5.- Relation of the T_c/R ratio to duration of rainfall excess for synthetic S-graphs that are generated from Clark unit-hydrographs.

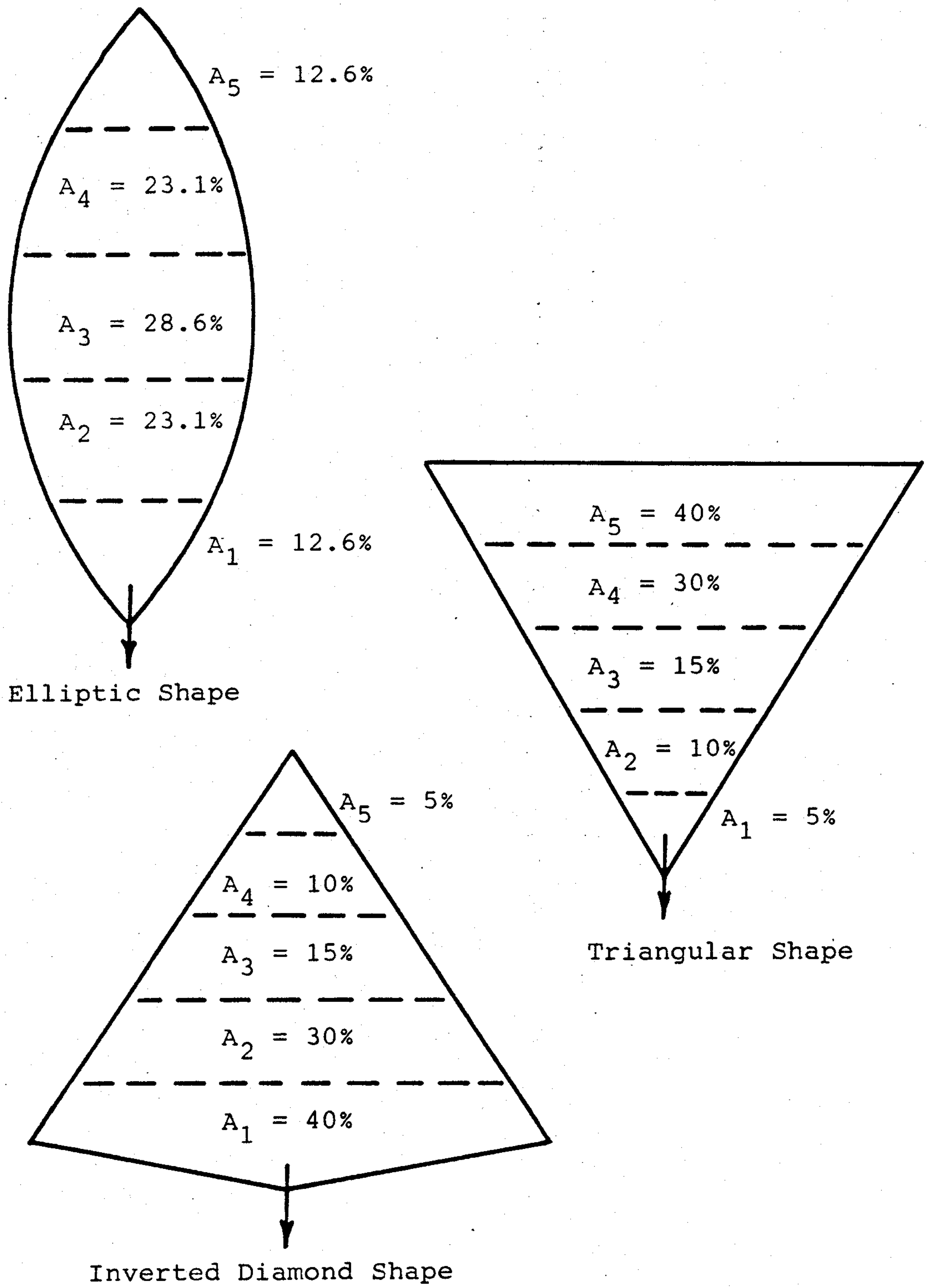


Figure 6.- Watershed shapes that have been considered for the synthesis of S-graphs from the Clark unit-hydrograph. Each is divided by isochrones of equal travel time with percent total area in each subarea for the time-area relation.

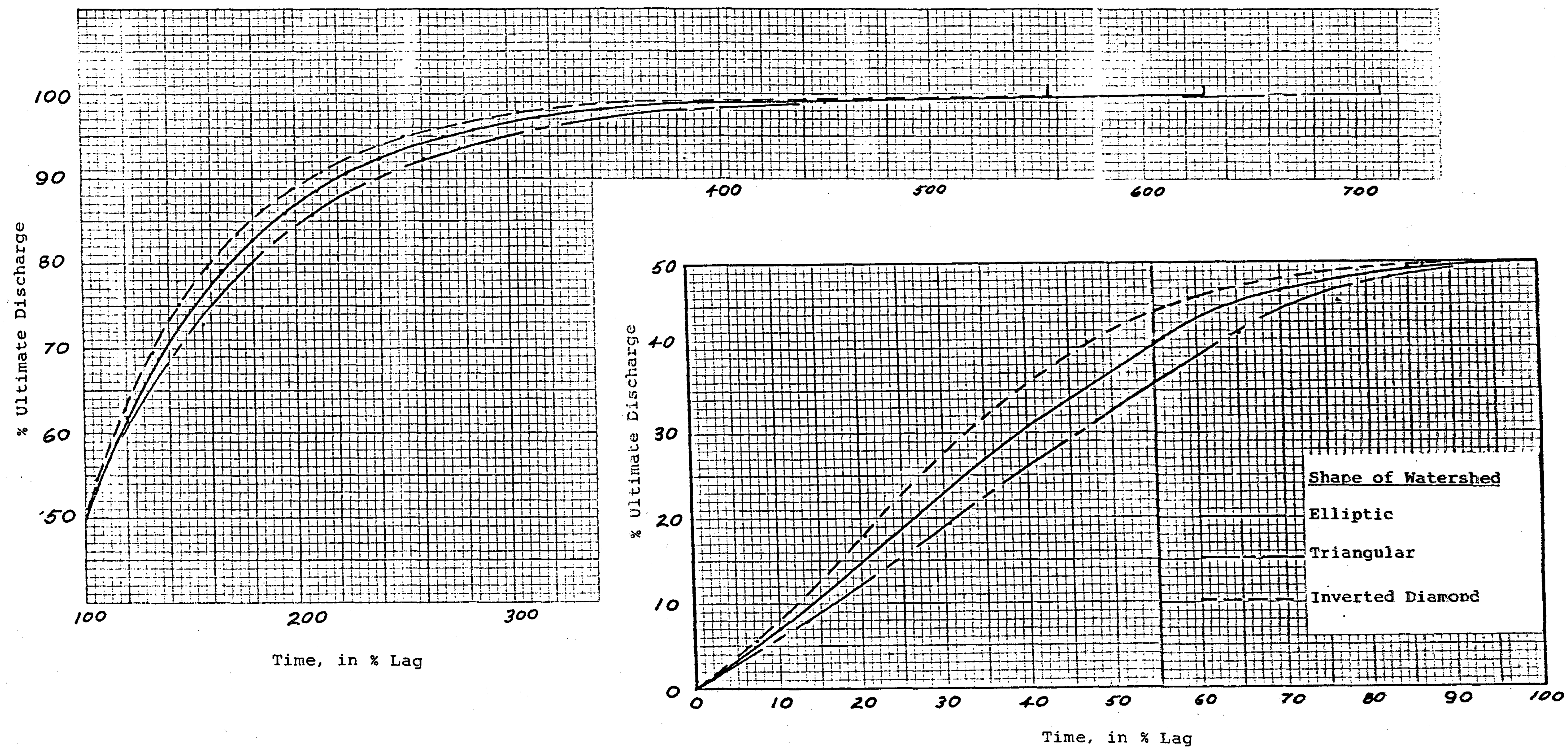


Figure 7.- Effect of watershed shape as represented by the time-area relation on synthetic S-graphs that are generated from Clark unit-hydrographs. The ratio of $T_c/R = 1.0$ for all cases, and the duration of rainfall excess is 20 percent of T_c.

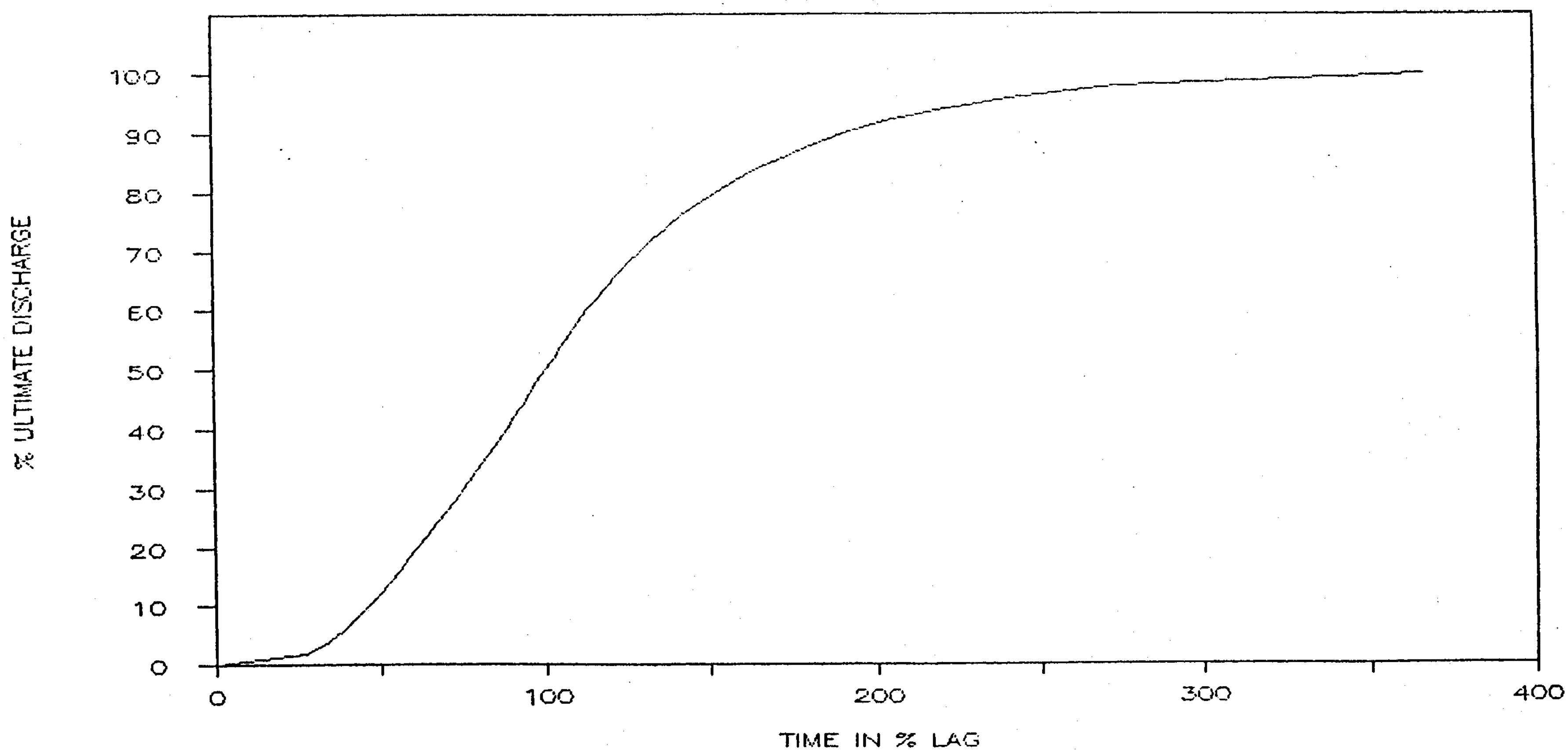
APPENDIX A

Graphs of Compiled S-Graphs

Each S-graph is presented in two separate figures; each with a different abscissa (Percent Lag) scale. The first figure presents the S-graph at full scale. The second figure is presented with the abscissa extending to either 700 or 1400 Percent Lag. The second figure can be used to compare the relative shapes of various S-graphs.

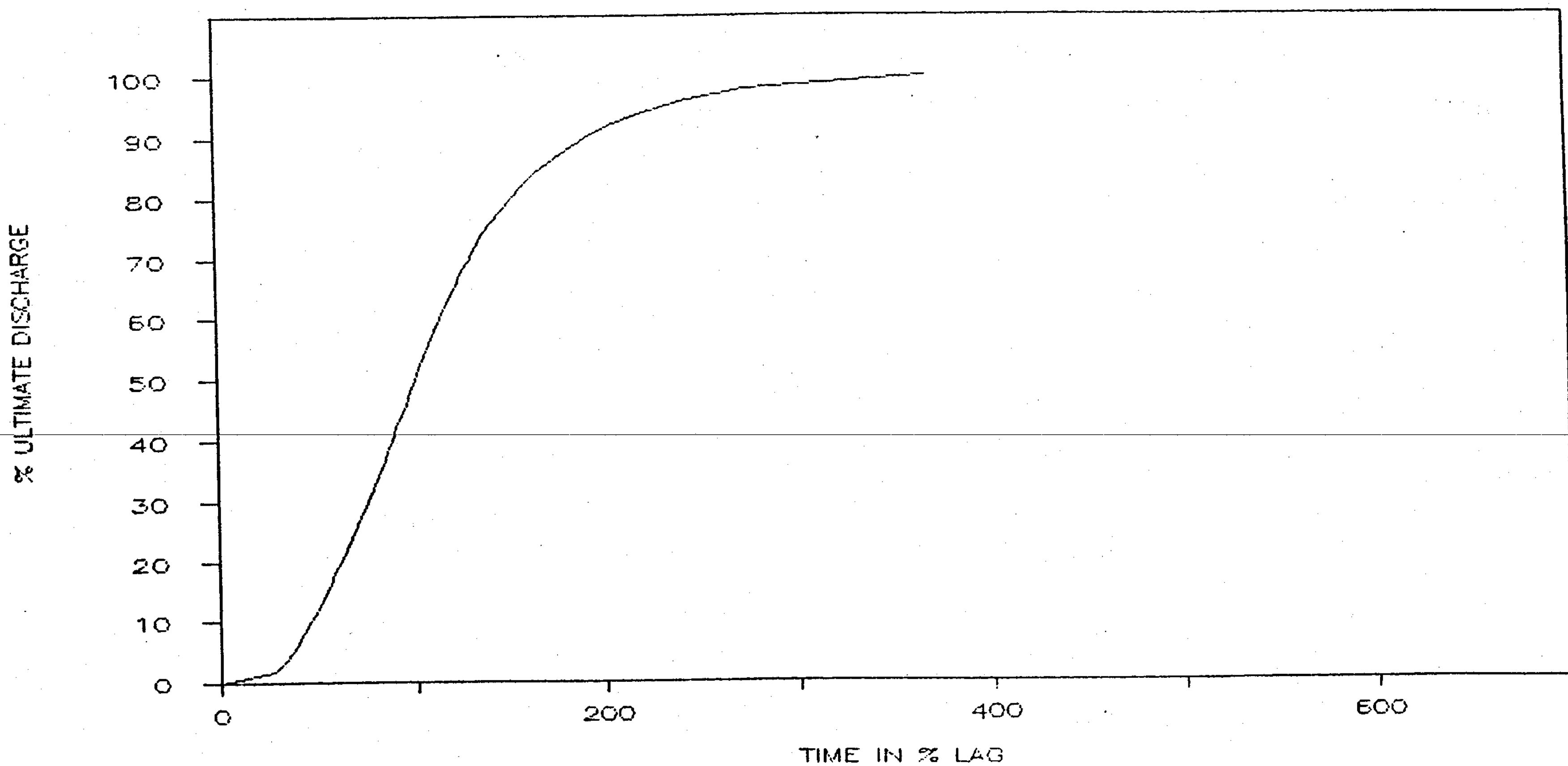
#1 NEW RIVER AT BELL ROAD

DECEMBER 1967



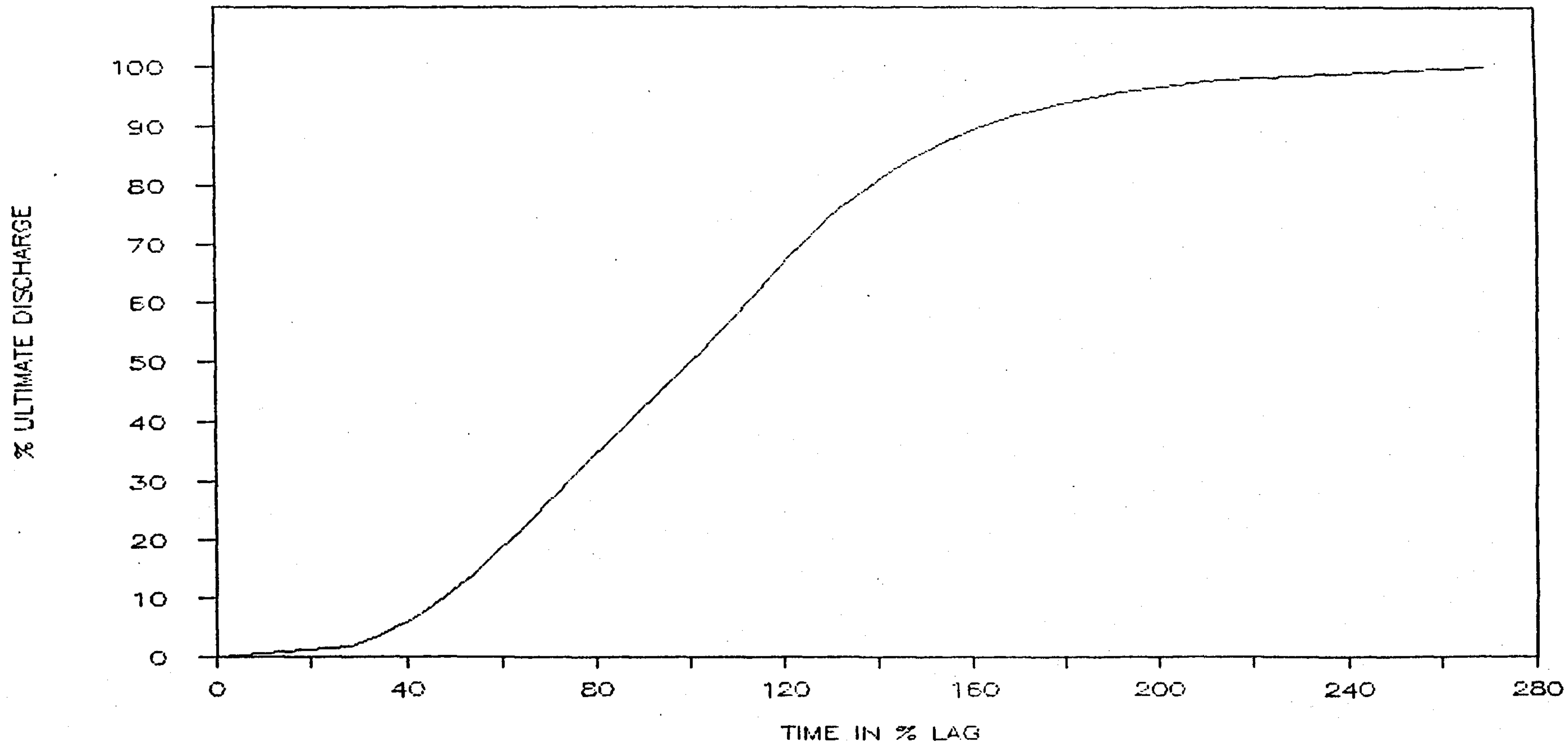
#1 NEW RIVER AT BELL ROAD

DECEMBER 1967



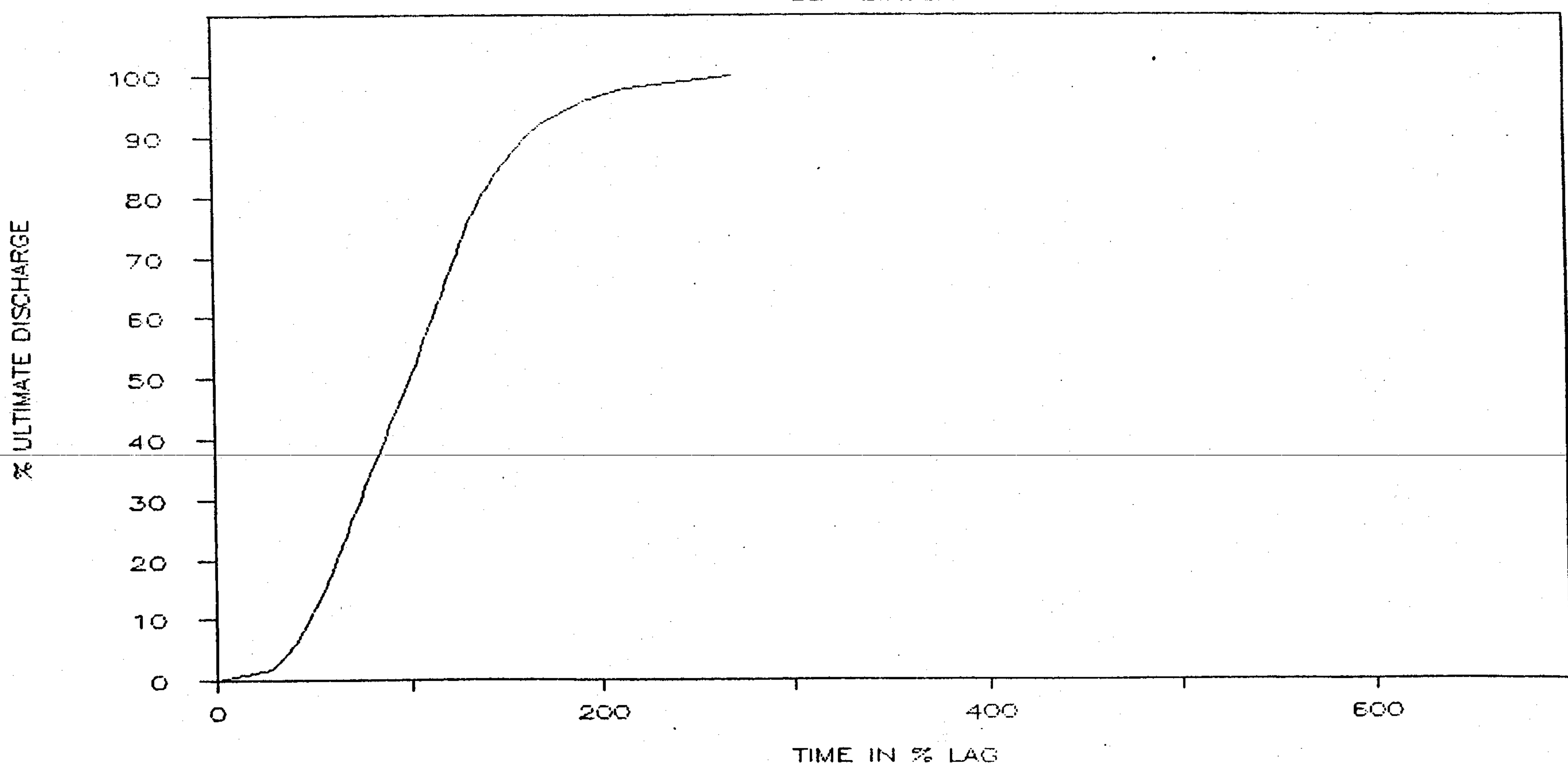
#2 NEW RIVER AT BELL ROAD

SEPTEMBER 1970



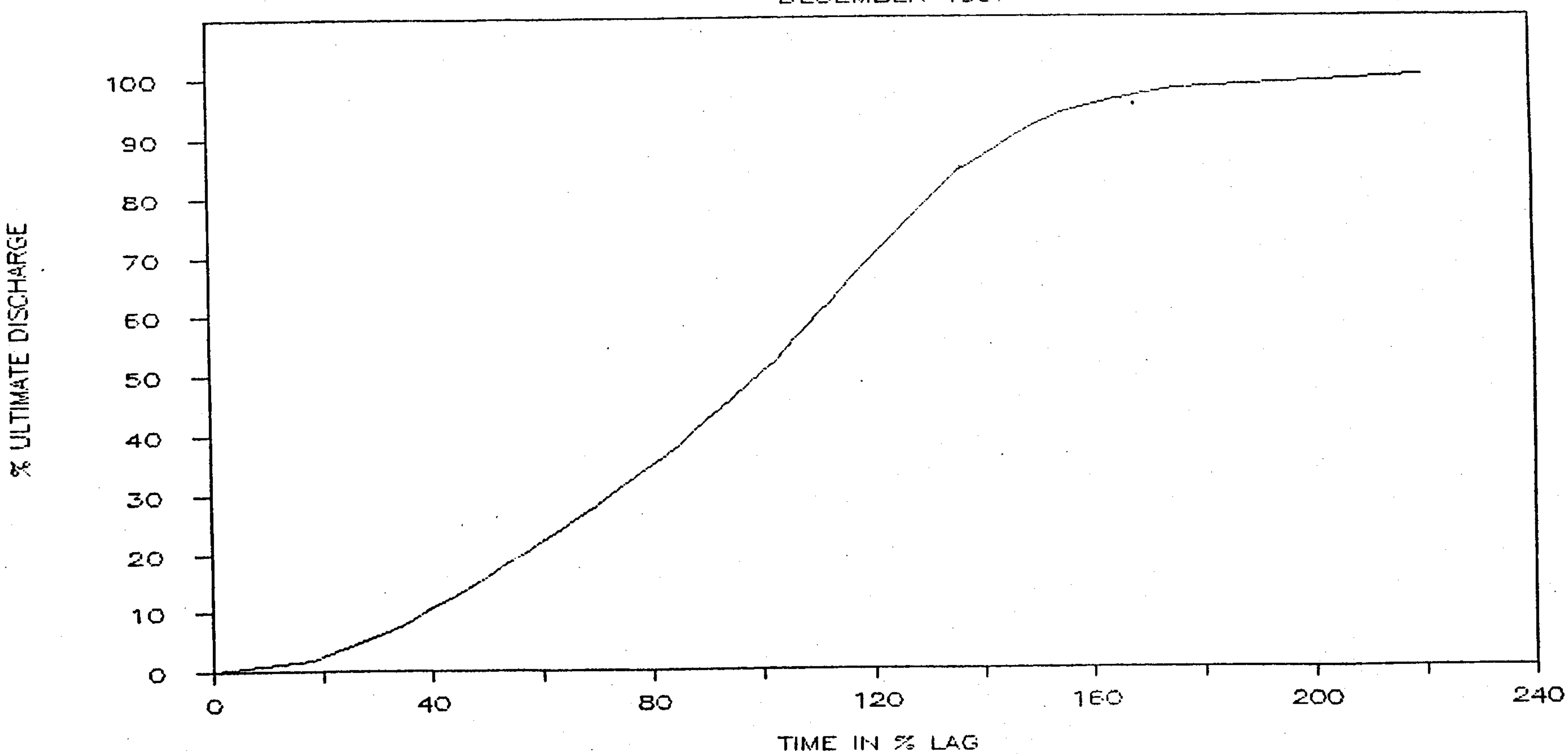
#2 NEW RIVER AT BELL ROAD

SEPTEMBER 1970



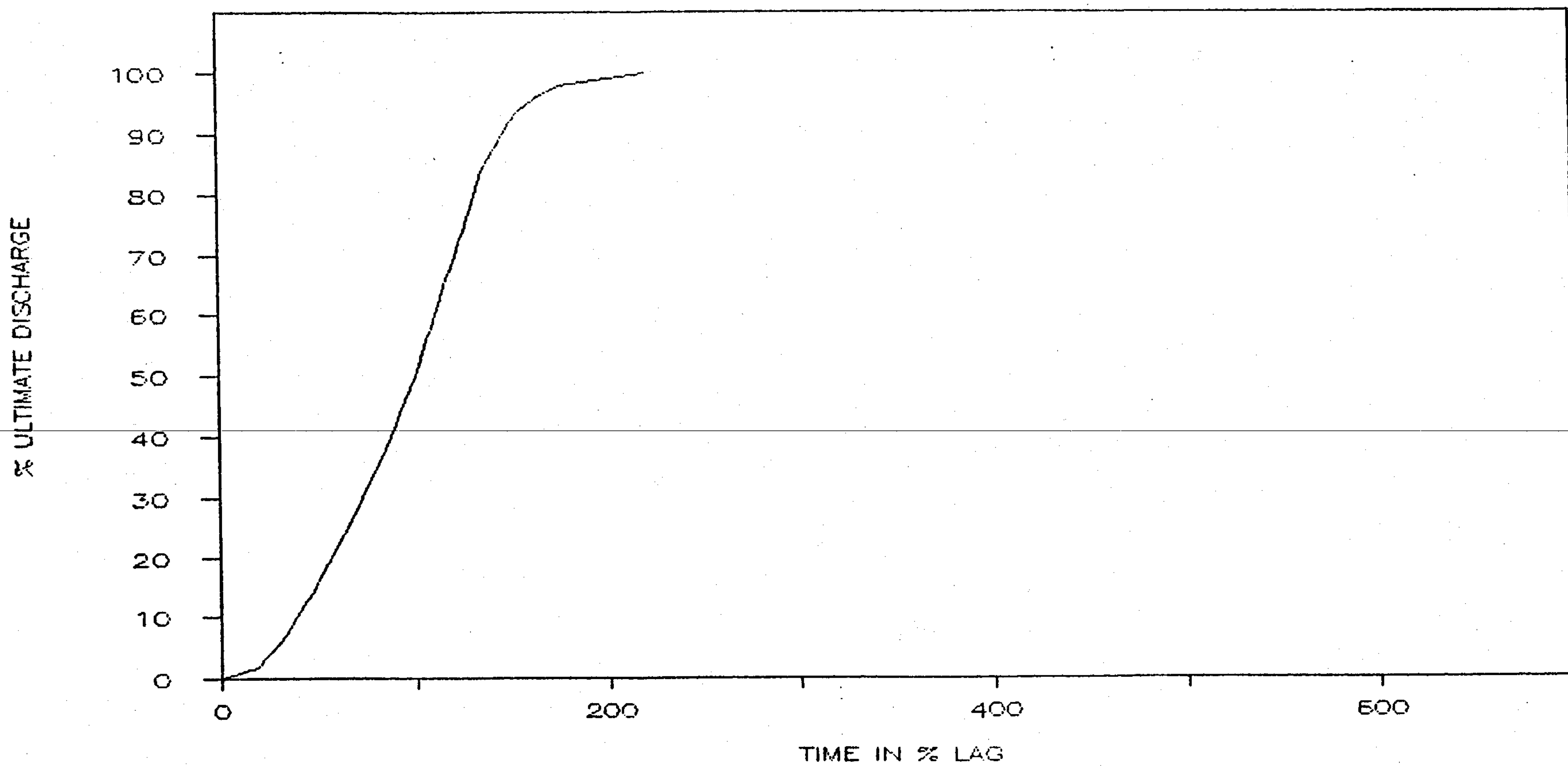
#3 SKUNK CREEK NEAR PHOENIX

DECEMBER 1967



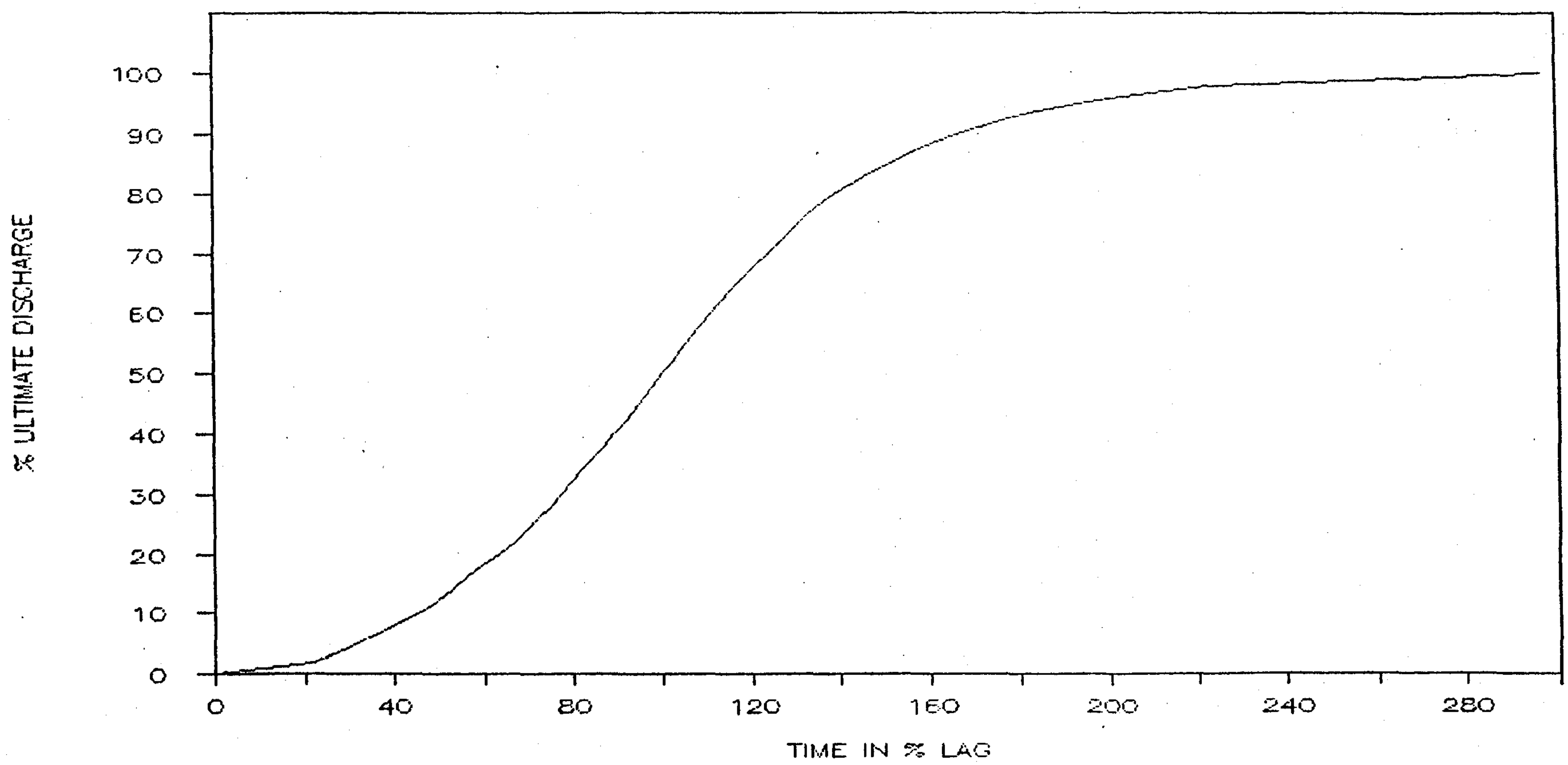
#3 SKUNK CREEK NEAR PHOENIX

DECEMBER 1967



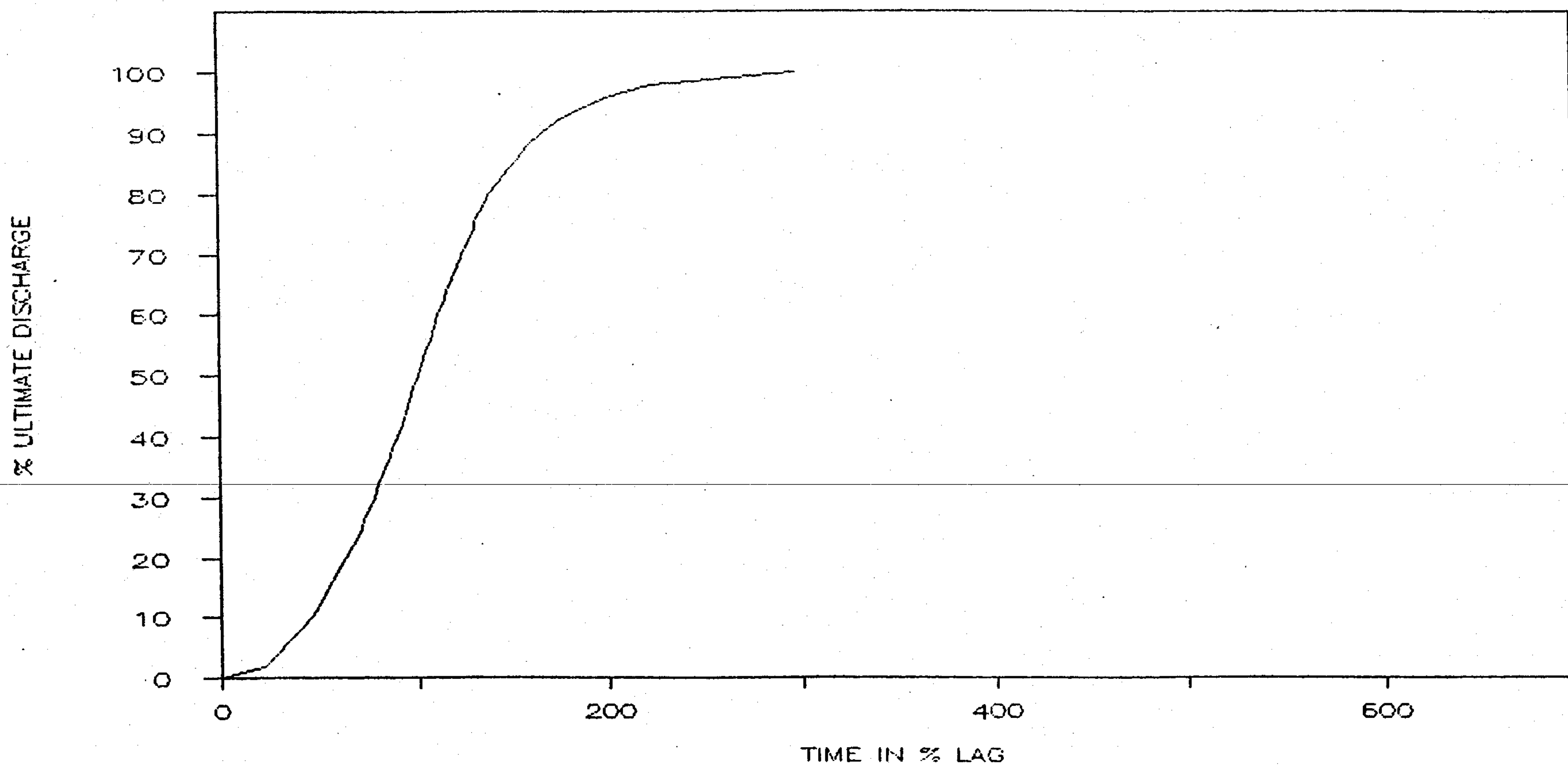
#4 SKUNK CREEK NEAR PHOENIX

SEPTEMBER 1970



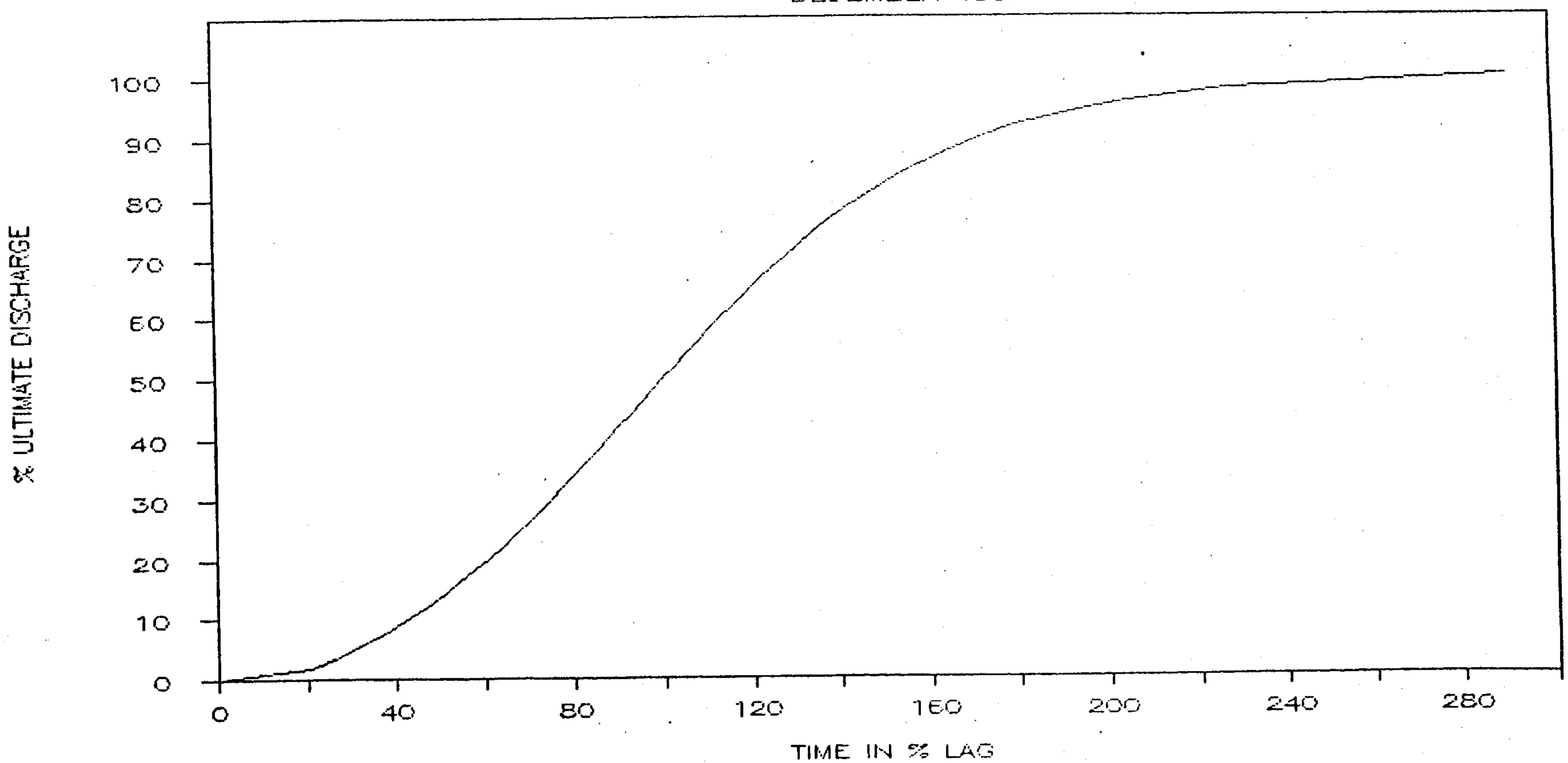
#4 SKUNK CREEK NEAR PHOENIX

SEPTEMBER 1970



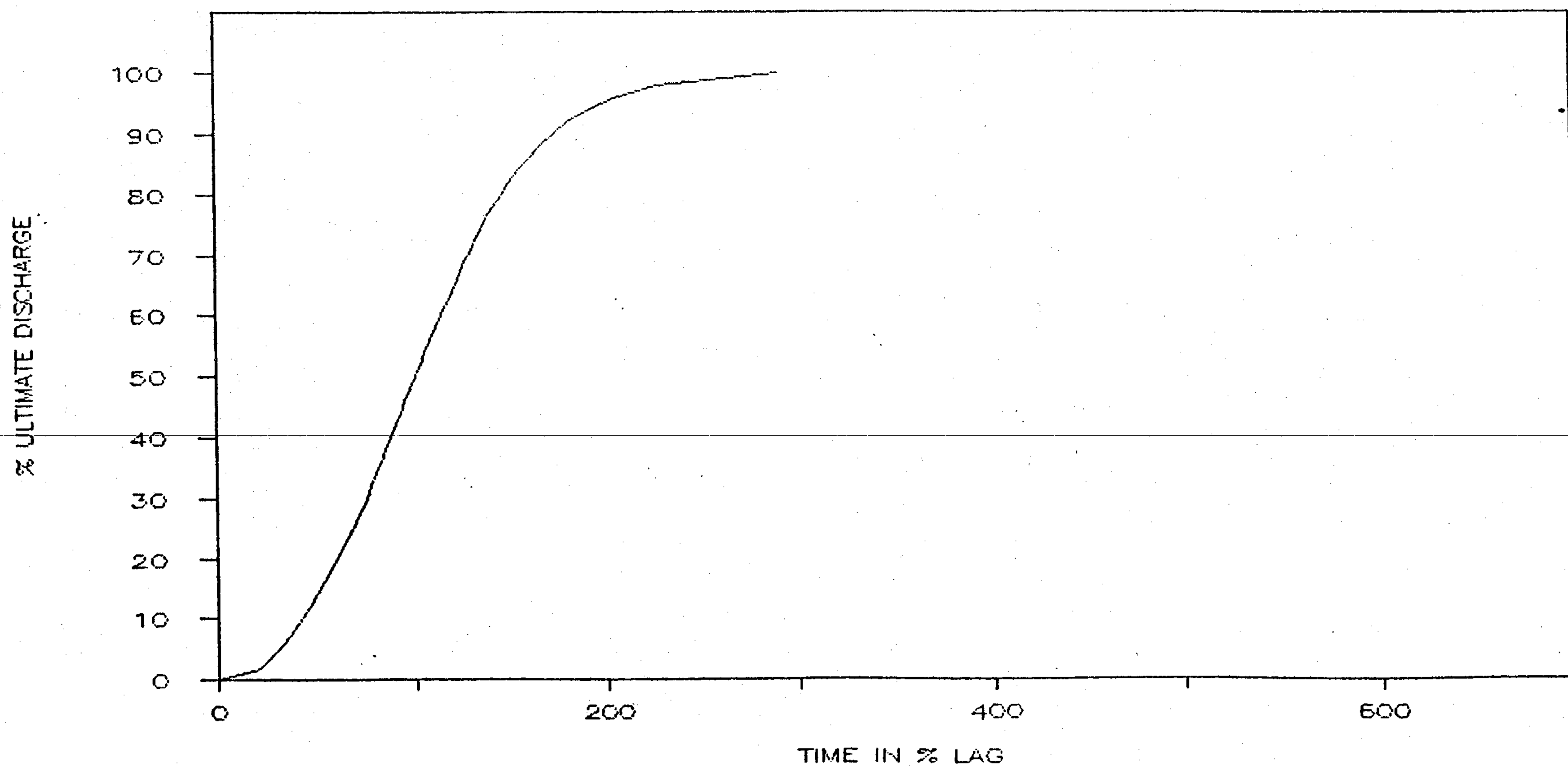
#5 CAVE CREEK AT PHOENIX

DECEMBER 1967



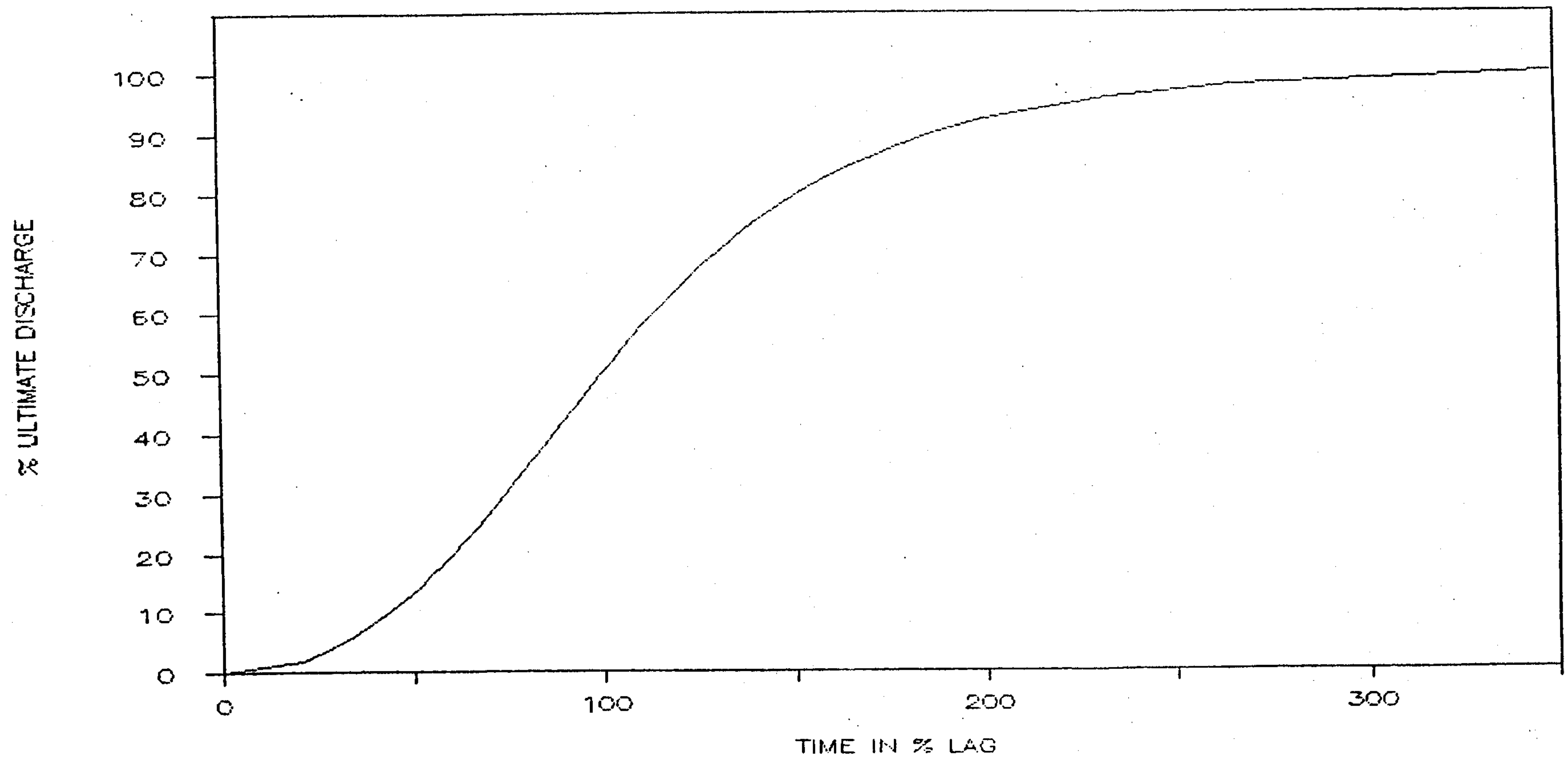
#5 CAVE CREEK AT PHOENIX

DECEMBER 1967



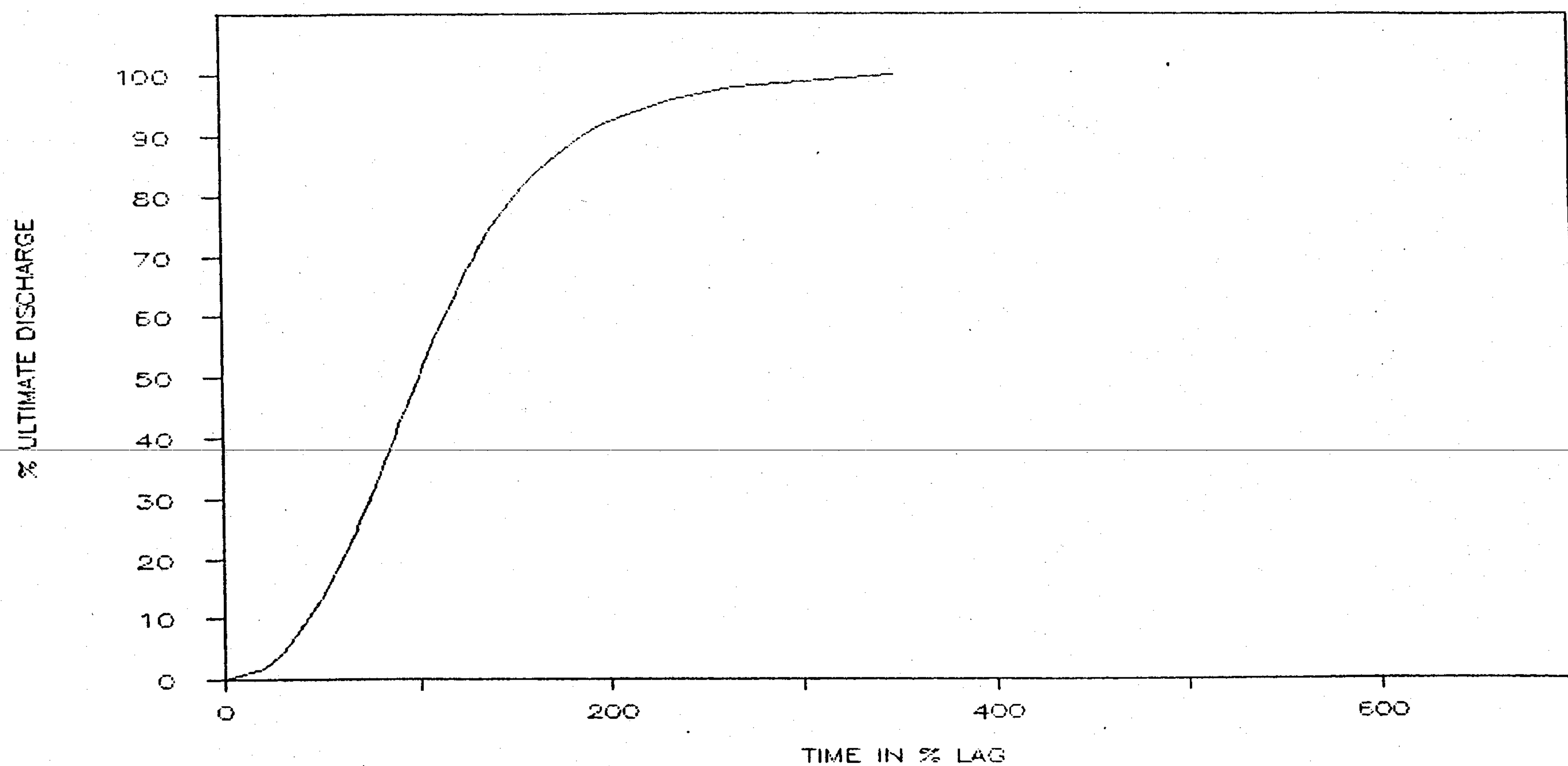
#6 CAVE CREEK AT PHOENIX

SEPTEMBER 1970



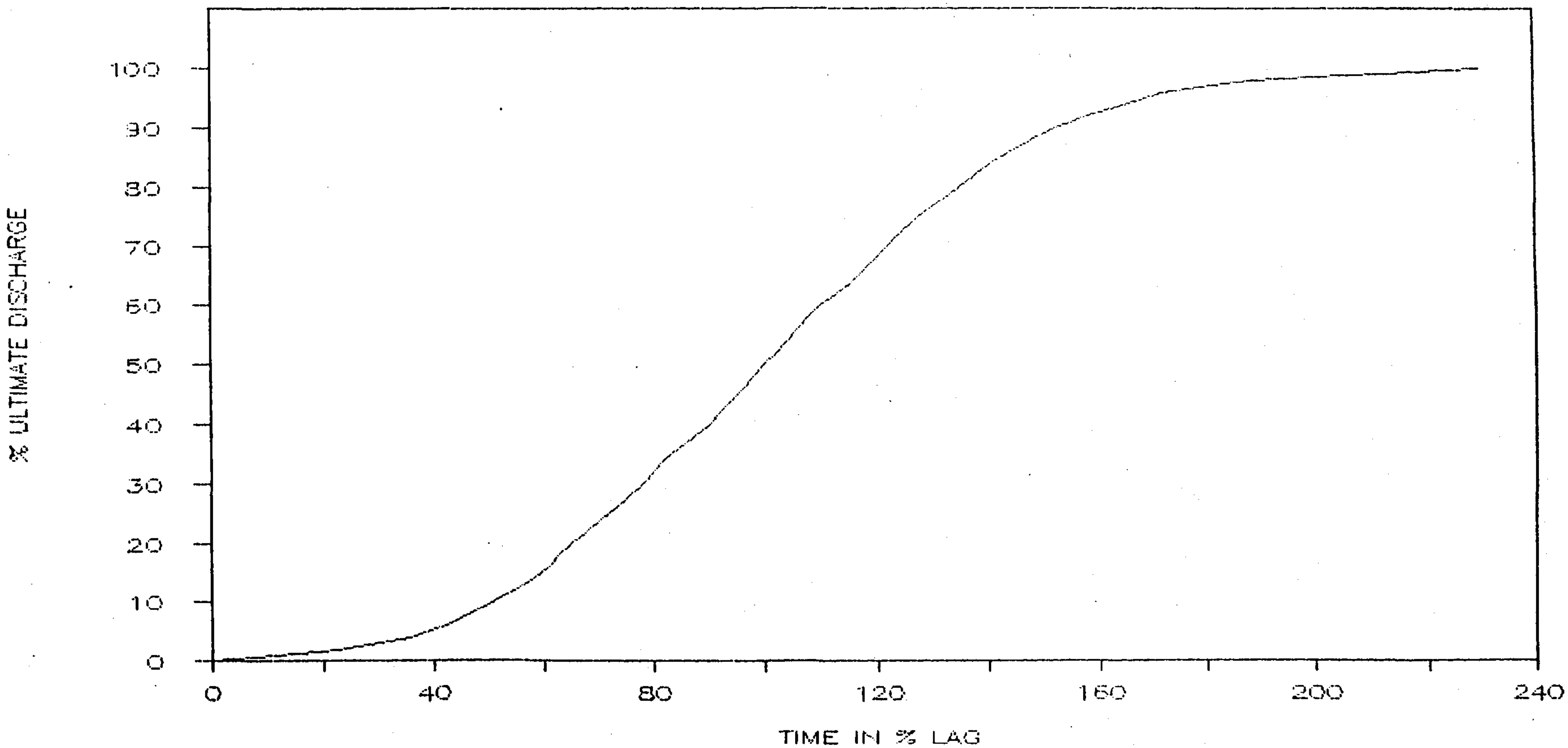
#6 CAVE CREEK AT PHOENIX

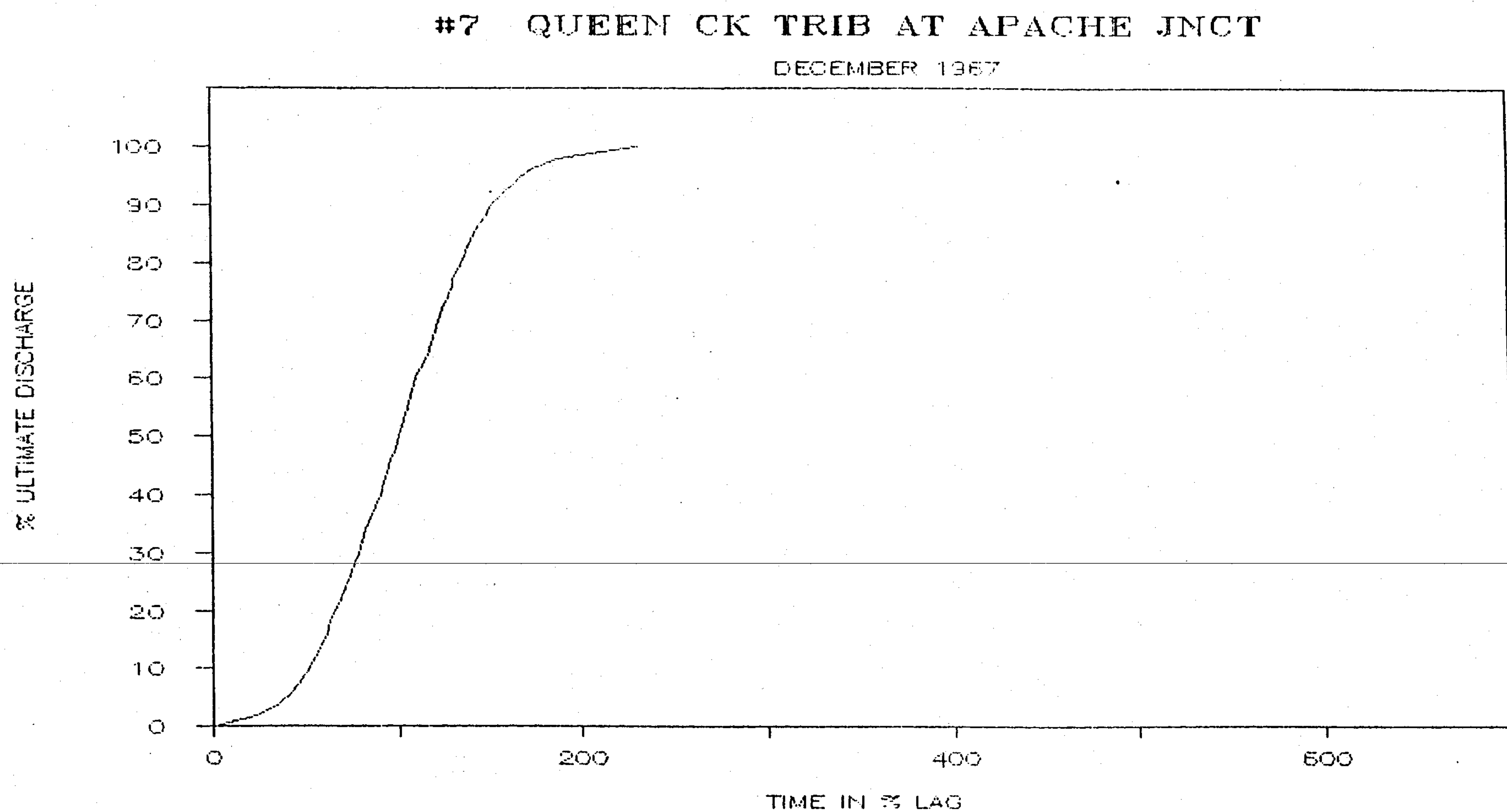
SEPTEMBER 1970



#7 QUEEN CK TRIB AT APACHE JNCT

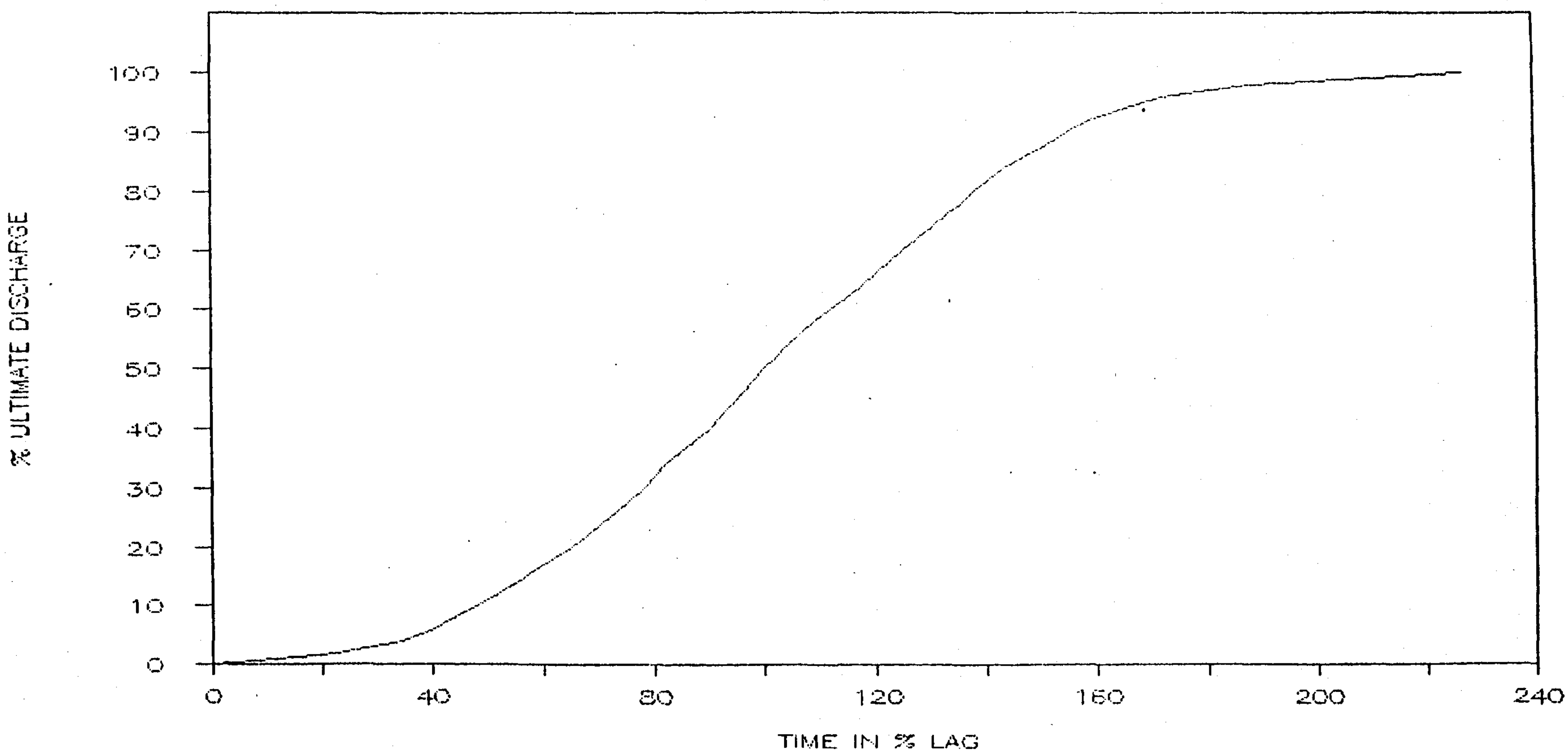
DECEMBER 1967




#7 QUEEN CK TRIB AT APACHE JNCT
DECEMBER 1967
% ULTIMATE DISCHARGE
100
90
80
70
60
50
40
30
20
10
0
0
200
400
600
TIME IN % LAG

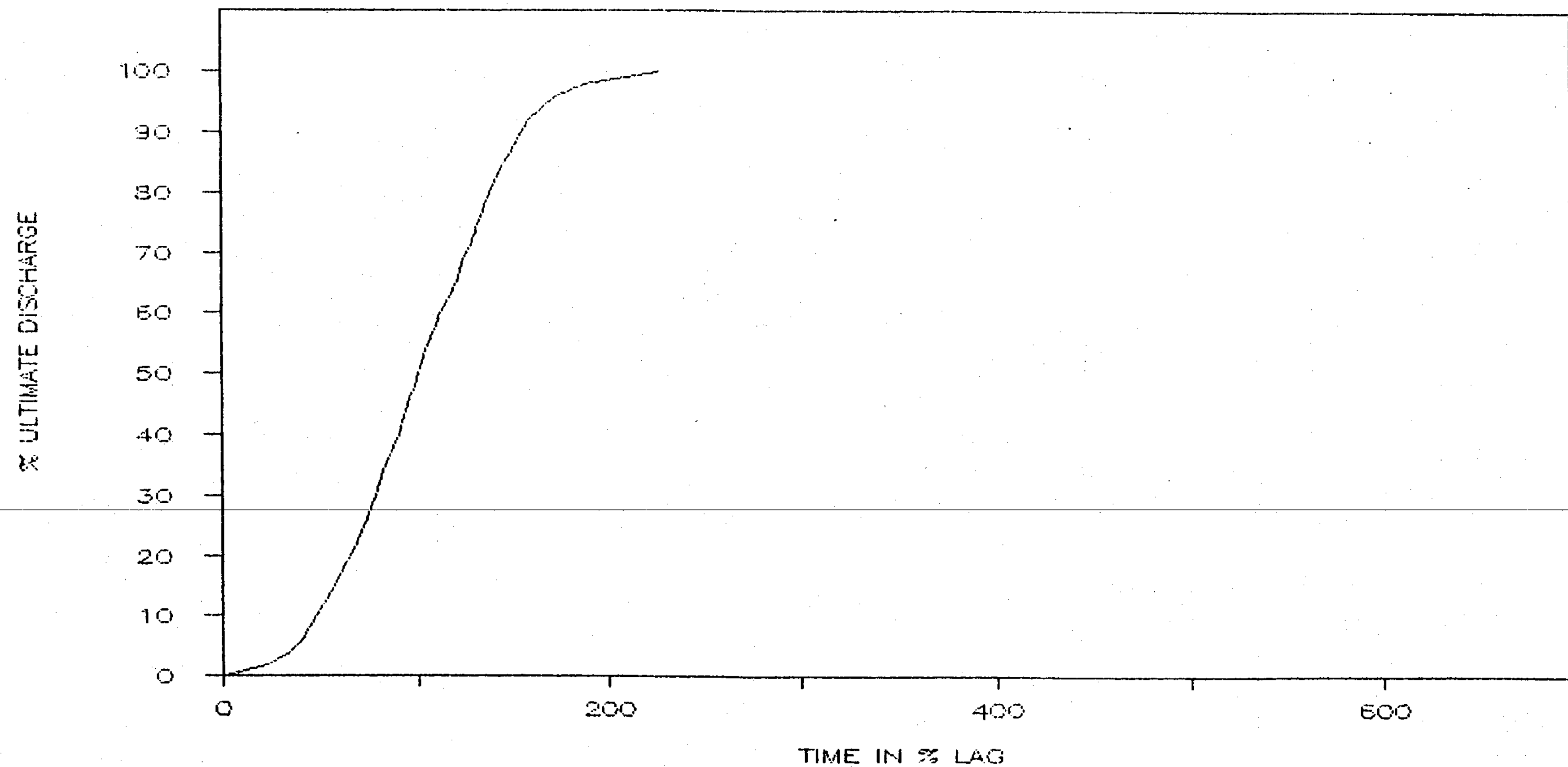
#8 QUEEN CK TRIB AT APACHE JNCT

SEPTEMBER 1970 PART 1



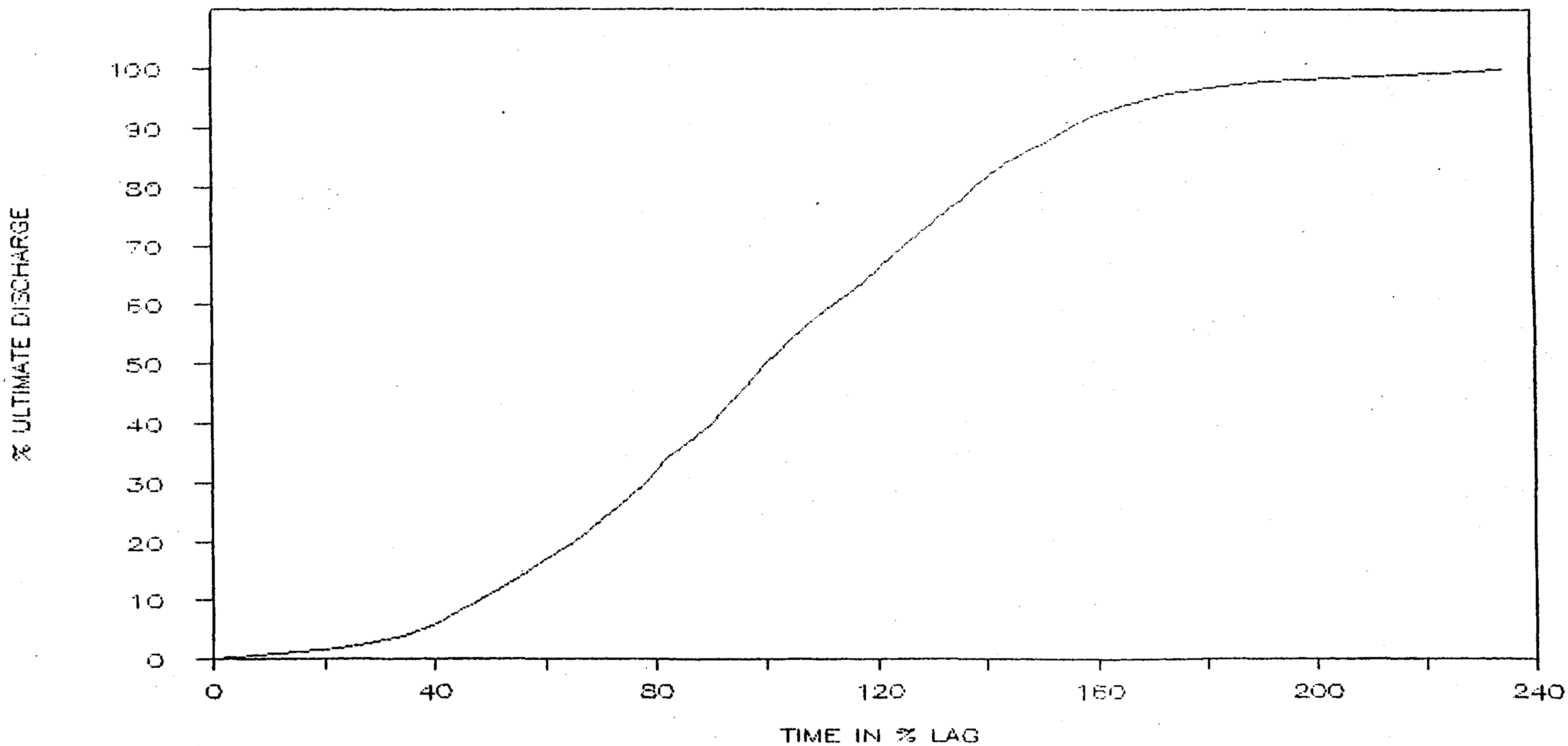
#8 QUEEN CK TRIB AT APACHE JNCT

SEPTEMBER 1970 PART 1



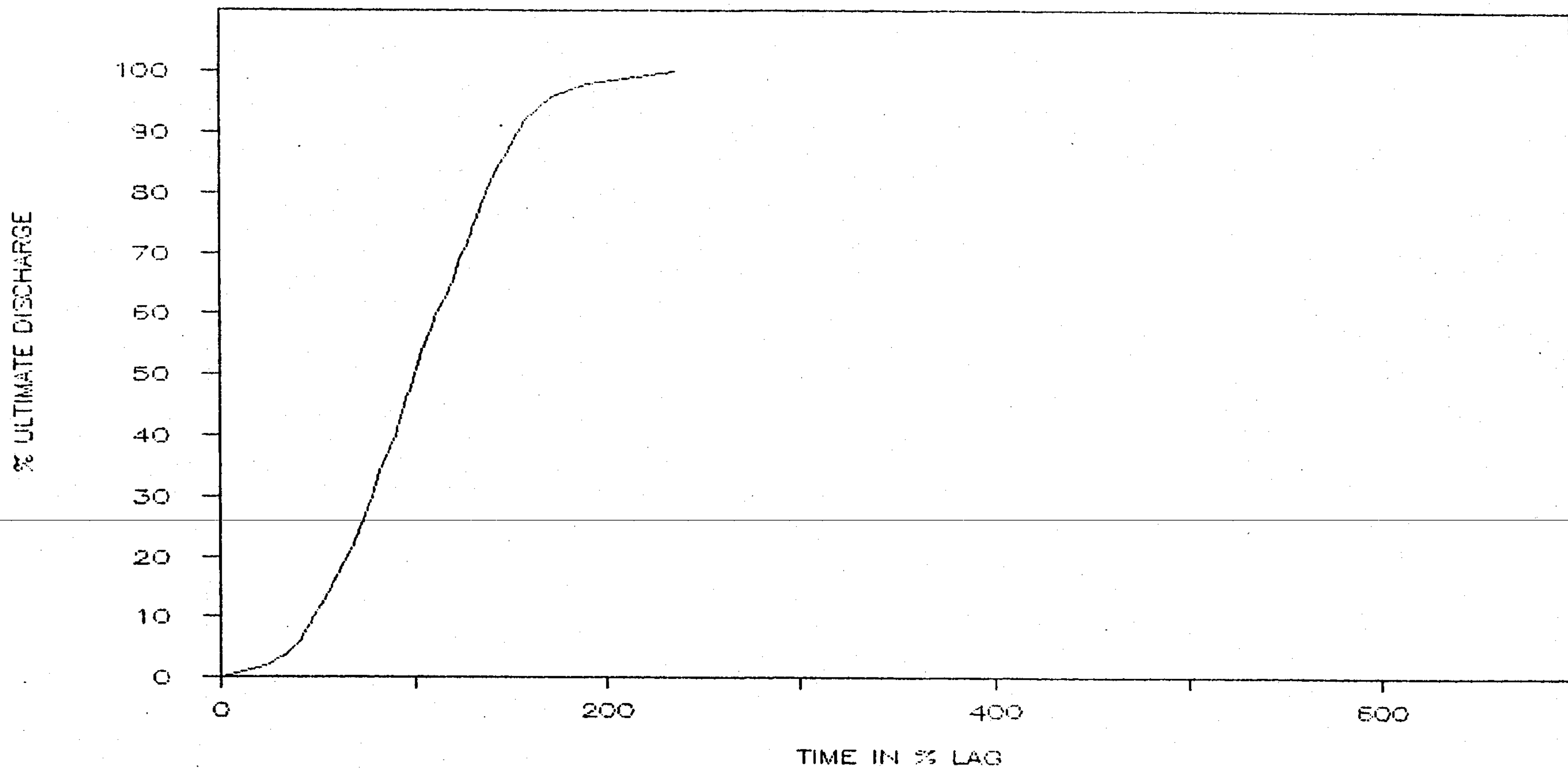
#9 QUEEN CK TRIB AT APACHE JNCT

SEPTEMBER 1970 PART 2



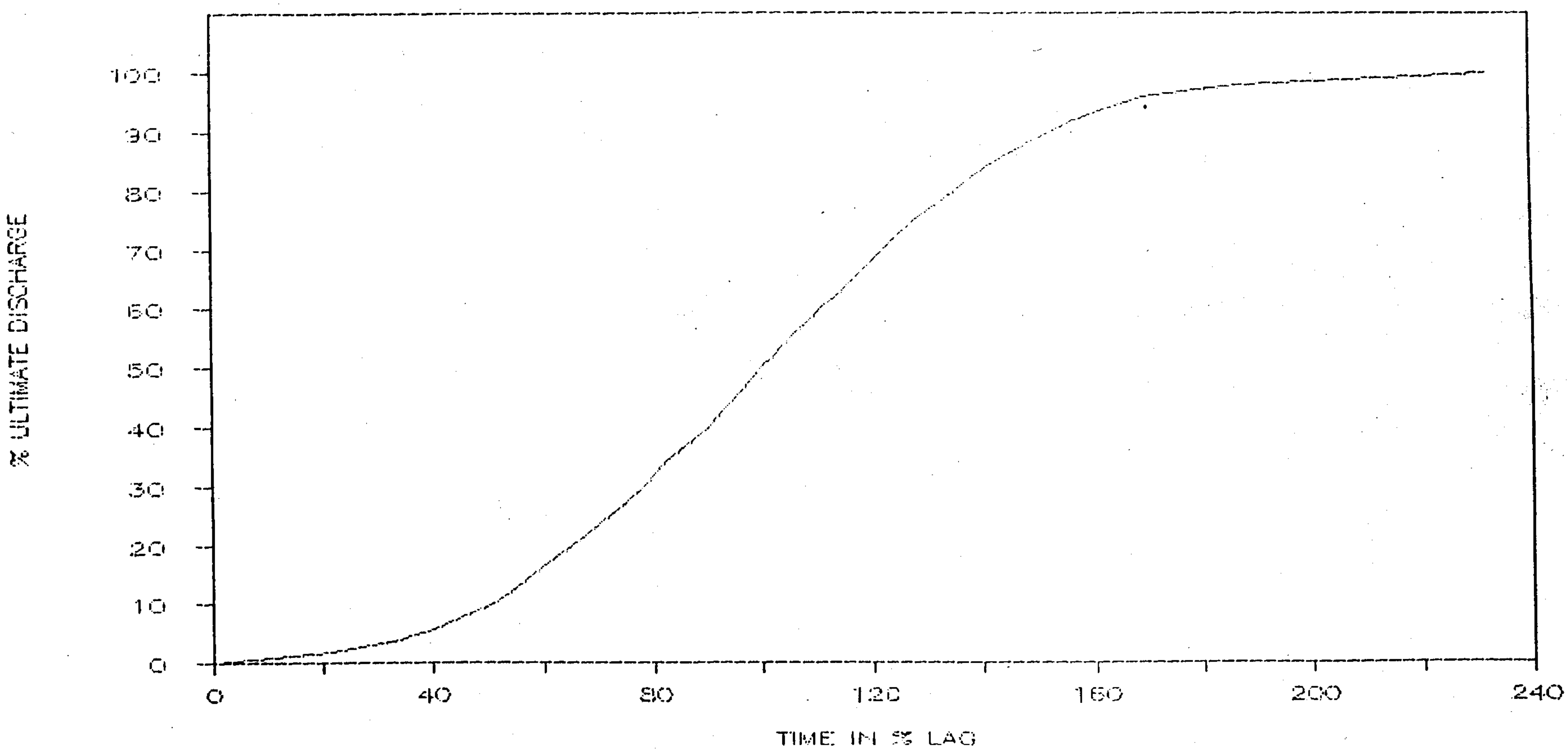
#9 QUEEN CK TRIB AT APACHE JNCT

SEPTEMBER 1970 PART 2



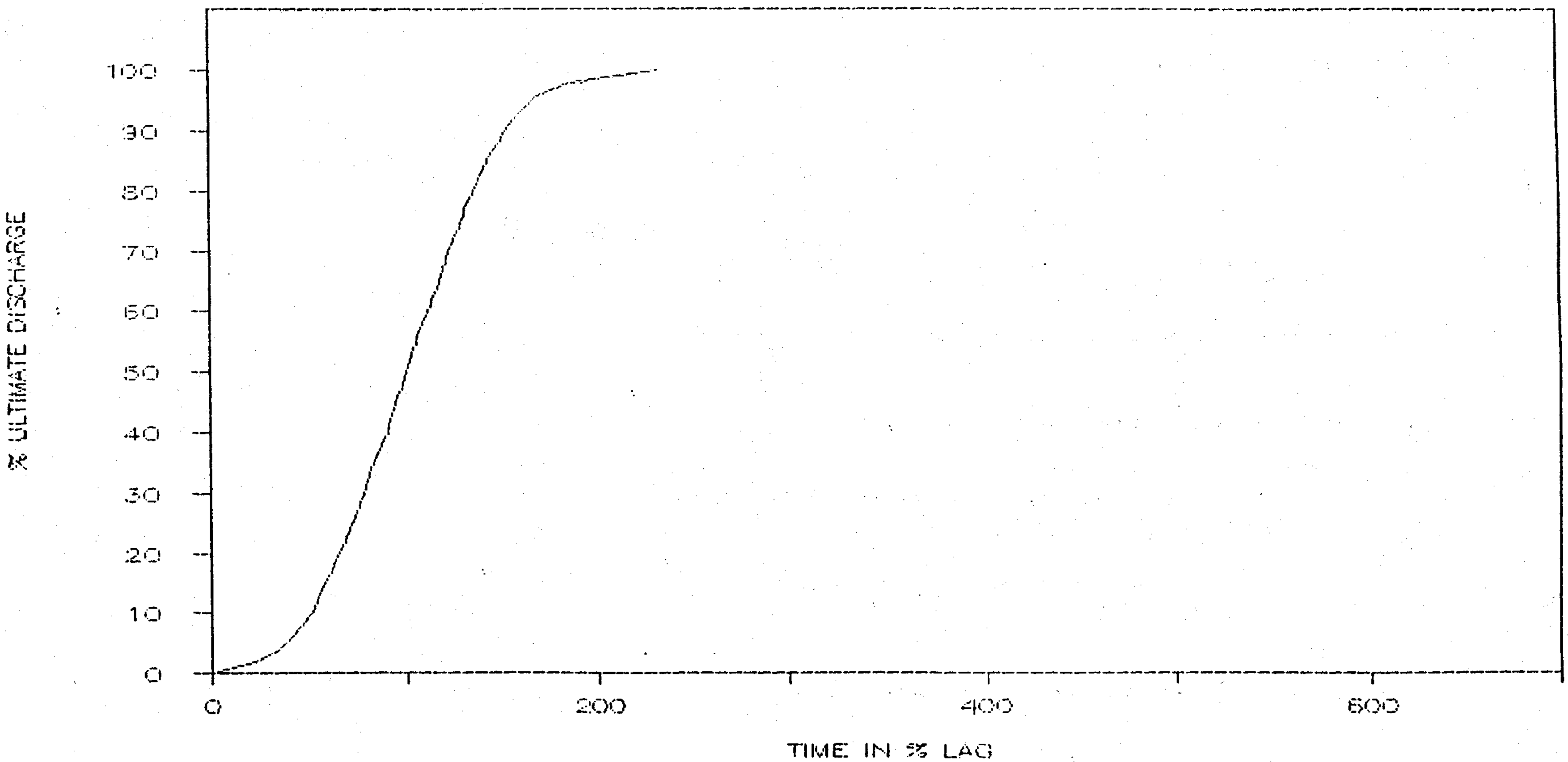
#10 AGUA FRIA TRIB AT YOUNGTOWN

SEPTEMBER 1970 PART 1



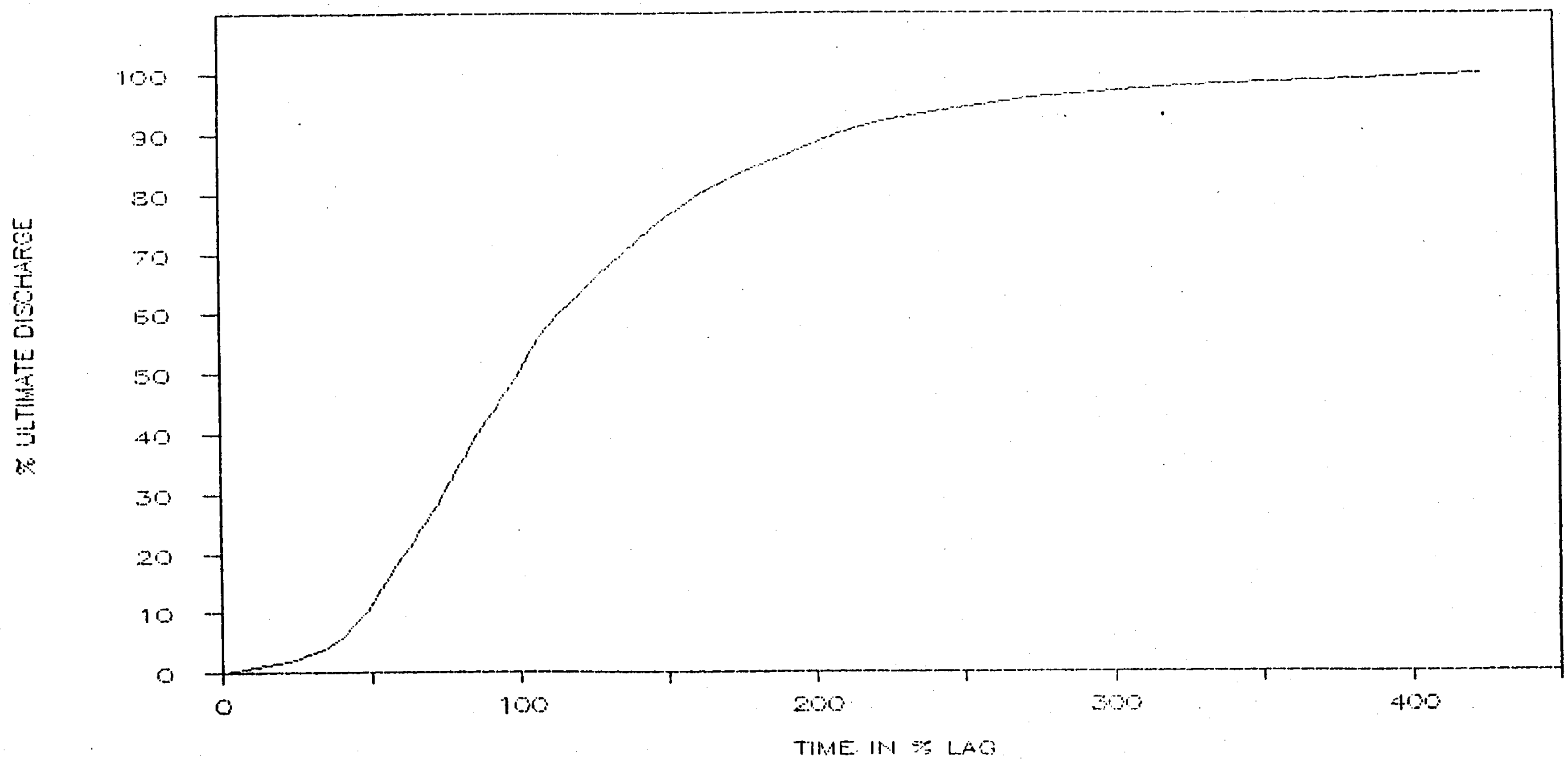
#10 AGUA FRIA TRIB AT YOUNGTOWN

SEPTEMBER 1970 PART 1

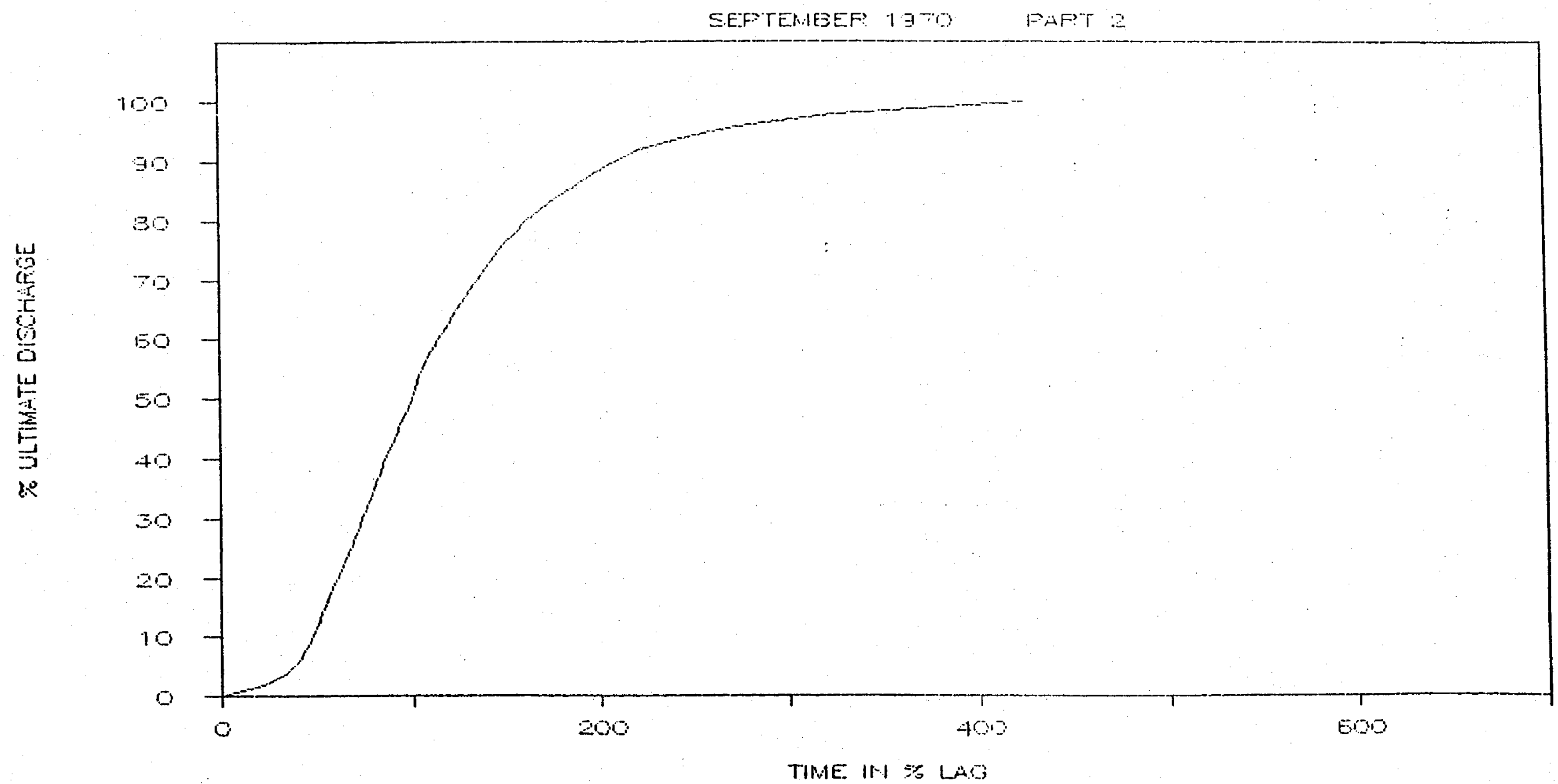


#11 AGUA FRIA TRIB AT YOUNGTOWN

SEPTEMBER 1970 PART 2

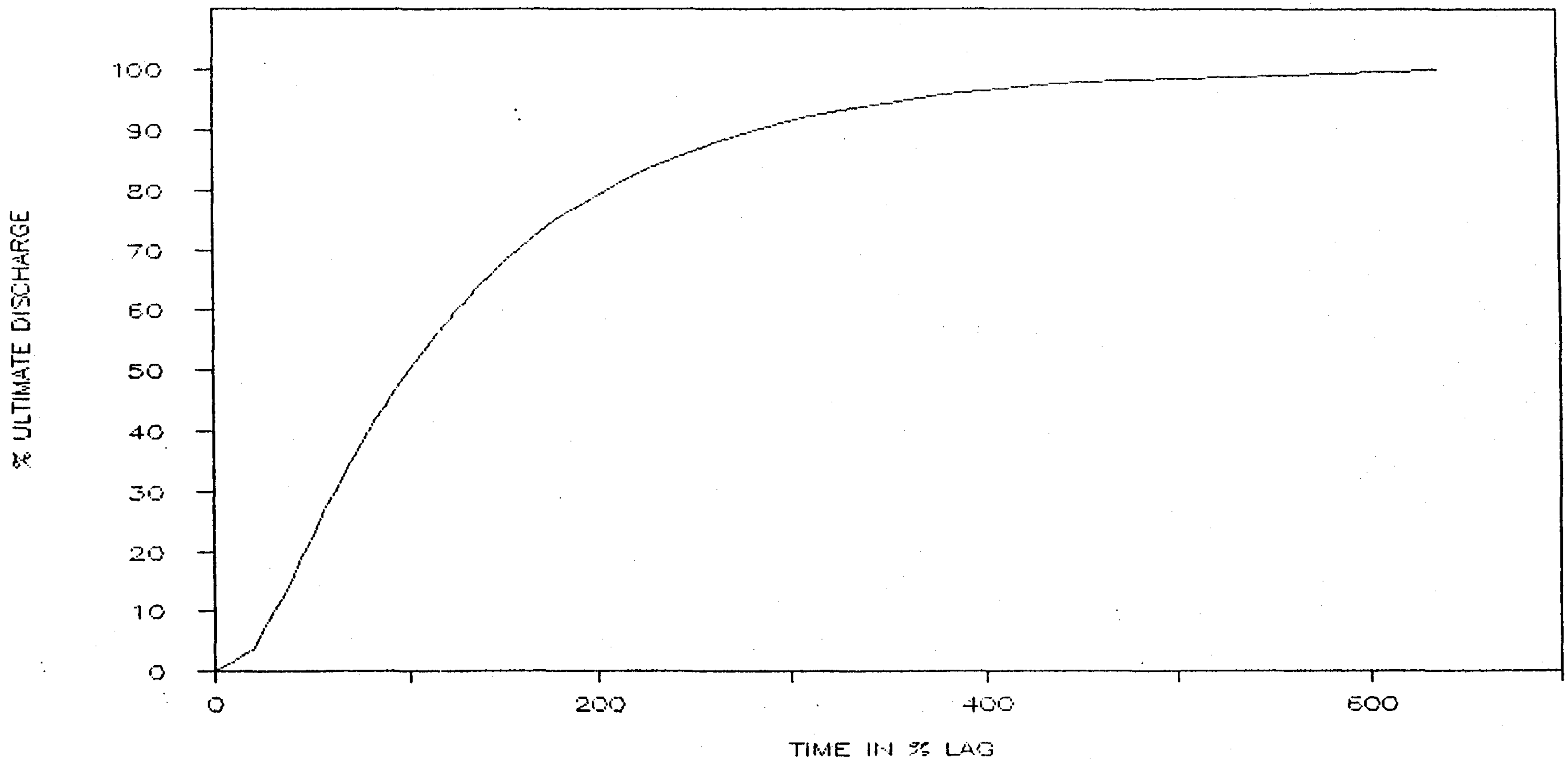


#11 AGUA FRIA TRIB AT YOUNGTOWN



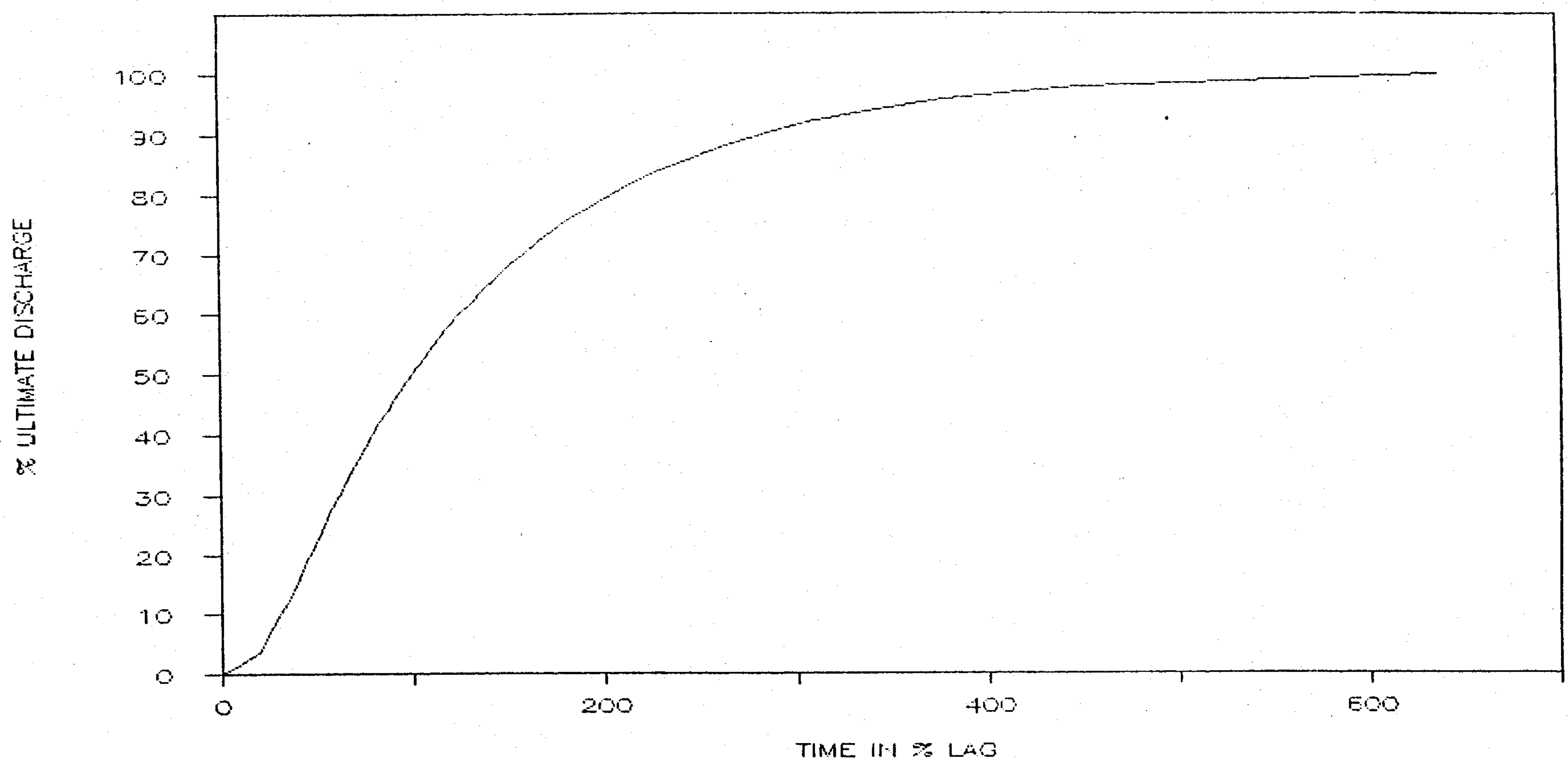
#12 NEW RIVER NEAR ROCK SPRINGS

DECEMBER 1967



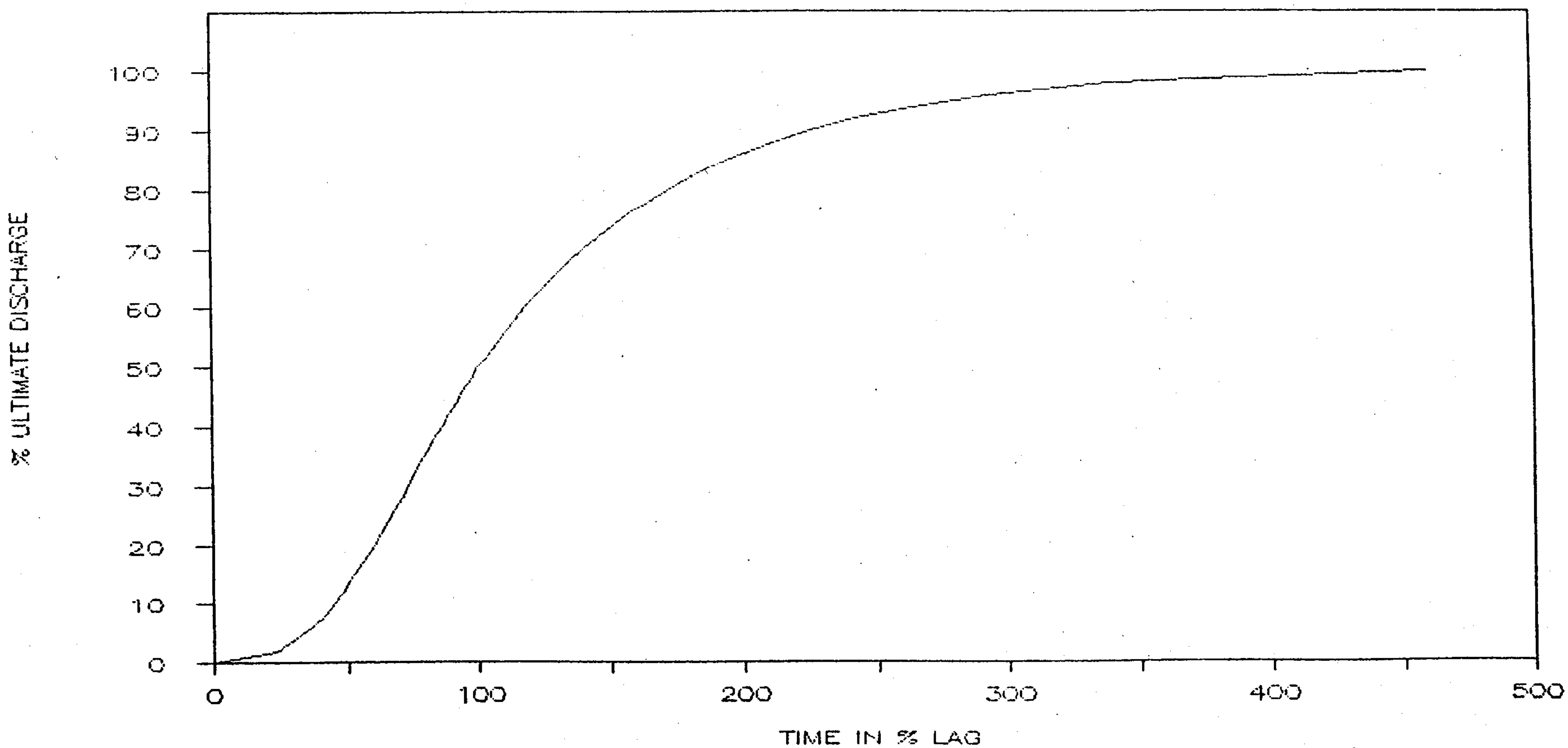
#12 NEW RIVER NEAR ROCK SPRINGS

DECEMBER 1967



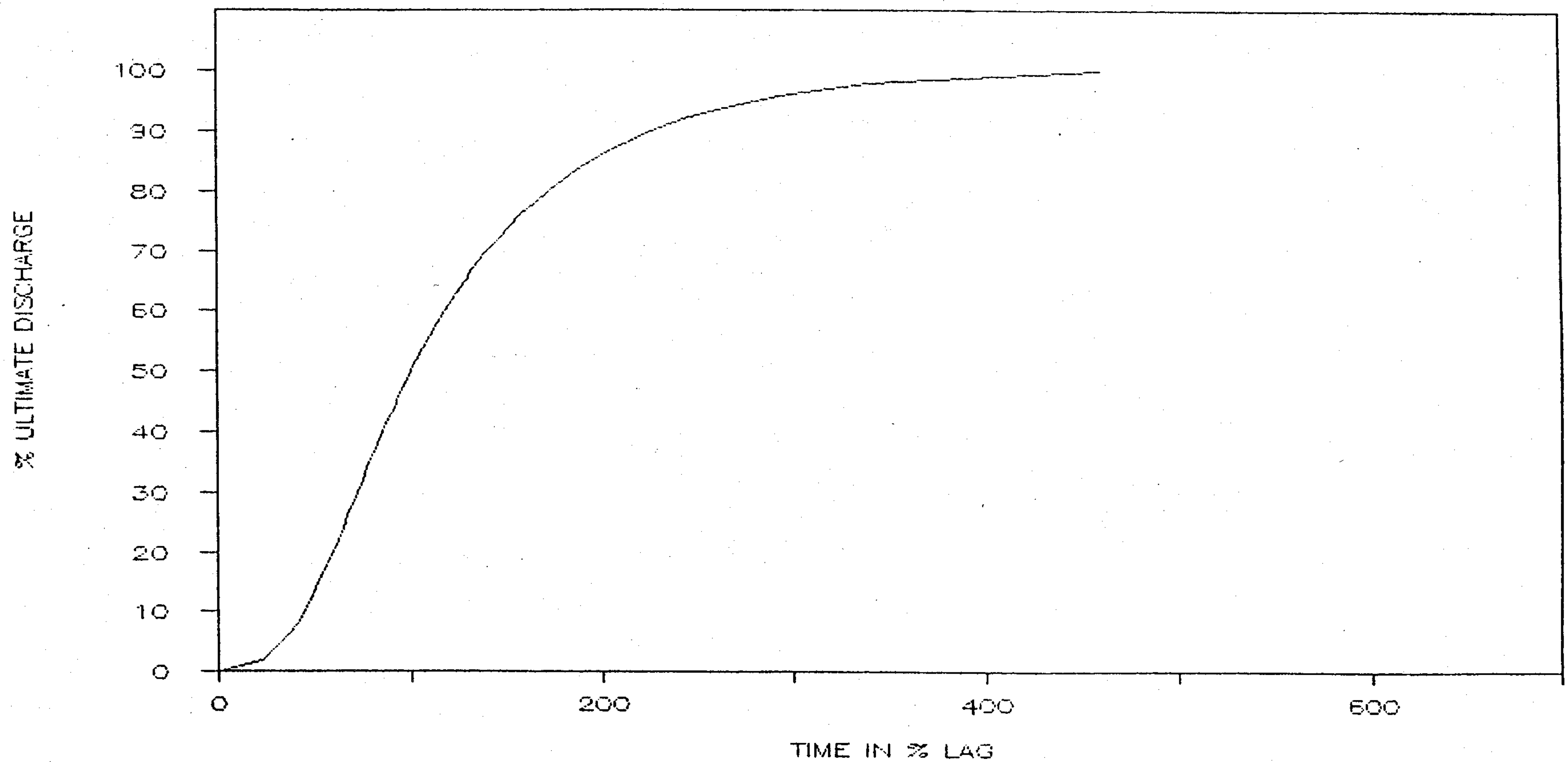
#13 NEW RIVER NEAR ROCK SPRINGS

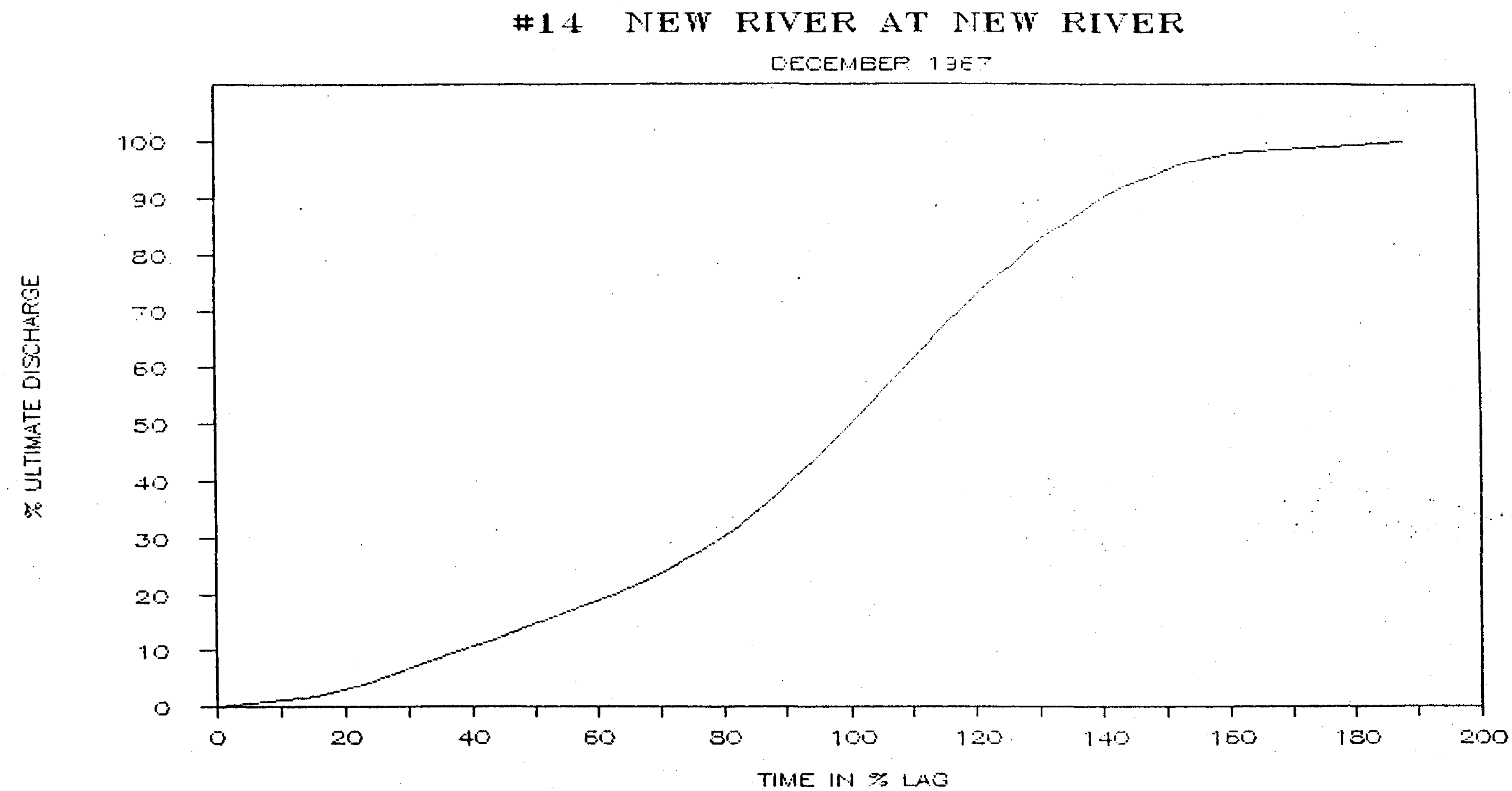
SEPTEMBER 1970



#13 NEW RIVER NEAR ROCK SPRINGS

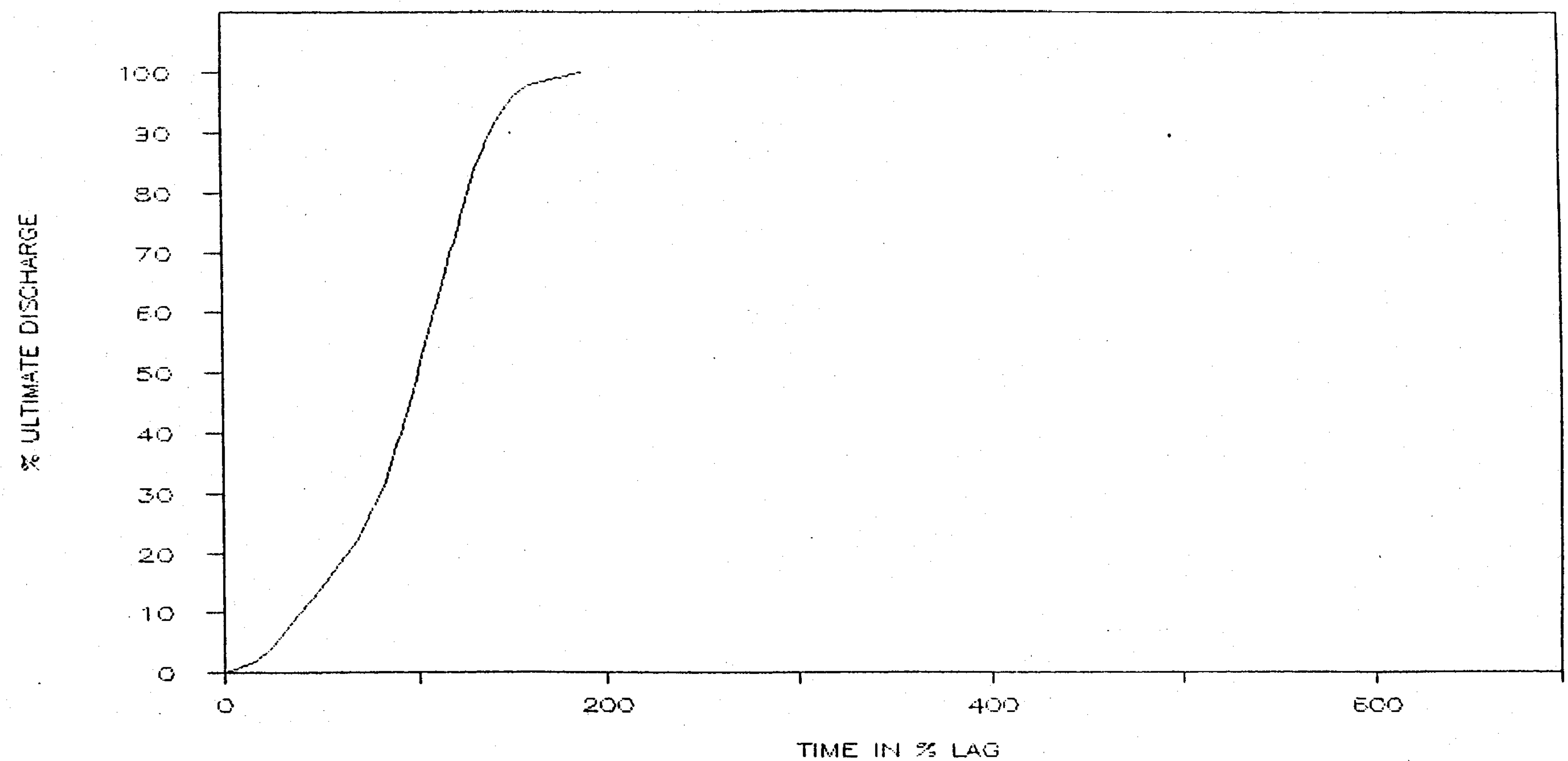
SEPTEMBER 1970




#14 NEW RIVER AT NEW RIVER
DECEMBER 1987
% ULTIMATE DISCHARGE
0
10
20
30
40
50
60
70
80
90
100
0
20
40
60
80
100
120
140
160
180
200
TIME IN % LAG

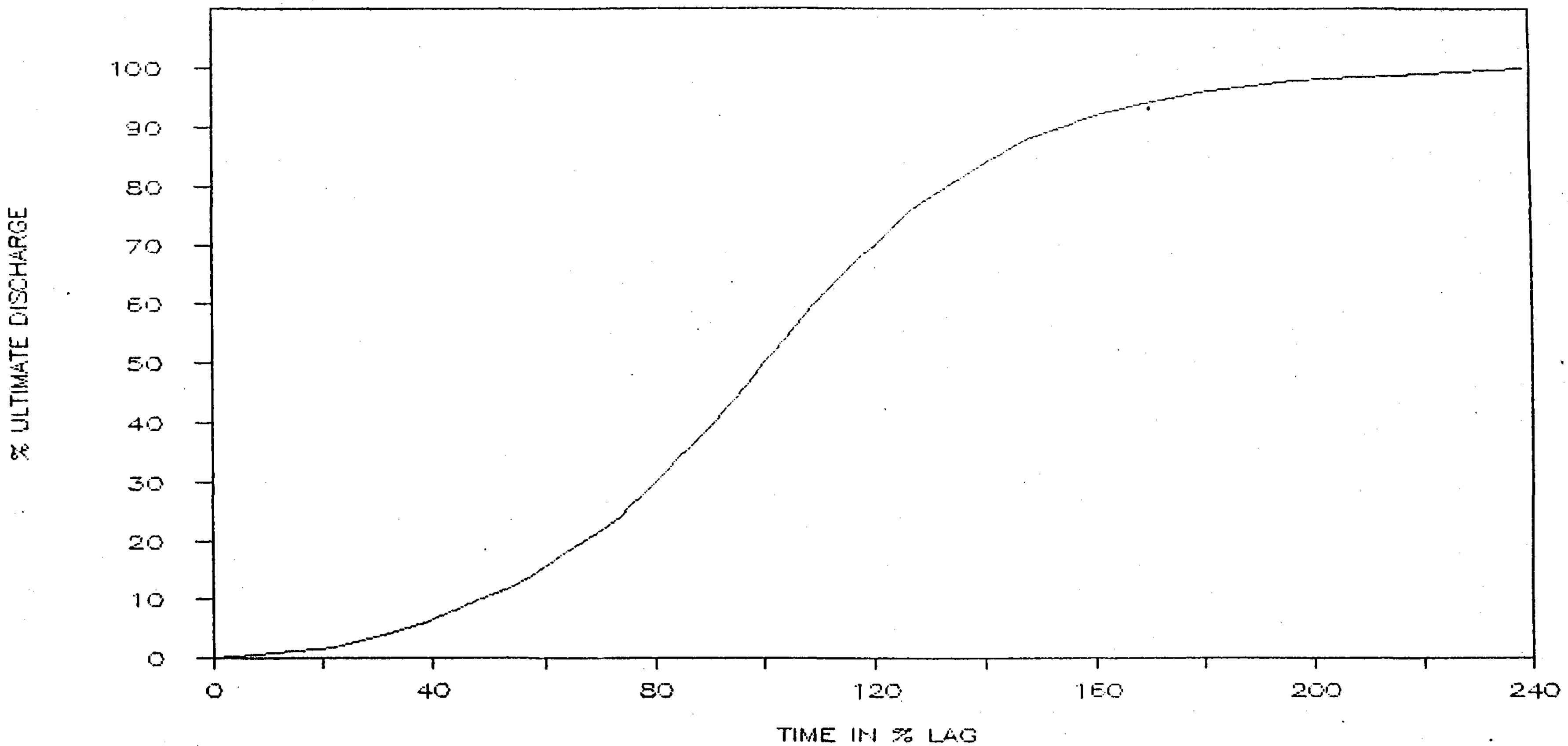
#14 NEW RIVER AT NEW RIVER

DECEMBER 1967



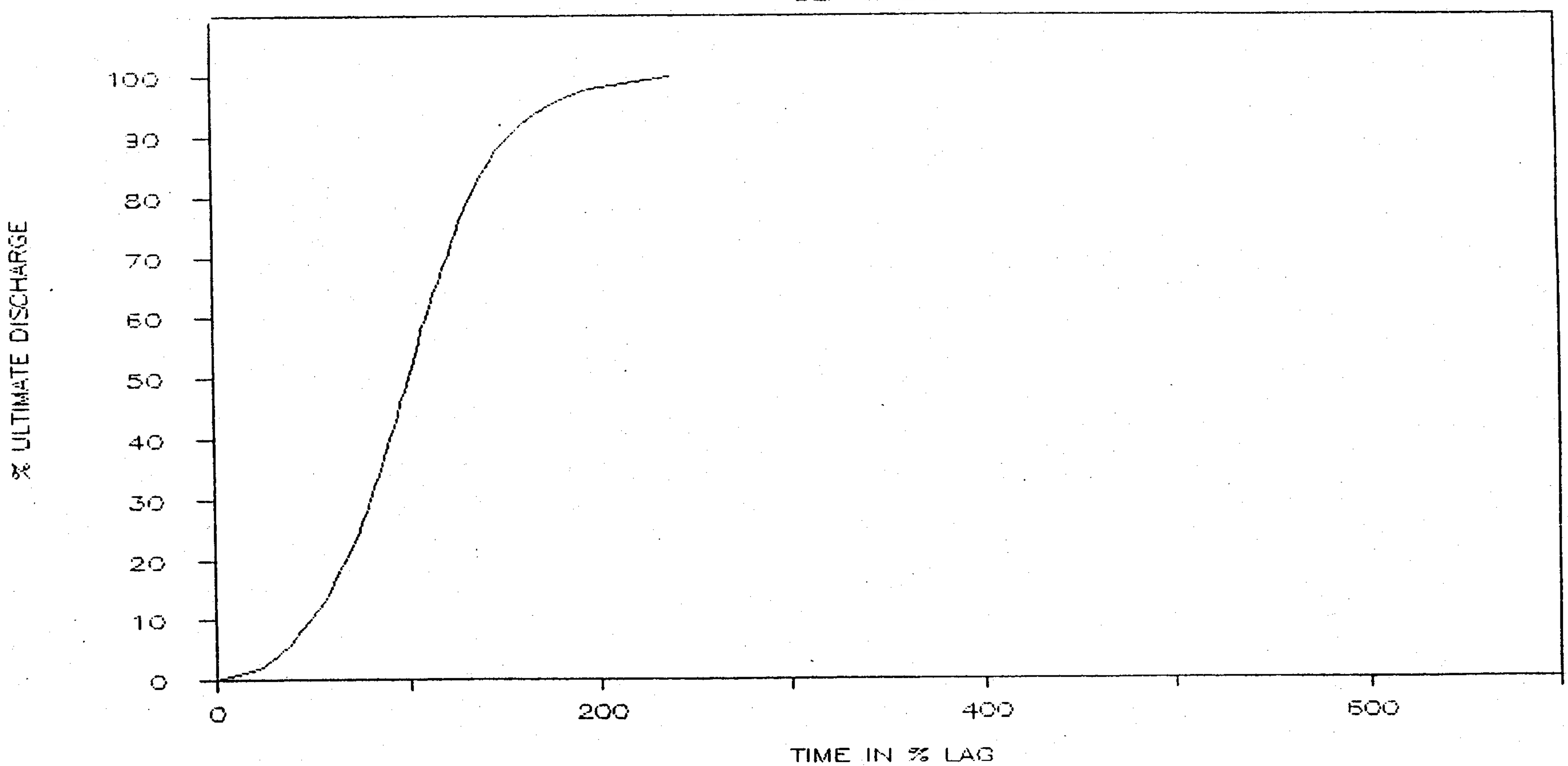
#15 NEW RIVER AT NEW RIVER

SEPTEMBER 1970



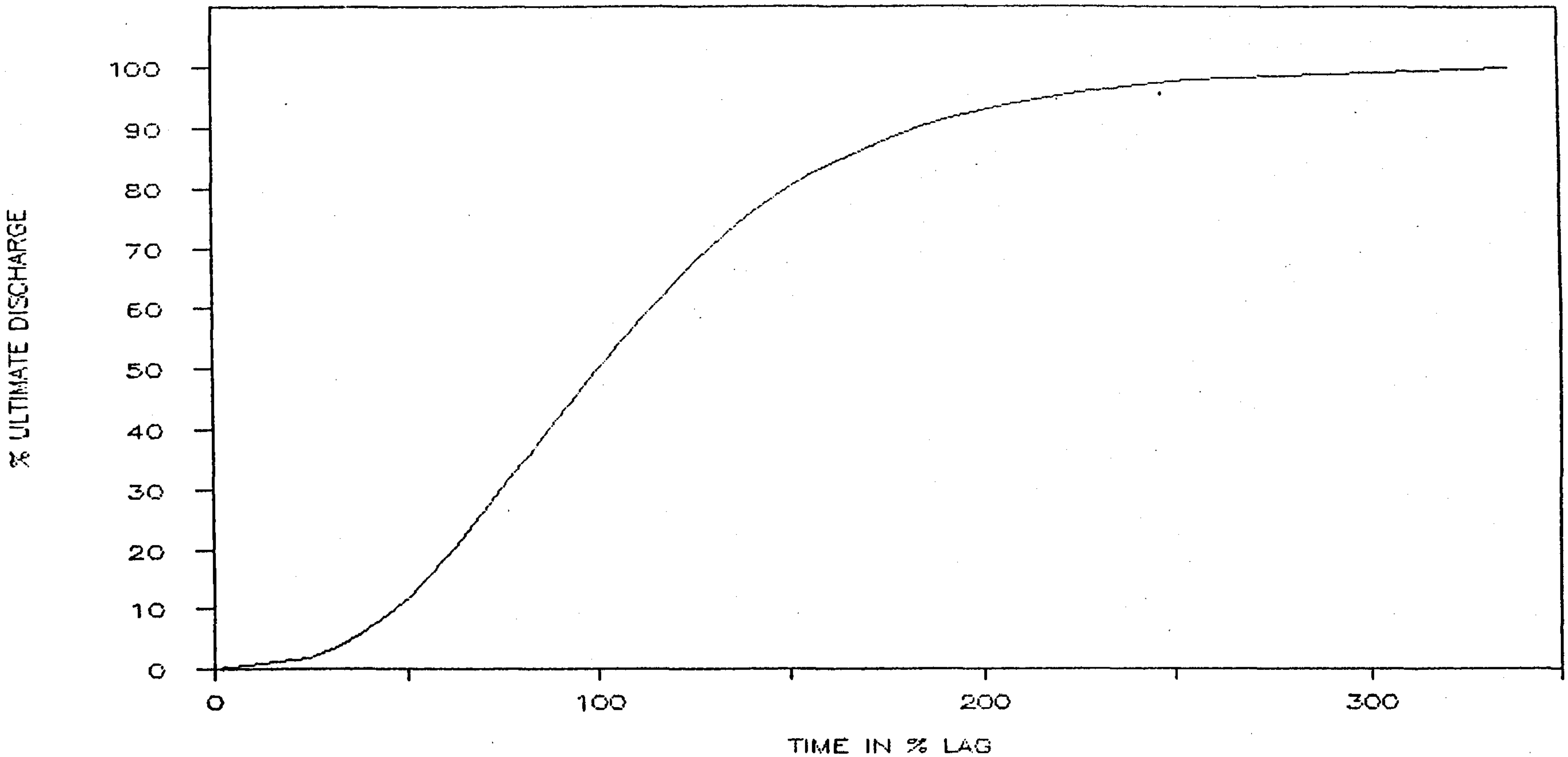
#15 NEW RIVER AT NEW RIVER

SEPTEMBER 1970



#16 INDIAN BEND WASH NEAR SCOTTSDALE

DECEMBER 1967



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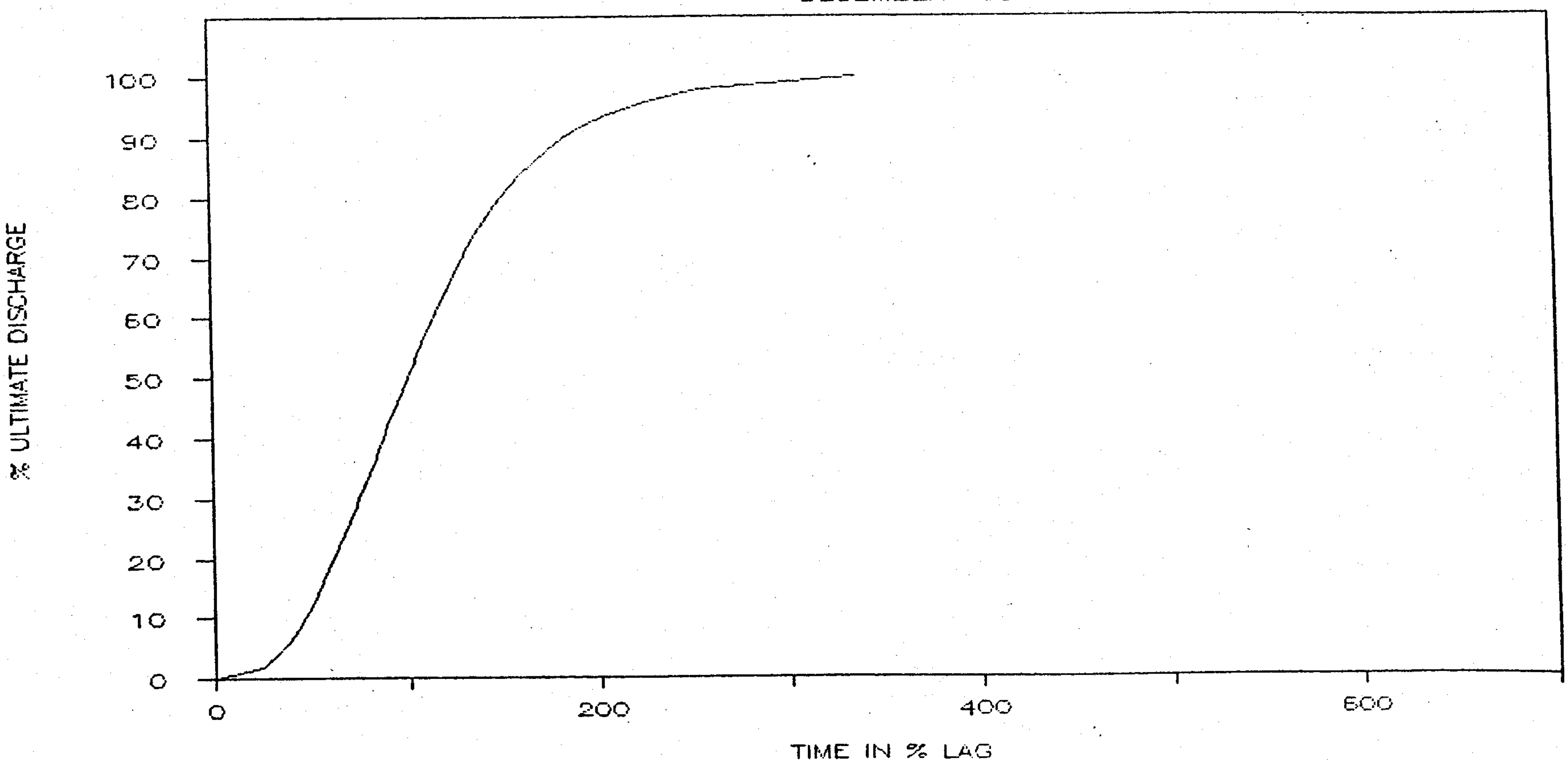

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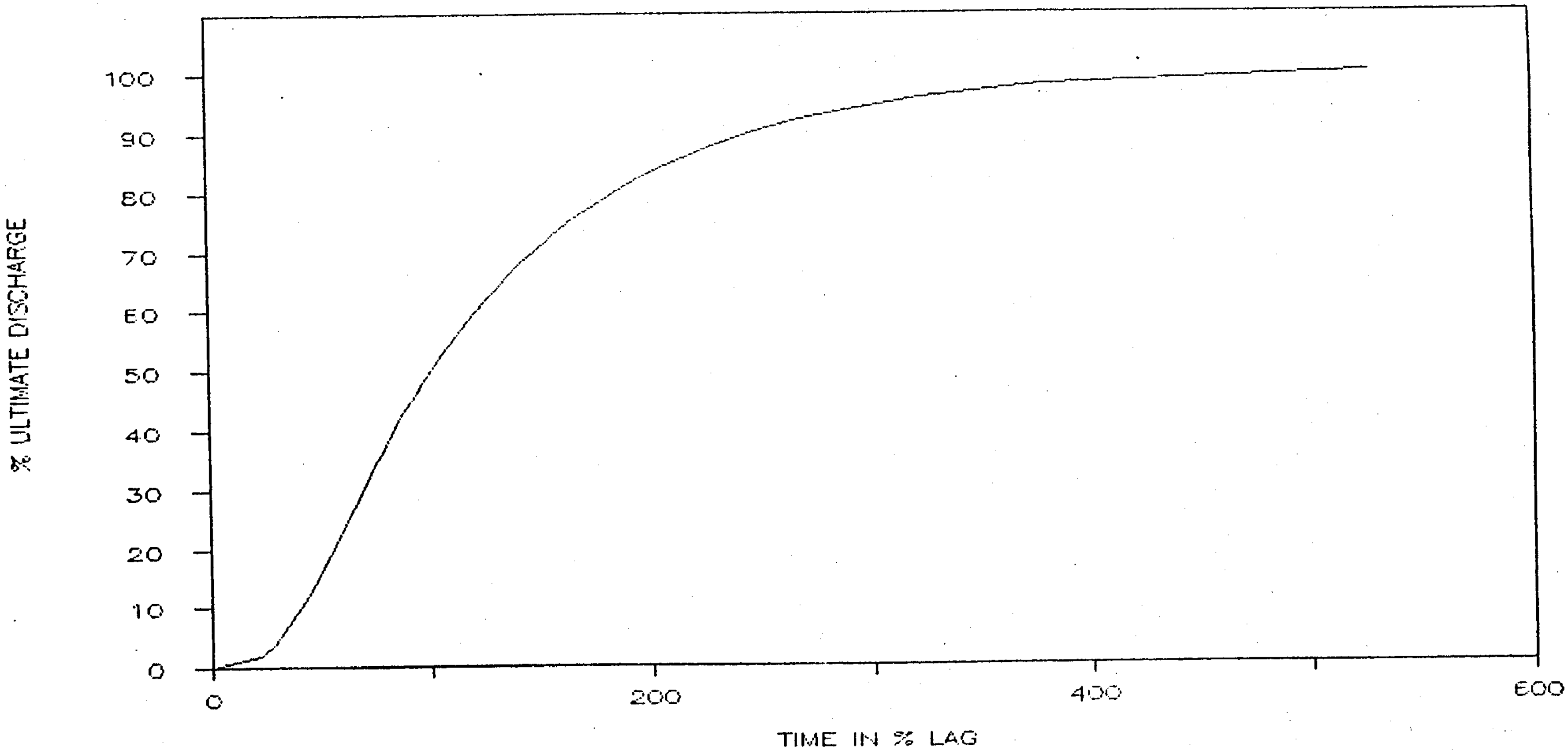
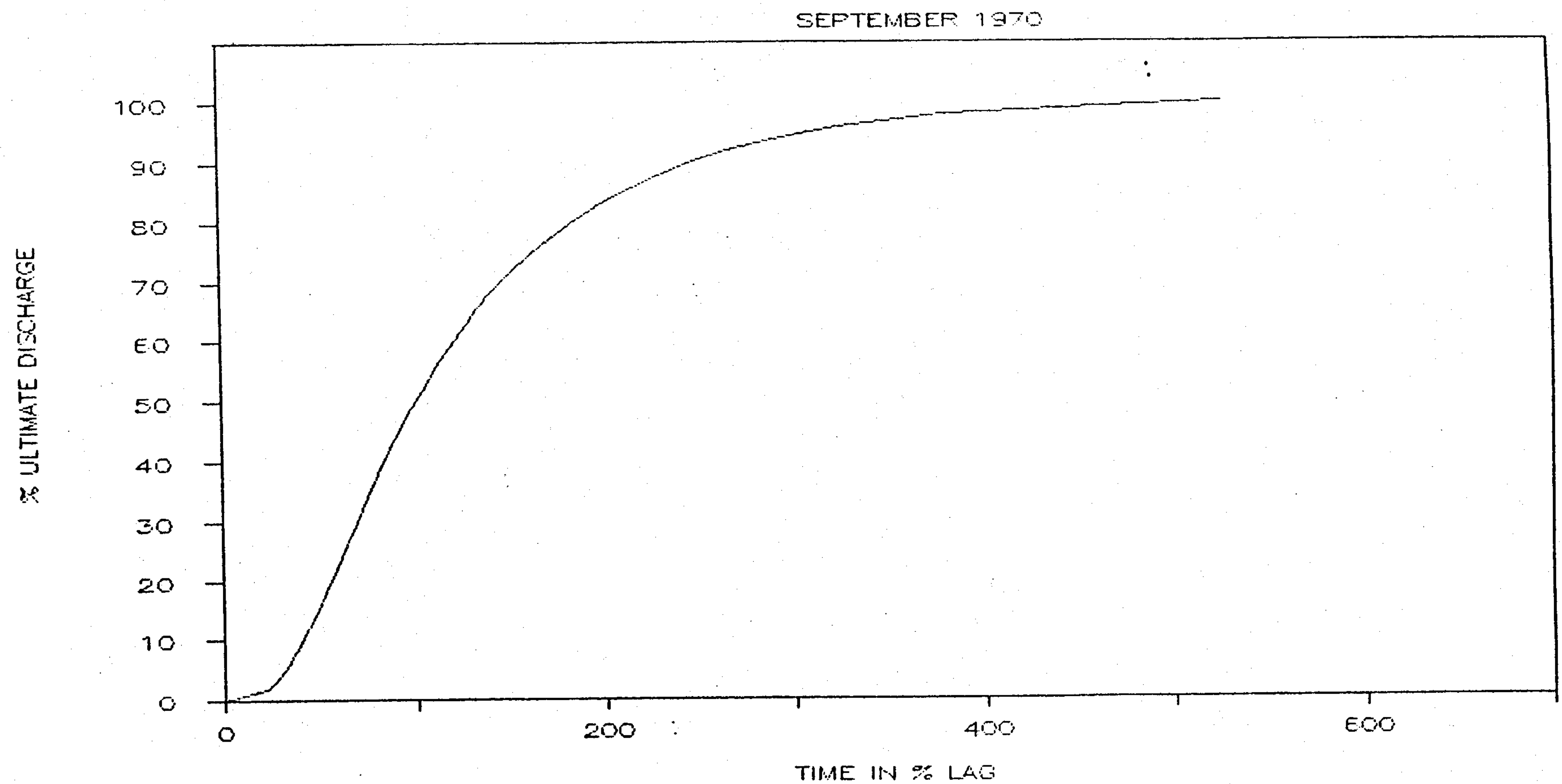
SEPTEMBER 1970

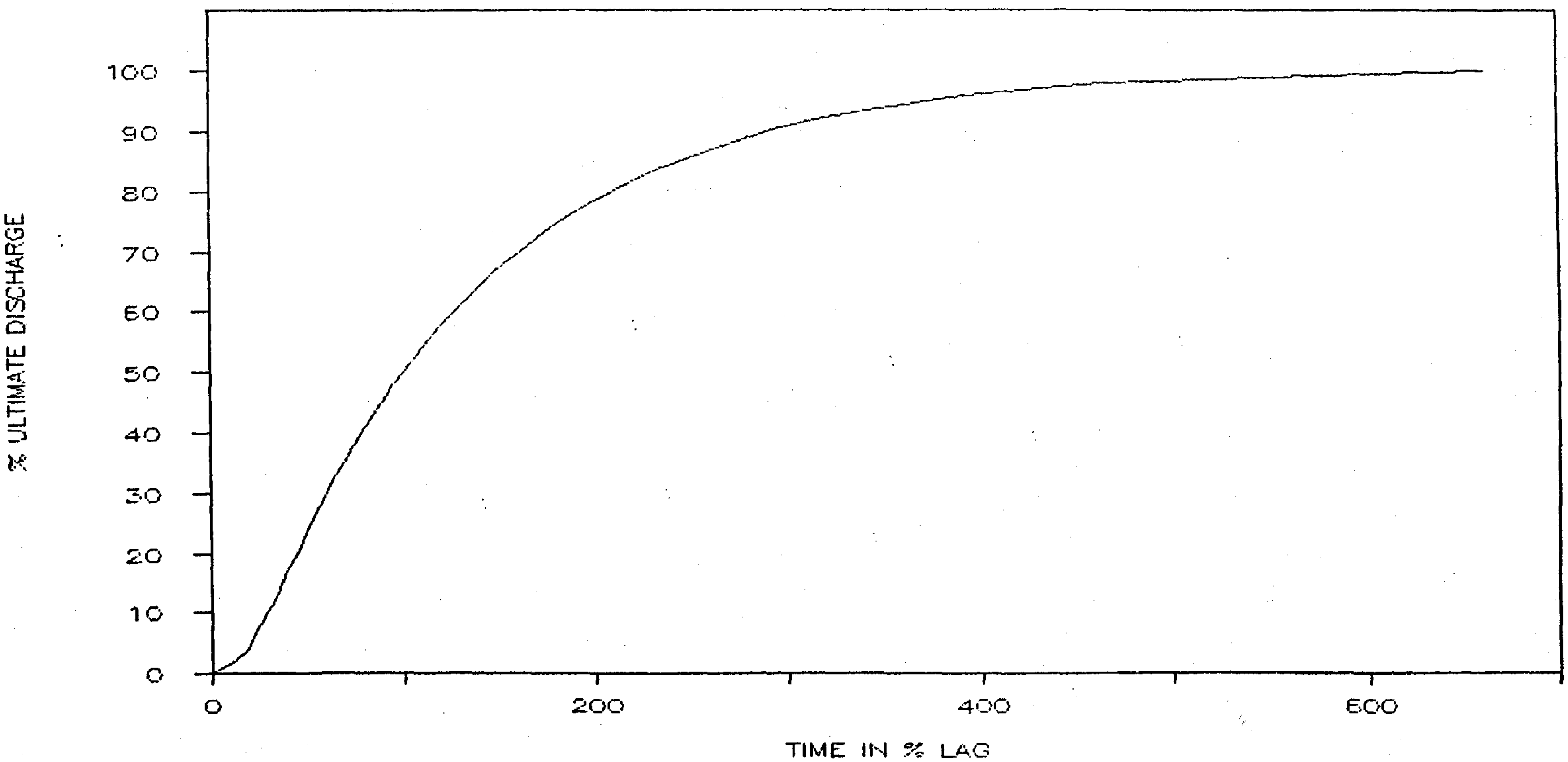


#17 INDIAN BEND WASH NEAR SCOTTSDALE



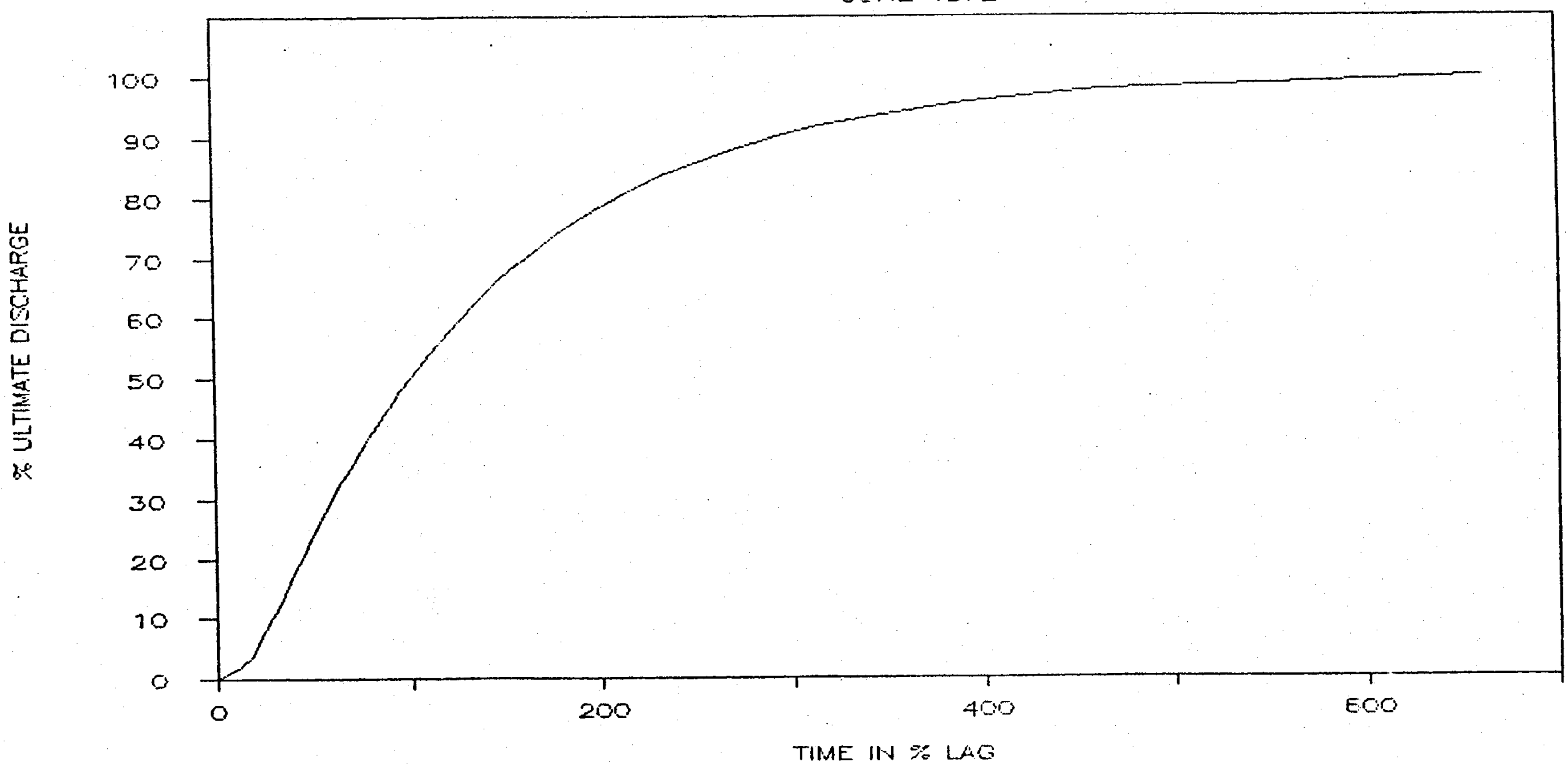
#18 INDIAN BEND WASH NEAR SCOTTSDALE

JUNE 1972



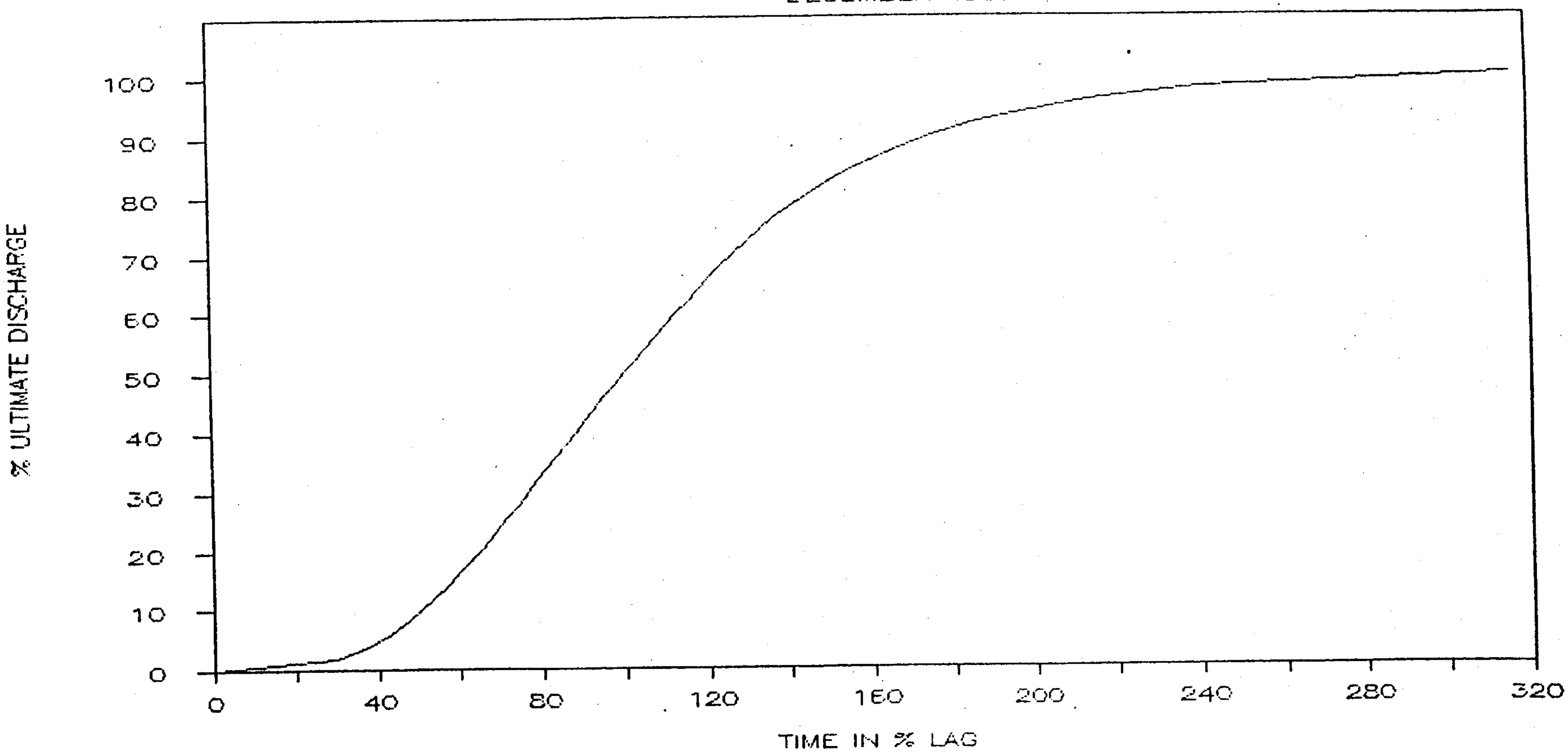
#18 INDIAN BEND WASH NEAR SCOTTSDALE

JUNE 1972



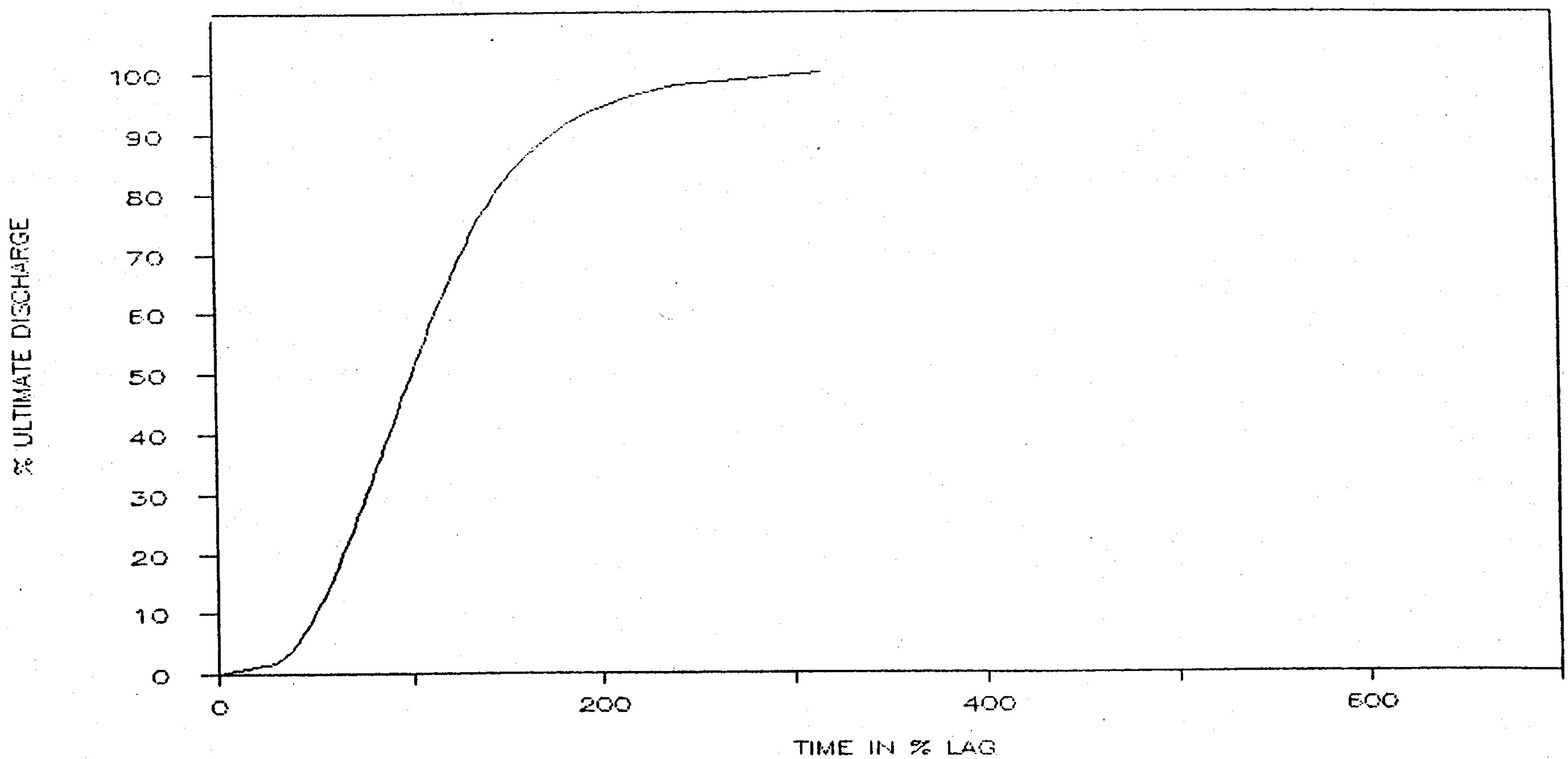
#19 NEW RIVER NEAR GLENDALE

DECEMBER 1967



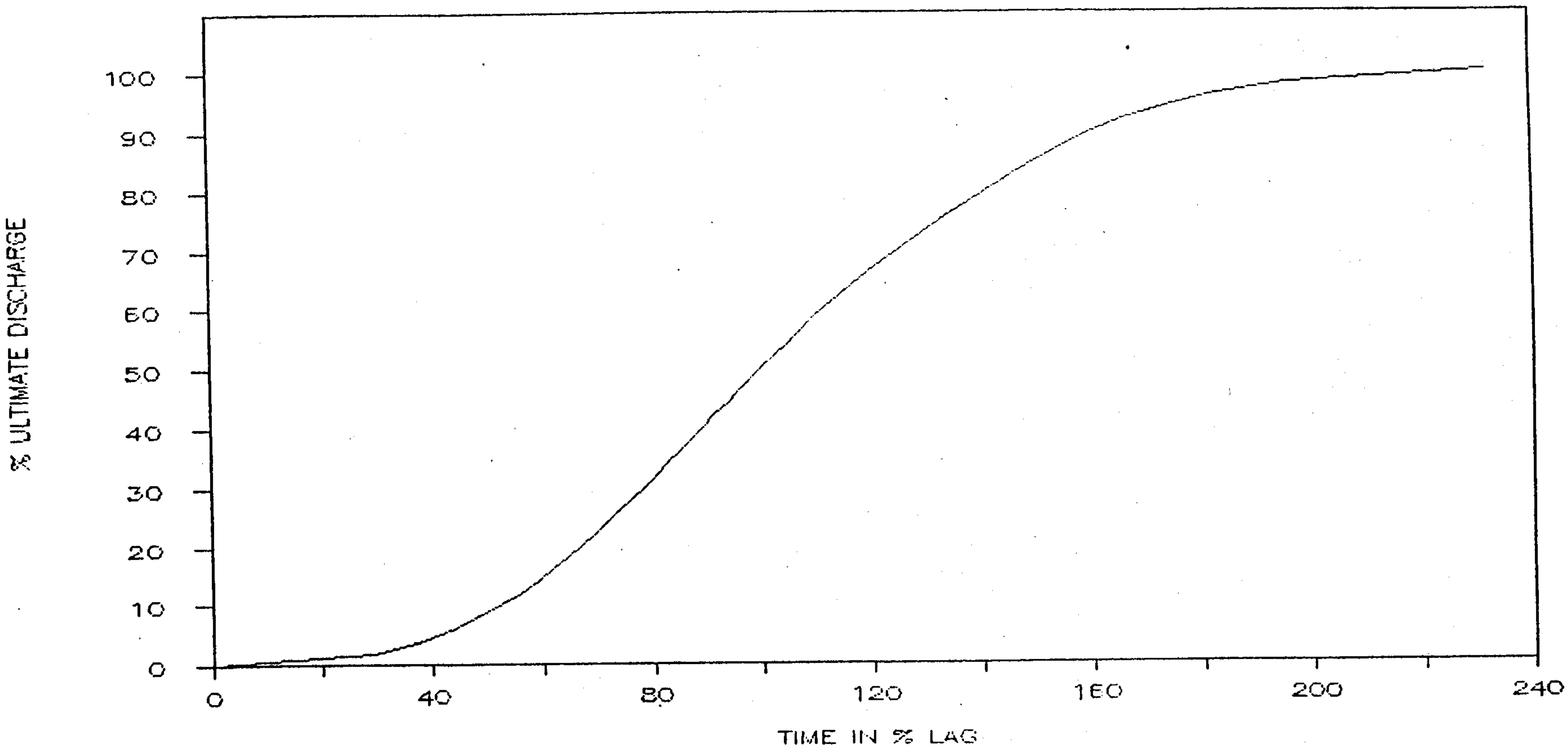
#19 NEW RIVER NEAR GLENDALE

DECEMBER 1967



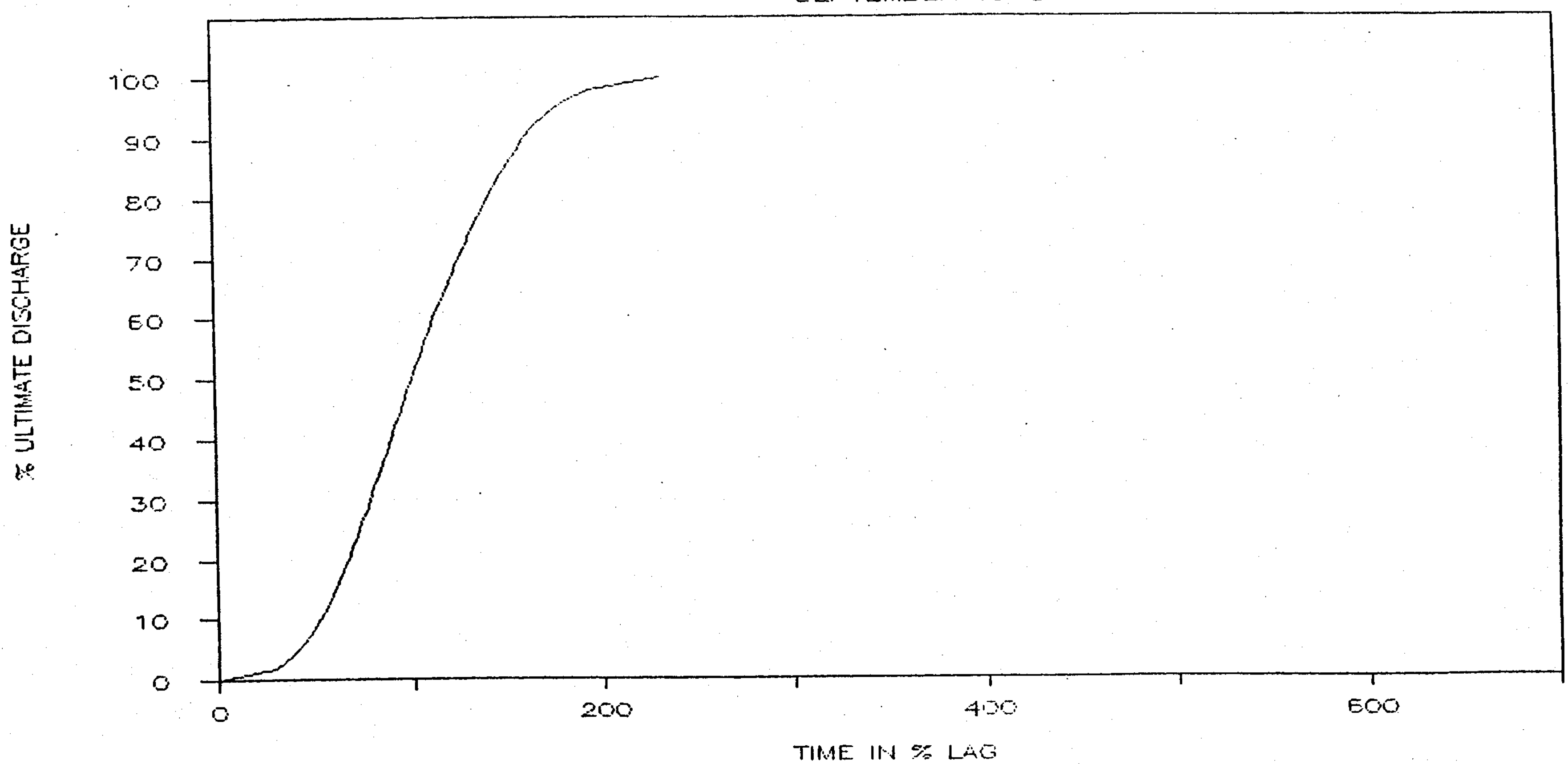
#20 NEW RIVER NEAR GLENDALE

SEPTEMBER 1970



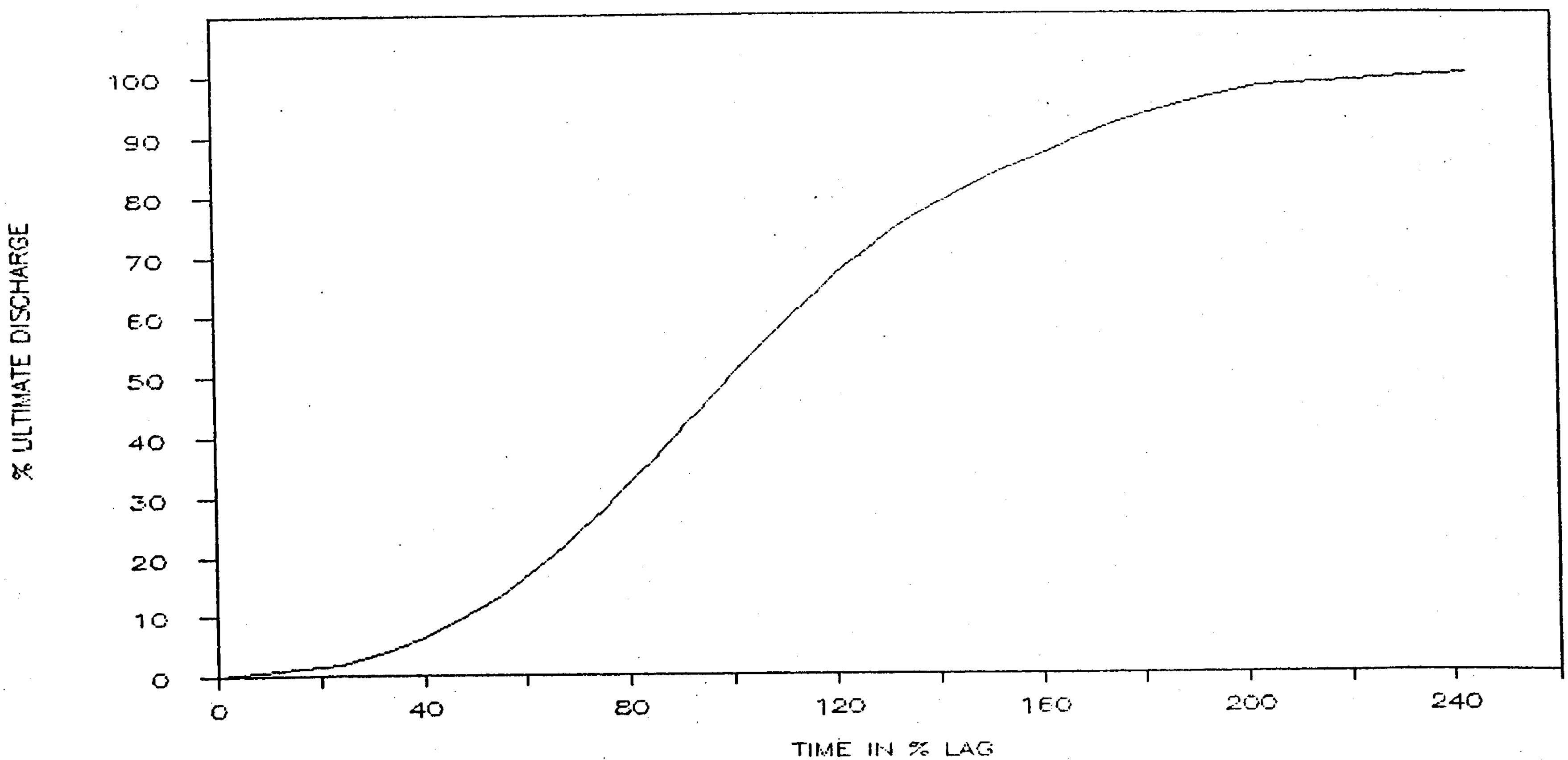
#20 NEW RIVER NEAR GLENDALE

SEPTEMBER 1970



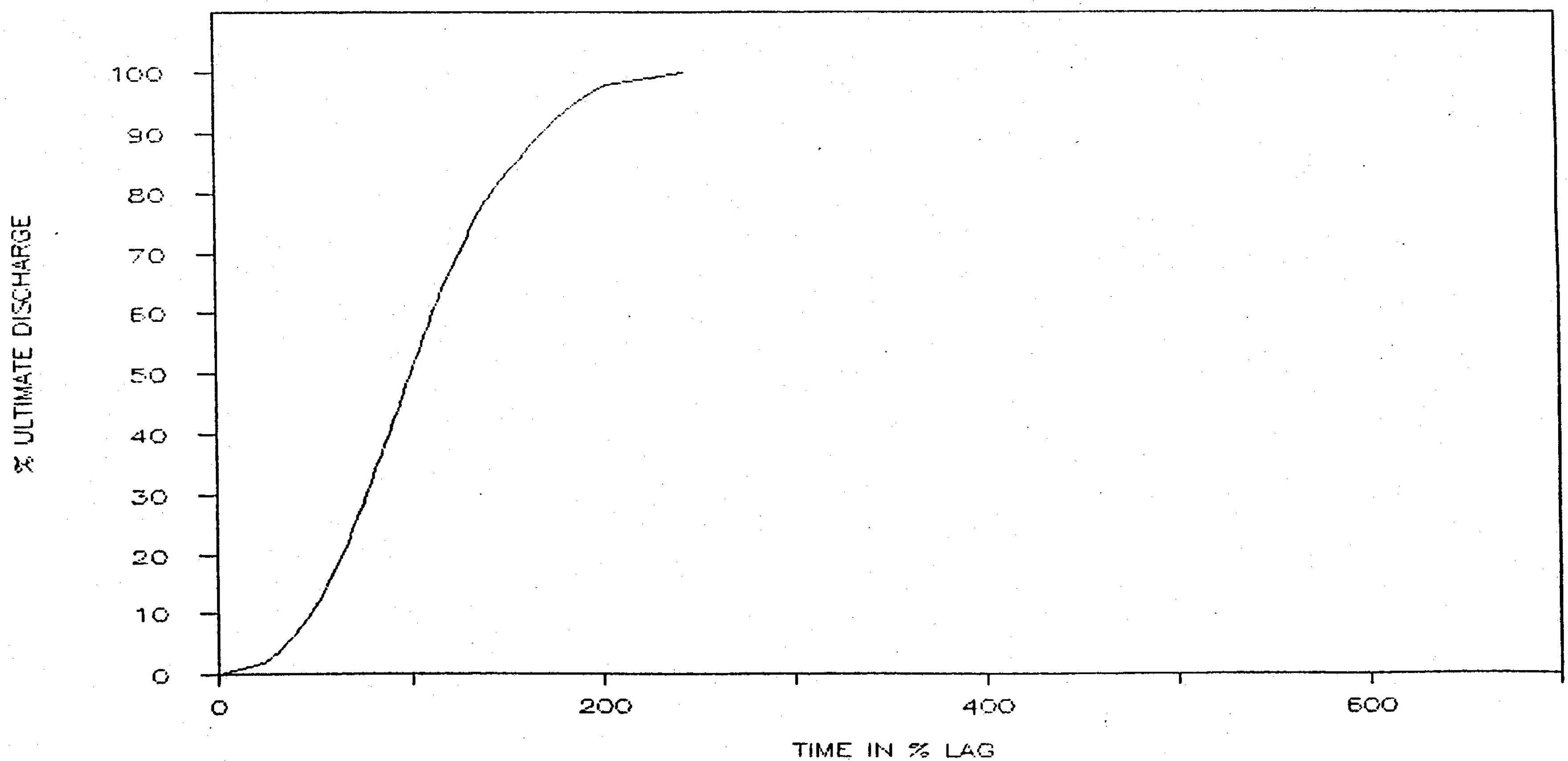
#21 AGUA FRIA AT AVONDALE

DECEMBER 1967



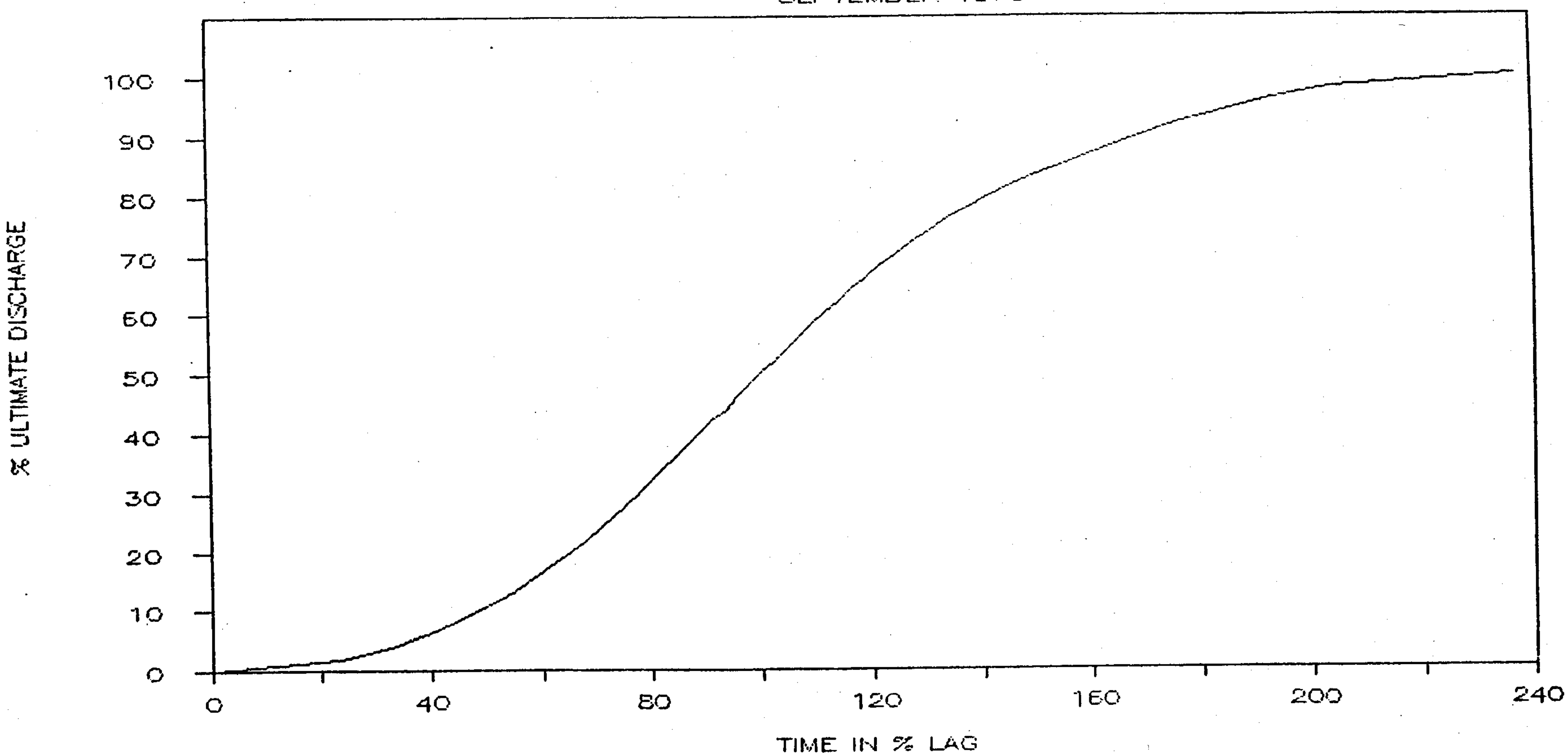
#21 AGUA FRIA AT AVONDALE

DECEMBER 1967



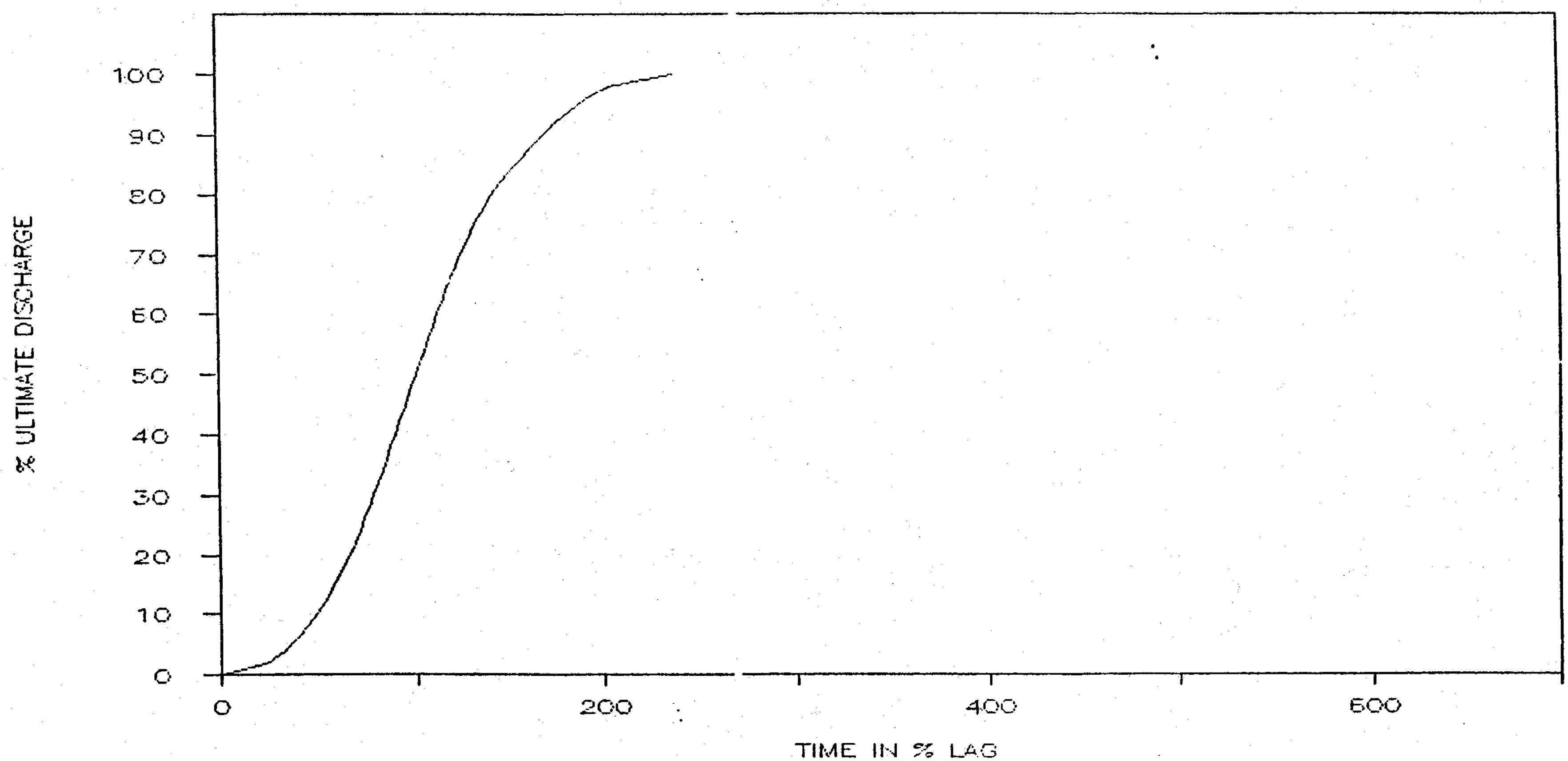
#22 AGUA FRIA AT AVONDALE

SEPTEMBER 1970



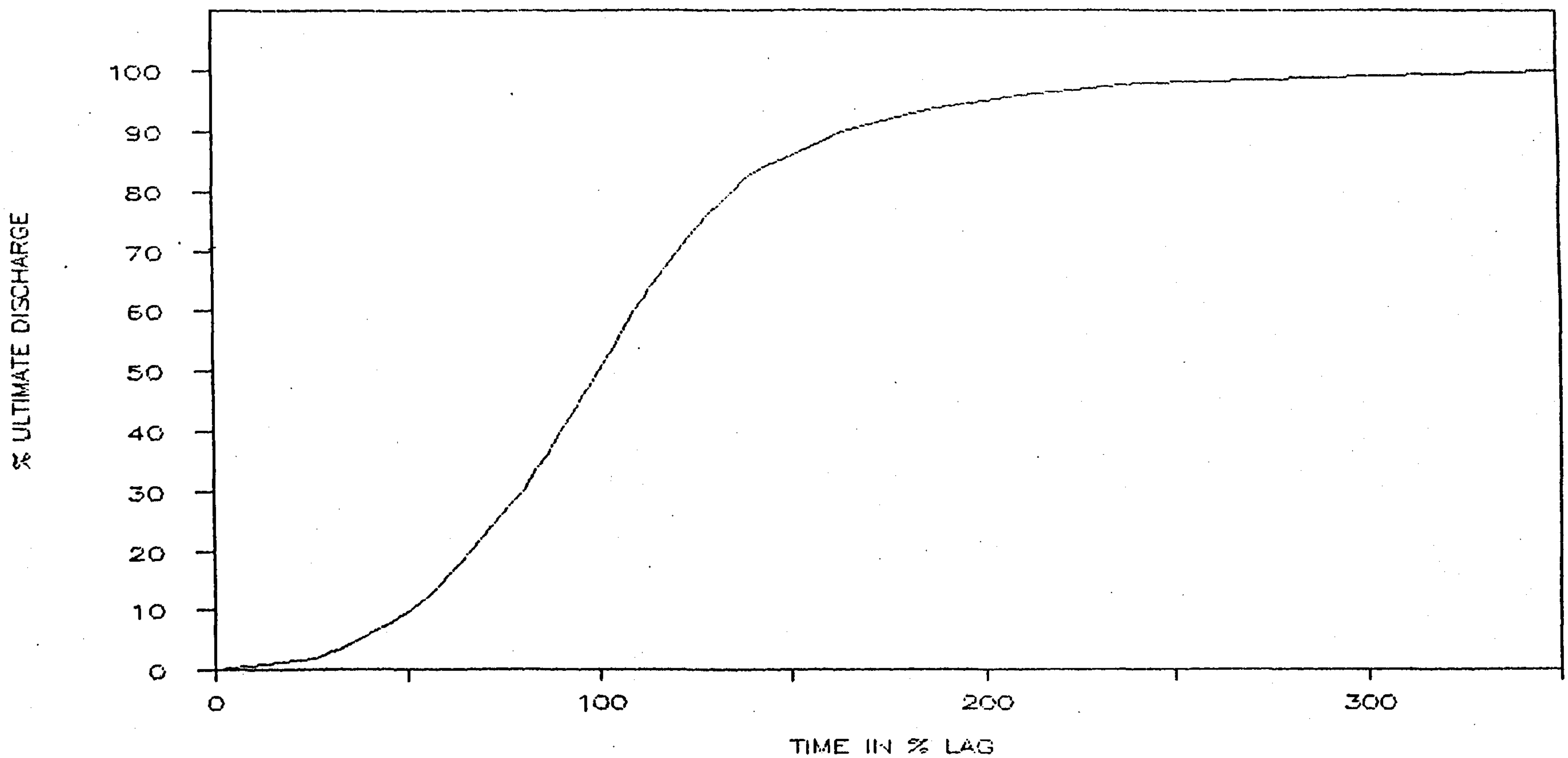
#22 AGUA FRIA AT AVONDALE

SEPTEMBER 1970



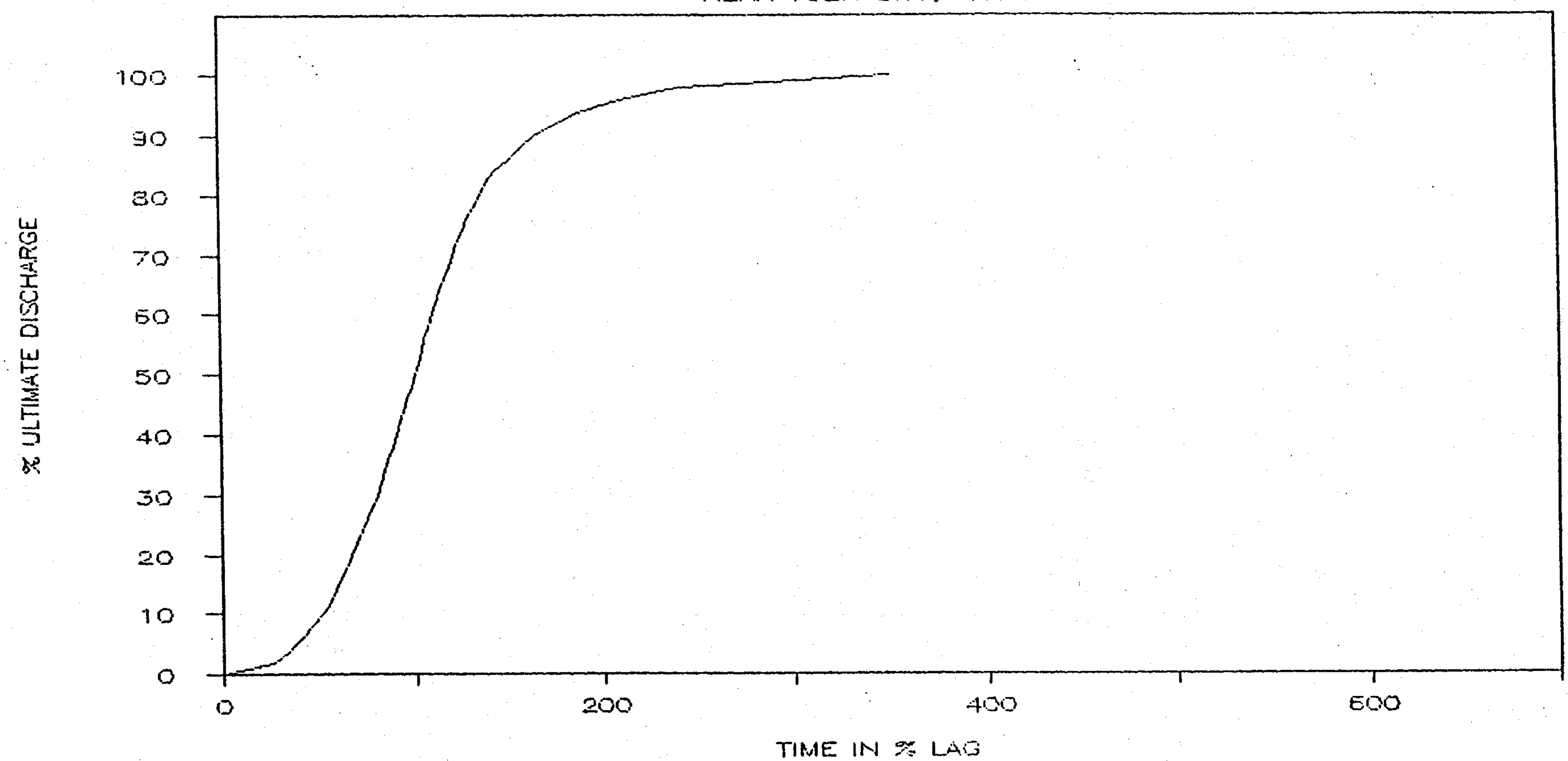
#23 MOENCOPI WASH

NEAR TUBA CITY, ARIZONA



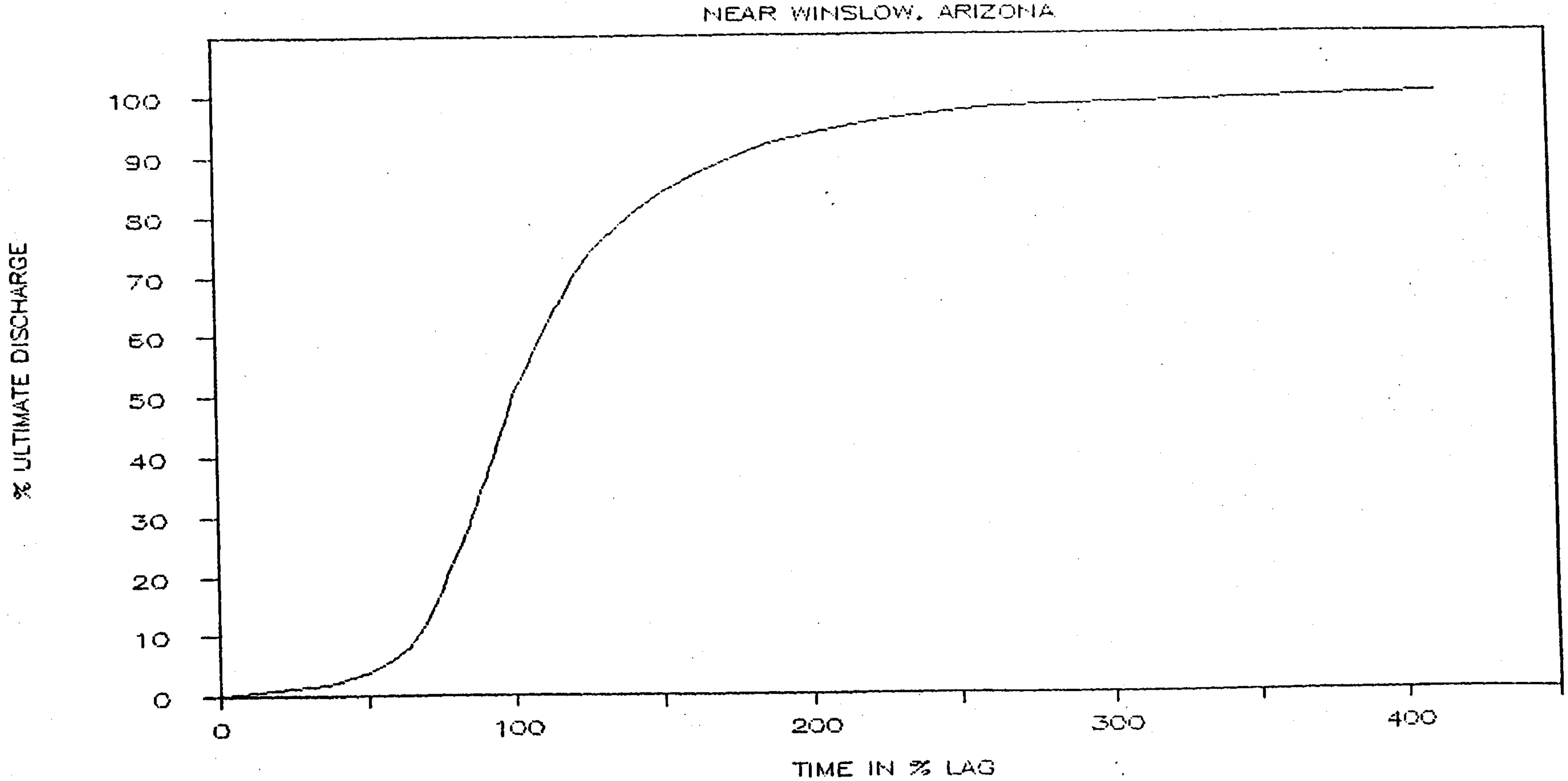
#23 MOENCOPI WASH

NEAR TUBA CITY, ARIZONA



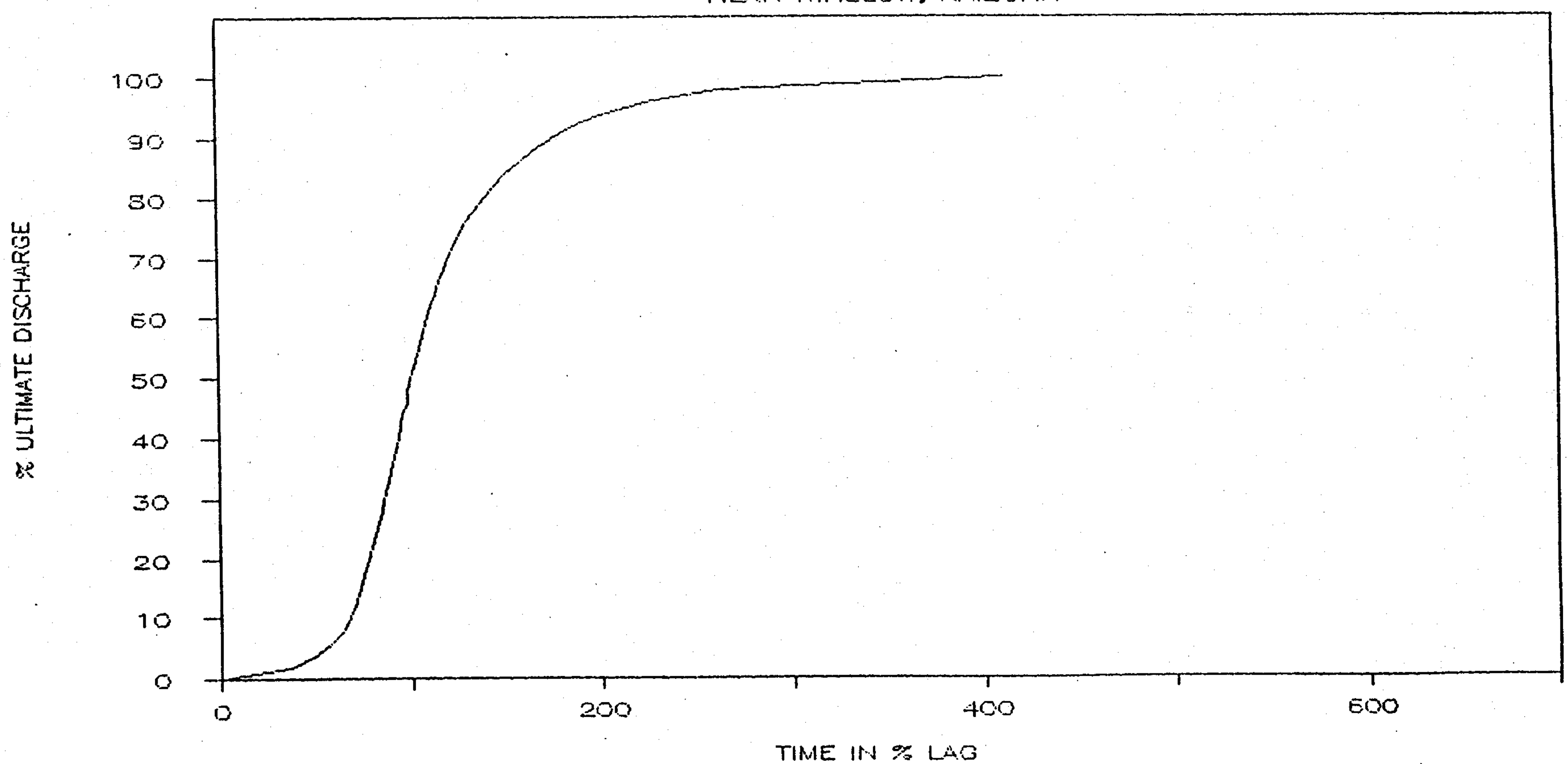
#24 CLEAR CREEK

NEAR WINSLOW, ARIZONA



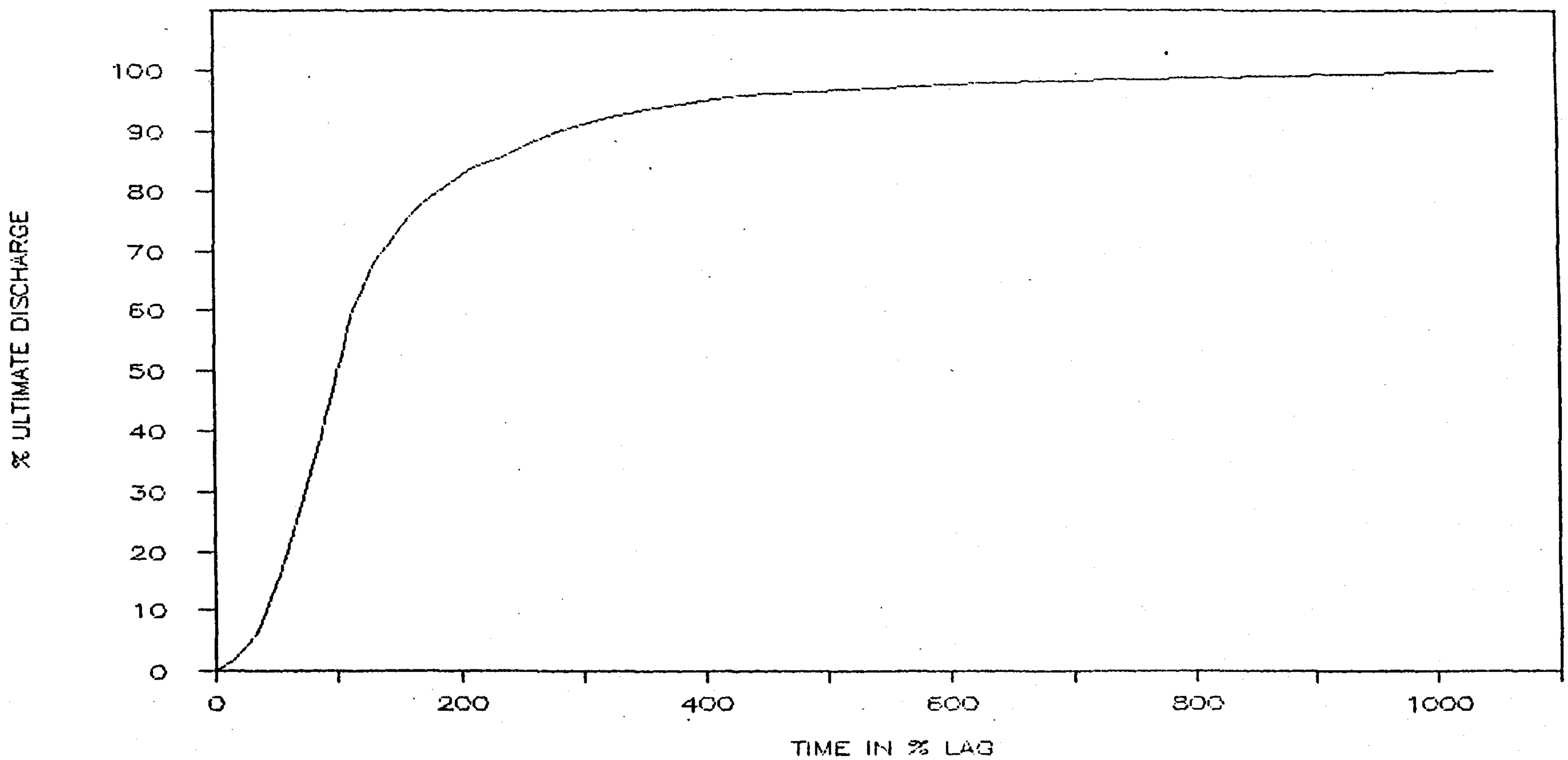
#24 CLEAR CREEK

NEAR WINSLOW, ARIZONA



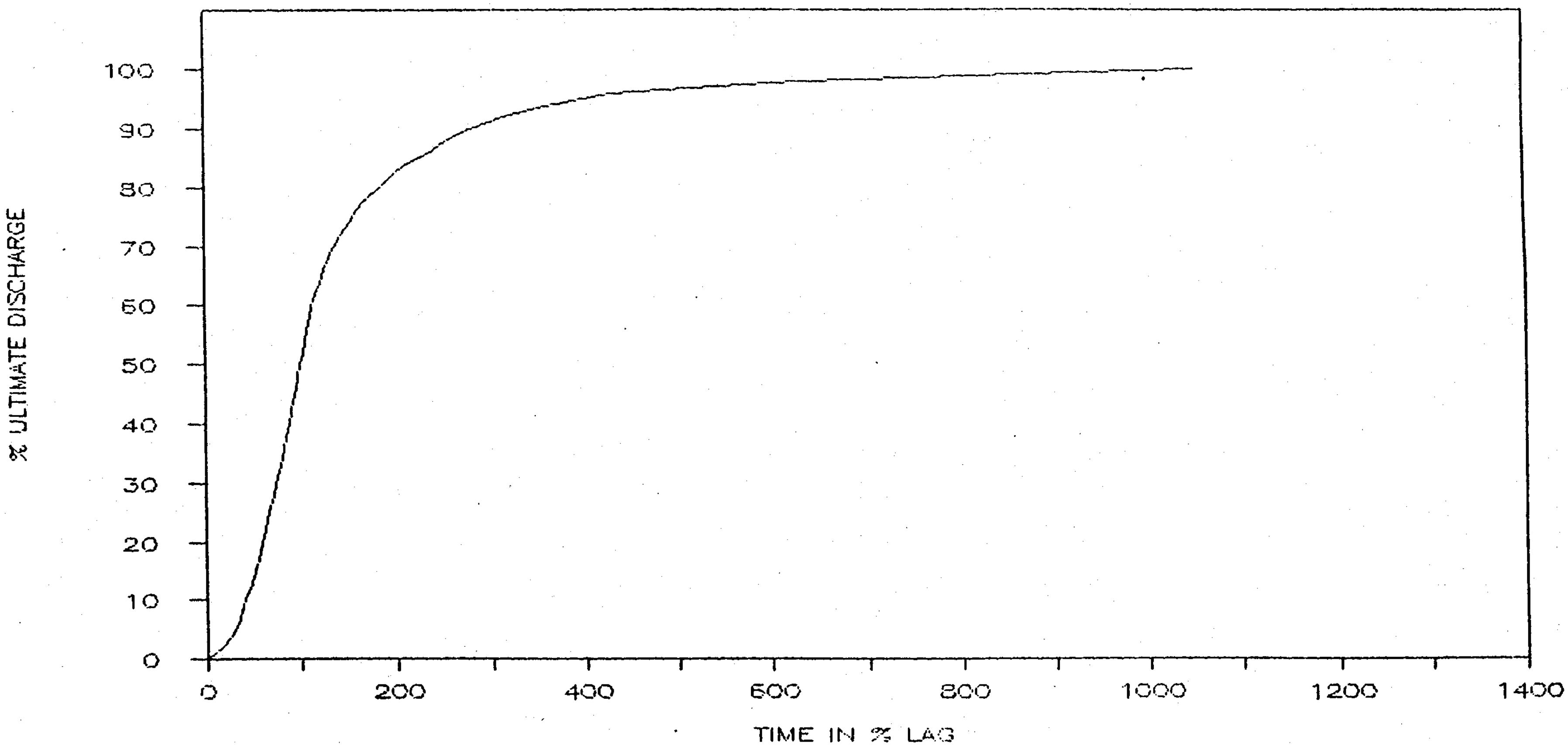
#25 MURRIETA CREEK

AT TEMECULA, CA



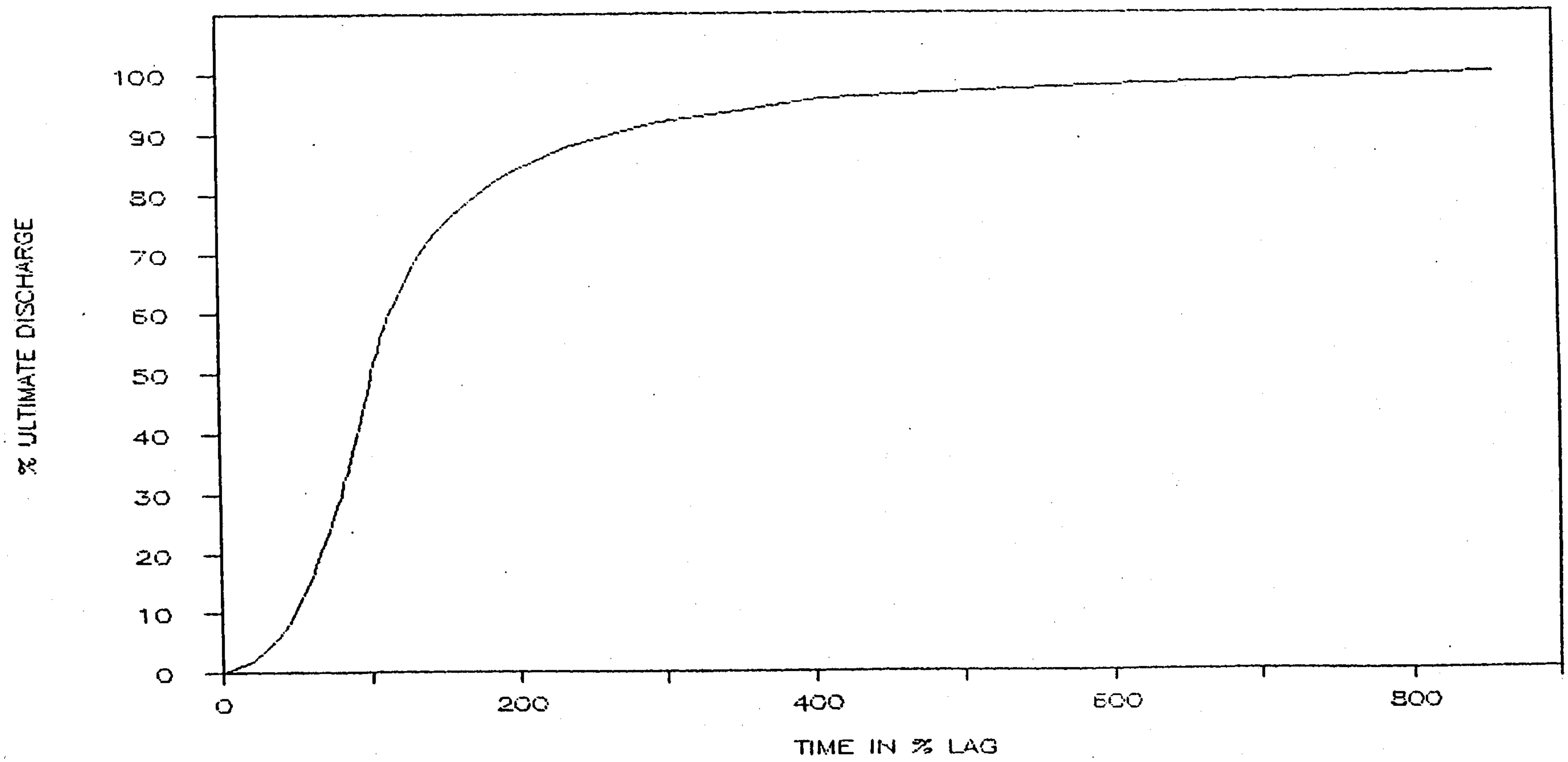
#25 MURRIETA CREEK

AT TEMECULA, CA



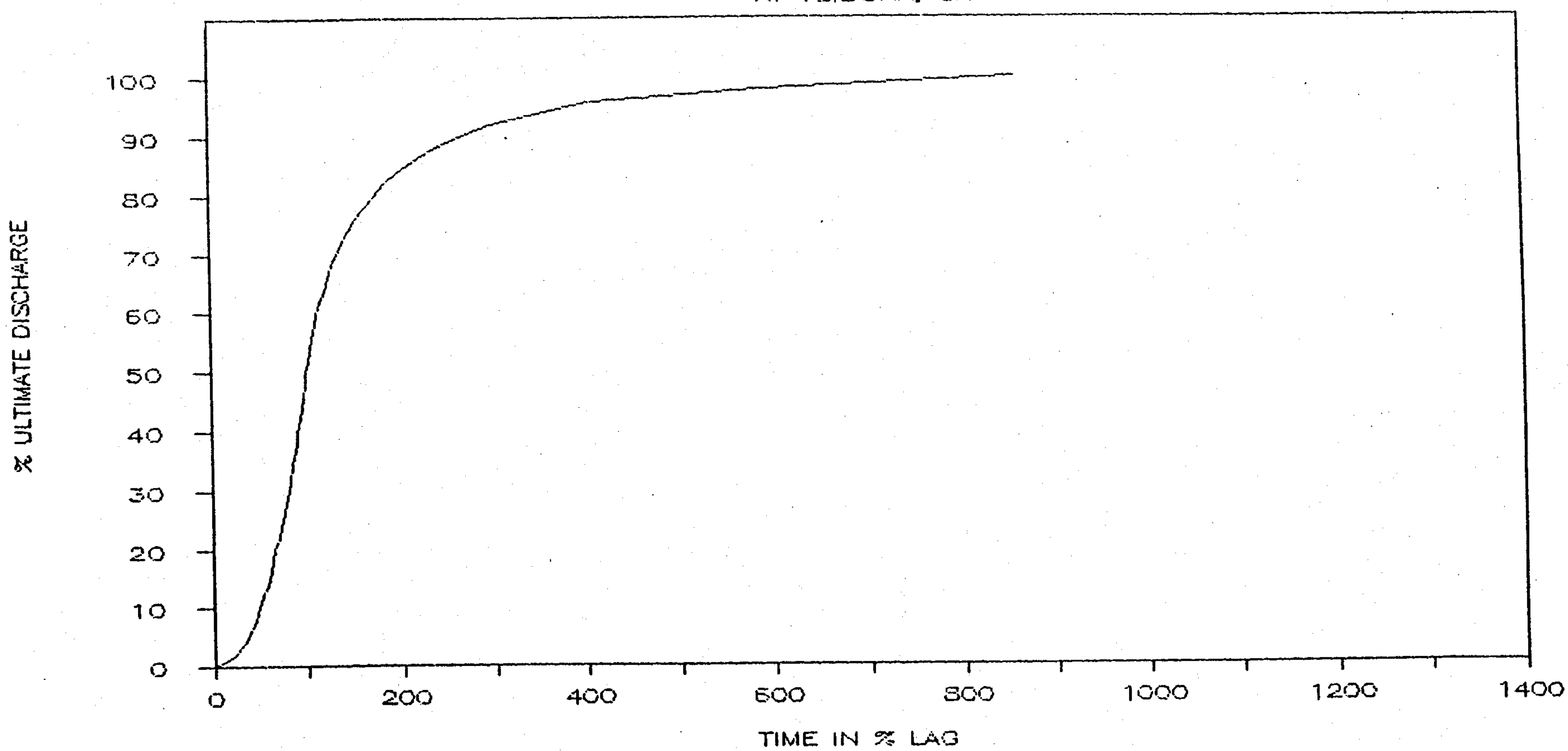
#26 SANTA MARGARITA RIVER

AT YSIDORA, CA



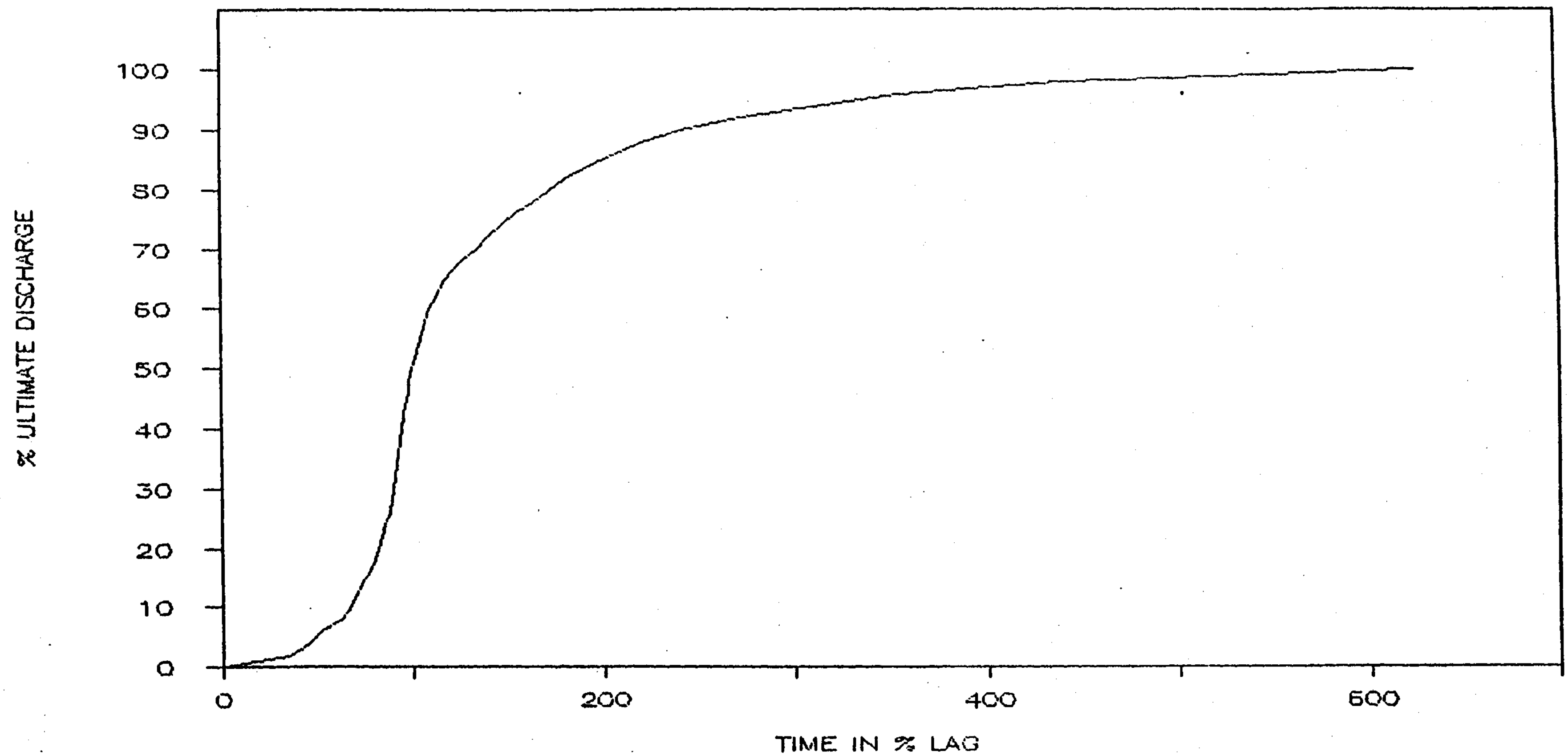
#26 SANTA MARGARITA RIVER

AT YSIDORA, CA



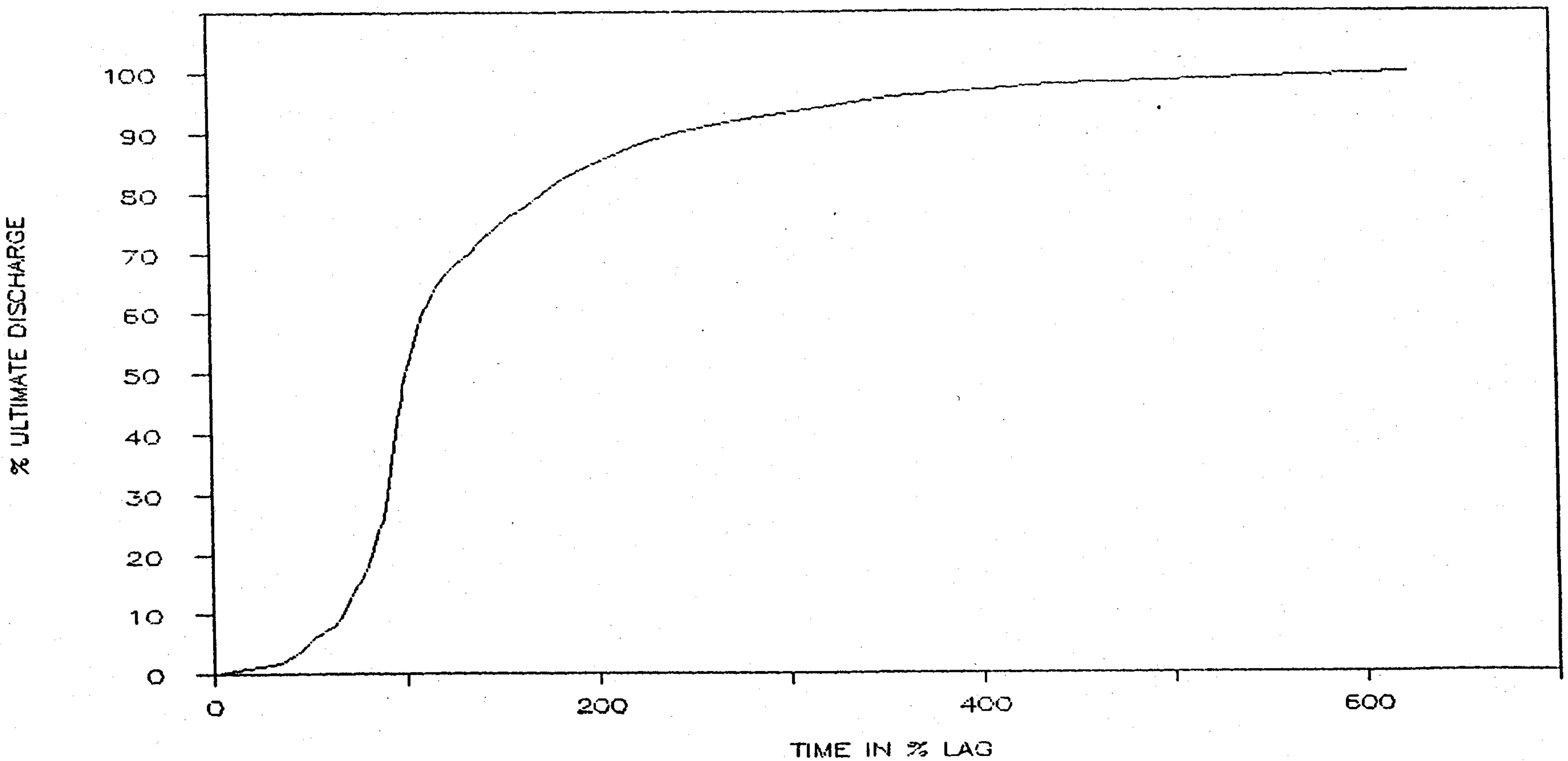
#27 SANTA MARGARITA RIVER

NEAR FALLBROOK, CA



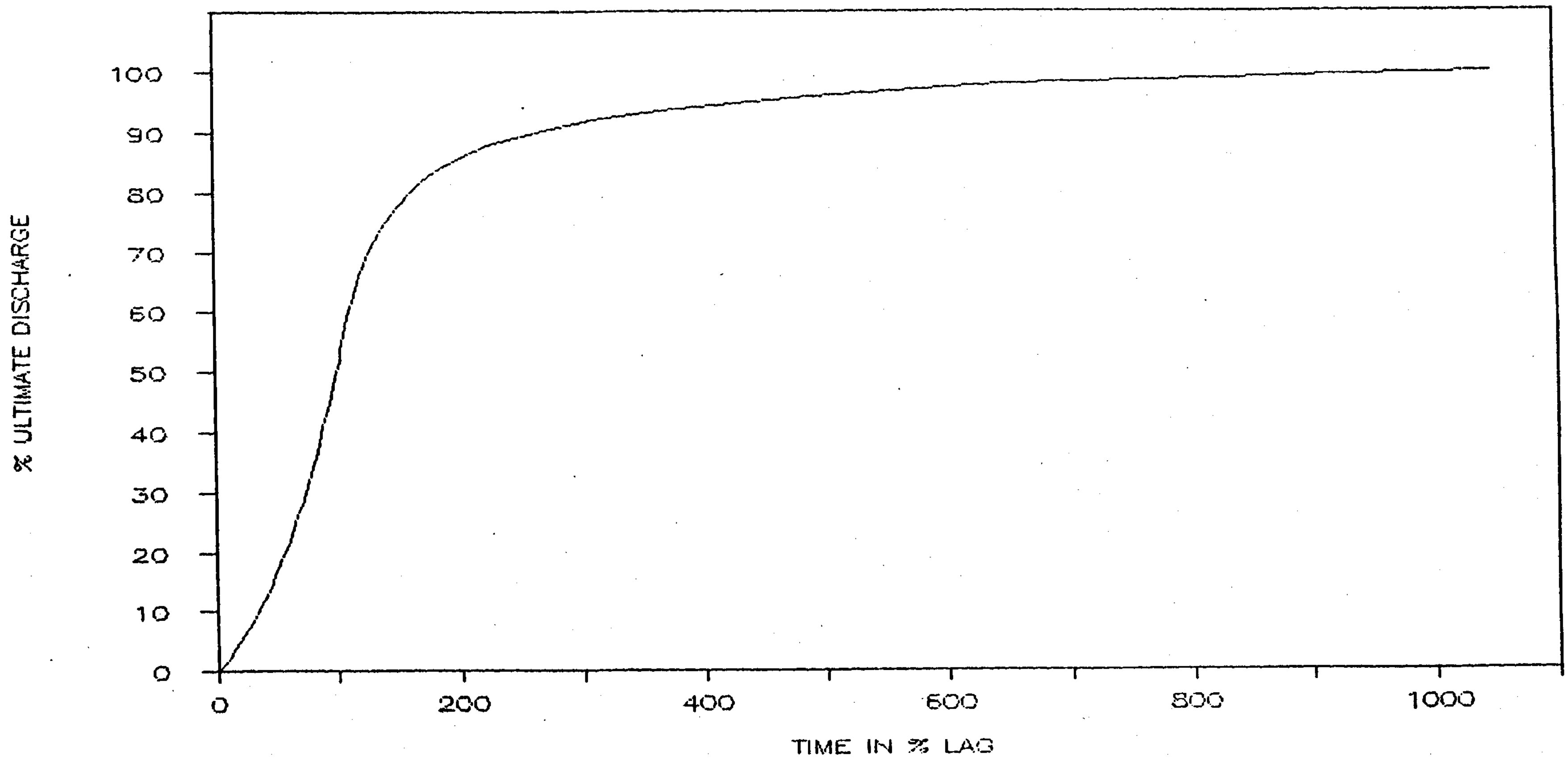
#27 SANTA MARGARITA RIVER

NEAR FALLBROOK, CA



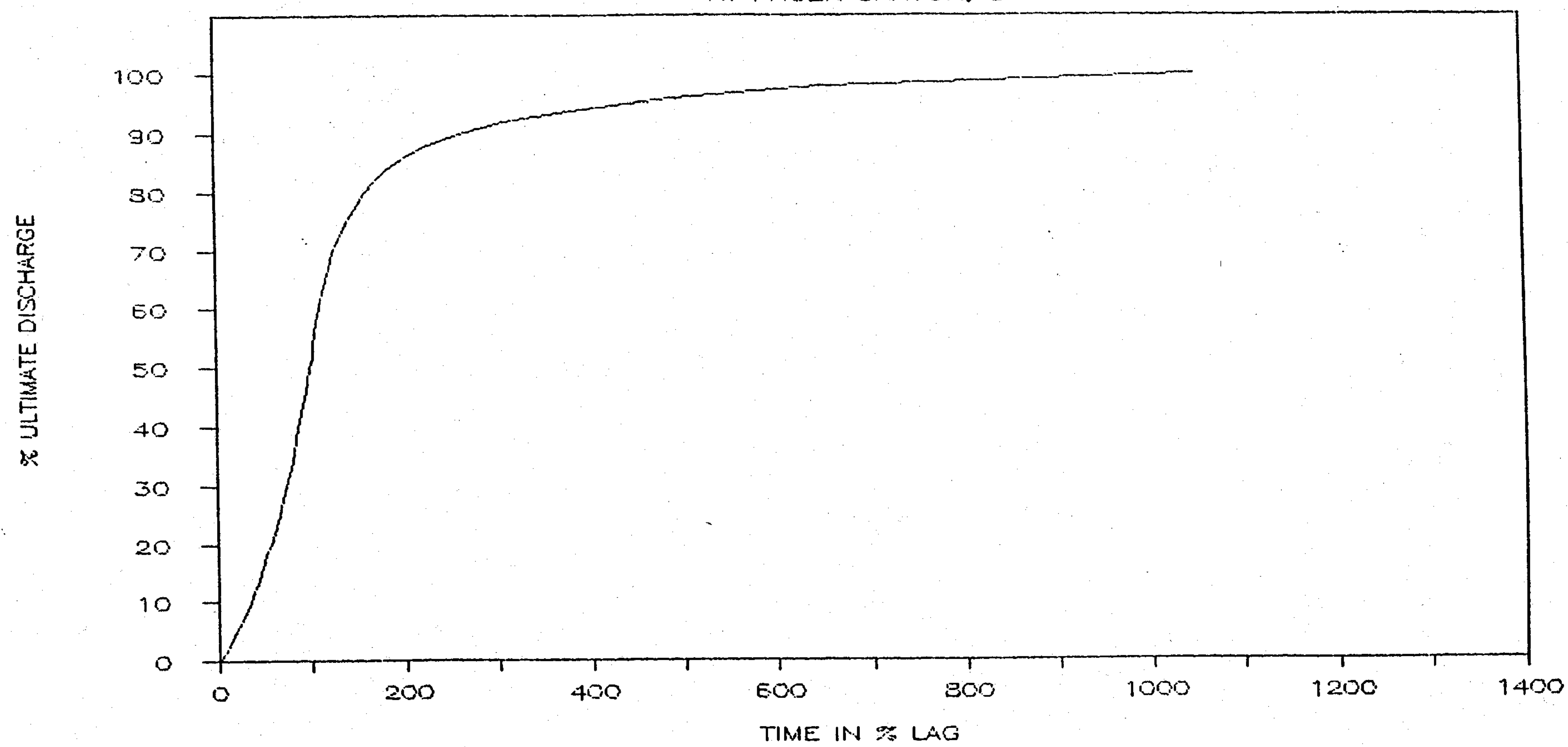
#28 TEMECULA CREEK

AT PAUBA CANYON, CA



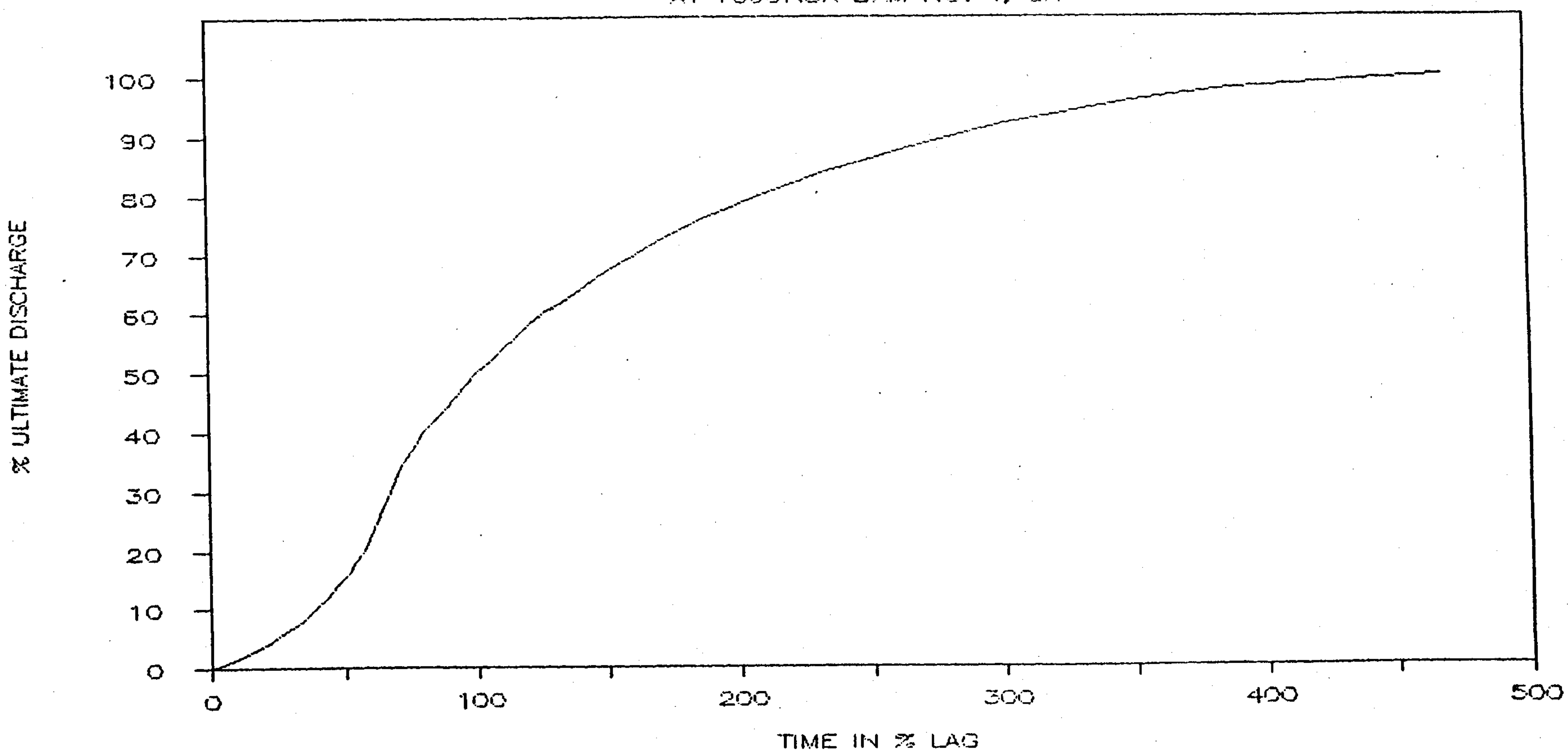
#28 TEMECULA CREEK

AT PAUBA CANYON, CA



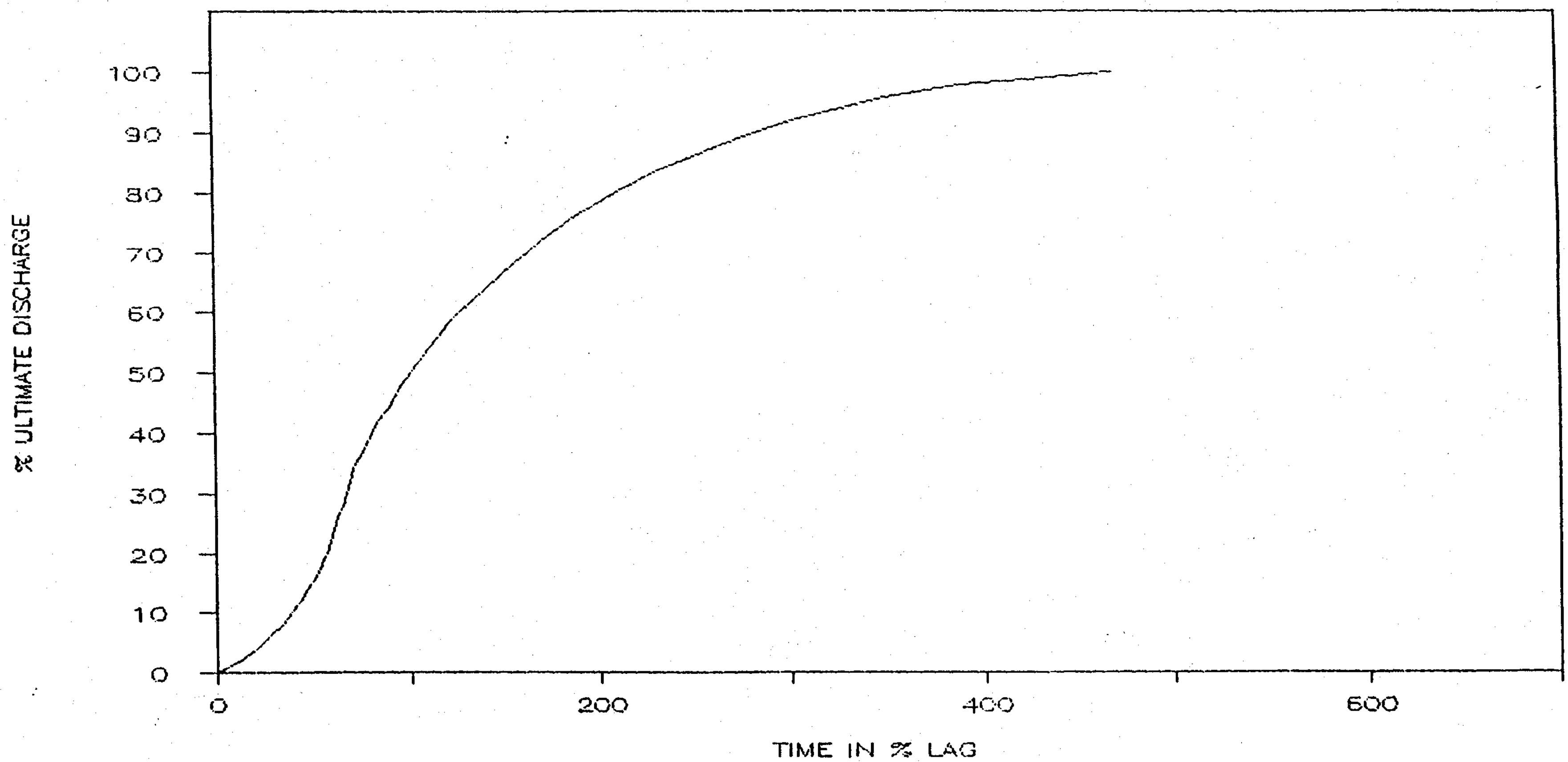
#29 TUJUNGA CREEK

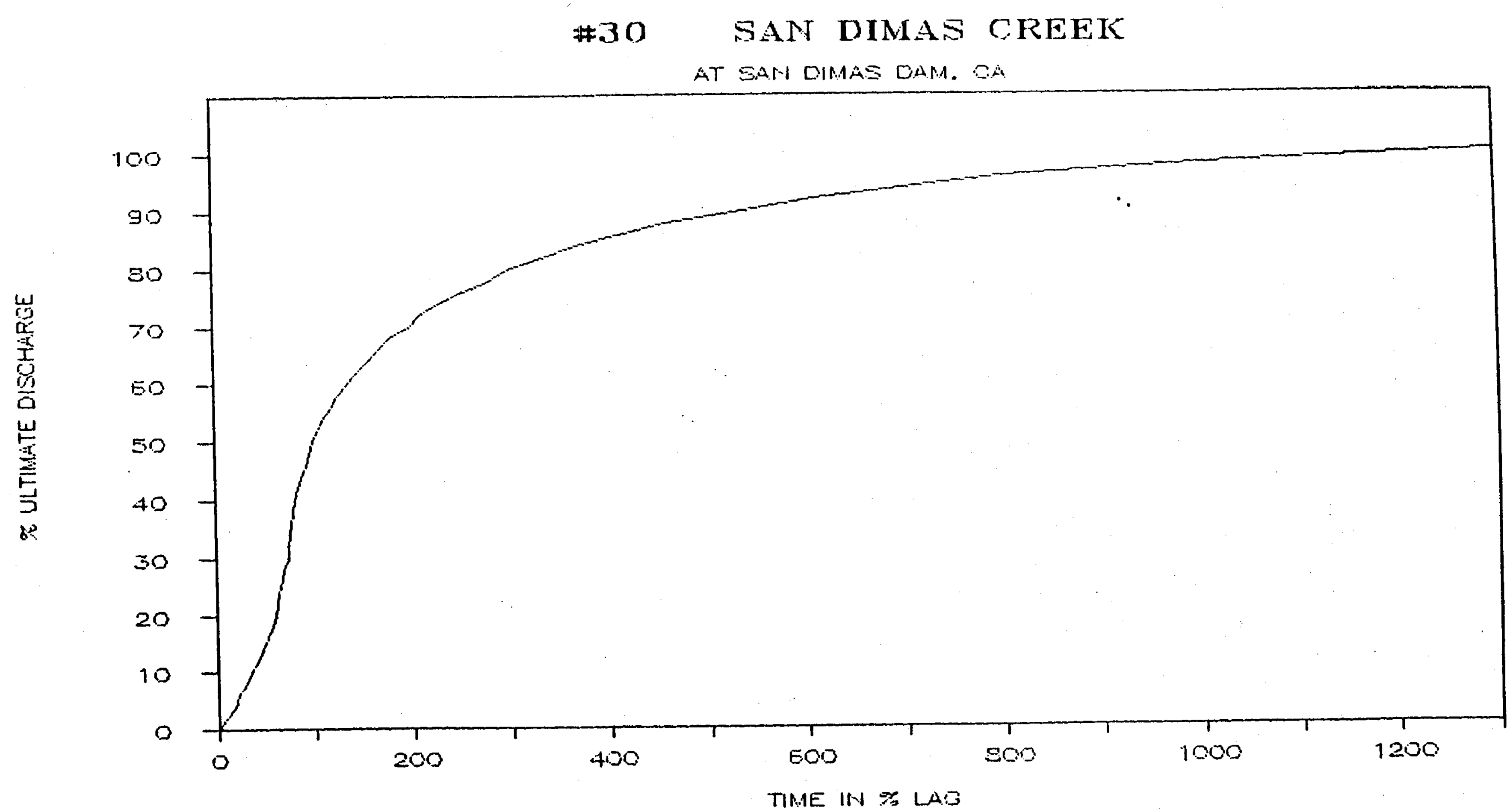
AT TUJUNGA DAM NO. 1, CA



#29 TUJUNGA CREEK

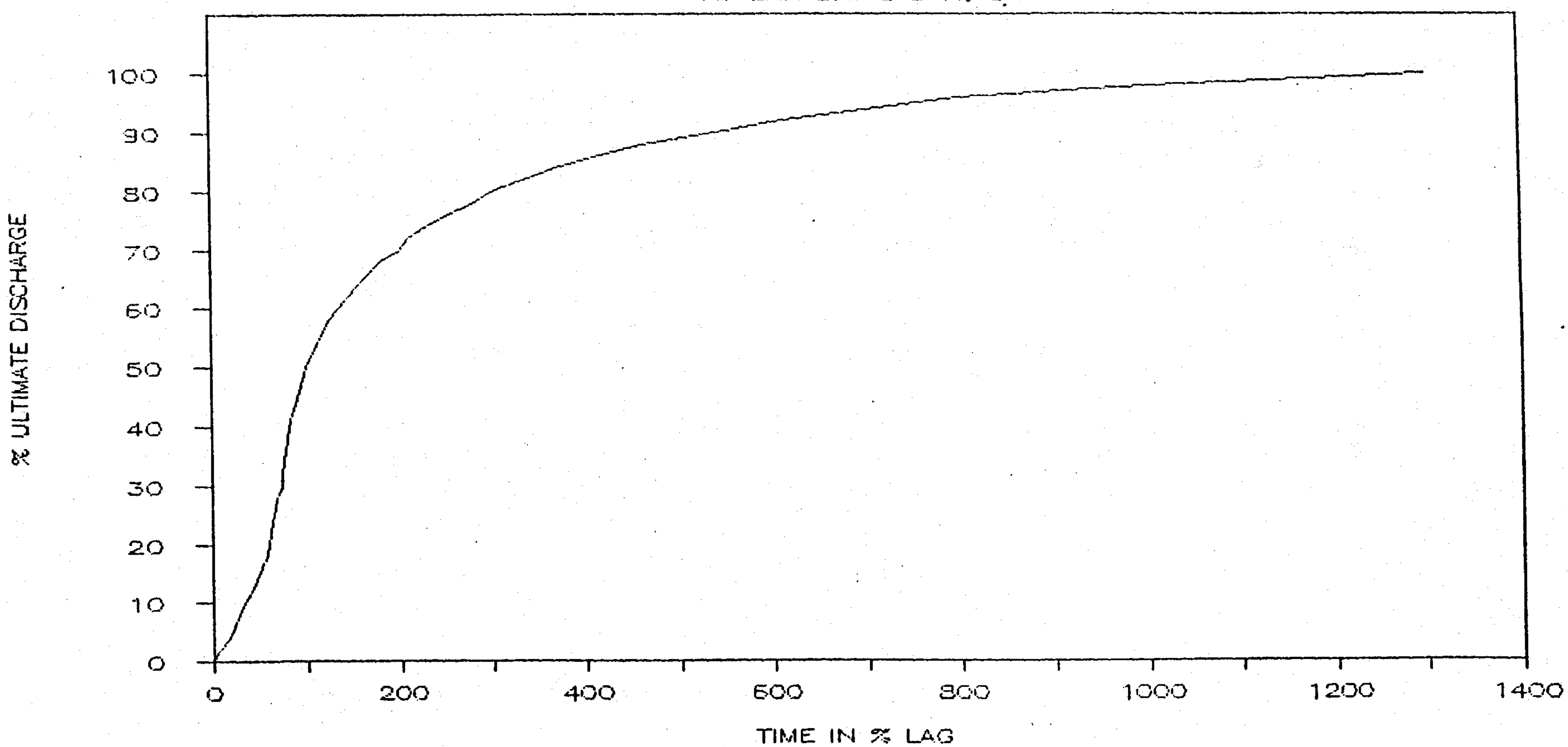
AT TUJUNGA DAM NO. 1, CA




#30 SAN DIMAS CREEK
AT SAN DIMAS DAM, CA
% ULTIMATE DISCHARGE
0
10
20
30
40
50
60
70
80
90
100
0
200
400
600
800
1000
1200
TIME IN % LAG

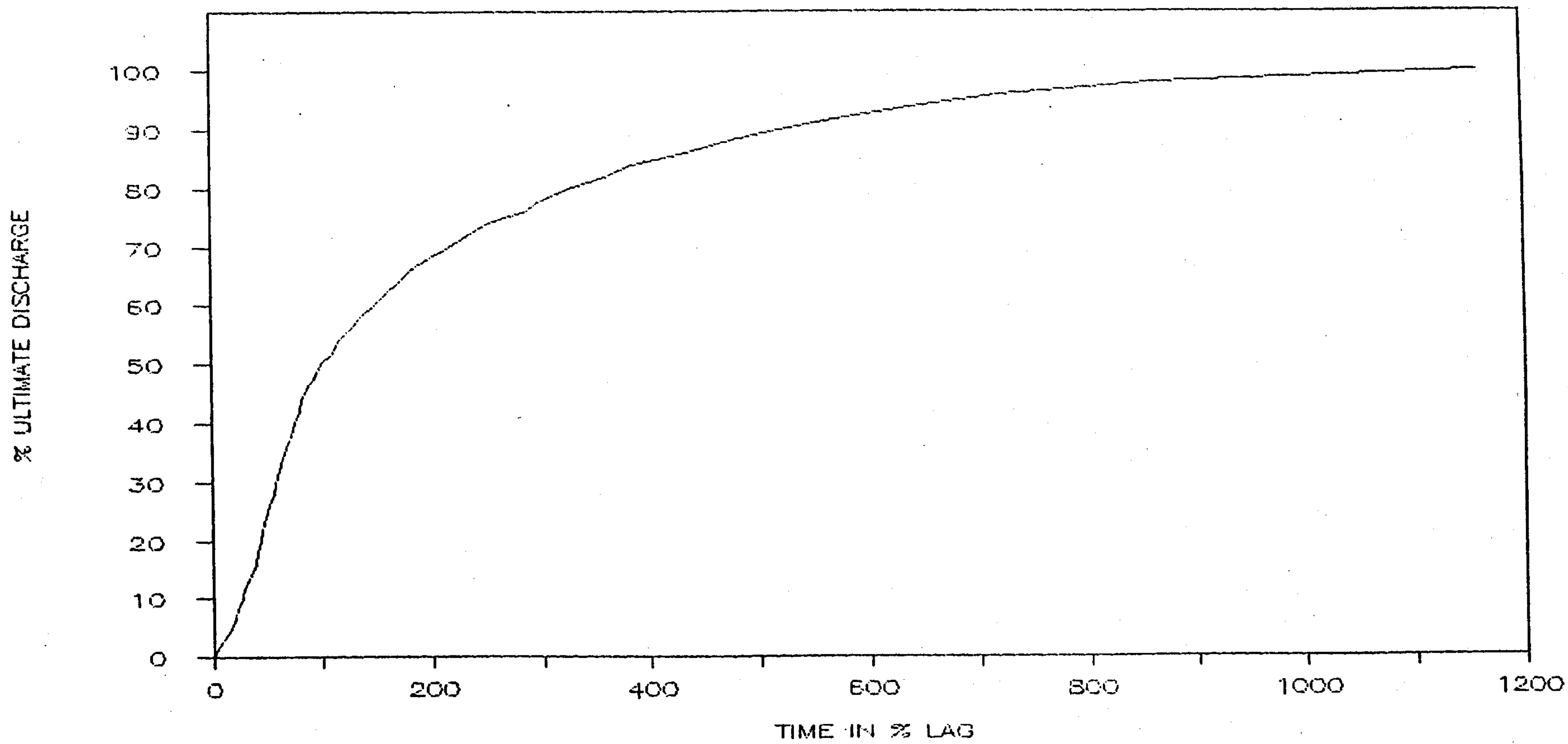
#30 SAN DIMAS CREEK

AT SAN DIMAS DAM, CA



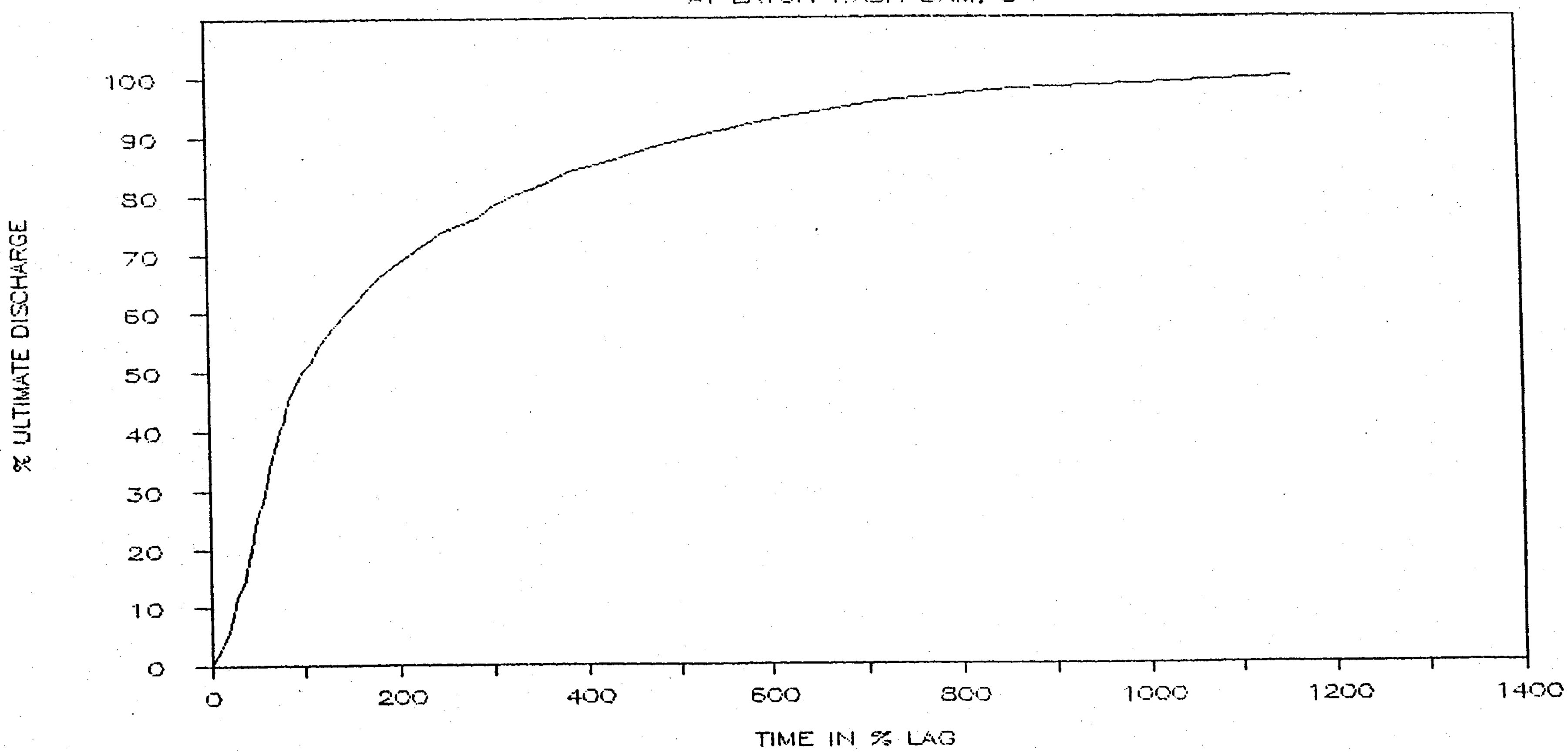
#31 EATON WASH

AT EATON WASH DAM, CA



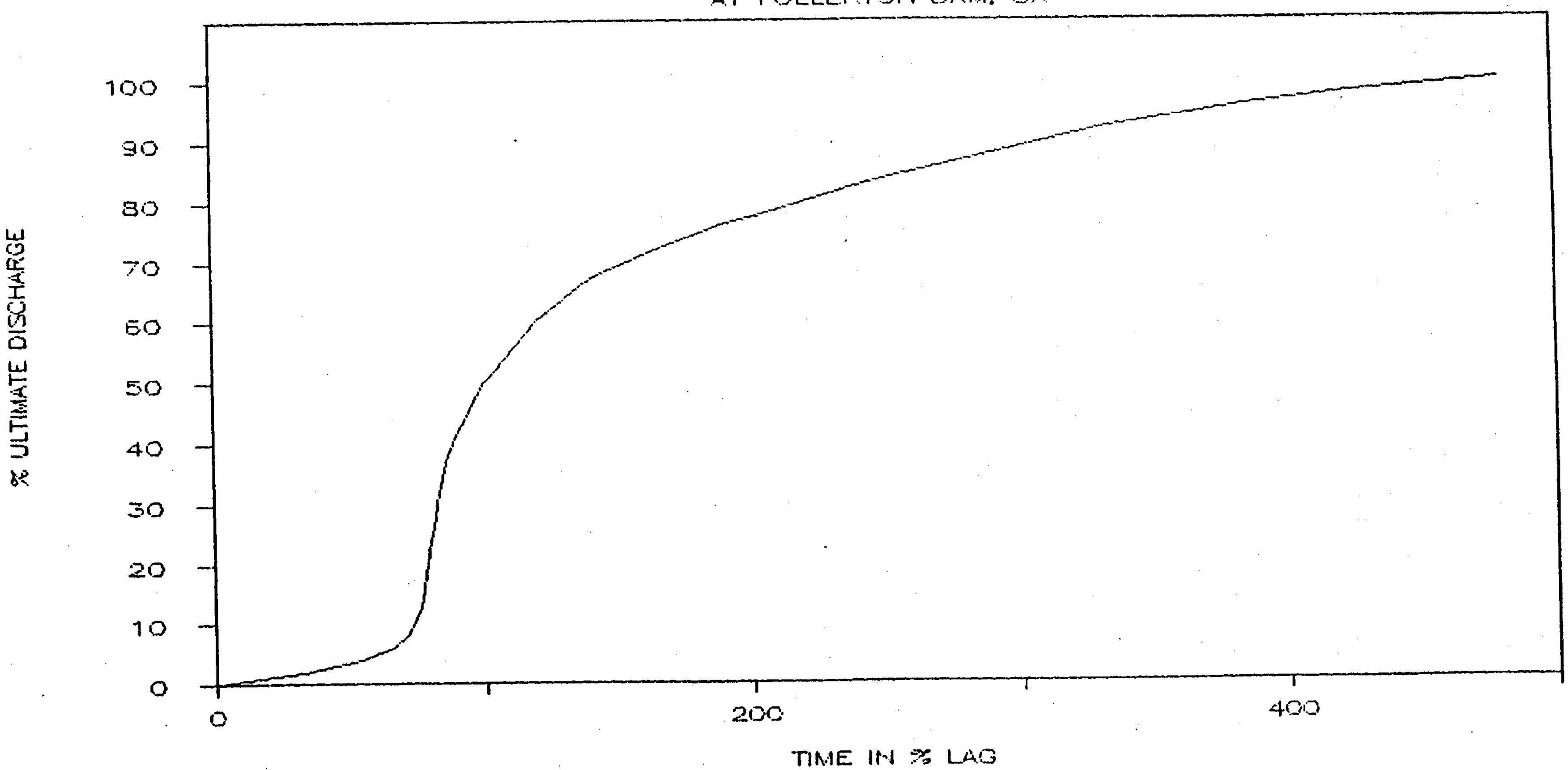
#31 EATON WASH

AT EATON WASH DAM, CA



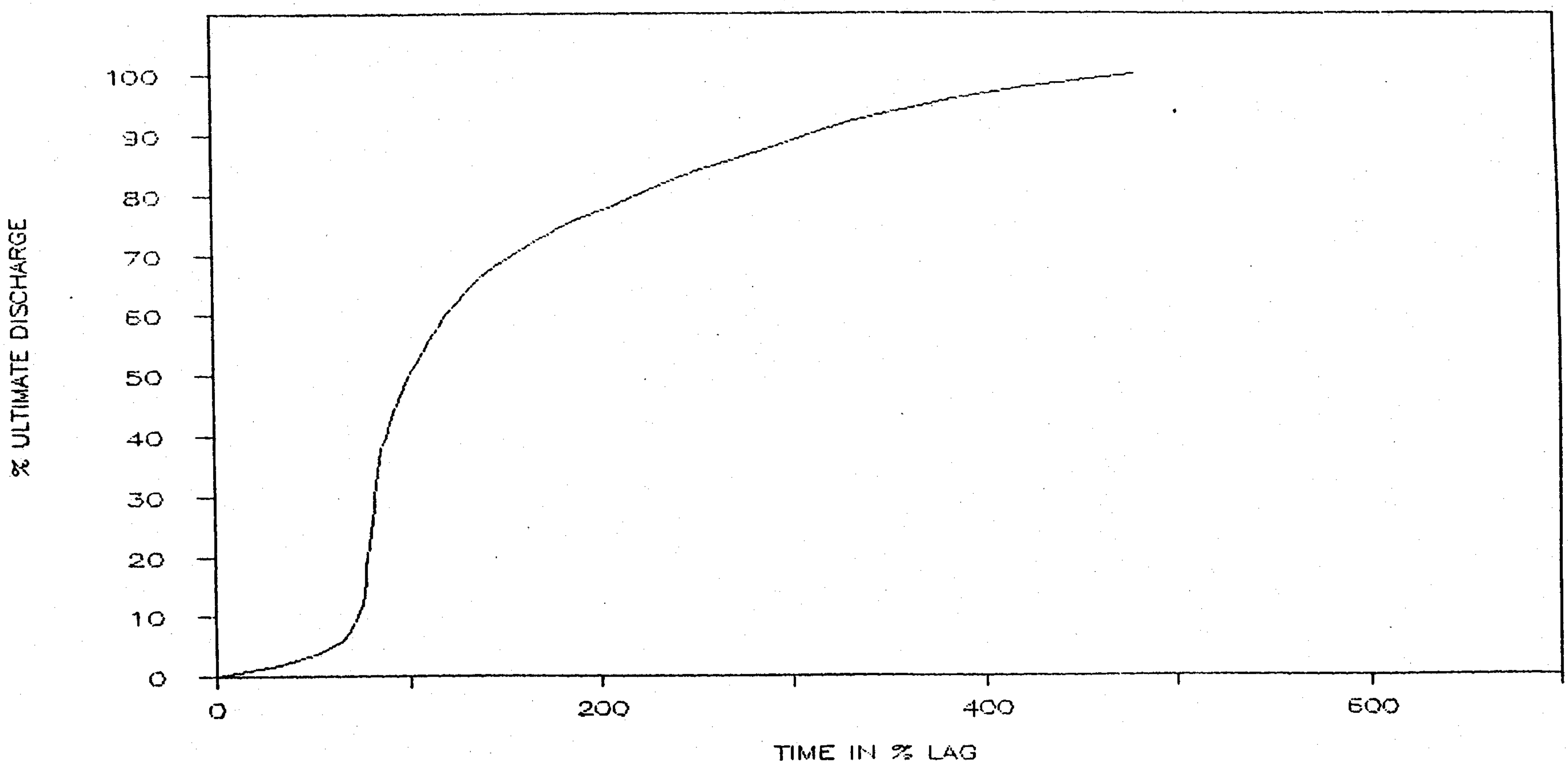
#32 EAST FULLERTON CREEK

AT FULLERTON DAM, CA



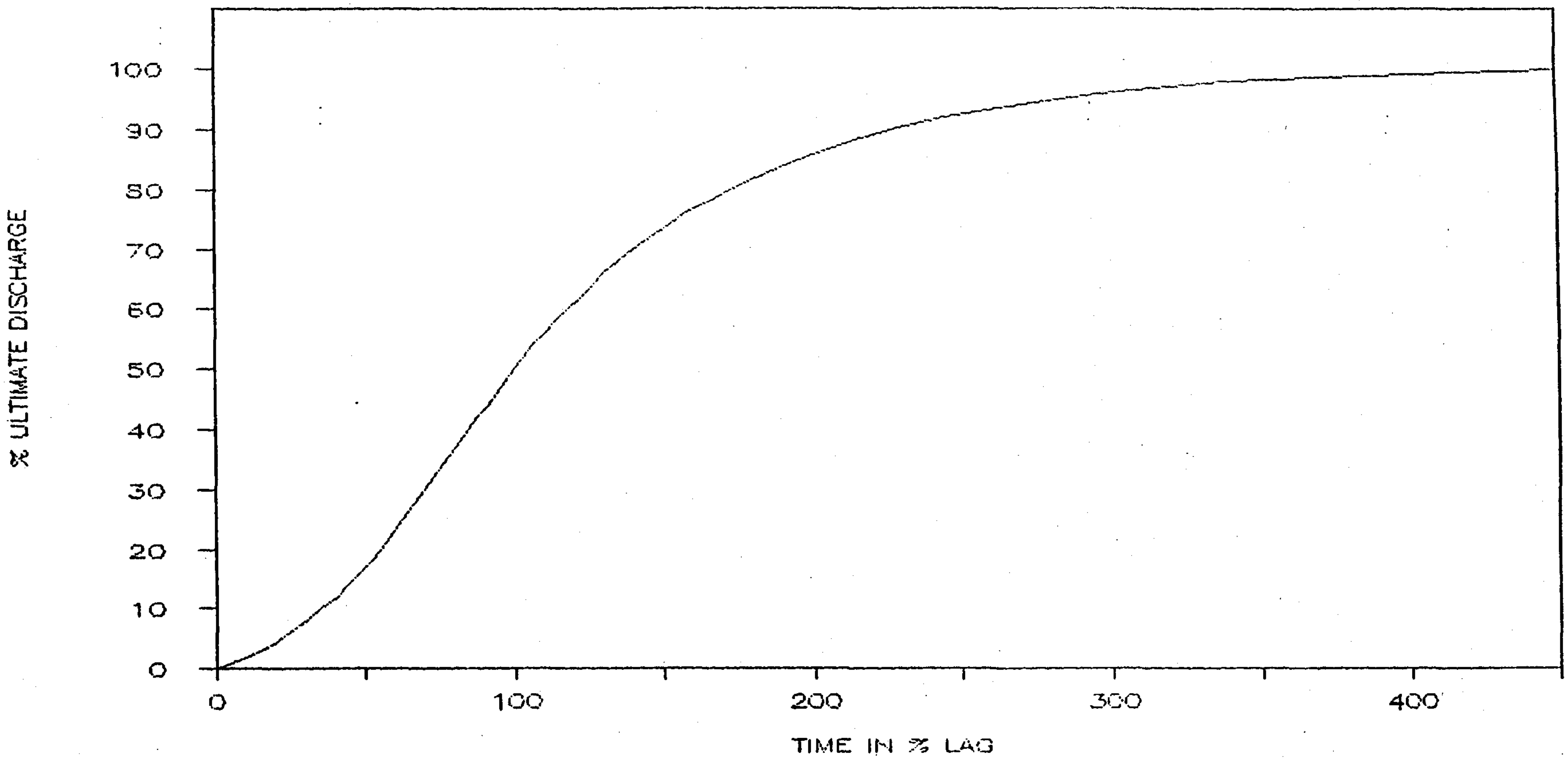
#32 EAST FULLERTON CREEK

AT FULLERTON DAM, CA



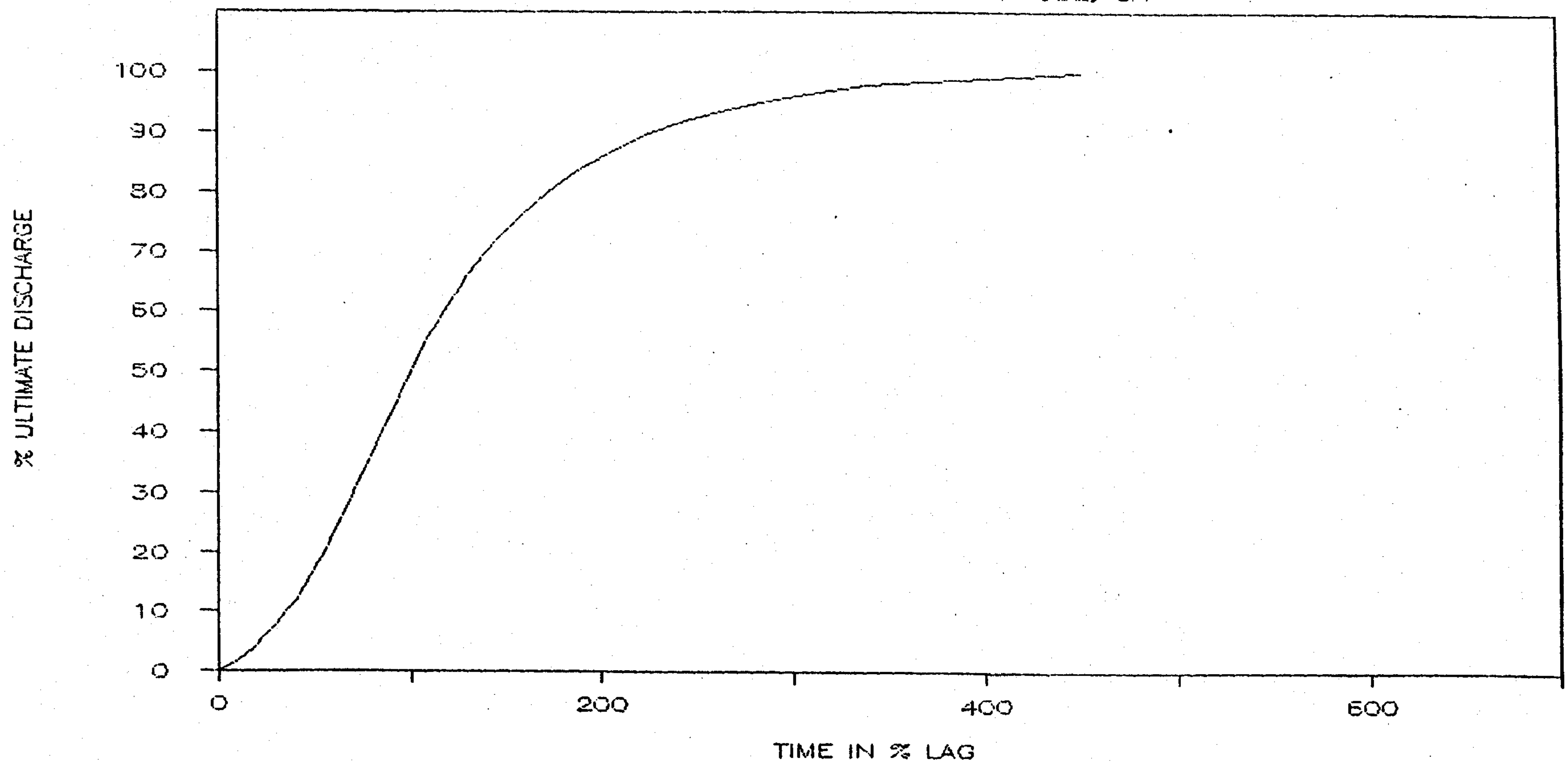
#33 SAN JOSE CREEK

AT WORKMAN MILL ROAD BRIDGE, CA



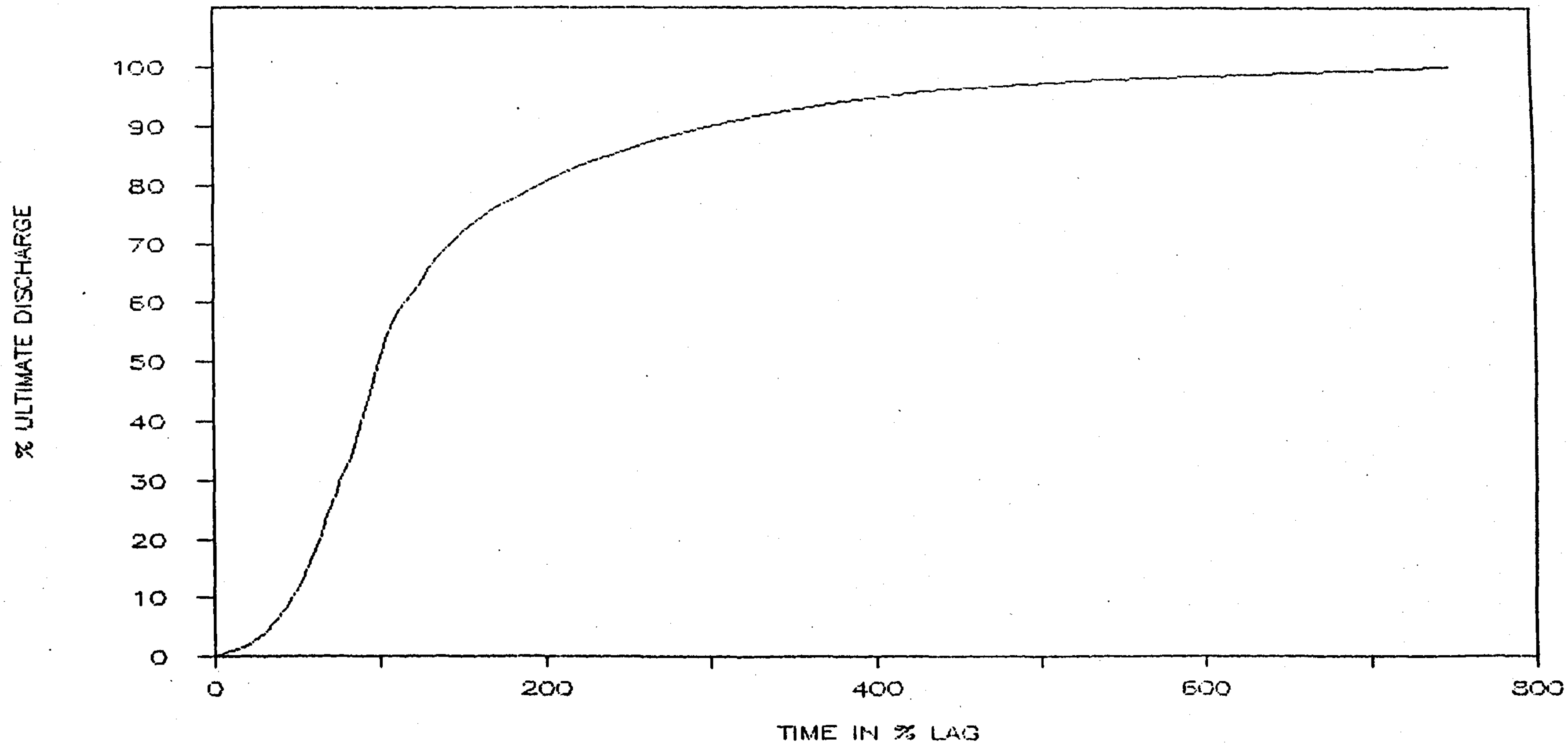
#33 SAN JOSE CREEK

AT WORKMAN MILL ROAD BRIDGE, CA



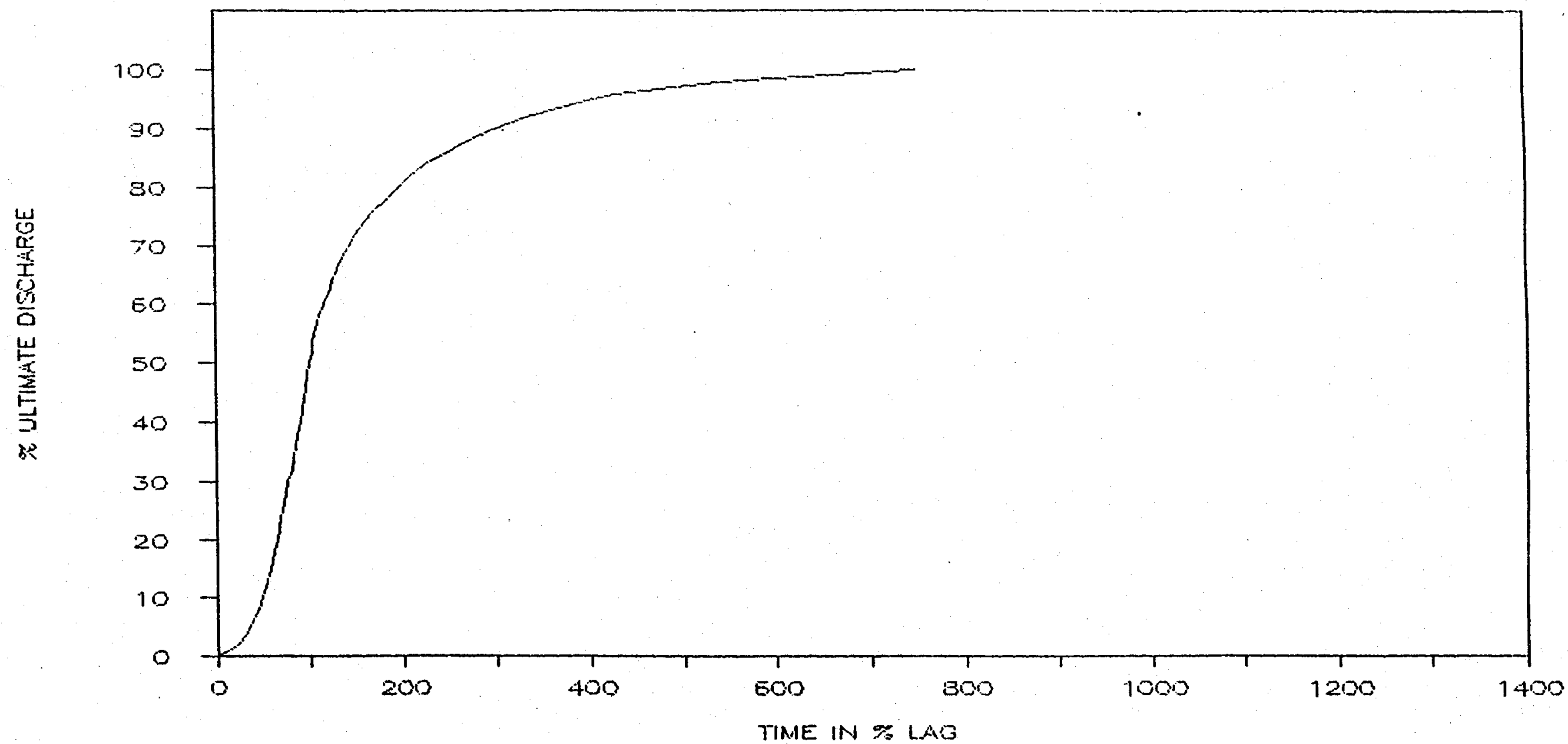
#34 ALHAMBRA WASH

ABOVE SHORT STREET BRIDGE, CA



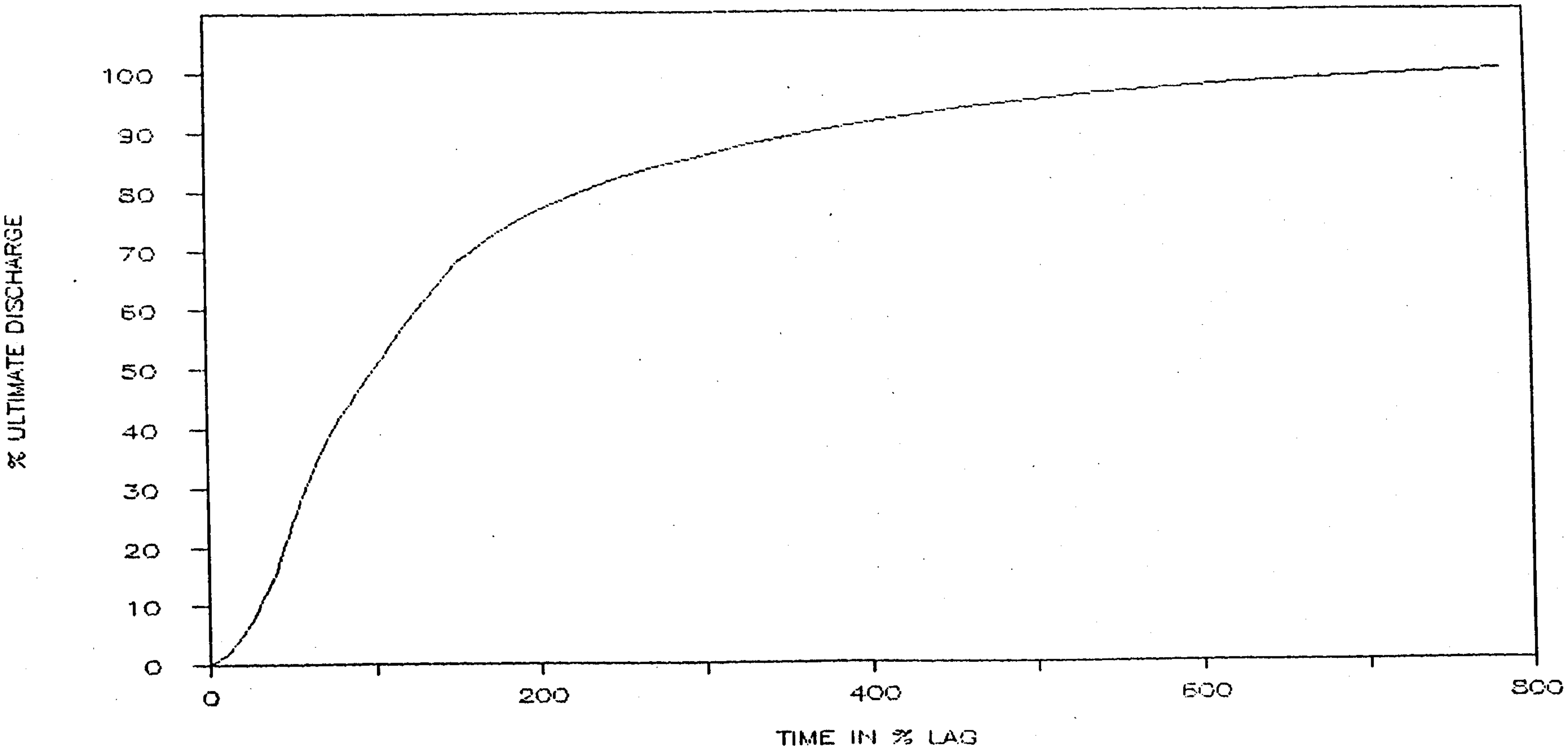
#34 ALHAMBRA WASH

ABOVE SHORT STREET BRIDGE, CA



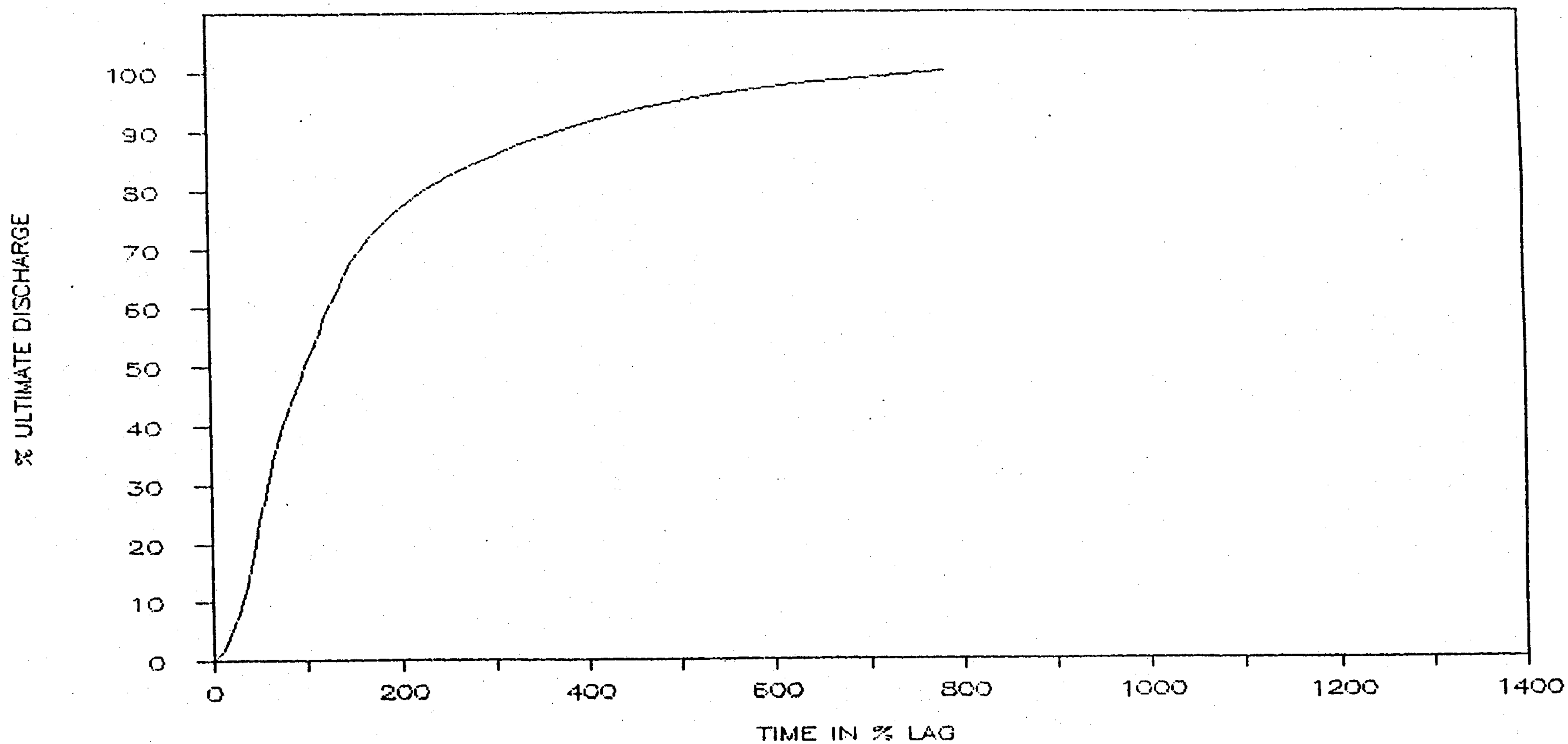
#35 BROADWAY DRAIN

ABOVE RAYMOND DIKE, CA



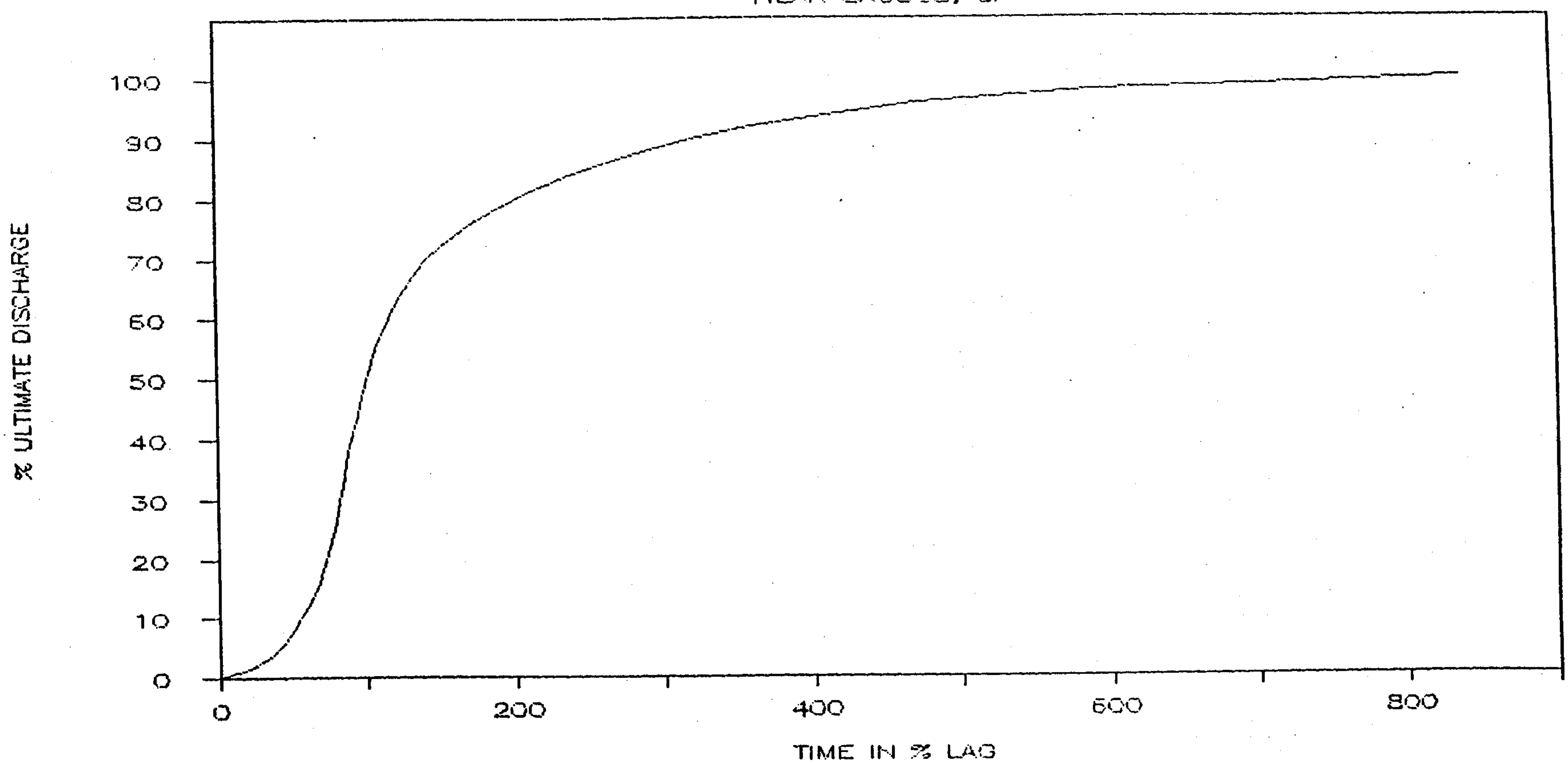
#35 BROADWAY DRAIN

ABOVE PAYMOND DIKE, CA



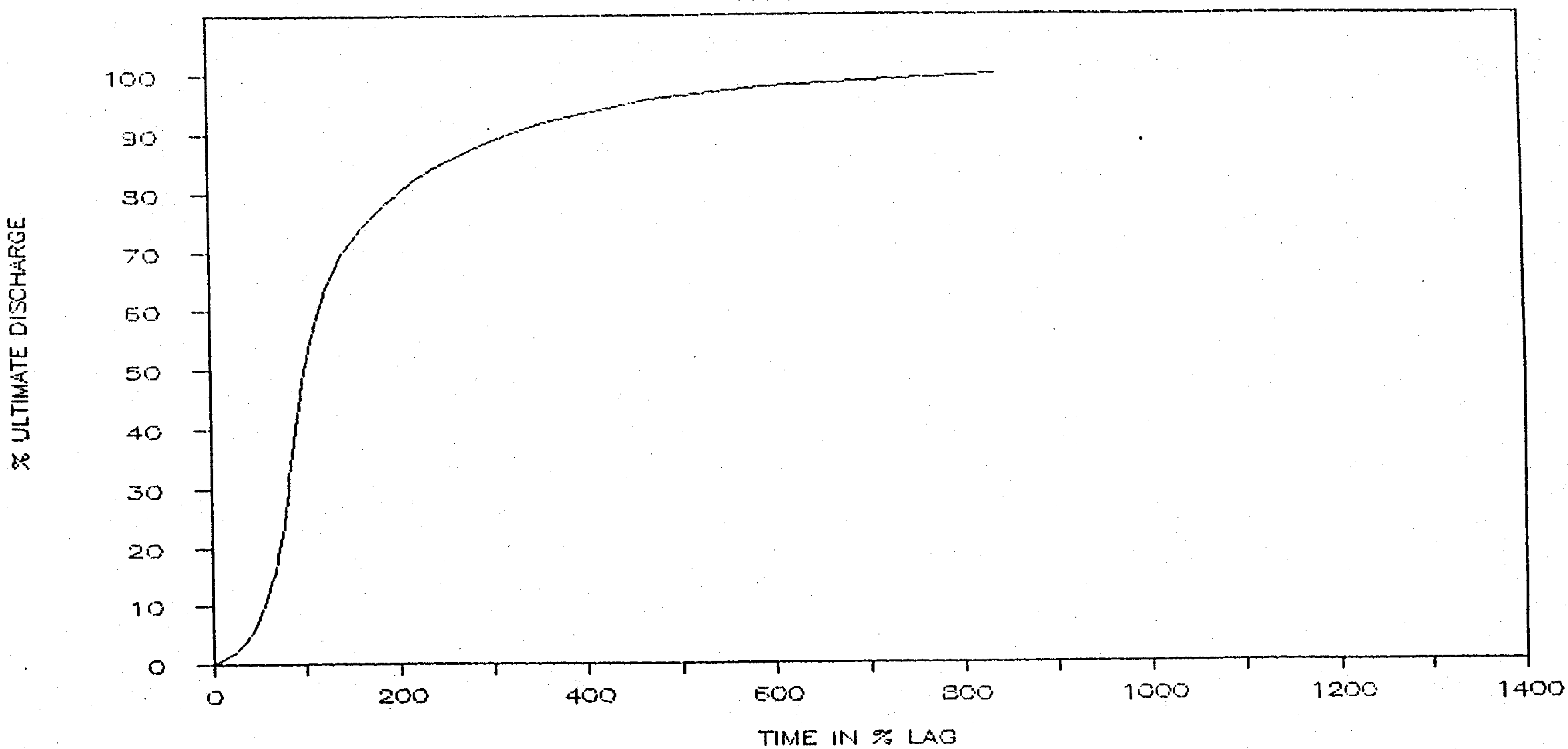
#36 SANTA CLARA RIVER

NEAR SAUGUS, CA



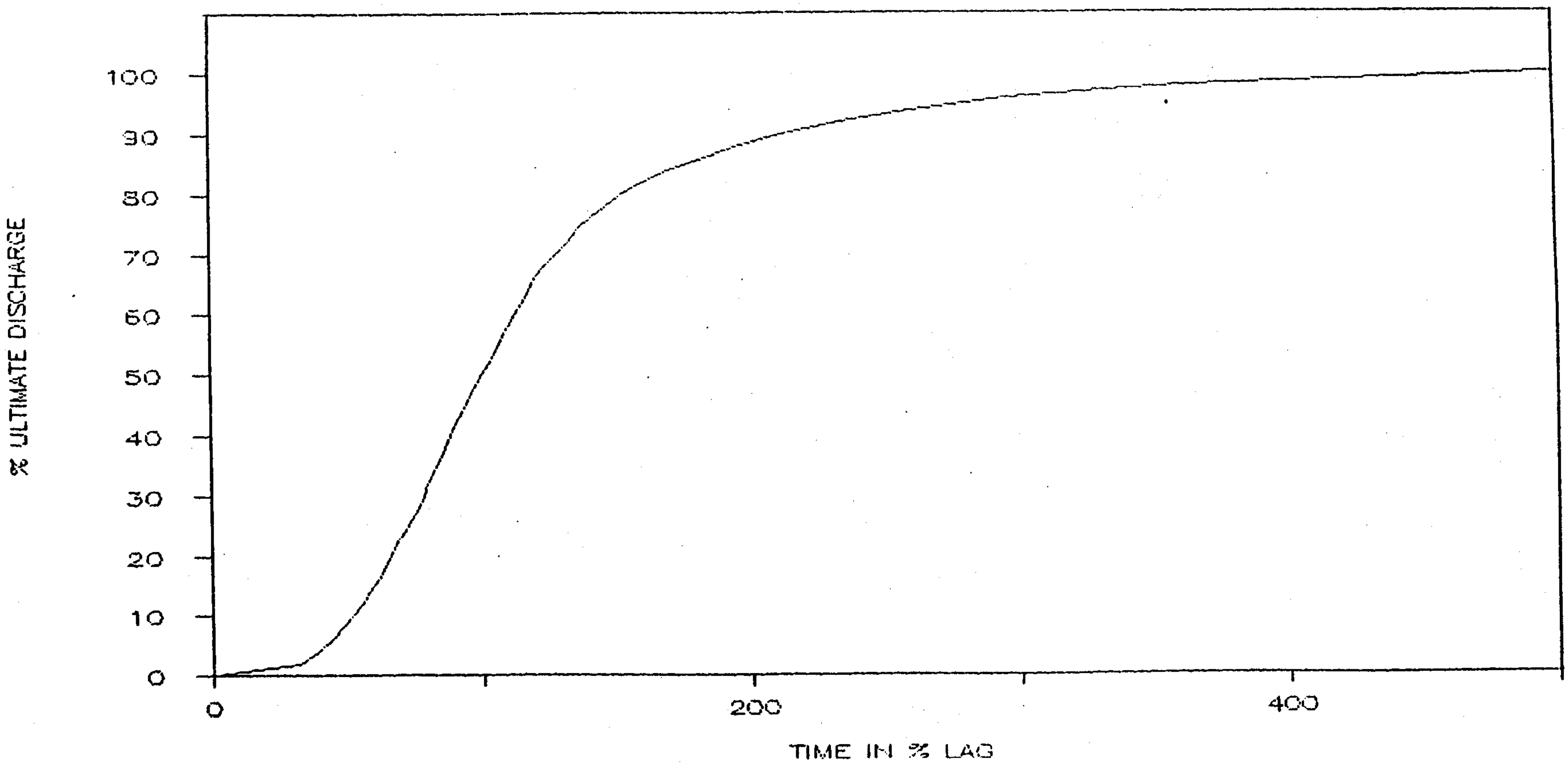
#36 SANTA CLARA RIVER

NEAR SAUGUS, CA



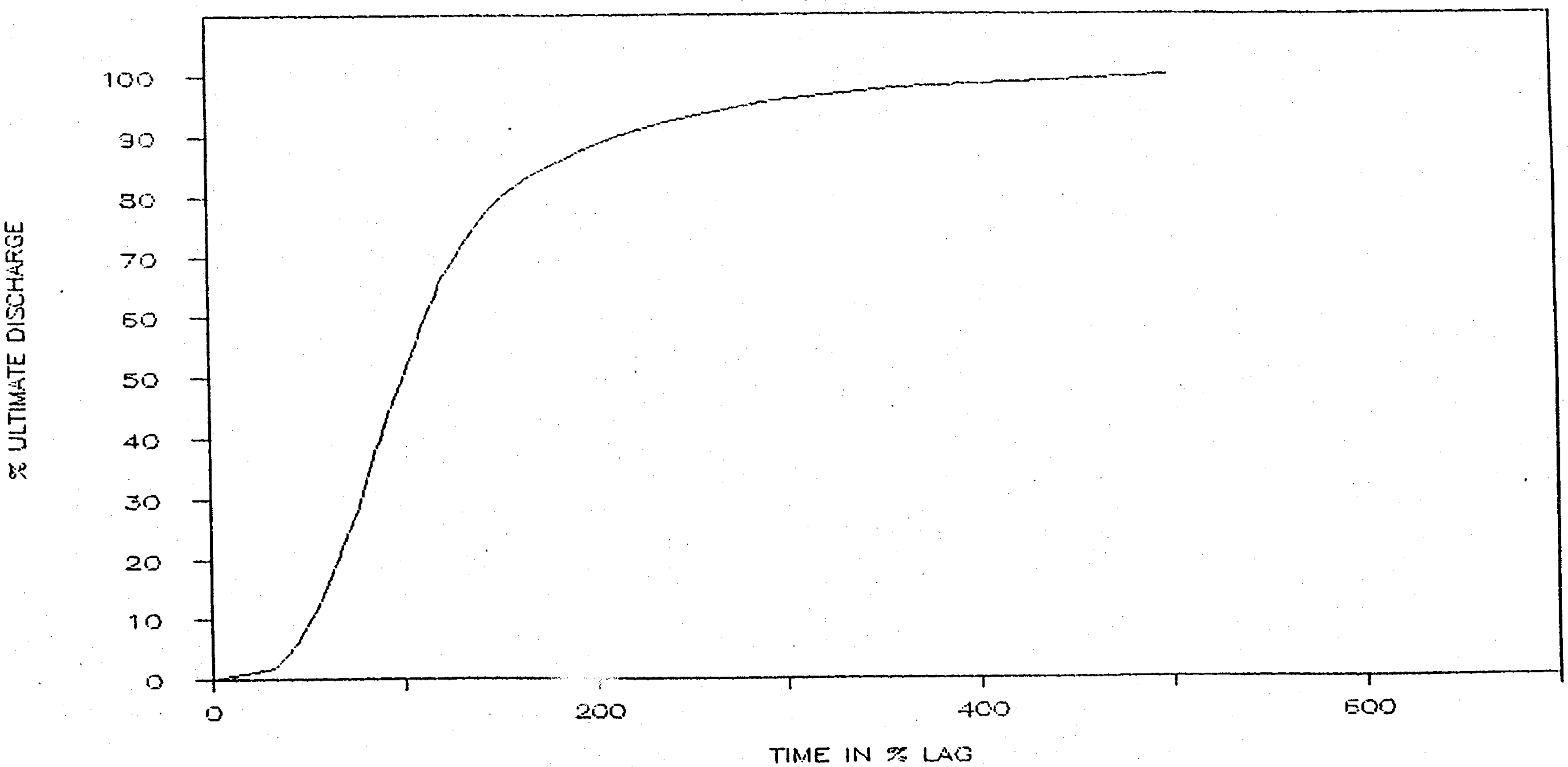
#37 COLMA CREEK BASIN

CALIFORNIA



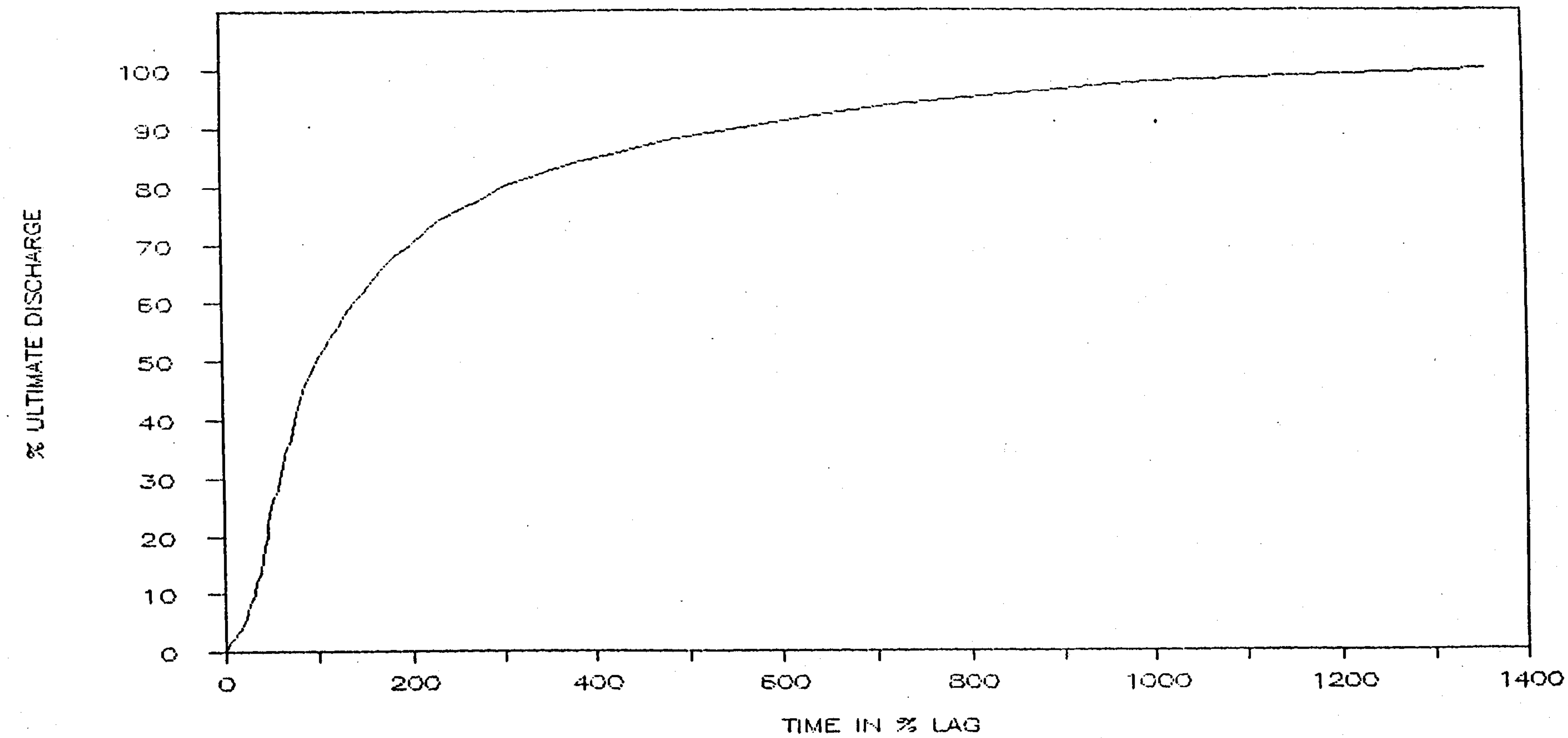
#37 COLMA CREEK BASIN

CALIFORNIA



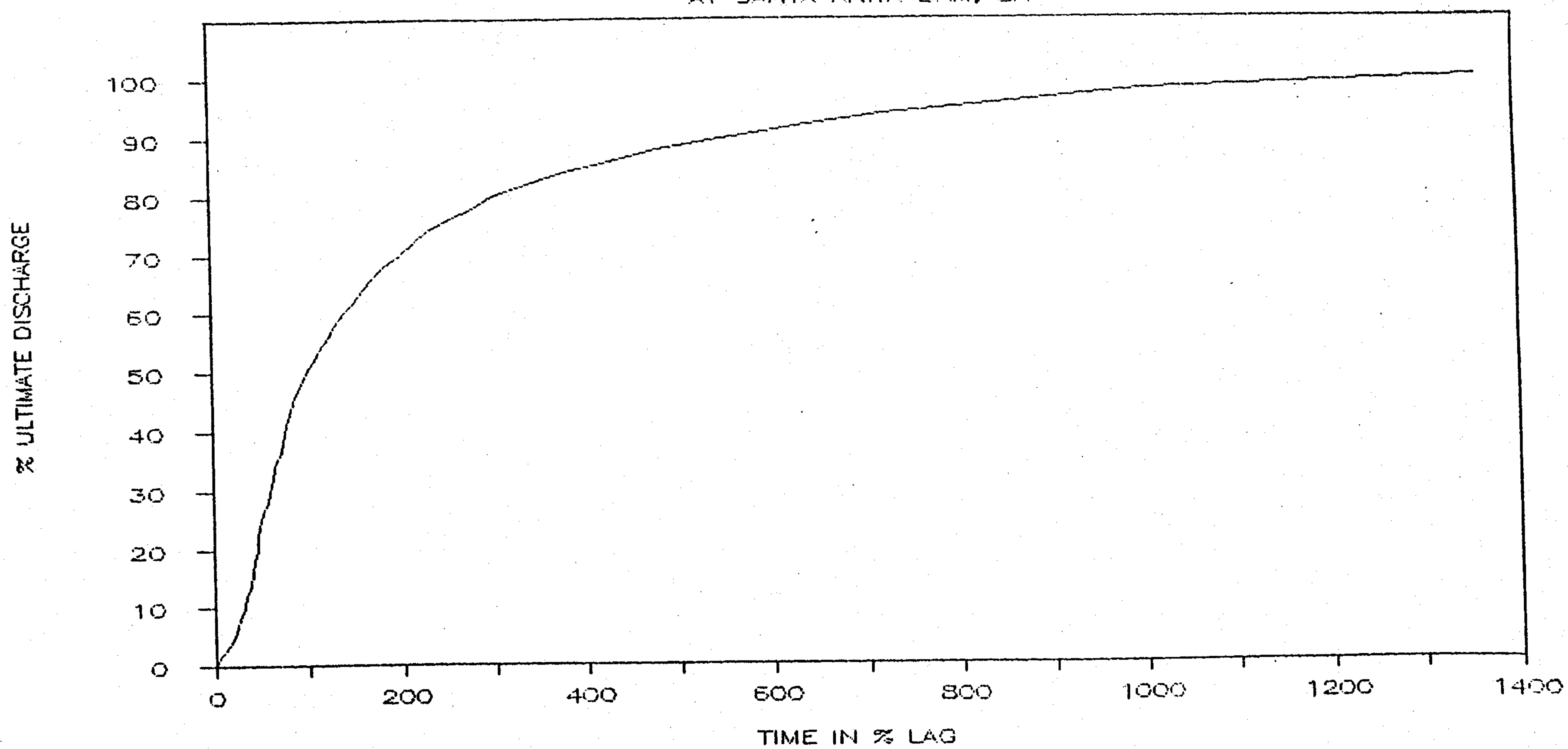
#38 SANTA ANITA CREEK

AT SANTA ANITA DAM, CA



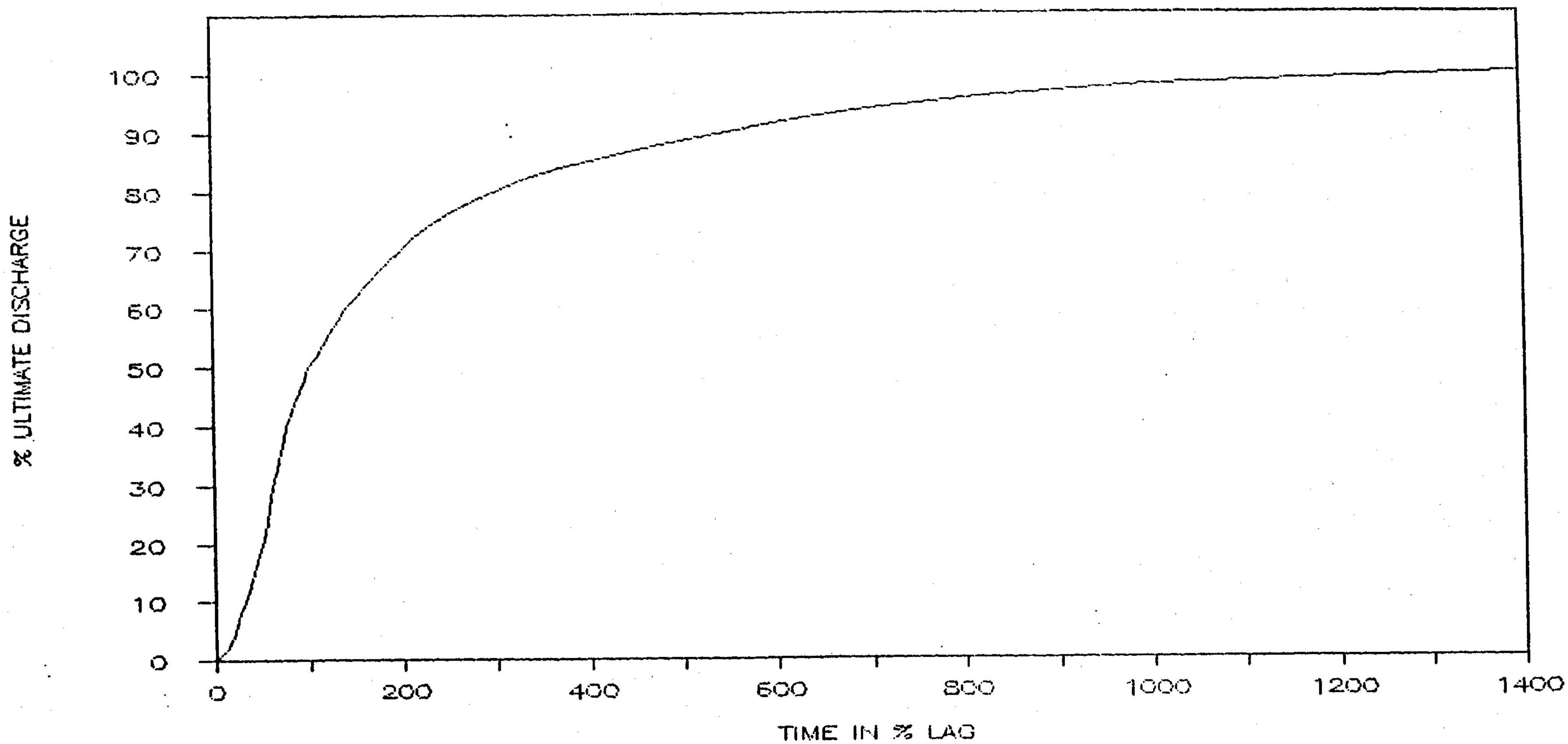
#38 SANTA ANITA CREEK

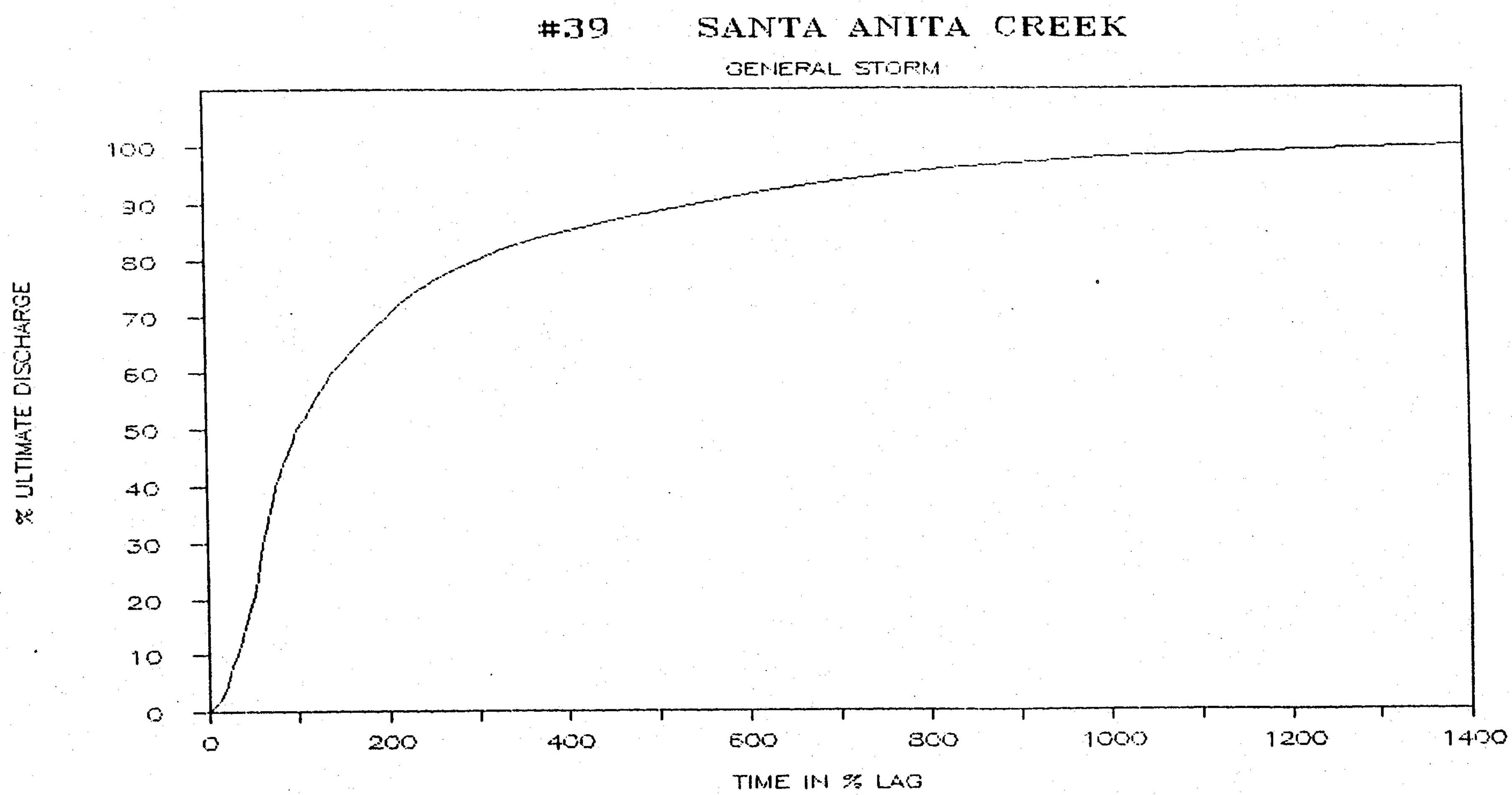
AT SANTA ANITA DAM, CA



#39 SANTA ANITA CREEK

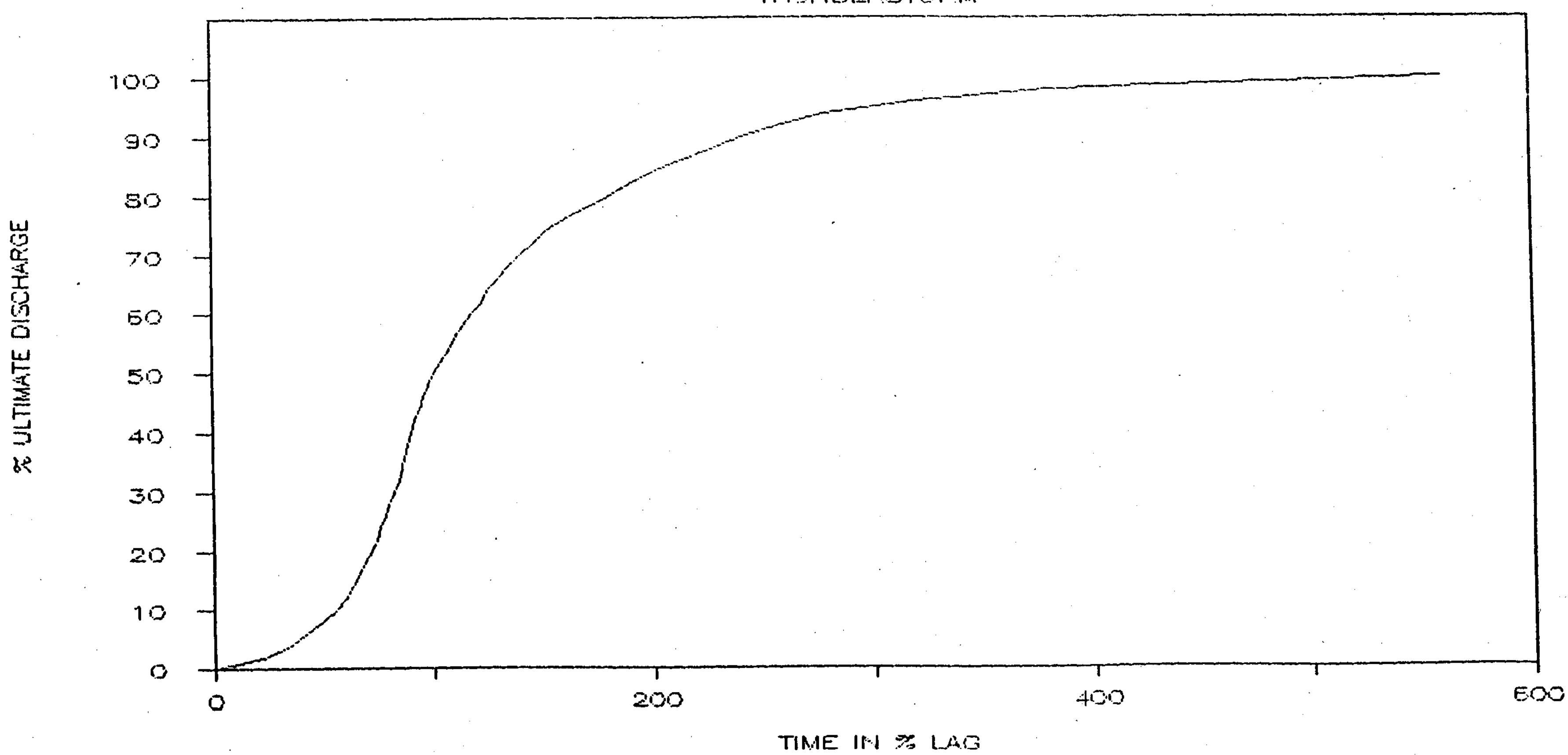
GENERAL STORM




#39 SANTA ANITA CREEK
GENERAL STORM
% ULTIMATE DISCHARGE
0
10
20
30
40
50
60
70
80
90
100
0
200
400
600
800
1000
1200
1400
TIME IN % LAG

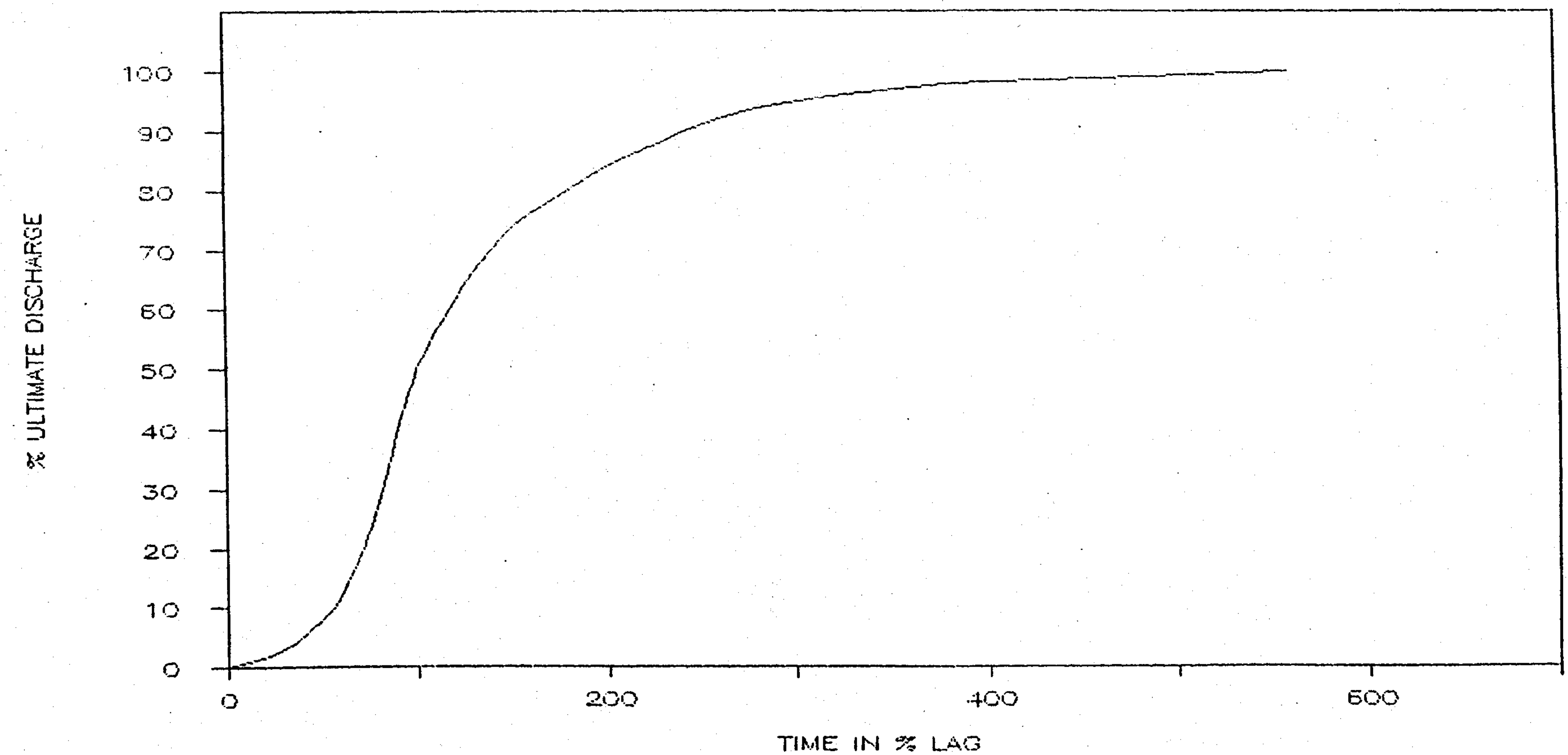
#40 SANTA ANITA CREEK

THUNDERSTORM



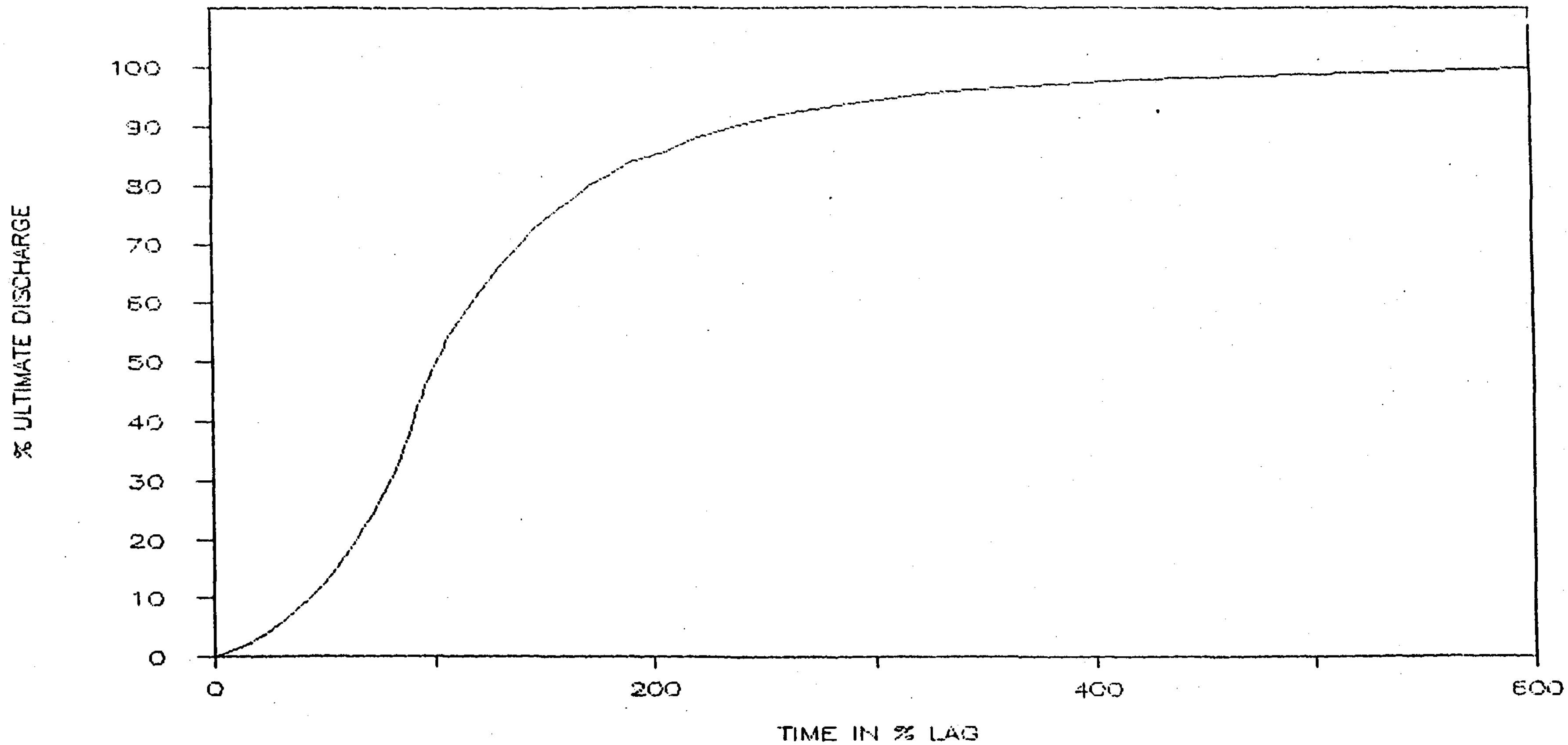
#40 SANTA ANITA CREEK

THUNDERSTORM



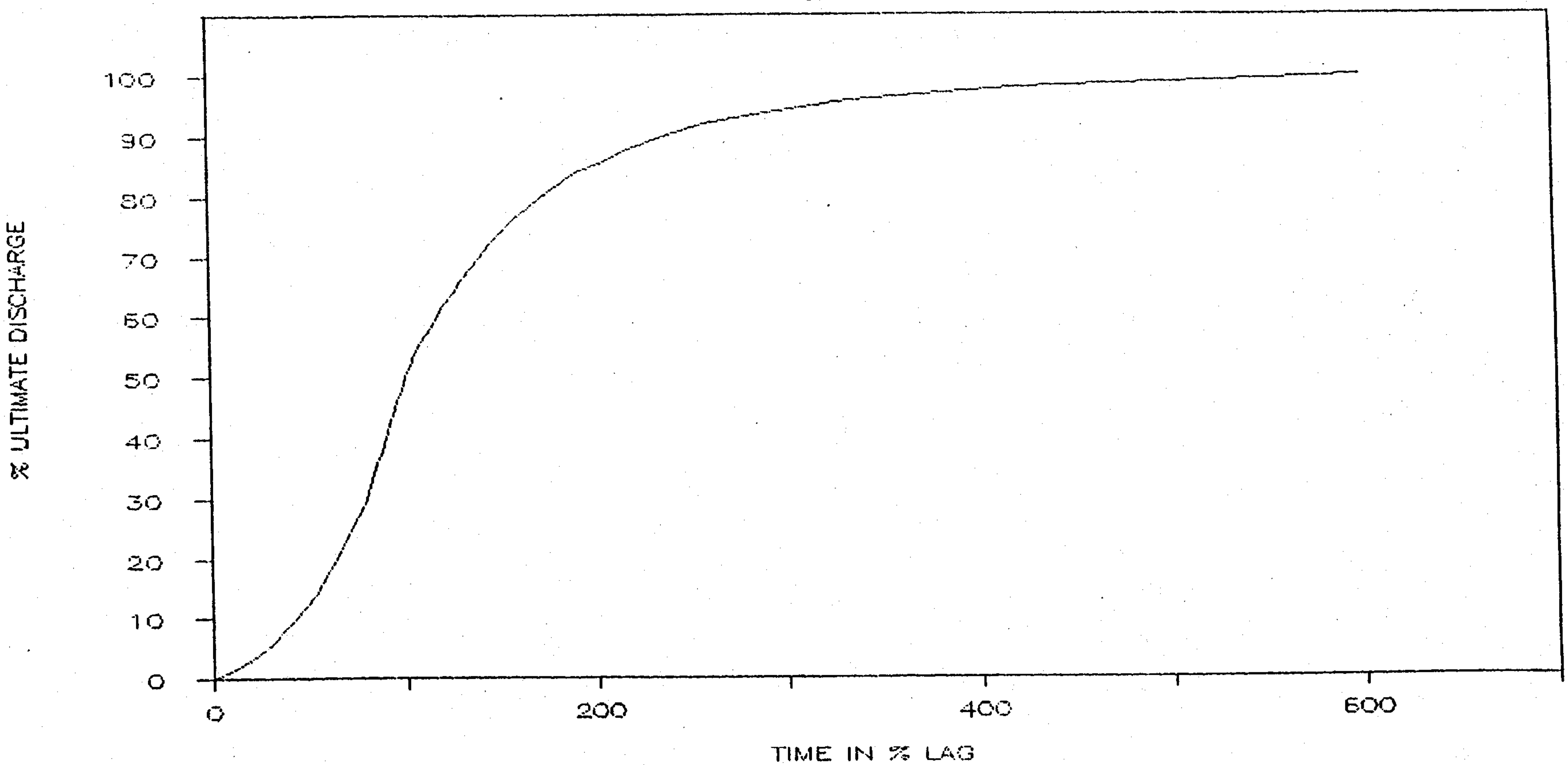
#41 SAN DIEGUITO RIVER

CALIFORNIA



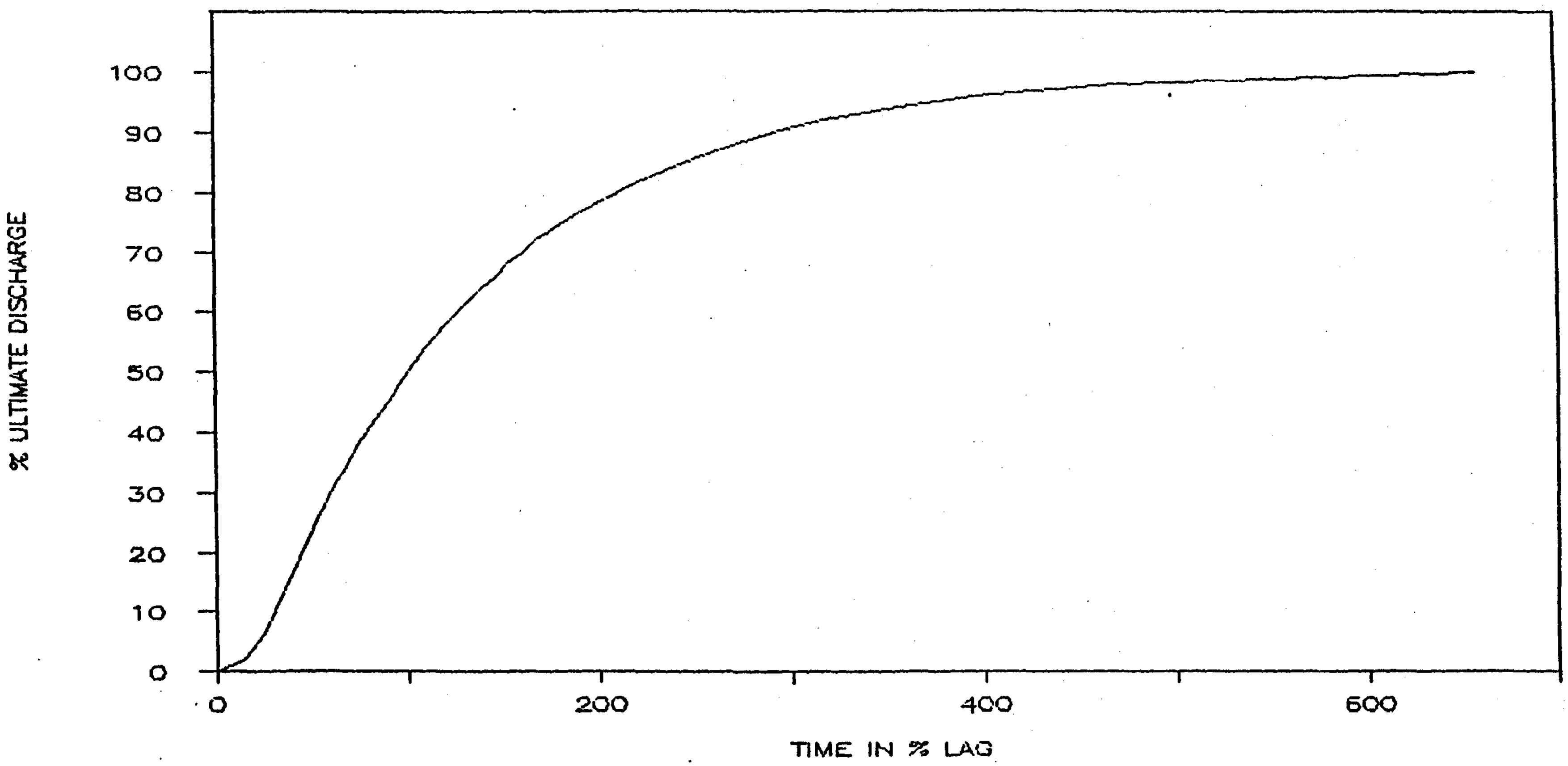
#41 SAN DIEGUITO RIVER

CALIFORNIA



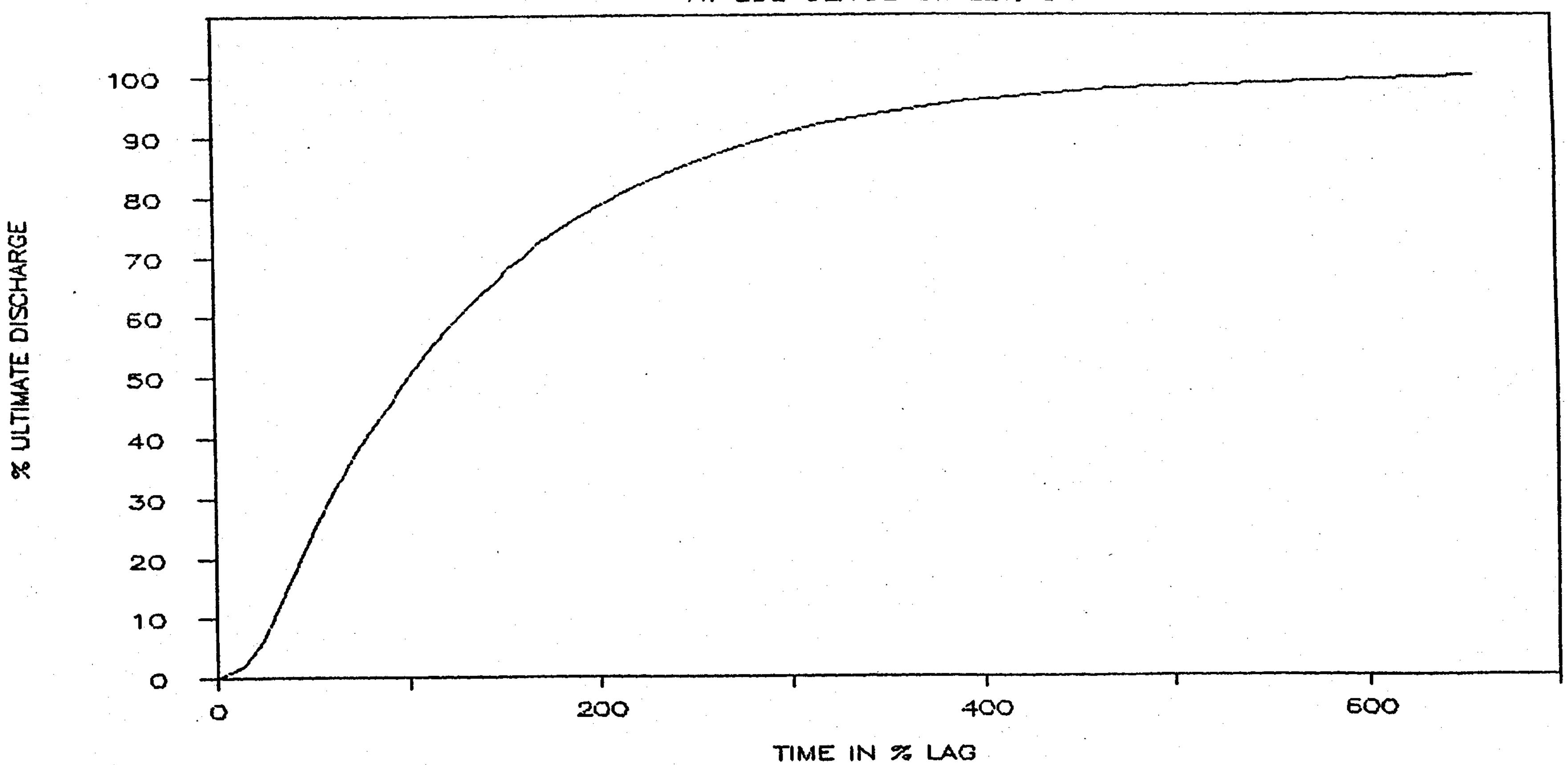
#42 SANTA BARBARA (MISSION CREEK)

AT LOS OLIVOS STREET, CA



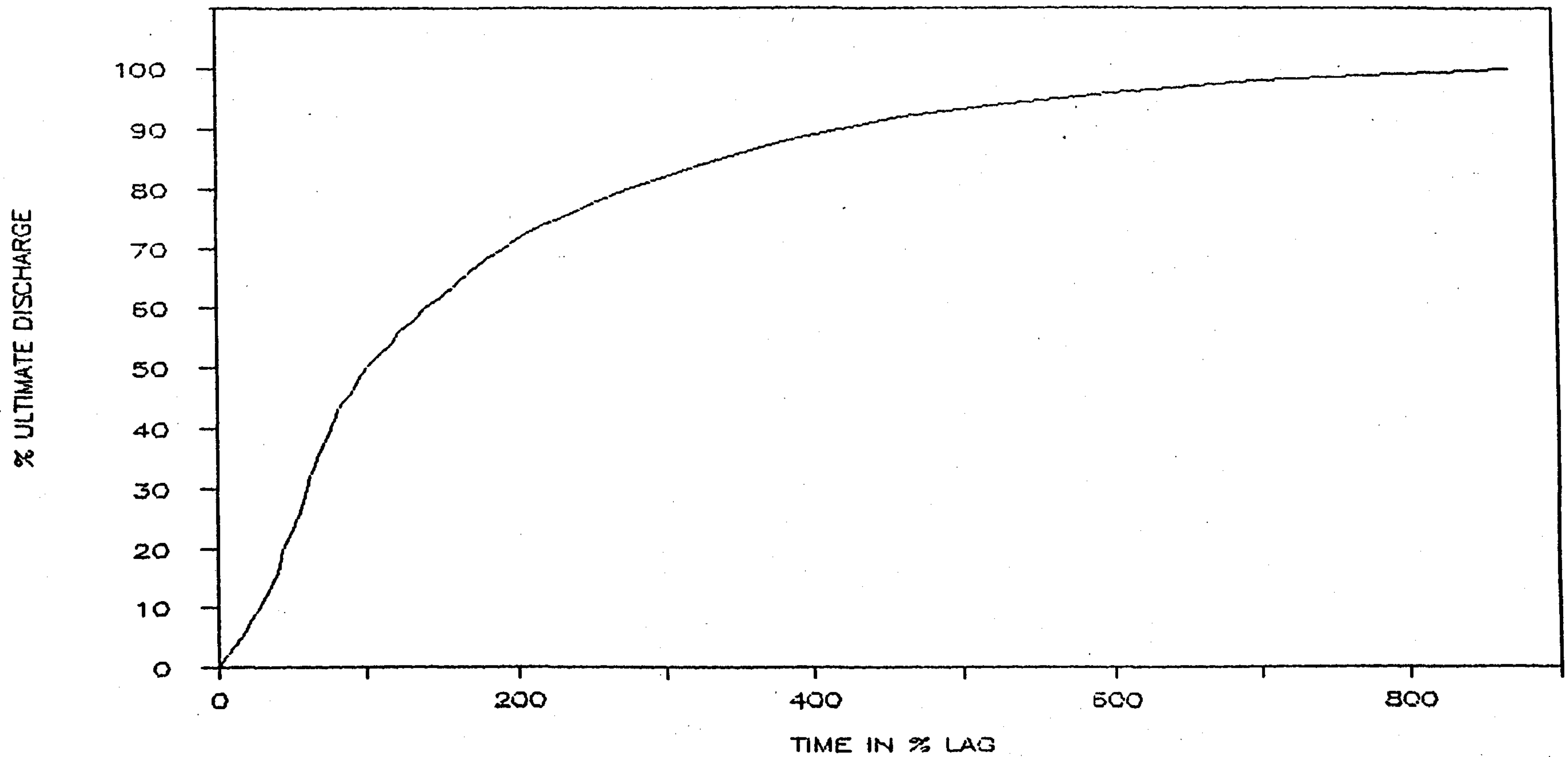
#42 SANTA BARBARA (MISSION CREEK)

AT LOS OLIVOS STREET, CA



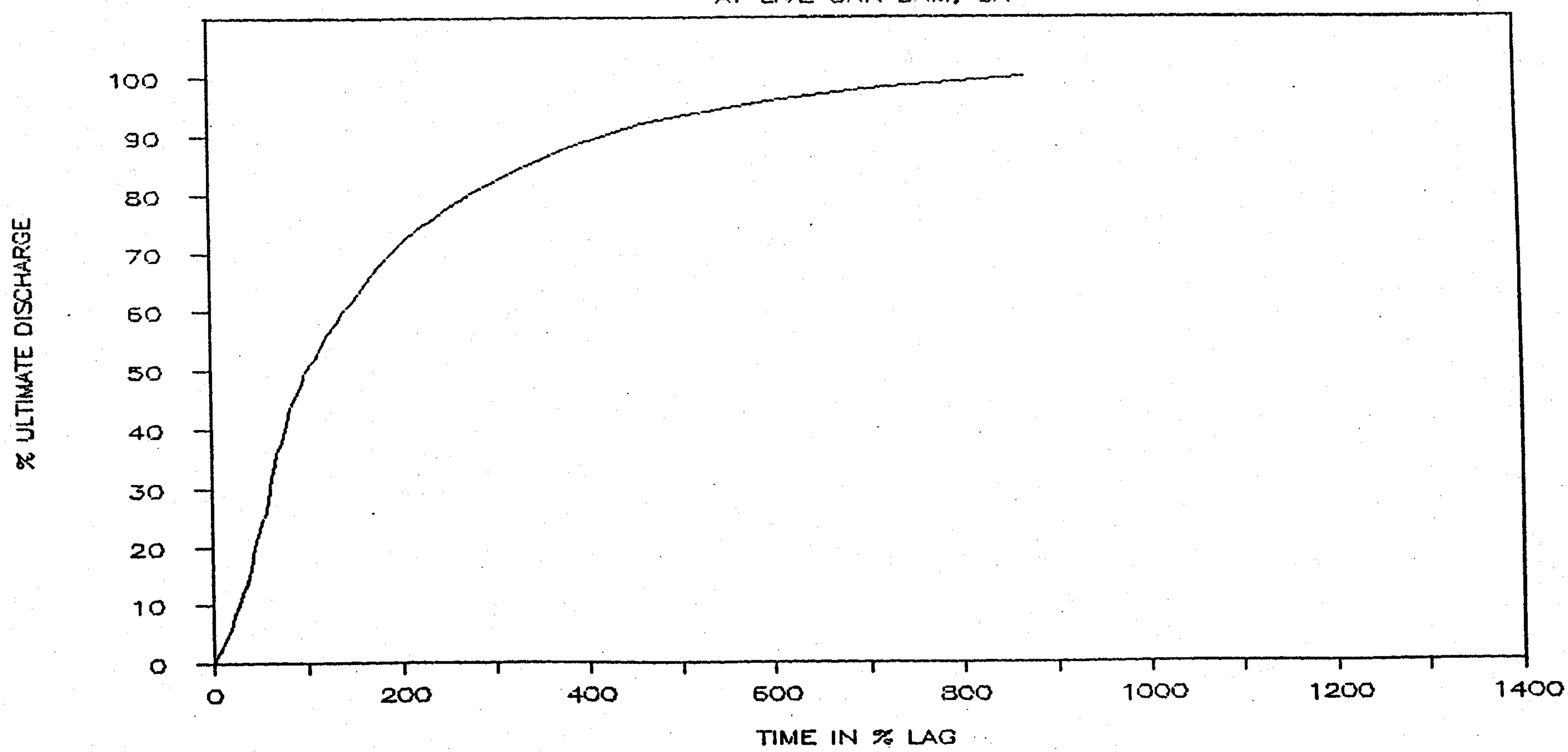
#43 LIVE OAK CREEK

AT LIVE OAK DAM, CA



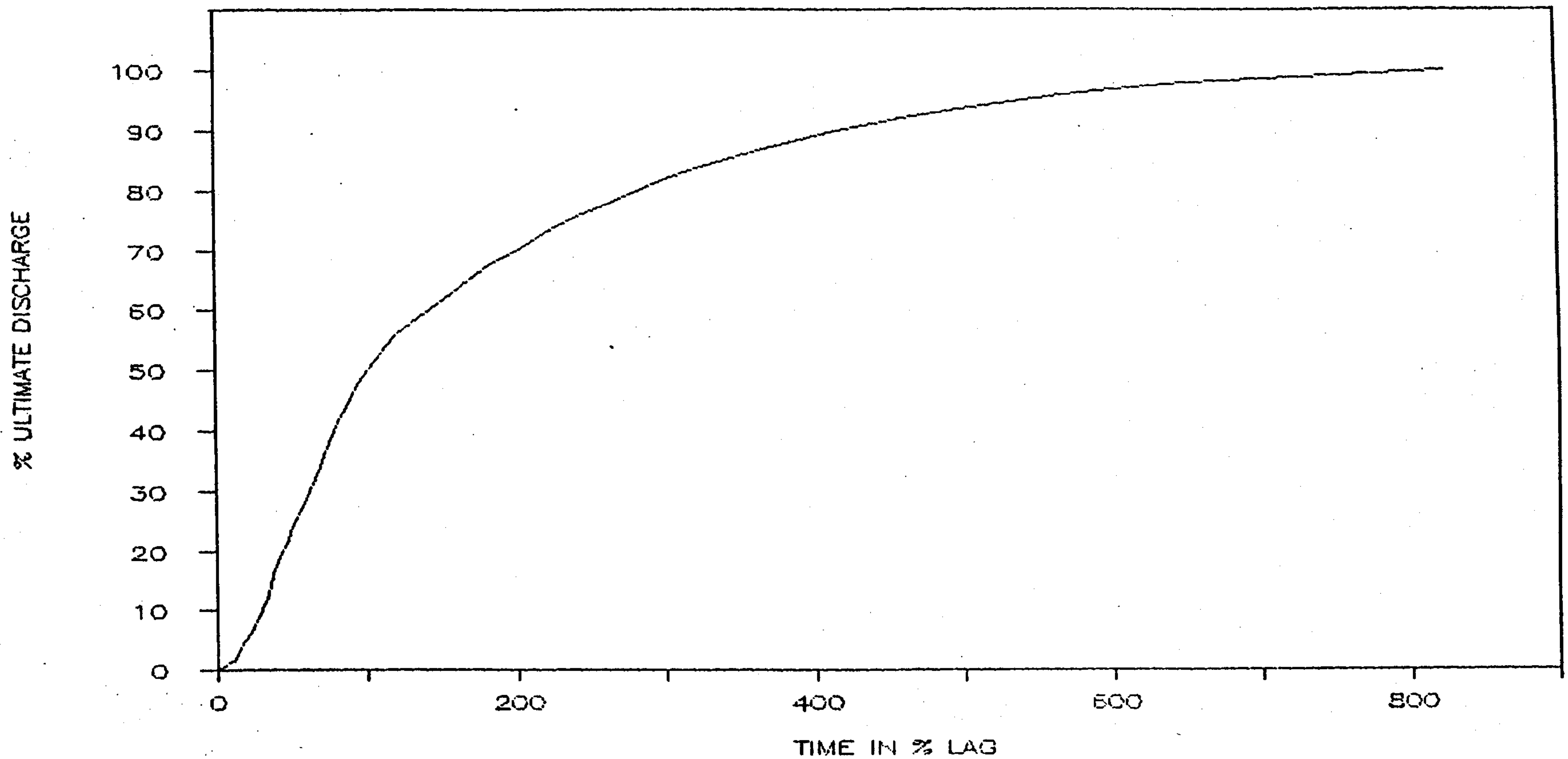
#43 LIVE OAK CREEK

AT LIVE OAK DAM, CA



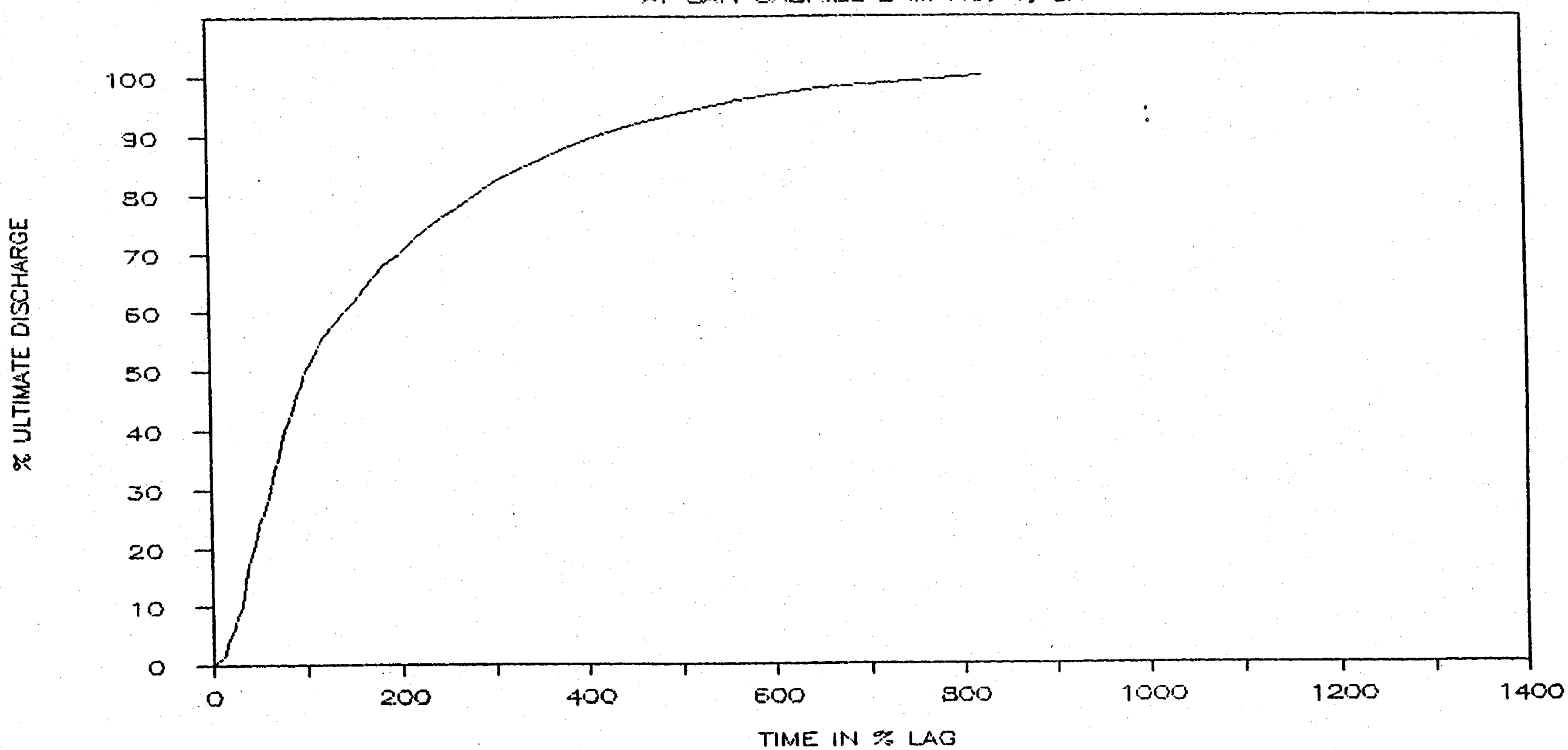
#44 SAN GABRIEL RIVER

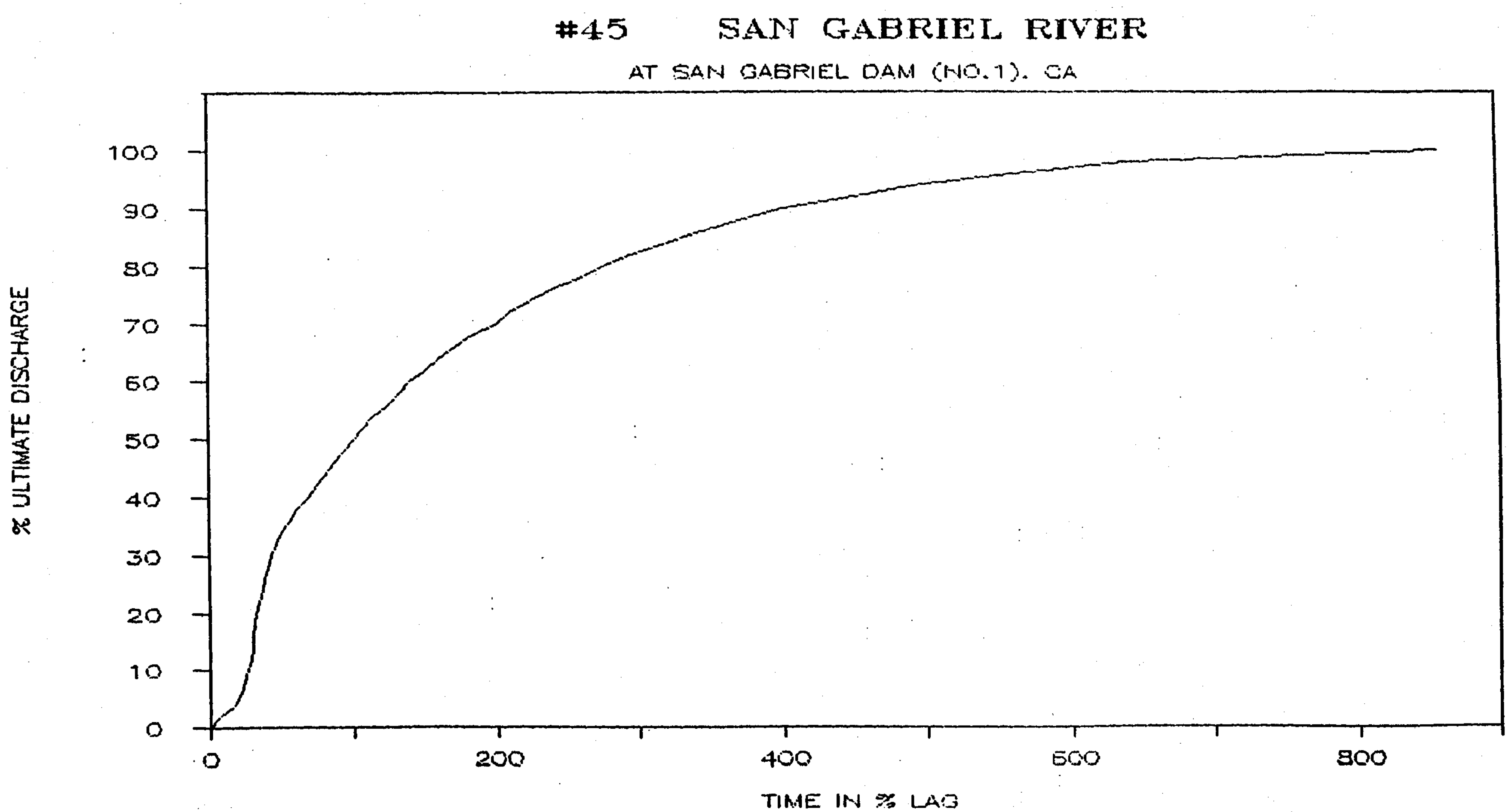
AT SAN GABRIEL DAM NO. 1, CA



#44 SAN GABRIEL RIVER

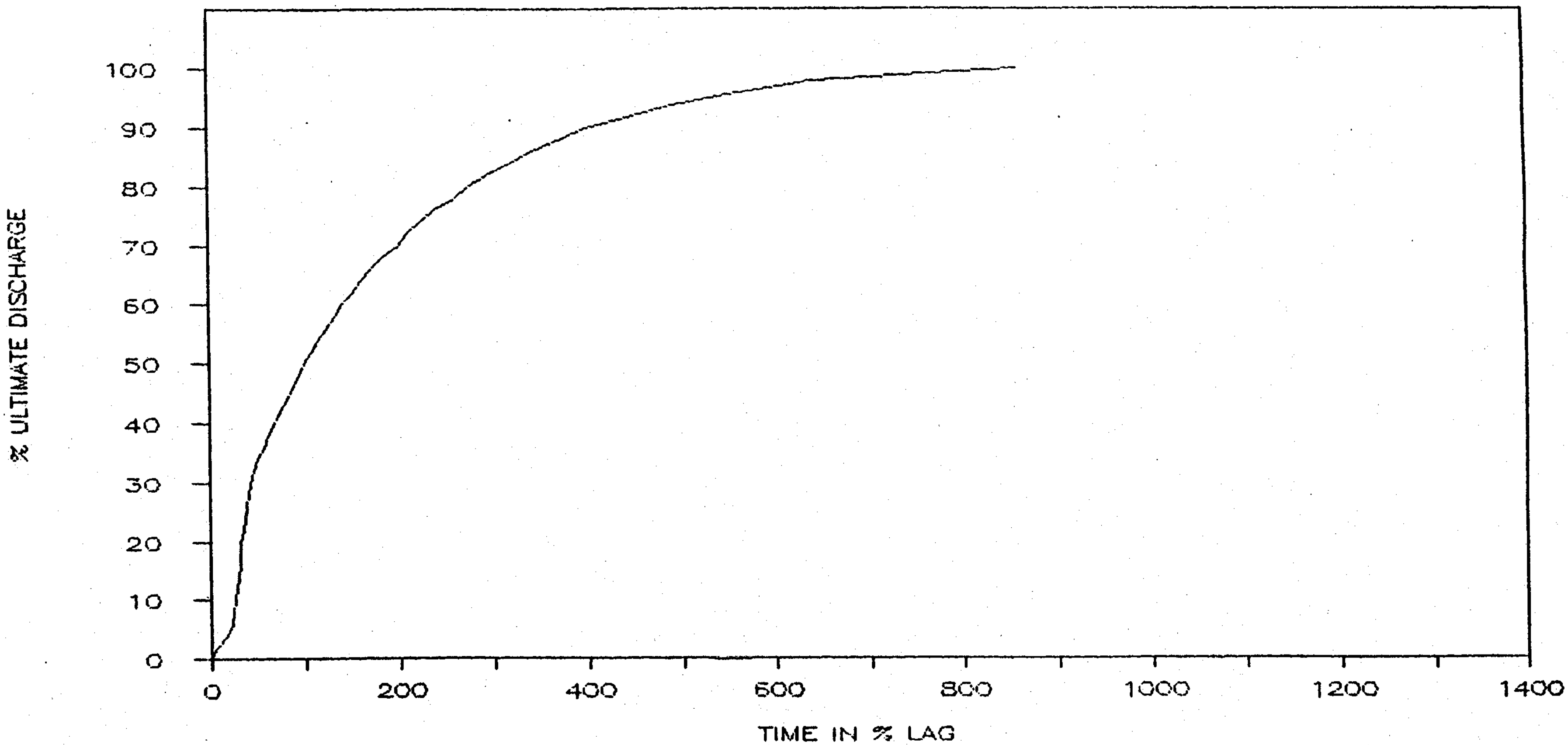
AT SAN GABRIEL DAM NO. 1, CA




#45 SAN GABRIEL RIVER
AT SAN GABRIEL DAM (NO.1), CA
% ULTIMATE DISCHARGE
100
90
80
70
60
50
40
30
20
10
0
0
200
400
600
800
TIME IN % LAG

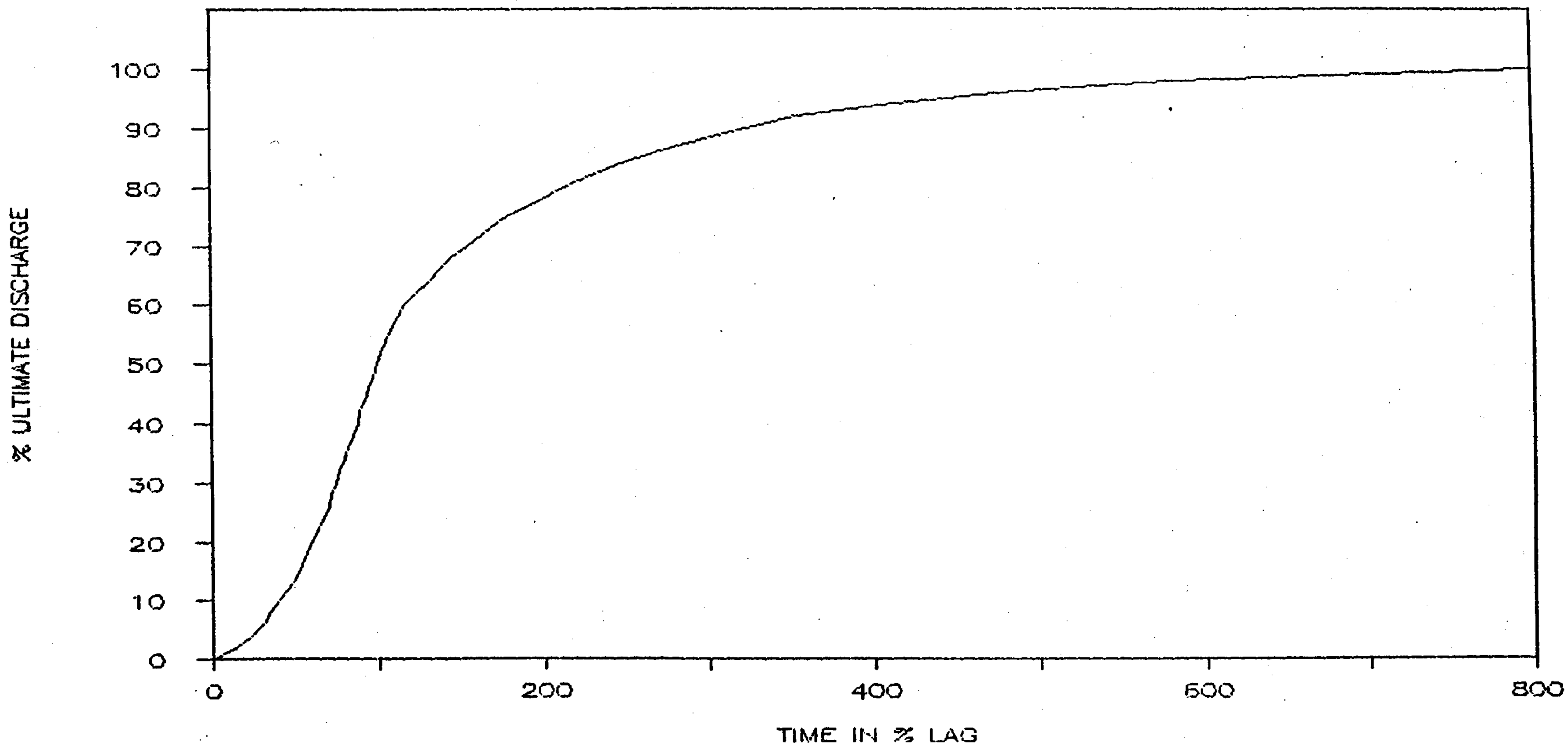
#45 SAN GABRIEL RIVER

AT SAN GABRIEL DAM (NO.1), CA



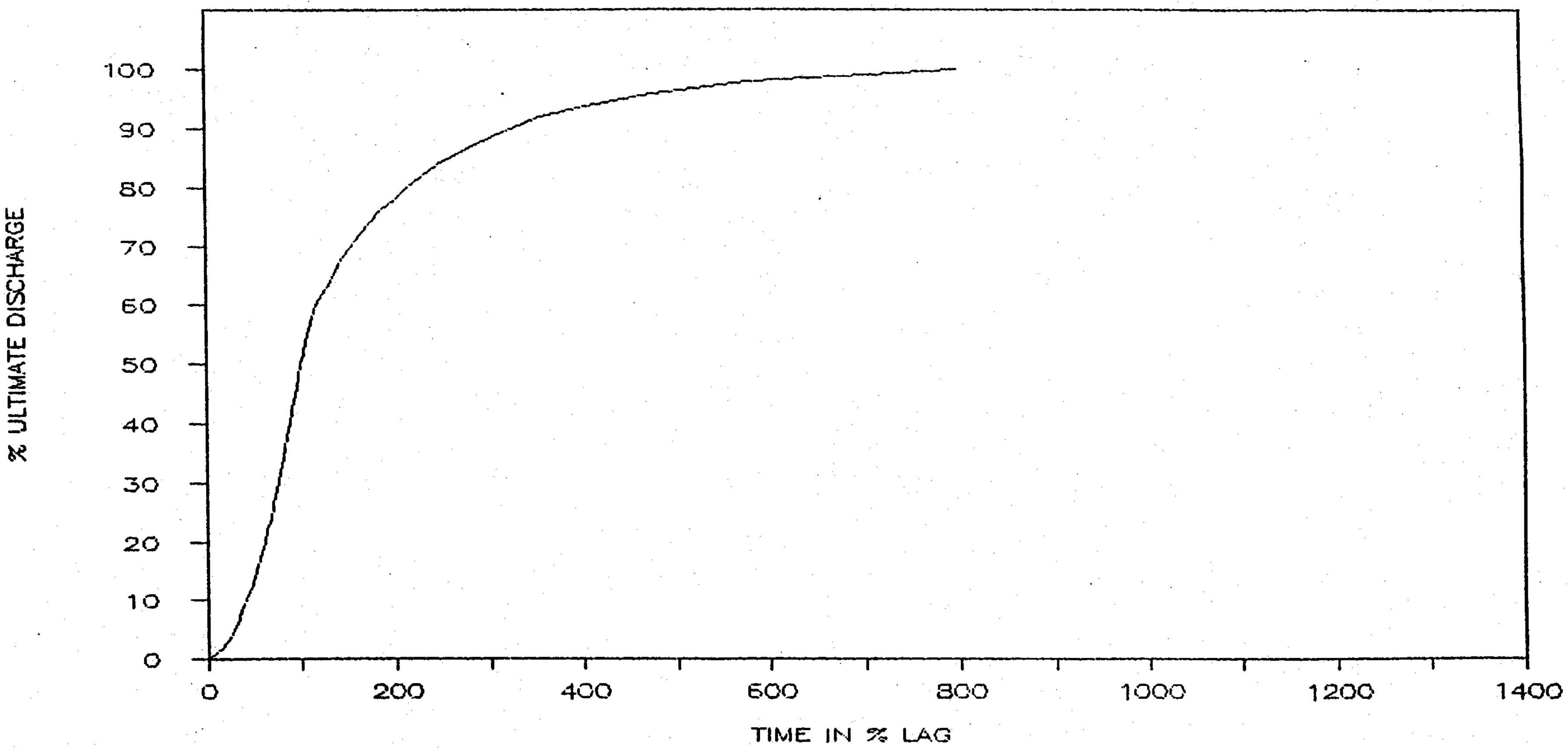
#46 WEST FORK OF SAN GABRIEL RIVER

AT COGSWELL DAM (NO. 2), CA



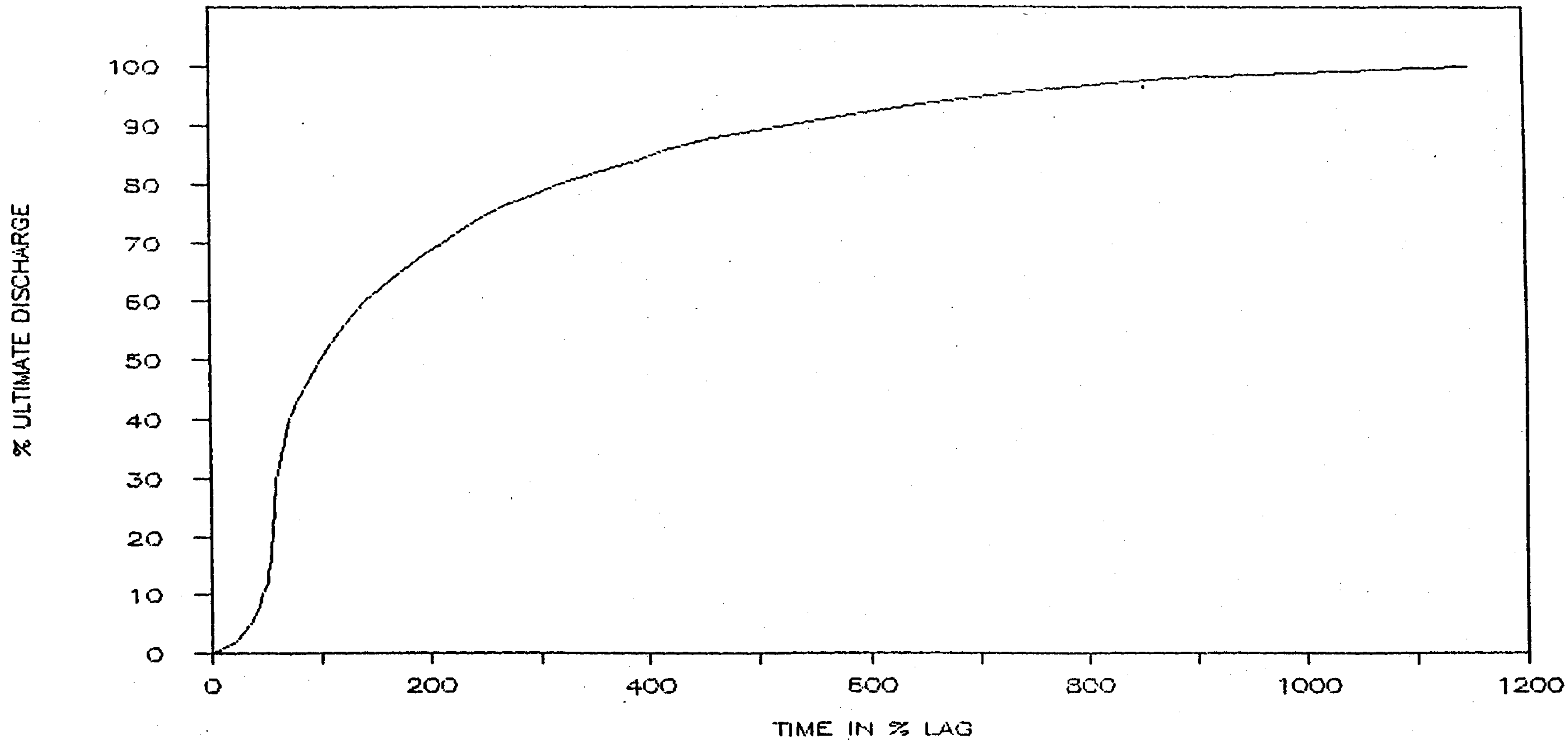
#46 WEST FORK OF SAN GABRIEL RIVER

AT COGSWELL DAM (NO. 2), CA



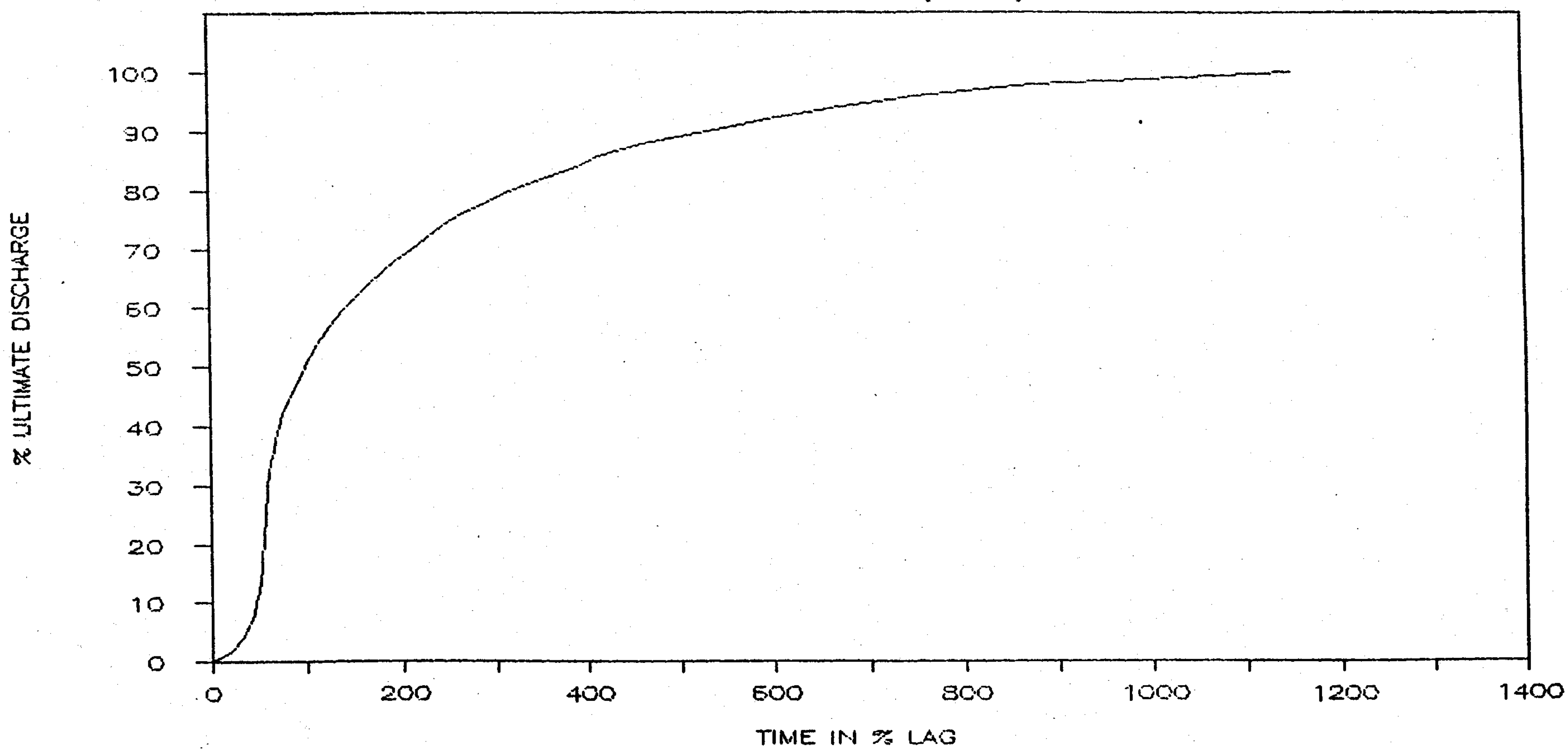
#47 WEST FORK OF SAN GABRIEL RIVER

AT COGSWELL DAM (NO. 2), CA



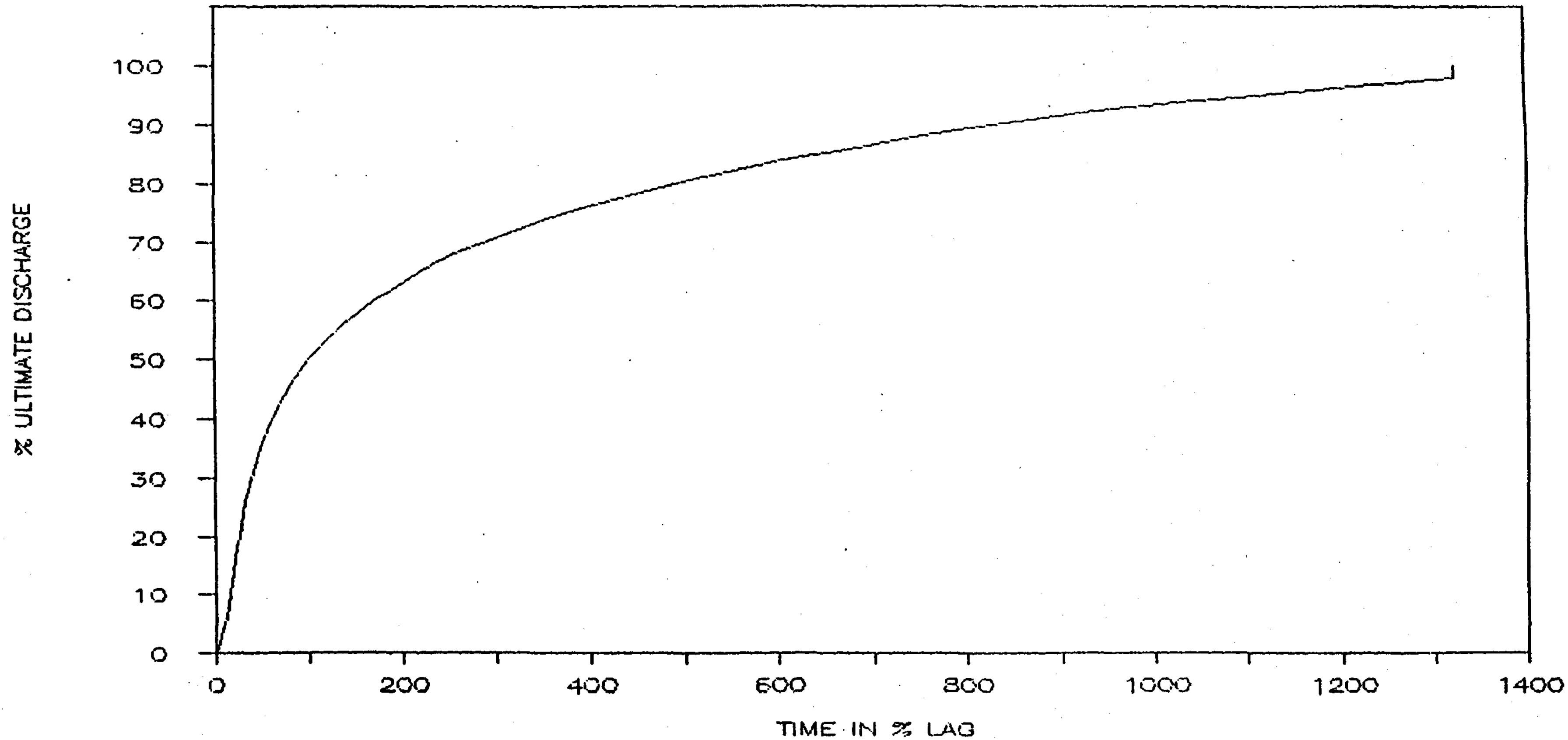
#47 WEST FORK OF SAN GABRIEL RIVER

AT COGSWELL DAM (NO. 2), CA



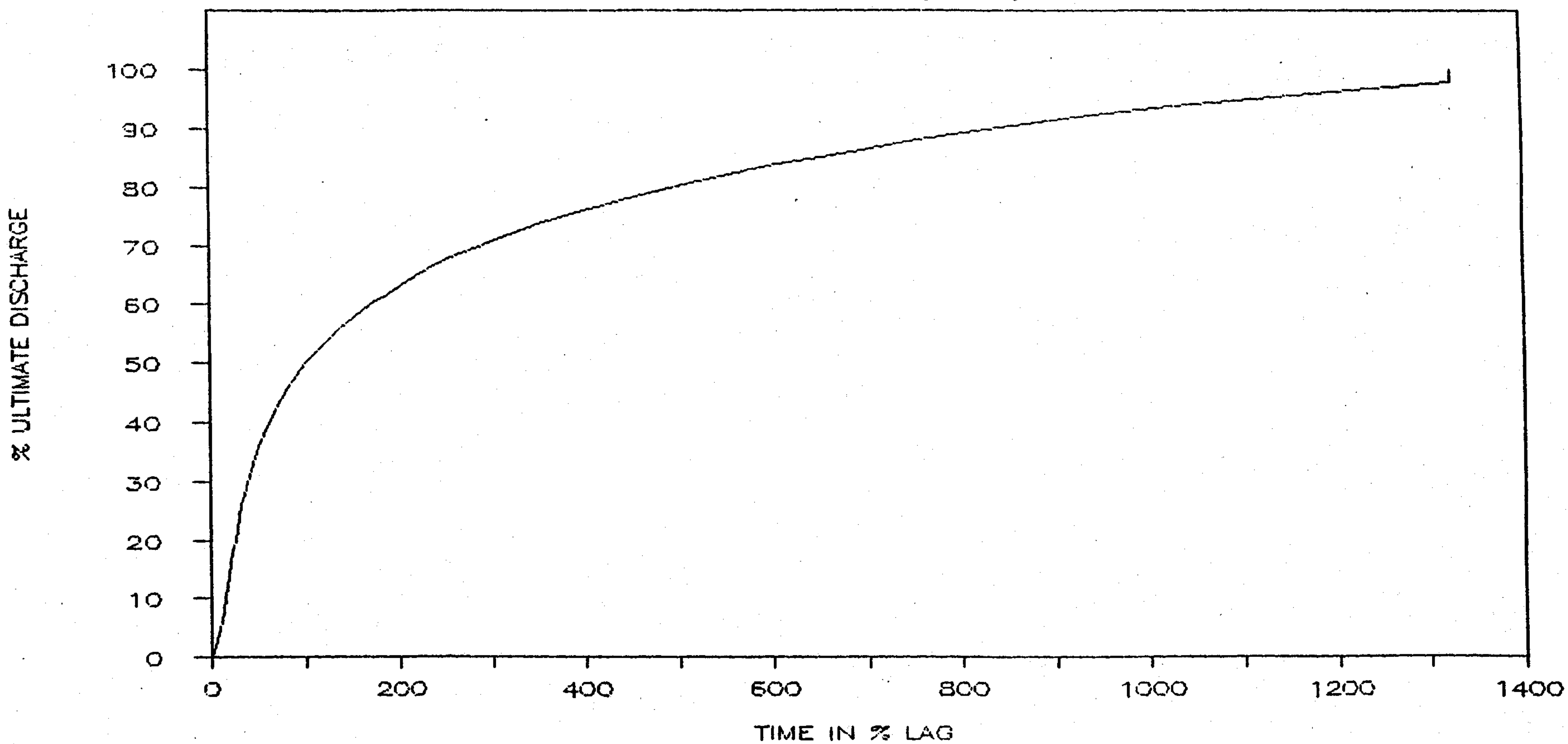
#48 WEST FORK OF SAN GABRIEL RIVER

AT COGSWELL DAM (NO. 2), CA



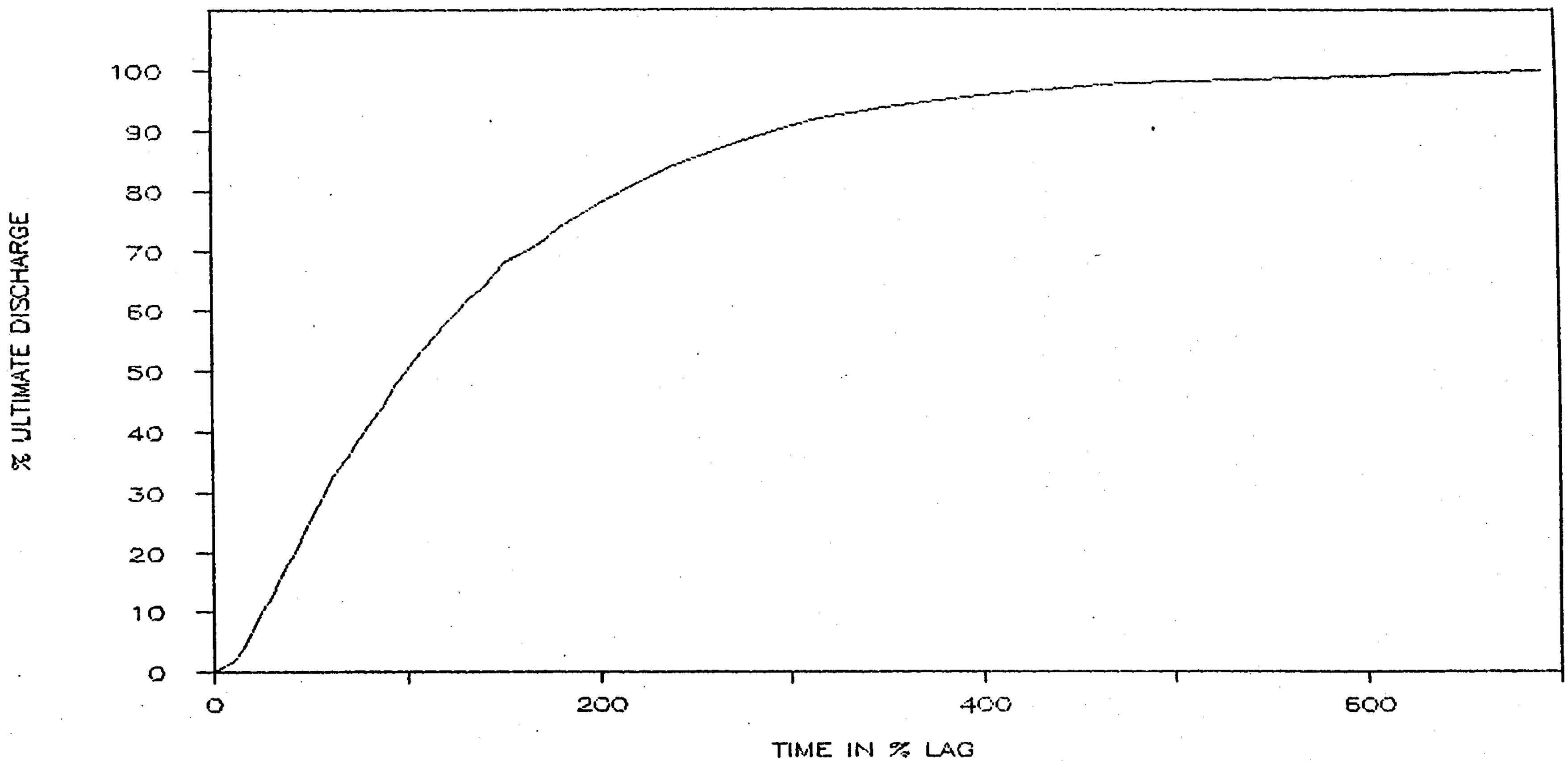
#48 WEST FORK OF SAN GABRIEL RIVER

AT COGSWELL DAM (NO. 2), CA



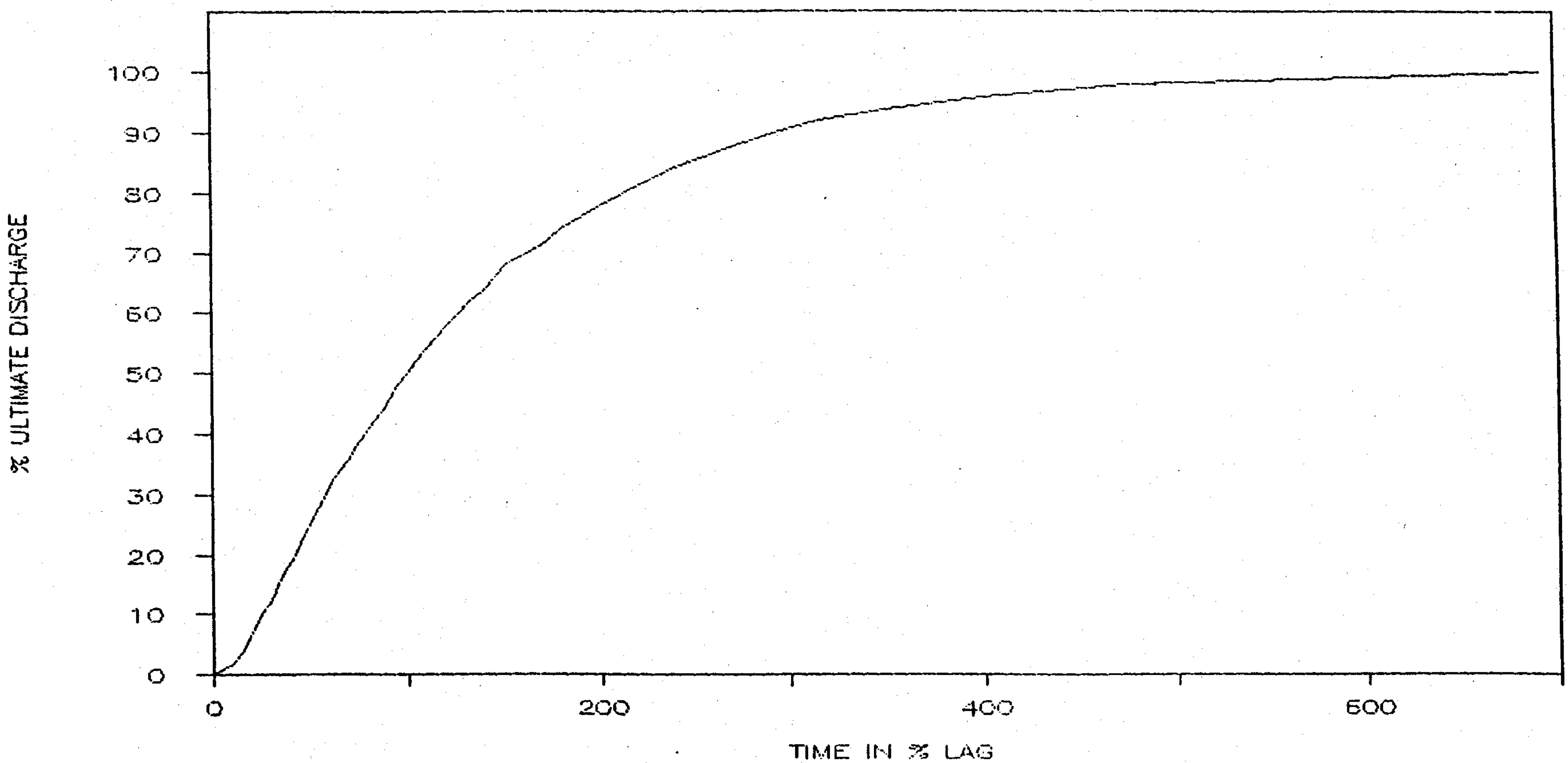
#49 SAN JOSE CREEK

CALIFORNIA, LACDA 1985 STUDY



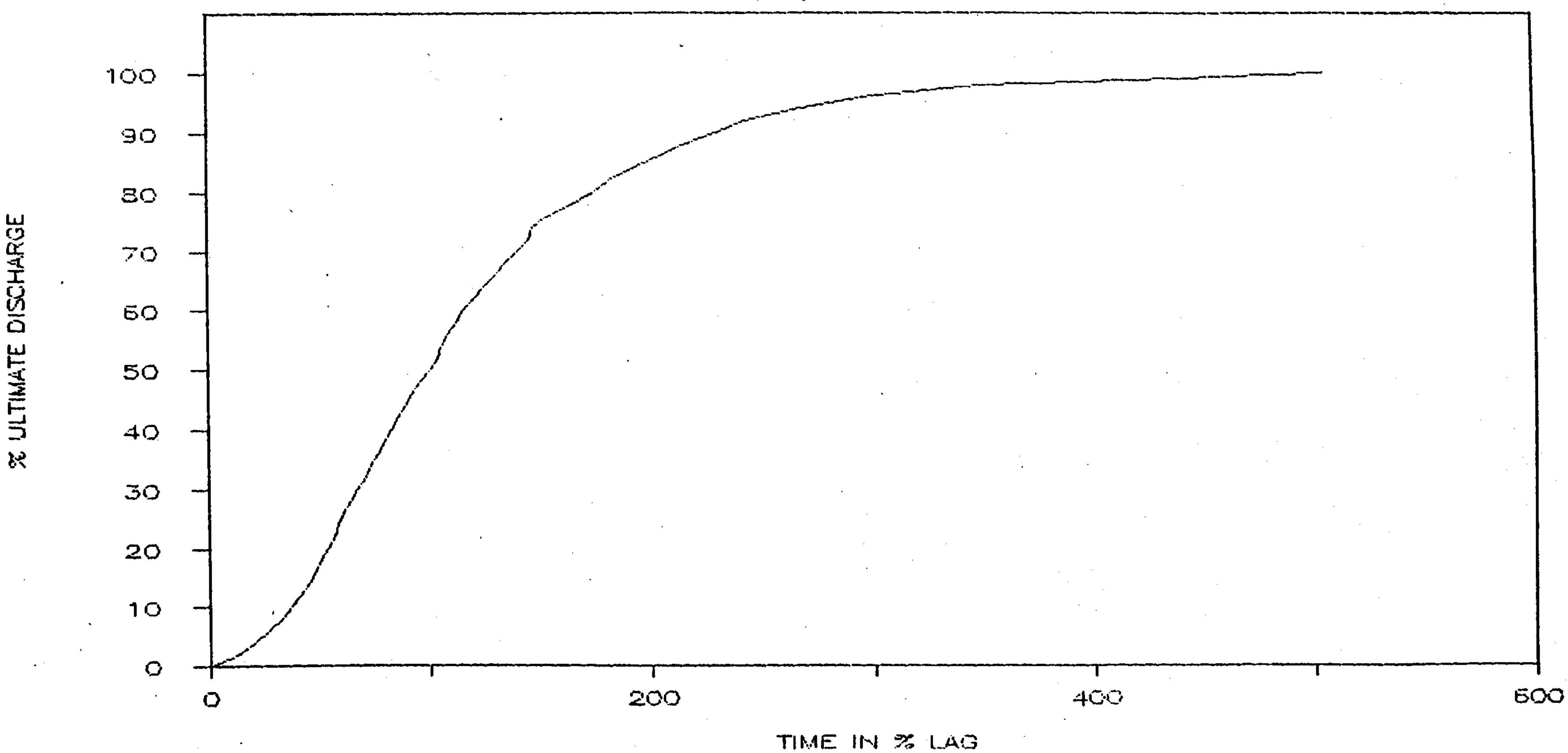
#49 SAN JOSE CREEK

CALIFORNIA, LACDA 1985 STUDY



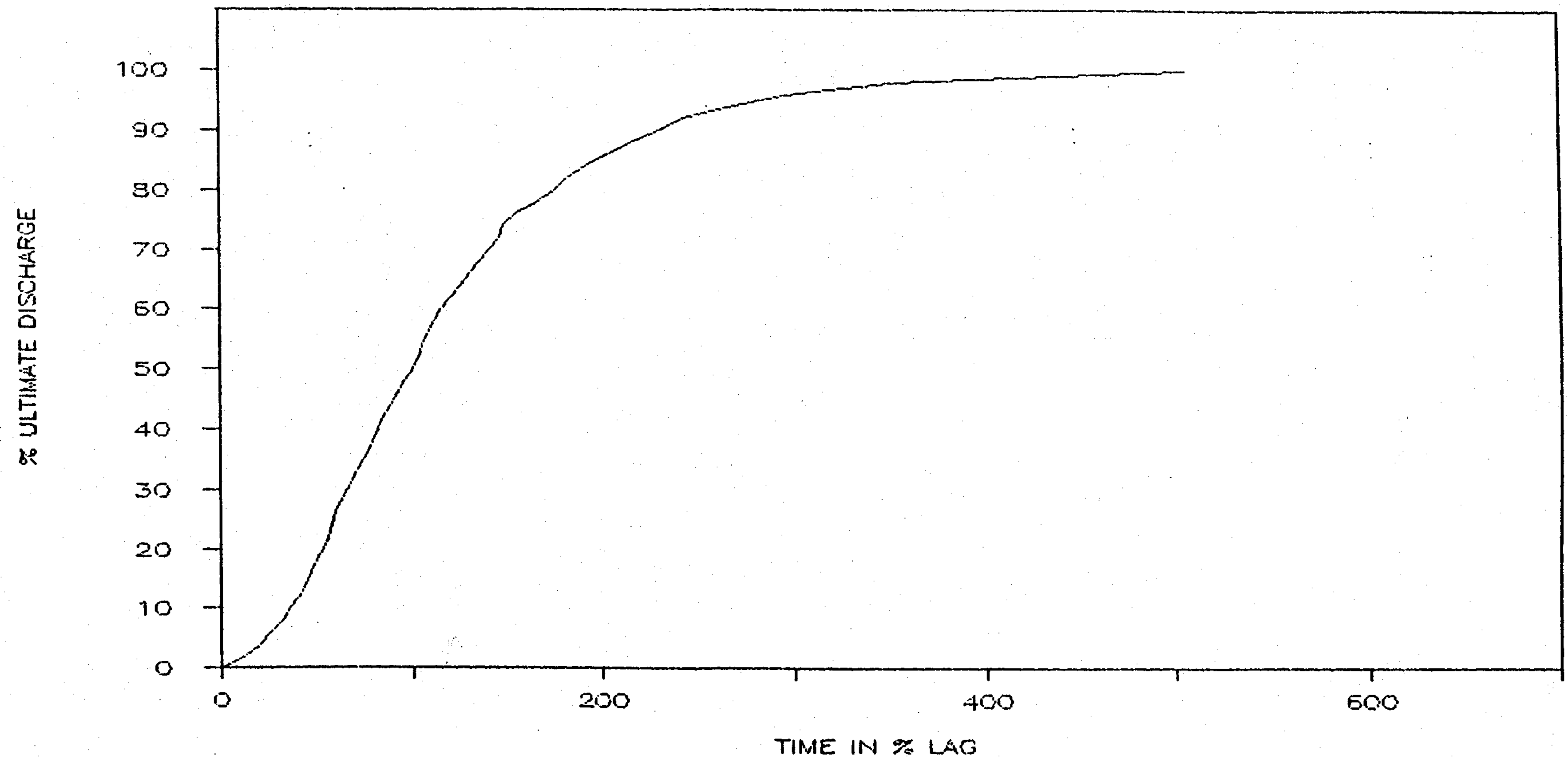
#50 VERDUGO WASH

CALIFORNIA, LACDA 1985 STUDY



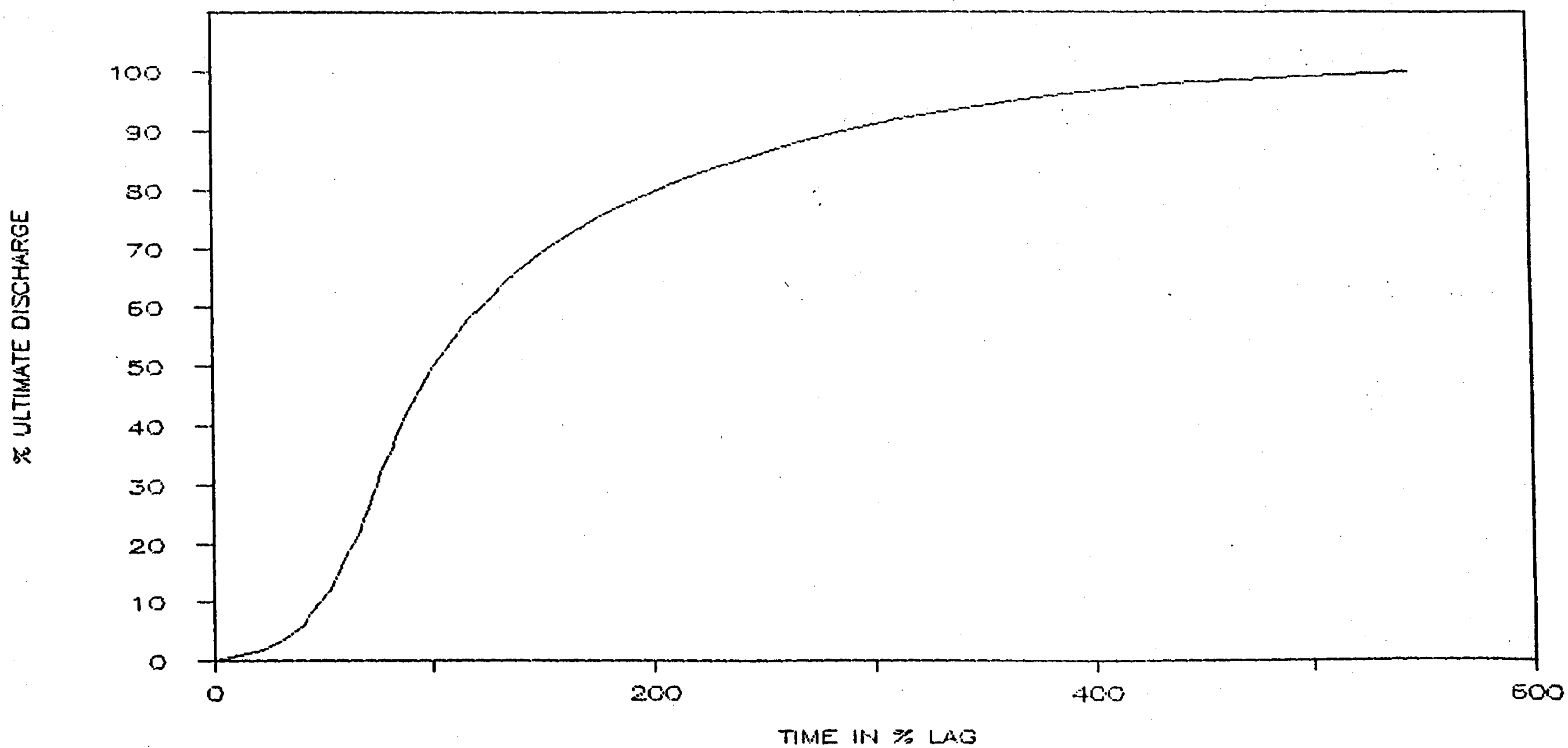
#50 VERDUGO WASH

CALIFORNIA, LACDA 1985 STUDY



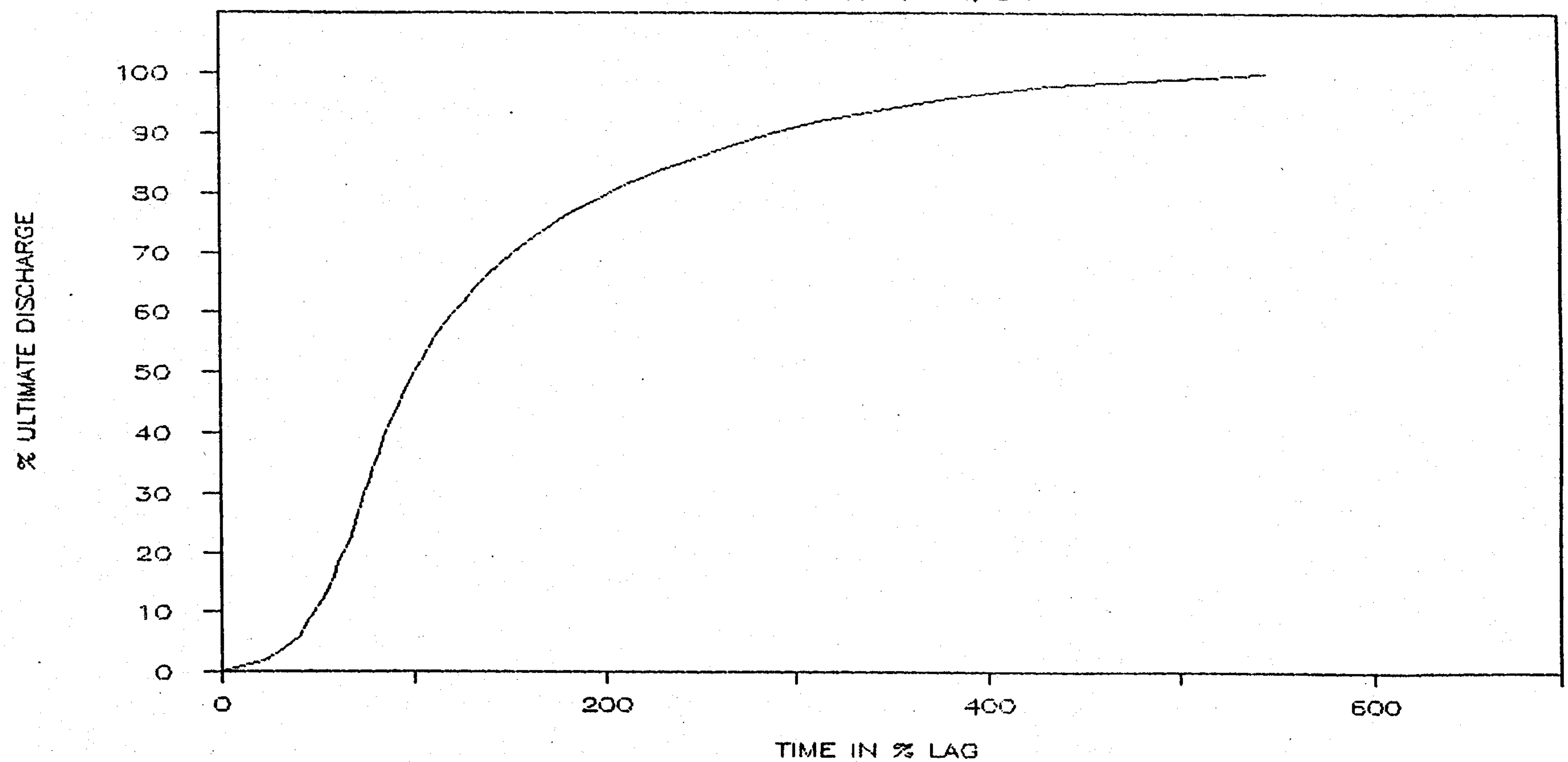
#51 TRINITY RIVER

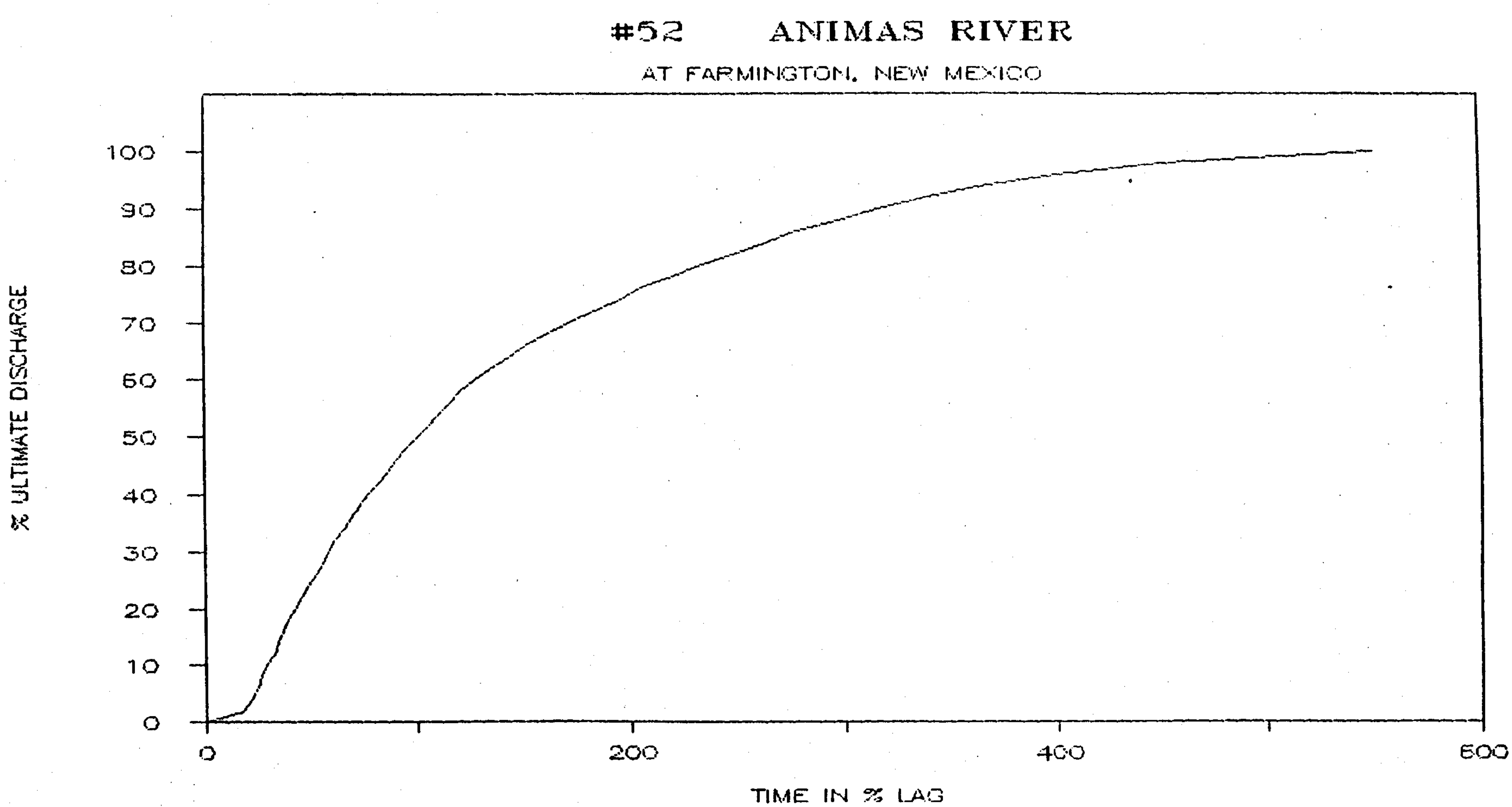
NEAR LOUISTON, CA



#51 TRINITY RIVER

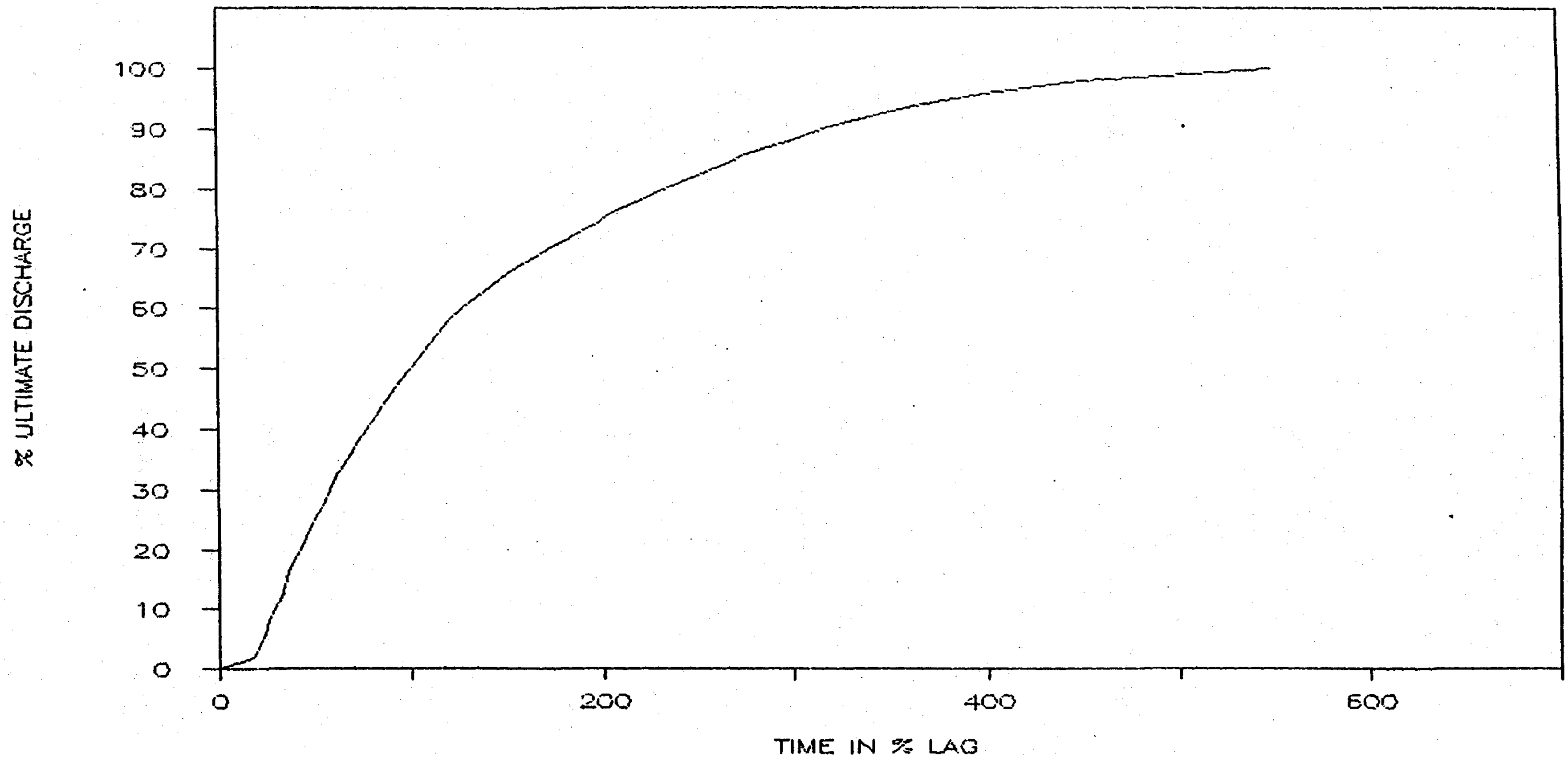
NEAR LOUISTON, CA




#52 ANIMAS RIVER
AT FARMINGTON, NEW MEXICO
% ULTIMATE DISCHARGE
100
90
80
70
60
50
40
30
20
10
0
0
200
400
600
TIME IN % LAG

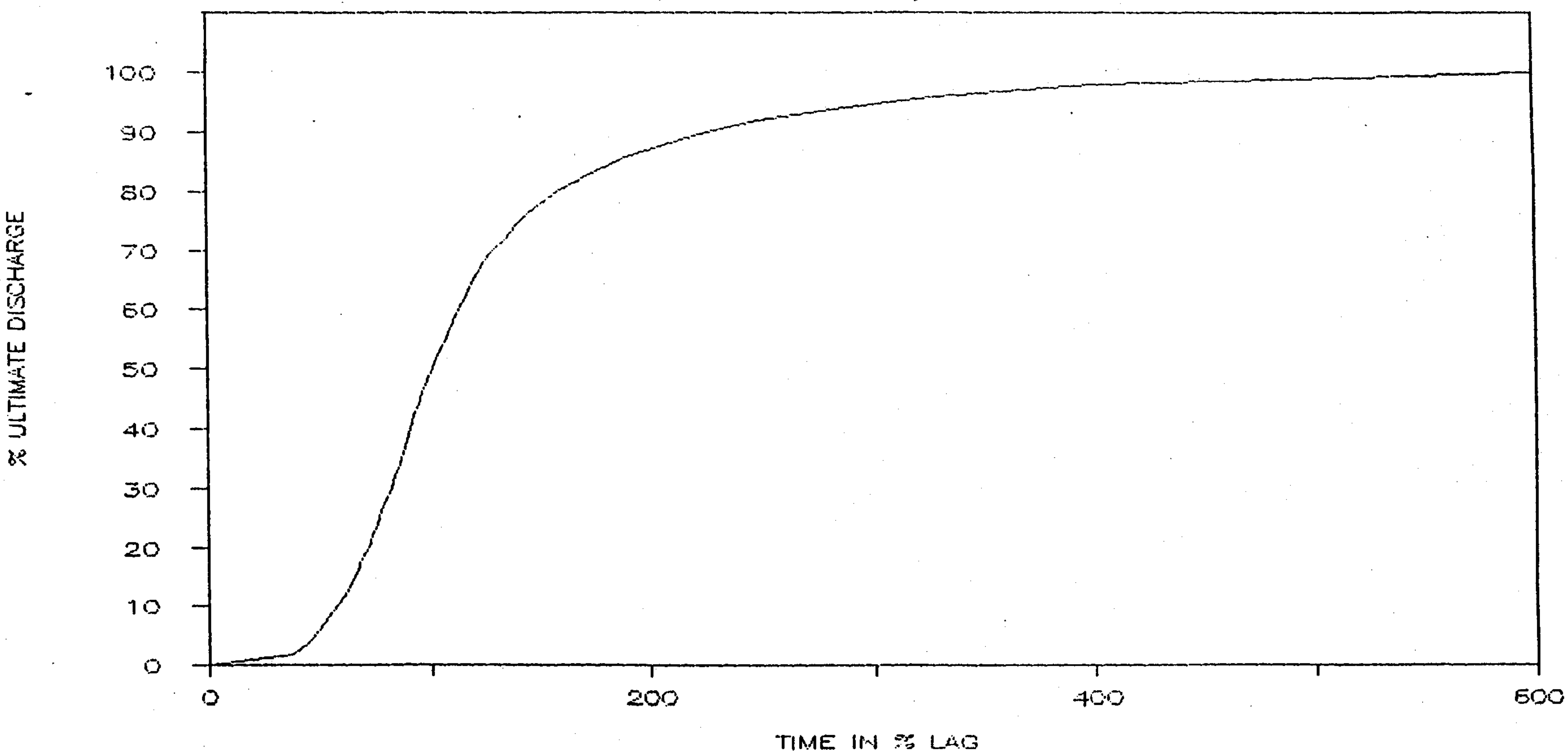
#52 ANIMAS RIVER

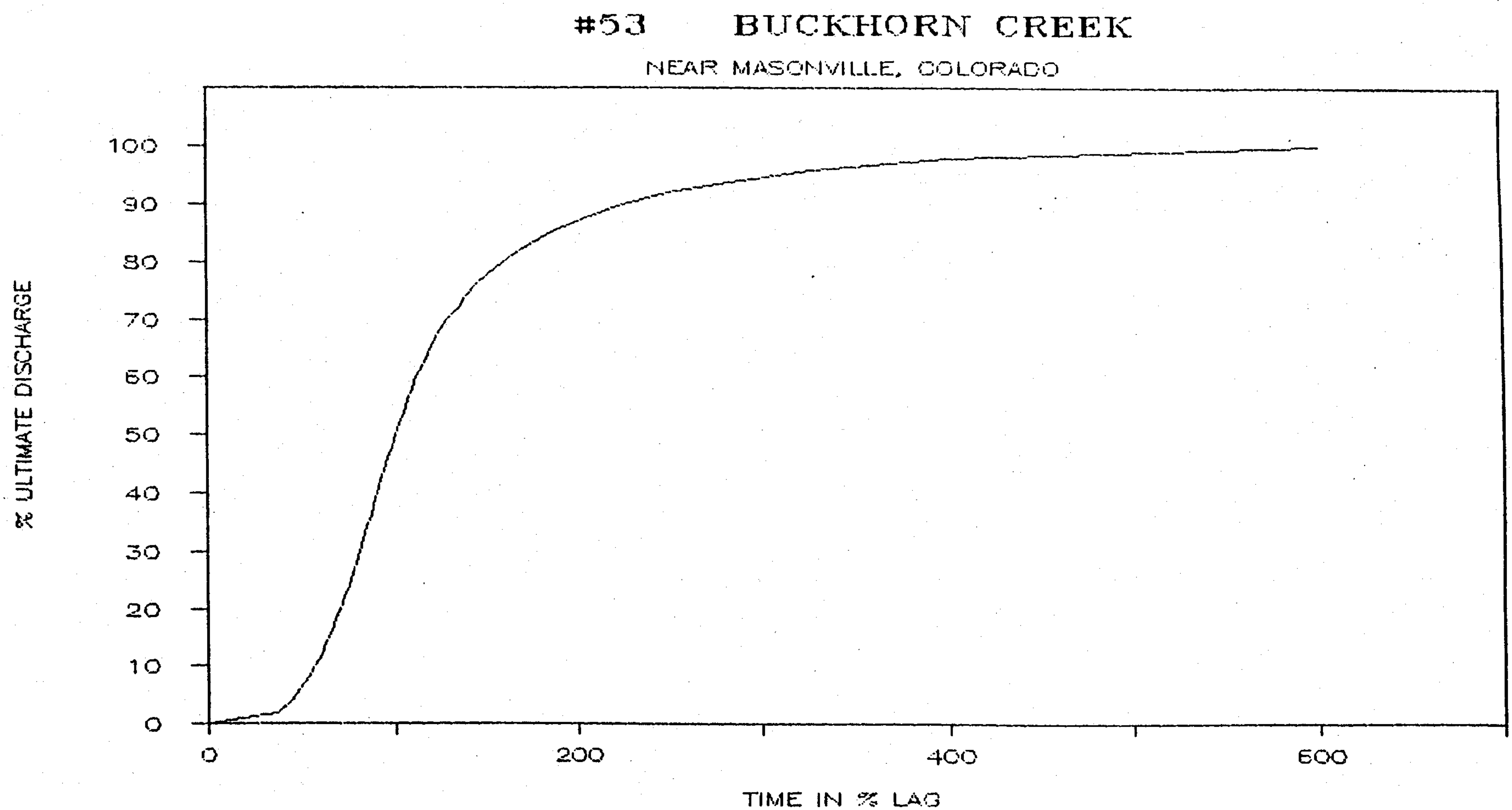
AT FARMINGTON, NEW MEXICO



#53 BUCKHORN CREEK

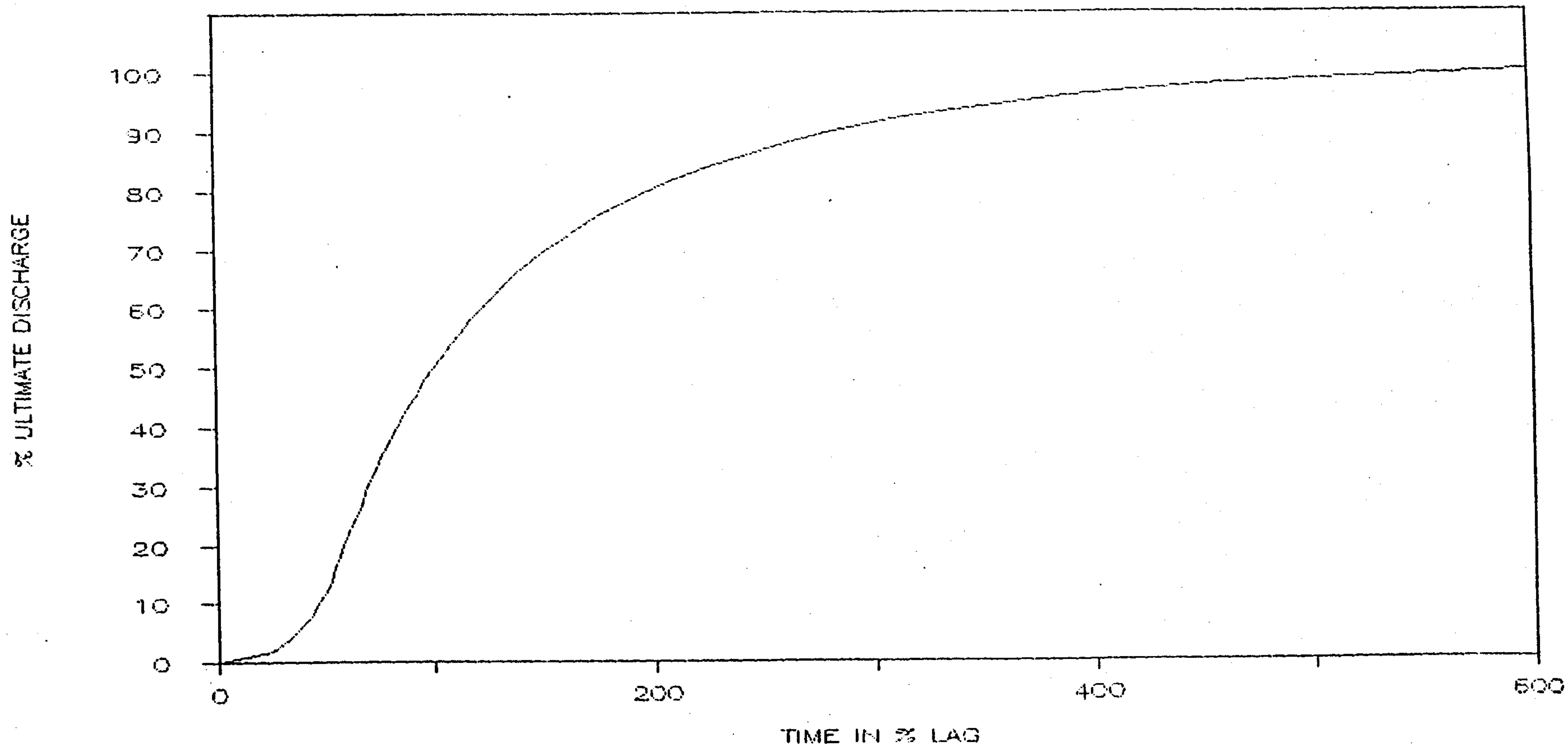
NEAR MASONVILLE, COLORADO




#53 BUCKHORN CREEK
NEAR MASONVILLE, COLORADO
% ULTIMATE DISCHARGE
100
90
80
70
60
50
40
30
20
10
0
0
200
400
600
TIME IN % LAG

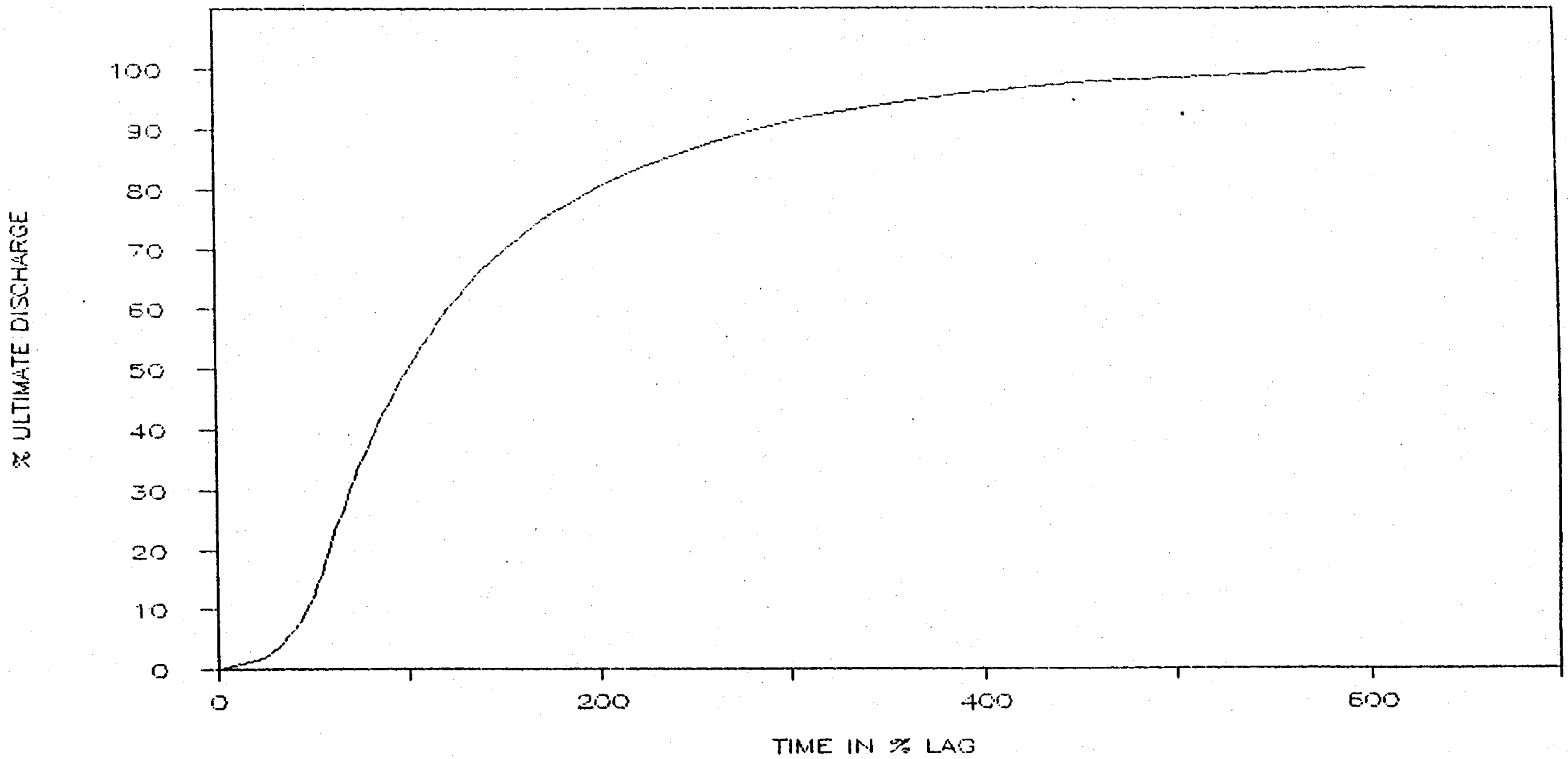
#54 UINTA RIVER

NEAR NEOLA, UTAH



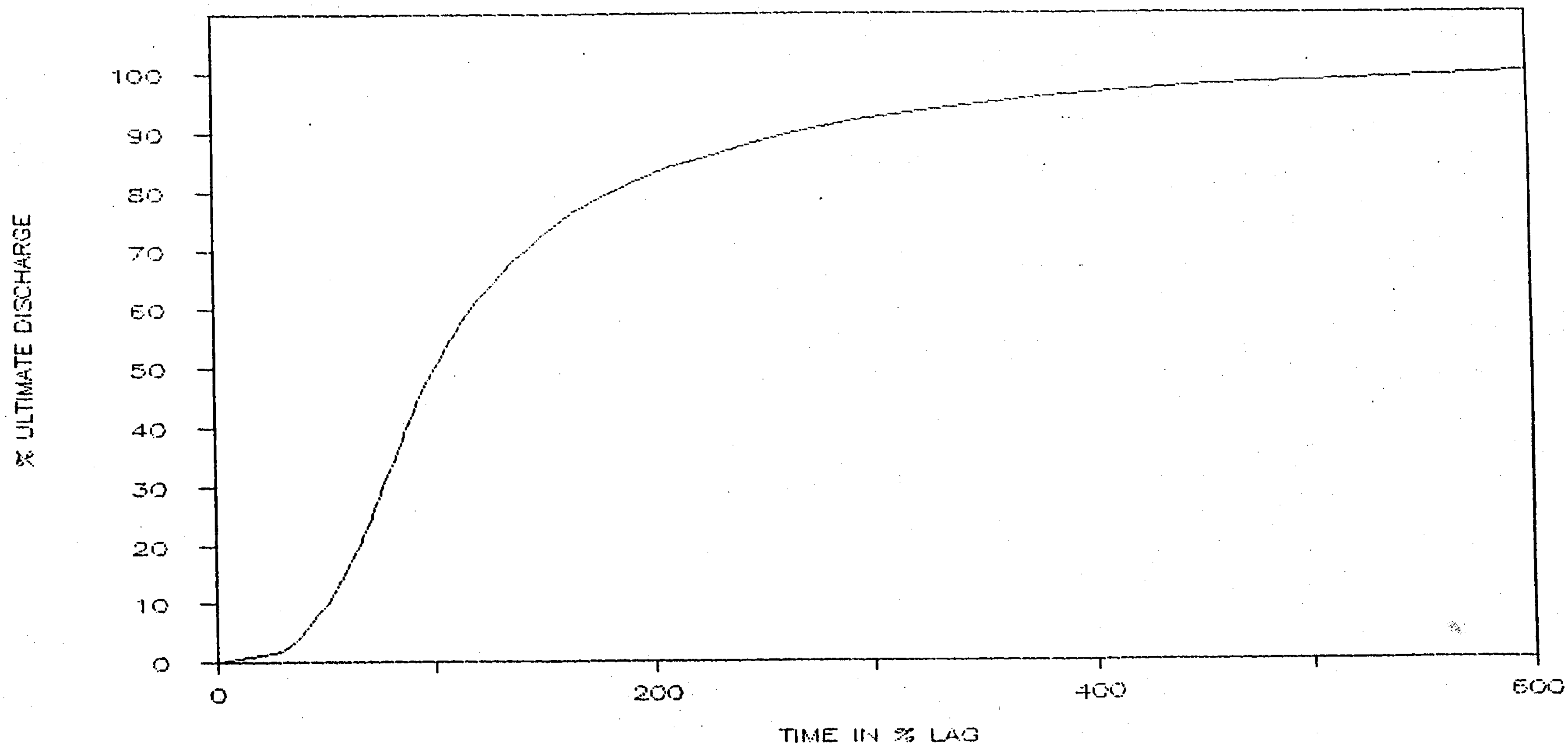
#54 UINTA RIVER

NEAR NEOLA, UTAH



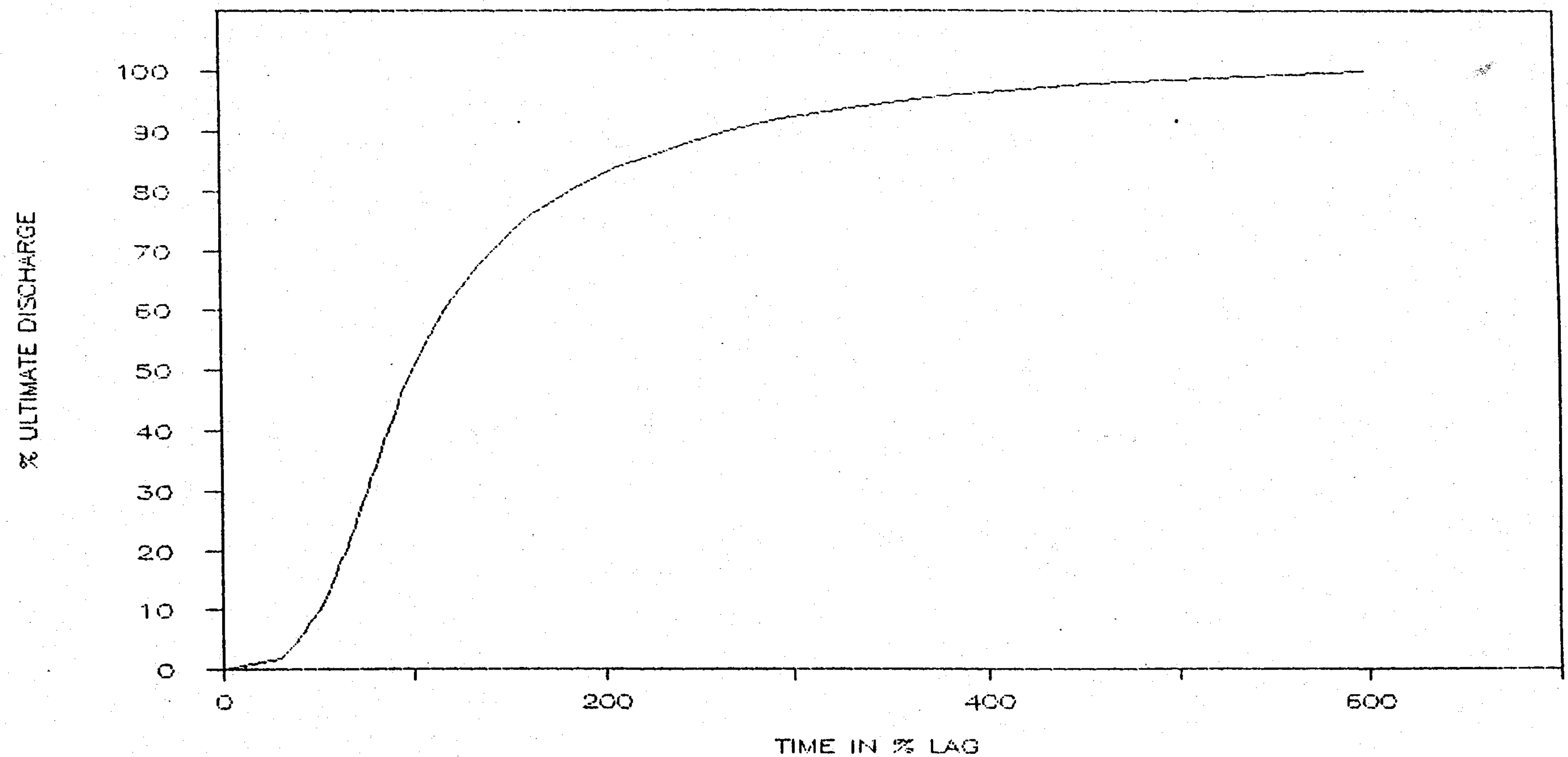
#55 ARBUCKLE CREEK AND DAM

OKLAHOMA



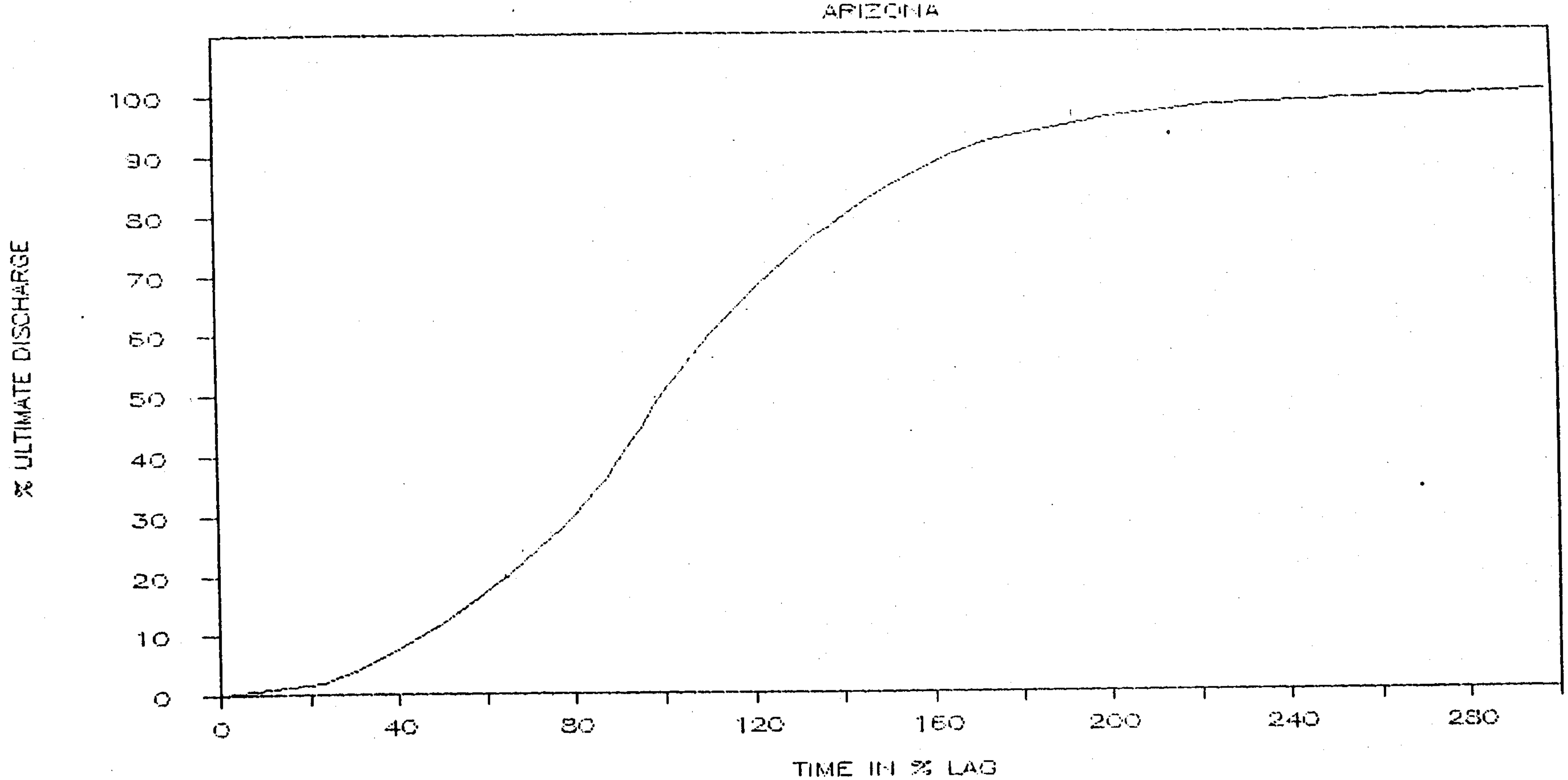
#55 ARBUCKLE CREEK AND DAM

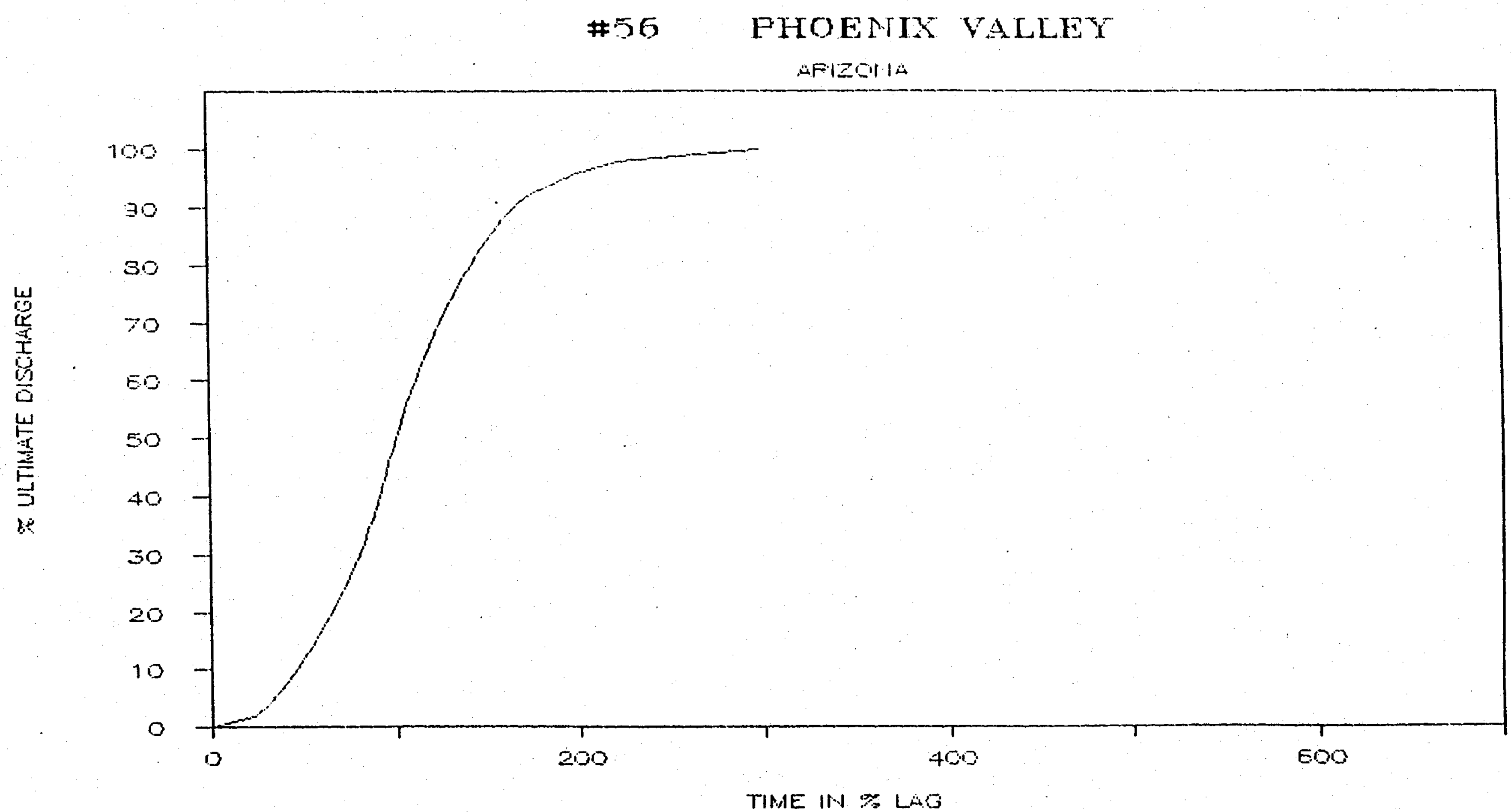
OKLAHOMA



#56 PHOENIX VALLEY

ARIZONA

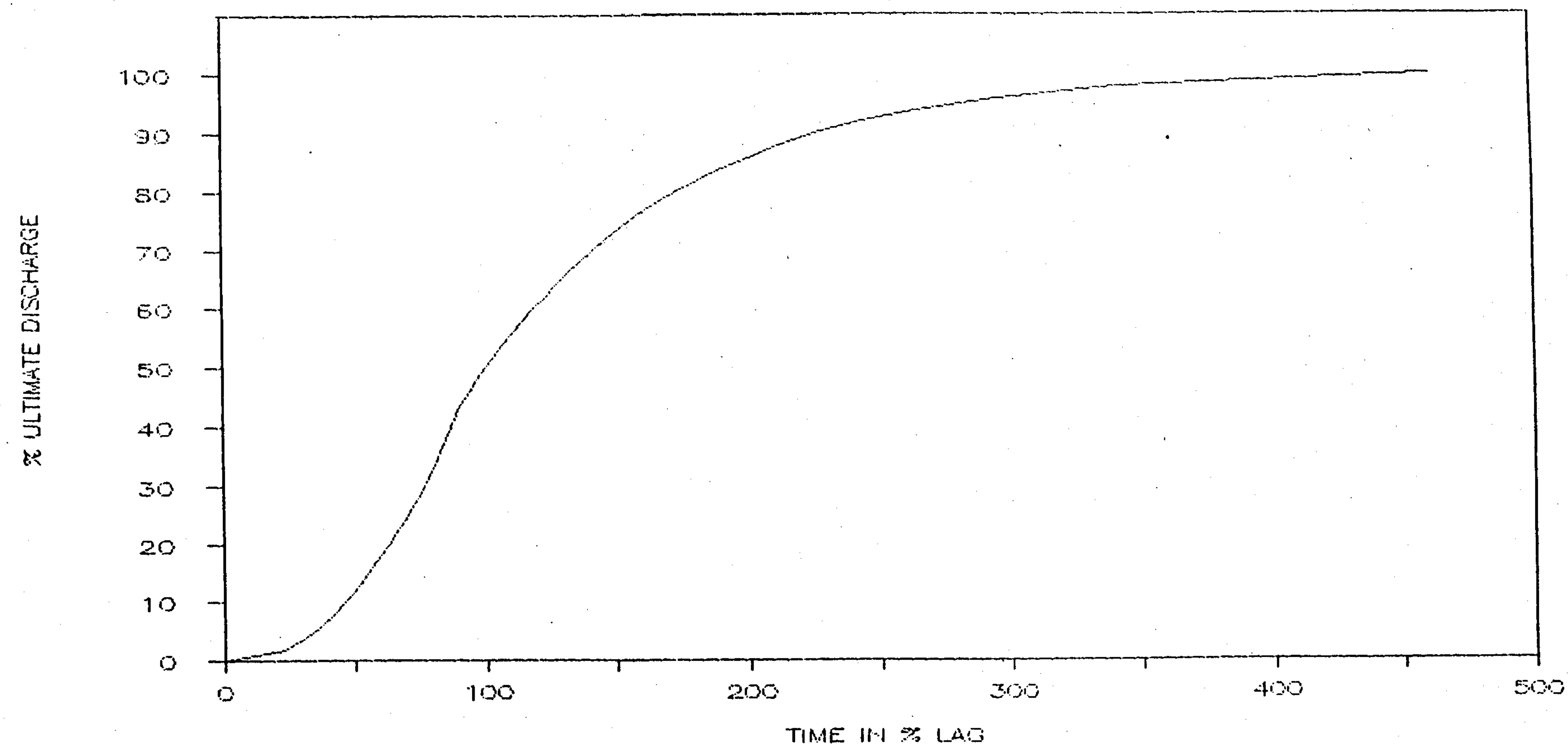




#56 PHOENIX VALLEY
ARIZONA
% ULTIMATE DISCHARGE
100
90
80
70
60
50
40
30
20
10
0
0
200
400
600
TIME IN % LAG

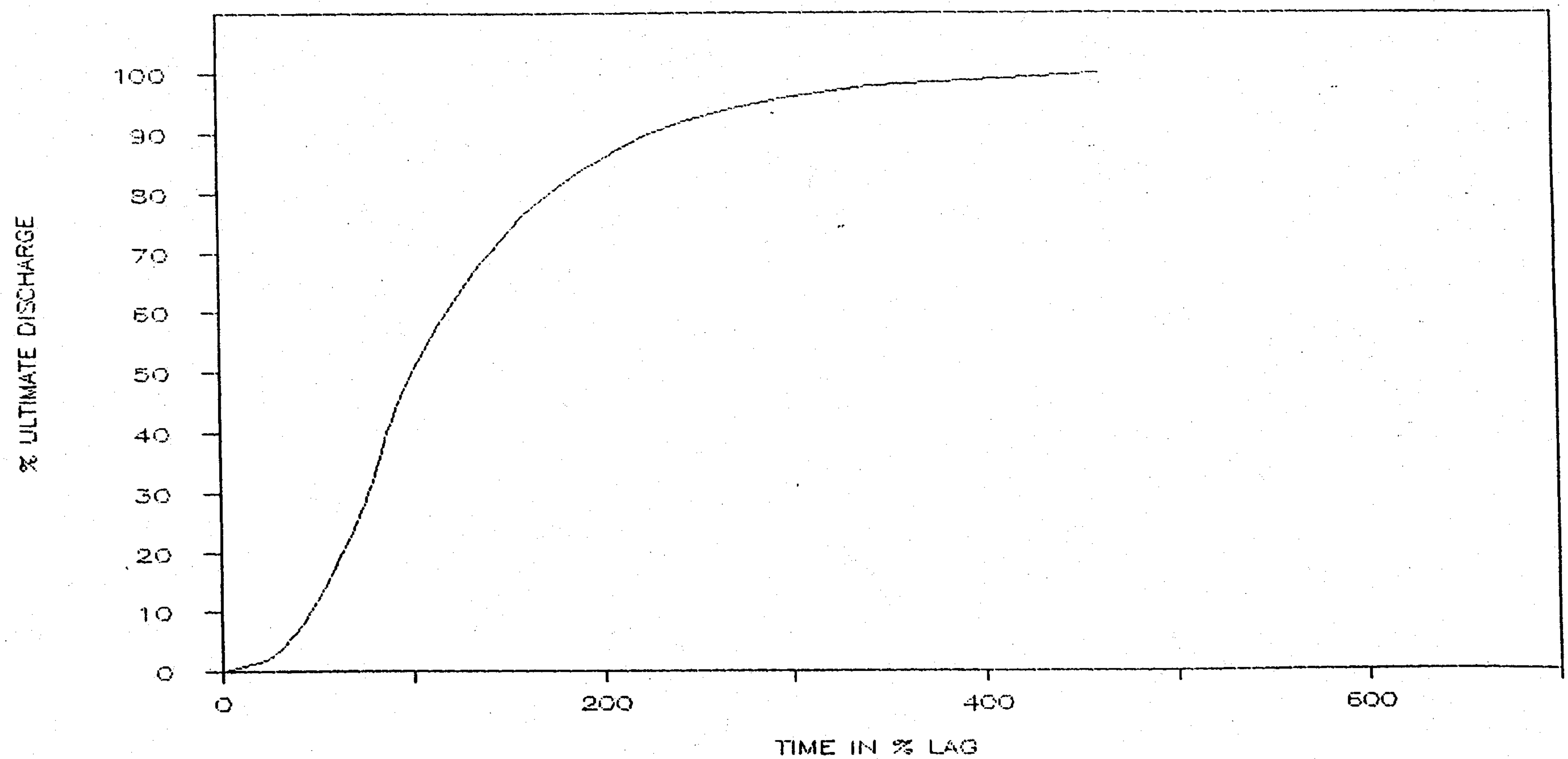
#57 PHOENIX MOUNTAIN

ARIZONA



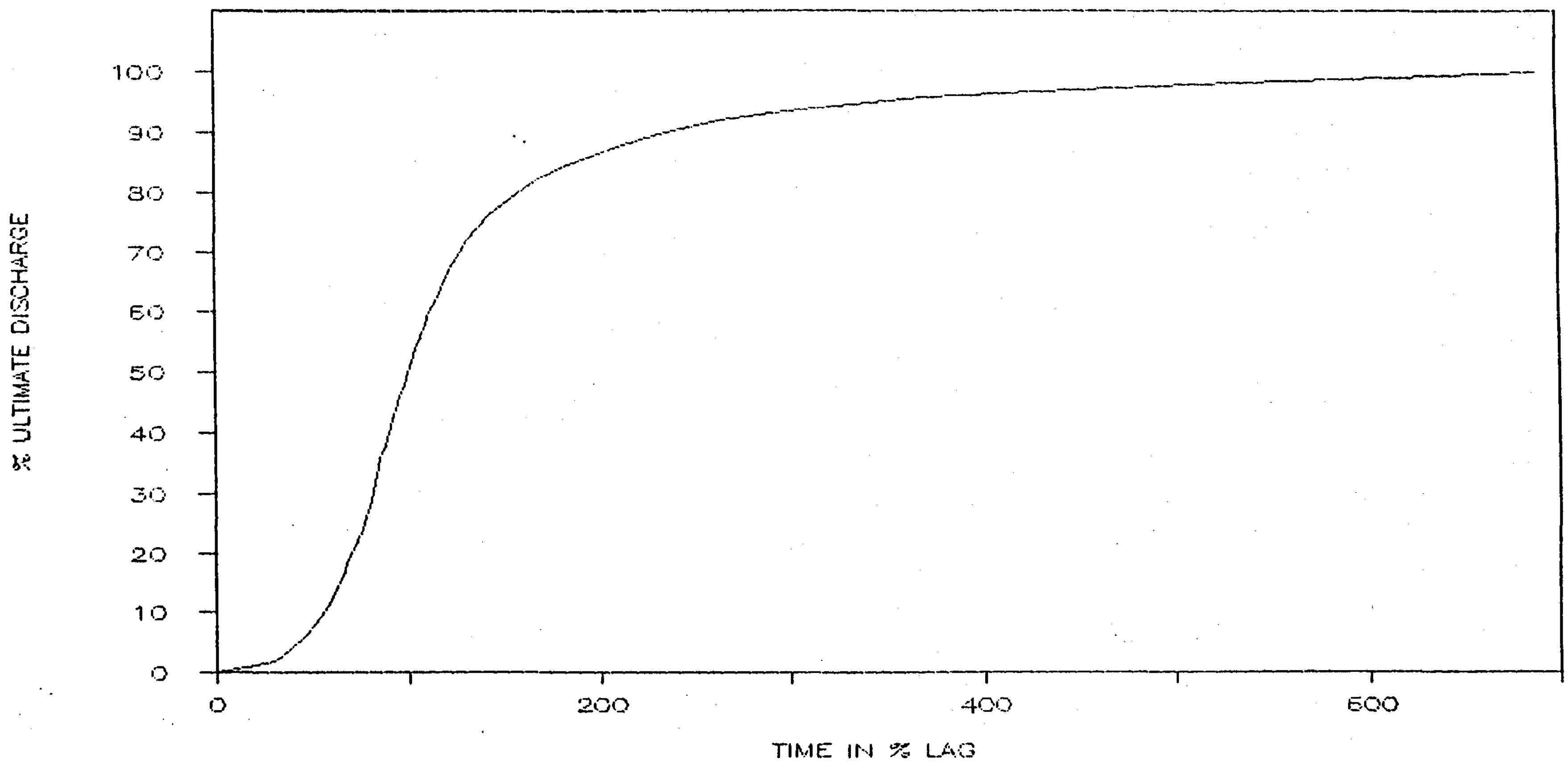
#57 PHOENIX MOUNTAIN

ARIZONA



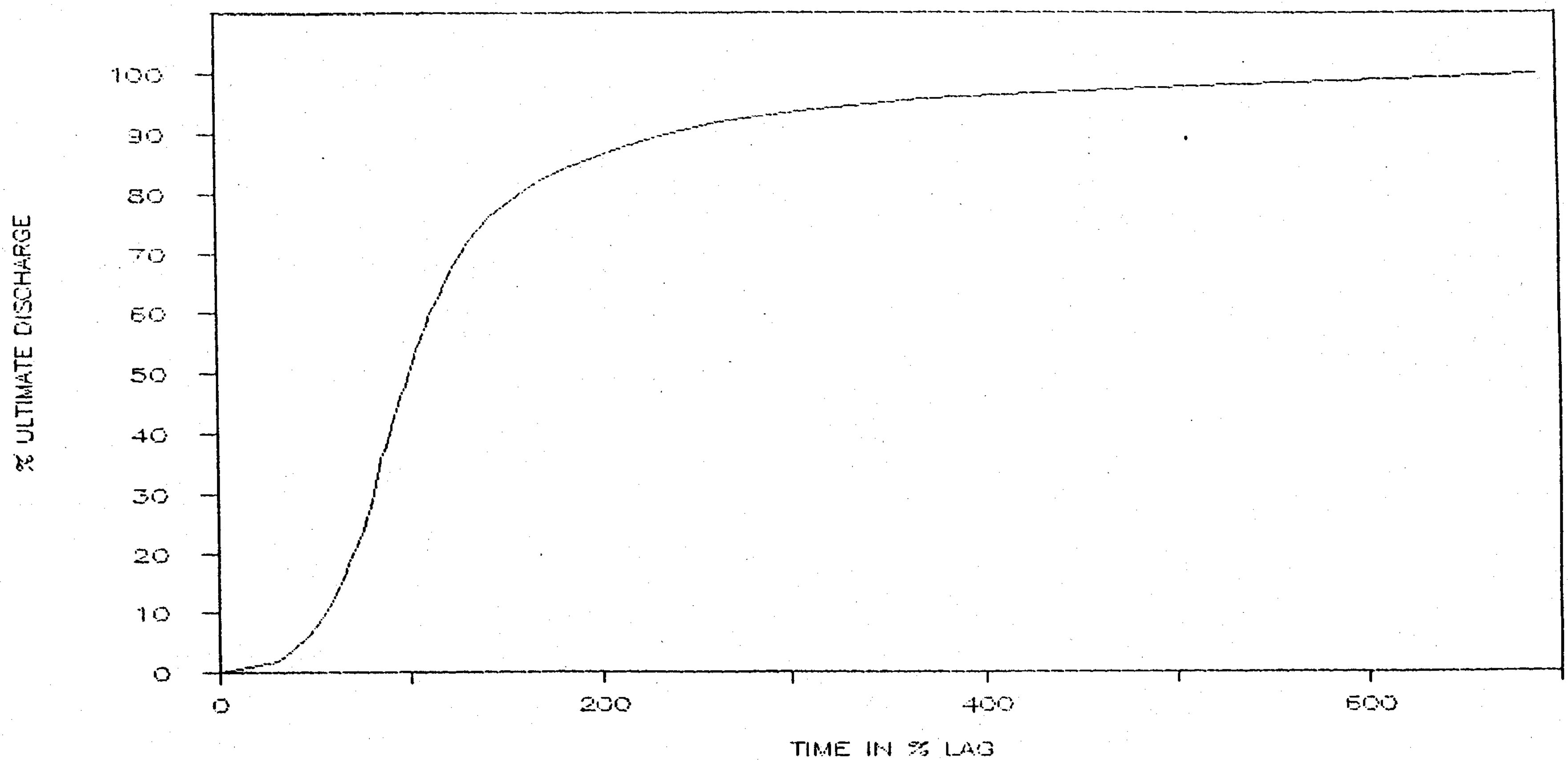
#58 GILA RIVER BASIN, ARIZONA

BASINS LESS THAN 1500 SQUARE MILES



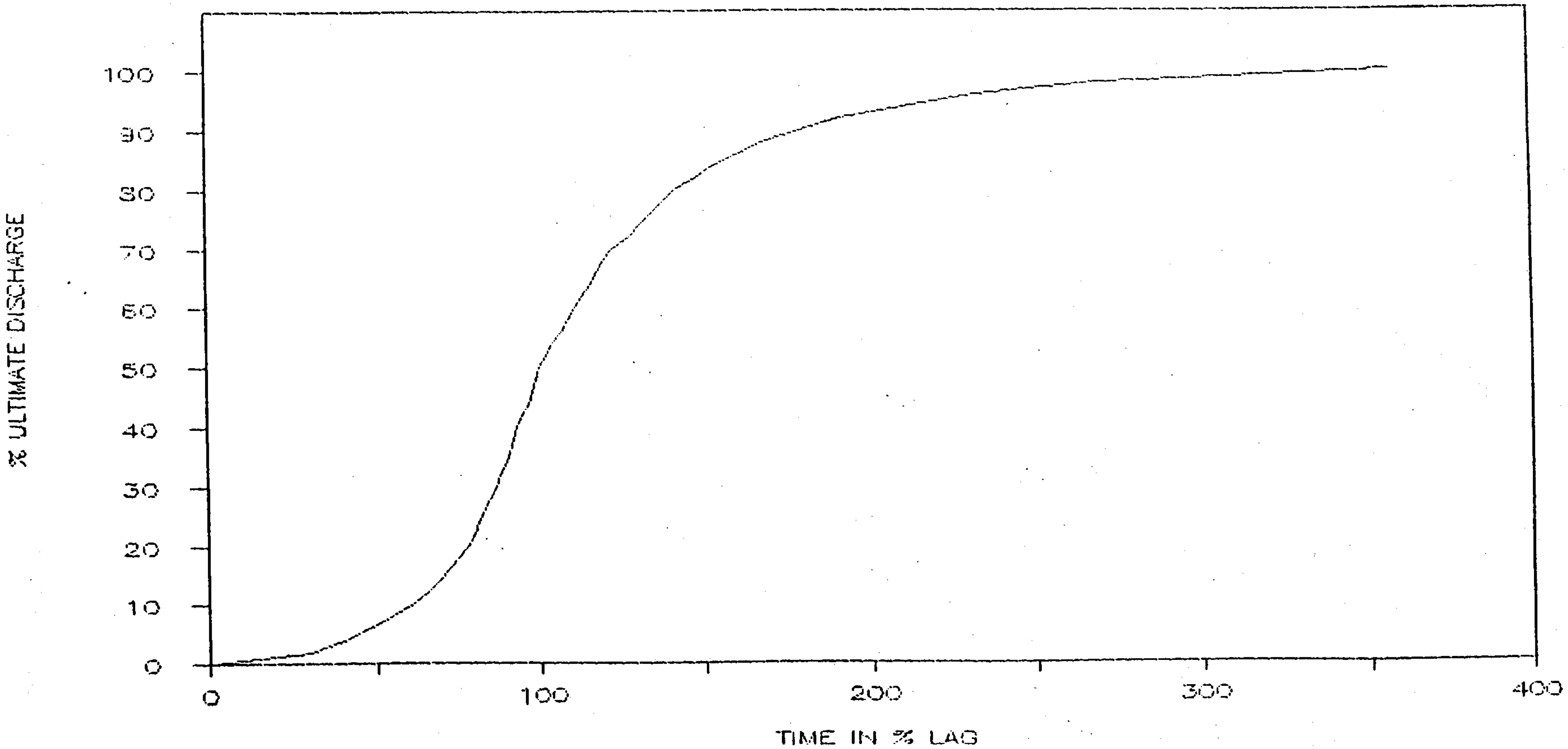
#58 GILA RIVER BASIN, ARIZONA

BASINS LESS THAN 1500 SQUARE MILES



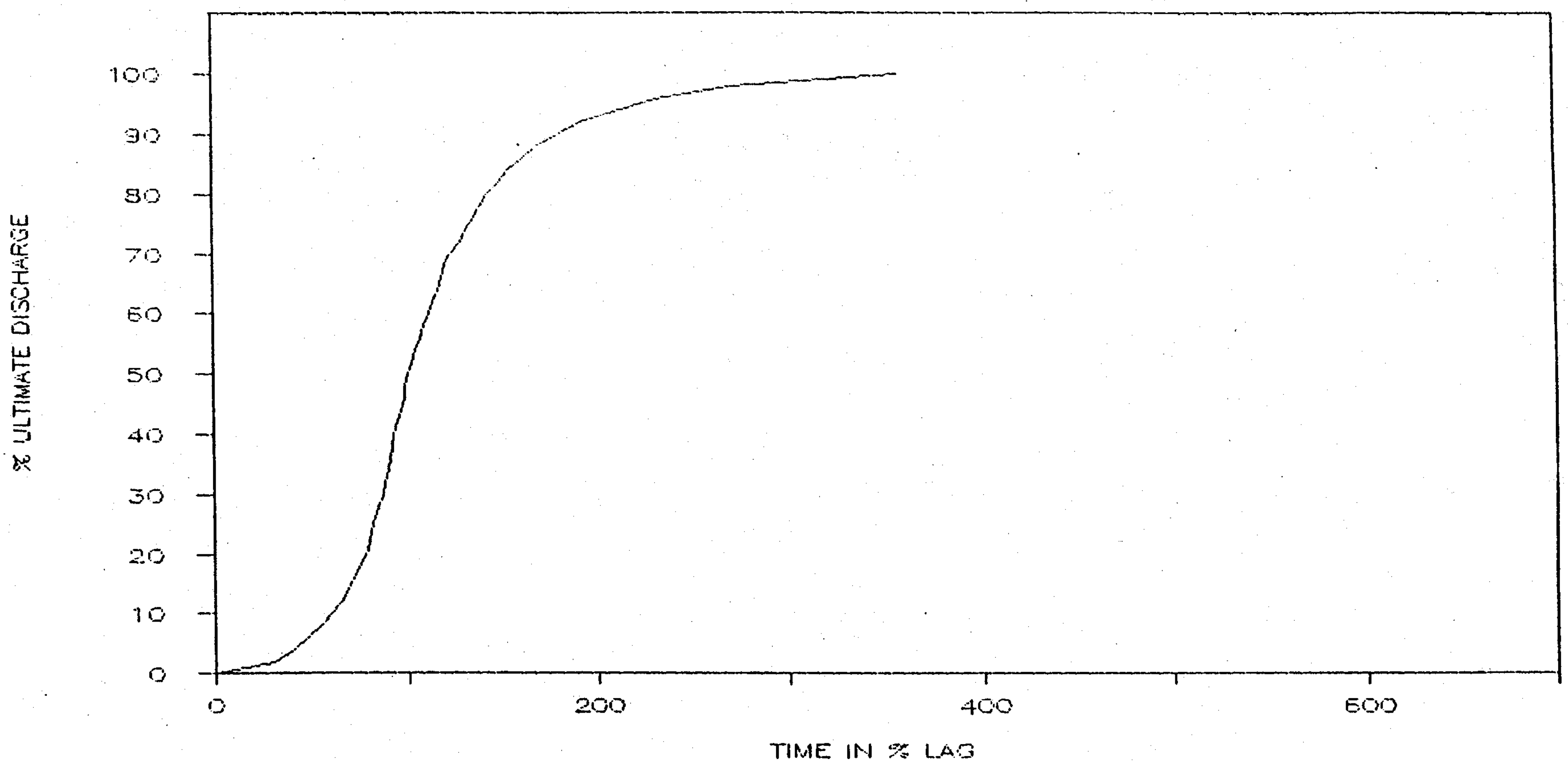
#59 GILA RIVER BASIN, ARIZONA

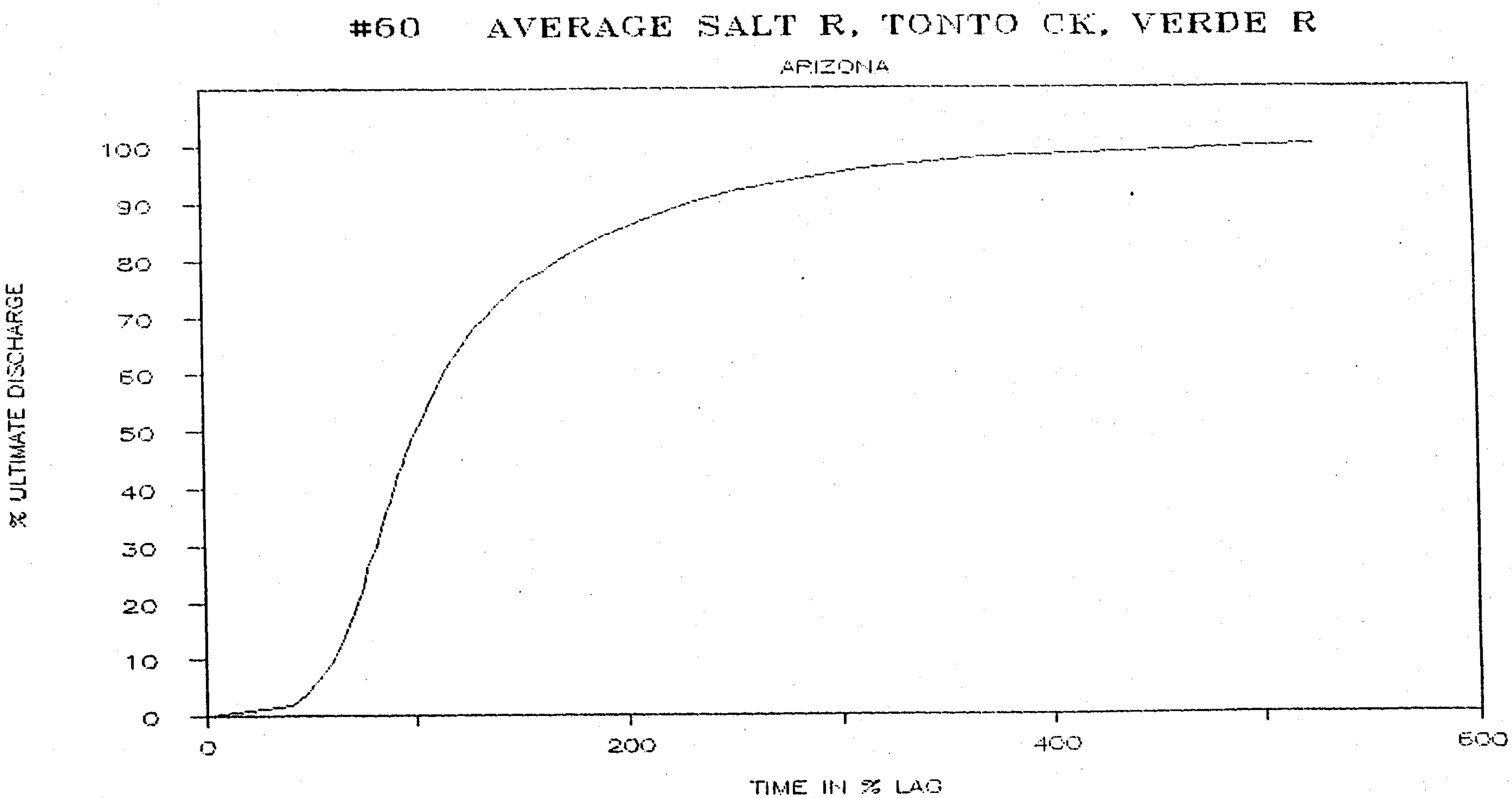
BASINS GREATER THAN 1500 SQUARE MILES



#59 GILA RIVER BASIN, ARIZONA

BASINS GREATER THAN 1500 SQUARE MILES

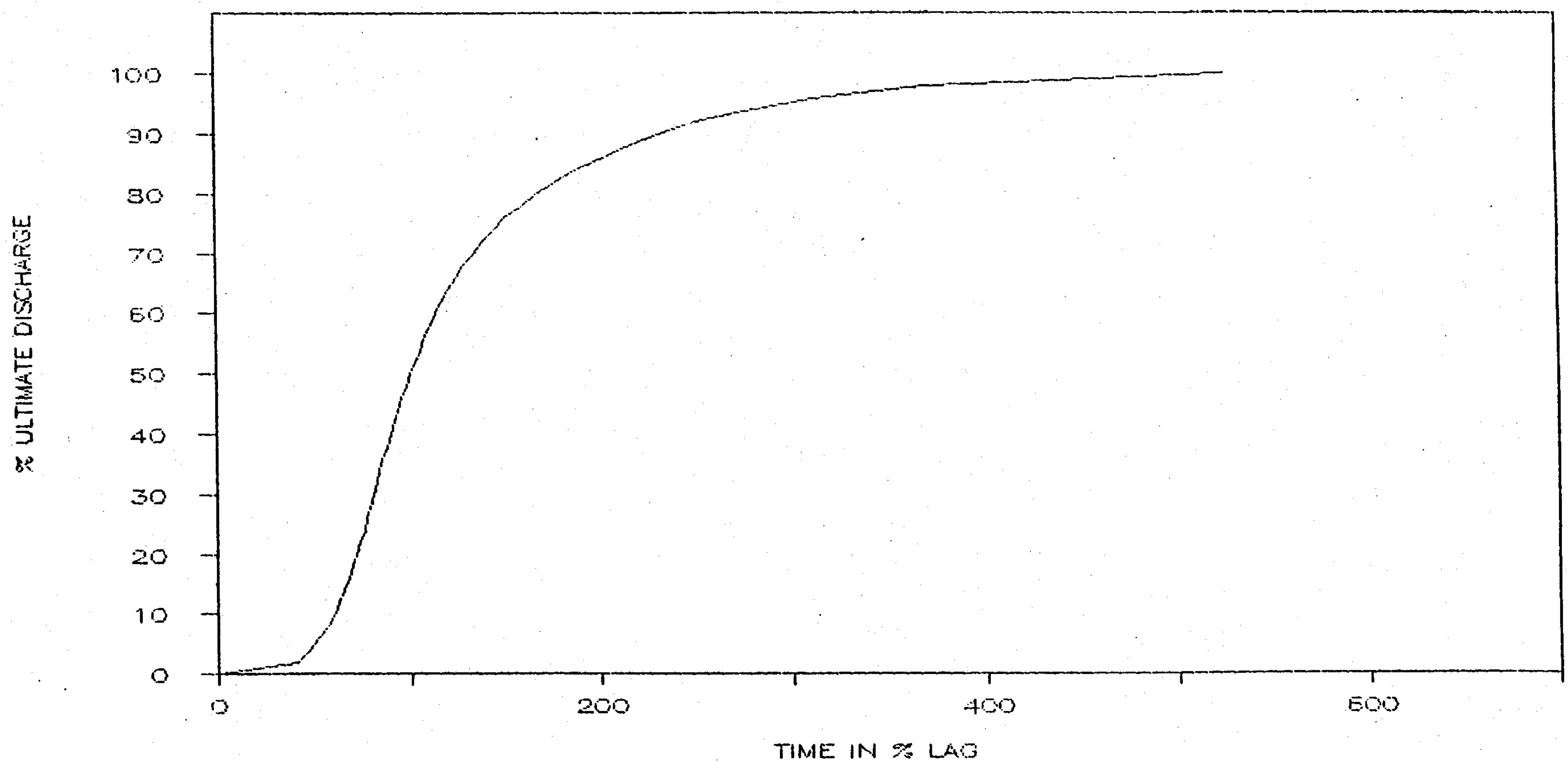




#60 AVERAGE SALT R, TONTO CK, VERDE R
ARIZONA
% ULTIMATE DISCHARGE
0
10
20
30
40
50
60
70
80
90
100
0
200
400
600
TIME IN % LAG

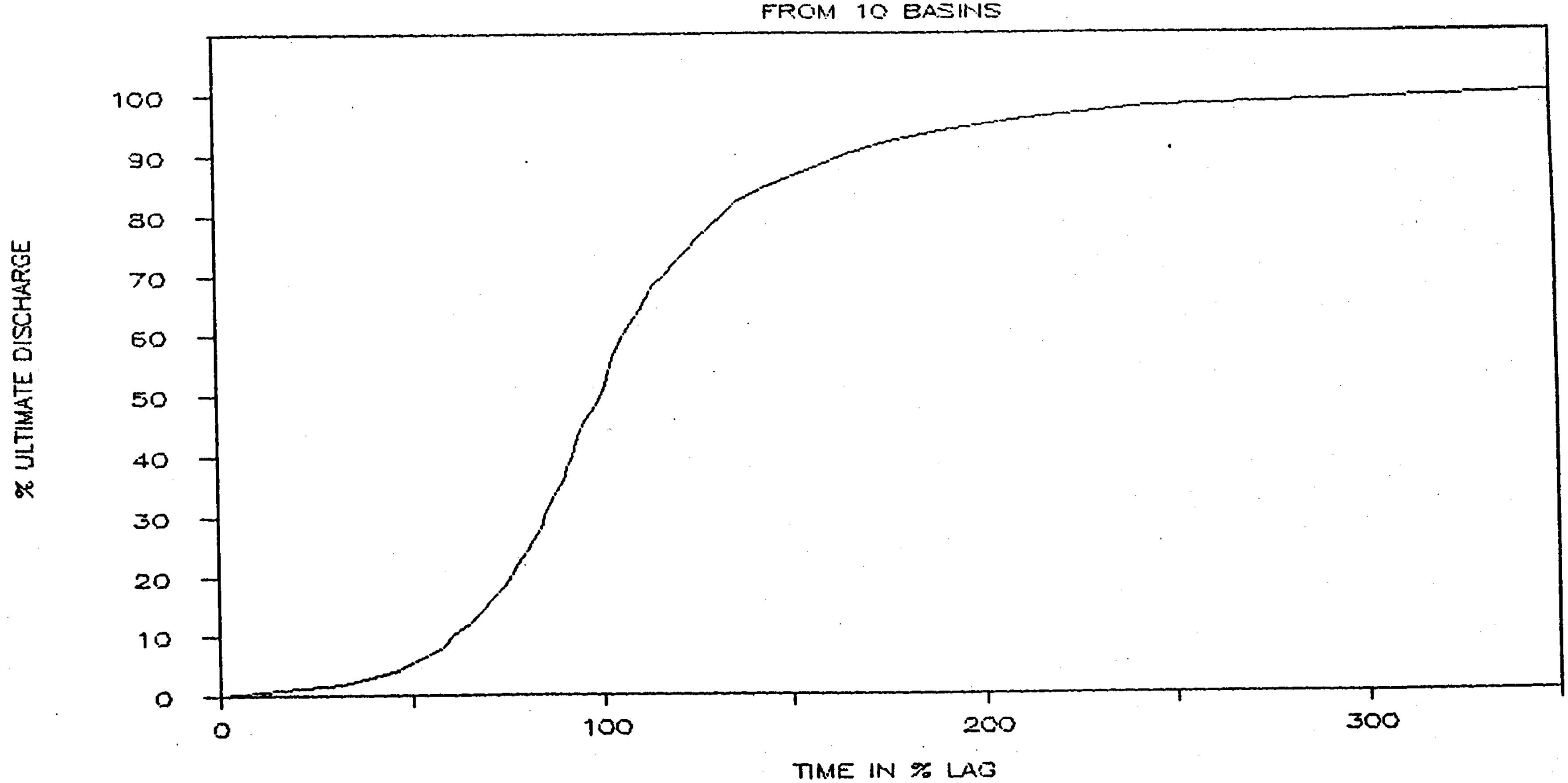
#60 AVERAGE SALT R, TONTO CK, VERDE R

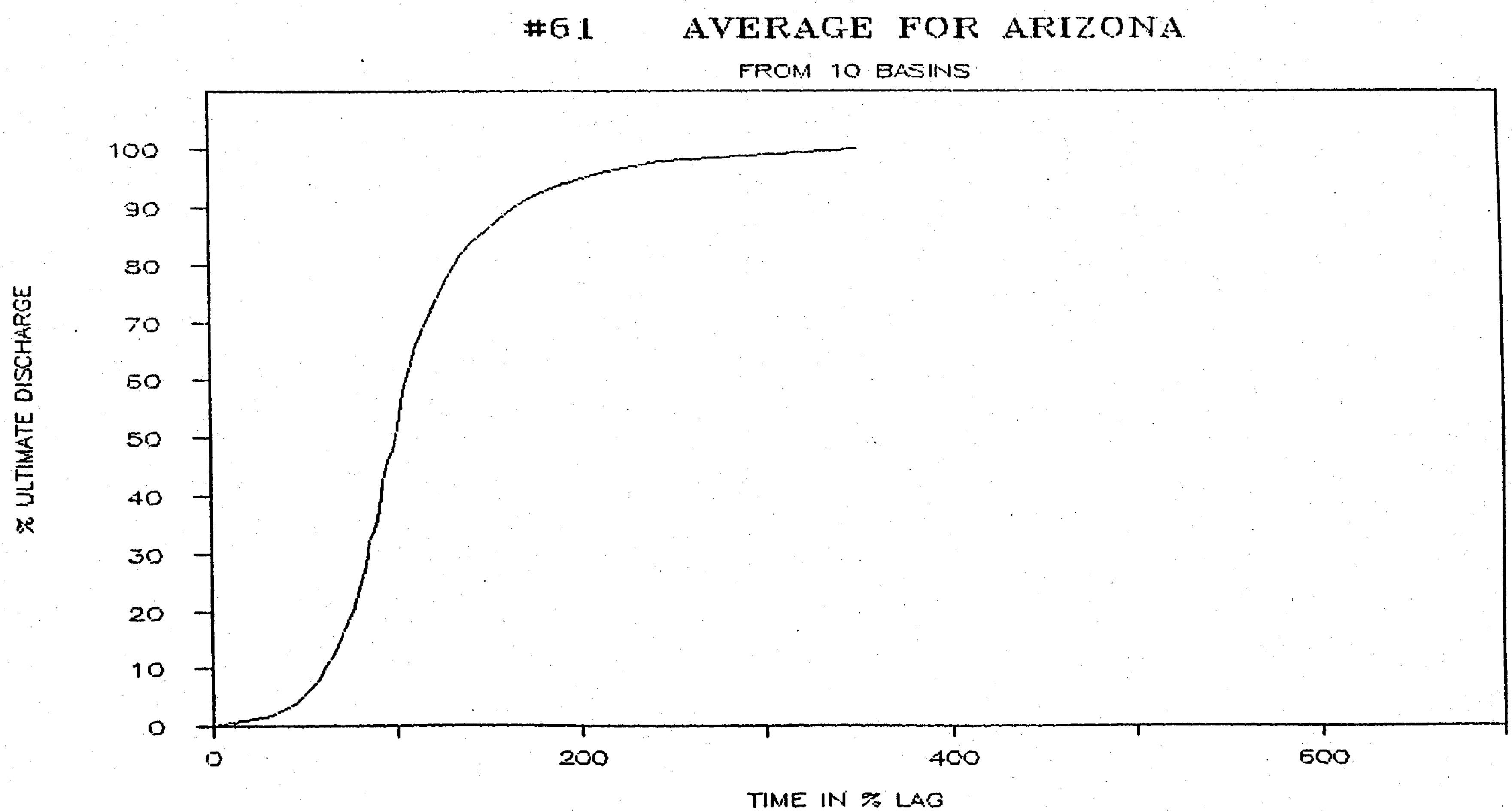
ARIZONA



#61 AVERAGE FOR ARIZONA

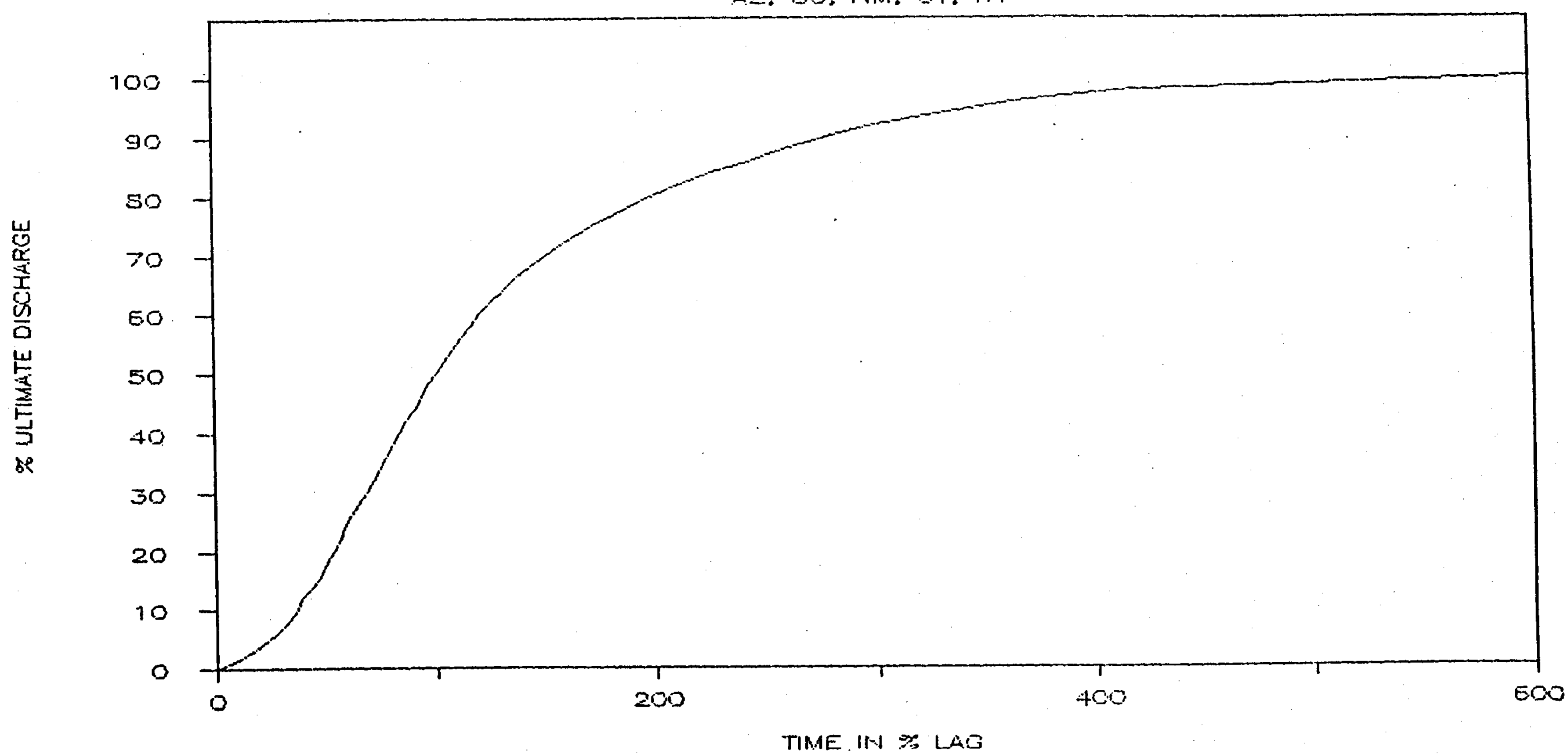
FROM 10 BASINS




#61 AVERAGE FOR ARIZONA
FROM 10 BASINS
% ULTIMATE DISCHARGE
100
90
80
70
60
50
40
30
20
10
0
0
200
400
600
TIME IN % LAG

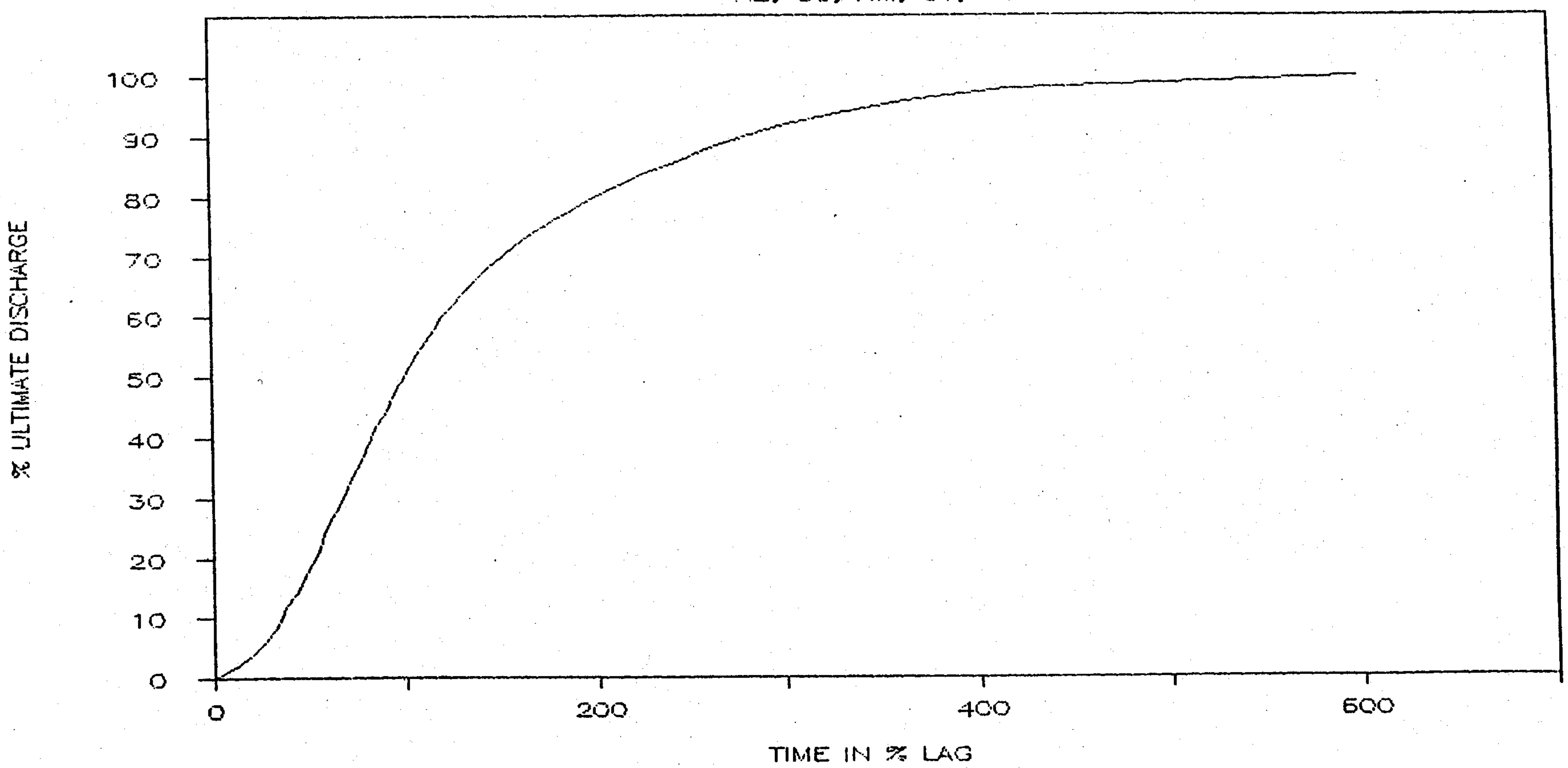
#62 AVERAGE MOUNTAIN

AZ, CO, NM, UT, WY



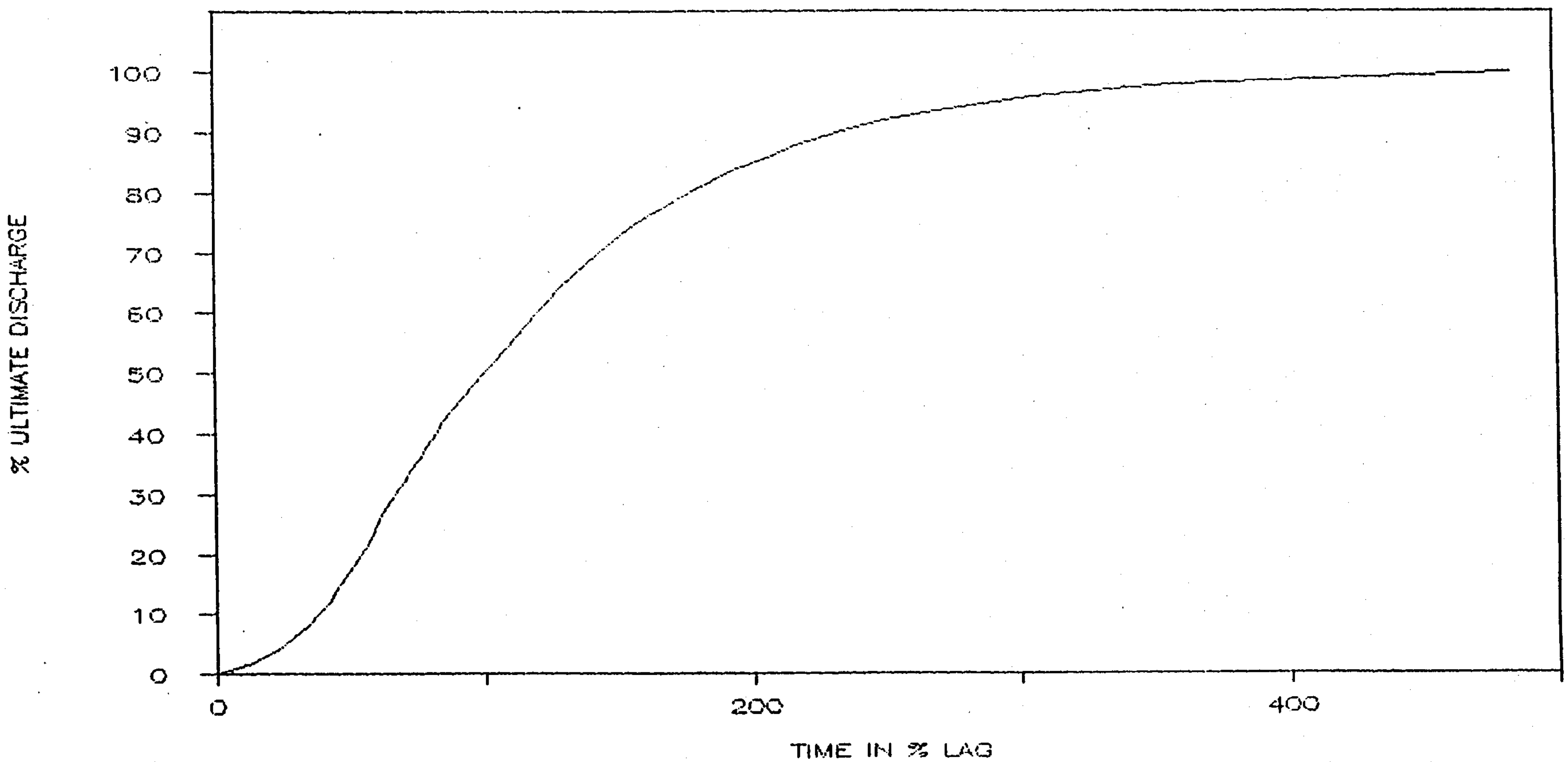
#62 AVERAGE MOUNTAIN

AZ. CO. NM. UT. WY



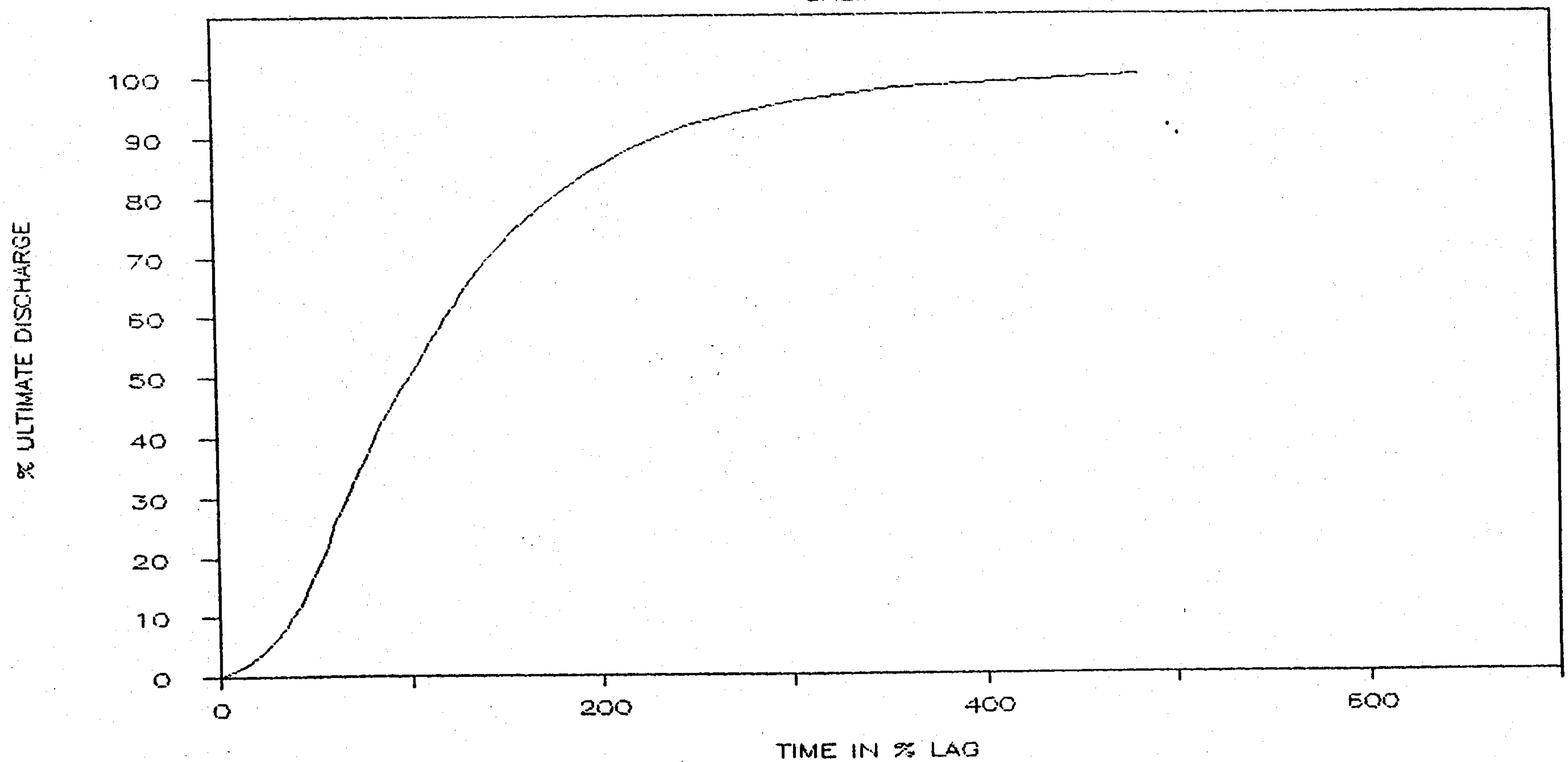
#63 COASTAL SAN DIEGO COUNTY

CALIFORNIA



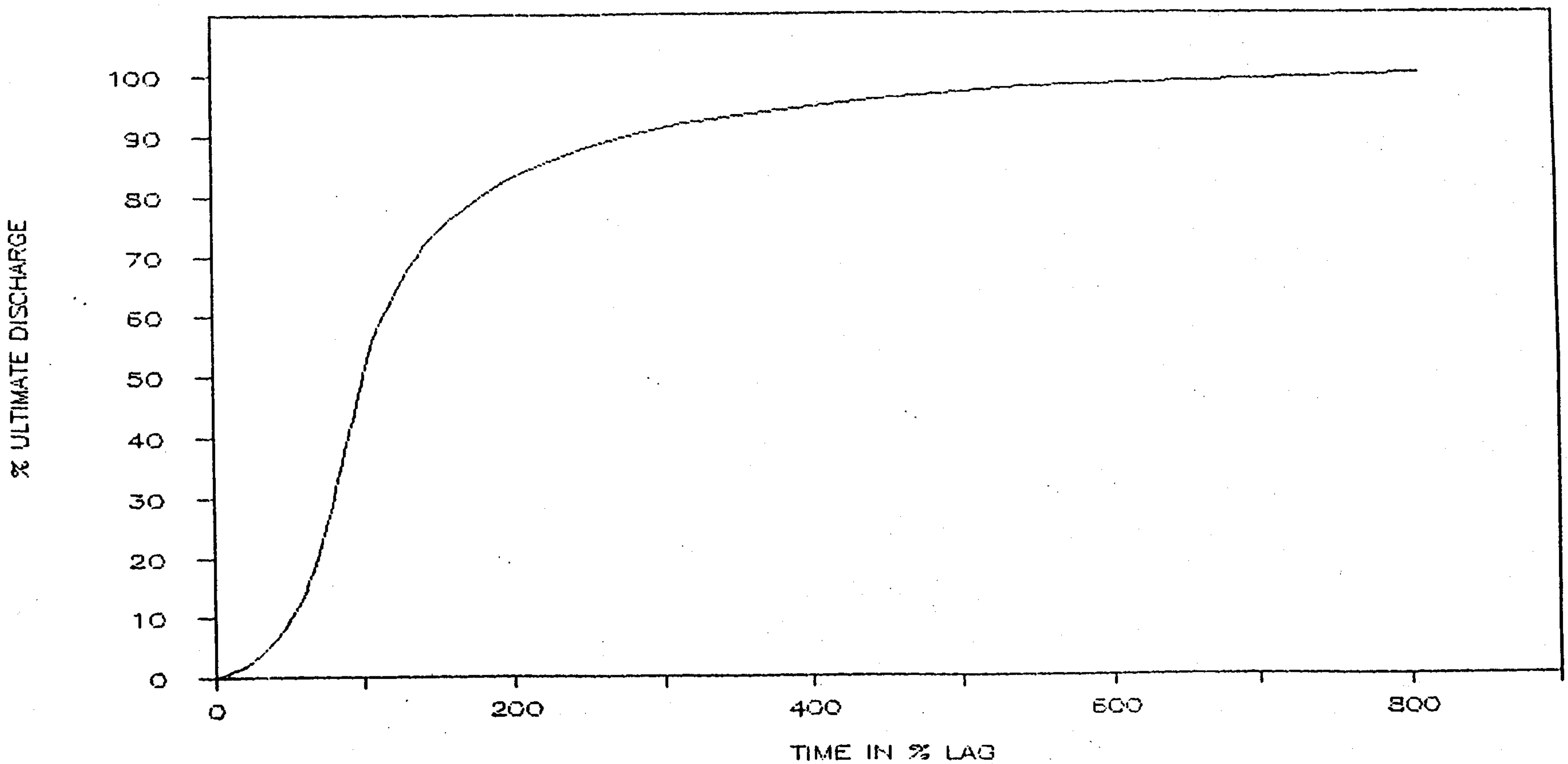
#63 COASTAL SAN DIEGO COUNTY

CALIFORNIA



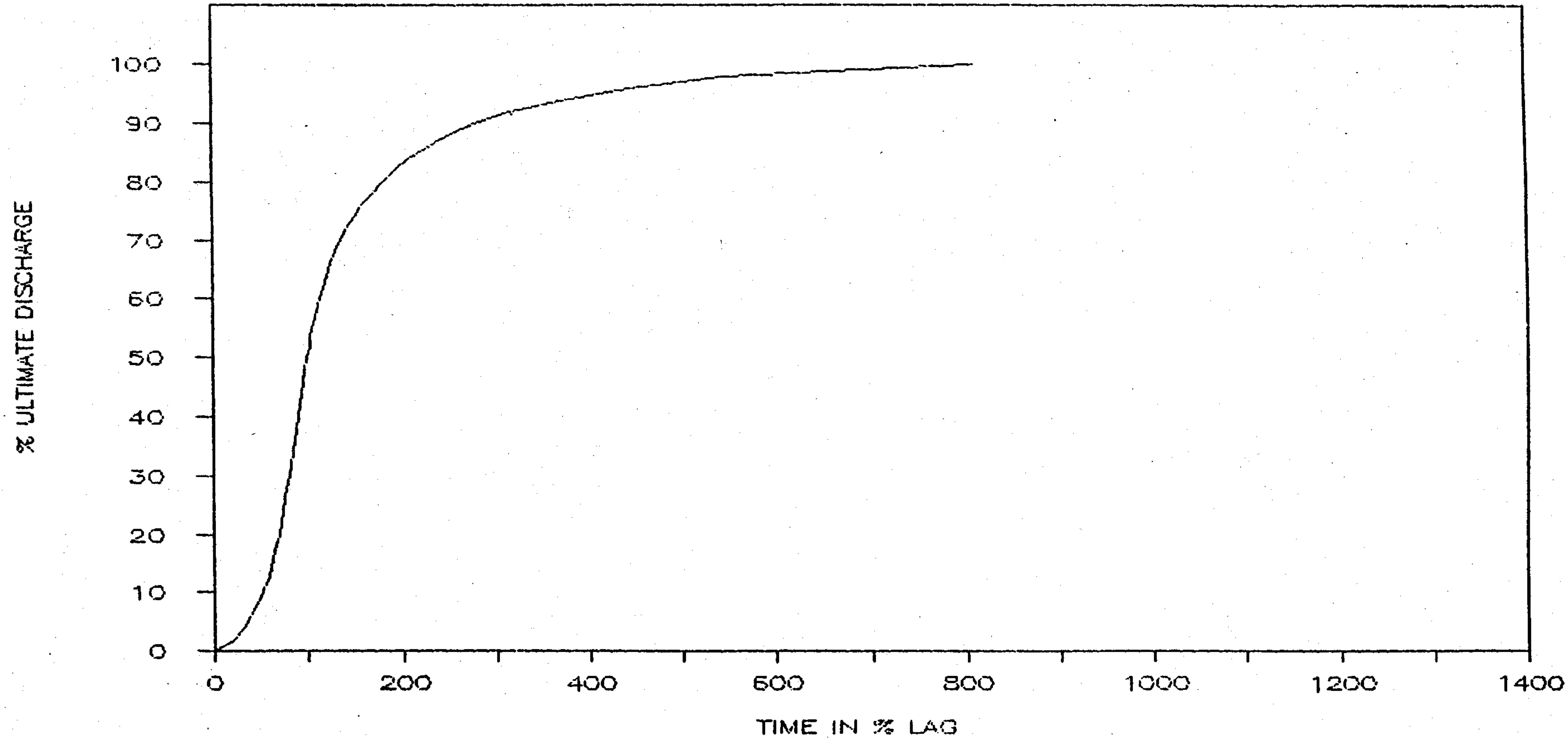
#64 AVERAGE OF SANTA YNEZ RIVER

CALIFORNIA



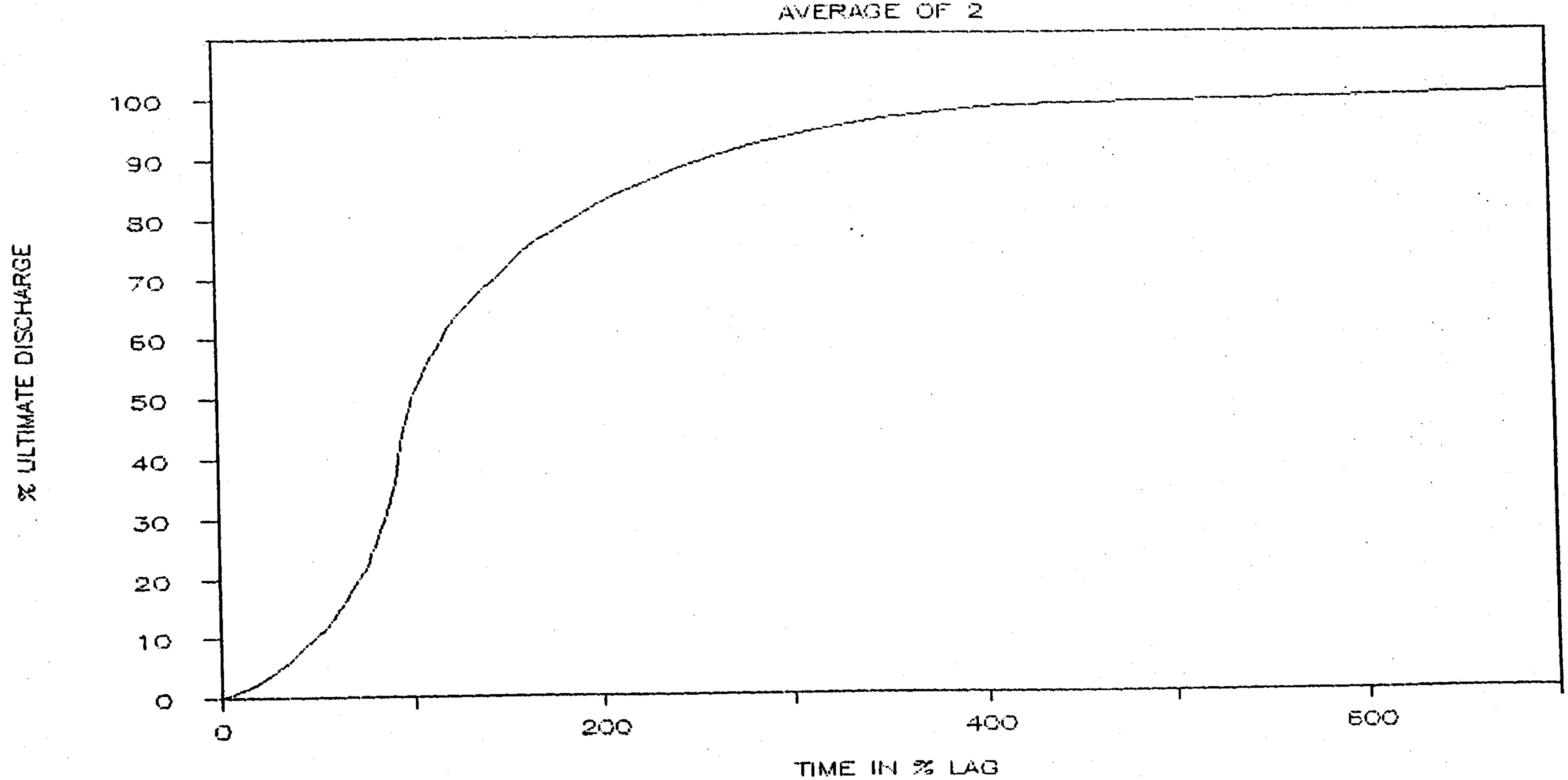
#64 AVERAGE OF SANTA YNEZ RIVER

CALIFORNIA



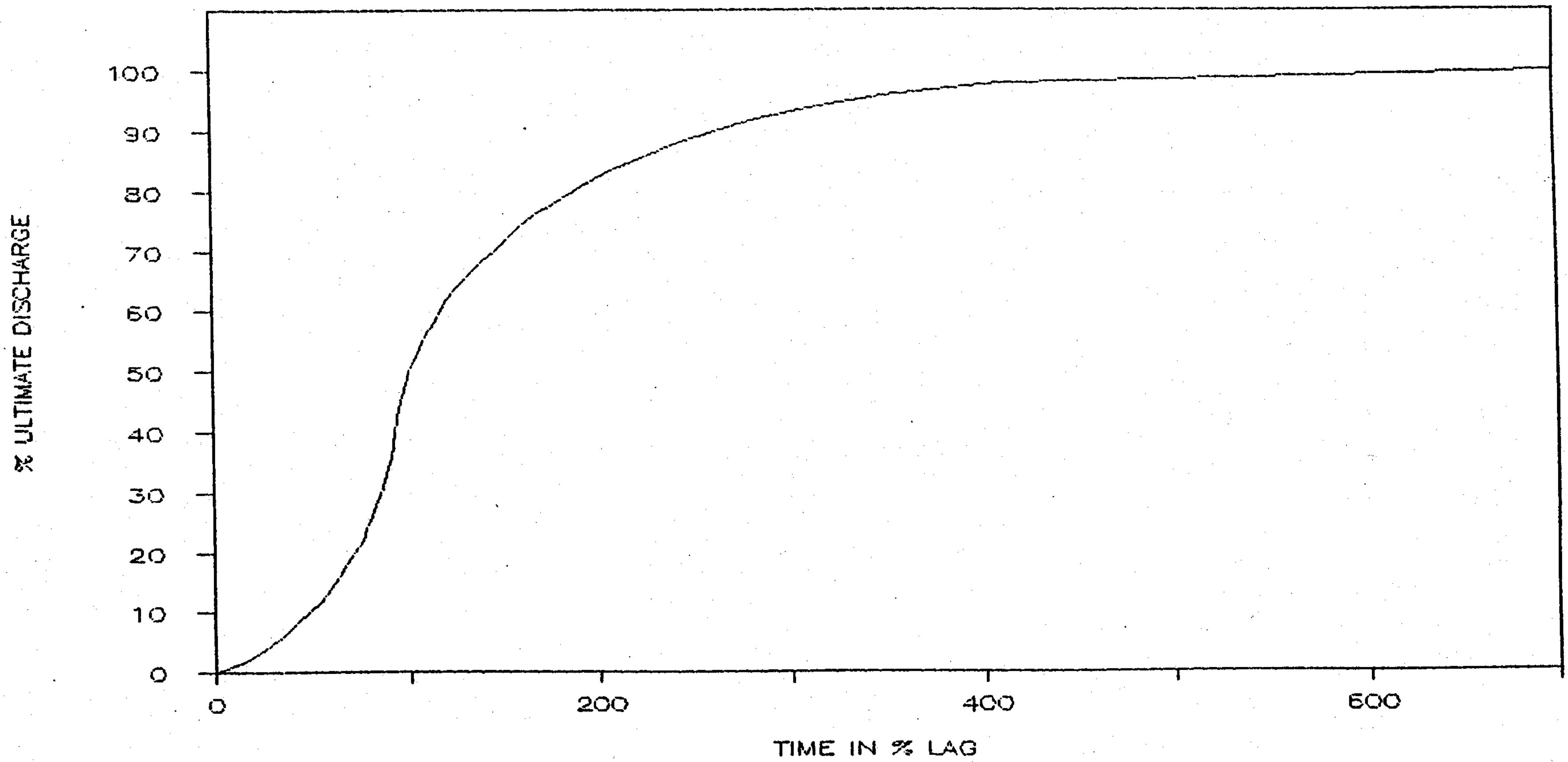
#65 SOUTHERN CALIFORNIA

AVERAGE OF 2



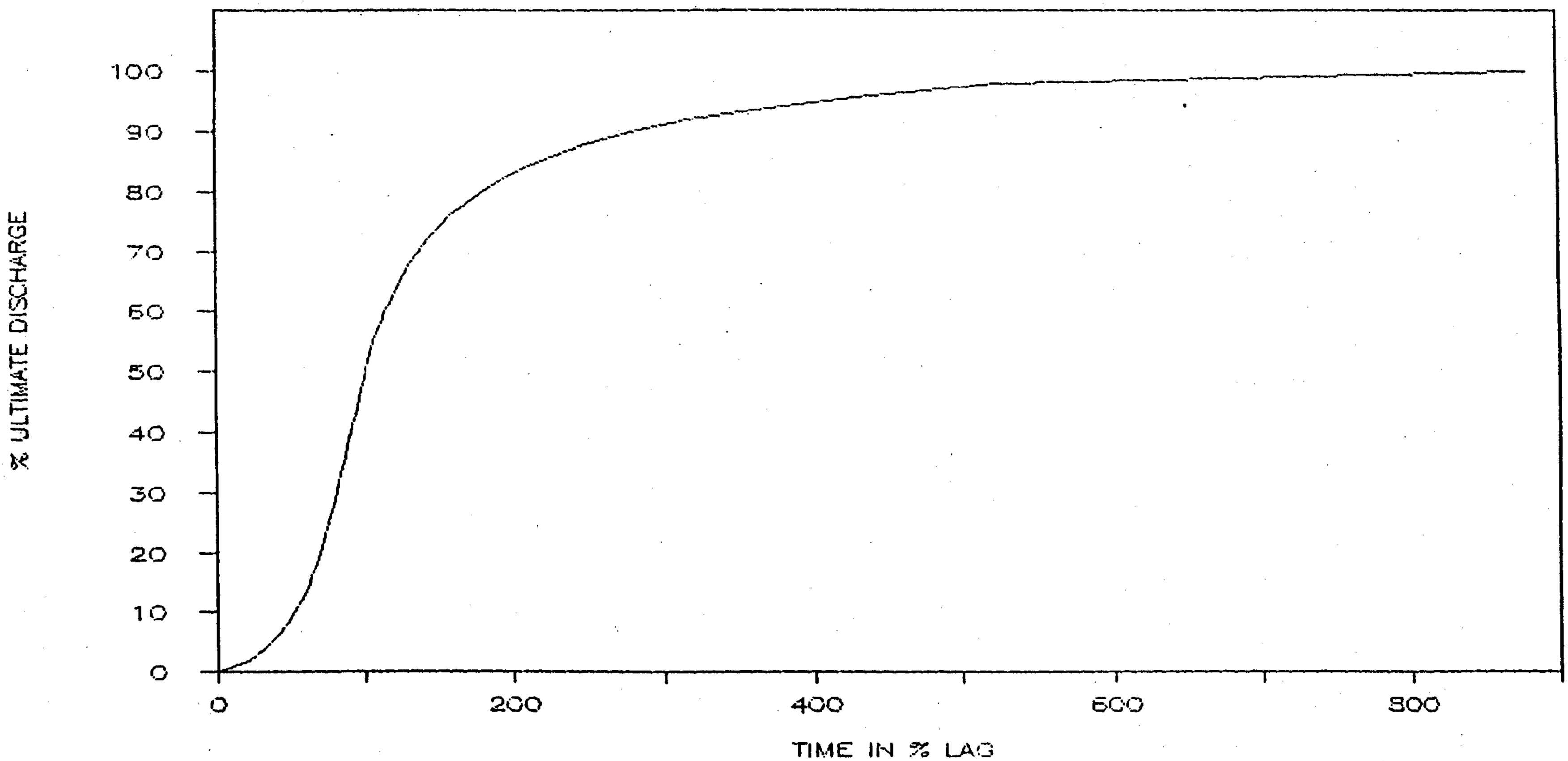
#65 SOUTHERN CALIFORNIA

AVERAGE OF 2



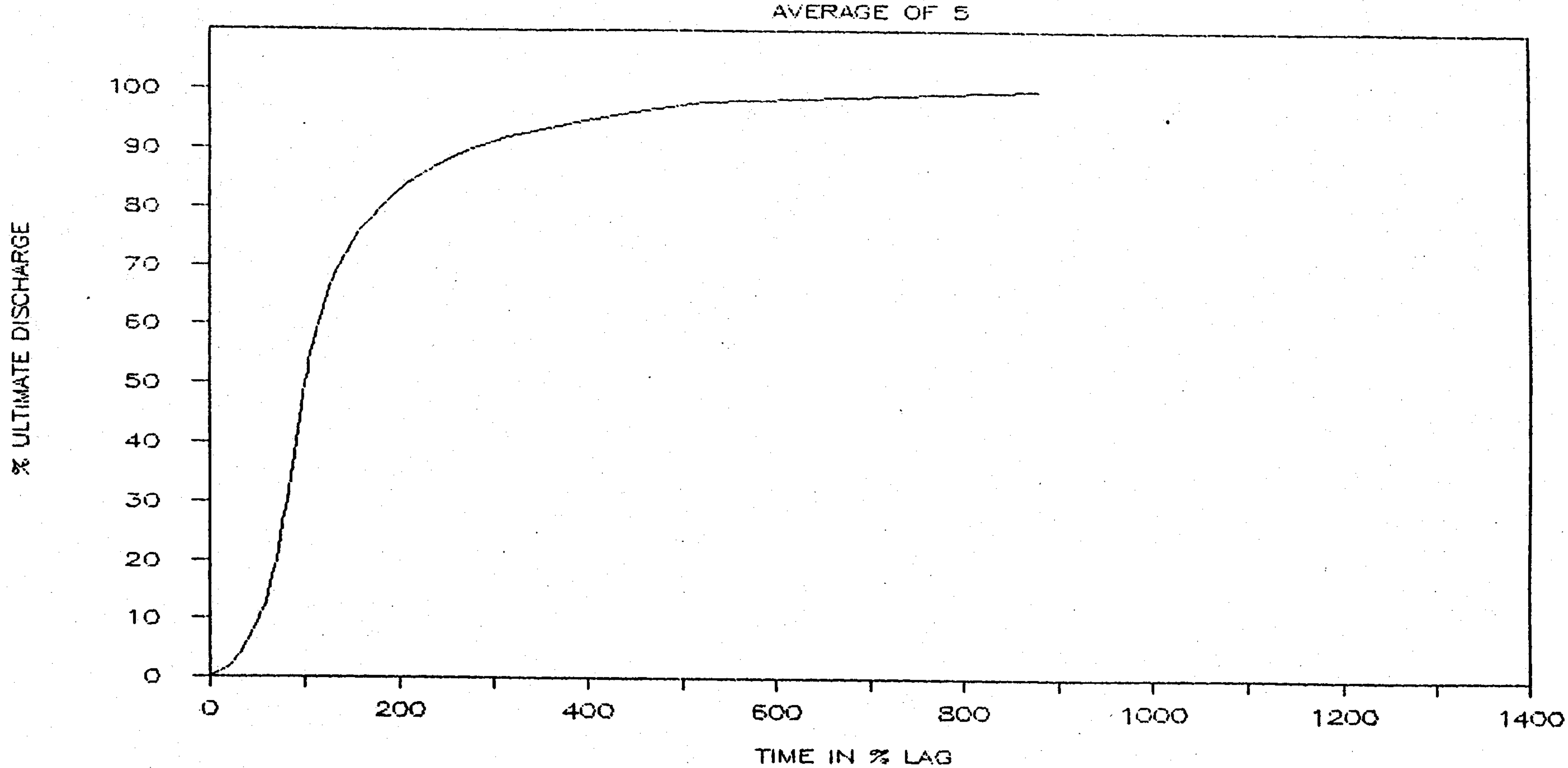
#66 SANTA CLARA RIVER, CALIFORNIA

AVERAGE OF 5



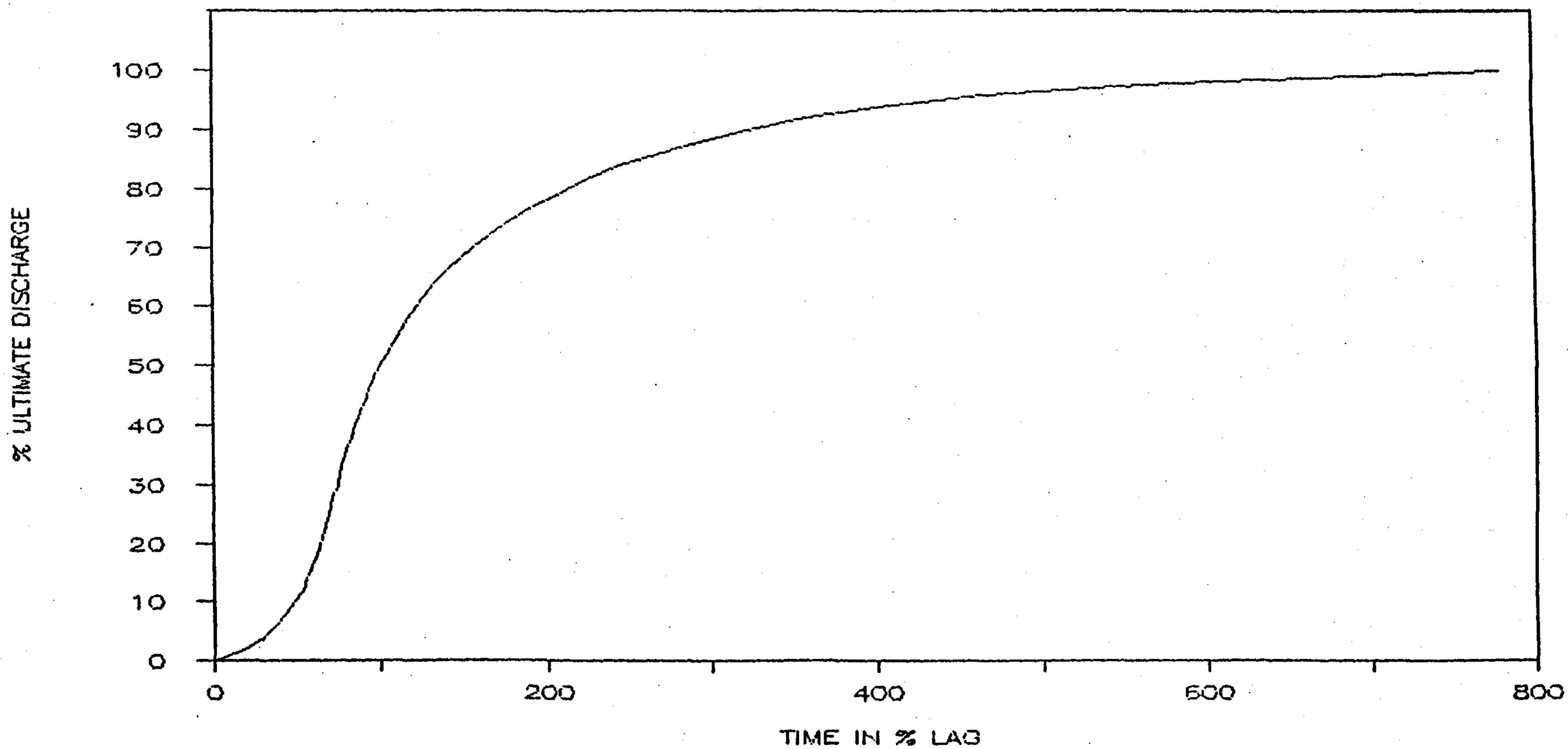
#66 SANTA CLARA RIVER, CALIFORNIA

AVERAGE OF 5

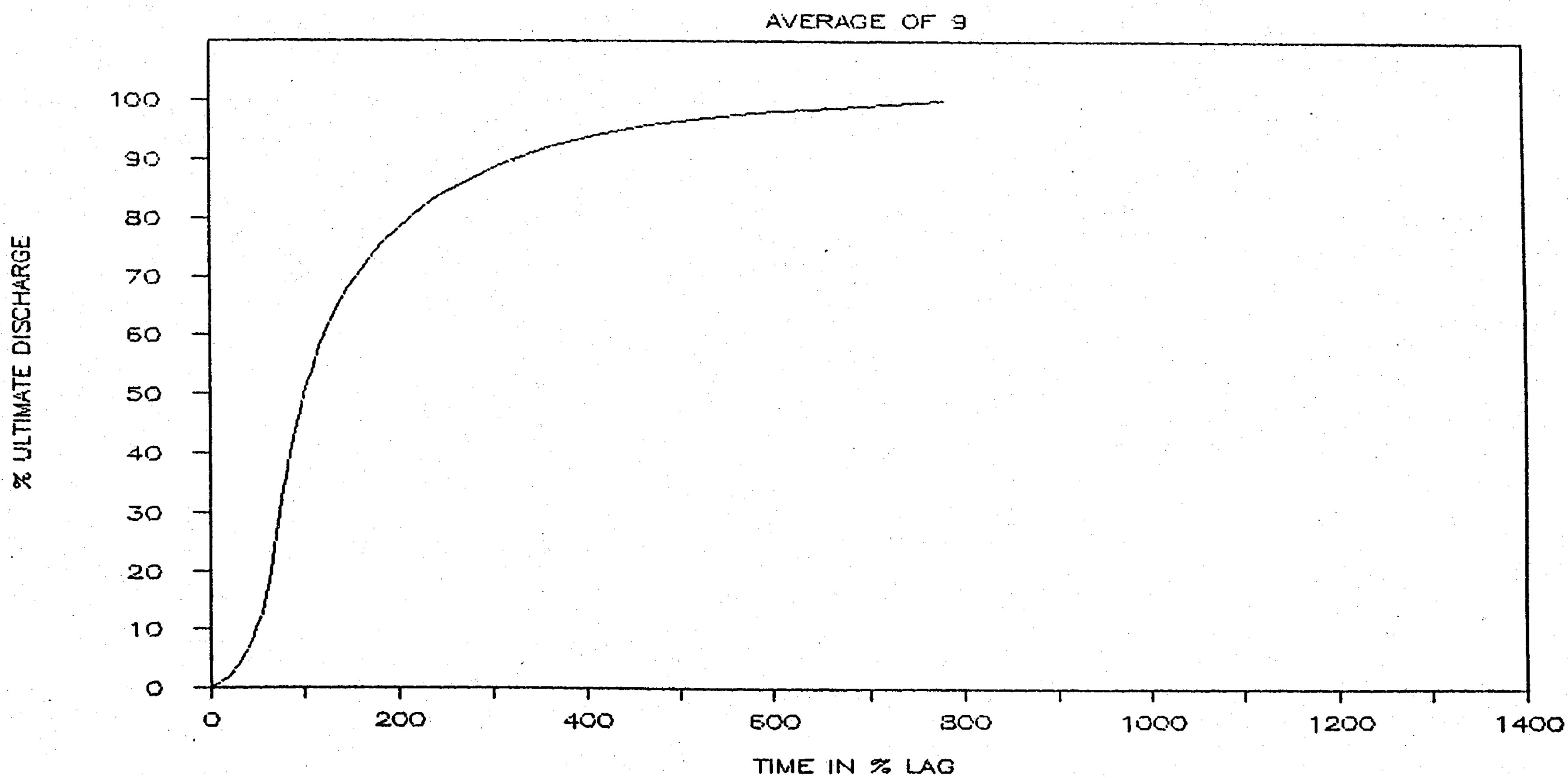


#67 WHITEWATER RIVER, CALIFORNIA

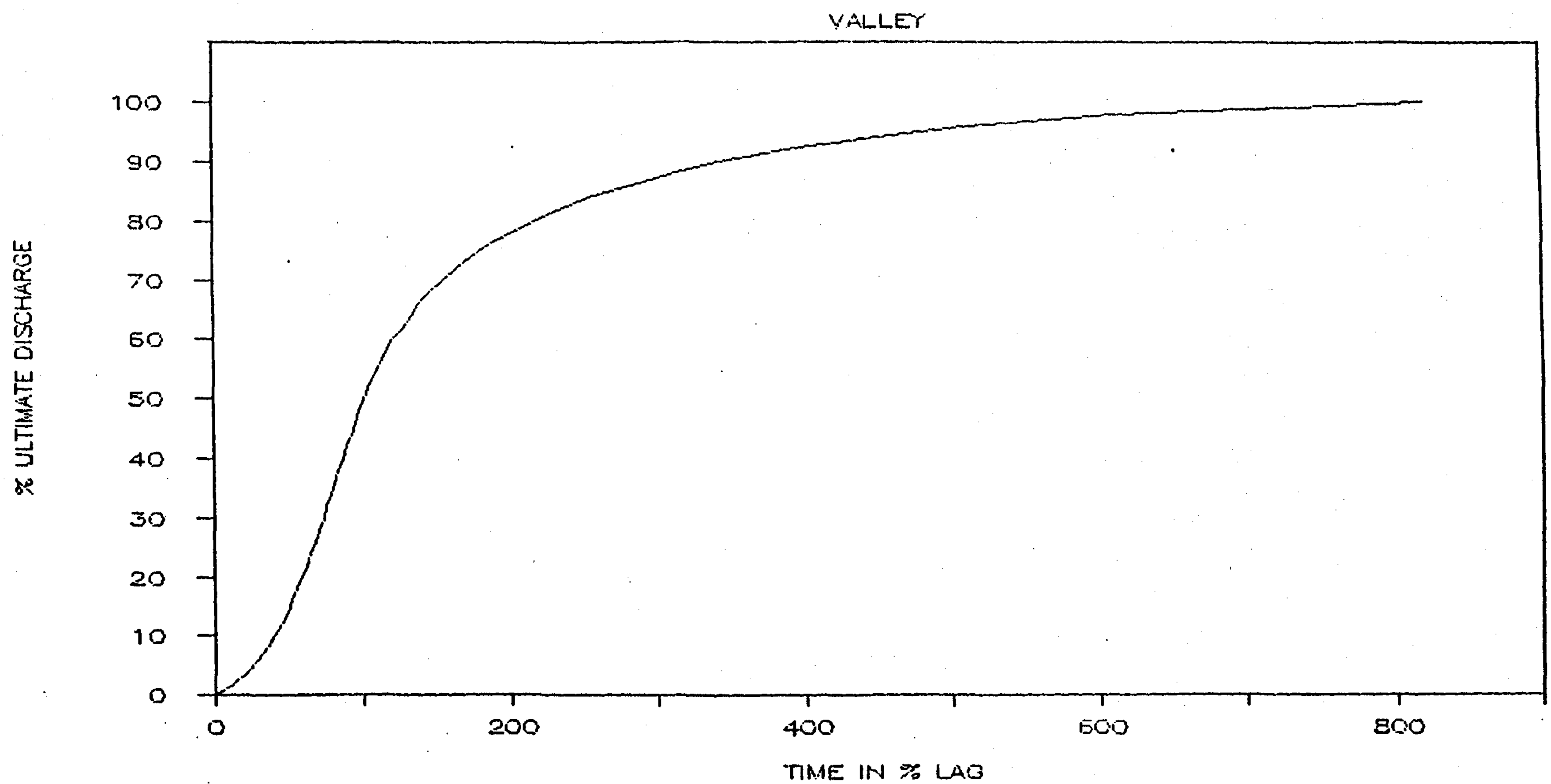
AVERAGE OF 9



#67 WHITEWATER RIVER, CALIFORNIA

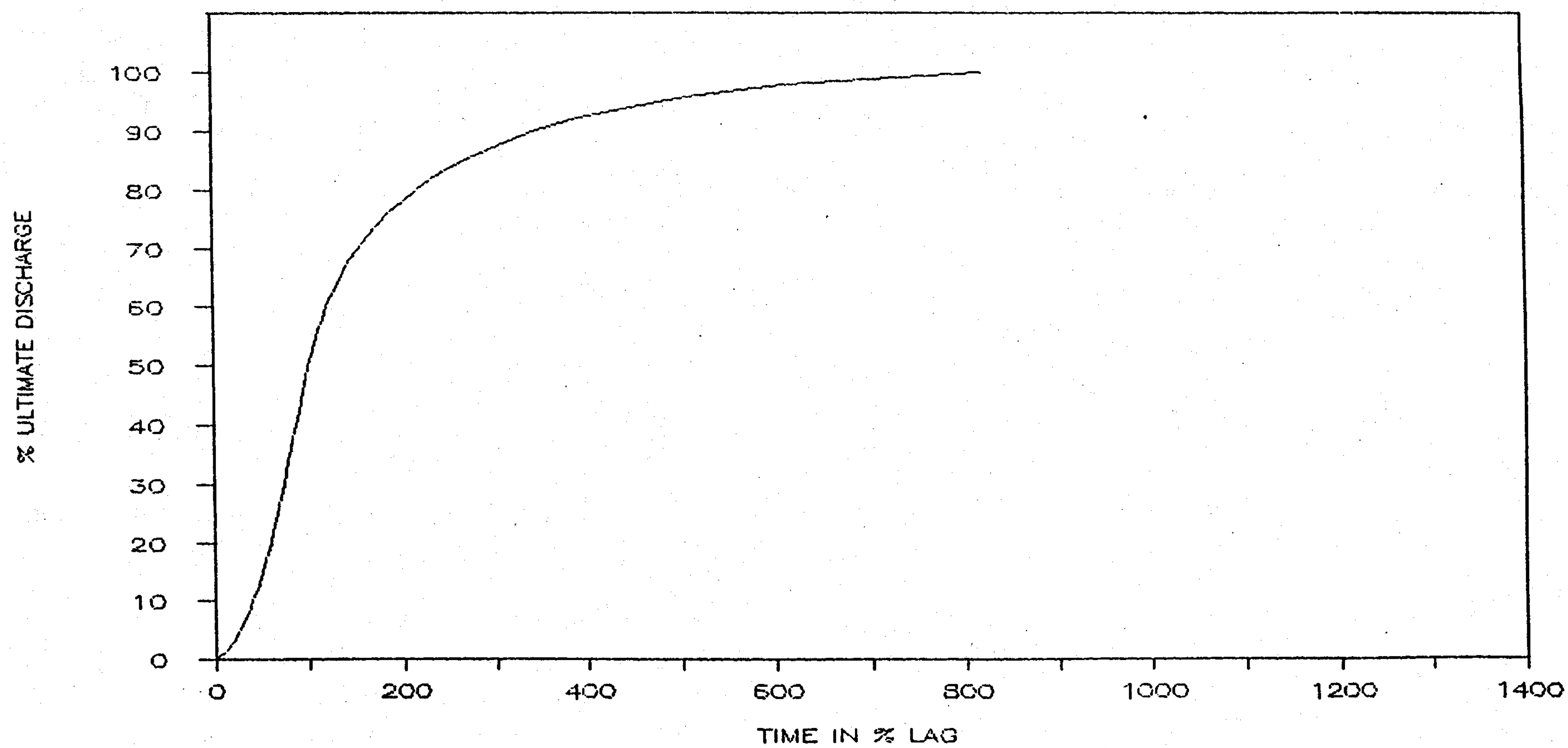


#68 LOS ANGELES COUNTY, CA



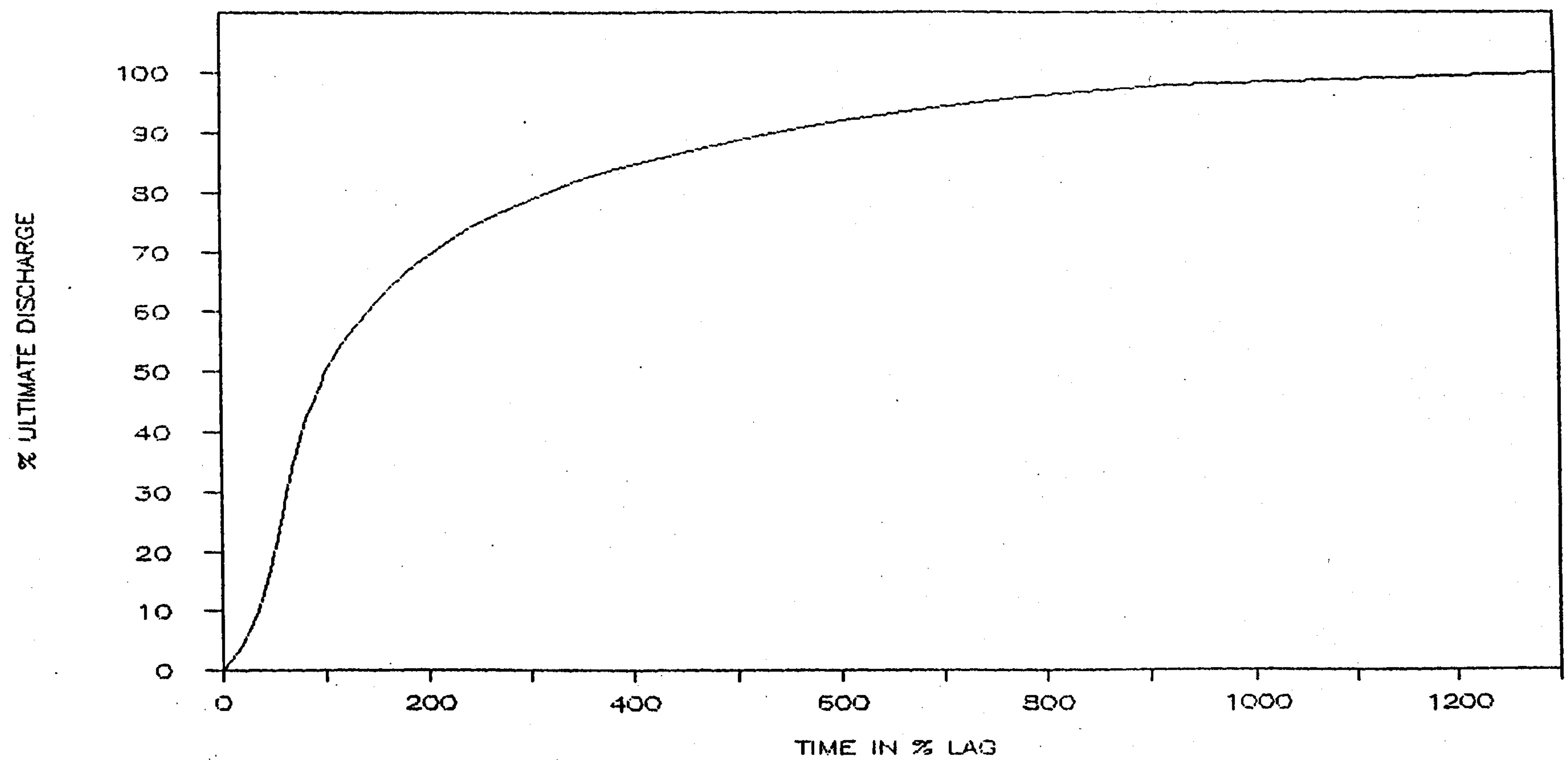
#68 LOS ANGELES COUNTY, CA

VALLEY

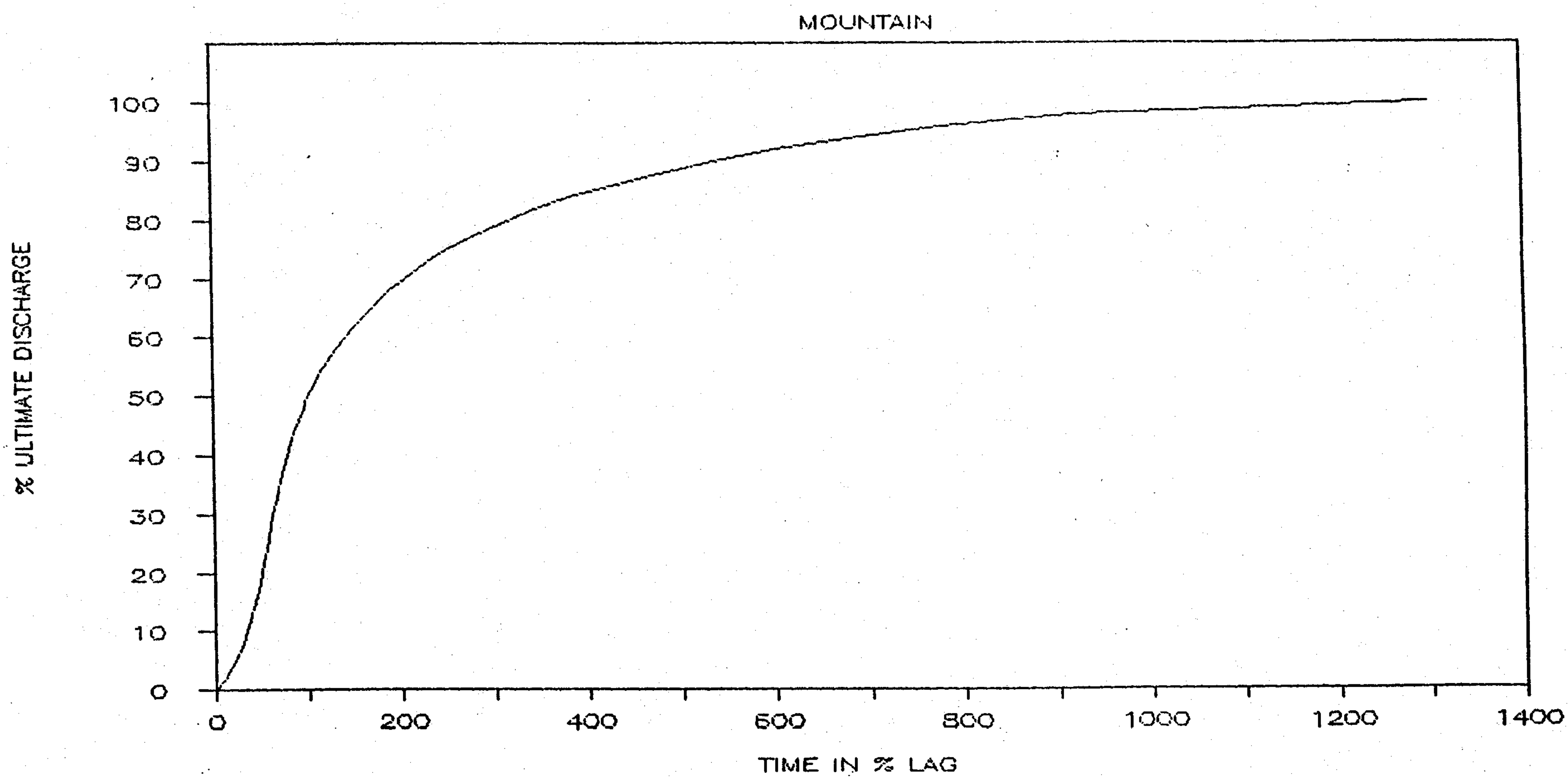


#69 LOS ANGELES COUNTY, CA

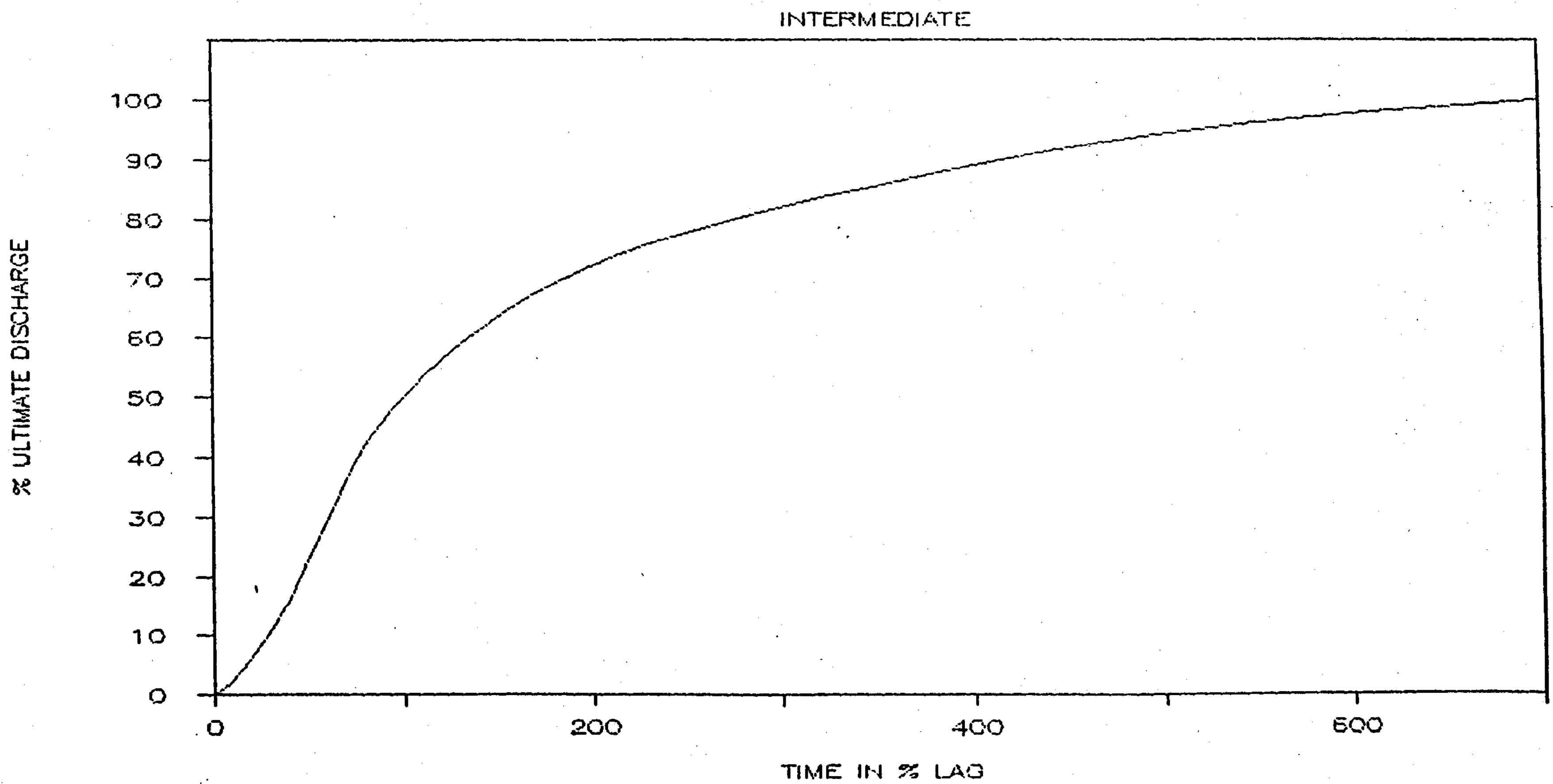
MOUNTAIN



#69 LOS ANGELES COUNTY, CA

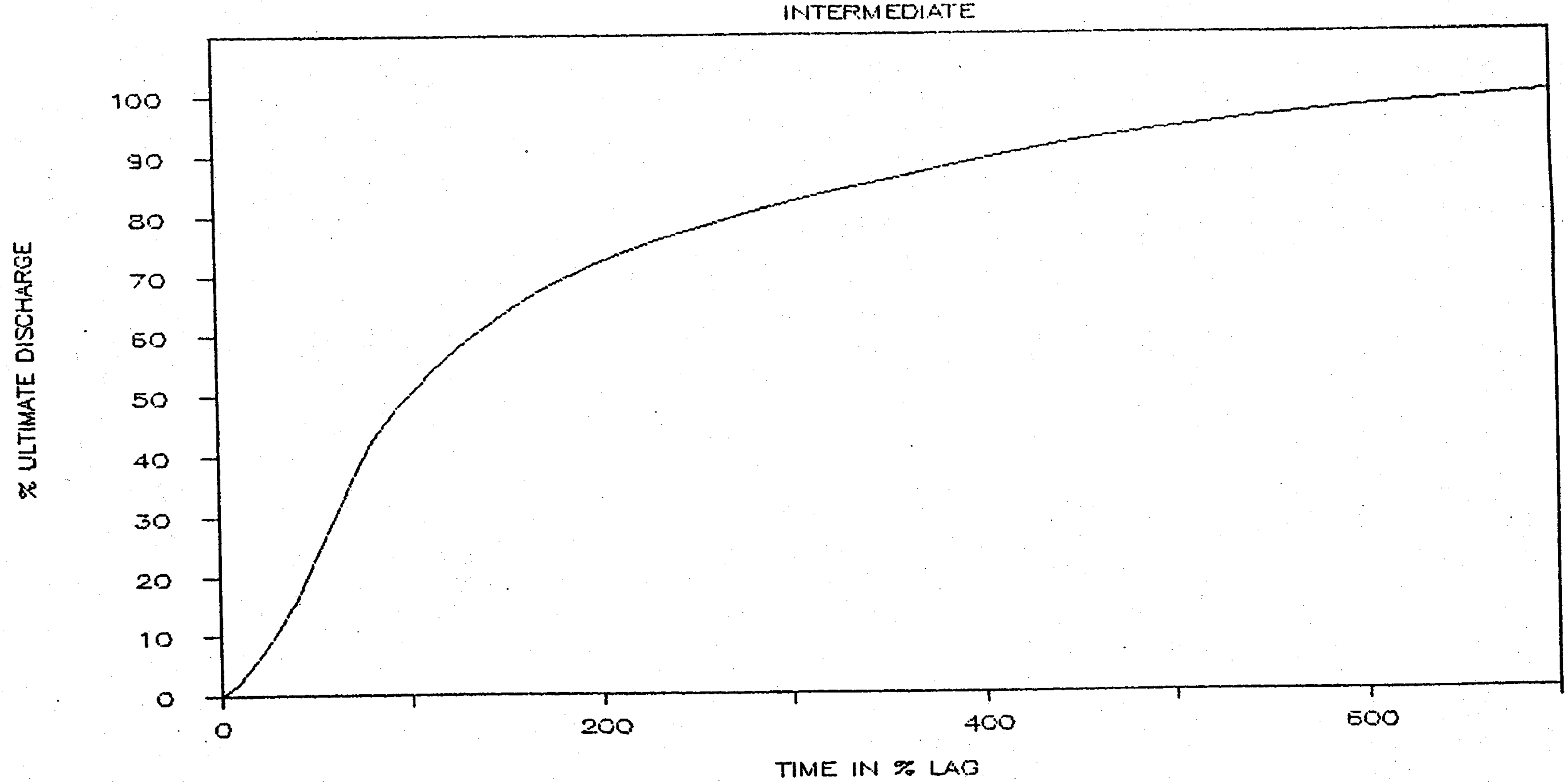


#70 LOS ANGELES COUNTY, CA

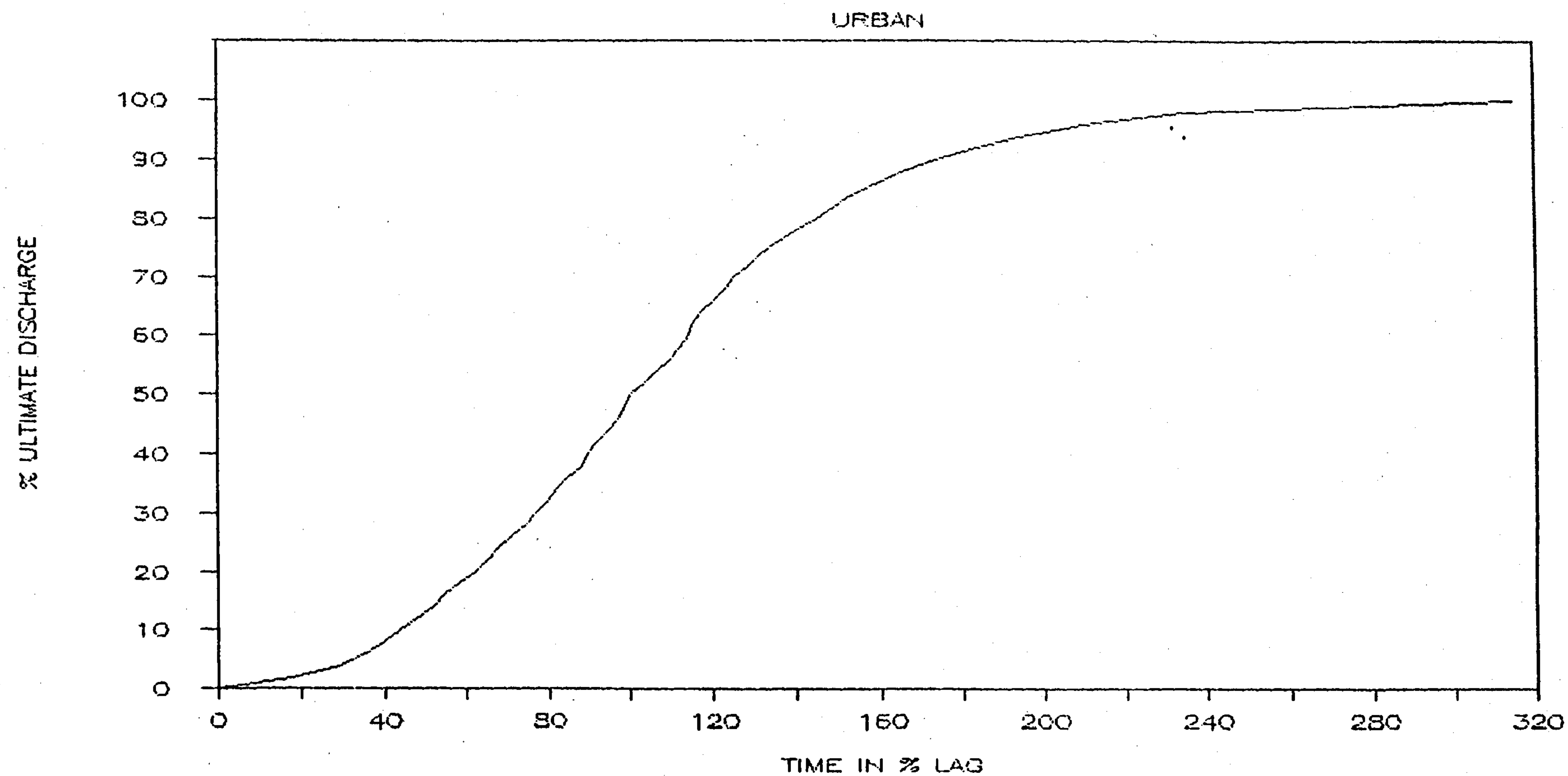


#70 LOS ANGELES COUNTY, CA

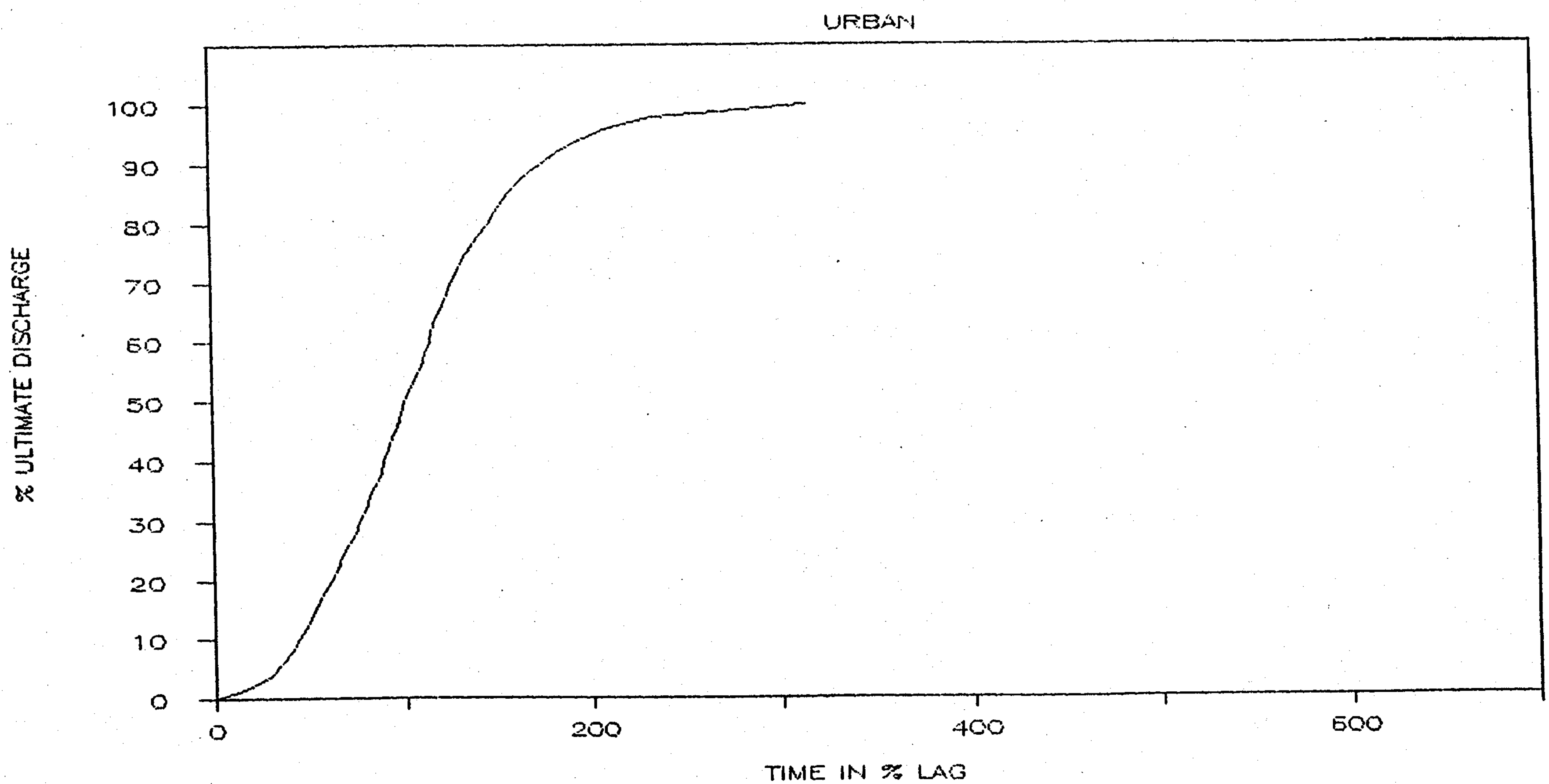
INTERMEDIATE



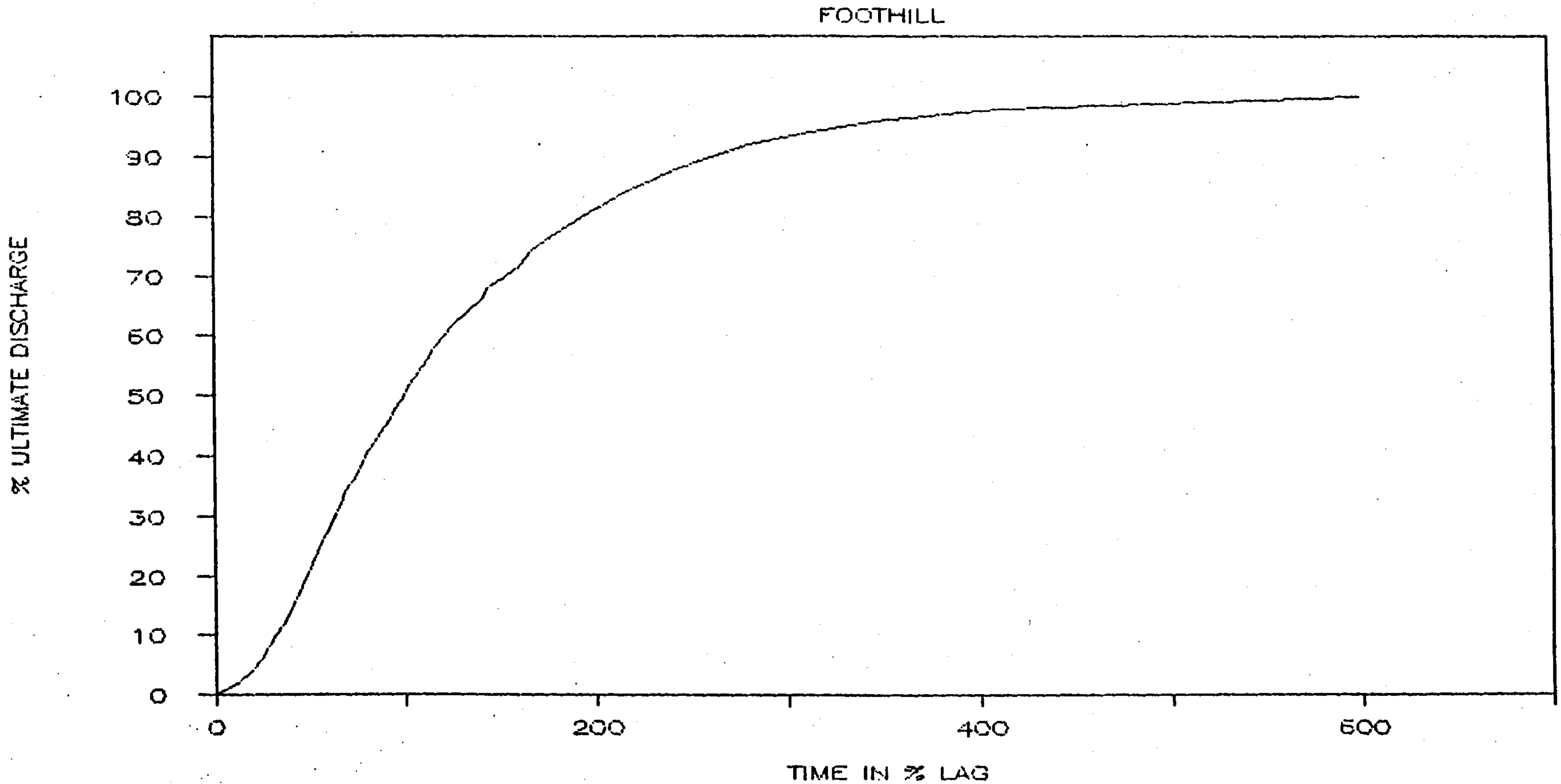
#71 LOS ANGELES COUNTY DRAINAGE AREA



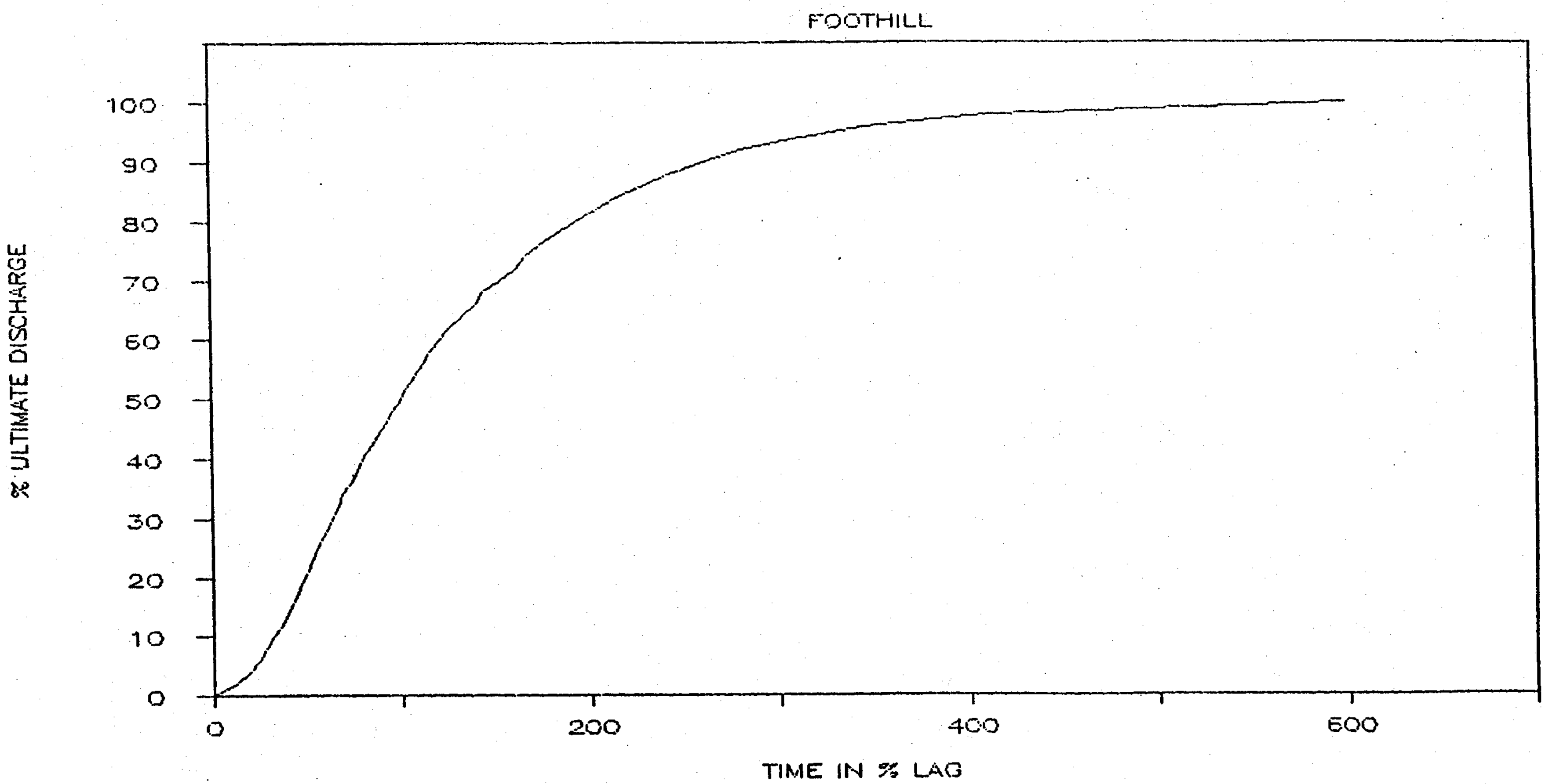
#71 LOS ANGELES COUNTY DRAINAGE AREA

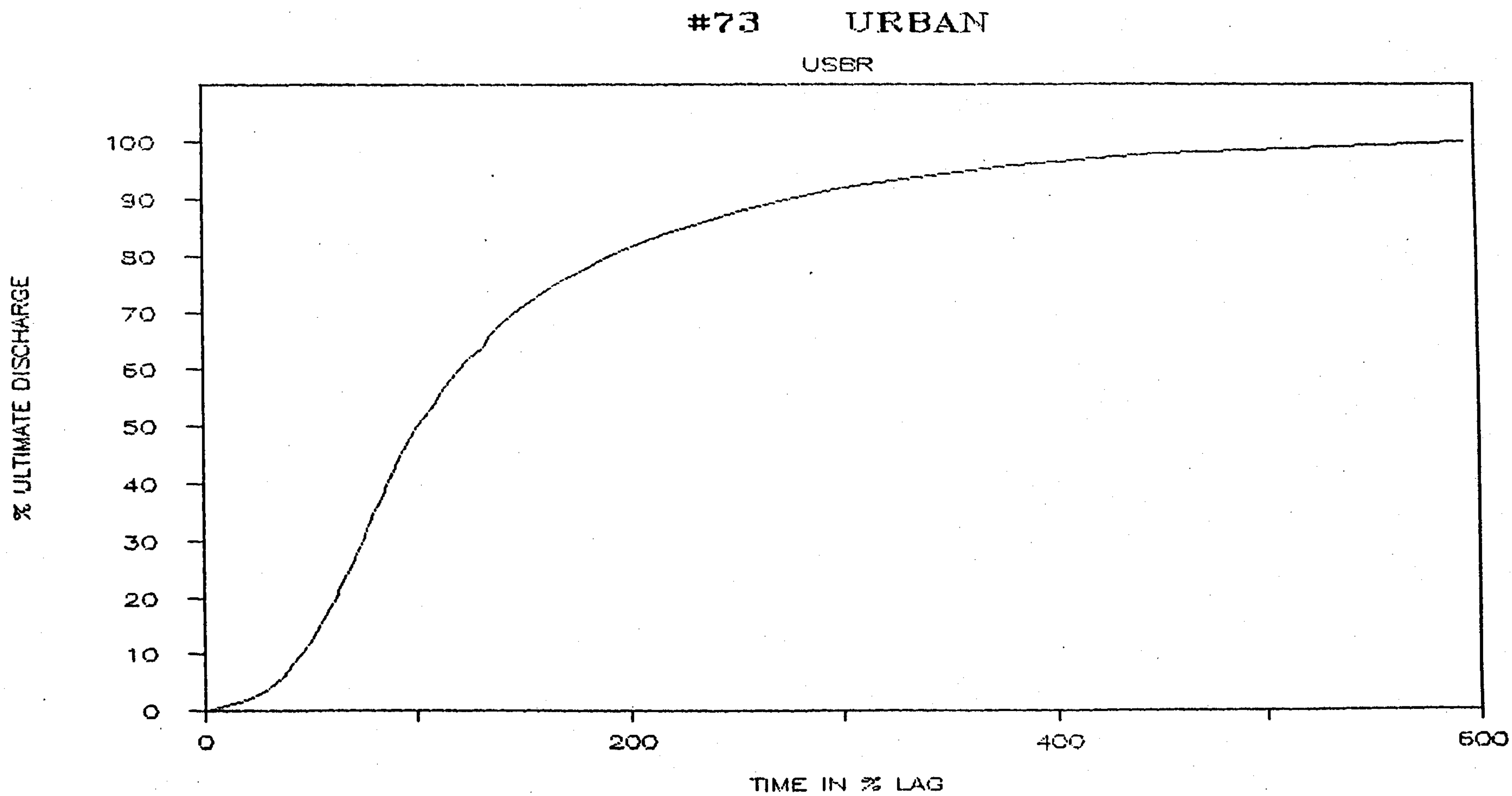


#72 LOS ANGELES COUNTY DRAINAGE AREA

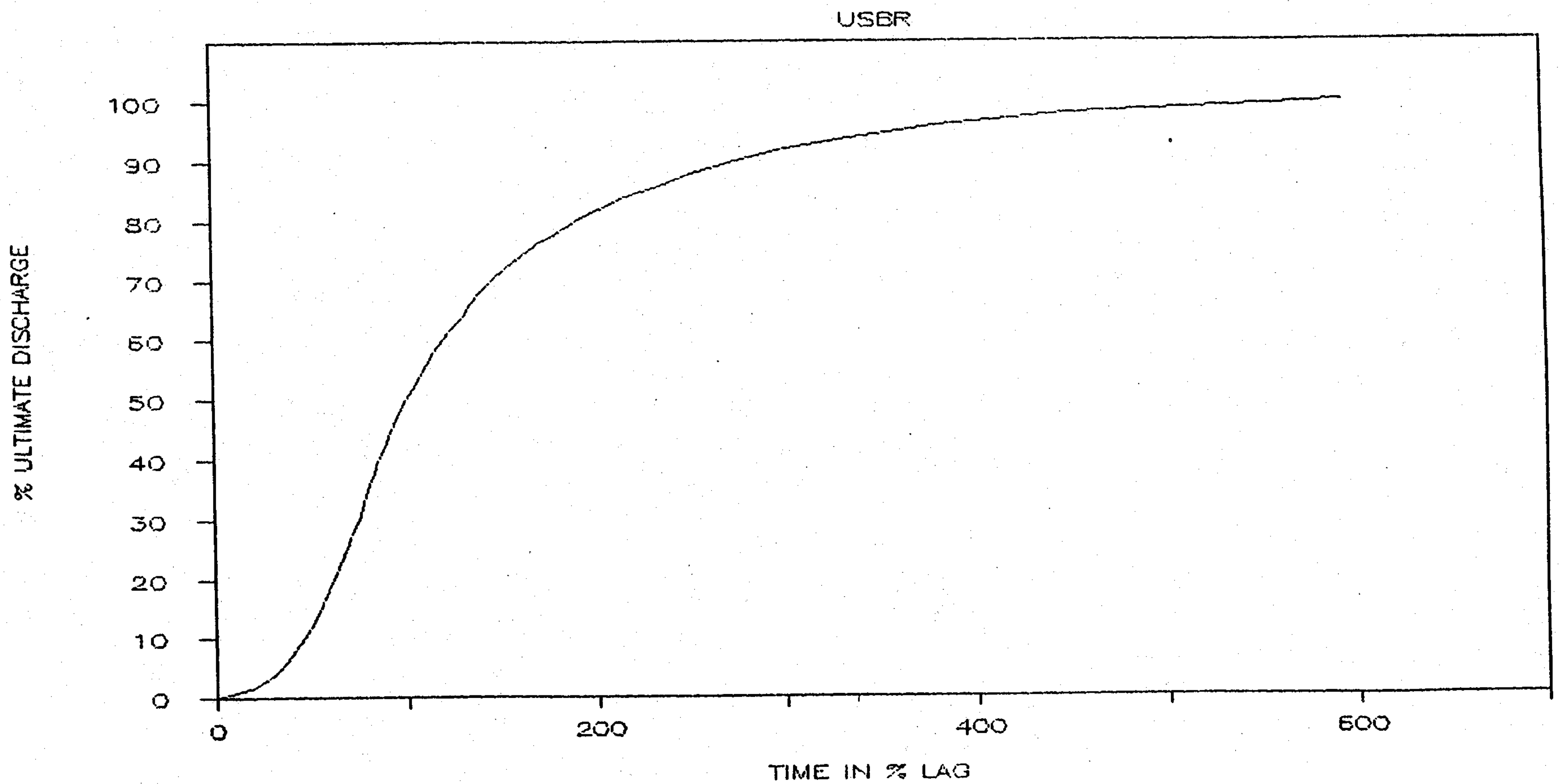


#72 LOS ANGELES COUNTY DRAINAGE AREA




#73 URBAN
USBR
% ULTIMATE DISCHARGE
100
90
80
70
60
50
40
30
20
10
0
0
200
400
600
TIME IN % LAG

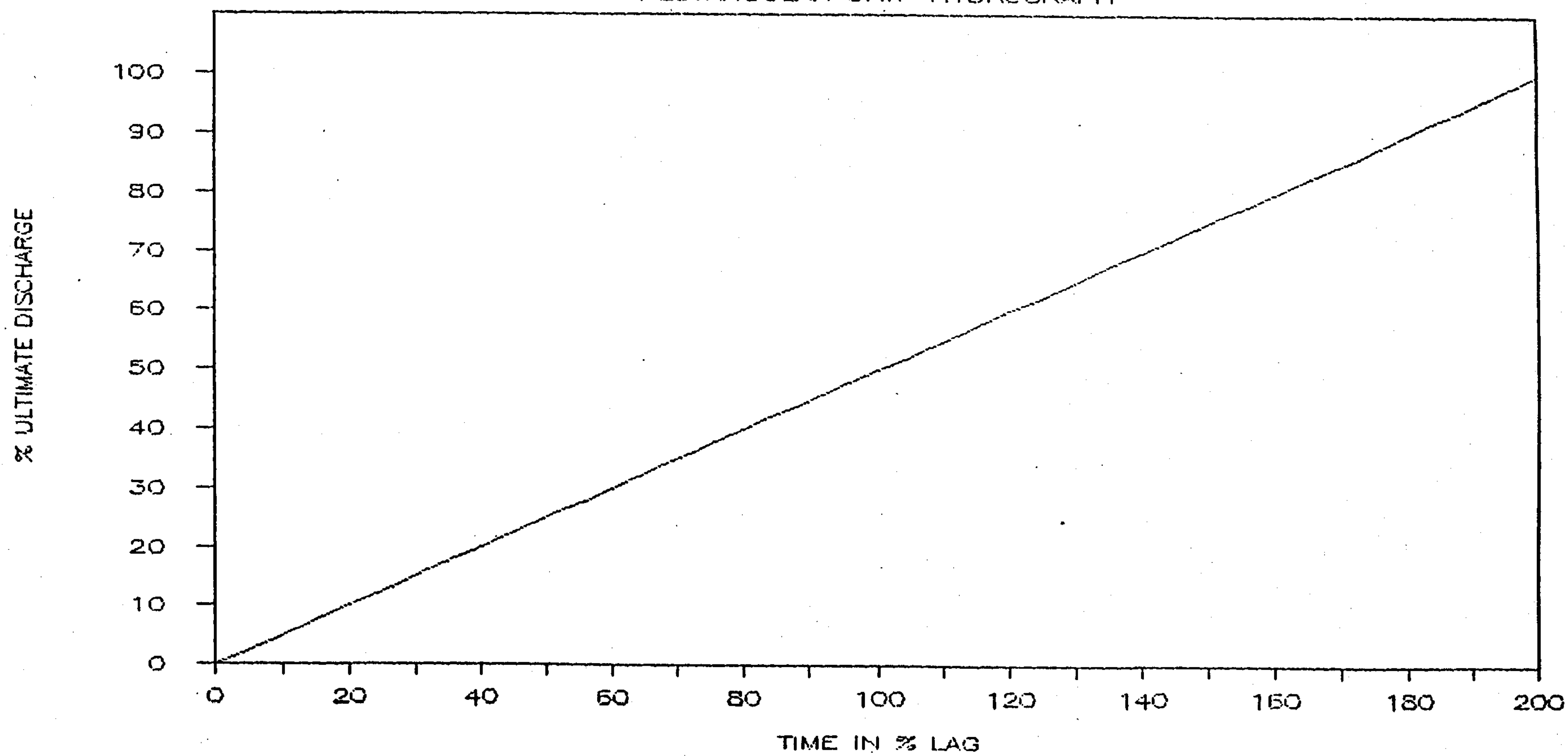
#73 URBAN



USBR
% ULTIMATE DISCHARGE
100
90
80
70
60
50
40
30
20
10
0
0
200
400
600
TIME IN % LAG

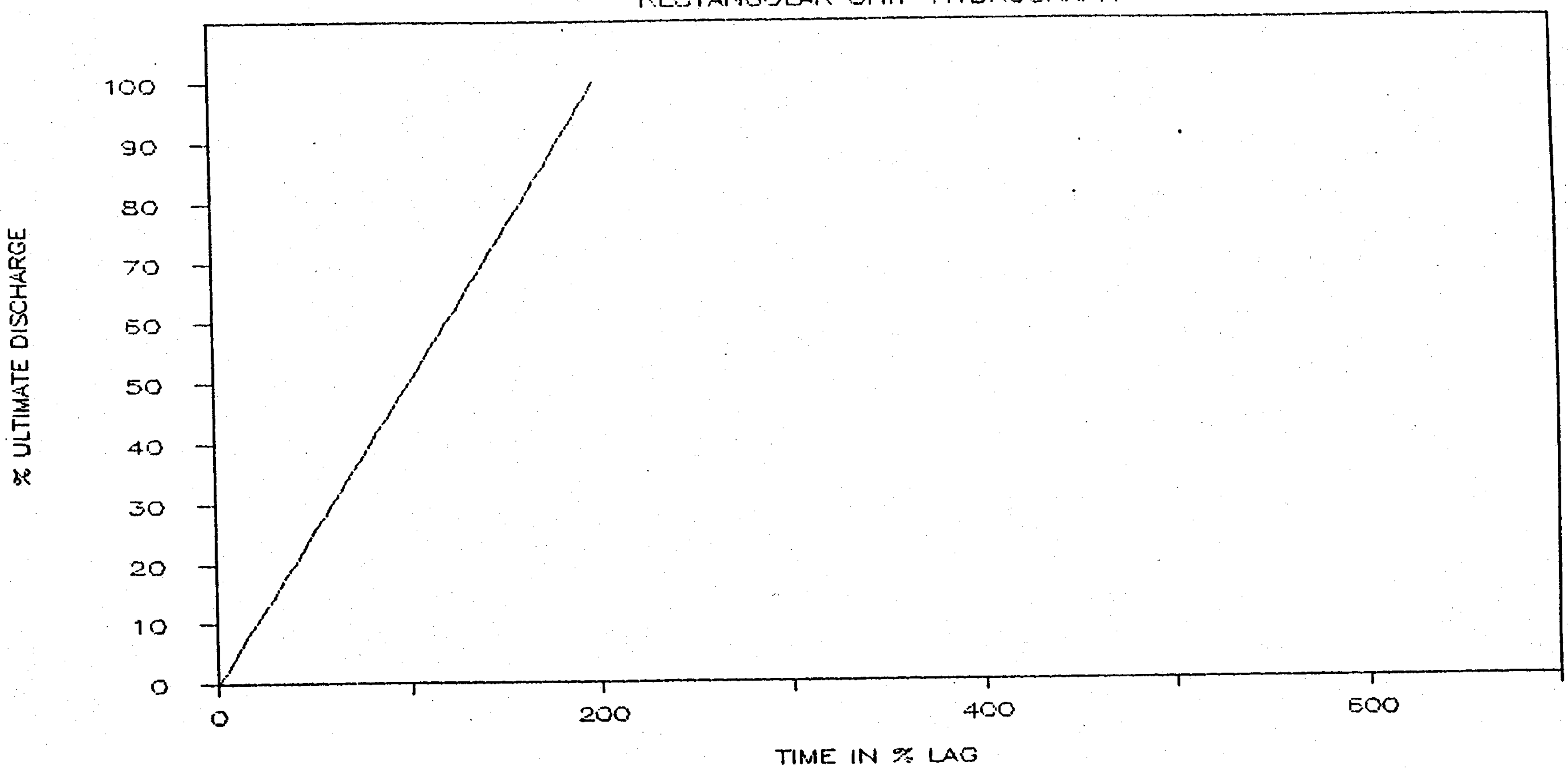
#74 OVERLAND FLOW

RECTANGULAR UNIT-HYDROGRAPH

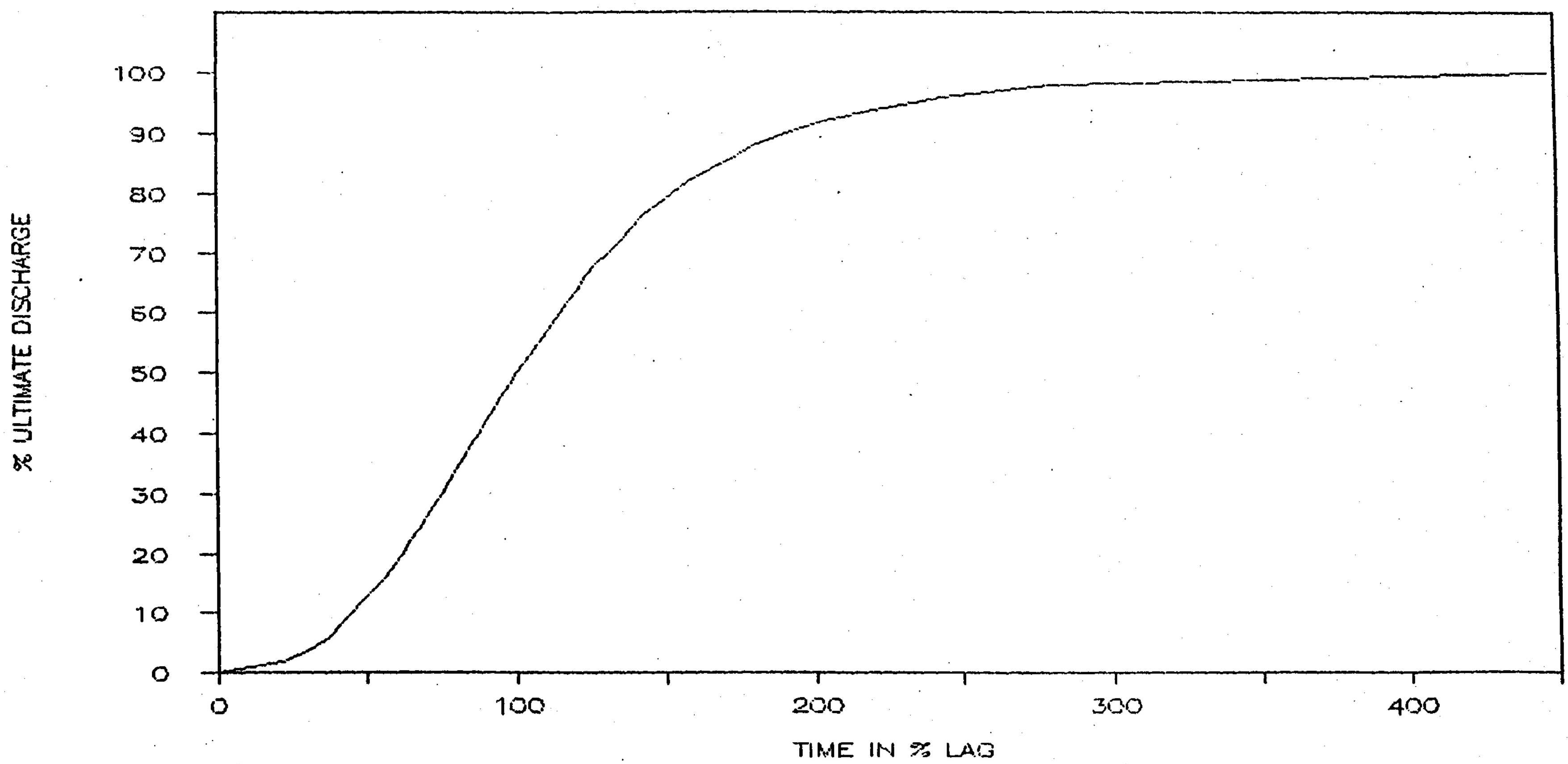


#74 OVERLAND FLOW

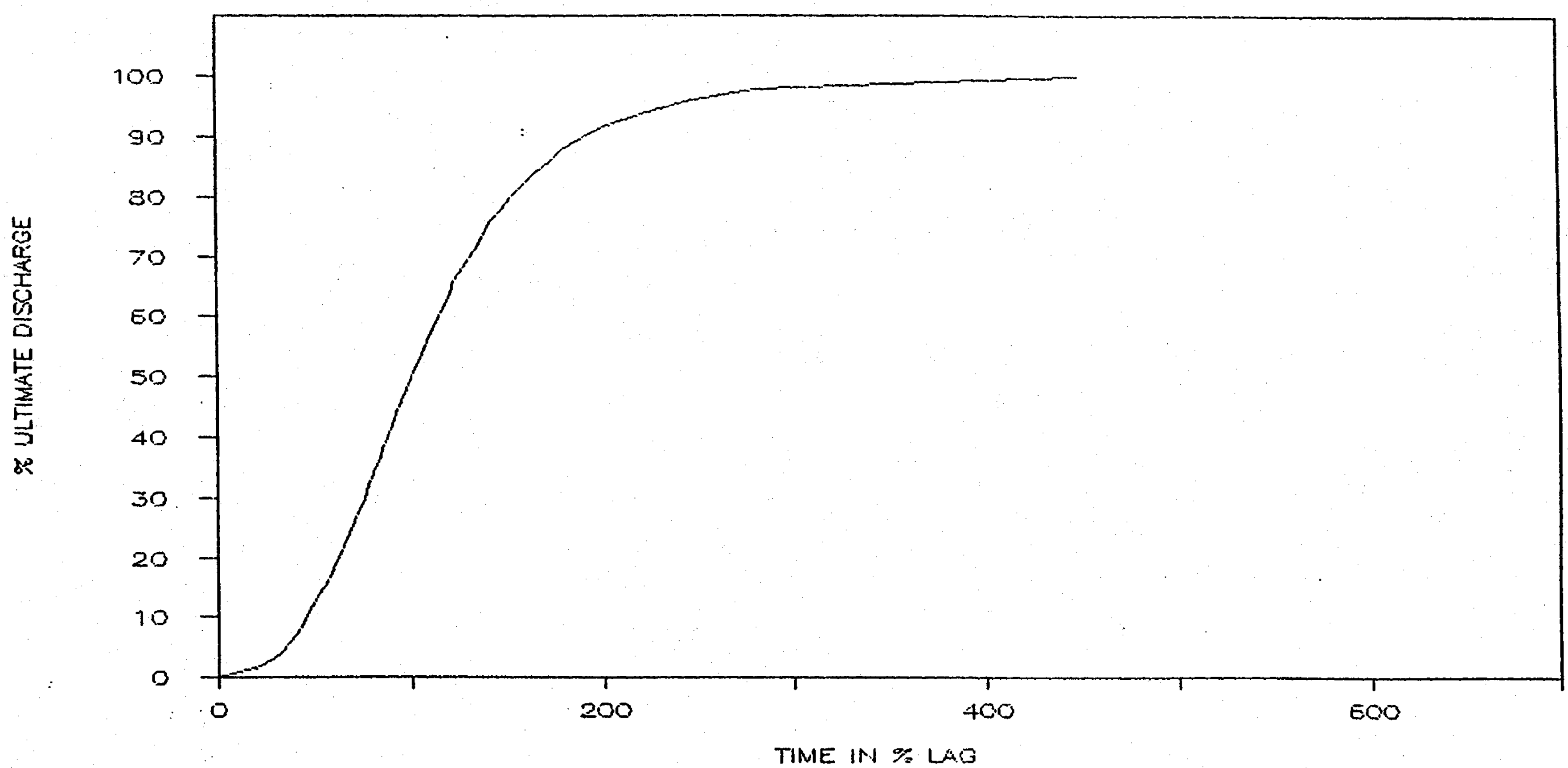
RECTANGULAR UNIT-HYDROGRAPH



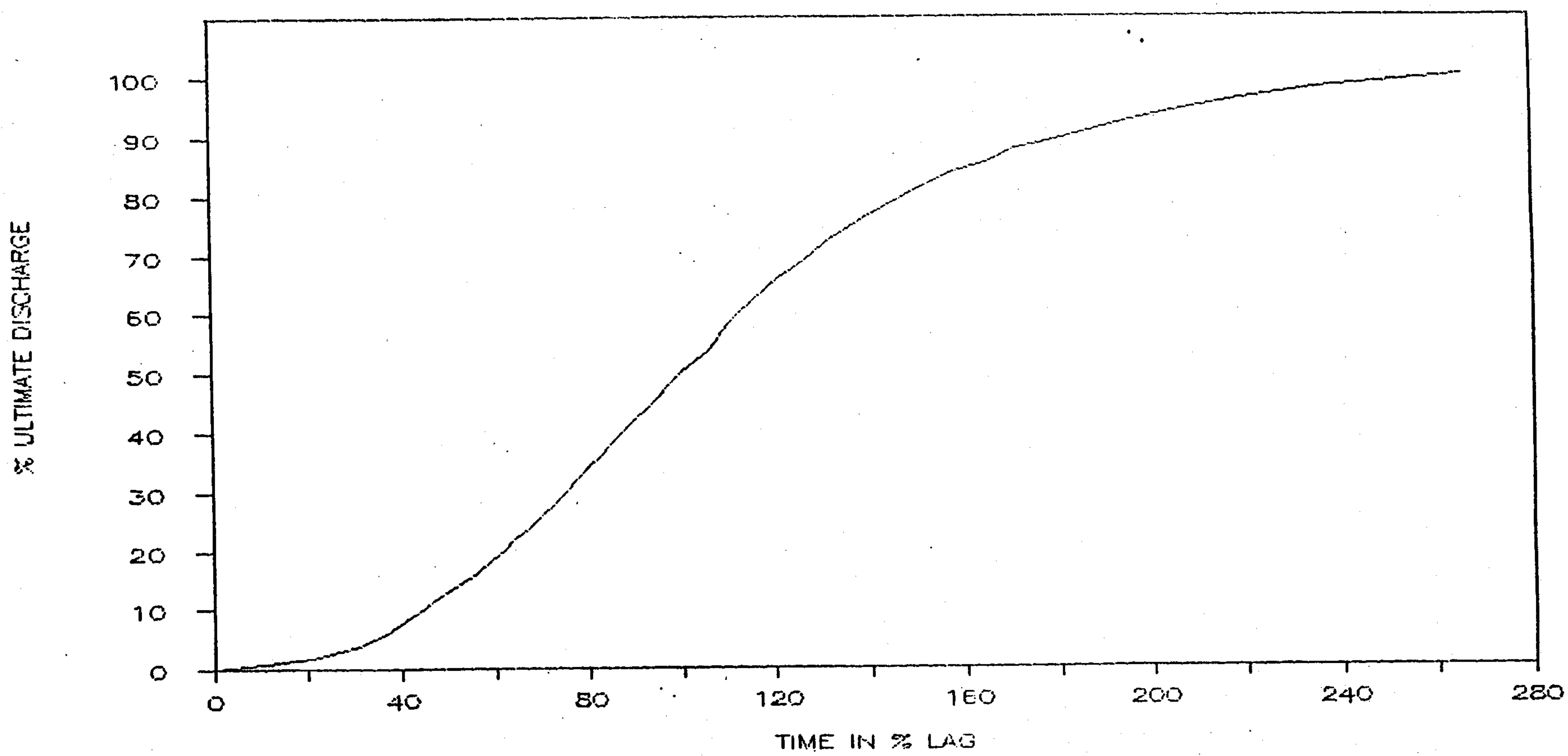
#75 SCS DIMENSIONLESS



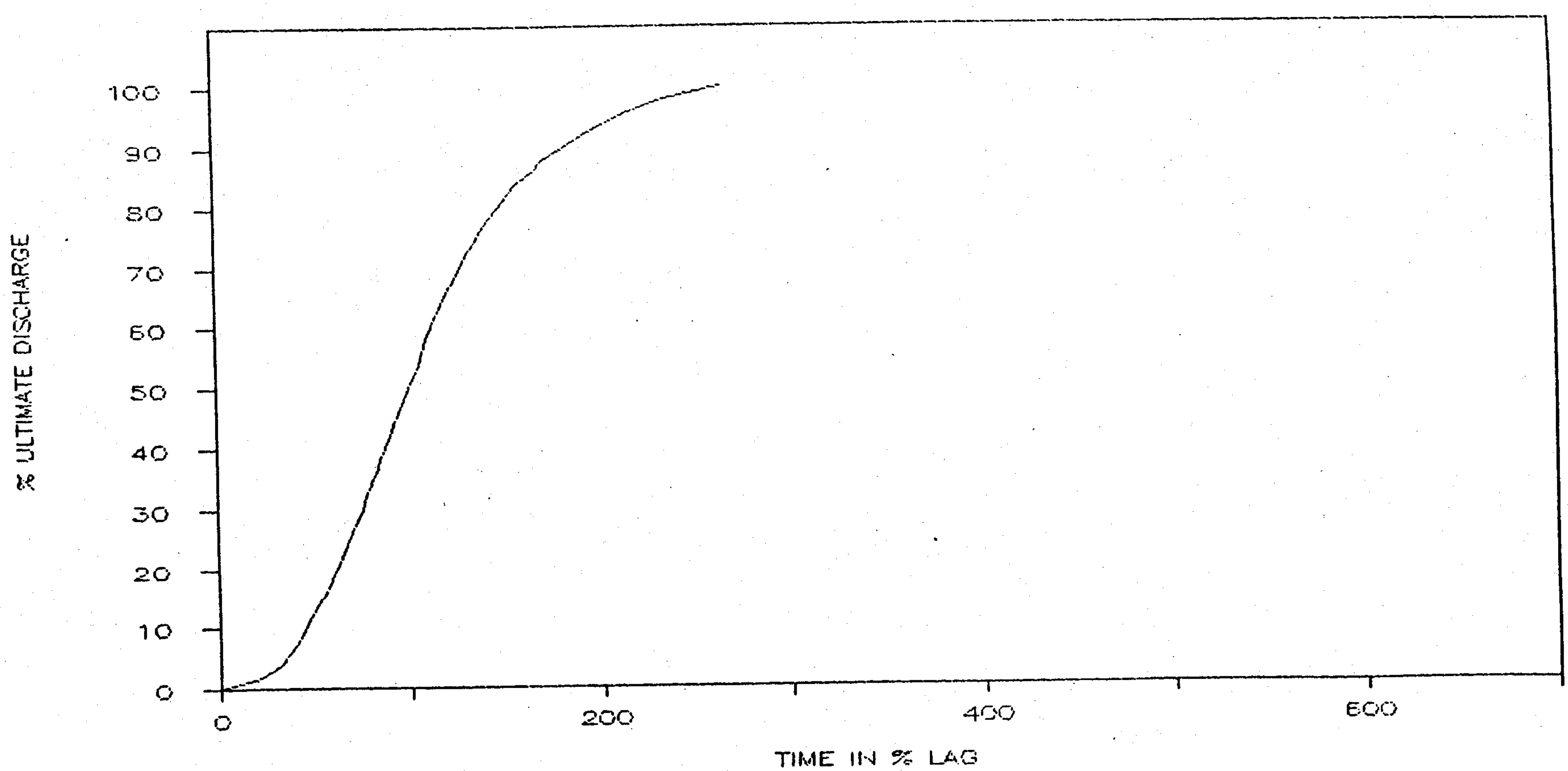
#75 SCS DIMENSIONLESS



#76 SCS TRIANGULAR



#76 SCS TRIANGULAR



APPENDIX B

Listings of Digitized S-Graphs

% ULTIMATE DISCHARGE	TIME IN % LAG (S-graph is identified by number) #1	#2	#3	#4	#5	#6	#7	#8
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	27.3	28.2	18.1	21.7	20.7	20.6	22.4	22.4
4	33.9	35.1	24.1	28.4	27.9	28.2	35.2	34.0
6	38.9	40.1	30.0	34.3	33.5	34.2	42.2	40.0
8	42.8	44.2	35.2	40.1	38.6	39.0	46.6	44.0
10	46.3	47.9	38.9	45.9	42.9	43.6	51.0	48.0
12	49.6	50.9	42.7	49.3	46.9	47.4	54.6	51.6
14	52.7	54.0	46.4	52.8	50.8	51.3	58.2	55.2
16	55.6	56.8	50.2	56.2	54.2	54.5	61.0	58.6
18	58.5	59.4	53.5	59.7	57.6	57.8	63.0	61.8
20	61.3	61.9	56.8	63.1	60.8	60.9	65.0	65.0
22	64.2	64.5	60.1	66.6	63.8	63.8	67.8	67.8
24	67.1	67.0	63.4	69.6	66.7	66.7	70.6	70.6
26	69.9	69.4	66.7	72.0	69.7	69.4	73.2	73.2
28	72.8	71.9	69.8	74.5	72.3	72.0	75.6	75.6
30	75.5	74.3	72.8	76.9	75.0	74.6	78.0	78.0
32	78.2	76.8	75.8	79.4	77.6	77.2	80.0	80.0
34	80.8	79.3	78.9	81.8	80.2	79.7	82.0	82.0
36	83.4	81.8	81.9	84.2	82.7	82.2	84.4	84.4
38	85.9	84.4	84.9	86.7	85.2	84.7	87.2	87.2
40	88.3	87.0	87.4	89.1	87.7	87.2	90.0	90.0
42	90.6	89.6	89.9	91.5	90.2	89.7	92.0	92.0
44	93.0	92.2	92.4	93.7	92.7	92.2	94.0	94.0
46	95.3	94.8	94.9	95.8	95.1	94.8	96.0	96.0
48	97.6	97.4	97.4	97.9	97.6	97.3	98.0	98.0
50	100.0	100.0	99.9	100.1	100.1	99.9	100.0	100.0
52	102.5	102.6	102.3	102.2	102.6	102.5	102.0	102.0
54	105.0	104.9	104.3	104.4	105.1	105.3	104.0	104.0
56	107.5	107.3	106.3	106.5	107.7	108.0	106.0	106.4
58	110.2	109.7	108.3	108.6	110.2	110.8	108.0	109.2
60	112.9	112.1	110.4	110.8	113.0	113.8	110.0	112.0
62	115.9	114.4	112.4	112.9	115.8	116.8	112.8	114.8
64	119.0	116.7	114.4	115.3	118.5	119.9	115.6	117.6
66	122.3	119.1	116.4	118.1	121.4	123.1	118.0	120.2
68	125.8	121.4	118.4	121.0	124.4	126.4	120.0	122.6
70	129.4	124.0	120.5	123.8	127.5	129.9	122.0	125.0
72	133.4	126.6	122.7	126.6	130.6	133.6	124.4	127.8
74	137.7	129.2	124.8	129.4	134.1	137.5	126.8	130.6
76	142.3	132.2	127.0	132.2	137.6	141.7	129.4	133.2
78	147.2	135.4	129.1	135.0	141.2	146.2	132.2	135.6
80	152.6	138.6	131.3	138.5	145.4	151.2	135.0	138.0
82	158.5	142.4	133.4	143.4	149.6	156.7	137.8	140.8
84	165.0	146.4	135.6	148.4	154.3	162.7	140.6	143.6
86	172.8	150.9	139.2	153.4	159.2	169.5	144.0	147.0
88	181.3	156.1	142.8	158.3	165.3	177.5	148.0	151.0
90	191.5	162.4	146.4	165.9	171.9	186.7	152.0	155.0
92	203.4	169.9	150.0	174.7	179.9	198.3	158.4	159.0
94	219.5	179.4	155.0	184.2	190.3	213.7	164.8	164.8
96	240.7	192.2	163.5	200.0	204.8	233.4	172.0	172.0
98	274.1	213.7	175.5	222.9	227.4	265.9	188.4	187.8
100	367.3	269.4	220.3	296.8	290.4	348.9	230.0	227.0

TIME IN % LAG
(S-graph is identified by number)

% ULTIMATE DISCHARGE	#9	#10	#11	#12	#13	#14	#15
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	22.4	21.6	21.6	10.2	22.7	15.5	22.0
4	34.0	33.6	33.6	19.7	29.5	22.8	30.9
6	40.0	40.6	40.0	23.2	36.3	28.1	38.5
8	44.0	45.8	44.0	26.7	41.4	33.2	43.6
10	48.0	51.0	48.0	30.2	44.5	38.3	48.7
12	51.6	53.8	50.4	33.7	47.7	43.3	53.8
14	55.2	56.6	52.8	37.2	50.8	48.3	57.5
16	58.6	59.4	55.4	40.4	53.9	53.3	60.7
18	61.8	62.2	58.2	43.3	57.0	58.3	63.9
20	65.0	65.0	61.0	46.2	60.1	62.6	67.1
22	67.8	67.8	63.8	49.2	62.6	66.8	70.3
24	70.6	70.6	66.6	52.1	65.2	70.9	73.5
26	73.2	73.2	69.2	55.1	67.7	73.8	75.6
28	75.6	75.6	71.6	58.0	70.2	76.7	77.8
30	78.0	78.0	74.0	61.4	72.7	79.6	79.9
32	80.0	80.0	76.4	64.9	75.2	82.5	82.1
34	82.0	82.0	78.8	68.3	77.7	84.6	84.2
36	84.4	84.4	81.2	71.8	80.3	86.6	86.3
38	87.2	87.2	83.6	75.2	83.1	88.7	88.5
40	90.0	90.0	86.0	78.9	85.9	90.7	90.6
42	92.0	92.0	88.8	83.0	88.7	92.8	92.6
44	94.0	94.0	91.6	87.2	91.5	94.7	94.5
46	96.0	96.0	94.4	91.3	94.4	96.5	96.3
48	98.0	98.0	97.2	95.4	97.2	98.2	98.2
50	100.0	100.0	100.0	100.0	100.0	100.0	100.0
52	102.0	102.0	102.0	104.8	103.6	101.7	101.9
54	104.0	104.0	104.0	109.6	107.1	103.5	103.7
56	106.4	106.2	106.8	114.5	110.7	105.2	105.6
58	109.2	108.6	110.4	120.0	114.3	106.9	107.4
60	112.0	111.0	114.0	125.7	117.9	108.7	109.3
62	114.8	113.4	118.0	131.5	121.8	110.4	111.3
64	117.6	115.8	122.0	137.6	126.4	112.2	113.6
66	120.2	118.0	126.2	144.3	131.0	113.9	115.8
68	122.6	120.0	130.6	150.9	135.6	115.7	118.1
70	125.0	122.0	135.0	158.2	140.3	117.4	120.4
72	127.8	124.4	139.8	166.3	146.2	119.4	122.6
74	130.6	126.8	144.6	174.4	152.1	121.3	124.9
76	133.2	129.4	149.8	183.8	157.9	123.3	127.1
78	135.6	132.2	155.4	193.2	165.0	125.3	129.8
80	138.0	135.0	161.0	204.2	172.7	127.2	133.3
82	140.8	137.8	169.4	215.8	180.5	129.2	136.8
84	143.6	140.6	177.8	229.2	190.0	131.8	140.3
86	147.0	144.0	187.2	244.3	199.5	134.5	143.8
88	151.0	148.0	197.6	261.3	211.9	137.2	147.6
90	155.0	152.0	208.0	281.9	225.6	139.9	153.9
92	159.0	156.8	222.4	306.6	242.1	143.4	160.3
94	164.8	162.2	243.4	337.3	264.0	147.7	167.6
96	172.8	169.0	273.0	379.2	293.3	152.0	179.1
98	191.0	186.4	325.0	449.2	340.0	160.5	196.7
100	235.0	232.0	425.0	637.6	460.0	188.2	238.8

% ULTIMATE DISCHARGE	TIME IN % LAG (S-graph is identified by number) #16	#17	#18	#19	#20	#21	#22
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	24.3	21.9	10.5	29.3	29.5	23.9	23.3
4	32.4	28.3	17.8	37.4	37.8	32.4	32.4
6	38.3	32.7	21.4	42.7	44.0	38.9	38.8
8	42.9	36.6	25.0	47.0	48.5	44.2	44.1
10	46.8	40.2	28.5	50.4	52.4	48.6	48.5
12	50.5	43.4	32.1	53.6	55.8	52.5	52.5
14	53.6	46.4	35.1	56.7	58.9	56.0	56.0
16	56.6	49.3	38.0	59.5	61.6	59.3	59.2
18	59.3	52.2	40.9	62.2	64.3	62.3	62.3
20	62.0	55.0	43.8	64.7	66.8	65.2	65.2
22	64.7	57.7	46.7	67.2	69.1	67.8	67.8
24	67.3	60.5	49.8	69.6	71.5	70.3	70.5
26	69.8	63.2	53.1	72.0	73.8	72.8	72.9
28	72.3	66.0	56.5	74.4	76.0	75.2	75.3
30	74.8	68.7	59.8	76.7	78.3	77.5	77.7
32	77.3	71.5	63.1	79.0	80.5	79.8	80.0
34	79.8	74.3	66.7	81.2	82.6	82.1	82.3
36	82.3	77.2	70.6	83.5	84.8	84.4	84.5
38	84.8	80.2	74.4	85.9	87.0	86.7	86.7
40	87.3	83.2	78.3	88.3	89.1	88.9	88.9
42	89.8	86.3	82.3	90.7	91.2	91.1	91.1
44	92.3	89.5	86.6	92.8	93.4	93.4	93.9
46	94.8	92.9	90.9	95.0	95.5	95.6	95.5
48	97.4	96.3	95.2	97.6	97.7	97.8	97.8
50	100.1	100.0	99.9	100.1	100.0	100.0	100.0
52	102.7	103.7	105.0	102.5	102.2	102.2	102.3
54	105.3	107.7	110.1	105.0	104.5	104.5	104.5
56	108.1	111.8	115.4	107.6	106.8	106.9	106.8
58	110.8	115.9	121.0	110.1	109.1	109.3	109.1
60	113.7	120.4	126.7	112.7	111.6	111.7	111.5
62	116.6	125.1	132.8	115.3	114.1	114.1	114.0
64	119.6	130.0	139.2	118.0	116.7	116.6	116.4
66	122.7	135.3	145.8	120.7	119.5	119.3	119.1
68	125.9	140.9	153.3	123.6	122.2	122.1	121.7
70	129.2	146.8	160.8	126.6	125.2	125.0	124.6
72	132.8	153.2	169.2	129.8	128.3	128.0	127.5
74	136.5	159.9	177.7	133.1	131.5	131.3	130.8
76	140.5	167.3	187.5	136.6	134.7	134.8	134.2
78	144.8	175.1	197.7	140.5	137.9	138.7	137.9
80	149.4	183.9	208.9	144.8	141.3	143.0	141.8
82	154.6	193.2	221.1	149.6	144.7	147.7	146.4
84	160.3	203.7	234.9	154.8	148.2	152.7	151.7
86	166.7	215.9	250.8	160.6	151.8	158.1	157.4
88	174.2	229.3	268.9	167.5	156.1	163.6	163.3
90	182.7	245.5	289.6	175.6	160.6	169.2	169.4
92	193.3	265.8	315.7	185.2	165.9	175.7	175.8
94	206.5	290.2	348.1	197.6	172.6	182.6	182.9
96	225.4	324.0	393.0	214.4	181.2	191.5	191.5
98	254.1	379.8	463.0	240.8	195.7	203.0	203.8
100	336.7	527.0	662.2	316.4	232.0	243.5	237.3

% ULTIMATE DISCHARGE	TIME IN % LAG (S-graph is identified by number) #23	#24	#25	#26	#27	#28
0	0.0	0.0	0.0	0	0	0
2	26.0	36.0	15.0	20	35	9
4	34.0	50.0	25.0	30	45	15
6	40.0	58.0	33.0	38	52	22
8	46.0	64.0	37.0	44	63	29
10	51.0	67.0	41.0	48	67	34
12	55.0	70.0	45.0	52	70	39
14	58.0	72.0	49.0	56	73	44
16	61.0	74.0	53.0	60	77	48
18	64.0	75.5	56.0	63	80	52
20	66.5	77.0	59.0	65	82	57
22	69.0	79.0	62.0	69	84	61
24	72.0	81.0	65.0	72	86	64
26	74.5	83.0	68.0	75	88	67
28	77.0	84.5	71.0	77	89	70
30	80.0	86.0	74.0	80	90	73
32	82.0	87.5	77.0	82	91	77
34	84.0	89.0	80.0	85	92	80
36	86.0	90.5	82.5	87	93	82
38	88.0	92.0	85.0	89	94	85
40	90.0	93.5	87.5	91	95	87
42	92.0	95.0	90.0	93	96	90
44	94.0	96.0	92.5	95	97	92
46	96.0	98.0	95.0	97	98	95
48	98.0	99.0	97.5	99	99	97
50	100.0	100.0	100.0	100	100	100
52	102.0	102.0	102.5	102	102	102
54	104.0	104.0	105.0	105	104	103
56	105.5	106.0	107.5	107	106	105
58	107.5	108.0	110.0	110	108	107
60	109.5	110.0	113.0	113	110	110
62	111.5	112.0	117.0	117	113	113
64	113.5	114.0	121.0	121	116	116
66	116.0	116.5	126.0	125	121	119
68	118.5	119.0	131.0	129	127	123
70	120.5	121.0	137.0	134	134	126
72	123.0	124.0	144.0	140	140	132
74	126.0	127.0	152.0	147	147	138
76	128.5	131.0	160.0	155	155	145
78	132.0	135.0	170.0	164	164	152
80	135.0	140.0	183.0	174	172	160
82	138.0	145.0	197.0	185	181	171
84	143.0	151.0	212.0	199	193	185
86	150.0	158.0	236.0	215	205	201
88	157.0	166.0	255.0	235	221	225
90	164.0	176.0	280.0	265	242	263
92	176.0	187.0	315.0	298	273	310
94	188.0	202.0	360.0	351	310	380
96	210.0	225.0	430.0	407	355	490
98	242.0	264.0	630.0	590	440	650
100	350.0	412.0	1050.0	860	625	1050

% ULTIMATE DISCHARGE	TIME IN % LAG (S-graph is identified by number) #29	#30	#31	#32	#33	#34
0	0	0	0	0.0	0	0
2	11	6	5	32.0	10	20
4	20	16	12	53.0	18	30
6	27	21	19	65.0	24	37
8	34	28	22	70.0	30	43
10	39	33	26	73.0	35	47
12	43	40	28	75.0	40	51
14	47	46	34	76.0	44	55
16	51	51	39	77.0	48	58
18	54	56	41	77.5	52	61
20	57	59	44	78.0	55	64
22	59	61	46	79.0	58	66
24	61	63	48	80.0	61	68
26	63	66	52	81.0	64	71
28	65	68	56	81.5	67	74
30	67	73	59	82.0	70	76
32	69	74	62	83.0	73	80
34	71	75	65	84.0	76	83
36	74	77	68	85.0	79	85
38	77	79	72	86.0	82	87
40	80	80	75	88.0	85	90
42	84	84	80	90.0	88	92
44	88	88	82	92.5	91	94
46	92	92	87	95.0	94	96
48	96	96	94	97.5	97	98
50	100	100	100	100.0	100	100
52	105	105	110	104.0	103	102
54	110	110	116	108.0	106	104
56	115	118	126	112.0	110	107
58	120	124	136	116.0	114	111
60	126	135	148	120.0	118	116
62	133	143	158	125.0	122	121
64	140	155	170	131.0	126	126
66	147	168	182	137.0	130	131
68	155	180	199	145.0	135	137
70	162	200	216	155.0	140	143
72	170	210	234	165.0	146	151
74	179	230	252	177.0	152	160
76	188	255	287	190.0	158	171
78	198	280	300	205.0	165	183
80	209	300	325	220.0	172	196
82	221	335	360	235.0	181	210
84	234	370	385	252.0	190	227
86	248	410	430	270.0	200	248
88	264	460	470	290.0	212	270
90	282	540	520	310.0	226	300
92	302	610	580	330.0	244	335
94	324	700	640	355.0	266	375
96	350	800	720	385.0	296	430
98	388	1000	860	425.0	338	540
100	469	1300	1160	480.0	450	750

% ULTIMATE DISCHARGE	TIME IN % LAG (S-graph is identified by number) #35	#36	#37	#38	#39	#40
0	0	0.0	0.0	0.0	0	0
2	10	22.0	32.0	6.0	10	22
4	17	35.0	39.0	16.0	18	35
6	22	44.0	44.0	21.0	22	42
8	27	50.0	48.0	25.0	26	50
10	30	55.0	52.0	30.0	30	56
12	34	59.5	55.0	33.0	34	60
14	38	63.5	58.0	38.0	38	63
16	41	67.0	61.0	40.0	42	66
18	43	70.0	63.5	42.0	46	69
20	45	72.0	66.0	45.0	50	72
22	48	75.0	68.0	46.0	53	74
24	50	77.0	71.0	48.0	55	76
26	53	79.0	74.0	52.0	57	78
28	56	80.5	76.0	56.0	59	80
30	59	82.0	78.0	59.0	61	82
32	62	83.5	80.0	62.0	64	84
34	65	85.0	82.0	65.0	67	86
36	68	86.5	84.0	70.0	70	87
38	72	88.0	86.0	73.0	73	88
40	76	90.0	88.0	76.0	76	90
42	80	92.0	90.0	79.0	80	92
44	85	94.0	92.5	83.0	85	94
46	90	96.0	95.0	87.0	90	96
48	95	98.0	97.5	94.0	95	98
50	100	100.0	100.0	100.0	100	100
52	105	102.5	102.5	107.0	108	103
54	110	105.0	105.0	114.0	116	107
56	115	108.0	107.5	124.0	124	110
58	120	112.0	110.0	130.0	132	114
60	126	116.0	112.5	140.0	140	118
62	132	120.0	115.0	150.0	150	122
64	138	124.0	117.5	160.0	162	125
66	144	130.0	120.0	172.0	175	130
68	150	136.0	124.0	184.0	188	135
70	160	142.0	128.0	200.0	200	140
72	170	152.0	132.0	215.0	214	146
74	182	162.0	136.0	230.0	230	152
76	195	174.0	141.0	255.0	250	160
78	210	186.0	146.0	280.0	270	170
80	227	202.0	152.0	300.0	300	180
82	248	218.0	160.0	340.0	330	190
84	272	238.0	170.0	380.0	370	200
86	300	260.0	182.0	430.0	420	212
88	330	288.0	195.0	480.0	480	228
90	370	320.0	212.0	560.0	550	242
92	415	360.0	234.0	640.0	620	260
94	460	410.0	260.0	720.0	700	280
96	530	470.0	295.0	860.0	820	320
98	625	590.0	360.0	1000.0	1000	380
100	785	840.0	500.0	1360.0	1400	560

% ULTIMATE DISCHARGE	TIME IN % LAG (S-graph is identified by number)					
	#41	#42	#43	#44	#45	#46
0	0	0.0	0	0	0	0.0
2	13	12.5	5	12	6	14.0
4	23	18.0	12	15	16	23.0
6	31	23.0	18	21	21	30.0
8	37	27.0	22	26	24	35.0
10	43	29.0	28	30	26	40.0
12	48	32.5	32	33	28	45.0
14	53	35.0	36	35	29	50.0
16	57	37.5	40	37	30	53.0
18	61	41.0	42	40	31	57.0
20	64	43.0	44	44	32	60.0
22	67	47.0	48	47	34	63.0
24	71	49.5	52	50	36	67.0
26	74	52.5	56	55	38	70.0
28	77	56.0	58	58	40	72.0
30	80	59.0	60	62	42	75.0
32	82	62.5	63	65	46	77.0
34	84	67.0	66	68	50	80.0
36	86	70.0	68	71	56	82.0
38	88	74.0	73	74	60	85.0
40	90	78.0	77	78	68	88.0
42	92	82.5	81	82	74	90.0
44	94	87.0	83	86	80	92.5
46	96	92.0	91	90	87	95.0
48	98	96.0	95	95	93	97.5
50	100	100.0	100	100	100	100.0
52	103	105.0	108	106	107	102.0
54	105	110.0	117	112	114	105.0
56	109	115.0	122	120	124	108.0
58	113	121.0	132	130	132	112.0
60	117	127.0	140	142	140	117.0
62	120	133.0	150	152	150	123.0
64	125	139.0	160	162	160	132.0
66	129	147.0	170	173	172	138.0
68	134	153.0	180	185	184	145.0
70	139	161.0	192	200	200	155.0
72	144	168.0	204	213	210	164.0
74	150	178.0	220	228	225	174.0
76	157	187.5	240	245	240	186.0
78	164	198.0	255	263	260	200.0
80	171	210.0	275	282	275	213.0
82	181	223.0	300	301	295	230.0
84	190	237.5	325	325	320	247.0
86	206	252.0	350	350	340	268.0
88	219	270.0	380	380	370	295.0
90	237	291.0	420	415	400	325.0
92	258	317.0	460	458	450	355.0
94	290	350.0	520	505	490	405.0
96	334	395.0	600	565	560	475.0
98	420	470.0	700	650	640	580.0
100	600	658.5	870	825	860	800.0

% ULTIMATE DISCHARGE	TIME IN % LAG (S-graph is identified by number) #47	#48	#49	#50	#51	#52
0	0.0	0.0	0	0	0	0
2	20.0	4.0	10	12	22	17
4	30.0	7.0	15	20	32	21
6	38.0	10.0	18	26	40	24
8	43.0	12.0	22	32	43	26
10	46.0	15.0	25	36	48	28
12	50.0	17.0	29	40	52	32
14	51.0	18.5	32	44	55	34
16	53.0	20.0	35	47	58	36
18	54.0	22.0	39	50	60	39
20	55.0	25.0	42	53	63	42
22	55.5	27.0	45	56	66	45
24	56.0	29.0	48	58	68	48
26	57.0	32.0	51	60	70	52
28	58.0	35.0	54	63	72	55
30	59.0	38.0	58	66	74	58
32	61.0	42.5	61	70	76	61
34	63.0	46.0	65	73	78	65
36	66.0	50.0	70	76	81	69
38	68.0	55.0	74	79	83	73
40	71.0	61.0	78	82	85	77
42	75.0	68.0	83	85	88	82
44	80.0	74.0	87	88	91	86
46	86.0	81.0	91	92	94	90
48	93.0	89.0	95	96	97	95
50	100.0	100.0	100	100	100	100
52	105.0	111.0	104	103	104	105
54	113.0	123.0	110	105	108	110
56	122.0	136.0	115	108	112	115
58	131.0	152.0	121	112	116	120
60	141.0	169.0	127	115	122	127
62	153.0	189.0	132	120	127	134
64	166.0	210.0	140	125	132	143
66	181.0	233.0	146	130	138	151
68	195.0	258.0	151	135	145	162
70	212.0	288.0	162	140	152	171
72	228.0	320.0	172	145	160	183
74	245.0	356.0	180	147	170	196
76	265.0	400.0	191	155	179	205
78	290.0	440.0	200	165	190	218
80	318.0	490.0	212	175	202	232
82	352.0	545.0	225	182	215	248
84	390.0	605.0	237	192	230	264
86	415.0	675.0	253	203	247	276
88	460.0	745.0	271	215	265	298
90	530.0	830.0	292	230	287	316
92	595.0	925.0	315	243	312	340
94	660.0	1025.0	350	265	343	364
96	750.0	1175.0	400	295	381	400
98	875.0	1325.0	475	350	433	450
100	1150.0	1325.0	693	505	545	550

% ULTIMATE DISCHARGE	TIME IN % LAG (S-graph is identified by number) #53	#54	#55	#56	#57	#58
0	0	0	0	0.0	0.0	0
2	37	24	30	23.0	23.0	30
4	44	32	37	30.0	31.0	39
6	49	38	42	36.0	37.0	46
8	53	43	46	41.0	42.0	51
10	57	46	51	45.7	46.0	56
12	61	50	54	50.0	49.8	60
14	63	52	57	54.1	53.4	63
16	66	54	60	58.0	56.8	66
18	68	56	62	61.7	60.0	68
20	71	58	65	65.2	63.1	71
22	73	60	67	68.5	66.1	74
24	75	62	70	71.6	69.0	76
26	77	65	72	74.6	71.8	78
28	79	67	74	77.5	74.4	80
30	81	69	76	80.2	76.8	82
32	83	72	78	82.7	79.1	83
34	85	74	81	85.0	81.2	85
36	87	77	83	87.2	83.2	86
38	88	80	85	89.0	85.1	88
40	90	83	87	91.1	86.8	90
42	92	86	90	92.9	88.8	92
44	94	89	92	94.6	91.0	94
46	96	93	94	96.3	93.8	96
48	98	96	97	98.1	96.8	98
50	100	100	100	100.0	100.0	100
52	102	104	103	102.0	103.4	102
54	105	108	106	104.1	107.0	104
56	107	113	110	106.3	110.8	107
58	110	117	113	108.6	114.7	110
60	112	122	117	111.0	118.7	112
62	115	127	121	113.5	122.9	115
64	118	133	126	116.1	127.3	118
66	121	138	131	118.8	131.9	121
68	124	145	136	121.6	136.7	124
70	128	152	142	124.5	141.7	128
72	134	160	148	127.5	147.1	132
74	138	168	155	130.7	152.8	137
76	144	177	162	134.1	158.8	143
78	150	187	171	137.7	165.5	150
80	158	198	182	141.5	172.9	159
82	168	211	194	145.5	181.6	168
84	179	226	207	149.9	191.0	180
86	190	242	225	154.6	201.0	194
88	207	261	244	159.6	212.0	213
90	226	283	266	165.6	226.0	235
92	250	310	294	173.6	244.0	264
94	283	345	330	186.6	265.0	306
96	327	390	378	200.6	295.0	371
98	400	460	455	223.6	342.0	510
100	600	600	600	298.6	462.0	690

% ULTIMATE DISCHARGE	TIME IN % LAG (S-graph is identified by number) #59	#60	#61	#62	#63	#64
0	0	0	0	0	0	0
2	30	40	32	11	13	20
4	40	47	45	20	22	31
6	48	52	52	27	28	39
8	55	57	58	32	34	46
10	61	61	61	36	38	51
12	65	63	65	38	42	56
14	69	65	68	43	45	60
16	72	68	71	47	48	63
18	75	70	74	50	51	66
20	78	72	76	53	54	69
22	80	74	78	56	57	71
24	81	76	80	58	59	73
26	83	77	82	61	61	76
28	85	79	84	64	64	78
30	87	81	85	68	67	80
32	88	83	86	71	70	82
34	90	84	88	74	73	84
36	91	86	90	77	76	86
38	92	88	91	80	79	88
40	93	90	92	83	82	90
42	95	92	93	86	85	92
44	97	94	94	90	88	94
46	98	96	96	93	92	96
48	99	98	98	96	96	98
50	100	100	100	100	100	100
52	102	103	101	103	104	102
54	104	106	102	107	108	104
56	107	108	103	111	112	107
58	109	111	104	116	116	110
60	111	114	106	120	120	114
62	113	117	108	125	124	118
64	116	121	110	131	128	122
66	118	125	112	137	133	126
68	120	129	114	144	138	131
70	123	134	117	151	143	137
72	128	139	120	159	149	142
74	131	145	123	168	155	150
76	135	151	126	178	162	159
78	138	160	129	188	169	169
80	142	168	133	199	177	180
82	148	178	136	213	186	193
84	153	188	142	227	195	208
86	160	201	149	243	206	226
88	168	215	157	259	217	249
90	180	231	165	279	232	279
92	192	251	176	301	250	317
94	210	277	190	328	274	371
96	232	312	212	364	305	444
98	270	370	245	418	357	544
100	357	525	350	600	484	810

% ULTIMATE DISCHARGE	TIME IN % LAG (S-graph is identified by number) #65	#66	#67	#68	#69	#70
0	0	0	0	0	0	0
2	15	20	18	12	9	8
4	26	31	29	21	17	14
6	35	39	37	28	23	19
8	41	46	43	34	29	24
10	49	51	48	39	33	28
12	55	56	53	44	37	32
14	60	60	56	48	41	36
16	64	63	59	51	44	40
18	68	66	62	55	47	43
20	72	69	64	58	50	46
22	76	71	66	61	52	49
24	78	73	68	64	55	52
26	81	76	70	67	57	55
28	83	78	72	70	59	58
30	86	80	74	73	61	61
32	87	82	76	75	64	64
34	89	84	78	78	67	67
36	91	86	80	81	70	70
38	92	88	83	83	73	73
40	93	90	85	86	77	76
42	94	92	88	89	81	80
44	95	94	91	92	85	84
46	97	96	94	94	90	89
48	98	98	97	97	95	94
50	100	100	100	100	100	100
52	103	102	104	103	106	106
54	106	104	108	107	113	112
56	109	107	112	111	121	119
58	113	111	117	115	131	126
60	117	114	122	120	141	134
62	120	118	127	126	151	143
64	125	122	133	132	163	152
66	132	126	140	138	176	162
68	138	131	148	146	190	173
70	145	137	156	154	206	185
72	152	143	165	164	222	199
74	159	151	175	174	242	215
76	167	159	186	186	264	233
78	177	169	199	200	288	253
80	188	180	213	215	316	275
82	199	193	228	233	346	299
84	212	208	246	254	383	325
86	226	226	268	279	428	353
88	242	249	293	309	479	383
90	262	279	323	343	536	415
92	284	317	359	386	601	450
94	311	370	402	440	678	490
96	348	438	466	508	779	540
98	410	524	580	611	918	610
100	700	880	780	820	1300	700

% ULTIMATE DISCHARGE	TIME IN % LAG (S-graph is identified by number)					
	#71	#72	#73	#74	#75	#76
0	0.0	0.0	0	0	0.0	0.0
2	17.5	11.0	20	4	21.0	21.0
4	29.0	18.0	30	8	31.0	31.0
6	35.3	23.8	37	12	37.0	37.0
8	40.0	27.8	41	16	41.0	41.0
10	43.8	31.5	46	20	45.0	45.0
12	47.8	35.5	50	24	48.0	48.0
14	51.8	38.5	53	28	52.0	52.0
16	54.3	42.0	56	32	56.0	56.0
18	58.0	44.5	59	36	59.0	59.0
20	61.8	48.0	62	40	62.0	62.0
22	64.8	50.5	64	44	64.0	64.0
24	67.3	53.5	67	48	67.5	67.5
26	70.8	56.0	70	52	70.0	70.0
28	74.3	59.5	72	56	72.5	72.5
30	76.8	62.5	75	60	75.0	75.0
32	79.8	66.0	77	64	77.5	77.5
34	81.8	68.5	79	68	80.0	80.0
36	84.3	72.5	81	72	82.5	82.5
38	88.0	76.5	84	76	85.0	85.0
40	89.3	79.0	86	80	87.5	87.5
42	92.0	83.5	89	84	90.0	90.0
44	94.3	87.0	91	88	92.5	92.5
46	96.9	92.0	94	92	95.0	95.0
48	98.8	96.0	97	96	97.5	97.5
50	100.0	100.0	100	100	100.0	100.0
52	103.0	103.5	104	104	103.0	103.0
54	106.0	108.0	108	108	106.0	106.0
56	109.5	112.5	111	112	109.0	108.0
58	112.0	116.5	115	116	112.0	110.0
60	114.0	121.5	120	120	115.0	112.5
62	115.0	126.5	124	124	117.5	115.0
64	117.3	133.5	131	128	120.5	118.0
66	120.5	141.0	134	132	123.0	121.0
68	123.5	144.5	140	136	127.0	125.0
70	125.3	153.5	145	140	131.0	128.0
72	129.0	162.0	153	144	135.0	131.0
74	132.0	167.0	161	148	138.6	135.0
76	136.0	175.5	170	152	142.0	139.0
78	140.0	183.5	180	156	147.0	143.0
80	145.0	193.5	190	160	152.5	148.0
82	149.0	204.5	203	164	158.0	153.0
84	153.5	215.0	217	168	165.0	158.0
86	158.8	228.0	234	172	172.5	166.0
88	165.3	242.5	252	176	179.0	171.0
90	173.8	260.5	275	180	190.0	182.5
92	183.3	280.0	302	184	203.0	192.5
94	193.8	307.5	336	188	220.0	203.0
96	209.5	345.0	381	192	243.0	217.0
98	235.0	412.5	450	196	280.0	235.0
100	315.0	600.2	595	200	448.0	266.0

APPENDIX C

Information on Runoff and Rainfall Data for the Maricopa County S-Graphs (#1 through #22)

Reconstitutions of flood events in Maricopa County

S-Graph No. (1)	Stream Gage (2)	USGS Gage No. (3)	Drainage area sq. mi. (4)	Peak Discharge from Storm, in cfs Dec 1967 (5)	Sept 1970 (6)	June 1972 (7)
12,13	New River near Rock Springs	09513780	67.3	10,500	18,600	
14,15	New River at New River	09573800	85.7	12,500	19,500	
1,2	New River at Bell Road	09513855	187.0	14,600	11,900	
19,20	New River at Glendale	09513910	323.0	19,800	19,200	
21,22	Agua Fria at Avondale	09513970	718.0	20,000	20,600	
3,4	Skunk Creek near Phoenix	09513860	64.6	6,800	9,650	
5,6	Cave Creek at Phoenix	09512400	70.0[1]	4,080	780	
16,17,18	Indian Bend Wash near Scottsdale	09512100	142.0	2,000	1,120	20,000
	Queen Creek Trib. at Apache Junct	09479200	.51			
7,8	Part 1			28	138	
9	Part 2				84.5	
	Agua Fria Trib. at Youngtown	09513700	.13			
10	Part 1				15.8	
11	Part 2				40.5	

Notes: 1. USGS Water Resources Data for Arizona indicates drainage area of 252 square miles. The contributing drainage area is 70.0 square miles because of the noncontributing drainage area controlled by Cave Creek Dam.

Description of the Storm and Flood of 12-21 December 1967

(Los Angeles District, 1974)

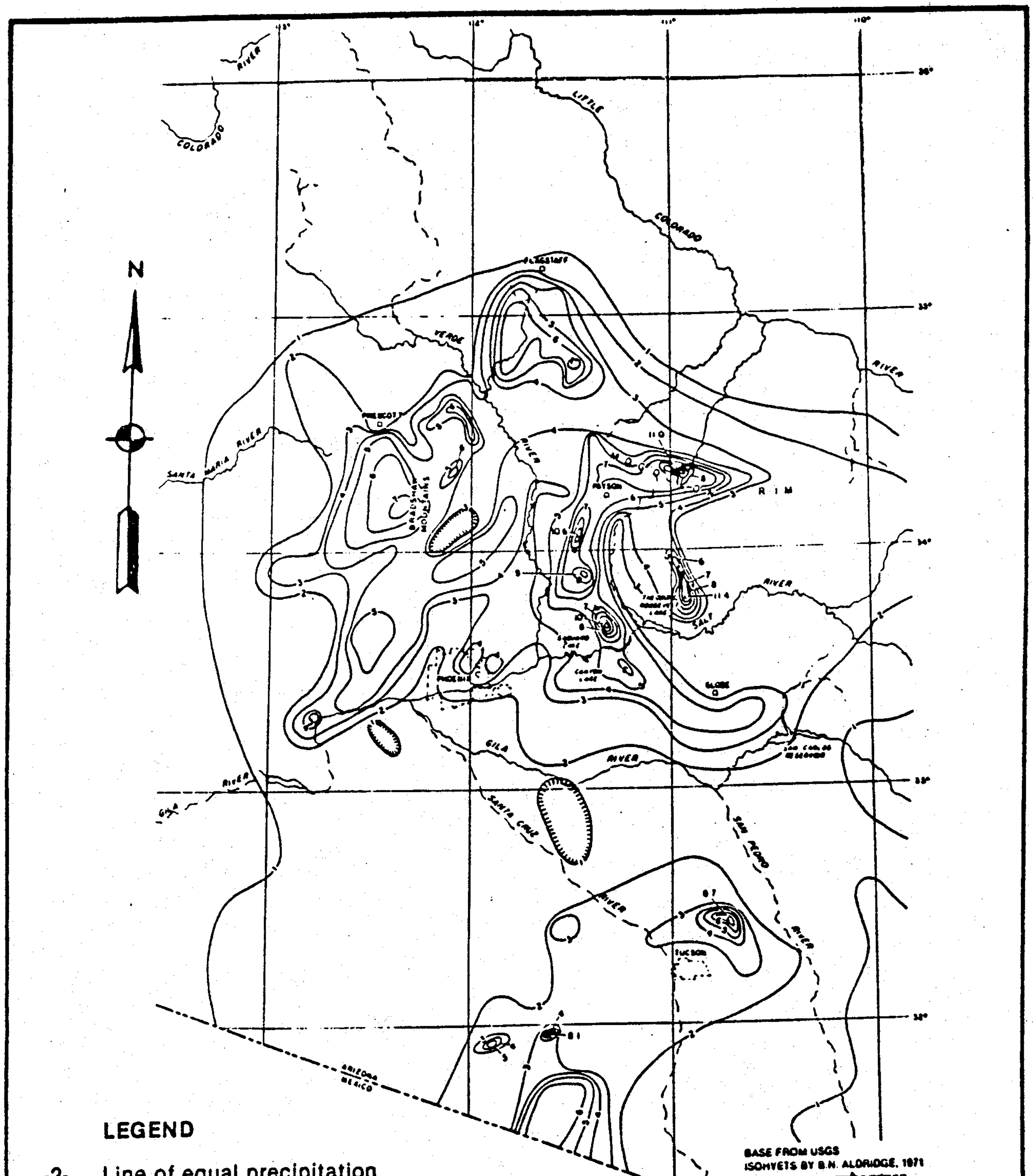
Storm and Flood of December 12-21, 1967. This storm period consisted of two general storm systems - one during December 12 through 16, and the other during December 17 through 21. During December 12 and 13, very cold air invaded Arizona from the north while a deepening upper level low pressure center off the southern California coast brought strong southerly winds aloft to Arizona and caused widespread substantial precipitation over much of the state. Snow fall was very heavy in the mountain areas with some stations reporting unprecedented snow depths and the snow level dropped to as low as 1,000 feet on December 13 and14. Precipitation from this first storm system generally diminished from December 15 through December 17, as the storm began moving to the east. A strong flow of warm moist air from the south began invading Arizona ahead of the second storm system and rainfall over the area began to increase with the snow level rising to around 5,000 feet. Around mid-day on December 19, precipitation became quite heavy over the Phoenix area as a cold front moved through the region from the northwest and a considerable amount of melting snow was added to the runoff. Precipitation intensities diminished and the snow level lowered once again late on December 19, after the passage of the cold front. New December precipitation records were set at several Arizona stations during December 1967, including 16.21 inches at Crown King, 7.30 inches at Flagstaff, and 3.92 inches at Phoenix. All of the months' precipitation fell during the 10 day period of December 12-21 in central Arizona. The heaviest daily precipitation occurred on December 19, with Crown King measuring 6.00 inches and Bumble Bee reporting 4.61 inches. With approximately 5 days of antecedent rainfall during the period December 13-18, the ground conditions were ripe to produce sizeable floods in the Phoenix area during the higher intensity rainfall which occurred during December 19. The New River-Skunk Creek system produced a peak of 19,800 c.f.s. near Glendale (323 square miles).

Description of the Storm and Flood of 3-7 September 1970

(Los Angeles District, 1982)

Isohyetal map on following page.

Storm and Flood of 3-7 September 1970. The storm began on 3 September in southern Arizona as moisture outflow from tropical storm Norma, west of Baja California, began to move into Arizona from the south. Showers pushed northward across the state on 4 September, becoming heavy at times. On 5 September, a strong cold front moved across Arizona from the west, triggering a 12- to 24-hour period of rain that reached unprecedented intensities at some stations. Precipitation tapered off rapidly late on 5 September, and only a few light showers lingered on 6-7 September. Total storm precipitation in central Arizona ranged from less than 1 inch around Coolidge Dam (San Carlos Reservoir) to nearly 12 inches in the Sierra Ancha Mountains northeast of Roosevelt Dam. Workman Creek, with a storm total of 11.92 inches, measured 11.4 inches in 24-hours—exceeding the previous all-time Arizona 24-hour record by more than 5 inches. Numerous other stations recorded from 5 to 8 inches during the heaviest 24 hours (mostly on 5 September). In and near the Agua Fria River drainage the storm total ranged from 1.78 inches at Prescott to 7.01 inches at Crown King. The latter station recorded 4.50 inches in the 24 hours ending at 6:00 p.m. on the 5th. A large portion of the maximum 24-hour precipitation fell within 4 to 6 hours. Total storm isohyets for 4-6 September are shown on plate 11. Much of central Arizona had received substantial precipitation during the first 3 to 4 weeks of August 1970. Thus, the ground was partially saturated in most areas at the beginning of the September storm. By the time of the heaviest burst of rain on 5 September conditions were favorable for heavy runoff. The high intensity rain that occurred on the 5th resulted in extensive flooding, with some streams recording all-time maximum discharges. On the New River USGS measurements at the gages near Rock Springs and at New River list peak discharges for 5 September of 18,600 and 19,500 ft^3/s, respectively. On the Agua Fria River near Rock Springs the peak discharge on 5 September was 40,100 ft^3/s (table 9). On the Hassayampa River at Box Damsite, near Wickenburg, the 58,000 ft^3/s recorded on 5 September is more than twice the previous known maximum of 27,000 ft^3/s, which is estimated to have occurred in February 1927 and which occurred again in August 1951.



LEGEND

-2- Line of equal precipitation

(3) Hactures indicate less rainfall than value shown

11.4 X Shows maximum rainfall where all isohyets cannot be shown.

NOTE: Some rainfall near the Mexican boundary occured before midnight on September 3.

SCALE 0 10 20 30 40 50 MILES

(SOURCE: REF. 2)

GILA RIVER BASIN,
NEW RIVER & PHOENIX CITY STREAMS, AZ

ISOHYETAL MAP
STORM OF SEPT. 4-6, 1970

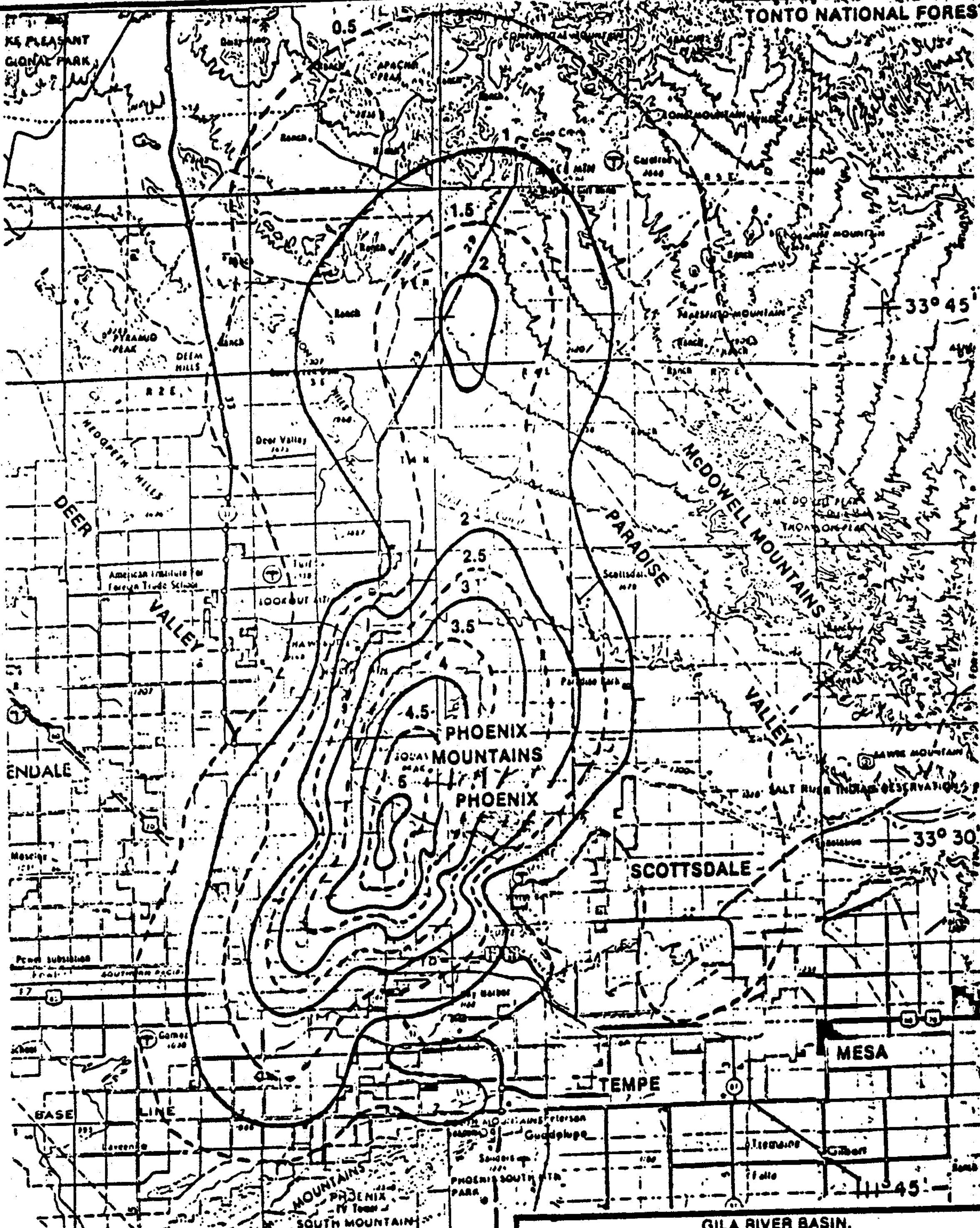
US ARMY CORPS OF ENGINEERS
LOS ANGELES DISTRICT

Description of the Storm and Flood of 22 June 1972

(Los Angeles District, 1982)

Isohyetal map on following page.

Storm and Flood of 22 June 1972. The heavy thunderstorm that occurred over northeastern Phoenix and adjacent communities on the morning of 22 June 1972 was a part of a series of early summer thunderstorms over the entire southwestern United States from 20 through 23 June 1972 that resulted from a deep flow of very moist, tropical air into the region from off the west coast of Mexico. In Phoenix the unofficial maximum rainfall was 5.25 inches during an estimated 2 hours near 4th Street and Camelback Road. Bucket survey amounts of 4.87 inches at 24th Street and Indianola Avenue and 4.8 inches at 28th Street and Indian School Road were confirmed by the National Weather Service. The maximum recording-gage intensity was 3.85 inches in 80 minutes at 18th Street and Turney Avenue. Large hail also fell in the area. The storm was highly localized, with only 10 square miles having greater than 4 inches of rainfall and only 200 square miles with more than 2 inches. Total storm isohyets for 21-22 June are shown on plate 12. Estimates of peak discharges for 22 June made by the USGS include: Shea Wash at Shea Boulevard (1.79 square miles), 945 ft^3/s; Cudia City Wash 1000 feet upstream from McDonald Drive (2.16 square miles), 4200 ft^3/s; Dreamy Draw at 16th Street (1.62 square miles), 860 ft^3/s; Indian Bend Wash (at Indian Bend Road) near Scottsdale (142 square miles), 21,000 ft^3/s.



N

SCALE IN MILES

1 0 4 8

LEGEND

—— 2 —— LINE OF EQUAL PRECIPITATION IN INCHES

(SOURCE: REF. 2)

GILA RIVER BASIN,
NEW RIVER & PHOENIX CITY STREAMS, AZ

ISOHYETAL MAP
STORM OF JUNE 21-22, 1972

US ARMY CORPS OF ENGINEERS
LOS ANGELES DISTRICT

PLATE 12

Point Rainfalls for the December 1967 Storm

Gage Location (1)	Rainfall Depth Inches (2)	Type of Gage Recording (R) Nonrecording (N) (3)
Black Canyon 4NE	3.53	R
Carefree	2.75	R
New River	2.70	R
Rock Springs	3.19	R
Thunderbird Airport	1.42	R
Skunk Creek	3.59	R
Youngtown	2.35	R
Phoenix 11 NNW	1.89	R
Castle Hot Springs	4.07	N
Lake Pleasant	2.26	N
Cave Creek Dam	2.83	N
Beardsley	1.99	N
Paradise Valley	1.93	N
Litchfield Park	2.03	N
Alhambra 2NE	1.86	N
Arizona Falls	1.45	N
Tolleson 1E	1.77	N
T3N, R3E, Sec 34	2.46	N
T3N, R5E, Sec 15	2.67	N
T3N, R5E, Sec 16	2.02	N

Point Rainfalls for the September 1970 Storm

Black Canyon 4NE	2.82	R
Rock Springs	2.81	R
New River	5.39	R
Carefree	2.12	R
Skunk Creek	2.53	R
Youngtown	4.24	R
Phoenix	1.92	R
Thunderbird Airport	3.07	N
Lake Pleasant	4.11	N
Horseshoe Dam	3.94	N
Castle Hot Springs	4.56	N
Beardsley	5.04	N
Litchfield Park	3.09	N
Tolleson 1E	2.00	N

Point Rainfalls for the June 1972 Storm

Phoenix	3.13	R
Thunderbird Airport	.87	R
Carefree	.80	R