SIZING OF SURFACE WATER RUNOFF DETENTION PONDS

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ABSTRACT

Traditionally, storm water management programs and criteria have focused on quantity issues related to flooding and drainage system design. Traditional designs are based on large rainfall-runoff events such as those having 2-year to 100-year return periods. While these are key criteria for management and control of peak flows, detention basins designed based on these criteria may not provide optimal treatment of the storm runoff. As evidenced by studies performed by numerous public and private organizations, the water quality impacts of storm water runoff are more a function of the frequent daily rainfall-runoff events rather that the less frequent events that cause peak flooding.

Prior to this study there had been no detailed studies to characterize the variability of the more frequent rainfall events on Guam. Also there was a need to develop some design criteria that could be applied by designers, developers and agency officials in order to reduce the impact of storm water runoff on the receiving bodies.

The objectives of this study were three-fold as follows:

1. Characterize the daily rainfall-runoff events with respect to volume, frequency duration and the time between storm events.
2. Evaluate the rainfall-runoff characteristics with respect to capture volume for water quality treatment.
3. Prepare criteria for sizing and design of storm water quality management facilities.

The rainfall characterization studies have provided insight into the characteristics of rainstorms that are likely to produce non-point source pollution in storm water runoff. The studies made concerning time intervals between storms have added insight into the period of time that pollutant debris will have to collect in urban runoff situations thus contributing to a better understanding of what levels of pollutants to expect in the storm water runoff.

By far the most significant findings are the development of a series of design curves and equations that can be used in the actual sizing of storm water detention and treatment facilities. This kind of information was not previously available and will be most valuable to those designing storm water detention and treatment facilities and to those in Guam's governmental agencies who are regulating non-point pollution. If applied correctly, these design curves could lead to a reduction of non-point runoff to Guam's streams, estuaries and coastal environments.

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INTRODUCTION

The quality of life and economic prosperity in Guam is intimately tied to the quality of its water resources. As urbanization, resort development and land use intensification continue to increase, these resources are becoming more and more stressed. Degradation of water quality has occurred due in part to storm water runoff and non-point pollution sources. Management and control of these pollution sources is imperative if the quality of Guam's water resources is to be maintained.

Efficient operation and cost effective design of facilities to control the quality of storm water runoff requires a better understanding of the tropical rainfall-runoff process experienced on Guam. Traditionally, storm water management programs and design criteria have focused on quantity issues related to flooding and drainage system design. Design criteria were based on large rainfall-runoff events such as those having 2 to 100-year return periods. A 2 year rainfall event would be considered fairly small by those doing traditional flood control design work, but in fact the 2 year event is larger than 95 percent of the storms that normally occur in an urban watershed (Guo, 1992). Designing a storm water control facility to accommodate the more rare 2 to 100-year return period storms does not insure that the facility will provide the appropriate amounts of detention time storage required to remove or reduce the impact of the storm water on the receiving waters (Guo, 1992).

The Goal of this study was to make an in depth investigation of rain storms on Guam and to develop a set of design graphs and tables so that governmental regulators can adopt an appropriate set of regulations for detention pond sizing for minimizing the impact of storm water runoff on the receiving waters of Guam.

This study begins with an examination of storm rainfall events at the National Weather Service rain gage located at Taguac, Finagagen. A complete characterization of rain storms is developed from the hourly precipitation data obtained from the National Climatic Data Center at Asheville, North Carolina. The storm events developed in the first phase of the study were then examined using a program called "PONDRISK" developed by James C. T. Guo of the Department of Civil Engineering at the University of Colorado at Denver Colorado (Guo, 1992). This program was used to explore various scenarios of detention pond size, detention time, runoff coefficients, and degree of treatment. A series of graphs and table are provided to show the relationships between these design variables. A final portion of the investigation presents a case study to show how the design curves could be used in the actual design and evaluation of a storm water detention facility.

STUDY AREA

Guam is the largest island in the Western Pacific with a land area of 212 square miles (Fig. 37). The island is the southern most of the Mariana Islands and is located about 1,500 status miles south of Tokyo, 1,730 status miles east of Manila and 3,840 status miles west of Honolulu, Hawaii. The northern half of the island is a generally uniform limestone plateau. No stream exist on the plateau as rain water rapidly percolates into the limestone. The southern half of the island is volcanic in origin with numerous rivers.

Located in the tropics, the weather on Guam is uniformly warm with wet and dry seasons. The mean annual temperature near sea level is about 81 F (27.2 C). Guam has two major seasons, the

wet and dry seasons. The major dry season is the four-month dry period from January through April. The second major season is the four-month rainy season that extends from mid-July to mid-November. The mean annual rainfall varies from about 80 inches on the central and coastal lowlands to about 110 inches on the uplands in southern Guam.

Over the years a total of twenty five rain gauges have been located on Guam. There are four continuos recording rain gages that are operated by the US National Weather Service Office on Guam. The location of these rain gauges are shown in Fig. 37. The rest are non-continuos rain gauge which record daily and monthly rainfall.

OBJECTIVES

The first objective of this study was to characterize rain storms on Guam. Included among these characteristics were:

1. Number of rainfall events versus rainfall depths.
2. Duration of rainfall events.
3. Frequency characteristics of rainfall events.
4. Time between rainfall events.

The second objective was to use the rain storm data developed in the first objective to develop a set of graphs and diagrams illustrating the relationships between rainfall-runoff volume characteristics and capture volume requirements for various levels of storm water treatment.

RELATED RESEARCH

In the past there was little data available regarding the more frequent daily rainfall-runoff events that are likely to affect storm water quality on Guam. Previous studies have been completed by others with regard to water quality facility criteria (United States Army Corps of Engineers, 1980) and non-point pollution sources (Dames and Moore, 1982). Some data and criteria have previously been developed for Guam as part of the National Urban Runoff Program (United States Environmental Protection Agency, 1986). These data and criteria are very general and were not based on local rainfall-runoff data.

This topic has, however, been the subject of considerable discussion and study throughout other regions of the United States. Notable among municipalities and agencies currently investigating this topic are Florida, Washington, D. C., Seattle, Washington and Denver, Colorado.

METHODS AND PROCEDURES

I. RAIN STORM ANALYSIS

Rainfall Data

The first phase of the study was dedicated to the characterization of hourly rainfall patterns. These characterizations were carried out using a computer program entitled *PONDRISK* that was

developed by Dr. James Guo at the University of Colorado. This program has been used in Colorado and California in developing design criteria for storm water detention basins.

Hourly rainfall data that was input to the model was obtained from the National Climatic Data Center in Asheville, North Carolina. Hourly data was available for only one rainfall measurement site on Guam. The data available was from the National Weather Service Meteorological Observatory (WSMO) at Taguac Finegayan (Station 4229) for the period September 1982 to September 1992.

Storm Grouping

The rainfall data was analyzed using the rainfall analysis option of the *PONDRISK* program. The method used by the program is called the Runoff Volume Point Diagram (RVPD) method. (Gou, 1992)

This method was developed from previous work on predicting rainfall runoff volumes by von den Herik (1976) and Pecher (1978). The RVPD method involves the grouping of 15 minute or hourly rainfall data into individual storms. In this study hourly data was used. Individual storms are identified by grouping all rainfall events (hourly or 15 min.) that are not separated by a non-rainfall period of a specified time. For example, if the rainfall record shown in table 1 were being examined and a 3 hour non-rainfall period was being used as the storm identification factor then two separate storms would be identified in the 12 hour period shown. Notice that the non-rainfall hour at 4:00 did not result in a new storm starting since the total non-rainfall period (1 hour) was less than the required minimum of 3 hours. The non-rainfall period that began at 7:00 and ended at 9:00 did result in a new storm (STORM 2) being identified since the non-rainfall period (3 hours) was equal or greater than the required non-rainfall period.

Table 1. Example of Grouping Rainfall Events into Storms

TIME (hr.)	RAINFALL (inches)	STORM GROUP
1:00	.10	STORM 1
2:00	.12	STORM 1
3:00	.05	STORM 1
4:00	.00	STORM 1
5:00	.07	STORM 1
6:00	.10	STORM 1
7:00	.00	
8:00	.00	
9:00	.00	
10:00	.06	STORM 2
11:00	.10	STORM 2
12:00	.15	STORM 2

Selection of the non-rainfall period depends on the minimum drain time for the detention pond. The minimum drain time however depends on the settling time for the pollutants that are being carried by the storm runoff. Therefore, if a detention pond with a 12 hour drain time is being proposed then the non-rainfall period must be equal to or greater than 12 hours. This will be discussed in more detail later in Section II.

Incipient Rainfall

Another important factor in determining storm size is a term called incipient rainfall (Pi). This is the minimum amount of rainfall that must fall in order for runoff to occur. This is the amount that it takes to wet the runoff surface and is lost from the total runoff in each storm. If we examine the two storms in table 1 we see that the total precipitation that fell in STORM 1 was 0.44 inches. If the incipient rainfall required to cause runoff is 0.10 inches then the total rainfall for STORM 1 would be 0.34 inches. The procedure requires that each storm be reduced by the user supplied incipient rainfall. Any storm that has a total equal to or less than the incipient rainfall is dropped from the analysis.

Statistics of Storms

After each of the rain storms have been identified and adjusted for incipient rainfall, a statistical analysis was performed. The data computed for each storm included, adjusted rainfall depth, duration of storm and time interval between each storm. The mean, standard deviation and skewness were computed for each of the parameters for the entire period of record.

A series of rainfall characterization curves was generated by varying the minimum non-rainfall period used to isolate individual storms. Values of 1 hour, 6 hours, 12 hours and 24 hours were used as the minimum non-rainfall periods. This variable is shown on the following Figures as Time Between Storms minimum (TBSmin). Figures 1 through 16 summarize these rainfall characterizations. These figures are shown in reduced size on the following pages and are available in full size form in Appendix I.

Figure 1 through 4 contain the rainfall characterizations for storms grouped using 1 hour as the minimum non-rainfall period. A total of 3,383 rainfall records were analyzed to produce a total of 1,689 storms. Table 2 contains a summary of the characterization for each of the computed parameters.

Table 2. Rainfall Characteristics for Storms with TBSmin = 1 hour, Pi = 0.1

PARAMETER	STORMS ANALYZED	AVERAGE	STANDARD DEVIATION	SKEWNESS
Rainfall Duration	1689	2.00 hours	2.156	5.227
Rainfall Depth	1225	0.24 inches	0.528	7.294
Interval between storms	1687	11.33 hours	17.703	4.290

MINIMUM NON-RAINFALL PERIOD = 1 HOUR

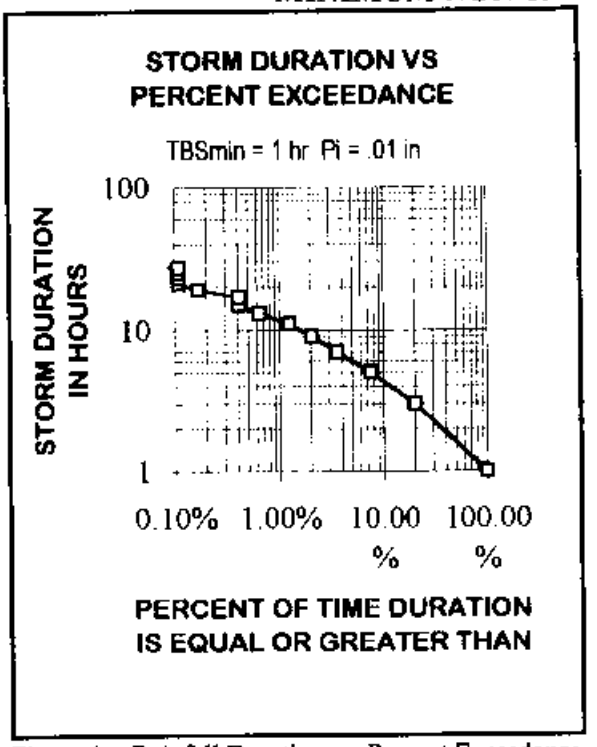

Figure 1. Rainfall Duration vs. Percent Exceedance TBSmin = 1 hour

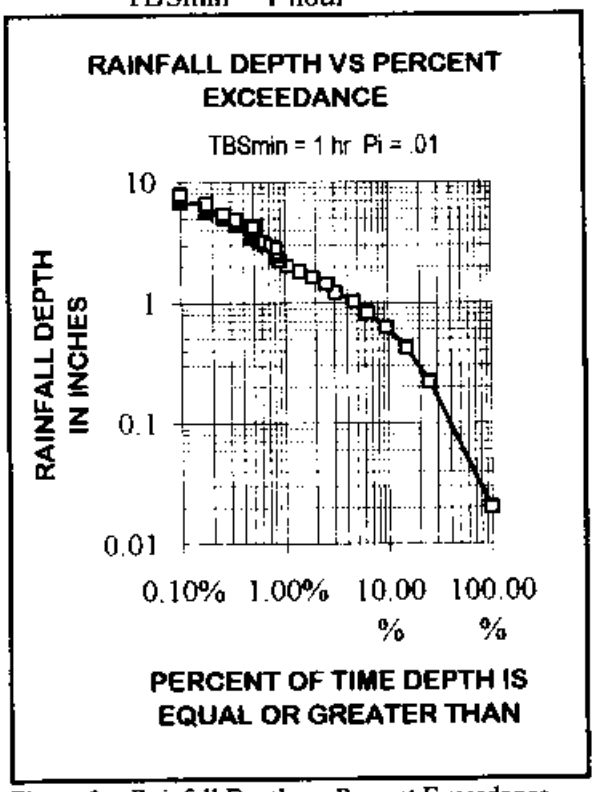

Figure 2. Rainfall Depth vs. Percent Exceedance. TBSmin = 1 hour

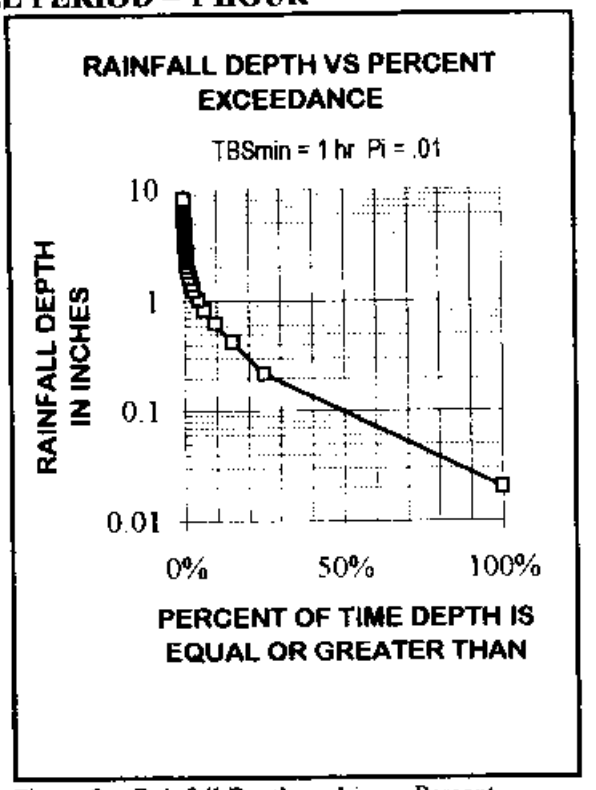

Figure 3. Rainfall Depth vs. Linear Percent Exceedance. TBSmin = 1 hour

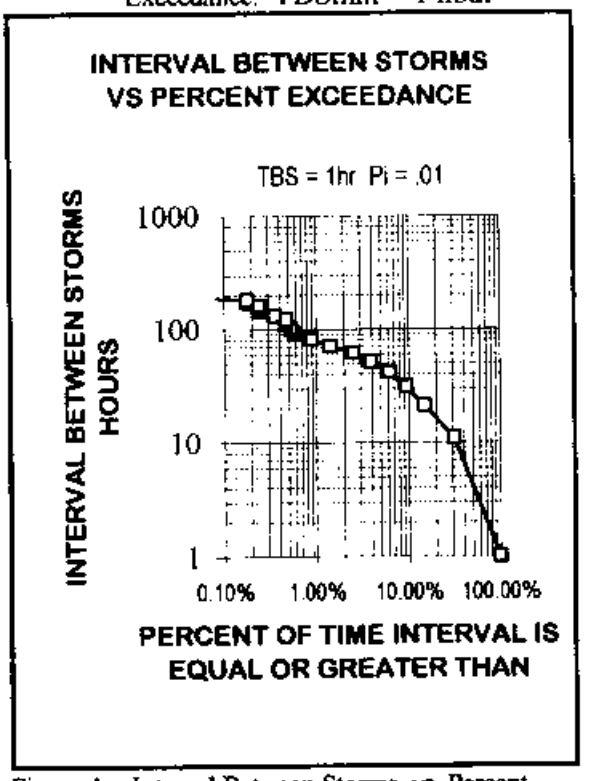

Figure 4. Interval Between Storms vs. Percent Exceedance. TBSmin = 1 hour

Figure 1 is a graph of rain storm duration vs. exceedance percentage. This graph illustrates the relationship between how long a rainstorm lasts and the percent of time we would expect a storm to be equal to or longer than that particular storm. For example, from Figure 1 we would expect only 10 percent of the storms to exceed 4.5 hours in length.

Figure 2 is a graph of rain storm depth vs. exceedance percentage. This graph illustrates the relationship between the depth of rain that falls during a storm and the percent of time we would expect the depth of rainfall to be equal to or larger than that particular depth. For example, from Figure 2 we would expect only 10 percent of the storms to exceed 0.6 inches of total rainfall.

Figure 3 illustrates the same rainfall depth vs. exceedance percent relationship but with exceedance percentage on a linear scale. This plot lacks the detail of Figure 2 but gives a more realistic overview of the relationships of the exceedance percentage distribution.

Figure 4 is a graph of time interval between rain storms vs. exceedance percentage. This graph illustrates the relationship between how long the non-rainfall period lasts and the percent of time we would expect this non-rainfall period to be equal to or longer than that particular length of time. For example, from Figure 4 we would expect only 10 percent of the time intervals between storms to exceed 30 hours in length.

We have developed sets of curves similar to those in Figure 1 through 4 for minimum non-rainfall periods between storms of 6, 12, and 24 hours. For TBSmin = 1 hour, a total of 3,383 hourly rainfall records were analyzed. These curves are shown in Figures 5 through 16. Table 3 summarizes the results of the statistical analyses for these sets of curves and also includes the results of the 1 hour minimum non-rainfall period studies.

Figures 17 through 20 are combined curves which shows exceedance percentage vs. storm duration, Storm depth, and time between storms for minimum times between storms of 1,6,12, and 24 hours.

Table 3. Rainfall Characteristics for all Storms Studied

PARAMETER	# OF STORMS ANALYZED	AVERAGE	STANDARD DEVIATION	SKEWNESS
TBSmin = 1 hour, Pi = 0.01		**Hourly rainfall records used = 3,383**		
Rainfall Duration	1689	2.00 hours	2.156	5.227
Rainfall Depth	1225	0.24 inches	0.528	7.294
Interval between storms	1687	11.33 hours	17.703	4.290
TBSmin = 6 hour, Pi = 0.01		**Hourly rainfall records used = 6,863**		
Rainfall Duration	1689	6.61 hours	8.853	2.959
Rainfall Depth	1352	0.40 inches	0.884	6.755
Interval between storms	1687	21.58 hours	23.478	4.802
TBSmin = 12 hour, Pi = 0.01		**Hourly rainfall records used = 10,700**		
Rainfall Duration	1501	2.00 hours	2.156	5.227
Rainfall Depth	1305	0.24 inches	0.528	7.294
Interval between storms	1499	11.33 hours	17.703	4.290
TBSmin = 24 hour, Pi = 0.01		**Hourly rainfall records used = 10,700**		
Rainfall Duration	679	2.00 hours	2.156	5.227
Rainfall Depth	619	0.24 inches	0.528	7.294
Interval between storms	677	11.33 hours	17.703	4.290

MINIMUM NON-RAINFALL PERIOD = 6 HOURS

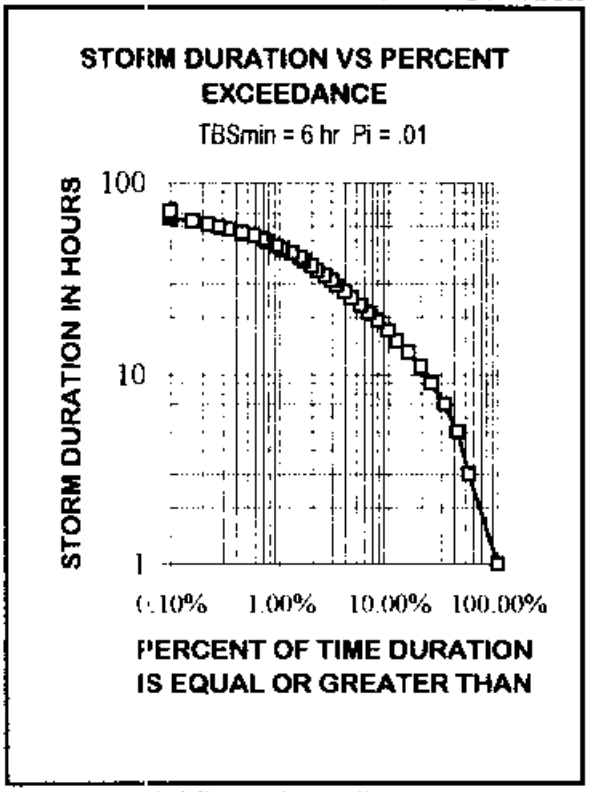

Figure 5. Rainfall Duration vs. Percent Exceedance. TBSmin = 6 hours

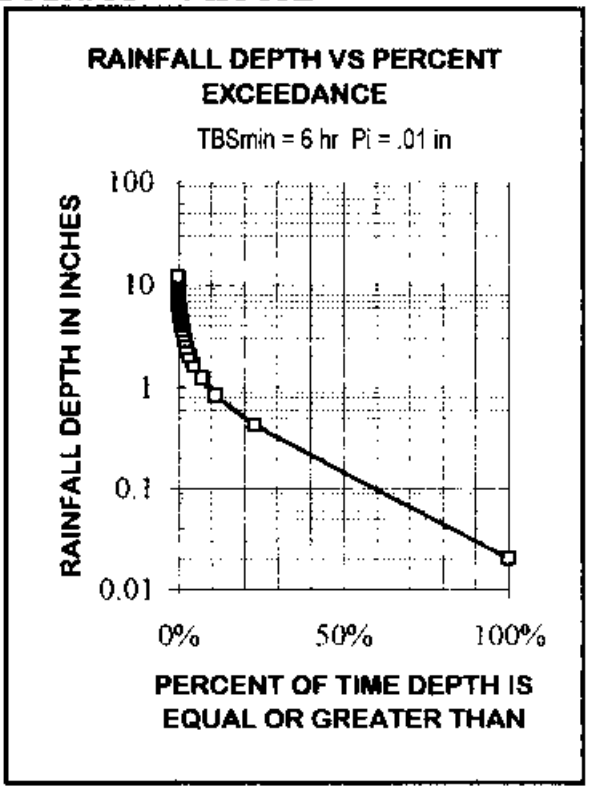

Figure 7. Rainfall Depth vs. Linear Percent Exceedance. TBSmin = 6 hours

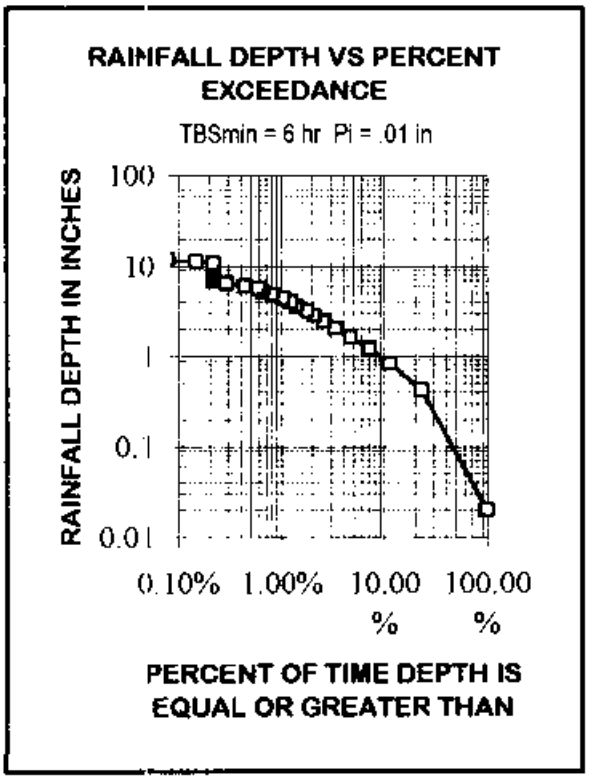

Figure 6. Rainfall Depth vs. Percent Exceedance. TBSmin = 6 hours

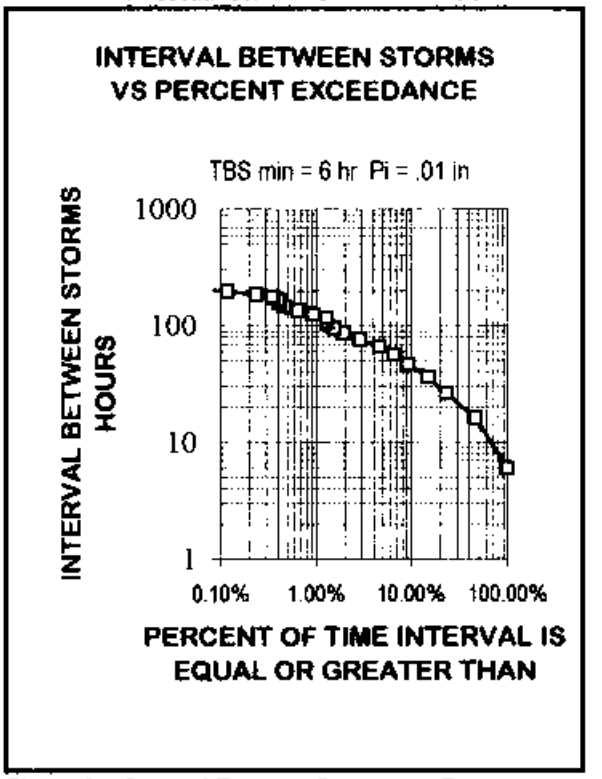

Figure 8. Interval Between Storms vs. Percent Exceedance. TBSmin = 6 hours

MINIMUM NON-RAINFALL PERIOD = 12 HOURS

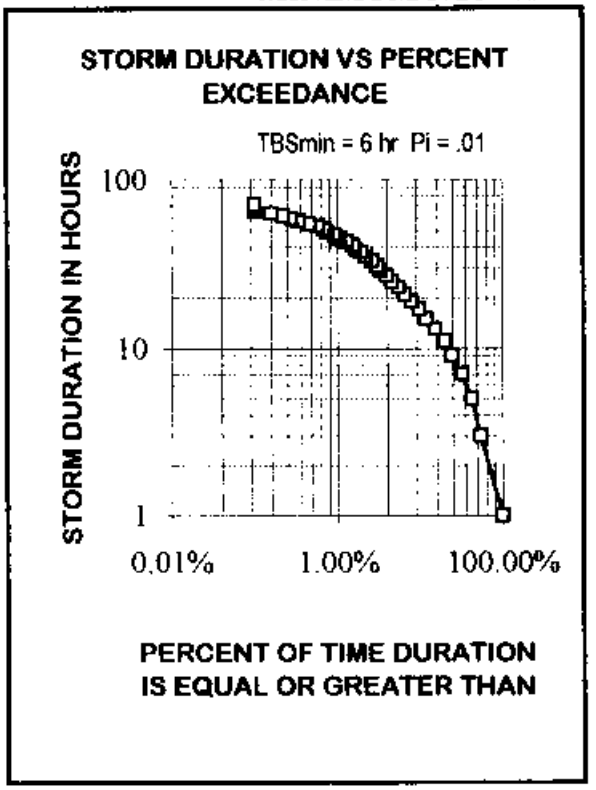

Figure 9. Rainfall Duration vs. Percent Exceedance. TBSmin = 12 hours

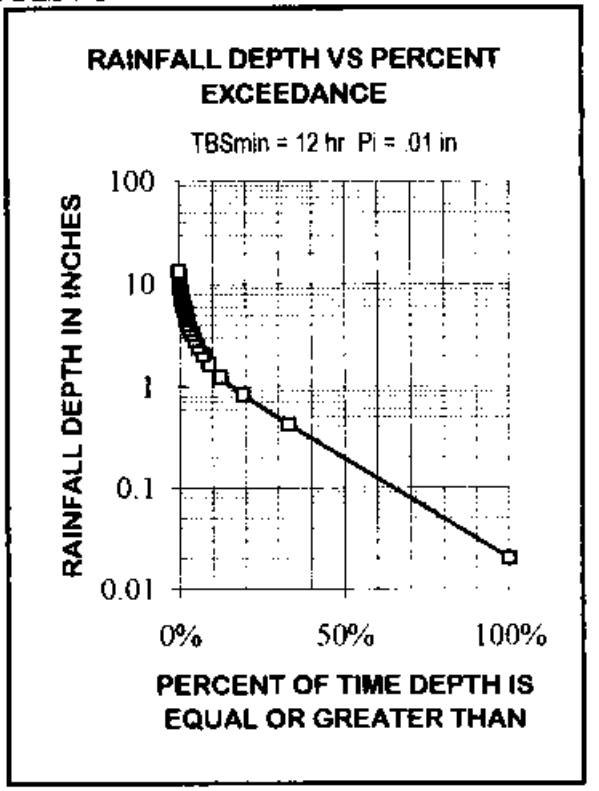

Figure 11. Rainfall Depth vs. Linear Percent Exceedance. TBSmin = 12 hours

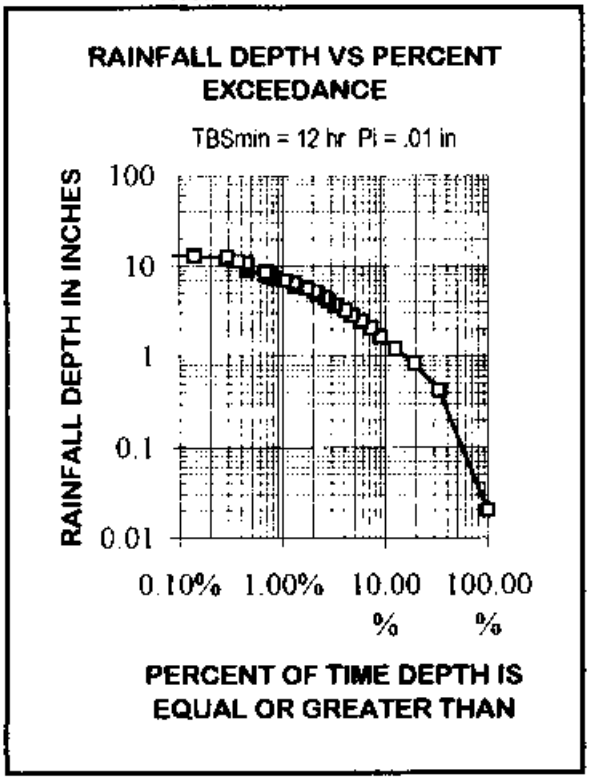

Figure 10. Rainfall Depth vs. Percent Exceedance. TBSmin = 12 hours

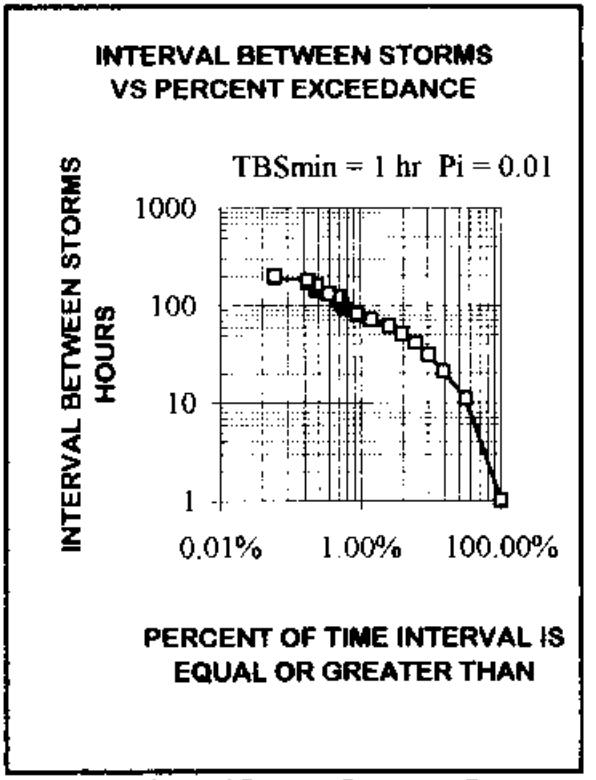

Figure 12. Interval Between Storms vs. Percent Exceedance. TBSmin = 12 hours

MINIMUM NON-RAINFALL PERIOD = 24 HOURS

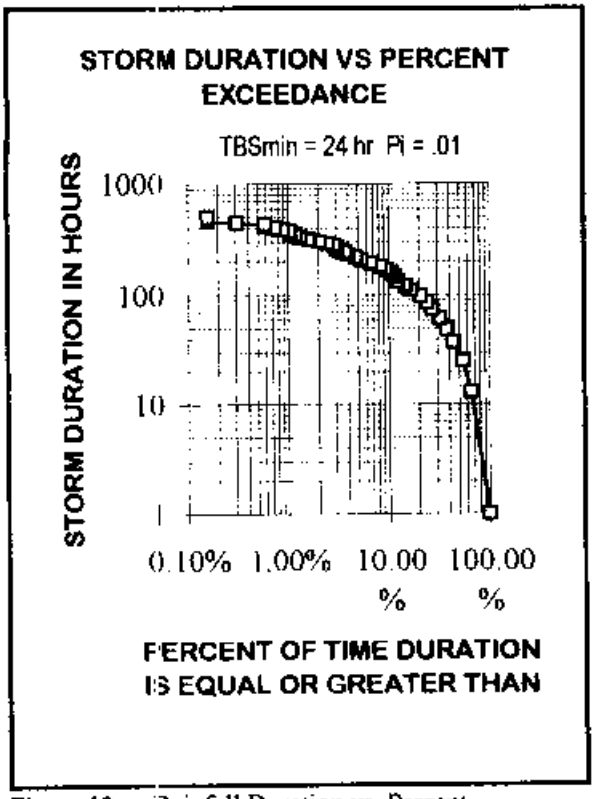

Figure 13. Rainfall Duration vs. Percent Exceedance. T.BSmin = 24 hours

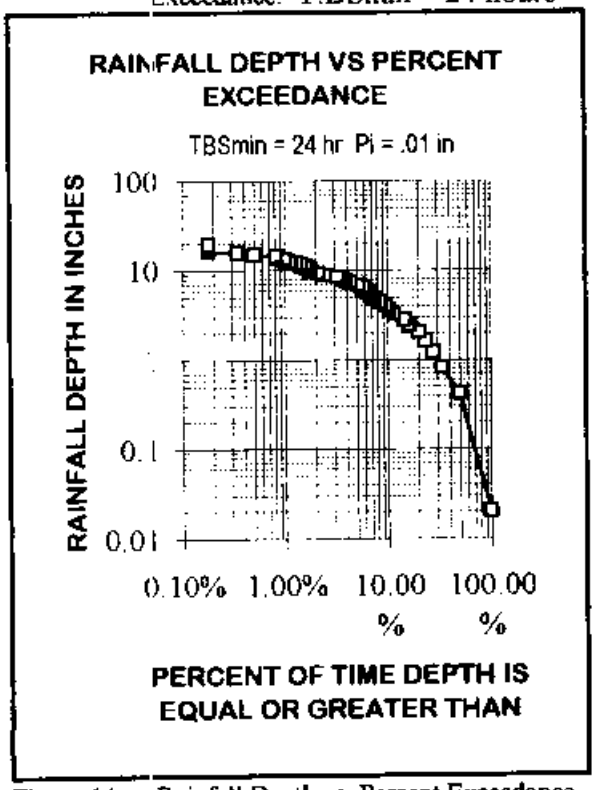

Figure 14. Rainfall Depth vs. Percent Exceedance. TBSmin = 24 hours

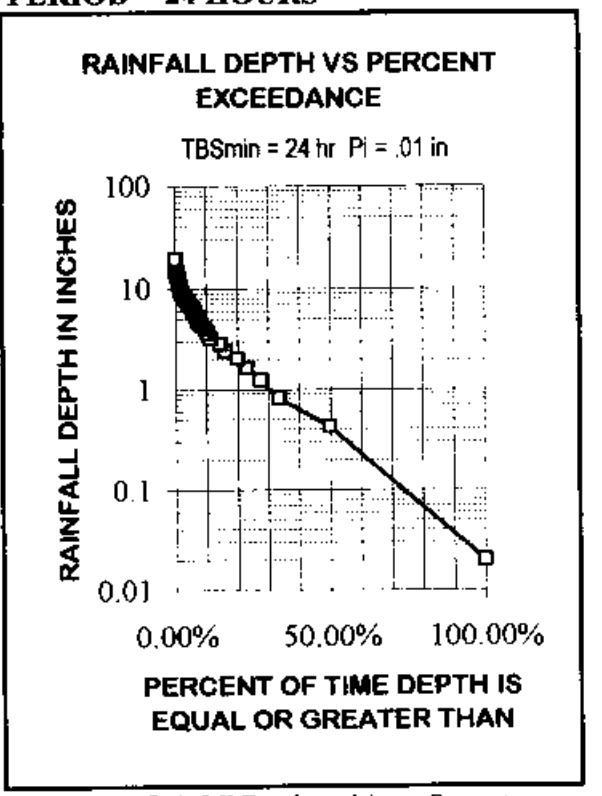

Figure 15. Rainfall Depth vs. Linear Percent Exceedance. TBSmin = 24 hours

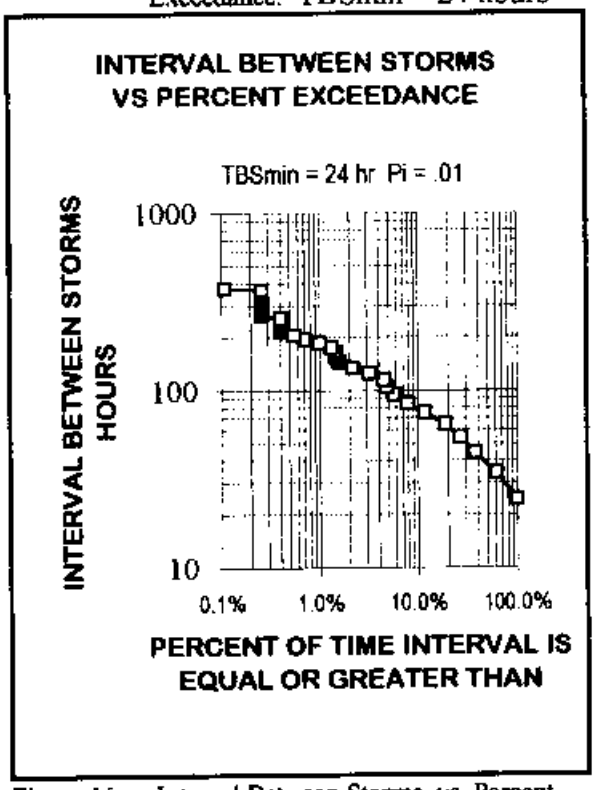

Figure 16. Interval Between Storms vs. Percent Exceedance. TBSmin = 24 hours

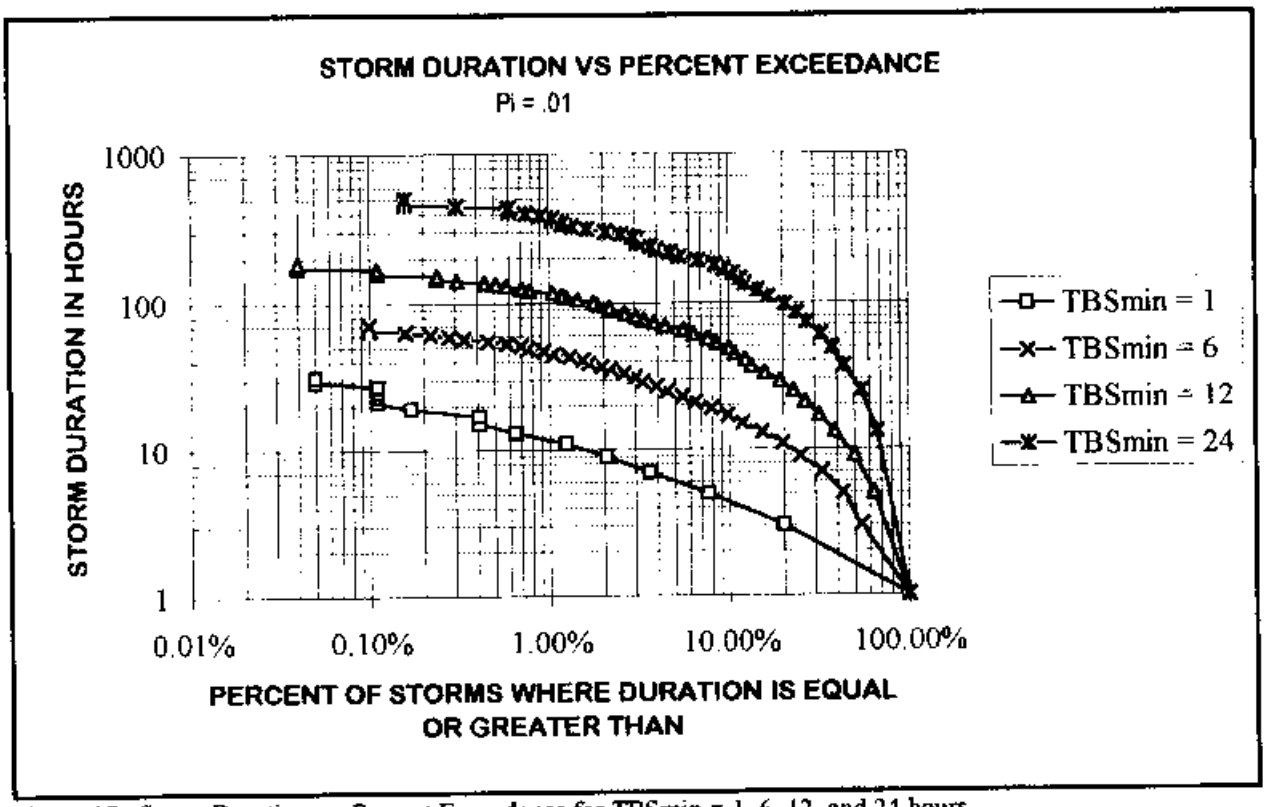

Figure 17. Storm Duration vs. Percent Exceedance for TBSmin = 1, 6, 12, and 24 hours

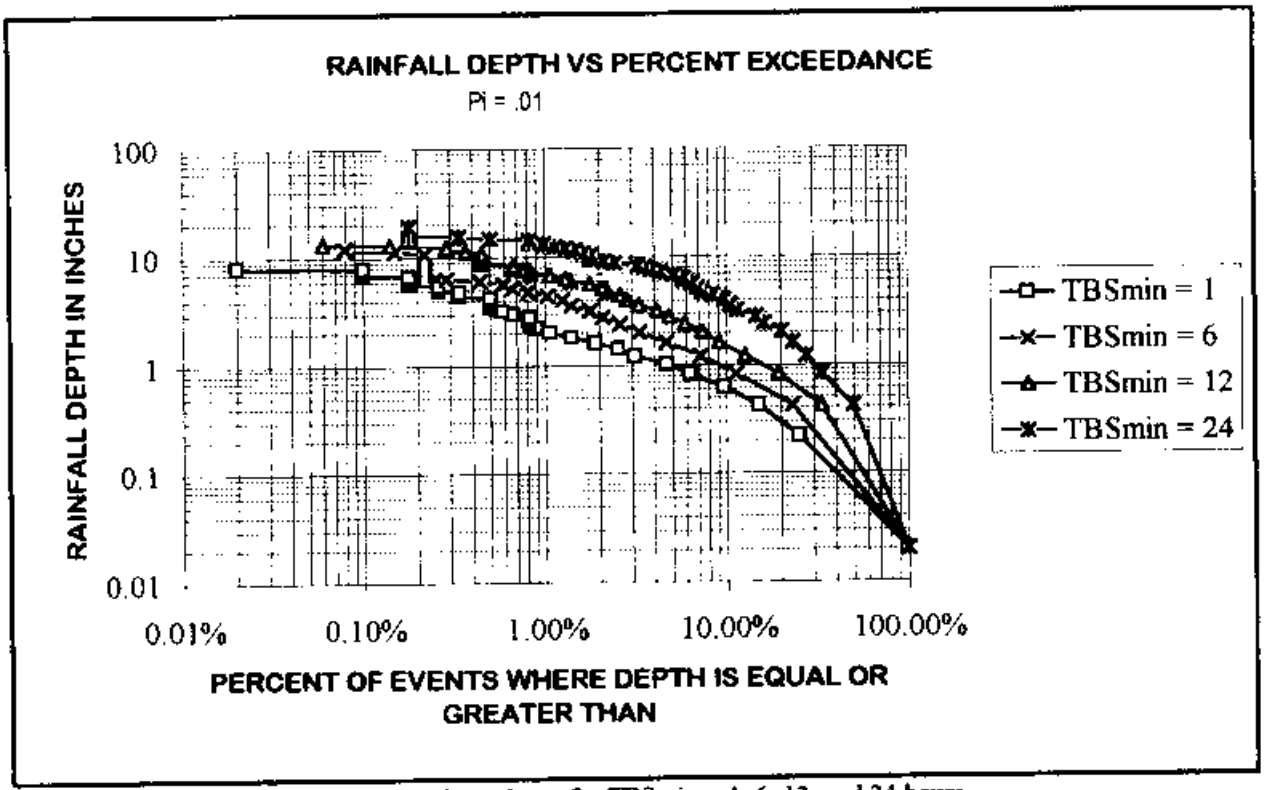

Figure 18. Rainfall Depth vs. Percent Exceedance for TBSmin = 1, 6, 12, and 24 hours

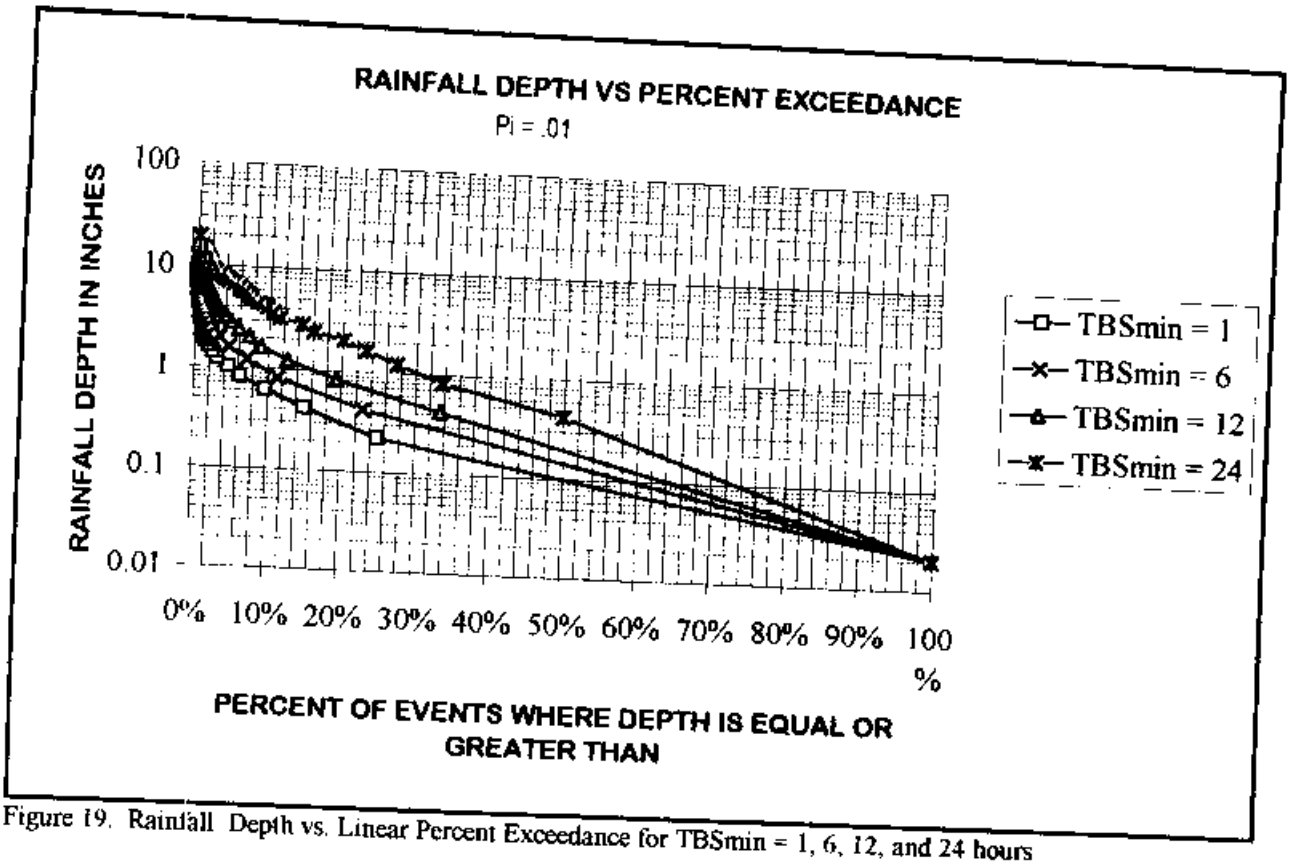

Figure 19. Rainfall Depth vs. Linear Percent Exceedance for TBSmin = 1, 6, 12, and 24 hours

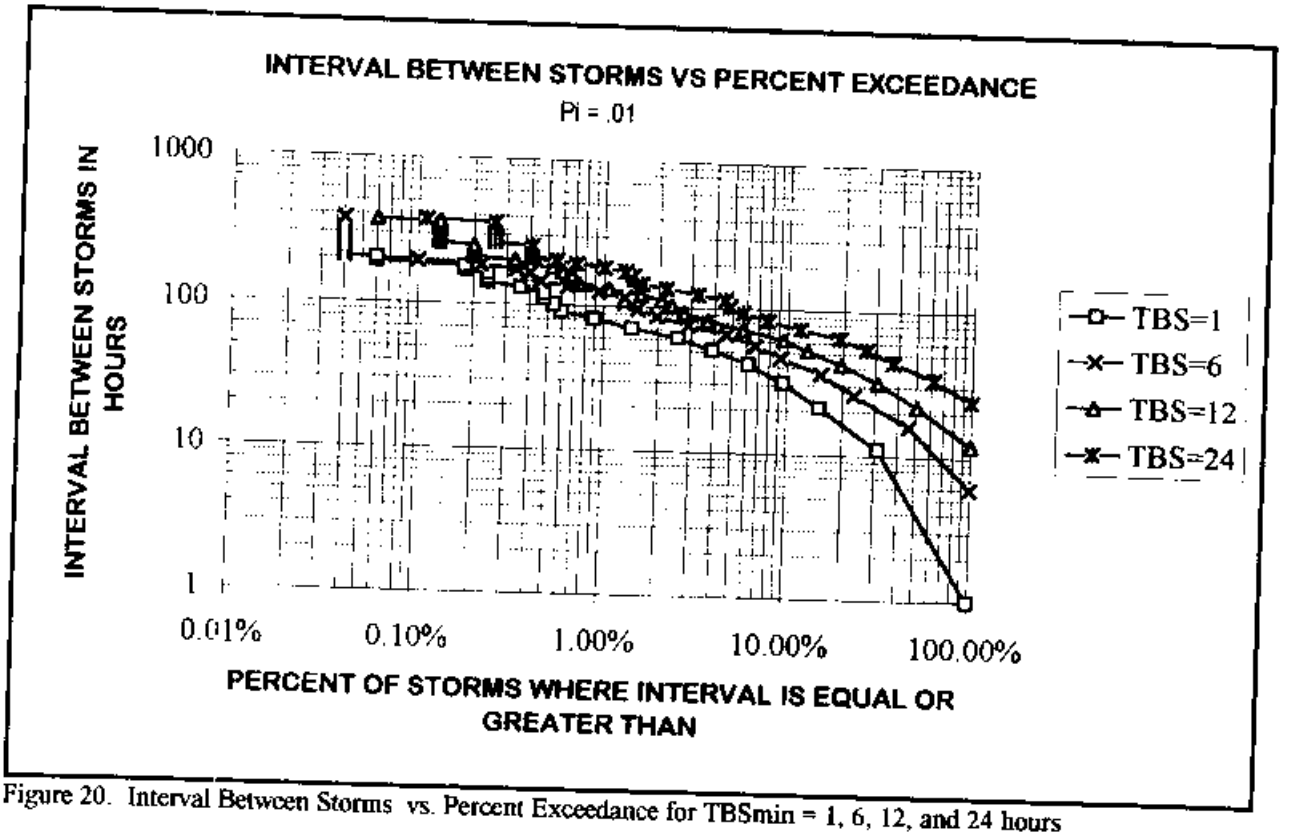

Figure 20. Interval Between Storms vs. Percent Exceedance for TBSmin = 1, 6, 12, and 24 hours

II. Pond Sizing and Optimization

Storm Runoff Pond Detention Time

The next phase of the study involved evaluating the rainfall, and runoff characteristics with respect to capture volume required for water quality treatment of the storm runoff. We analyzed the storm data developed in the rainfall analysis phase of the project using the detention pond sizing option of the *PONDRISK* program described previously.

This option evaluates the performance of a series of pond sizes based on the volume capture efficiency. Volume capture efficiency is the percentage of the total storm runoff volume produced that is detained for the desired treatment time in the detention pond. It is a measure of the effectiveness of a certain sized pond to provide adequate treatment of the storm water runoff.

The analysis procedure assumes that the detention pond is empty at the beginning of each new storm event. In order for this to occur the emptying time for the pond must be equal to or less than the minimum time between storms (TBSmin). Normally the drain time is set by the amount of settling time that is desired for the pond. This value is determined by gravimetric or volumetric analysis of the suspended solids carried in the storm runoff. For example, if it is desired to provide a minimum of 24 hours of settling time for adequate treatment of the storm runoff, then a drain time of 24 hours or greater would be set. The TBSmin value would be selected to coincide with this drain time.

Note that volume units below are in inches. A capture area of unity is assumed so that it will be easy to convert runoff from any sized runoff area.

Capture Volume Calculations

The PONDRISK program analyzes each of the identified storm events in the following fashion:

1. Determine runoff depth from the storm

   $V_r = C(P_t - P_i)$
   V_r = Runoff Depth (inches)
   P_t = Total Storm Precipitation (inches)
   P_i = Incipient Precipitation (used 0.1 inches for all studies)
   C = Runoff Coefficient (can vary from 0 to 1.0)

2. Average release rate from the pond

   $q = V_p/T_e$
   q = Average release rate in/hr
   V_p = Brim full volume of pond (inches)
   T_e = Pond drain time

3. Determine the Maximum Runoff Volume Captured by the Pond (brim full capacity plus amount that runs out during filling period)

$V_m = V_p + q \times T_d$ (inches)
V_m = Maximum volume that pond can capture (inches)
V_p = Brim full capacity of the basin (inches)
q = Average release rate (inches/hr from step 2 above)
T_d = duration of the storm (hours)
$T_d \times q$ = volume that runs our of pond during the storm (inches)

4. Determine actual volume of storm captured

a) If $V_r > V_m$ Pond has overflowed therefore $V_c = V_m$
V_c = captured volume

b) If $V_r < V_m$ Pond did not fill $V_c = V_r$
V_c = captured volume

5. Determine total runoff and total captured volume

a) $V_{tr} = \sum_{i=1}^{n} V_{ri}$ = (Total runoff in inches for period of record)
i = storm number
n = total number of storms analyzed

b) $V_{tc} = \sum_{i=1}^{n} V_{ci}$ = (Total runoff captured in inches for period of record)

c) i = storm number
n = total number of storms analyzed

6. Determine runoff volume capture ratio

$R_v = V_{tc} / V_{tr}$
Rv = Runoff volume capture ratio
V_{tc} and V_{tr} from 5a and 5b above

7. Determine runoff event capture ratio

Re = N_f / N
Re = Runoff event capture ratio
N_f = Number of events where $V_r <= V_m$ (pond did not overflow)
N = Total number of storms

RESULTS OF POND SIZING STUDIES

A series of runs were made for different minimum times between storm and for different runoff coefficients. The program first generated a data set of rainstorms using the TBSmin and Pi criteria that was input using the techniques described earlier on page 4. Next the percent of storm water captured was determined for various pond sizes by applying the equations found on page 13. These equations were applied to the storm record using the input values for runoff coefficients. Figures 21 through 29 show the results of these runs. The graphs contained in these figures are plots of pond size in acre feet per 100 acres of drainage area vs. percent of total runoff water captured by the detention pond. Graphs are provide for TBSmin values of 12, 24, and 48 hours and drainage runoff coefficients (C) of 0.3, 0.6 and 0.9. These graphs are also contained in full size form in appendices Figures 21 through 29.

The final phase of the project was to bring together the data shown in Figures 21 through 29 into a series of curves that could be used by designers and governmental agency officials to determine the size of detention ponds required for various treatment efficiencies-minimum detention times and runoff coefficients.

Figures 30 is a plot of detention pond size vs. runoff coefficient for a pond emptying time of 12 hours. A family of curves are provided which include volume capture efficiencies of 70%, 80% and 90%. Figures 31 and 32 are similar to Figure 30 except that the pond emptying times are 24 and 48 hours respectively. These graphs are also contained in full size form in appendices Figures 30 through 32.

Figures 33 through 35 represents a slightly different way to view the data. Figures 33 is a plot of detention pond size vs. runoff coefficient for a 70% volume capture efficiency. A family of curves are provided which include pond emptying times of 12, 24 and 48 hours. Figures 34 and 35 are similar to Figure 30 except that the volume capture ratios are 80 and 90 percent respectively. These graphs are also contained in full size form in appendices Figures 33 through 35.

POND SIZE VS CAPTURE RATIO TBSmin = 12 hrs

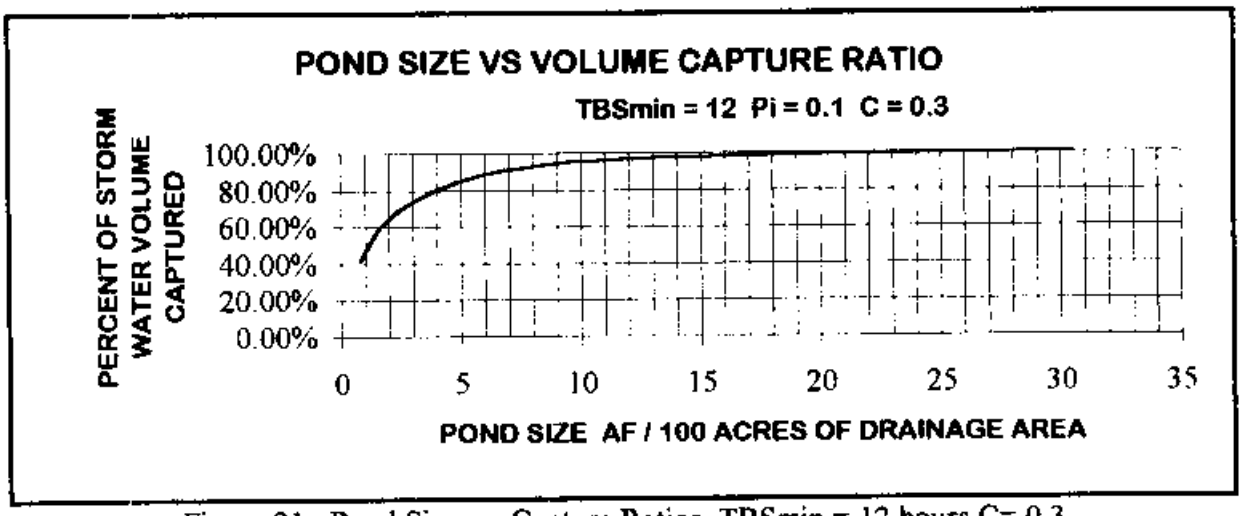

Figure 21. Pond Size vs. Capture Ratios TBSmin = 12 hours C= 0.3

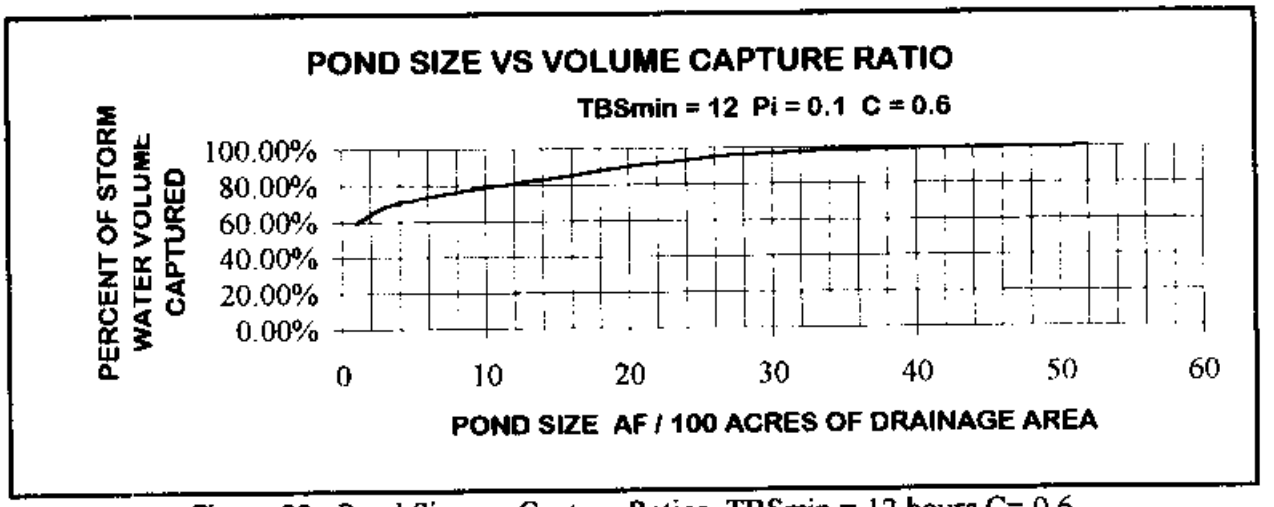

Figure 22. Pond Size vs. Capture Ratios TBSmin = 12 hours C= 0.6

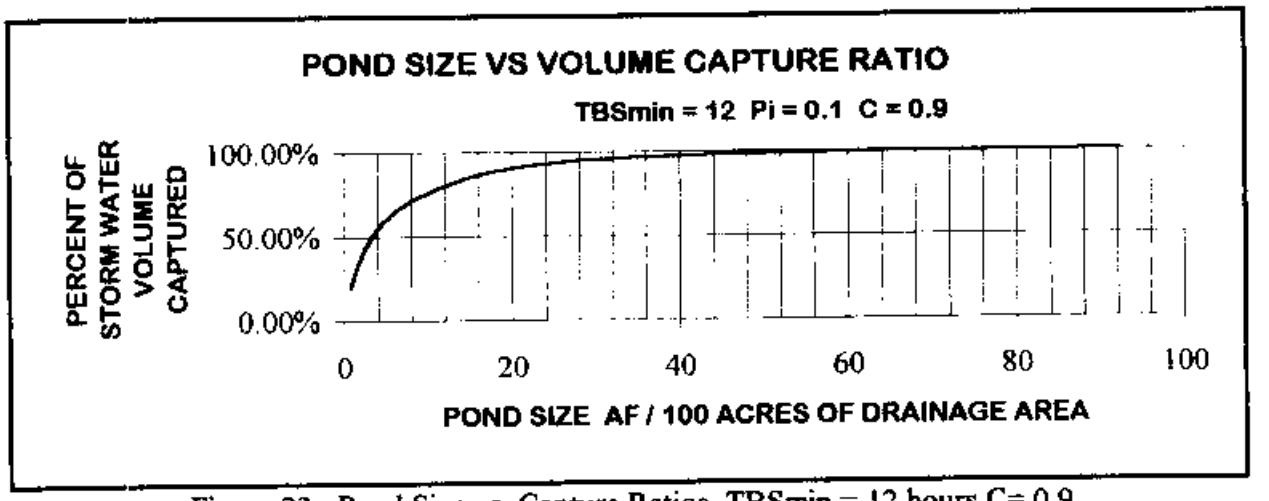

Figure 23. Pond Size vs. Capture Ratios TBSmin = 12 hours C= 0.9

POND SIZE VS CAPTURE RATIO TBSmin = 24 hrs

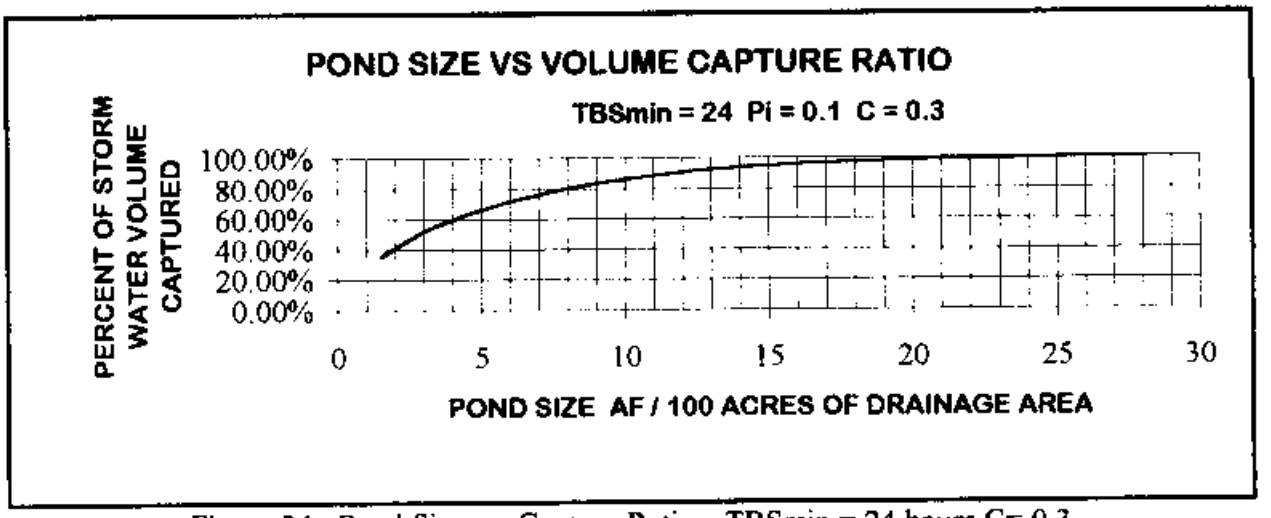

Figure 24. Pond Size vs. Capture Ratios TBSmin = 24 hours C= 0.3

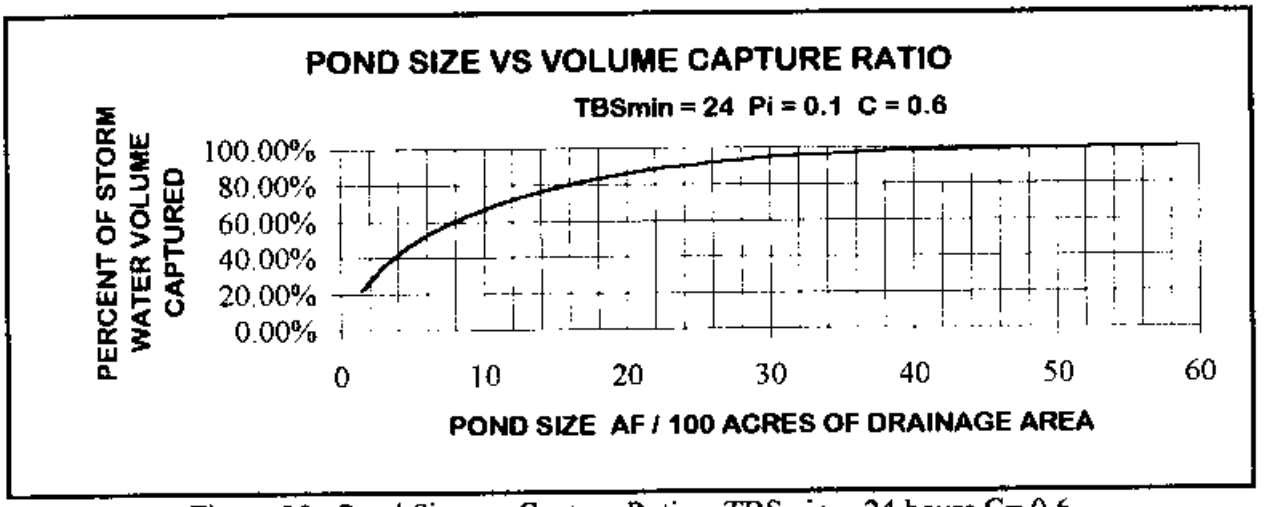

Figure 25. Pond Size vs. Capture Ratios TBSmin = 24 hours C= 0.6

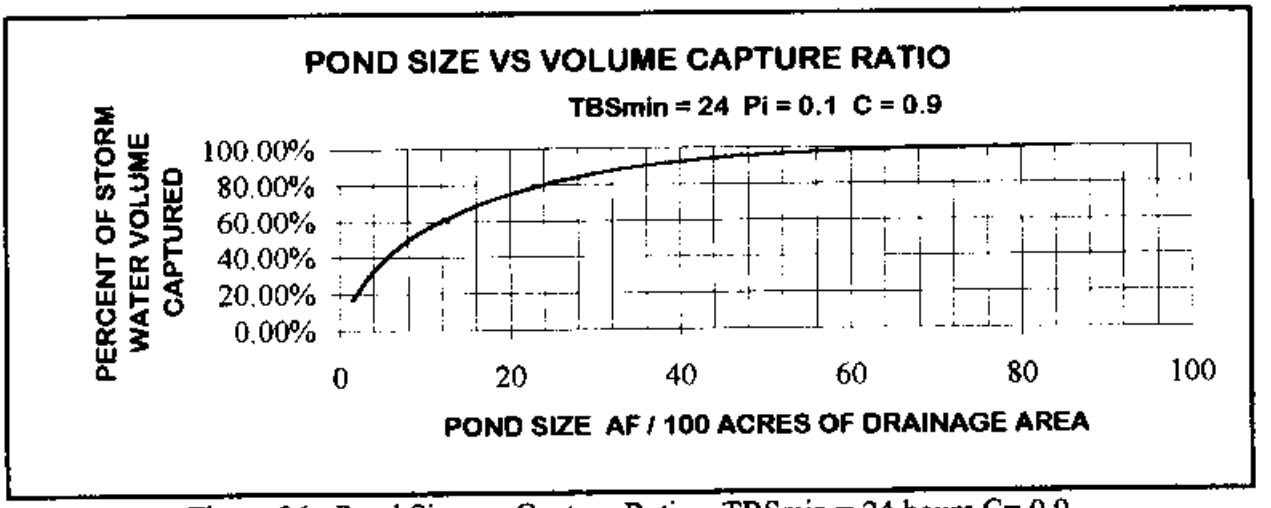

Figure 26. Pond Size vs. Capture Ratios TBSmin = 24 hours C= 0.9

DETENTION POND SIZE VS CAPTURE RATIO TBSmin = 48 hrs

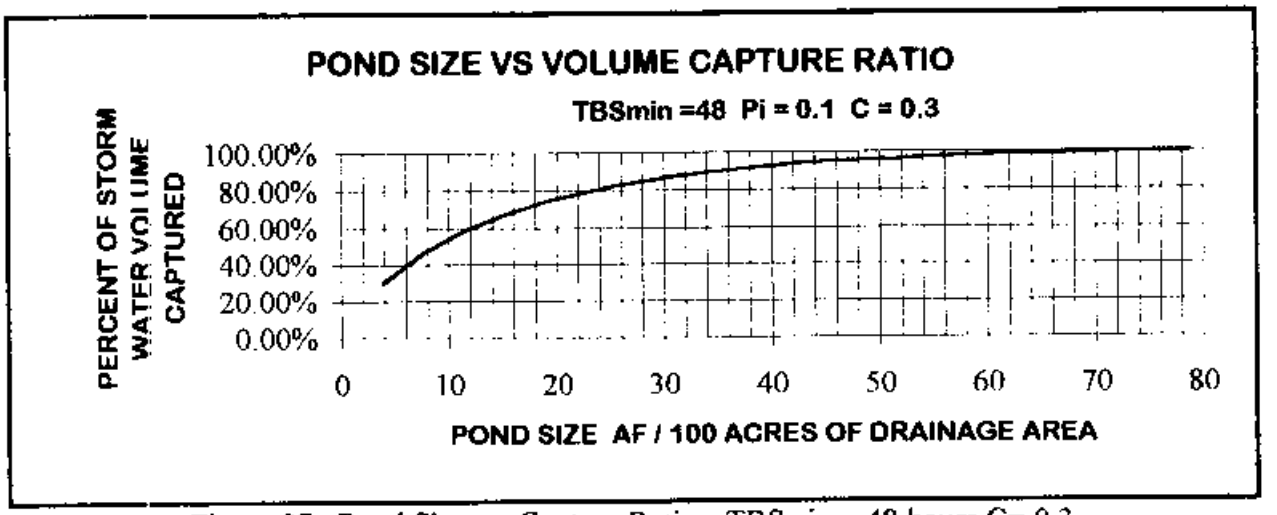

Figure 27. Pond Size vs. Capture Ratios TBSmin = 48 hours C= 0.3

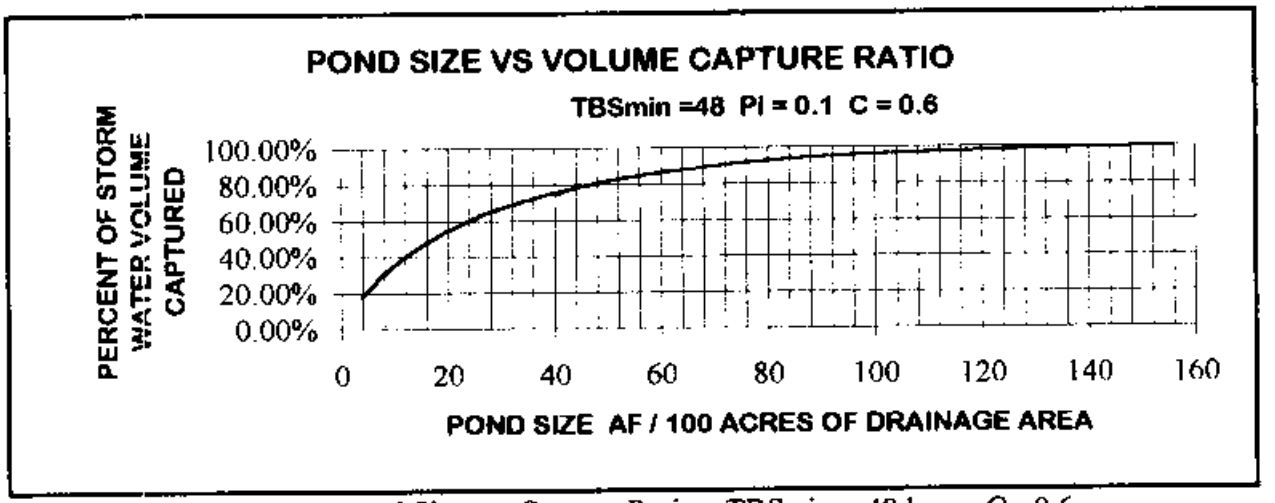

Figure 28. Pond Size vs. Capture Ratios TBSmin = 48 hours C= 0.6

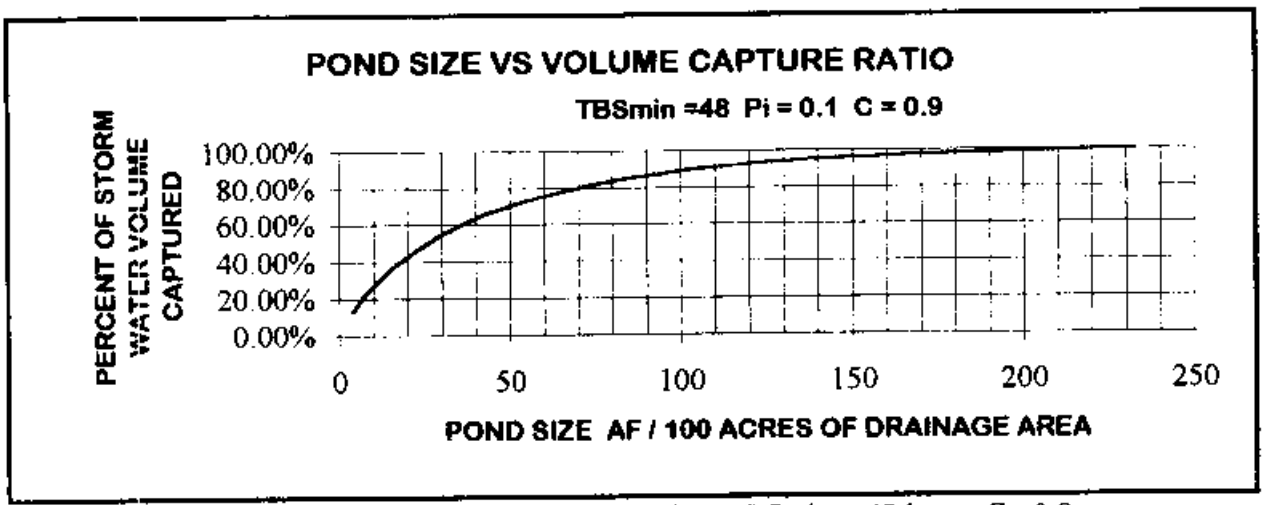

Figure 29. Pond Size vs. Capture Ratios TBSmin = 48 hours C= 0.9

DETENTION POND SIZE VS RUNOFF COEFFICIENT FOR VARIOUS POND DETENTION TIMES AND VOLUME CAPTURE RATIOS

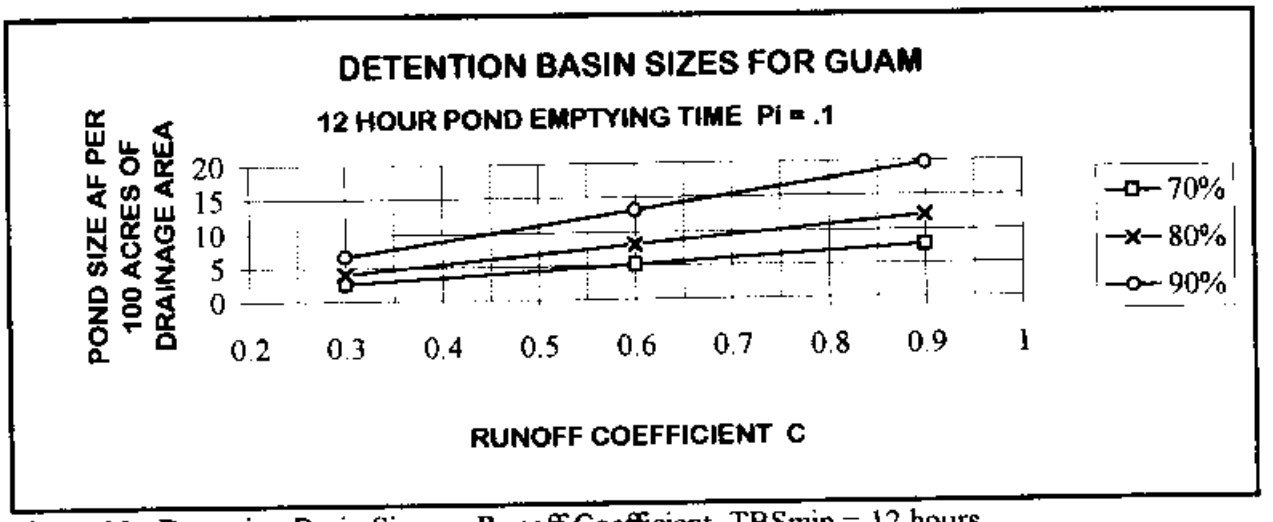

Figure 30. Detention Basin Size vs. Runoff Coefficient TBSmin = 12 hours

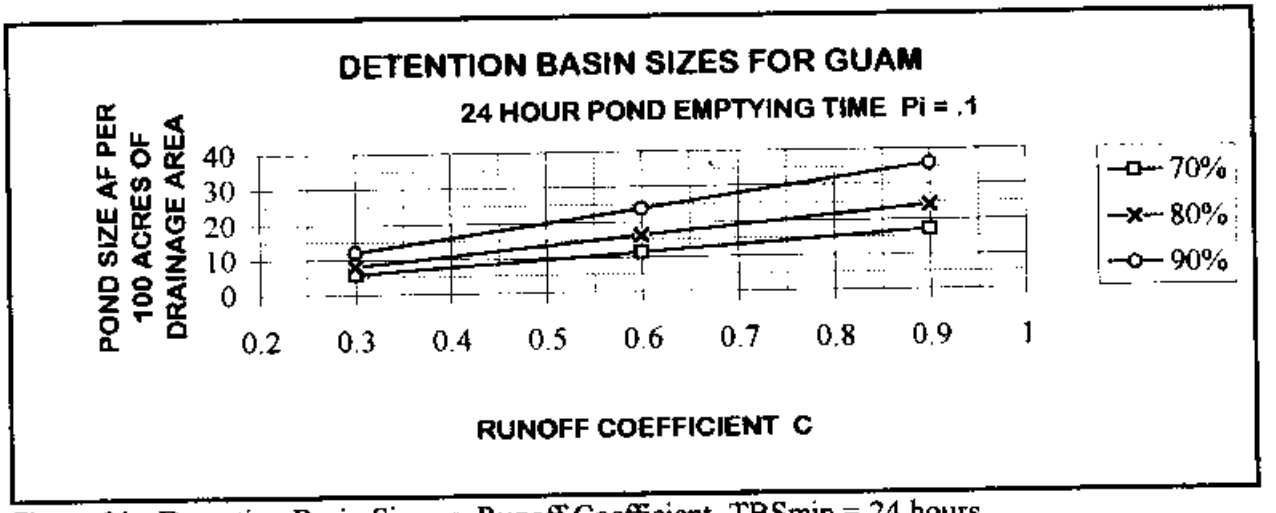

Figure 31. Detention Basin Size vs. Runoff Coefficient TBSmin = 24 hours

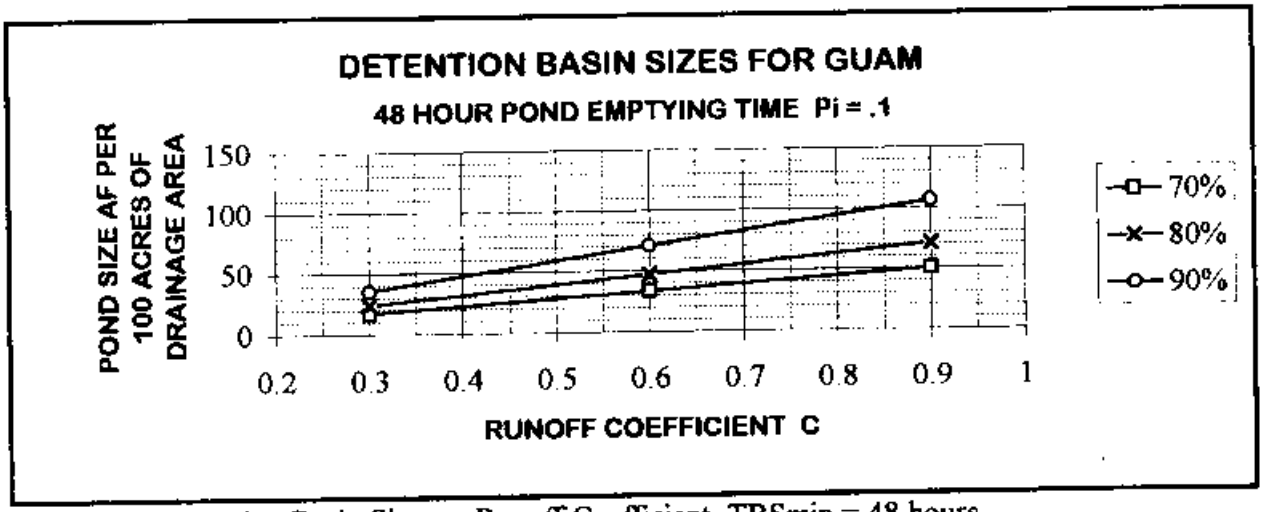

Figure 32. Detention Basin Size vs. Runoff Coefficient TBSmin = 48 hours

DETENTION POND SIZE VS RUNOFF COEFFICIENT FOR VARIOUS CAPTURE RATIOS AND POND DETENTION TIMES

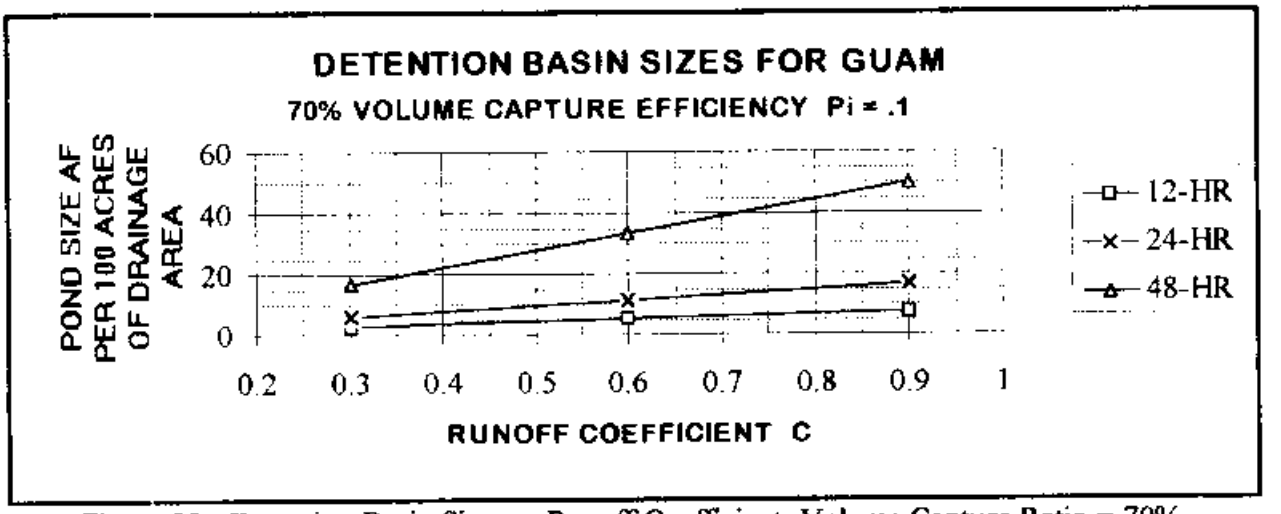

Figure 33. Detention Basin Size vs. Runoff Coefficient Volume Capture Ratio = 70%

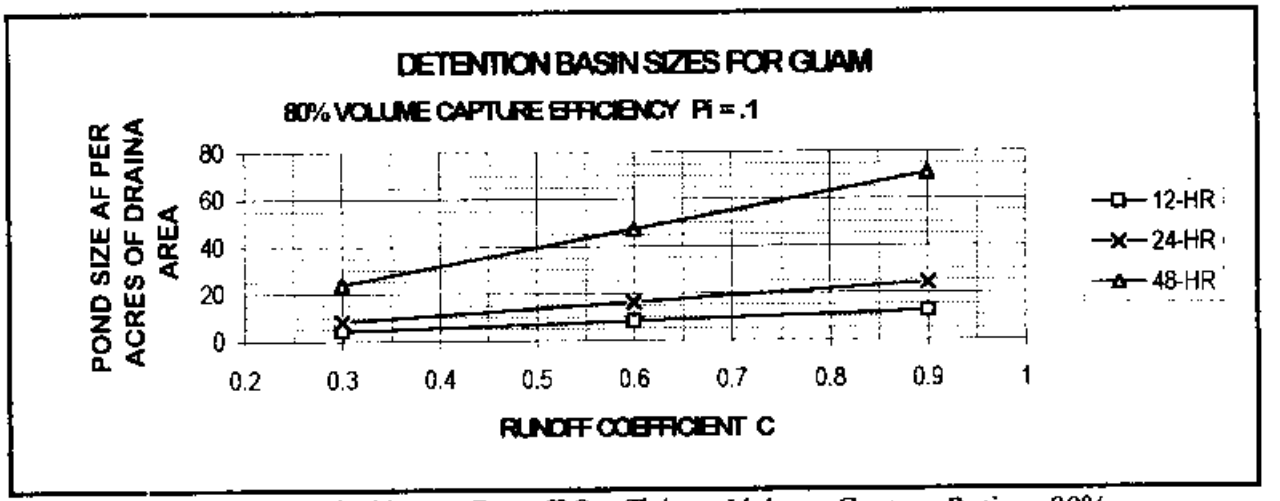

Figure 34. Detention Basin Size vs. Runoff Coefficient Volume Capture Ratio = 80%

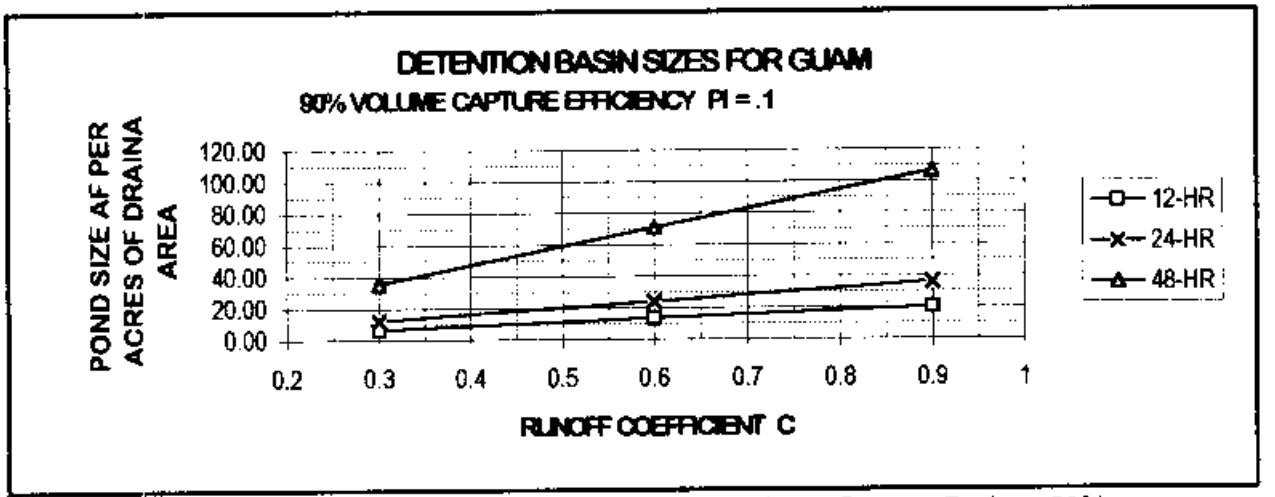

Figure 35. Detention Basin Size vs. Runoff Coefficient Volume Capture Ratio = 90%

EXPLANATION OF THE USE OF THE POND DESIGN CURVES

Figures 30 through 35 could be used by those designing runoff detention ponds or those reviewing the design of new or existing structures. In order to use these curves certain input parameters are required. These would include:

1. Catchment area to be served by the detention pond (in acres)
2. Runoff coefficient (C) for the catchment area (can vary from 0 to 1)
3. Minimum settling time to be provided by the pond (12, 24 or 48 hours)
4. Volume capture ratio desired (curves for 70, 80 and 90 percent)

The catchment area is probably the easiest of the input parameters to determine. One can simply measure the contributing areas to be served by the detention pond. This could be determined from subdivision plot plans or by planimetry of the areas to be served.

The runoff coefficient required is similar to that used in the Rational Formula (Linsley, Kohler and Pahlus, 1975). A value of C = 0.0 means 0.0% of the rain that falls on the area appears as runoff to the pond. A value of C = 1.0 means that 100% of the rain that falls appears as runoff to the pond. There are numerous ways to determine the required C value. One method suggested by the American Society of Civil Engineers Storm Sewer Design Manual (ASCE, 1969) is to adopt a C value based on the type of use for the entire contributing area. Table 4 shows the values recommended by the ASCE Storm Sewer design manual.

Table 4. Runoff Coefficients (C values) for Various Land Uses (ASCE, 1969)

DESCRIPTION OF AREA	RUNOFF COEFFICIENT (C)
Business	
Downtown	0.70 to 0.95
Neighborhood	0.50 to 0.70
Residential	
Single Family	0.30 to 0.50
Multi-units, detached	0.40 to 0.60
Residential (Suburban)	0.25 to 0.40
Apartments	0.50 to 0.70
Industrial	
Light	0.50 to 0.70
Heavy	0.60 to 0.90
Parks and cemeteries	0.10 to 0.25
Playgrounds	0.20 to 0.35
Unimproved	0.40 to 0.30

In some situations where the uses are quite varied it is more meaningful to develop an area weighted coefficient based on the types of surfaces contained in the drainage area. The ASCE Storm drainage manual contains values for several different types of surfaces that can be used in the composite analyses. Table 5 contains a listing of the values found in the ASCE manual.

Table 5. Runoff Coefficients (C values) for Various Runoff Surfaces (ASCE, 1969)

CHARACTER OF SURFACE	RUNOFF COEFFICIENT (C)
Pavement	
Asphalt and concrete	0.70 to 0.95
Brick	0.70 to 0.85
Roofs	0.75 to 0.95
Lawns, sandy soil	
Flat 2 percent	0.05 to 0.10
Average, 2 to 7 percent	0.10 to 0.15
Steep, 7 percent	0.15 to 0.20
Lawns, heavy soil	
Flat 2 percent	0.13 to 0.17
Average, 2 to 7 percent	0.18 to 0.22
Steep, 7 percent	0.25 to 0.35

An example of composite C value analysis using C values from table 5 is shown in Table 6.

Table 6. Sample Composite Runoff Coefficient (C Value) Calculation

AREA DESCRIPTION	AREA ACRES	C VALUE	PERCENT OF TOTAL AREA	WEIGHTED C VALUE
Streets	2	0.8	20%	0.16
Roofs	3	0.9	30%	0.27
Grass, heavy soil flat slopes	5	0.15	50%	0.075
TOTAL	10		100%	0.505

A third method of computing runoff coefficient values can be found in the U.S. EPA Final report on the Nationwide Urban Runoff Program (US. EPA, 1983). This method uses the percent of impervious services as a basis of determining the Runoff Coefficient. Table 7 shows values of Runoff Coefficient for various percentage of impervious cover for the drainage area. Figure 36 is the same data as in Table 7 plotted in graph form. All that is required to use the table or Figure is to determine the percentage of impervious cover in the runoff area. These would include areas such as pavement, sidewalks, roof tops and other areas where no percolation can occur.

Table 7. Runoff Coefficients (C values) vs. Percentage of Impervious Cover (EPA, 1983)

IMPERVIOUSNESS PERCENT	C - VALUE	IMPERVIOUSNESS PERCENT	C - VALUE
5.0	0.077	60.0	0.409
10.0	0.110	65.0	0.449
15.0	0.141	70.0	0.494
20.0	0.170	75.0	0.544
25.0	0.198	80.0	0.599
30.0	0.225	85.0	0.661
35.0	0.252	90.0	0.730
40.0	0.280	95.0	0.807
45.0	0.309	97.0	0.840
50.0	0.339	100.0	0.892
55.0	0.372		

NOTE: C - values were developed from daily runoff values

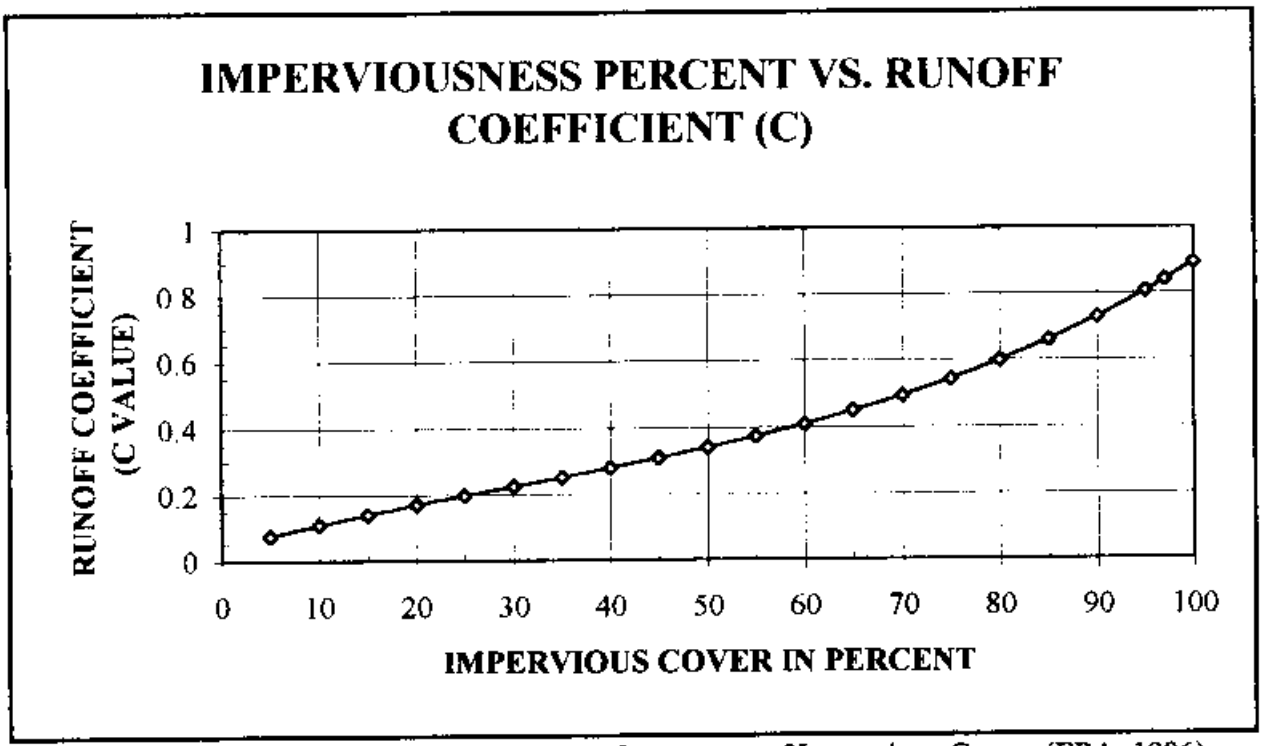

Figure 36. Runoff Coefficients (C values) vs. Percentage of Impervious Cover (EPA, 1986)

The next factor which must be determined is the minimum detention time desired for the pond. As was mentioned earlier the minimum detention times are reflected by the minimum time between storms (TBSmin values) used. These values are a function of suspended materials in the waste stream and the degree of treatment desired. Studies in the mainland U.S. by Grizzard et al. (1986) indicate that basins designed with a drain time of 24 hours provides acceptable levels of treatment. No such studies have been done on Guam to date. In light of the lack of Guam based data it is recommended that 24 hour detention time be a minimum standard until field studies can be made.

The final parameter that must be considered is the percent volume capture ratio. Figure 25 on page 18 shows that a pond designed with TBSmin = 24 hrs and Runoff Coefficient of 0.6 will capture approximately 65% of the total volume of runoff if sized at 10 AF of Volume for each 100 acres of area contributing runoff to the pond. In order to capture 100 percent of the runoff volume it would be necessary to build a pond sized at 58 AF per 100 acres of area contributing runoff. Note to gain a 50% increase in volume capture (from 65% to 100%) requires nearly a 6 fold increase in pond size. This can be explained if we look at the slope of the curve in Figure 25. For smaller size ponds and capture volumes the slope is very steep. This means that for small increases in pond size we get large increases in capture volume. As the volume capture ratios get larger the slope of the curve gets less. This means that relatively larger increases in pond size area are required to get increases in volume capture ratios.

Dr. Gou (Gou, 1992) has developed an optimization scheme for choosing pond sizes. This scheme finds the place where the slope of the Pond size vs. Volume capture curve has a slope of 1 to 1. His conjecture is that this is the point of diminishing returns for increasing the pond size. While theoretically this may be true, there my be a problem in the practical application of his theory. Since economics must come to bear in this situation we must look at the costs and benefits involved. Cost of providing the runoff pond and appurtenant structures are probably highly non-linear. Likewise the benefits of removing the pollutants from the waste stream at this time are very hard to determine and probably very non-linear also. To equate an optimal solution to a 1 to 1 slope on a curve one must have equivalent and comparable units on both axes. At this time it is felt that the more simplistic approach suggested by Dr. Gou may not adequately account for the non-linearity and non comparability of the values on the two axes. It is suggested that the governmental regulatory agency, in our case, Guam EPA, set a required volume capture ratio to be used. If the developer wants to choose a lesser value then he must require adequate justification for his choice. At this time it is suggested that a value of 60 to 80% be chosen as the desirable volume capture ratio.

Once the catchment area (in acres), the runoff coefficient (C value), Minimum Pond Settling Time (TBSmin), and desired volume capture ratio have been selected all that is required is to choose the appropriate curve from Figures 30 through 35 and read off the required pond size per hundred acre of contributing area.

The last step in the procedure is to account for rainfall variability with location through out the Guam. Since there is only one rain gage available on Guam with hourly rainfall data available it was not possible to develop a group of curves to account for rainfall variability with location. What is suggested is to adjust the final pond size based on the ratio of the average annual precipitation at the Guam WSMO site to the average precipitation at the site where the pond will

be located. The average annual precipitation at the Guam WSMO site is 102 inches per year based on the 1957 to 1993 record (Hydrosphere, 1994). Figure 37, which was developed by the Natural Resources Conservation Service (NRCS) provides estimates of the average annual precipitation through out the island.

To determine the correct pond sizing ratio simply divide the average precipitation value estimated from Figure 37 by the 102 inch value for the Guam WSMO Gage. Multiplying the pond size determined from the design curves by the by this ratio will give a location adjusted estimate of the required pond size. The case Study on page 28 provides an example of determining the required runoff detention pond size for a proposed development in Guam.

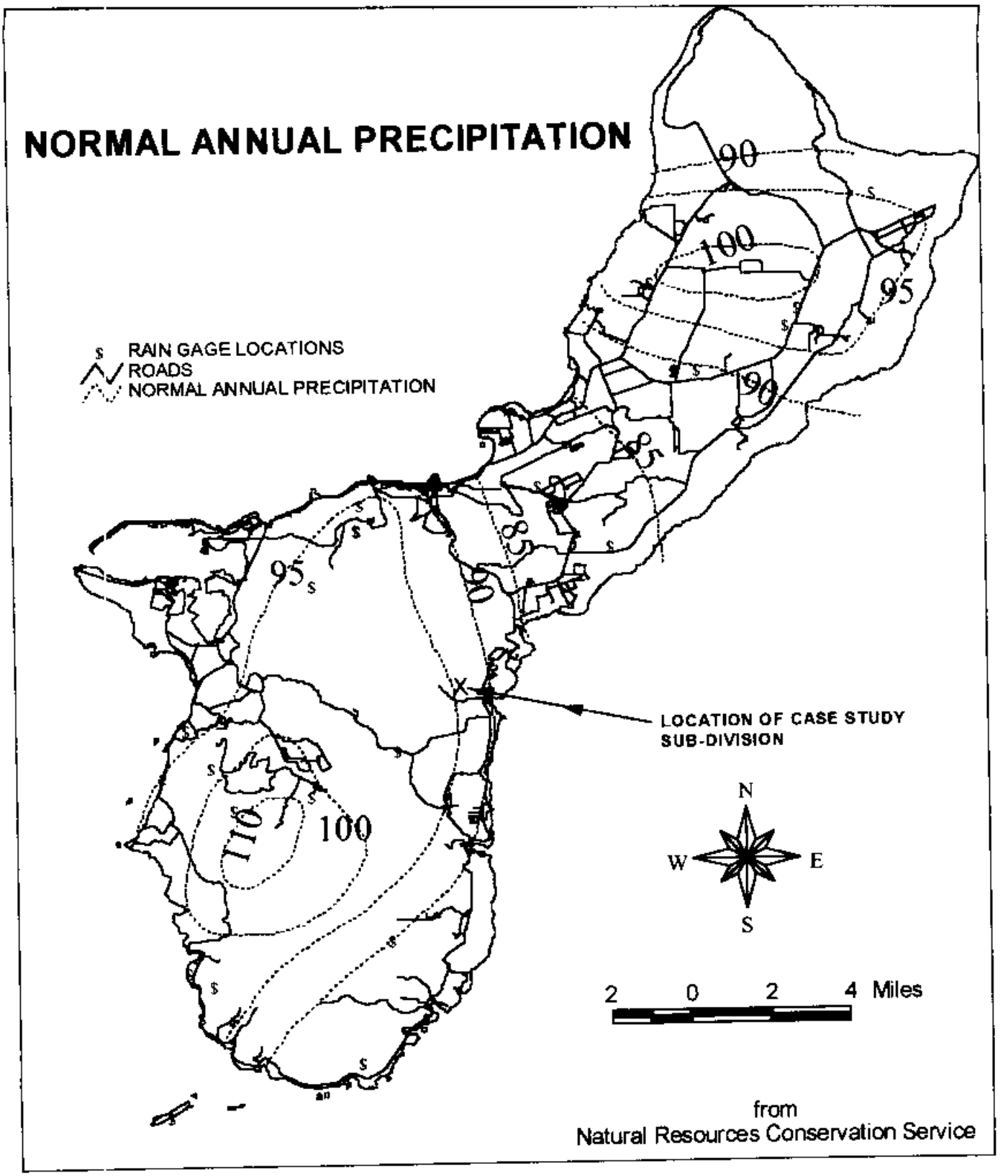

Figure 3-7. Normal Annual Precipitation and Rain Gage Locations

IMPLEMENTATION OF POND SIZING CRITERIA INTO GUAM'S REGULATORY STRUCTURE

The quality of life and economic prosperity in Guam is intimately tied to the quality of its water resources. As urbanization, resort development and land use intensification continue to increase, these resources are becoming more and more stressed. Degradation of water quality has occurred due in part to storm water runoff and non-point pollution sources. Management and control of these pollution sources is imperative if the quality of Guam's water resources is to be maintained.

The goal of this study was to make an in depth investigation of rain storms on Guam and to develop a set of design graphs and tables so that governmental regulators can adopt an appropriate set of regulations for detention pond sizing for minimizing the impact of storm water runoff on the receiving waters of Guam.

Certain steps will be required of Guam's Governmental Agencies in order for the work described in this report to be of any use in lessening the impact of surface runoff. We feel that the government of Guam should adopt a regulation requiring that all new developments provide storm water detention pond storage of all surface water leaving the development before entering any surface water streams or the ocean. This ordnance and ancillary documents should contain:

1. Specific requirements as to minimum detention time required in the storm water detention basins (TBSmin).

2. Specific requirements as to volume capture ratio of the sediment detention ponds.

3. Specific portions of this report such as:

    a) The design curves contained in figure 30 through 35.

    b) The data on runoff coefficients contained in Tables 4, 5,6 and 7 and Figure 36.

    c) The data on normal annual precipitation distribution contained in Figure 37.

    d) The case study that begins on page 28.

CASE STUDY TO ILLUSTRATE THE USE OF DESIGN CURVES

The following case study is provided to illustrate the use of the design curves and procedures developed as a result of this project. The objective of the study is to develop a pond size for the sample subdivision that is shown in Figure 38.

The first step of the study is to determine the factors needed as input to the design curves. These would include:

1. Catchment area to be served by the detention pond (in acres)
2. Runoff coefficient for the catchment area (can vary from 0 to 1)
3. Minimum settling time to be provided by the pond (12, 24 or 48 hours)
4. Volume capture efficiency desired (curves for 70, 80 and 90 percent)

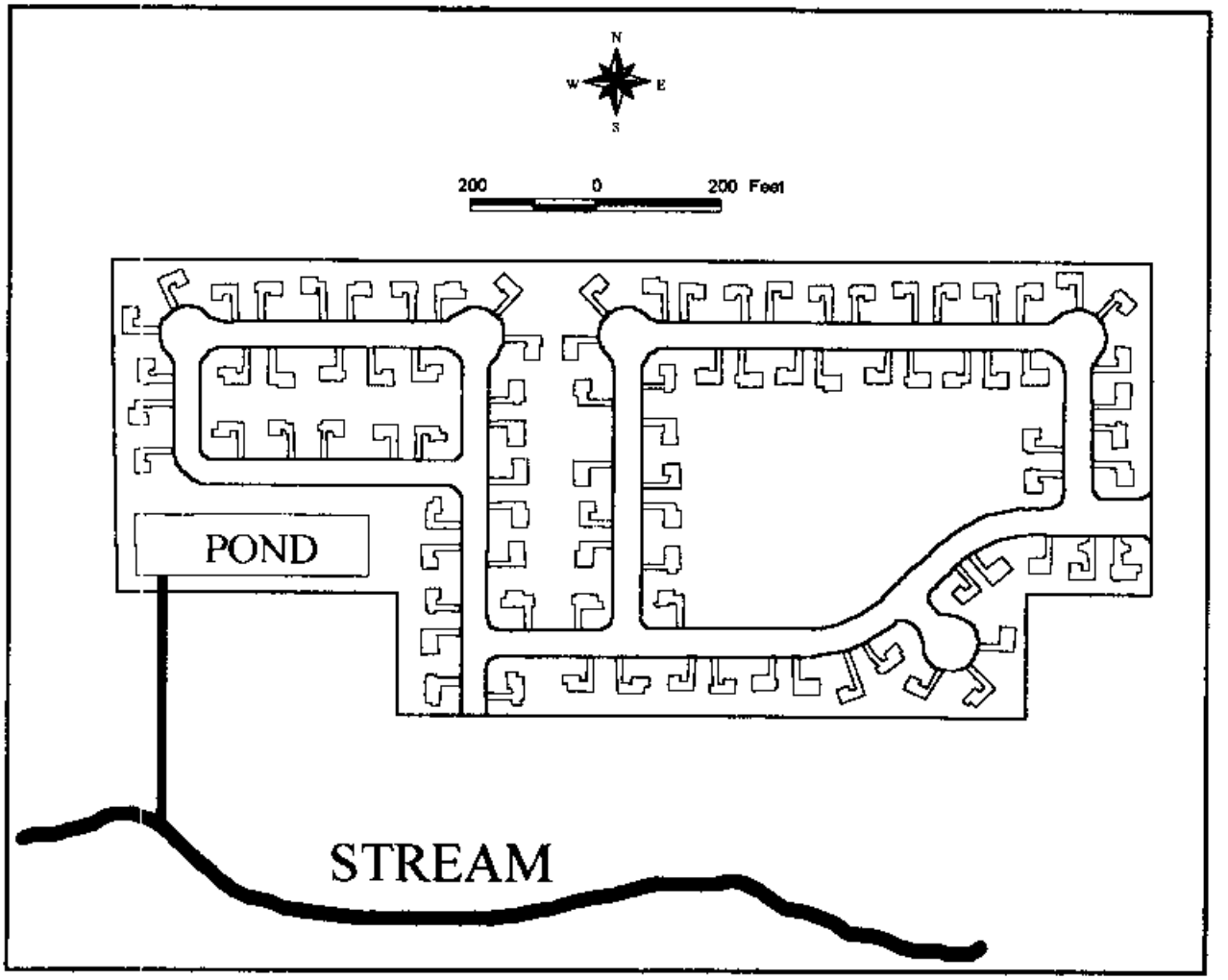

Figure 38. Sample Sub-Division for Case Study

Catchment area to be served by the detention pond (in acres): There are several methods which the total drainage area could be determined. In this particular example the entire subdivision was input into a Geographic Information System (GIS). The GIS computed the area values for the different land uses. Table 8 contains a tabulations of the values computed by the GIS. It is not necessary to use a GIS for this part of the process. Traditional planimmetry or other means of calculating areas would be perfectly acceptable. The total areas of the catchment served by the detention pond is 24.98 acres.

Table 8. Drainage Areas and Cover Types for Sample Sub-Division

IDENTIFICATION	AREA (acres)	USE TYPE
Roads and other paved areas	4.78	Pavement
House structure and driveways	2.82	Concrete
Detention pond	0.84	100% runoff
Grass covered lawns and parks	16.54	Grass heavy soil
TOTAL AREA	24.98	

Runoff coefficient for the catchment area: The runoff coefficient can be determine by several methods. There are several methods available to do this. The first method is to look at the runoff coefficient recommended in table 4 and choose the one that is appropriate for the areas under study. Since our area is single family residential we would choose a value of 0.30 to 0.50 say 0.40. The second method we will illustrate is the use of the composite weighted areas method using the ASCE Storm sewer design values as shown in Table 4 on page 21. Table 9 below shows the results of the weighted area calculations. The resulting C value of 0.40 agrees well with the first method described above.

Table 9. Composite Weighted Areas Calculation for Runoff Coefficient (C)

IDENTIFICATION	AREA (acres)	RUNOFF COEFCIENT	AREA TIMES RUNOFF
Roads and other paved areas	4.78	0.90	4.30
House structure and driveways	2.82	0.85	2.40
Detention pond	0.84	1.00	0.84
Grass covered lawns and parks	16.54	0.15	2.48
TOTALS	24.98		10.02
AVERAGE C VALUE		10.02/24.98	0.40

A third method would be to use the percent impervious area method illustrated on page 22. From Table 8 we can see that the roads, house structures and detention pound covers an area of 8.44 acres. This amounts 34 percent of the total area being covered with impervious material. From Table 7 we find a C value of approximately 0.25.

Table 10 shows a comparison of the three C-Value calculations. In this case because of the close agreement between the first two methods a C-Value of 0.40 should probably be chosen.

Table 10. Comparison of C-Value Computations

COMPUTATION TYPE	C-VALUE
General Land Use Classification	0.40
Composite Weighted Value	0.40
Impervious Percentage Method	0.25

Minimum settling time to be provided by the pond: It is expected that this requirement would be specified in the appropriate government regulations covering sedimentation ponds. This value could also be determined from field sampling of runoff from areas similar to the proposed development. For this case study we will use a value of 24 hours as discussed in the section on storm runoff pond detention time on page 24.

Volume capture efficiency desired: It is expected that this requirement would be specified in the appropriate government regulations covering sedimentation ponds. Adopted values would probably range from 60 to 80 percent. For this case study we will use a Volume Capture Ratio of 70 percent.

The next step is to find the size of the pond for this case study. Table 11 shows the factors that was obtained from step 1 through 4.

Table 11. Factors Needed for Selecting the Pond Size for the Case Study

TOTAL DRAINAGE AREA (ACRE)	RUNOFF COEFFICIENT (C)	MINIMUM SETTLING TIME	VOLUME CAPTURE EFFICENCY
24.98	0.4	24 - HOURS	70%

From Figure 31, on page 21, seven (7) acre feet pond is required for 100 acres of catchment area. Since the catchment area of the case study is 24.98 acres, the volume of the pond should be 1.7 acre feet (24.98 X 7 / 100).

The final step is to determine the correct pond sizing ratio and required pond size. We can see from Figure 37 that the average annual precipitation at the case study site location is 95 inches. The pond sizing ratio is computed by dividing the average precipitation at our site by the average precipitation at the Guam WMSO gage site that was used for this study. The WMSO gage site average annual precipitation is 102 inches as described on page 25. The pond sizing ratio is therefore 95/102 or 0.93. We multiply this ratio by the pond size above (1.7 acre feet x 0.93) to get our required pond size of 1.6 acre feet.

ACKNOWLEDGMENTS

We would like to express our appreciation to the Guam National Weather Service office for gathering the rainfall data that was essential for completing this project.

This research was supported by the US Geological Survey, and the University of Guam, Water and Energy Research Institute.

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APPENDICES

APPENDIX I (Continued) **Page**

APPENDIX II. POND SIZING CURVES

APPENDIX II (Continued) **Page**

APPENDIX I.

RAIN STORM CHARACTERIZATION CURVES

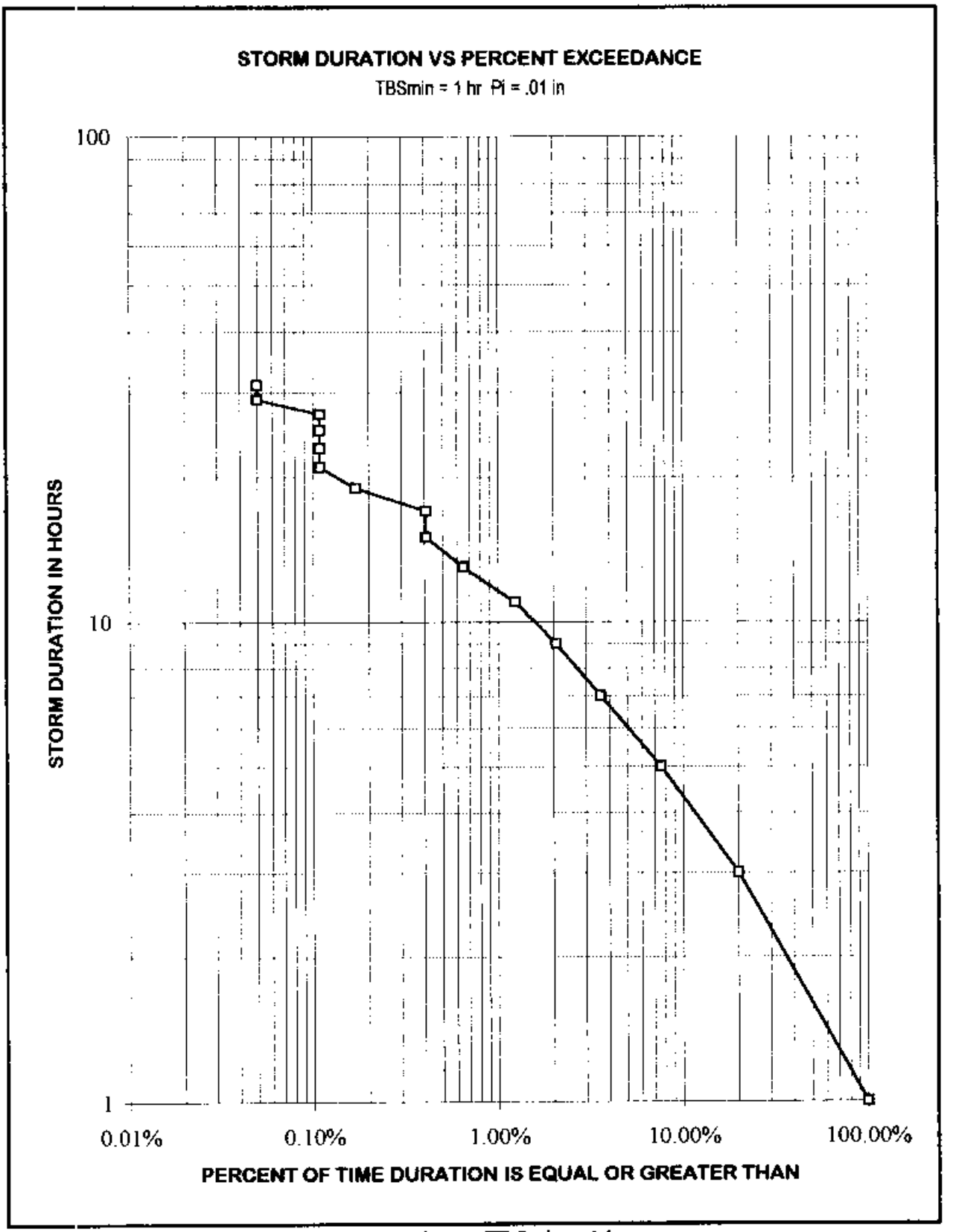

Figure 1. Rainfall Depth vs. Percent Exceedance TBSmin = 1 hour

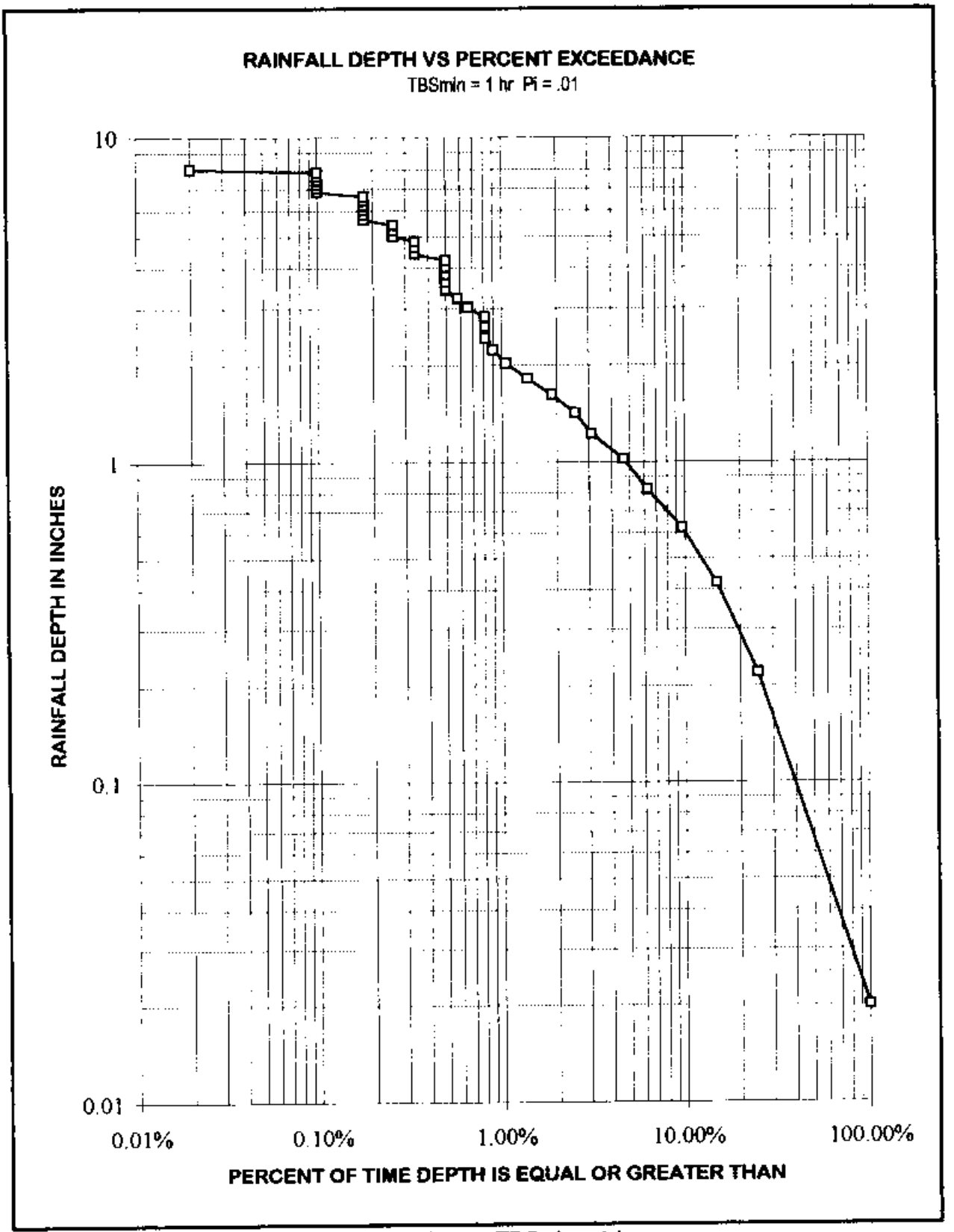

Figure 2. Rainfall Depth vs. Percent Exceedance TBSmin = 1 hour

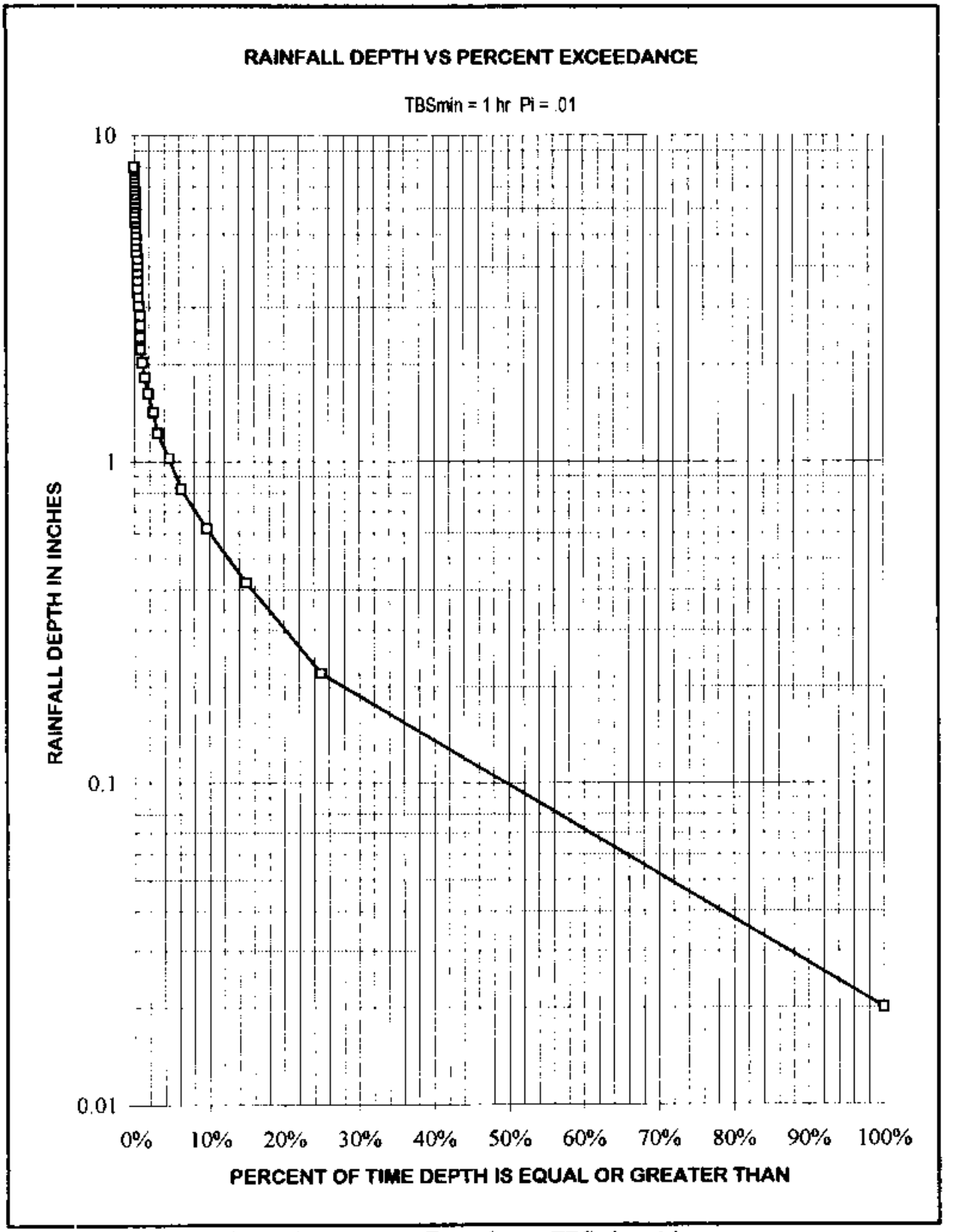

Figure 3. Rainfall Depth vs. Linear Percent Exceedance TBSmin = 1 hour

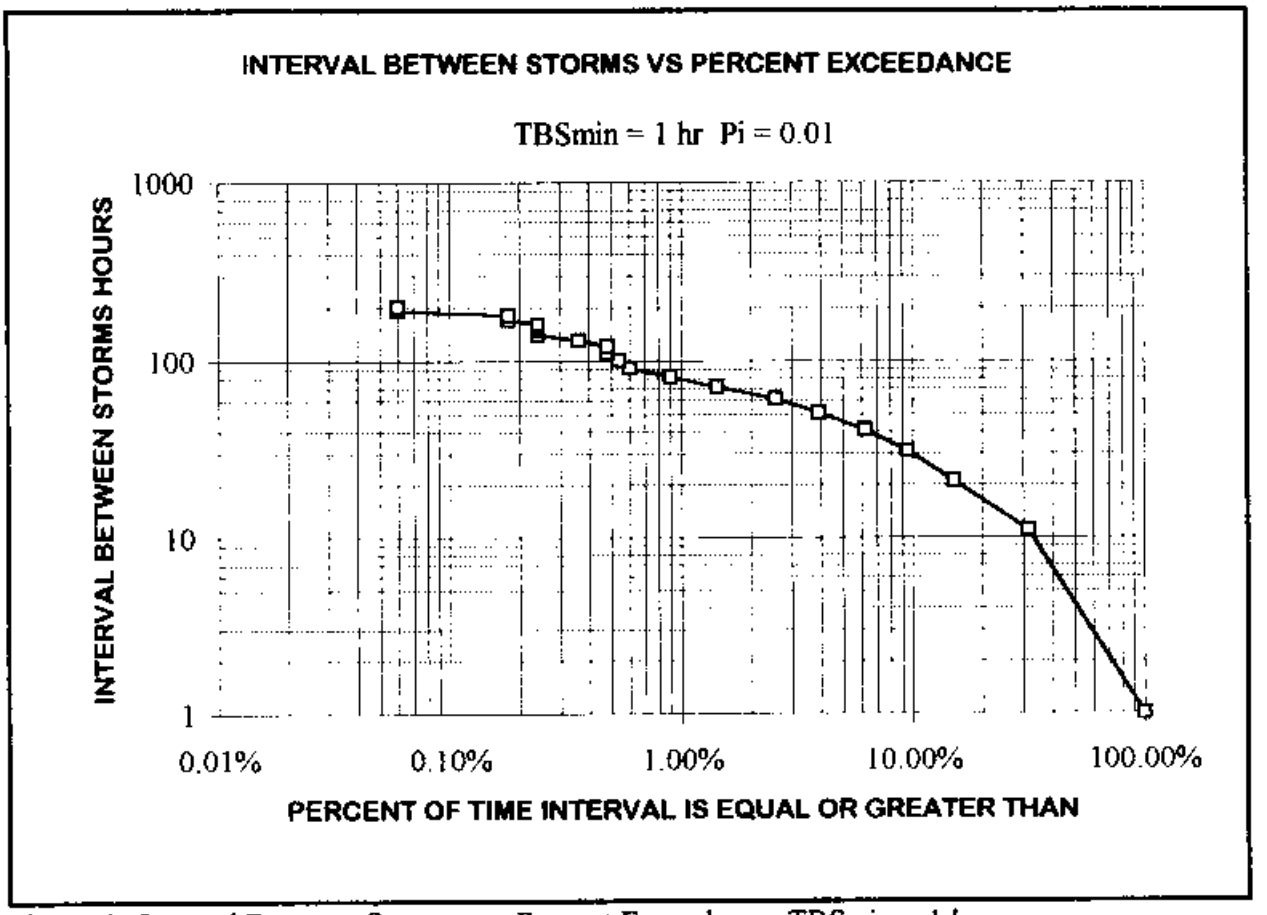

Figure 4. Interval Between Storms vs. Percent Exceedance TBSmin = 1 hour

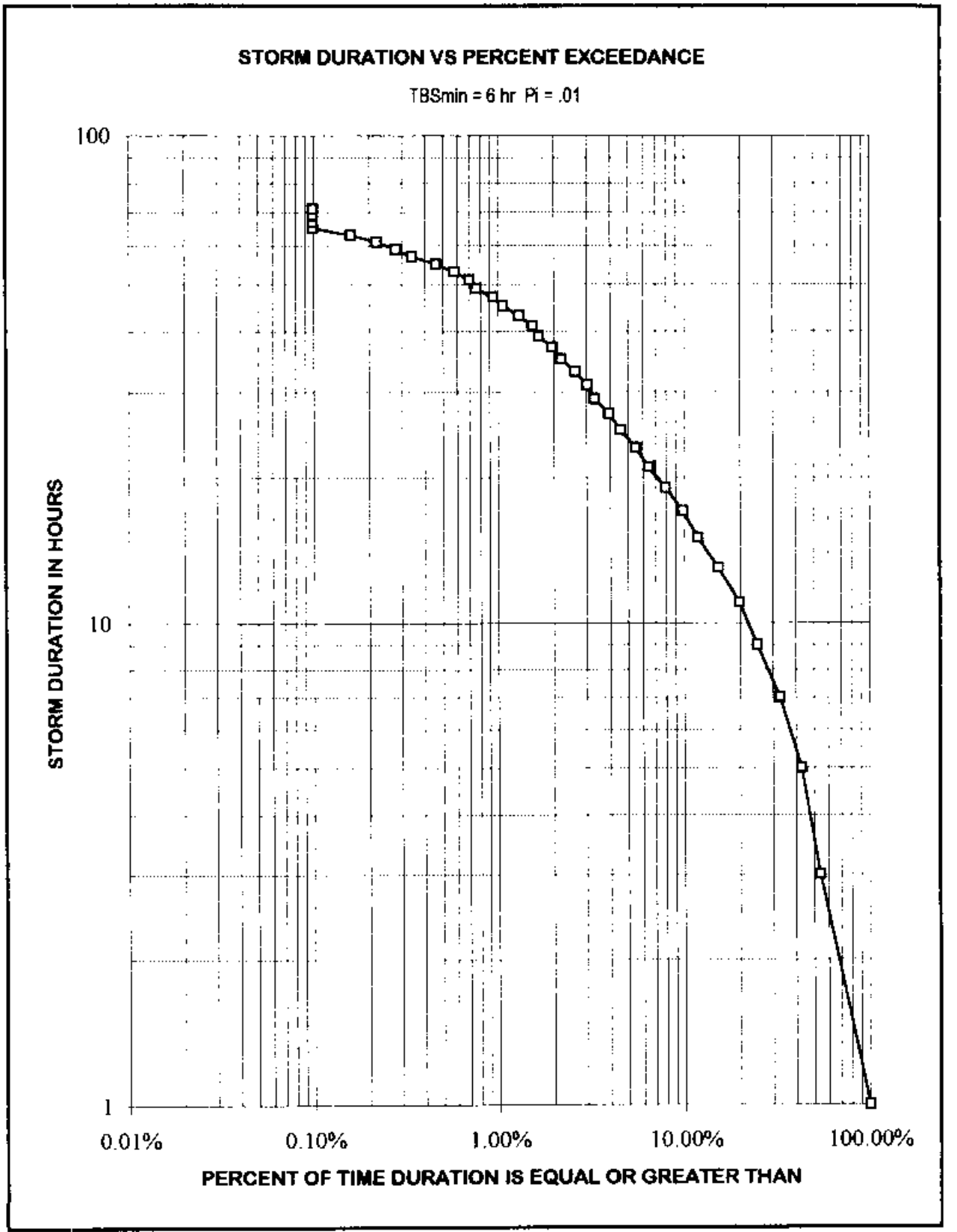

Figure 5. Rainfall Duration vs. Percent Exceedance. TBSmin = 6 hours

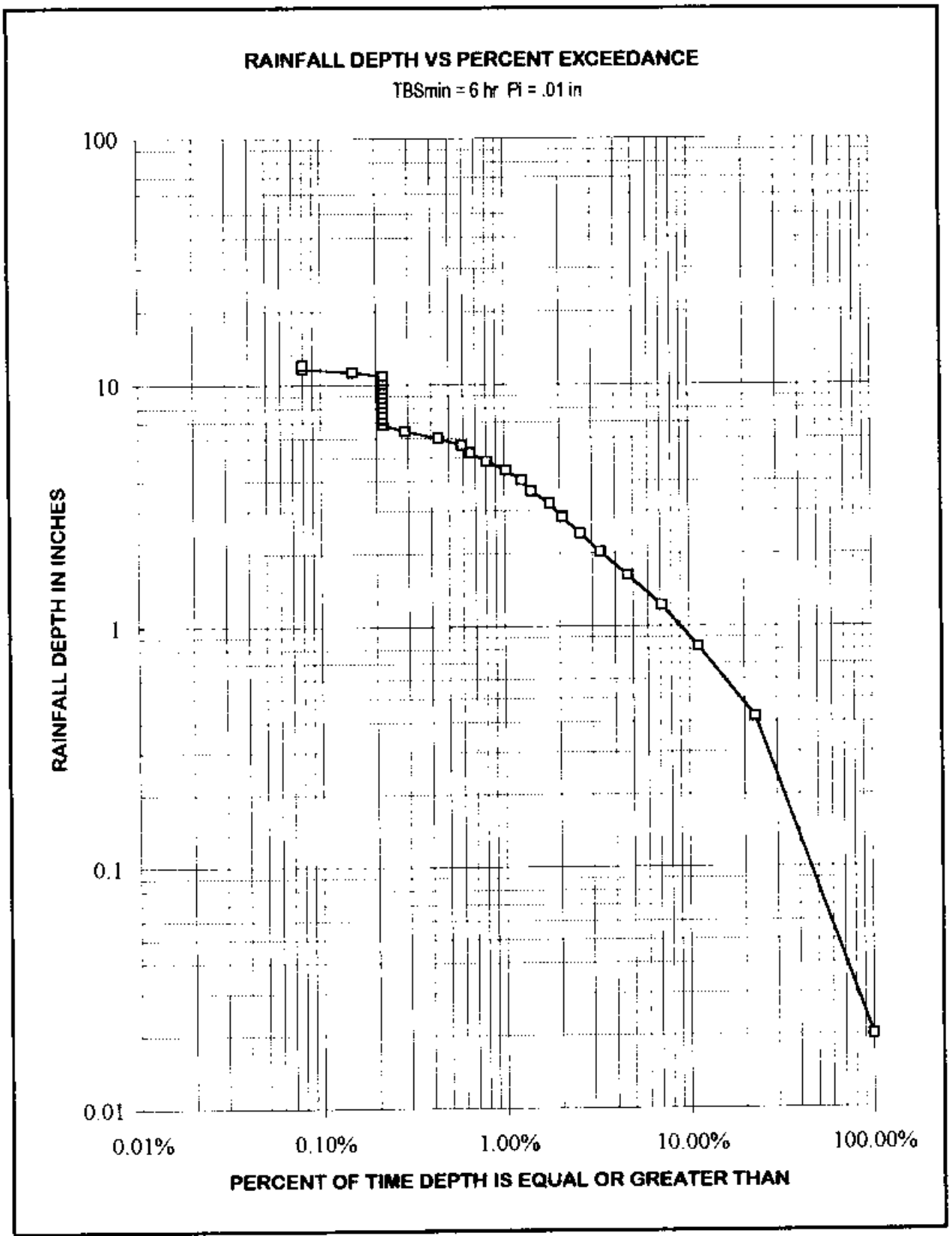

Figure 6. Rainfall Depth vs. Percent Exceedance. TBSmin = 6 hours

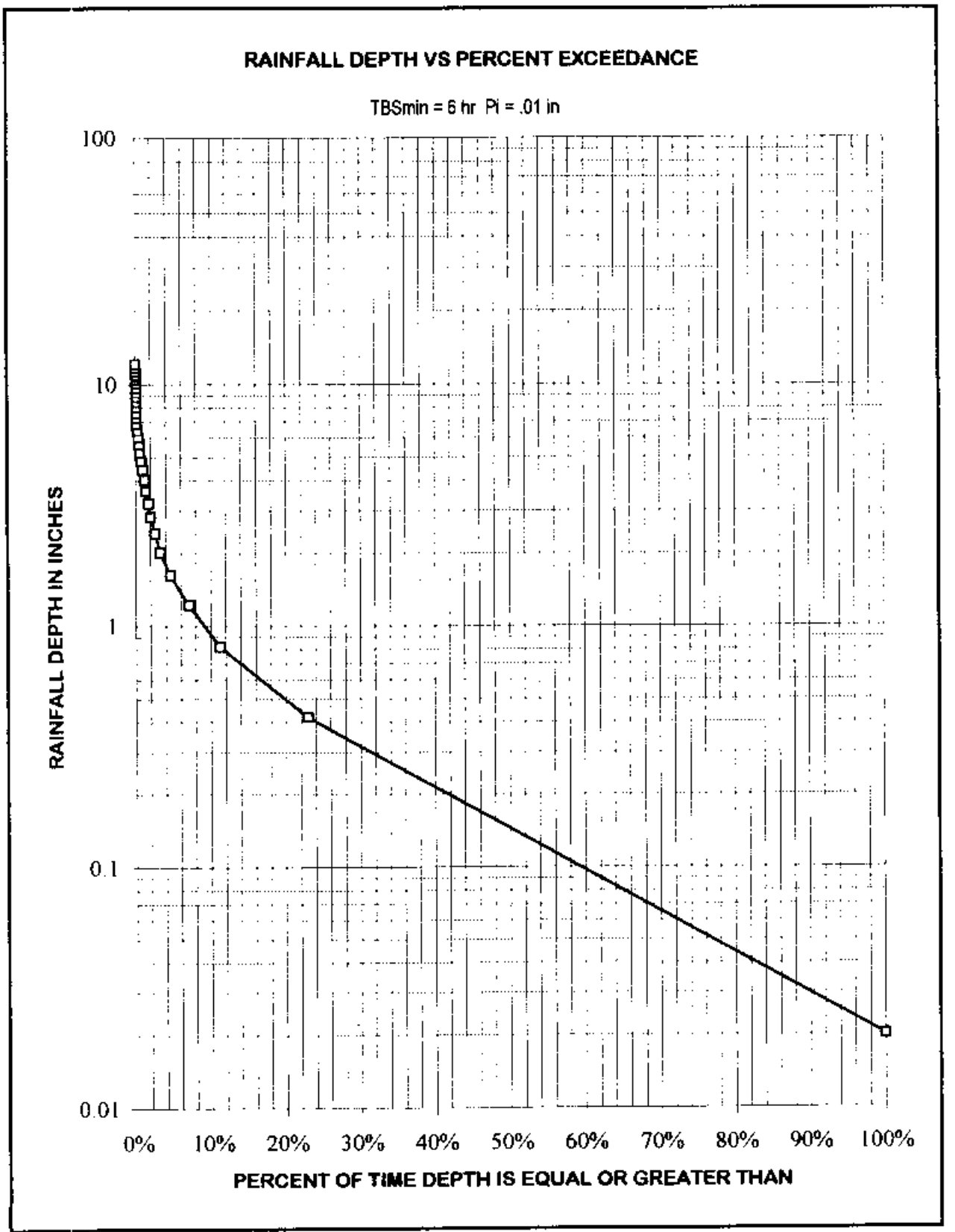

Figure 7. Rainfall Depth vs. Linear Percent. Exceedance. TBSmin = 6 hours

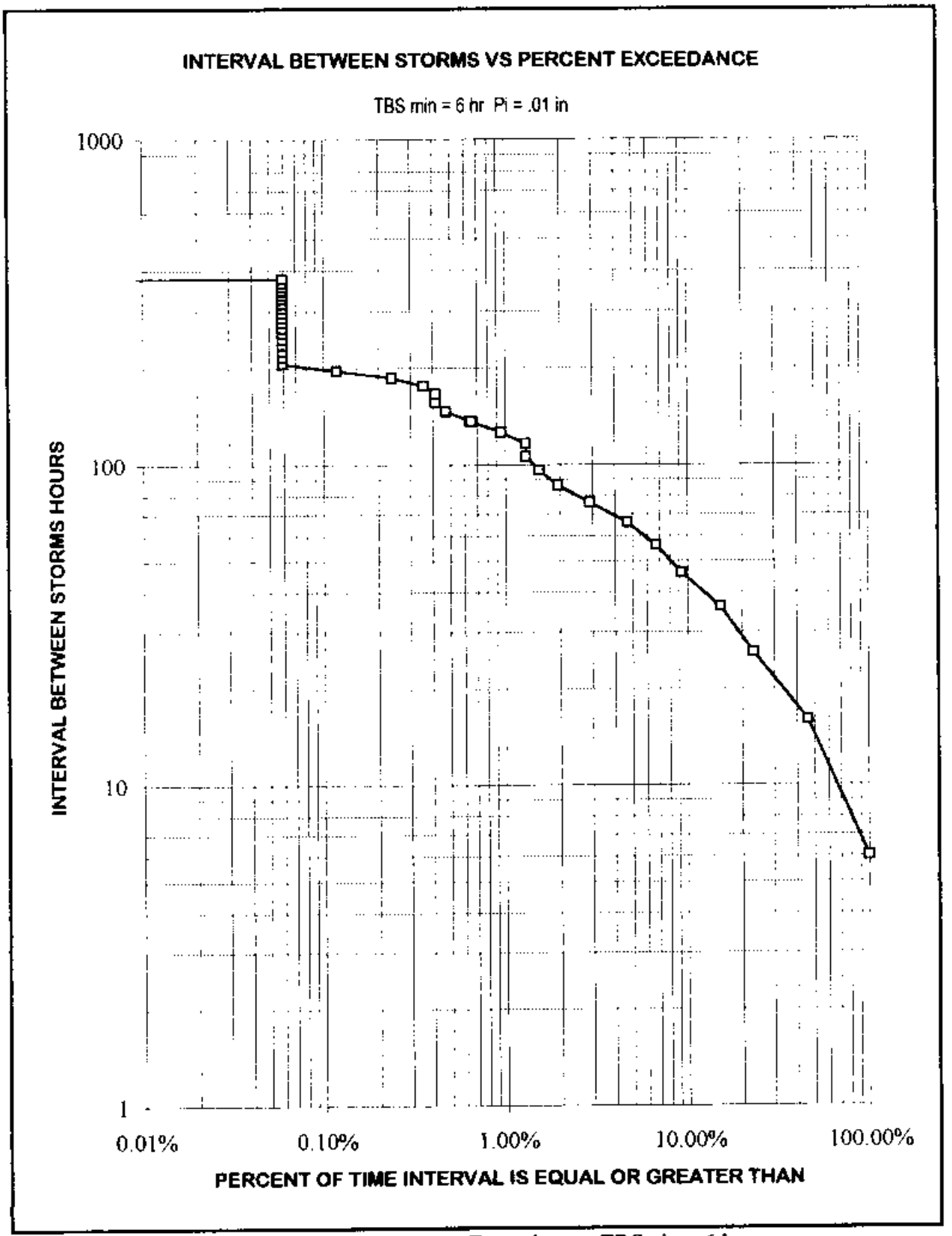

Figure 8. Interval Between Storms vs. Percent Exceedance. TBSmin = 6 hours

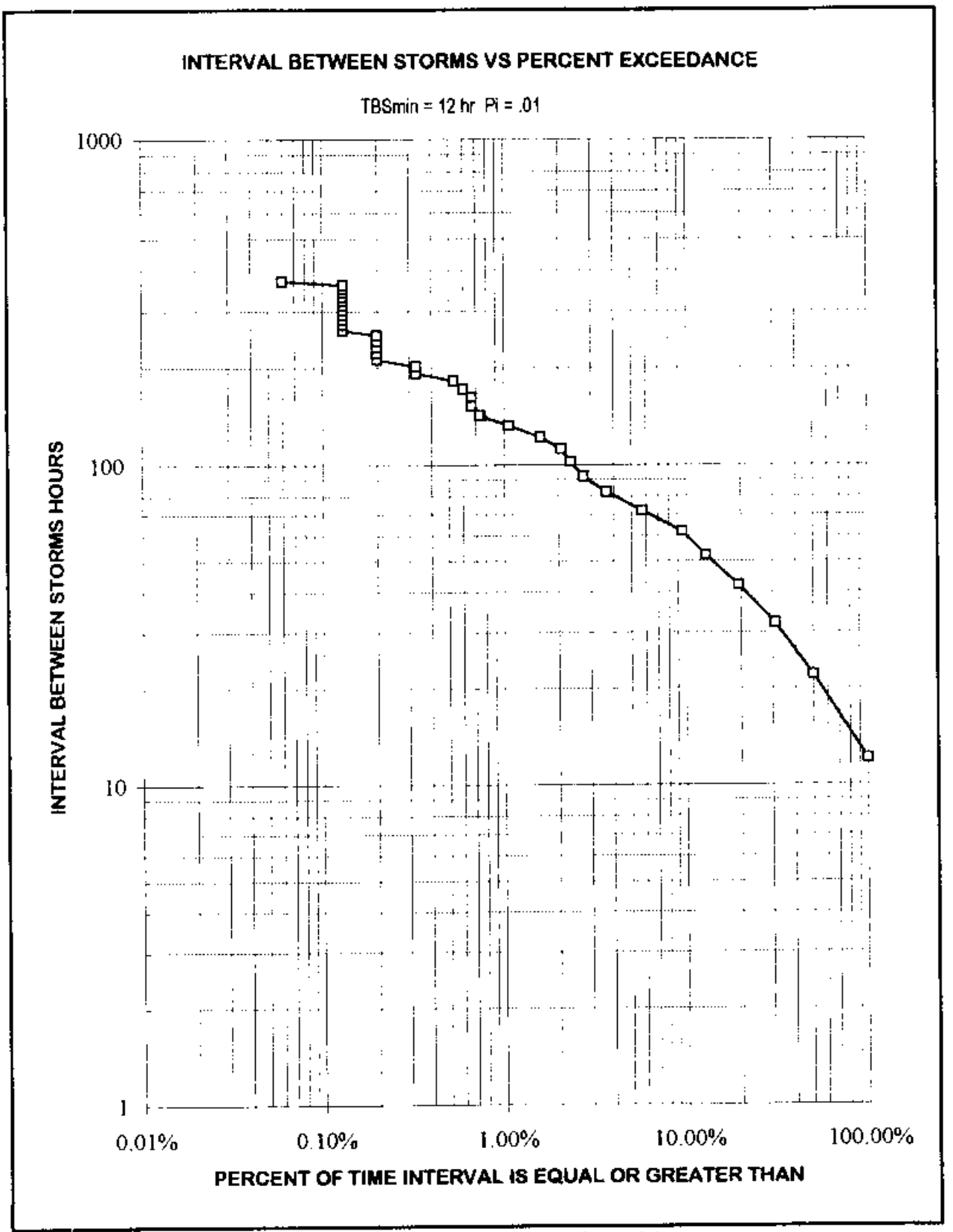

Figure 9. Rainfall Duration vs. Percent Exceedance. TBSmin = 12 hours

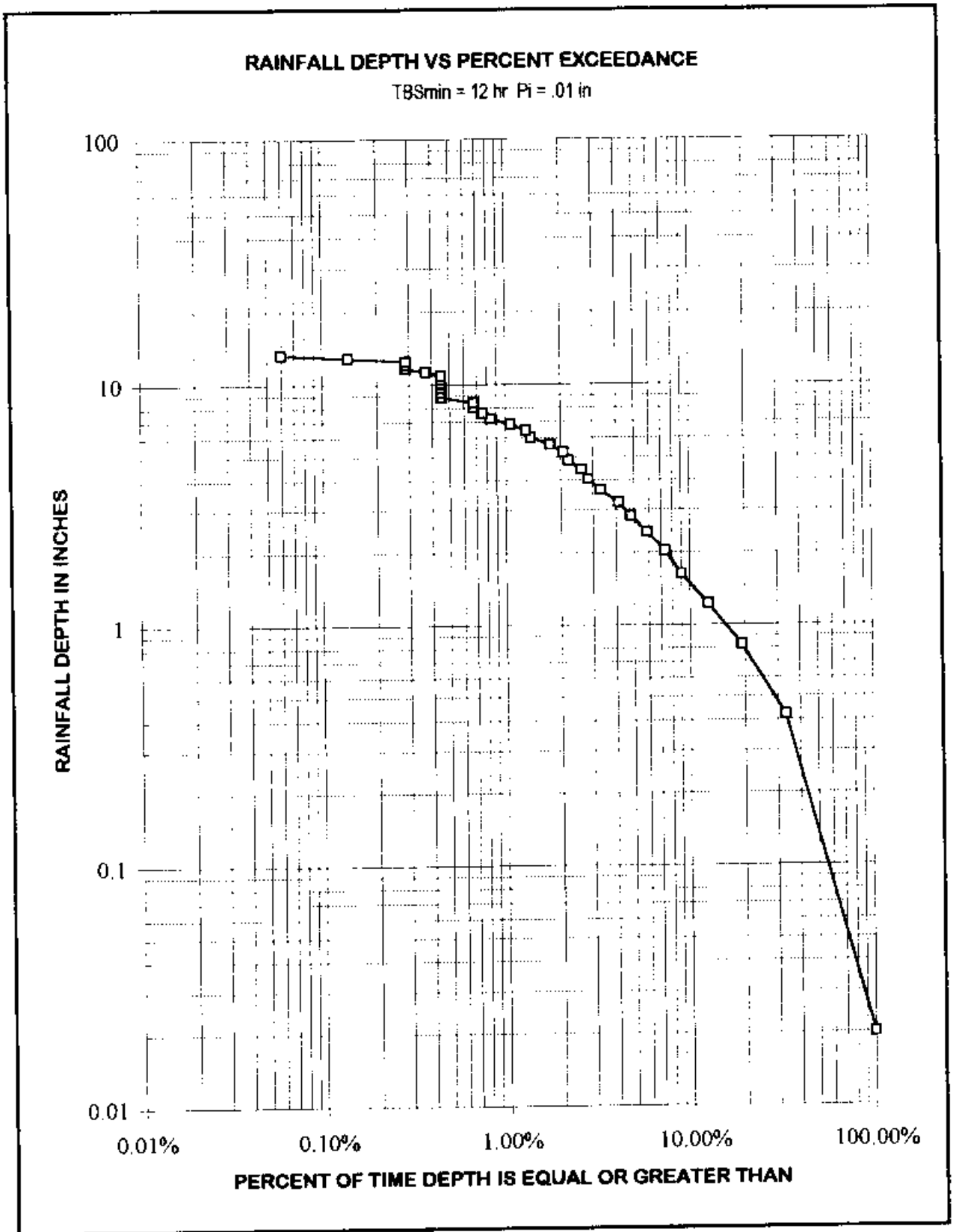

Figure 10. Rainfall Depth vs. Percent Exceedance. TBSmin = 12 hours

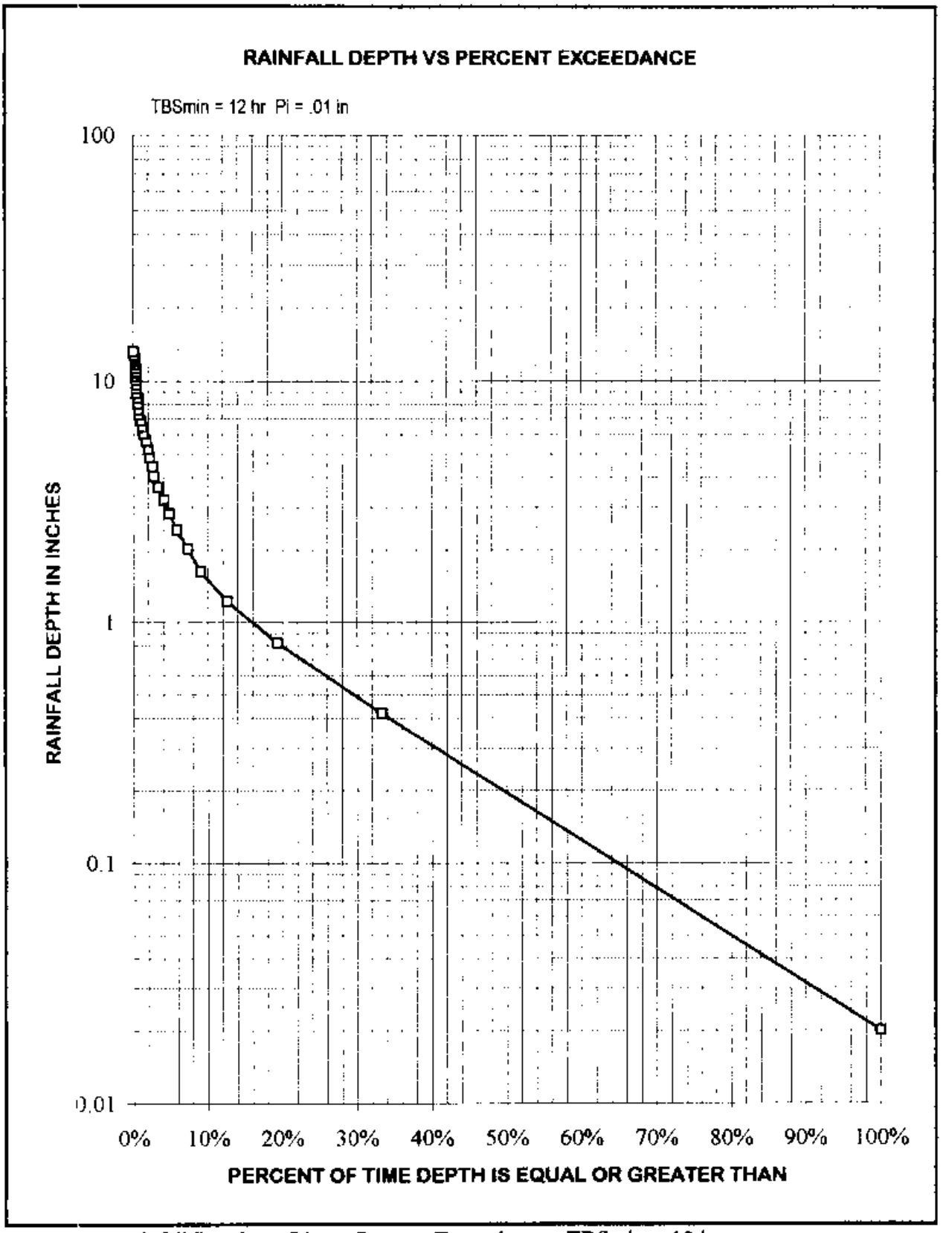

Figure 11. Rainfall Depth vs. Linear Percent Exceedance. TBSmin = 12 hours

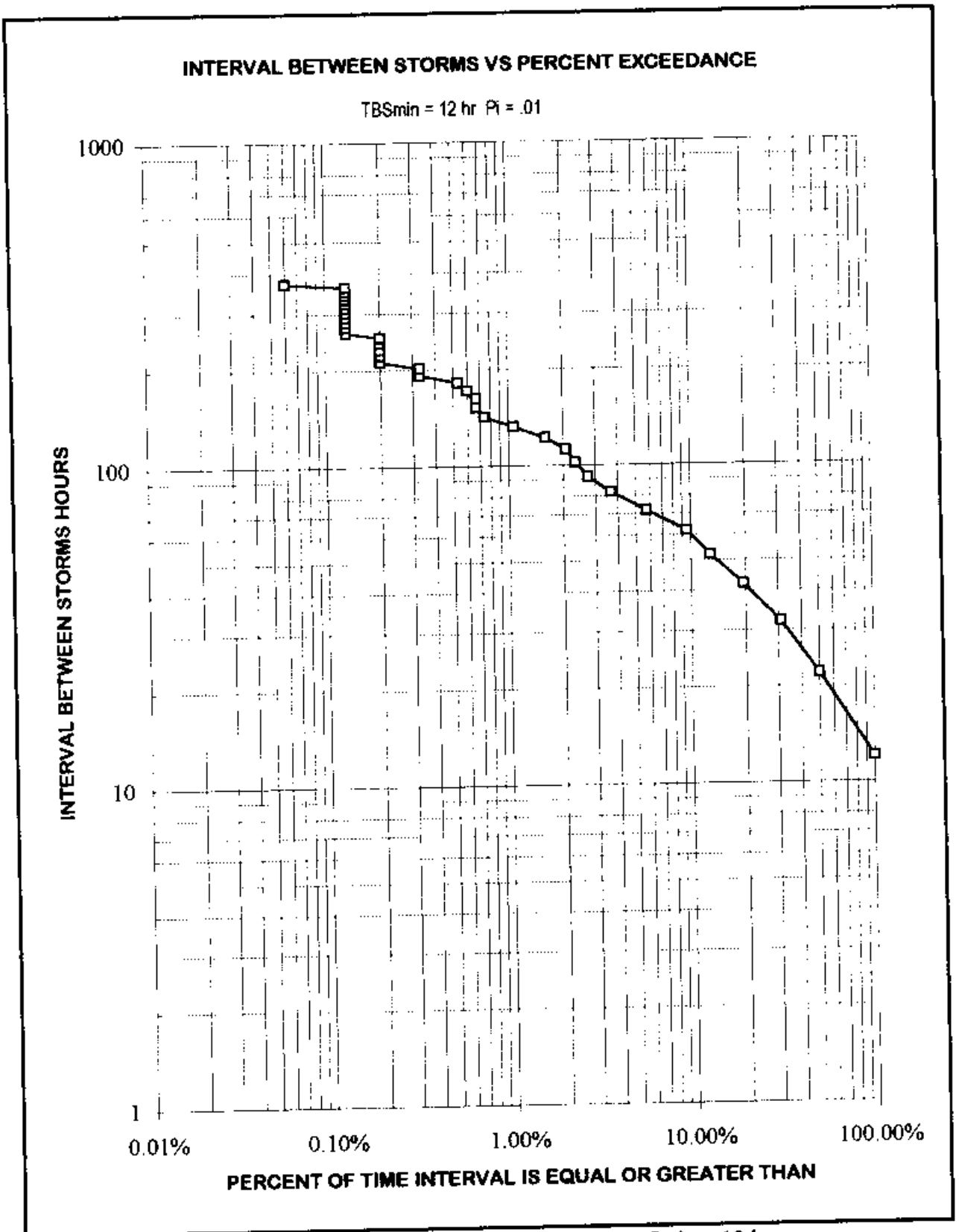

Figure 12. Interval Between Storms vs. Percent Exceedance. TBSmin = 12 hour

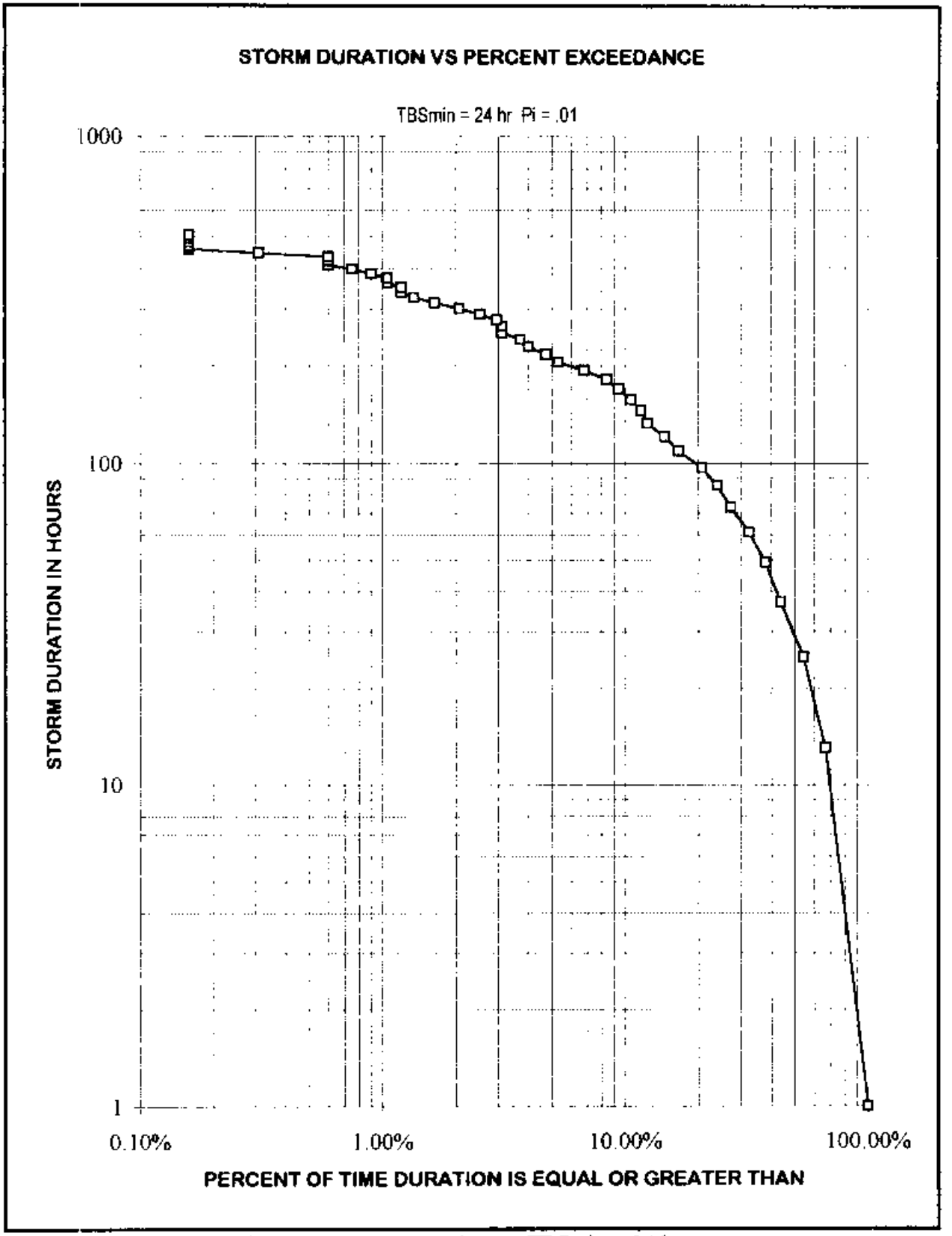

Figure 13. Rainfall Duration vs. Percent Exceedance. TBSmin = 24 hours

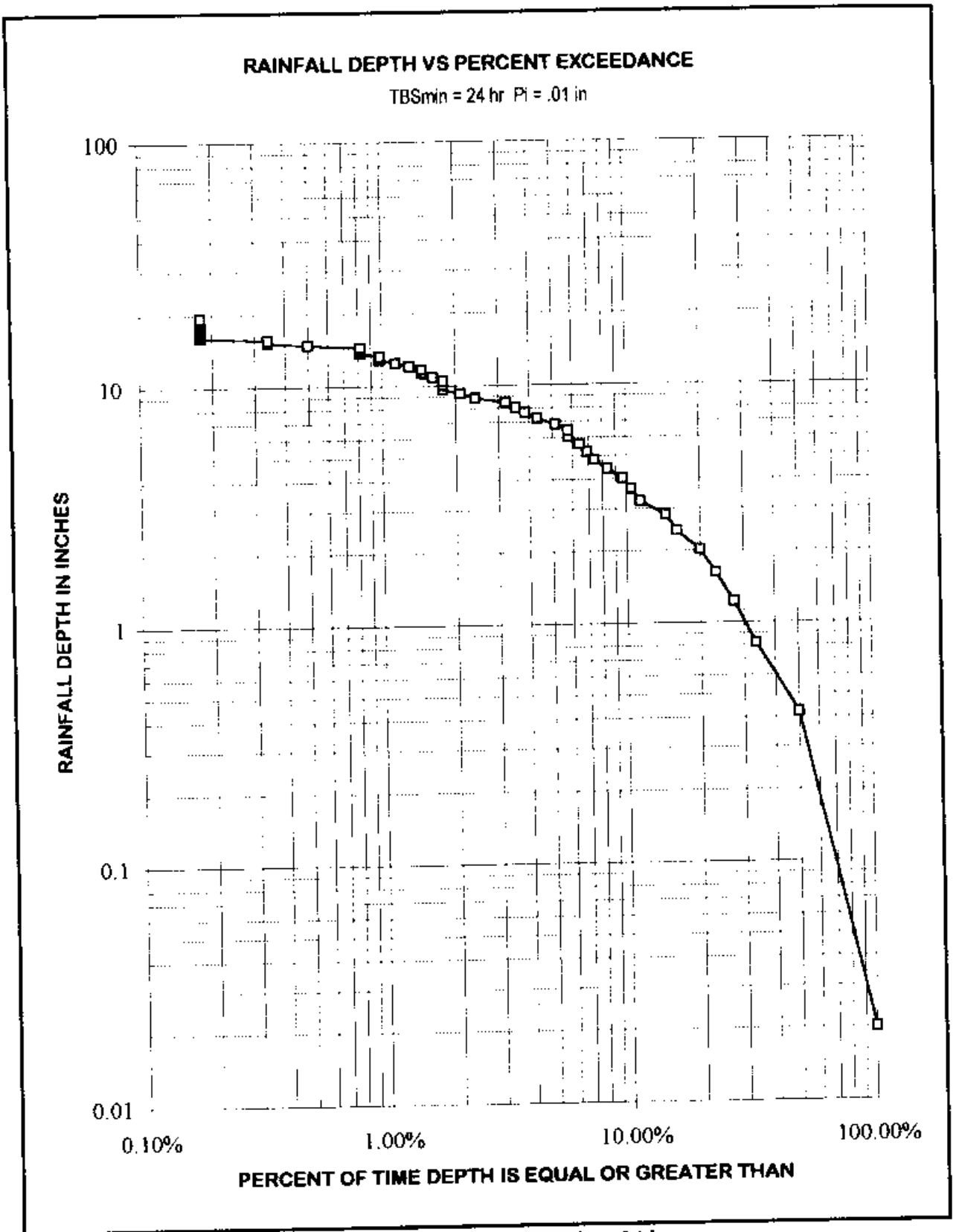

Figure 14. Rainfall Depth vs. Percent Exceedance. TBSmin = 24 hours

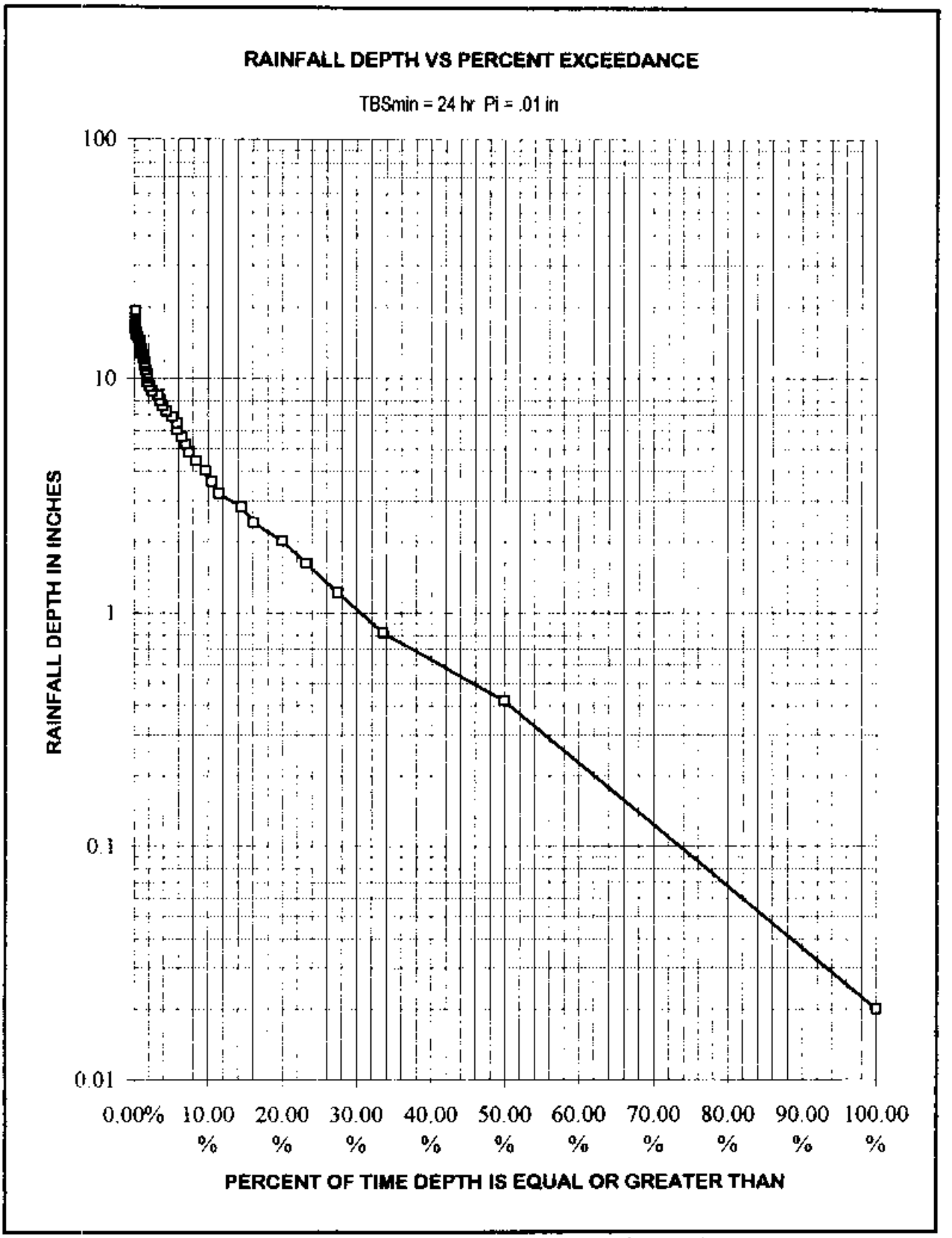

Figure 15. Rainfall Depth vs. Linear Percent Exceedance. TBSmin = 24 hours

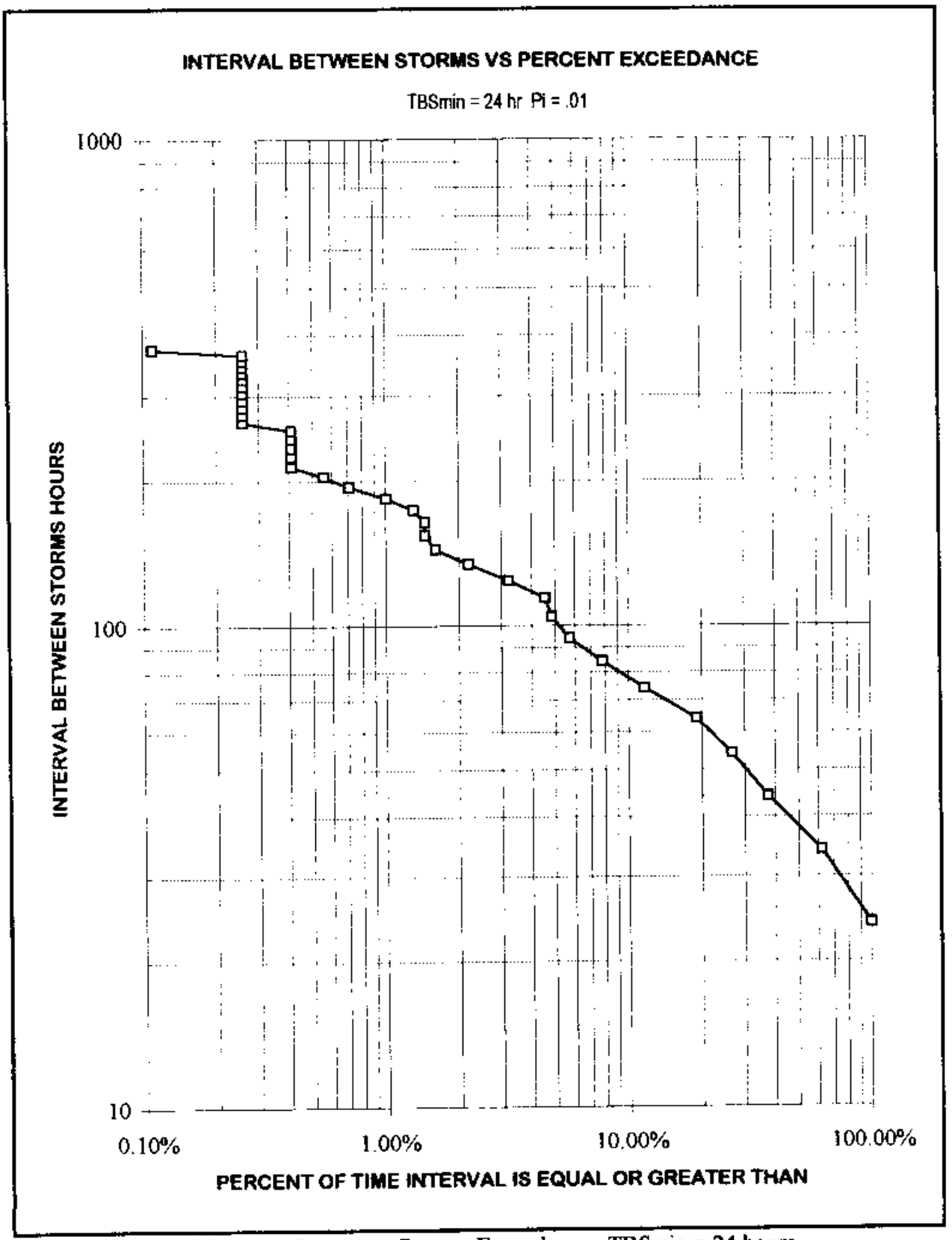

Figure 16. Interval Between Storms vs. Percent Exceedance. TBSmin = 24 hours

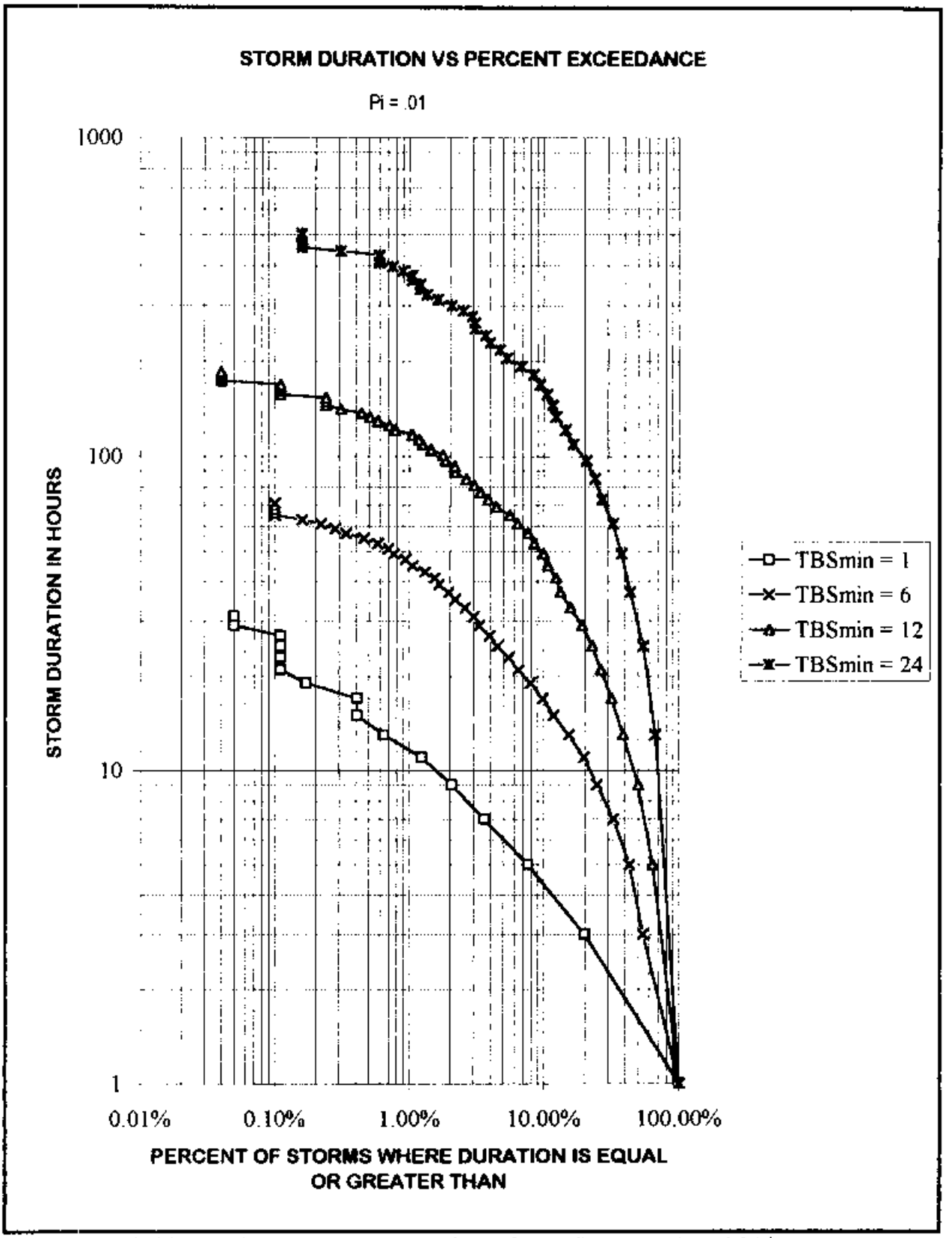

Figure 17. Rainfall Duration vs. Percent Exceedance for TBS = 1, 6, 12, and 24 hours

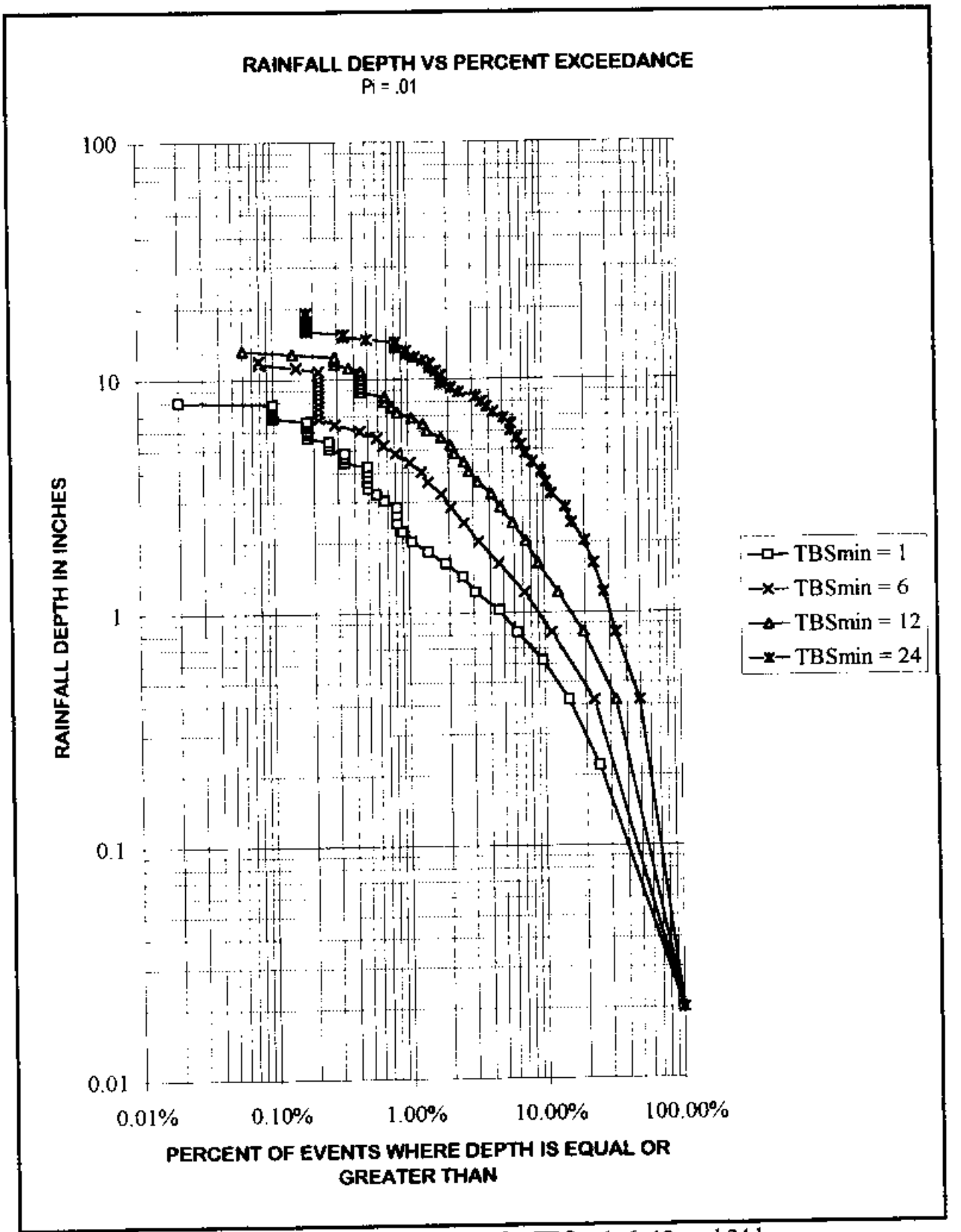

Figure 18. Rainfall Depth vs. Percent Exceedance for TBS = 1, 6, 12, and 24 hours

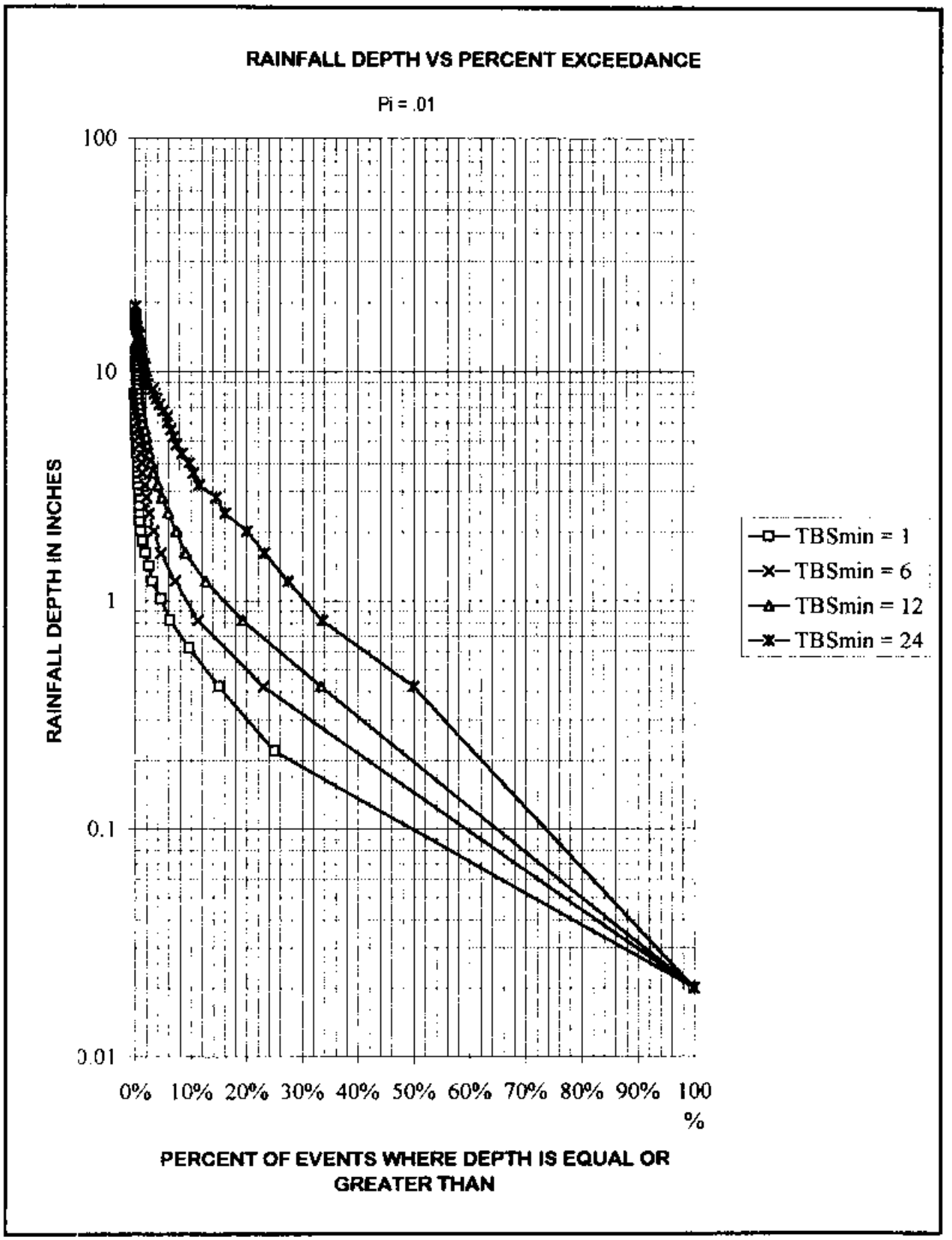

Figure 19. Rainfall Depth vs. Linear Percent Exceedance for TBS = 1, 6, 12, and 24 hours

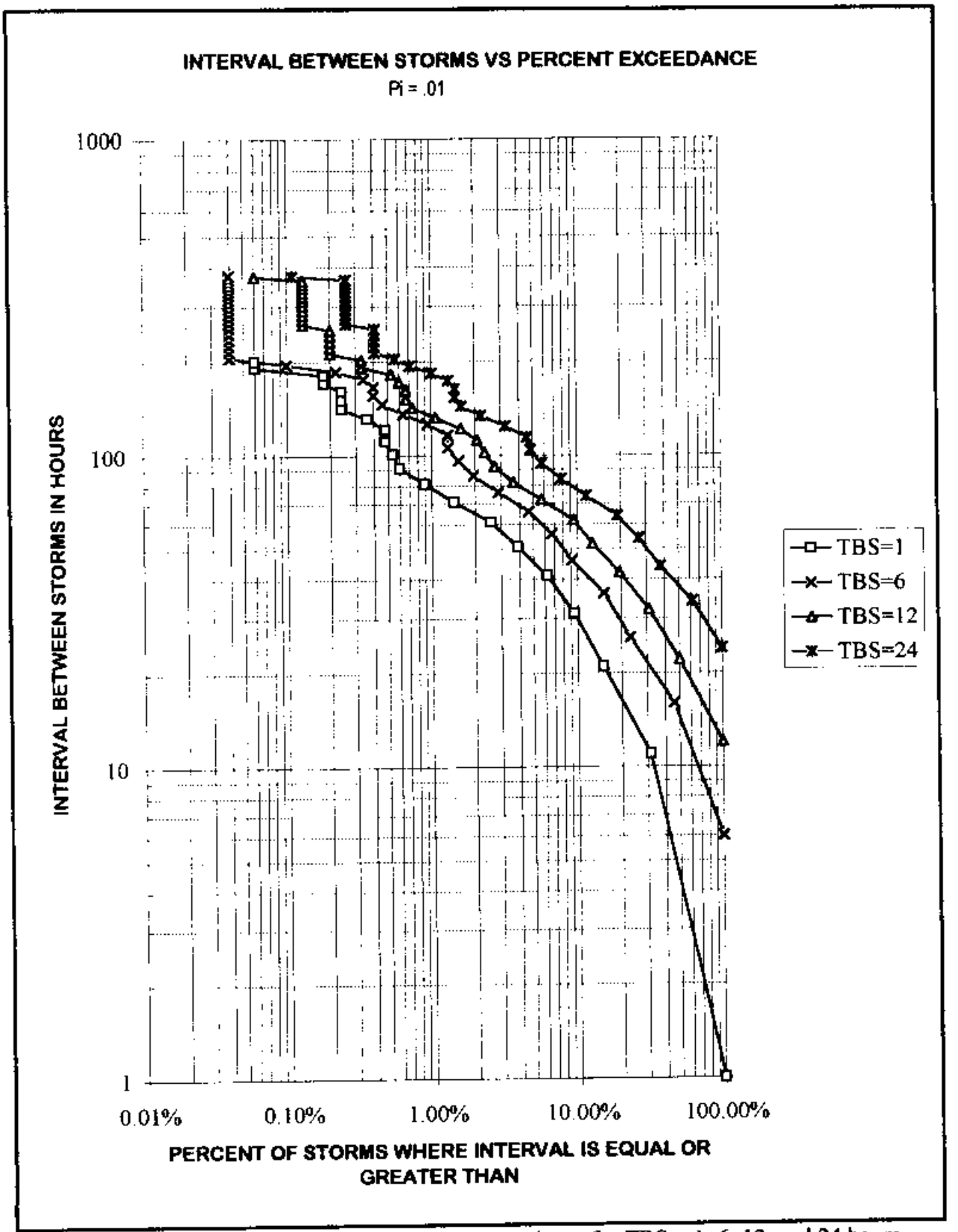

Figure 20. Interval Between Storms vs. Percent Exceedance for TBS = 1, 6, 12, and 24 hours

APPENDIX II.

POND SIZING CURVES

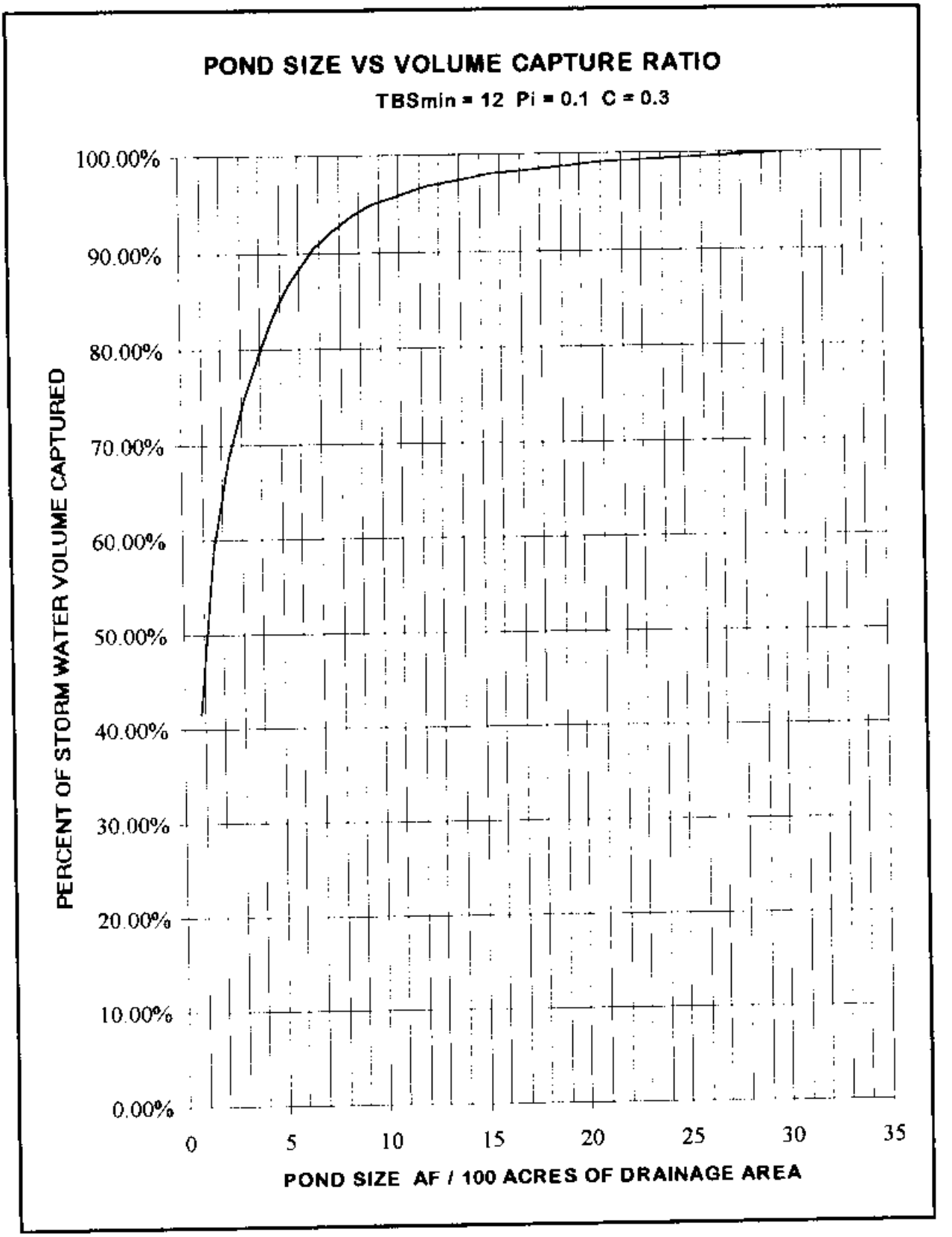

Figure 21. Pond Size vs. Capture Ratios TBSmin = 12 hours C= 0.3

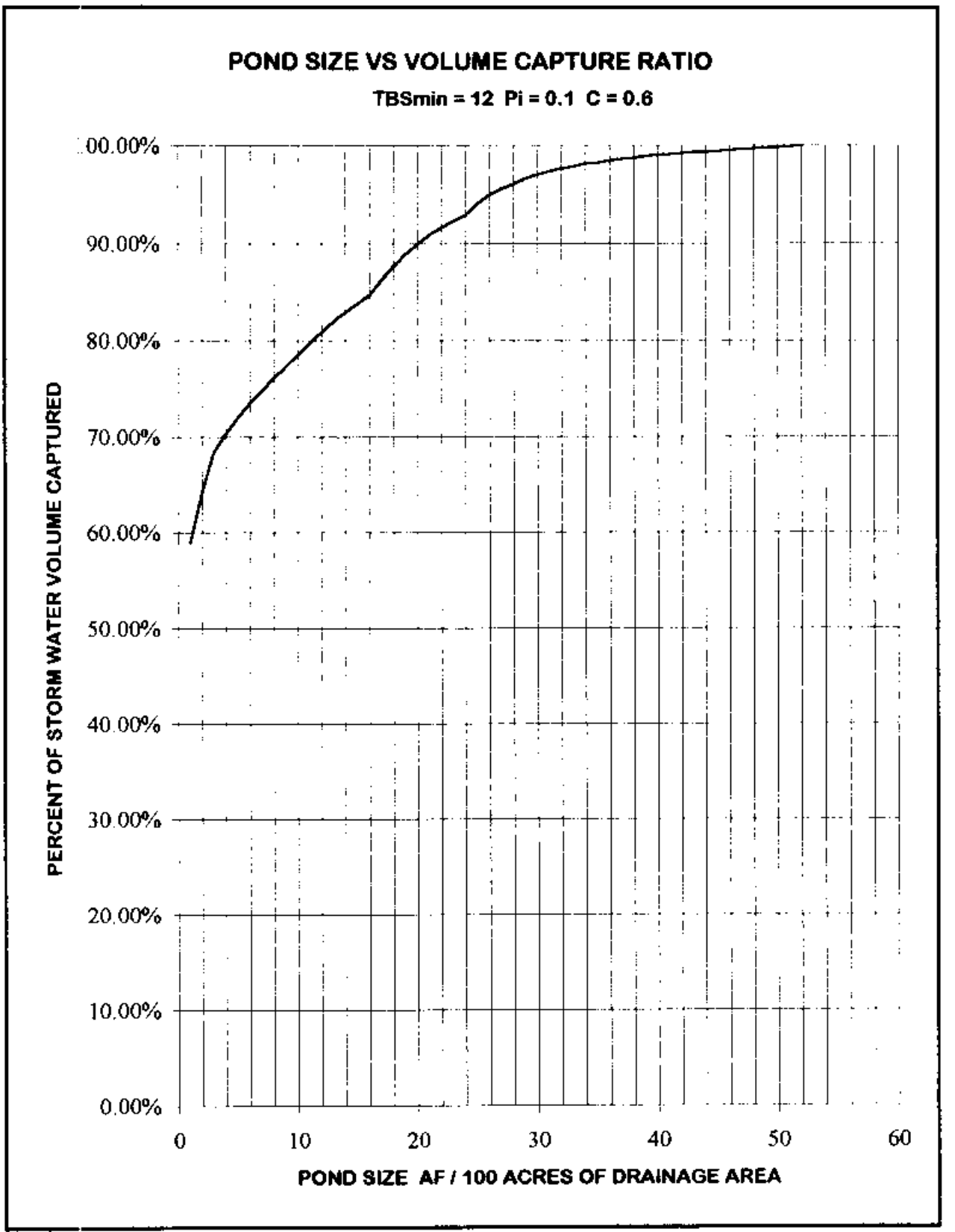

Figure 22. Pond Size vs. Capture Ratios TBSmin = 12 hours C= 0.6

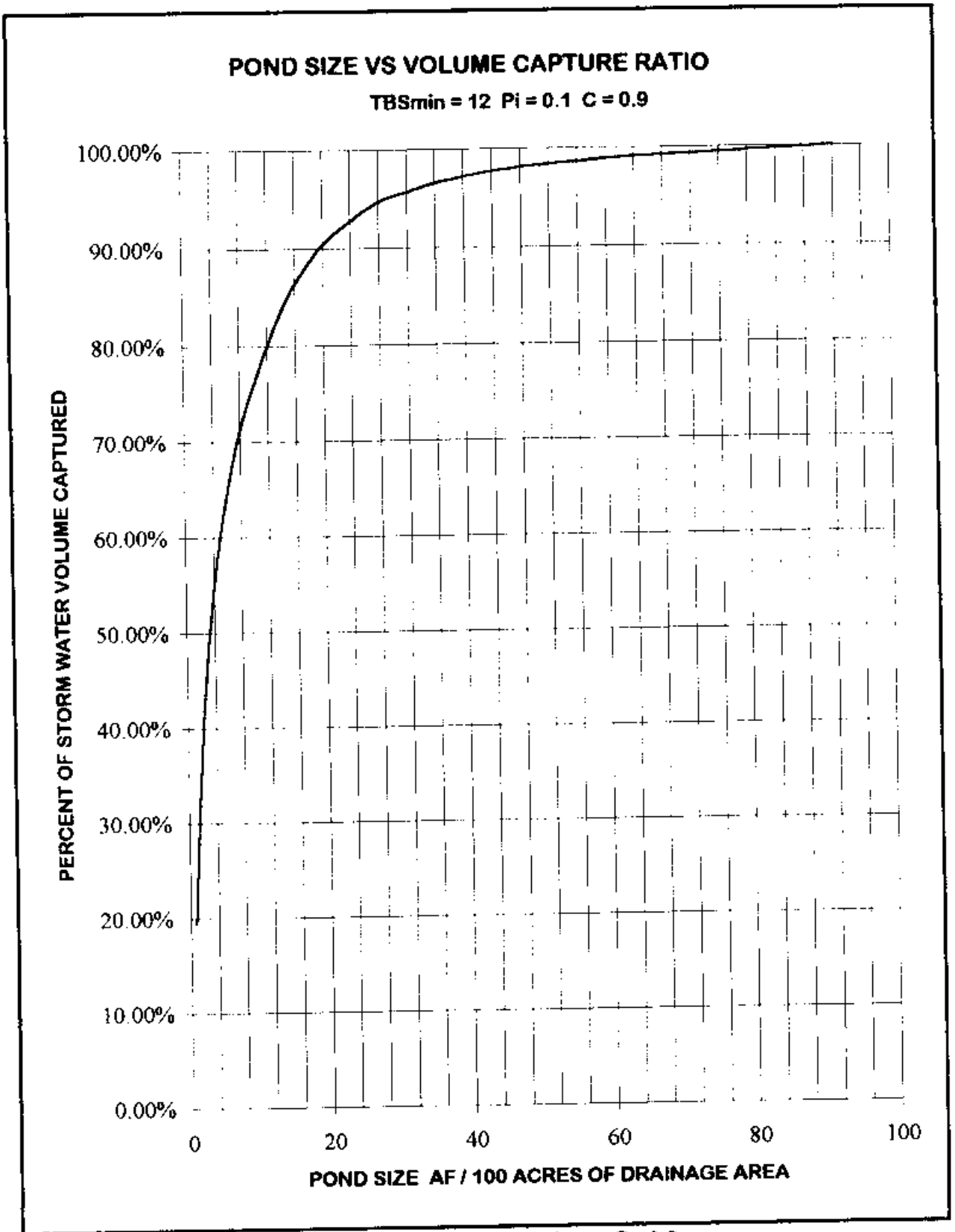

Figure 23. Pond Size vs. Capture Ratios TBSmin = 12 hours C= 0.9

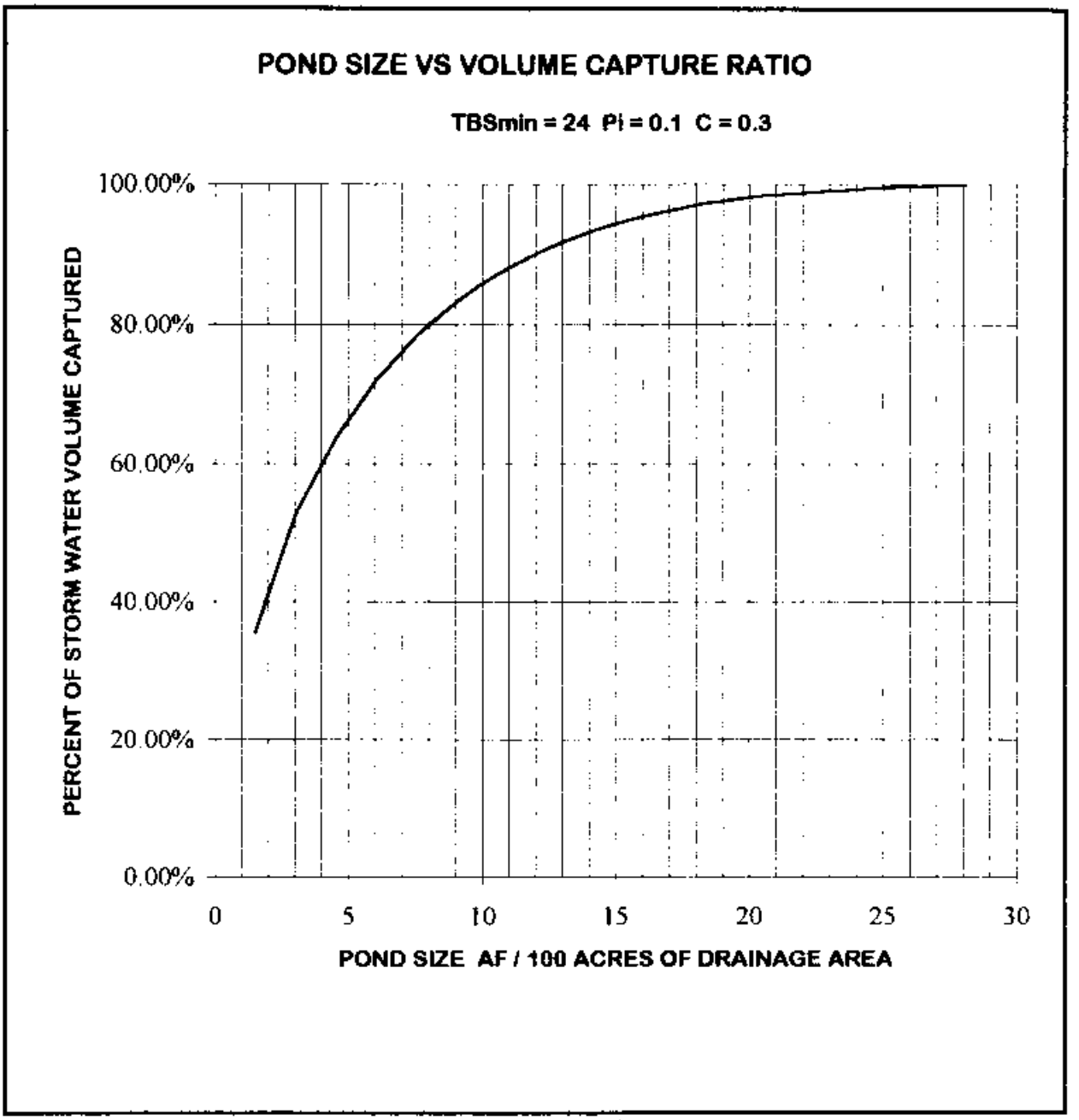

Figure 24. Pond Size vs. Capture Ratios TBSmin = 24 hours C= 0.3

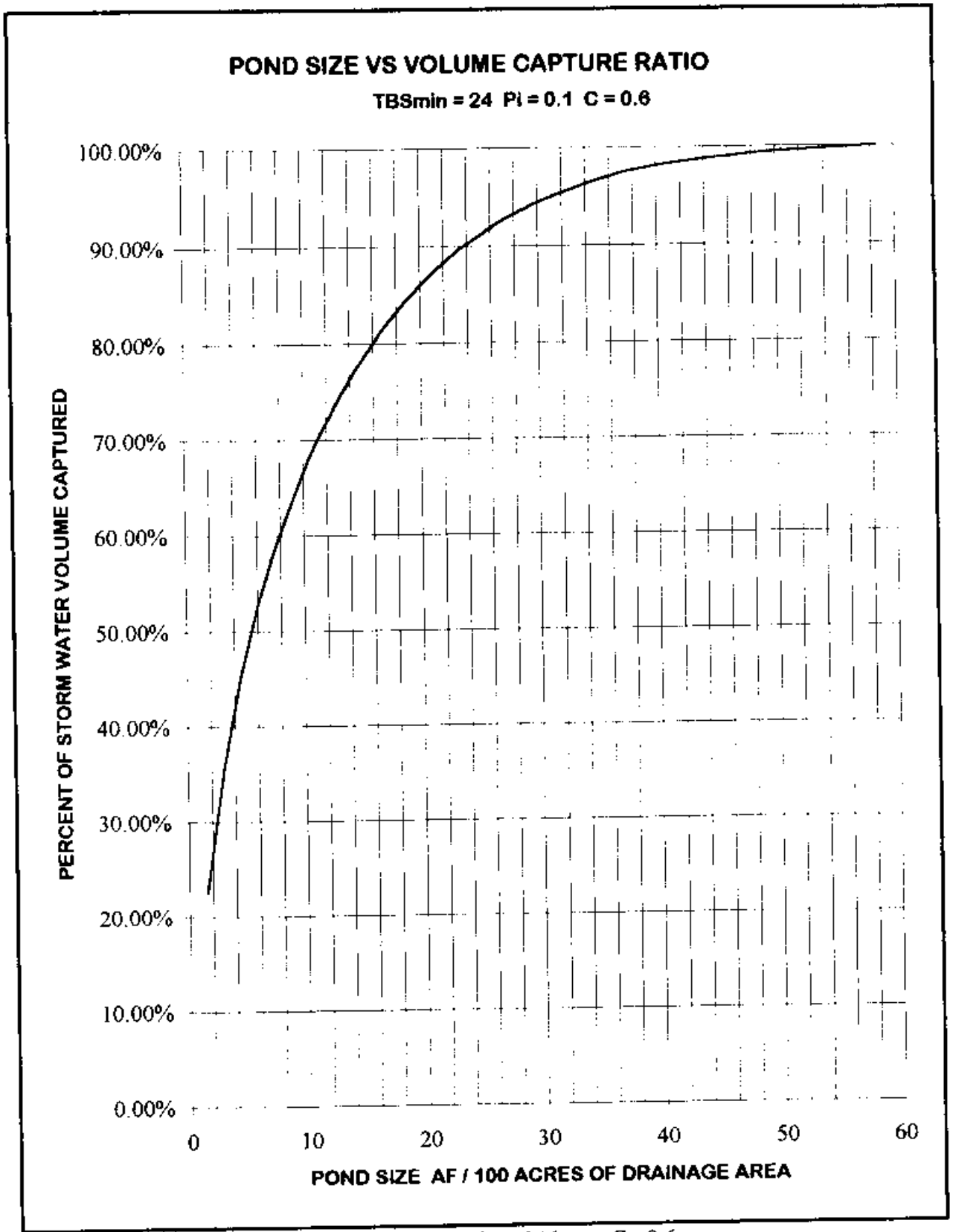

Figure 25. Pond Size vs. Capture Ratios TBSmin = 24 hours C= 0.6

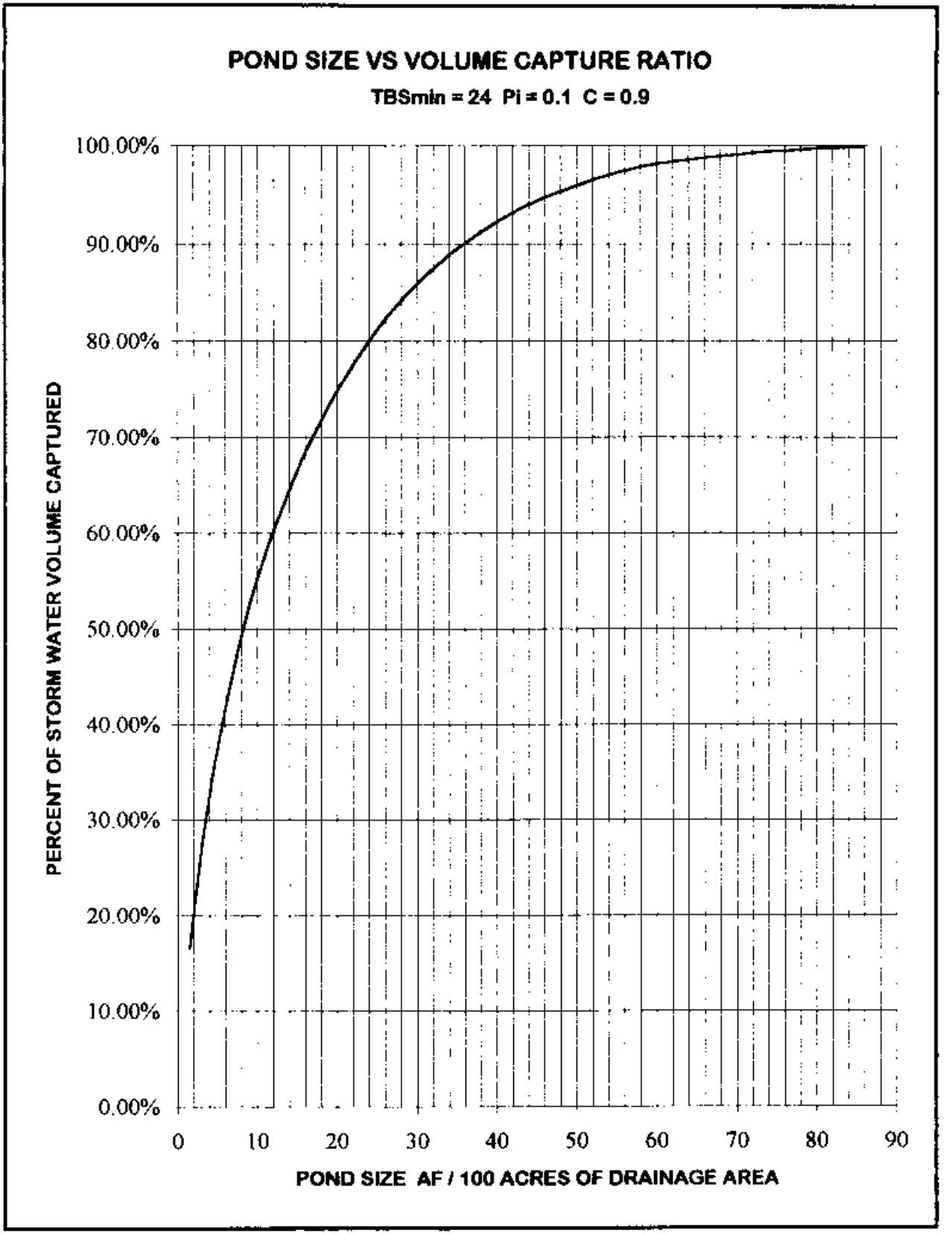

Figure 26. Pond Size vs. Capture Ratios TBSmin = 24 hours C= 0.9

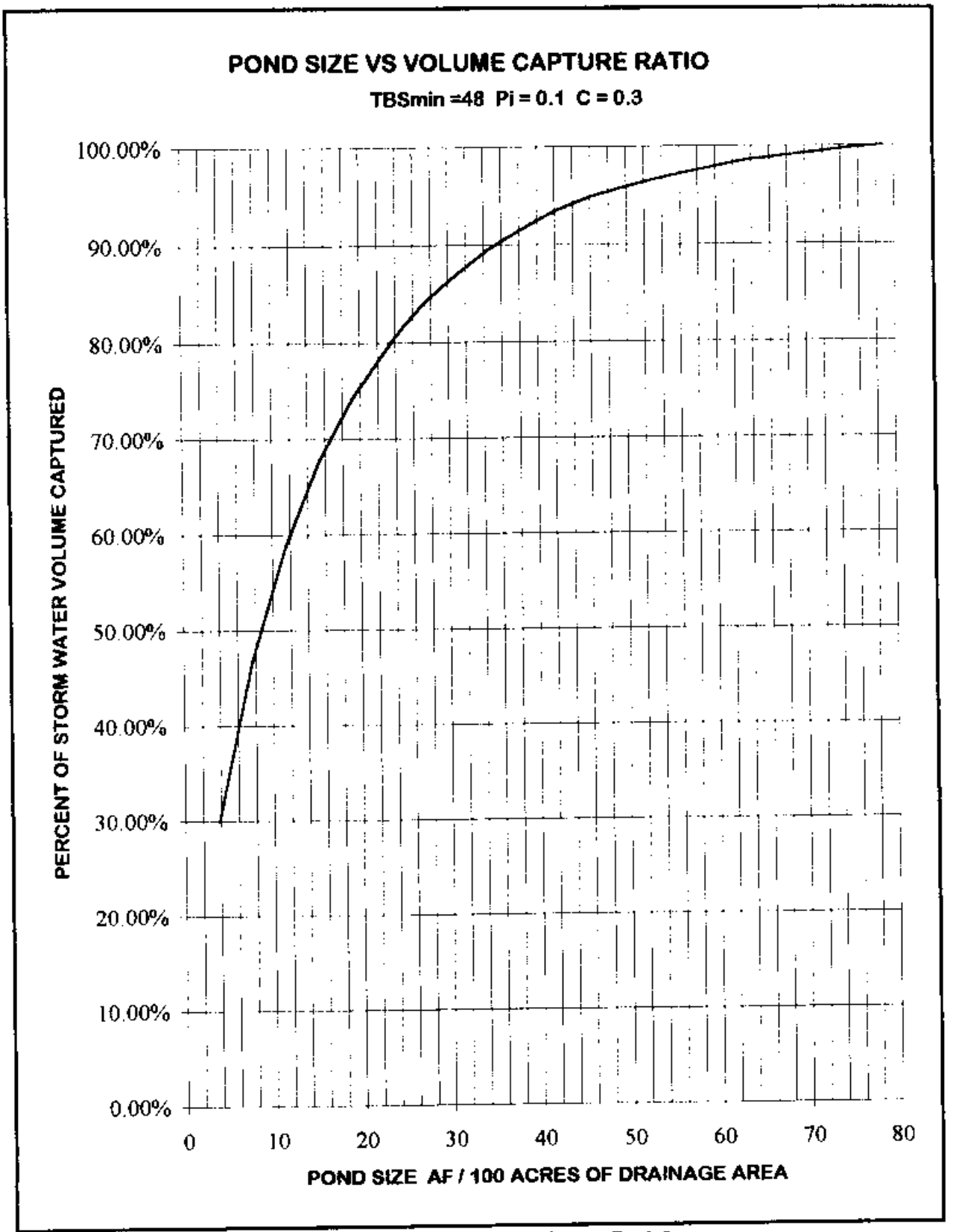

Figure 27. Pond Size vs. Capture Ratios TBSmin = 48 hours C= 0.3

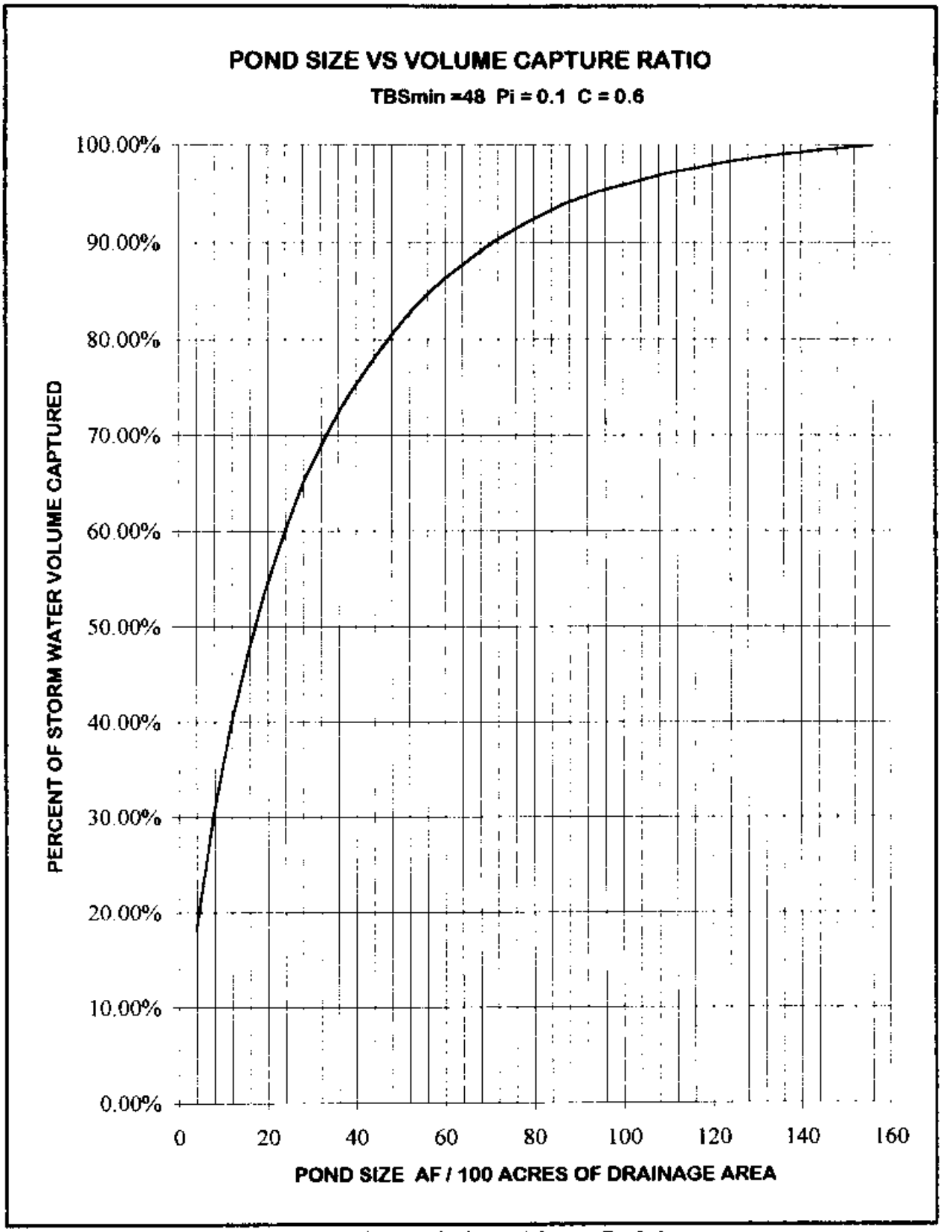

Figure 28. Pond Size vs. Capture Ratios TBSmin = 48 hours C= 0.6

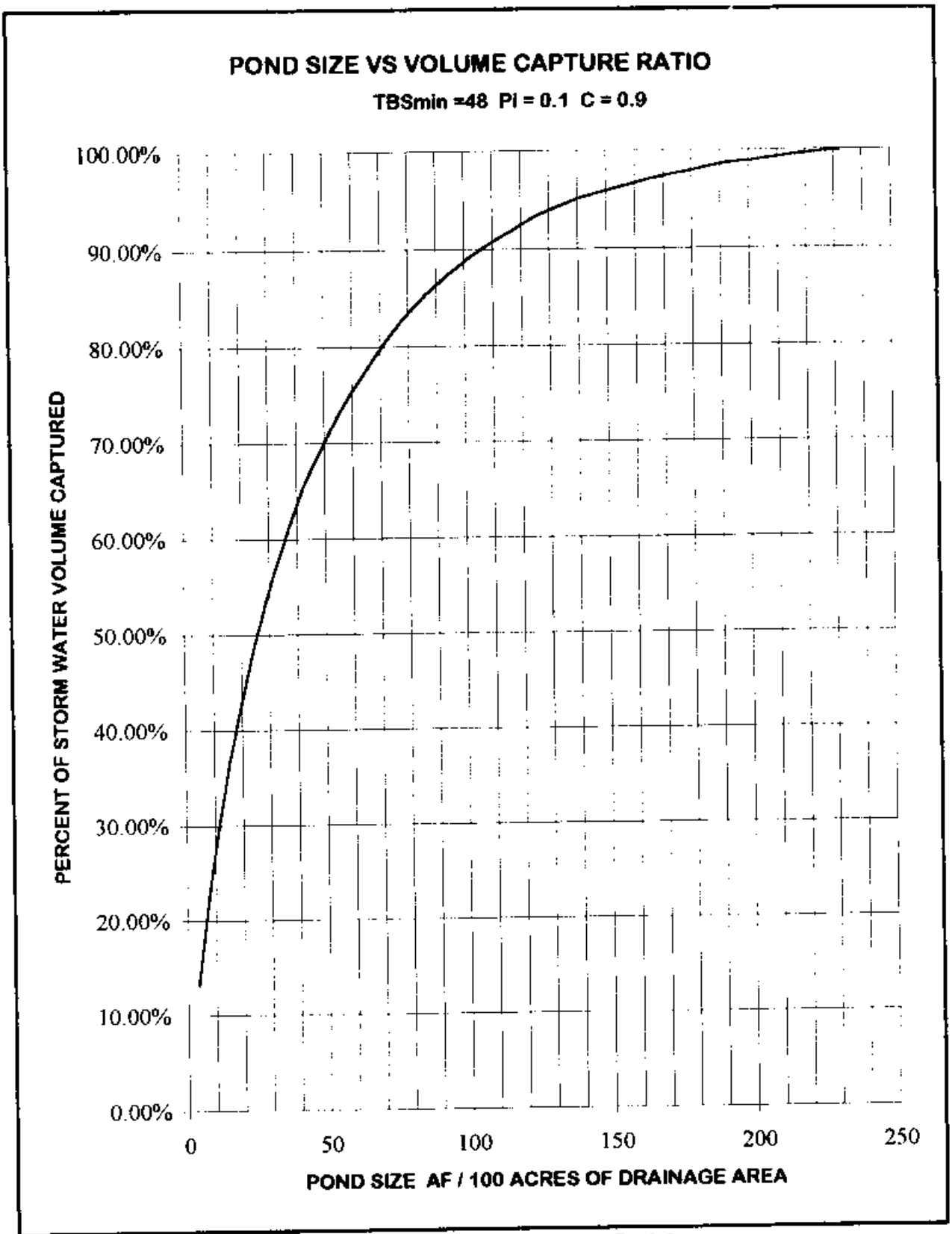

Figure 29. Pond Size vs. Capture Ratios TBSmin = 48 hours C= 0.9

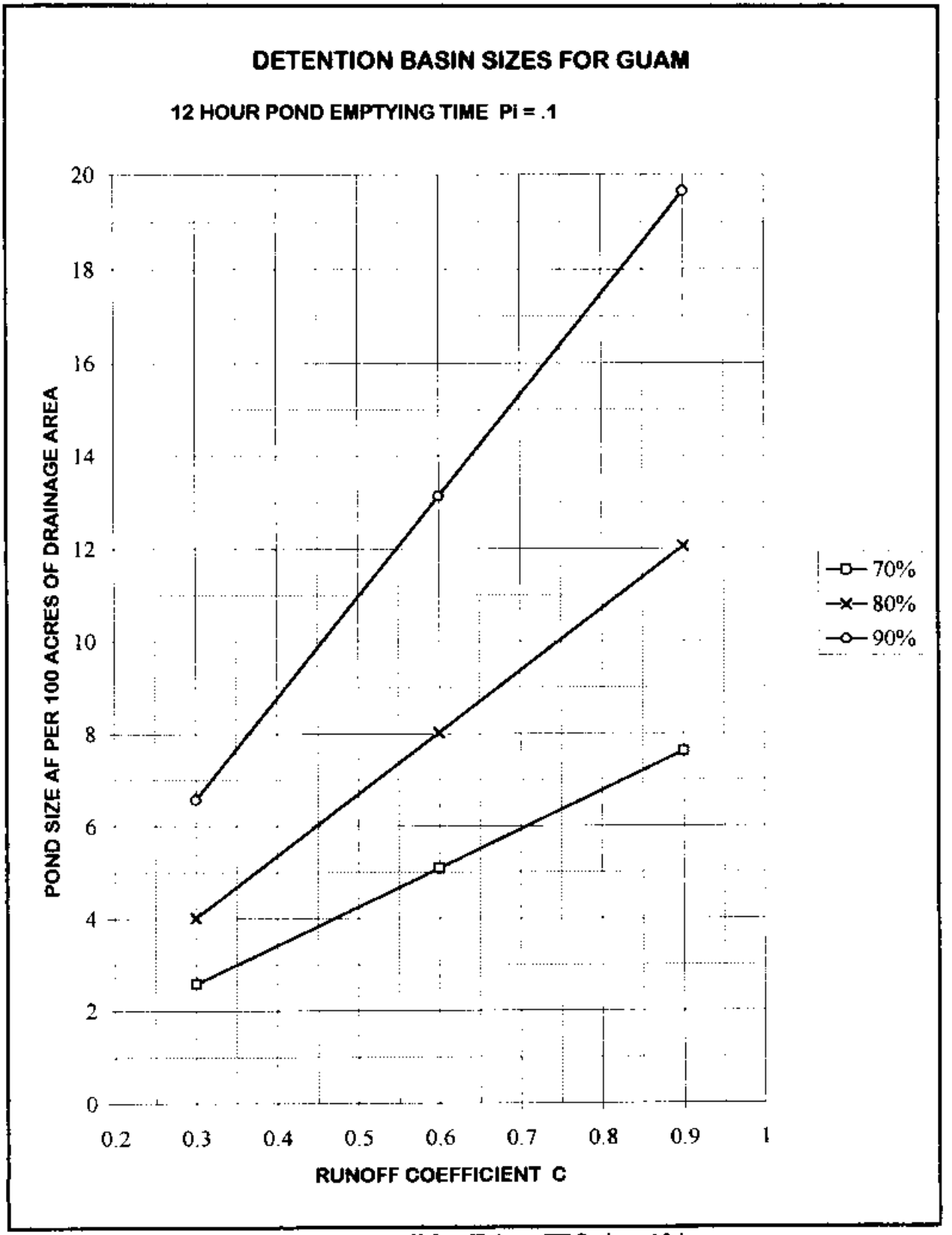

Figure 30. Detention Basin Size vs. Runoff Coefficient TBSmin = 12 hours

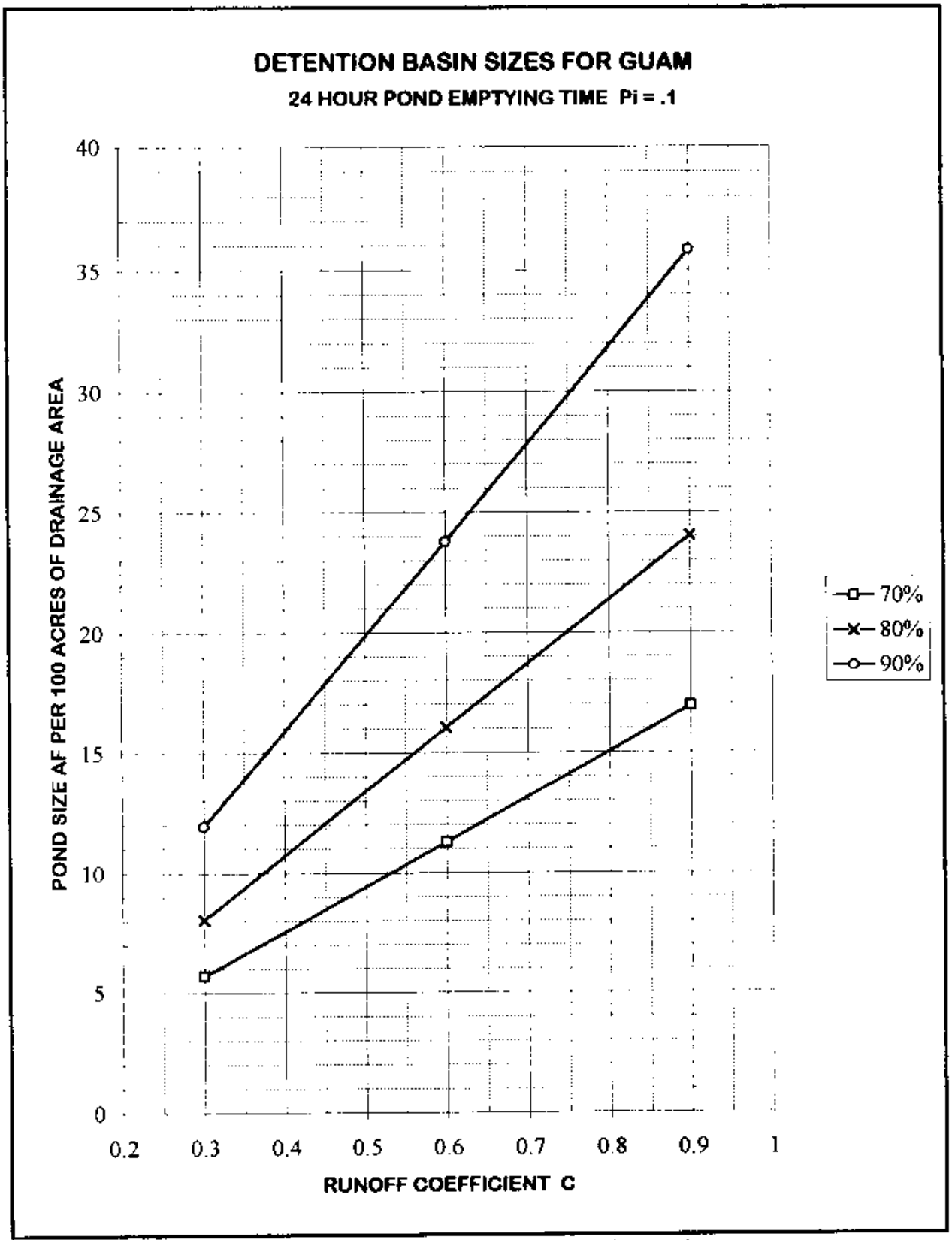

Figure 31. Detention Basin Size vs. Runoff Coefficient TBSmin = 24 hours

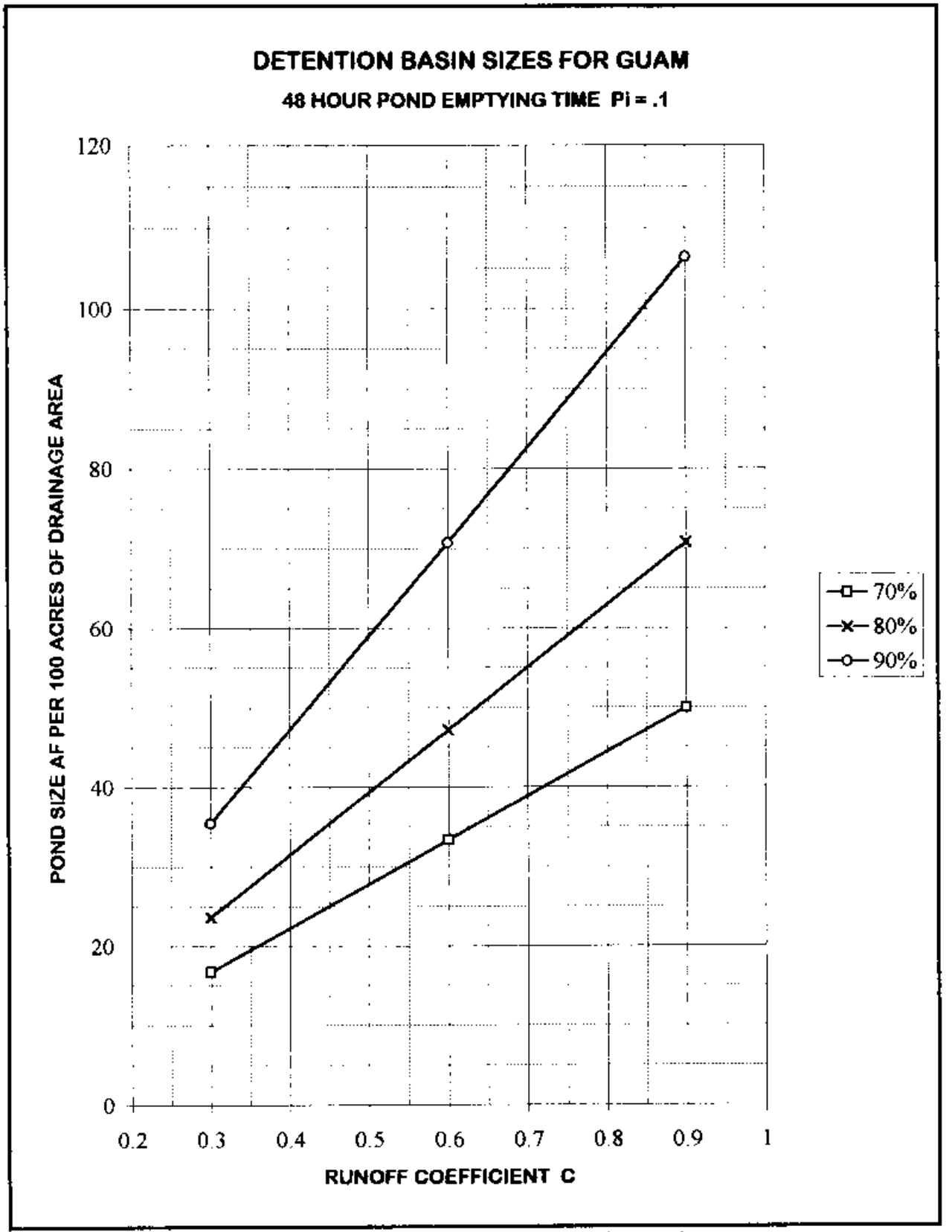

Figure 32. Detention Basin Size vs. Runoff Coefficient TBSmin = 48 hours

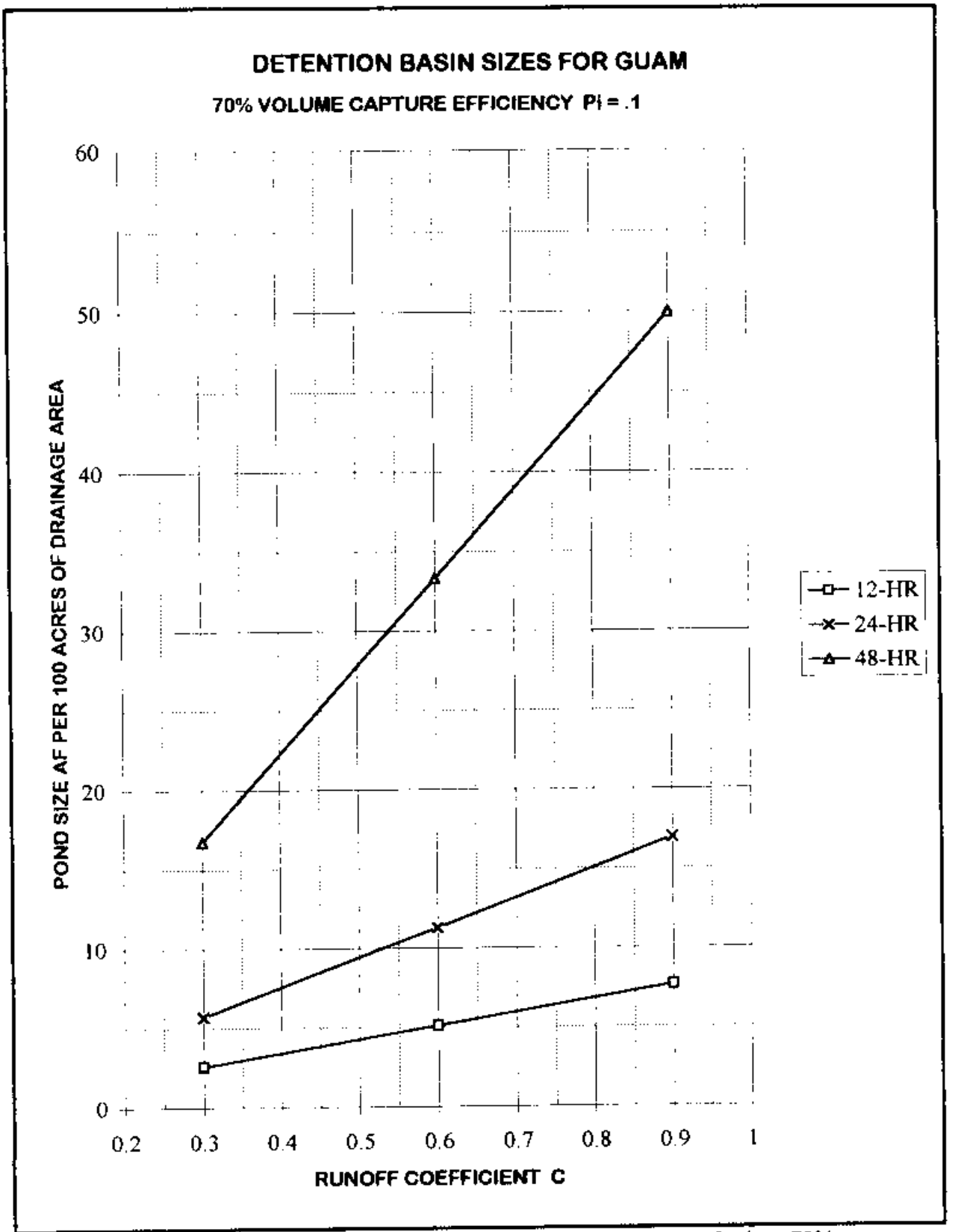

Figure 33. Detention Basin Size vs. Runoff Coefficient Volume Capture Ratio = 70%

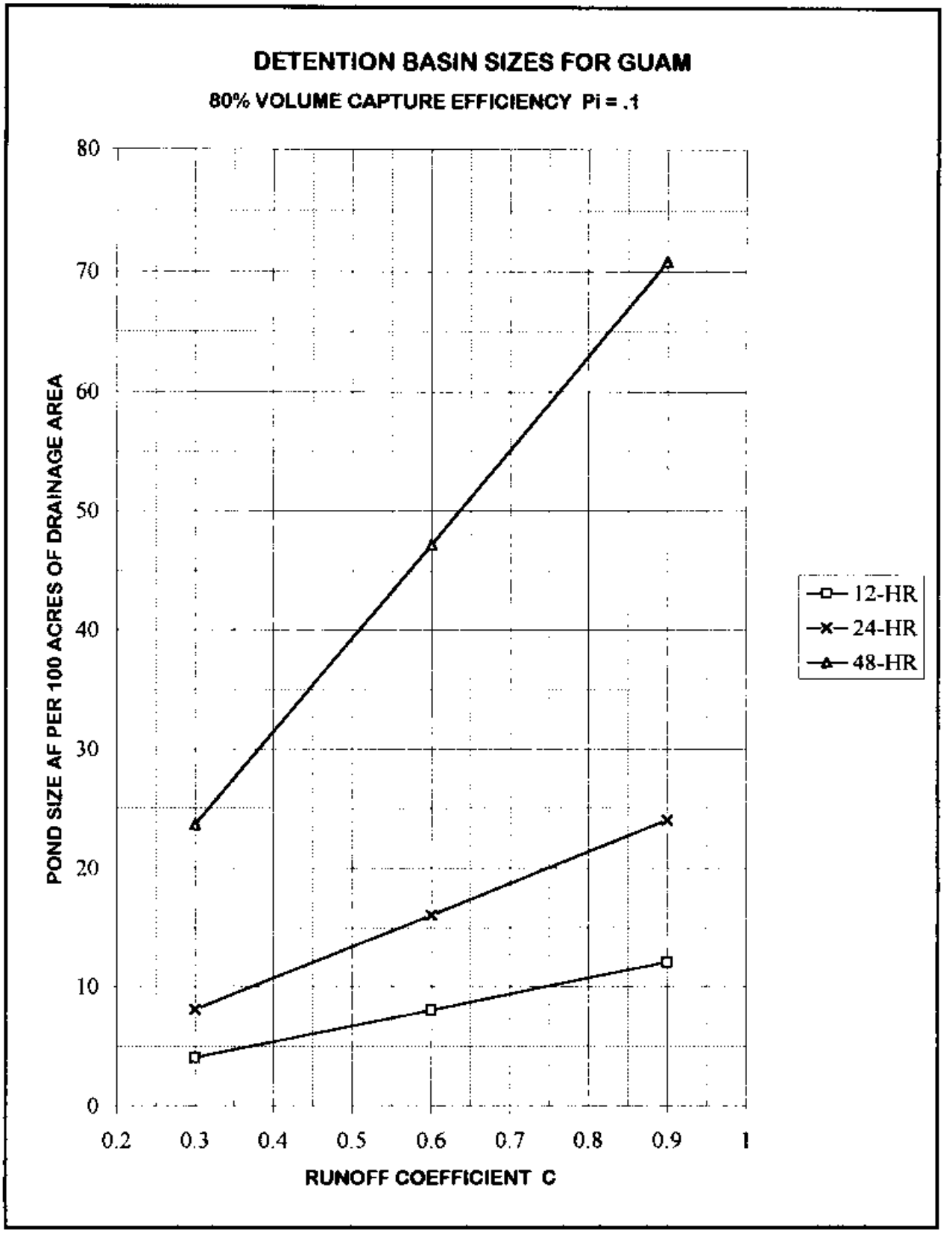

Figure 34. Detention Basin Size vs. Runoff Coefficient Volume Capture Ratio = 80%

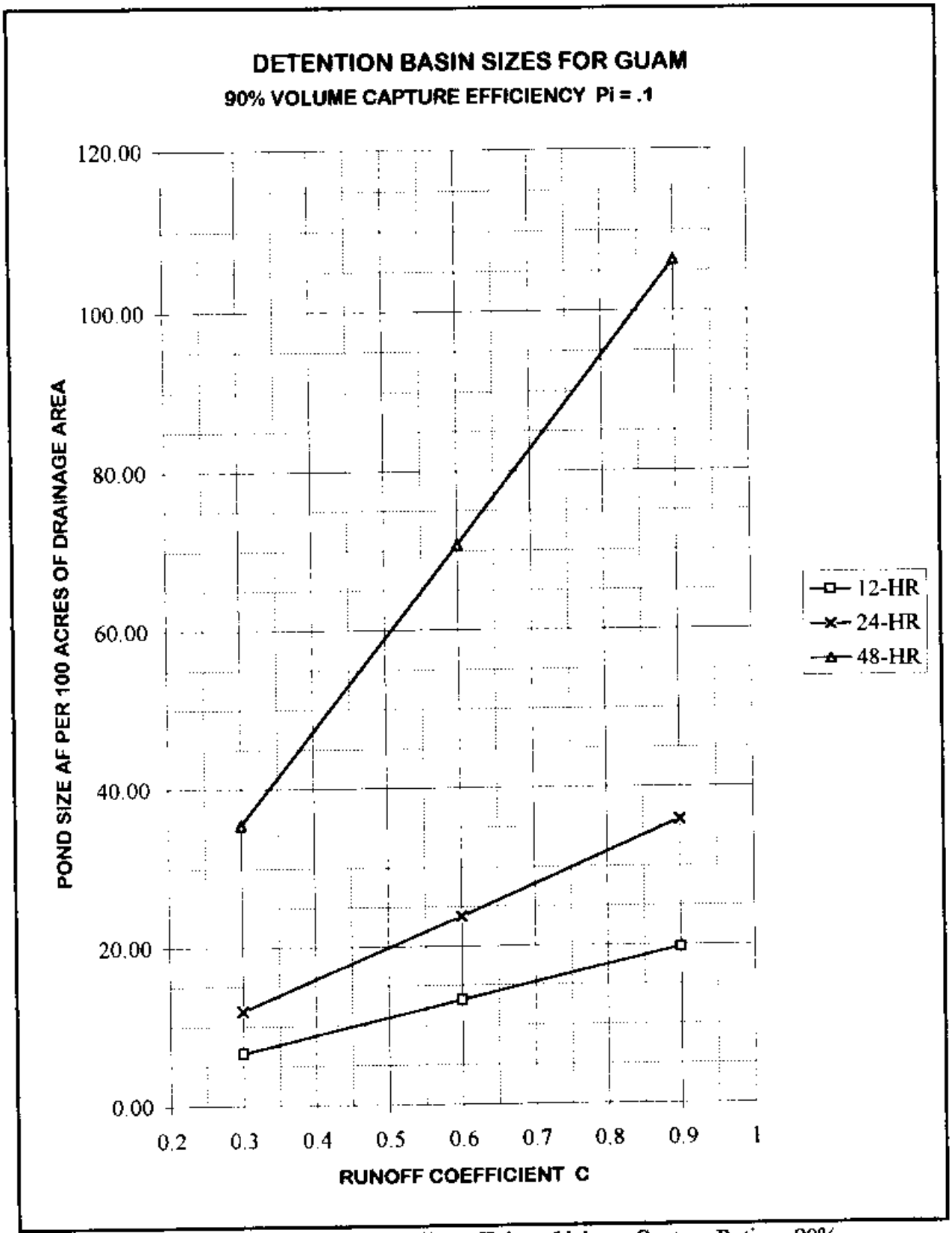

Figure 35. Detention Basin Size vs. Runoff Coefficient Volume Capture Ratio = 90%

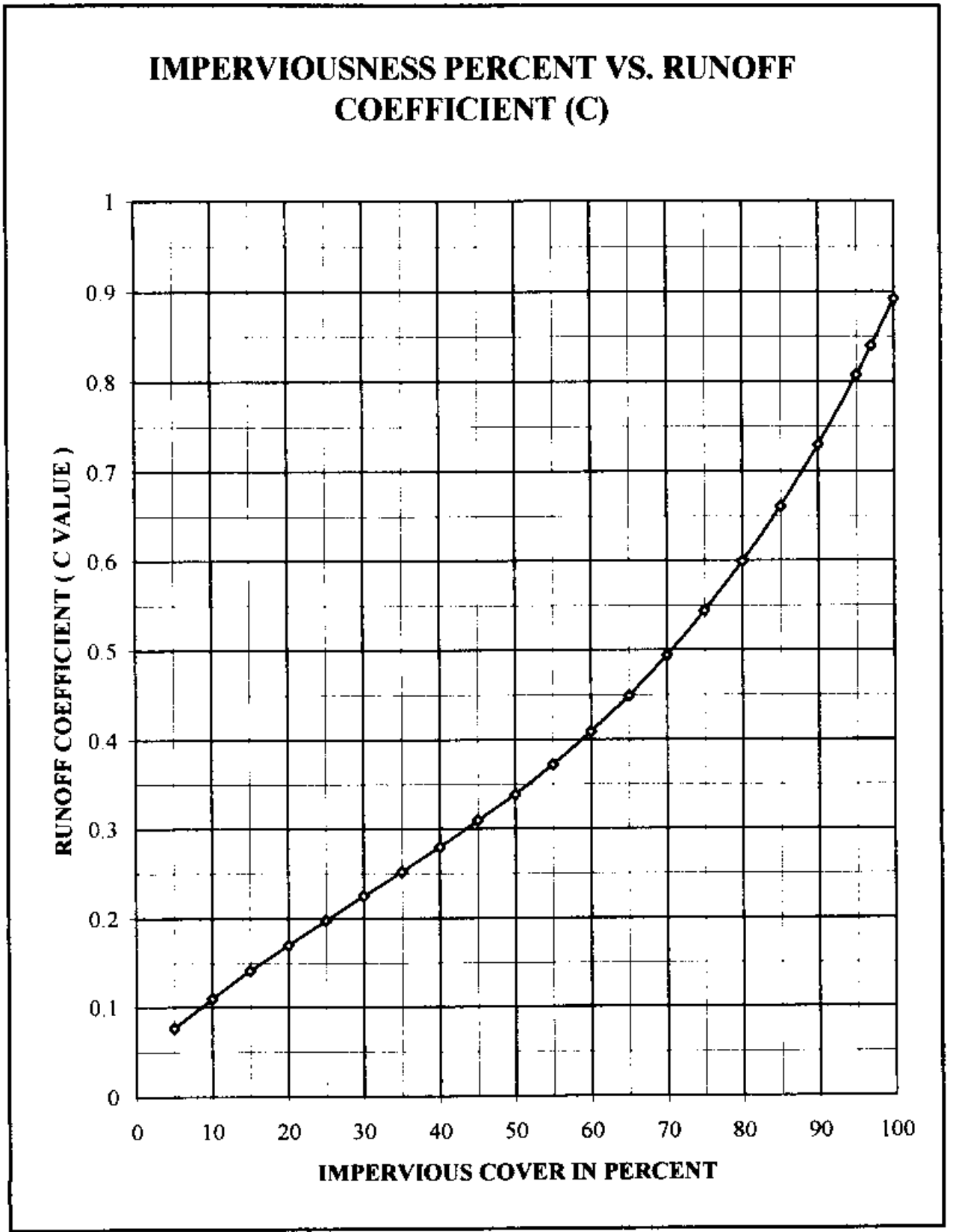

Figure 36. Runoff Coefficients (C values) vs. Percentage of Impervious Cover (EPA, 1986)