Department of

Civil Engineering

College of Engineering
The University of Iowa
Iowa City, Iowa

Management of Cattle Feedlot Wastes

by
Richard R. Dague
Kenneth J. Kline

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MANAGEMENT OF CATTLE FEEDLOT WASTES

Completion Report

of

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Iowa State Water Resources Research Institute

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Richard R. Dague
Assistant Professor of
Civil Engineering

Kenneth J. Kline
Graduate Student in
Environmental Engineering

UNIVERSITY OF IOWA

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INTRODUCTION

In the past, wastes from humans and industries have been considered the major sources of water pollution. With increases in population, the migration of people from rural to urban areas, and increasing industrial development, these waste sources have become even more significant. Along with population growth and the shift from an essentially rural to an essentially urban society has come increasing demand for food and fiber. This demand has been satisfied by decreasing numbers of farm operators on fewer farms. This has led to the concentration of greater numbers of livestock on fewer farms. In recent years, it has been recognized that the concentration of large numbers of livestock in small areas for feeding represents a significant source of water pollution.

During the past year the writers have conducted research in the area of the management of cattle feedlot wastes. The purpose of this report is to present the findings of the research.

OBJECTIVES

The objectives of this phase of the research, as set forth in the original proposal, were:

1. To evaluate the field conditions which will be of importance in the design of cattle feedlot waste management systems with emphasis on the hydrologic aspect as related to waste quantity, strength, and the resulting size of the waste treatment or holding system required.
2. To conduct and document a detailed literature review on the subject of cattle waste management.
3. To formulate recommendations for the management of feedlot wastes based on the findings of the research and the published research of others and to indicate areas

of further research needs in the area of cattle feedlot wastes management.

The objectives of the research were substantially accomplished. The principal objective was the hydrologic aspects of feedlot waste control (objective no. 1). The research procedures, results and conclusions are detailed in the M.S. thesis entitled, "Management of Cattle Feedlot Wastes" by Kenneth J. Kline, co-author of this report. This thesis presents the substantive technical aspects of the research and therefore, is included as a part of this report. Also, the paper entitled, "Hydrologic Aspects of Feedlot Waste Control" resulted from the research reported herein. Therefore, a copy of this paper is included as an attachment to this report.

PUBLICATIONS

Two publications resulted from the project. These are:

1. Dague, R.R., Paulson, W.C., and Kline, K.J., "Hydrologic Aspects of Feedlot Waste Control," Presented at the 24th Annual Purdue Industrial Waste Conference, Purdue University, Lafayette, Indiana, May 6-8, 1969.

2. Dague, R.R., "Animal Wastes--A Major Pollution Problem," 50th Anniversary Brochure, Iowa Water Pollution Control Association, 1968.

MANAGEMENT OF CATTLE FEEDLOT WASTES

by

Kenneth James Kline

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science
in the Department of Civil Engineering
in the Graduate College of
The University of Iowa

June, 1969

Thesis Supervisor: Assistant Professor Richard R. Dague

Graduate College
The University of Iowa
Iowa City, Iowa

CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's Thesis of

Kenneth James Kline

with a major in Civil Engineering has been approved by the Examining Committee as satisfactory for the thesis requirement for the Master of Science degree at the convocation of June, 1969.

Thesis committee: Richard R. Dague
Thesis supervisor

Wayne L. Paulson
Member

Donald B. McDonald
Member

J. W. Howe
Member

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INTRODUCTION

In the past, domestic and industrial wastes were considered the major sources of water pollution. Today, because of the population explosion and expansive industrial development, these sources are even more significant.

Along with the population growth, and the urbanization and increasing affluence of society, meat consumption has increased. For economic reasons, the meat-producing industries have been forced to concentrate livestock into large operations. The beef industry, being the largest, was one of the first to resort to large scale operation. Pastures, where cattle sought out and foraged on existing vegetation, have been replaced by confinements where all or most of the feed is brought to the animals. This has resulted in the concentration of waste matter in confined areas. In recent years, it has been recognized that confined feeding of cattle is a potentially significant source of water pollution. Cattle on open feedlots are of major concern.

The purpose of this research is to determine the effects of hydrologic factors on the control of runoff from open feedlots. In addition, consideration is given to possible management and treatment techniques.

FUNDAMENTAL CONSIDERATIONS

Feedlot

In 1968, the Iowa Water Pollution Control Commission defined a feedlot as "one or more adjacent or nearby cattle enclosures on a single property where animal density is greater than 50 head per acre"[1]. Dague[2] questioned the use of a density figure in defining a feedlot. He advocates that a proper definition of a feedlot might be "an enclosed area where cattle are confined with all or most of the feed being transported to the site for feeding as opposed to an enclosed area, commonly called a pasture, where the animals seek out and forage on vegetation existing within the enclosure". In 1969, the commission amended the original definition to read as follows "one or more adjacent or nearby cattle enclosures on a single property where there are at least 100 cattle and where the animal population is greater than 1 animal for each 600 square feet"[3]. The above definition still involves a density figure of about 73 head per acre. It is also stated that an operator must have at least 100 cattle in order to have a feedlot.

Whether or not to define a cattle feedlot on a density or total population basis is questionable. More appropriately a feedlot might be defined on a functional or operational standpoint as indicated by Dague[2].

Cattle Production-Magnitude and Trend

Iowa is the leading cattle feeding state in the United States. Its production accounted for nearly 19% of the cattle marketed from the 32 major cattle feeding states during 1967. Iowa's feedlots produced 30% of the cattle marketed from the 12 midwestern cattle feeding states in that same year. Table 1 shows the 1967 cattle production from the nation's top seven and top twelve midwestern cattle producing states. Respectively, these states account for nearly 70% and 62% of the cattle production in the United States.

Table 1. Cattle Production in the United States (1967). (From Statistical Reporting Service[4])

State	Number of Cattle Marketed
7 Leading States	
Iowa	4,057,000
Nebraska	3,066,000
California	2,049,000
Texas	1,654,000
Colorado	1,330,000
Kansas	1,321,000
Illinois	1,279,000
Total	14,756,000
12 Midwestern States	
Iowa	4,057,000
Nebraska	3,066,000
Kansas	1,321,000
Illinois	1,279,000
Minnesota	869,000
Missouri	690,000
S. Dakota	618,000
Indiana	496,000
Ohio	442,000
Michigan	240,000
Wisconsin	206,000
N. Dakota	139,000
Total	13,423,000

In the 32 major cattle feeding states, the number of feedlots with a capacity of 1,000 head or more totaled 2,008 during 1967, an increase of 32 percent since 1962 (Table 2). During 1967, the number of cattle marketed from feedlots with a capacity of 1,000 head or more totaled 9,854,000, a 77 percent increase from the 5,572,000 marketed from the same class of lots in 1962. The number of feedlots with a capacity of less than 1,000 head totaled 209,505 during 1967. This, compared to 234,646 such feedlots in 1962, is a decrease of 11 percent in the number of lots in this class.

The 32 major cattle feeding states marketed 21,679,000 head of cattle during 1967. Of this total, Iowa produced 4,057,000 head. As indicated in Table 3, the majority of cattle marketed were from feedlots with capacities less than 1,000 head. In Iowa, this feedlot class accounted for 93.4 percent of the total cattle marketed.

As indicated by the tables, the trend is toward producing more cattle from fewer lots and increasing capacities of existing lots.

Table 2. Number of Cattle Feedlots and Cattle Marketed by Size Group.[4]

Year	32 States: Less than 1,000 head	32 States: Greater than 1,000 head	Iowa: Less than 1,000 head	Iowa: Greater than 1,000 head
	Number of Feedlots by Size			
1962	234,646	1,517	49,964	36
1967	209,505	2,008	45,860	140
	Number of Cattle Marketed (1,000 head)			
1962	NA*	5,572	NA*	83
1967	11,825	9,854	3,790	267

*NA indicates that data are not available.

Cattle Wastes vs Human Wastes

Cattle wastes and human wastes are different both in composition and in the manner in which they are commonly released to the environment. Domestic sewage might be termed "water with some solids" whereas cattle waste is "solids with some water". Human wastes are generally deposited in sewers and delivered to a stream or treatment plant on a nearly continuous basis. The delivery of cattle feedlot waste is intermittent, occurring as a result of rainfall and runoff.

The composition of domestic sewage refers to the content of various waste materials, both organic and inorganic, suspended and dissolved. The most important quality factors are biochemical oxygen demand (BOD) and volatile (biodegradable) solids. These two parameters are used to design and evaluate the biological components of a sewage treatment plant and result in dissolved oxygen (DO) depletion in a stream. A typical quality analysis of domestic wastewater is shown in Table 4.

Table 3. Cattle Marketings by Feedlot Size (1967)[4].

Feedlot class (head)	32 State Total		Iowa	
	Cattle Marketed 1,000 head	Percent of the total	Cattle Marketed 1,000 head	Percent of the total
Under 1,000	11,825	54	3,790	93.4
1,000-1,999	1,209	6	133	3.3
2,000-3,999	1,464	7	66	1.6
4,000-7,999	1,947	9	48	1.2
8,000-15,999	2,166	10	20	0.5
16,000-31,999	2,124	10		
Over 32,000	946	4		
Total	21,679	100	4,057	100.0

The waste from a cattle feedlot consists of two components. One is the semi-solid portion (manure which accumulates on the feedlot). The other is the liquid portion which is produced as a result of rainfall-induced runoff. Not all of the waste is delivered to the stream. The bulk of the solid portion remains

Table 4. Typical Composition of Domestic Sewage.
(From Babbitt and Baumann[5])

All values in mg/liter

Constituent	Strong	Medium	Weak
Solids, total	1000	500	200
Volatile	700	350	120
Fixed	300	150	80
Suspended, total	500	300	100
Volatile	400	250	70
Fixed	100	50	30
Dissolved, total	500	200	100
Volatile	300	100	50
Fixed	200	100	50
BOD (5-day, 20°C)	300	200	100
Nitrogen, total	85	50	25
Organic	35	20	10
Free ammonia	50	30	15

behind as an accumulation on the feedlot surface. The liquid fraction flows overland until it encounters physical opposition or intersects a stream.

Cattle Waste Characteristics

The properties of cattle manures can be classified as physical, chemical, and biological. The physical and chemical properties of the waste vary with the size of the animal, the feed ration, and the environmental conditions under which the animal is raised. Animal size, in terms of live weight, is probably the most important factor affecting the physical and chemical properties of the excreta. As animals increase in weight they naturally eat more and the feed-conversion efficiency decreases therefore they excrete more waste. The digestibility, nature and content of protein, and the nature and digestibility of the other elements in the feed ration also affects the physical and chemical composition of the waste. Temperature, humidity, and activity are the most important environmental factors. When cattle are fed in confinement, spilled feed and bedding may become a part of the waste. In addition, antibiotics, may be passed in the feces. The biota found in cattle feces consists of survivors from the rumen and the usual intestinal flora of mammals[6]. Also, disease-causing organisms may be present in the feces.

The biochemical properties of cattle wastes are primarily related to the animal diet. Diets containing cellulose and other long-chain carbon compounds will result in a waste which has a low biodegradability compared to diets of simpler carbohydrates. Witzel et al.[6], reported a 20°C BOD rate constant of 0.089 for beef cattle on a high-concentrate feed. The K value commonly associated with domestic sewage is 0.17.

Taiganides and Hazen[7] compiled the properties of farm animal excreta as reported in technical publications. They considered the variety of values reported as being representative of the inherent variabilities of the factors affecting the characteristics of animal wastes. To represent daily manure production and composition they used the average of all reported values to develop guide values. Table 5 is the result of their findings for cattle waste properties as defecated.

The availability of plant nutrients and minerals in manures is a function of the animal's metabolism. A growing or milk-producing animal utilizes a higher percentage of these available elements than does a mature animal. Guide values for mineral and organic matter and major fertilizing elements as postulated by Taiganides and Hazen[7] are represented in Table 6.

Cattle Feedlot Runoff Characteristics

Runoff from cattle feedlots is a high strength organic waste resulting from rainfall-induced runoff. Its strengths can range from values typical of domestic sewage to as much as 10 times greater depending on rainfall rate, temperature, and feedlot

Table 5. Guide Values for Average Daily Manure Production by Cattle. (From Taiganides and Hazen[7])

Item	Units	Cattle (1000 lb.)
Wet Manure	lb./day	64.0
Total Solids	% Wet Basis	16.0
Volatile Solids	% Dry Basis	80.0
Nitrogen (N)	% Dry Basis	3.7
Phosphorous (P_2O_5)	% Dry Basis	1.1
Potassium (K_2O)	% Dry Basis	3.0
BOD	lb./day/100 lb.	0.13
COD	lb./day/100 lb.	1.05
COD/BOD Ratio		8.07
Population Equivalent[1/]		7.0

1/ Based on 0.20 lb. BOD/capita/day

conditions.

Table 6. Major Fertilizing Elements of the Complete Cattle Excrement per 1000 lb. of Live Animal Weight. (From Taiganides and Hazen[7])

Item	lb./day	lb./year
Wet Manure	64.0	20,600
Total Mineral Matter	2.1	800
Organic Matter	8.2	3,000
Nitrogen (N)	0.38	138
Phosphorus (P_2O_5)	0.11	41
Potassium (K_2O)	0.31	112

A study by Miner et al.[8] on two experimental feedlots at Kansas State University indicated that the greatest waste strengths resulted from warm temperature, low rainfall intensities, and previously moist feedlot surfaces. Their study indicated that runoff from a concrete-surfaced lot was more heavily polluted than that from a nonsurfaced lot under the same experimental conditions. Table 7 shows the results of the study for both types of feedlot surfaces at a cattle density of 200 head per acre.[8] The bulk of their study was conducted under uncleaned feedlot conditions. However, two weeks after the lots were cleaned the quality of the runoff was essentially the same as that before cleaning.

Table 7. Cattle Feedlot Runoff Characteristics[8]

Item	Units	Range	Median
(Concrete Lot)			
COD	mg/l	2,760-19,400	
COD/BOD		6.3-12.2 1/	8.8
Kjeldahl N	mg/l as N	94-1000	
Ammonia	mg/l as N	1.3-139	
Nitrite	mg/l as N	1.0-6.0	
Nitrate	mg/l as N	0.1-11	
Phosphate	mg/l as $PO_4^{=}$	20-80 1/	50
Suspended Solids	mg/l	1,100-13,500	
pH		7.5-8.2 1/	7.9
(Unsurfaced Lot)			
COD	mg/l	1,900-8,900	
COD/BOD		6.3-12.2 1/	8.8
Kjeldahl N	mg/l as N	50-540	
Ammonia	mg/l as N	1.0-62	
Nitrite	mg/l as N	1.0-23	
Nitrate	mg/l as N	0.1-6.0	
Phosphate	mg/l as $PO_4^{=}$	15-45 1/	26
Suspended Solids	mg/l	1,100-7,000	
pH		7.7-8.4 1/	8.2

1/ 70-percent limits

The Concept of Population Equivalent

The population equivalent (PE) of a waste source is normally based on some unit such as BOD, solids, or volume. It is defined as the human population which would contribute the same amount of that unit per day.

Most often, the PE of a waste source is based on BOD. It is this characteristic of wastes which is used extensively by engineers in the design of treatment facilities for organic wastes and which indicates the effect on the oxygen resources of a stream. Taiganides and Hazen[7] contend that the reason for the variance in PE values reported in technical publications is the different values used for daily BOD production per capita. On the basis of 0.20 lb./capita/day Taiganides and Hazen report a PE value for 1,000 lb. cattle of 7.0.[7] If the presently accepted value of 0.17 lb. BOD/capita/day is used the PE value is 7.6. However, it is the viewpoint of the writer that the principal variance results from differing waste characteristics (total waste production, volatile solids production, BOD, etc.) that are used as a basis for computing PE values. Also, differences in methods of analysis have a significant effect.

It should be emphasized that the PE values cited are for the cattle waste as defecated. In order for a PE value to be exerted it has to enter a stream or treatment facility. A more meaningful value of PE is that present in the runoff from cattle feedlots. Utilizing the empirical formula used to represent data by Miner et al.[8] the PE value of cattle feedlot runoff based on BOD is:

$$\text{PE per head} = \frac{FRw}{CN} \tag{1}$$

where

F = BOD in the runoff, mg/l.

R = total runoff, cubic feet.

w = unit weight of water (62.4 lb./ft.^{3}).

C = 1,000,000 x .17 lb. BOD per capita.

N = number of cattle on the feedlot.

The BOD in the runoff is given by

$$\text{BOD in runoff, mg/l} = \frac{K_C K_M K_T}{K_R} \left(\frac{1}{R}\right)^{1/3} \tag{2}$$

where

K_C = COD constant for nonsurfaced lots = 7000 mg/l.

K_M = moisture correction factor.

K_T = temperature correction factor.

K_R = COD/BOD ratio = 8.8

R = rainfall intensity, in./hr.

For critical conditions, (wet lot, K_M = 1; temp. above 78° F, K_T = 1), equation 2 reduces to

$$\text{BOD in runoff, mg/l} = 795 \left(\frac{1}{R}\right)^{1/3} \tag{2-1}$$

Population equivalents for a one-hour rainfall at various rainfall intensities are shown in Figure 1. It appears that higher rainfall intensities yield higher PE values. However, when computed for a given amount of rain at various rainfall intensities, e.g. a 1 inch rain at 1/2 inch per hour the reverse is shown to be true. Figure 2 shows the PE value per head for a one inch rainfall.

The total runoff from a cattle feedlot during a rainfall event might be a slug organic load for the receiving stream. However, by retaining the runoff and releasing it at a uniform rate for a week, month, or year the PE value exerted is averaged over the period of release thereby reducing the slug effect. For example the runoff from a one inch rain at 1/2 inch per hour, on a two acre feedlot containing 200 cattle, represents a PE value of 13.2 per head. If the runoff is retained and released over a 7 day period the PE value exerted is reduced to 1.9 per head per day.

Feedlot Management

Cattle feedlot waste is an industrial waste. As with any industrial waste, ways and means of volume and strength reduction are two of the first fundamental aspects investigated. The total cattle waste has two constituents, the manure accumulation on the lot and the liquid arising from rainfall and runoff.

The fresh manure from a 1,000 lb. beef animal as defecated on the lot has a moisture content of 84 percent (Table 5) and would occupy a volume of about 1.22 cubic feet. As indicated

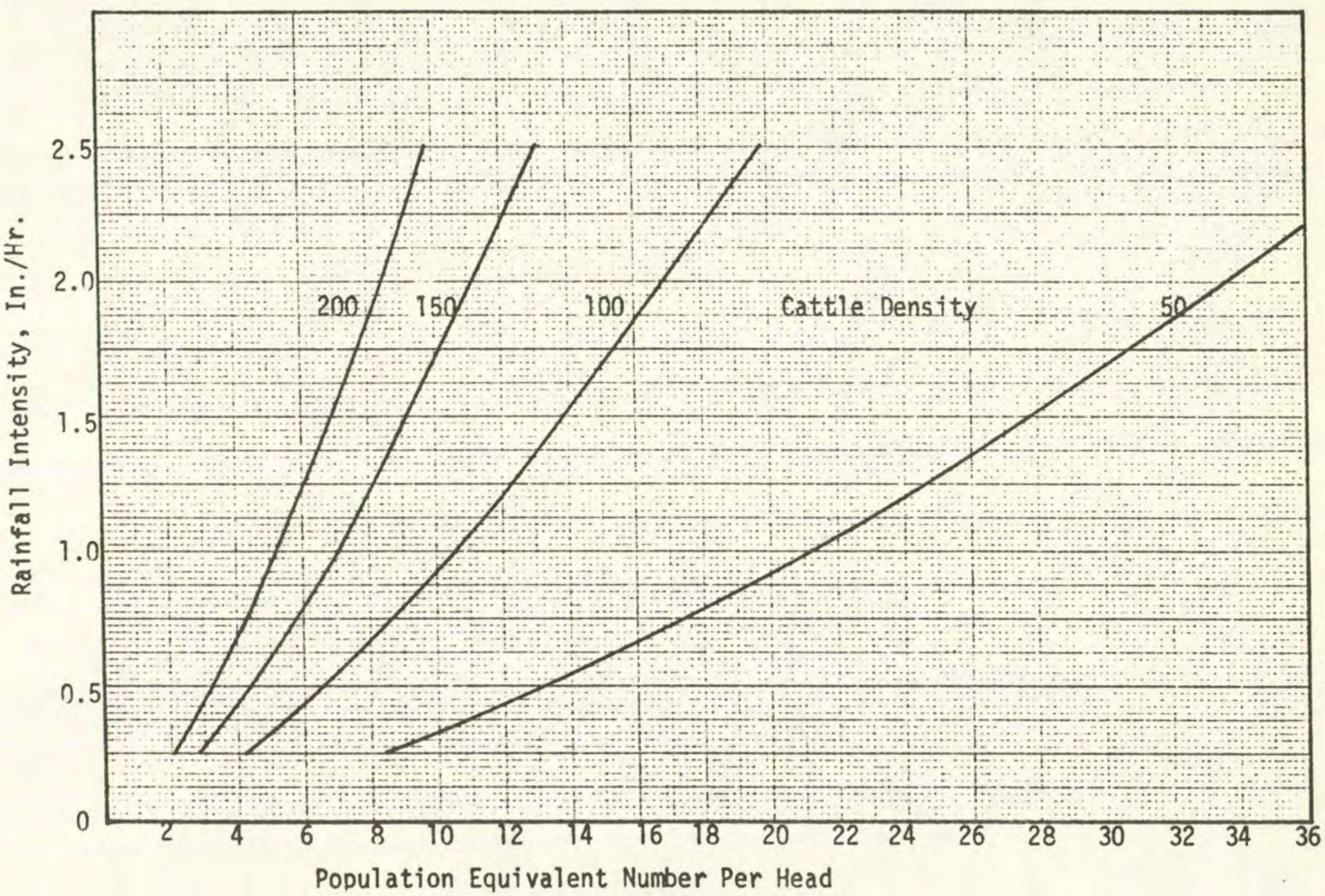

Fig. 1. Effect of Cattle Density and Rainfall Intensity on Population Equivalent.

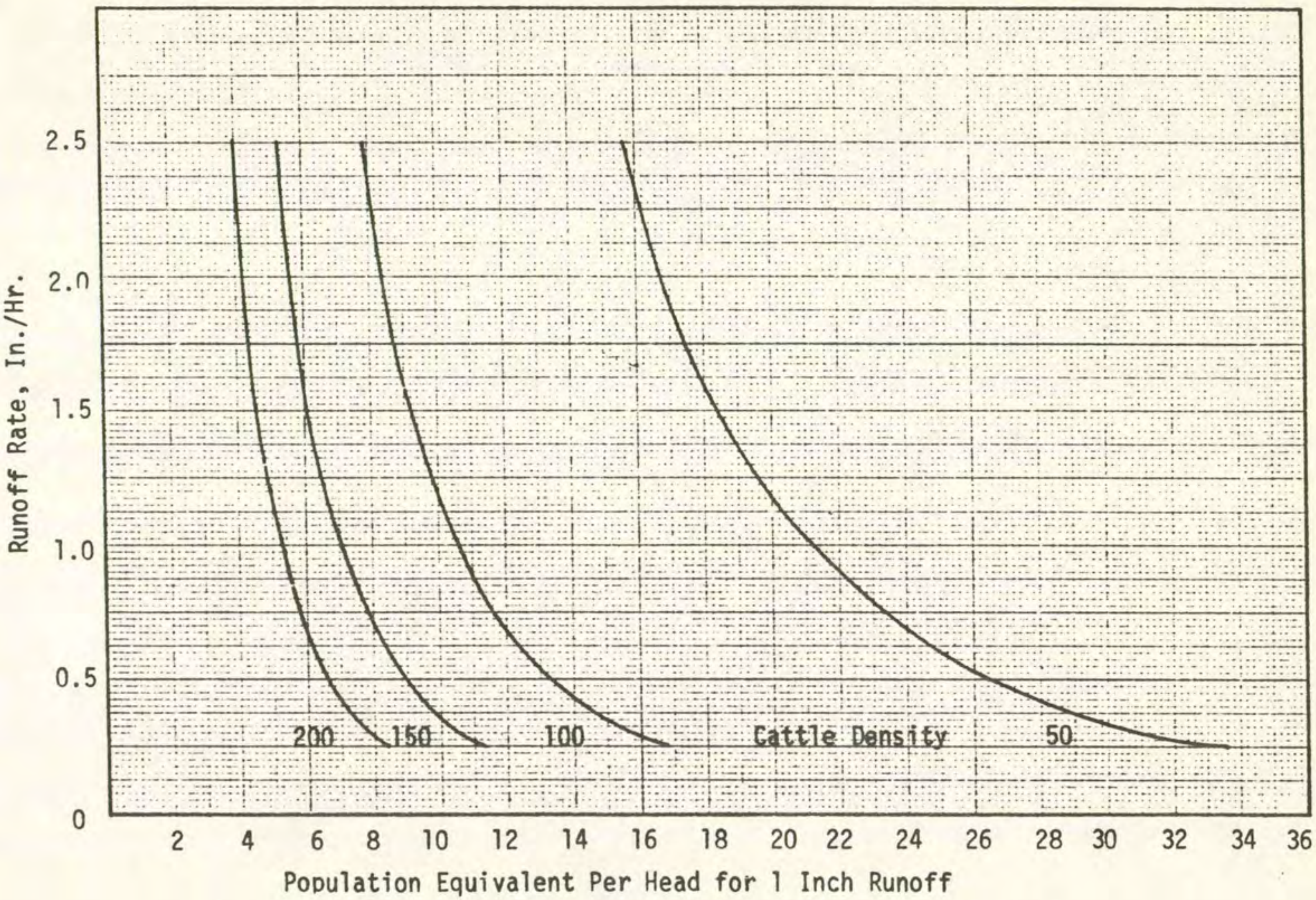

Fig. 2. Effect of Cattle Density and Runoff Rate on Population Equivalent for a 1 Inch Runoff.

by Loehr and Agnew[9] natural drying of the material on the feedlot surface can reduce the moisture content to 40 or 50 percent. This would result in a volume and weight reduction of 24 and 30 and 50 and 42 percent respectively. Therefore, by taking advantage of natural drying, considerably less weight and volume of material is left for final disposal. In addition, biological decomposition of the organic manure occurs on the lot. The extent of strength reduction by natural drying would depend upon the temperature and length of time the manure is left to accumulate.

Management of the liquid portion of the cattle wastes is a problem quite different from that of the solid portion. The liquid arises as a result of precipitation followed by surface runoff and, therefore, is directly related to the hydrology and topography of the area. To achieve a volume reduction one might put a roof over the feedlot and completely eliminate the liquid waste. However, such a practice would be costly. Also, there would be a reduced chance of natural drying of the manure accumulations on the lot. Another means of volume reduction is the prevention of runoff from areas exterior to the feedlot from entering the feedlot and becoming a part of the total yield.

The runoff from rainfall is given by the Rational Formula:

$$Q = CAIR \tag{3}$$

where

Q = runoff, in cfs.

C = a homogenous units coefficient.

A = area, in acres.

I = rainfall intensity, in in./hr.

R = runoff coefficient.

In looking at the equation, the only two elements which can be controlled are A and R. The runoff coefficient, R, is a function of the feedlot surface. As indicated by Miner et al.[8] using a runoff hydrograph from nonsurfaced and concrete-surfaced feedlots, after a period of initial rainfall the runoff is equal to the rainfall on a nonsurfaced lot. This indicates a runoff coefficient approaching that of concrete surfaces. The runoff rate is directly proportional to the area, A. Therefore, by reducing the area the runoff can be reduced. Reduction in area would mean higher cattle densities for a given number of cattle. For example if an operator were raising 1,000 cattle on 10 acres and he wanted to reduce runoff by a factor of 2 he would have to reduce the lot size to 5 acres. The cattle desity would become 200 head per acre compared to the previous 100 head per acre.

Increased cattle densities may be at odds with the feedlot managers, but this is one method of reducing the volume of runoff. As indicated by Miner et al.[8] the increased cattle density does not result in a proportionate increase in the strength of the runoff, however the manure accumulation on the lot is more rapid.

A number of other factors affect the nature of feedlot runoff. Miner et al.[8] discovered that the pollutant concentration in runoff was a function of temperature, rainfall rate, and the moisture content of the manure accumulated on the lot. The greatest concentrations of pollutants were obtained during warm weather, low rainfall intensity, and when the manure on the lot was moist. These observations can be explained by the increased solubilities of substances at higher temperatures and the greater contact time at low rainfall rates. Also the chemicals in solution on the wetted surfaces of the particles are easily passed to the runoff.

Another aspect of the runoff is its suspended solids content. The amount of solids in the runoff is related to the characteristics of the manure accumulation, the rainfall rate, and the slope of the feedlot. With higher rainfall rates and steeper slopes the degree of solids transport is greater. As a feedlot modification to prevent solids transport, Dague[2] advocates the use of bench terraces if necessary to minimize solids transport and to gain the advantage of natural decomposition and drying of solids on the feedlot surface.

The type of feedlot surface affects the suspended solids concentration, with concrete surfaces yielding the higher concentrations. Also affected by the surface type is the percent of the suspended solids which are volatile. As indicated by Miner et al.[8] the suspended solids transported from a concrete surface have a higher percent volatility. These aspects might be explained in the light of the degree of intermingling between manure and the soil brought about by the hoofs of the animal on a nonsurfaced feedlot.

Treatment and Disposal

The Manure Accumulation

The disposal of feedlot manure accumulations can be a major problem, particularly for a big operation. On a dry weight basis the daily contribution of each 1,000 lb. beef animal is about 10 lb. of solids. This can become a significant problem if viewed on a monthly or annual basis. The nitrogen and phosphorous production per 1,000 lb. animal per day are 0.4 lb. and 0.1 lb. respectively (Table 6). On an annual basis, this represents vast quantities of fertilizing elements from a single animal. To merge these quantities of wastes into the environment without creating disturbances or imbalance is the major problem in disposal.

Application of the waste to cropland in order to utilize the fertilizer value is one alternative for disposal. However, the situation is complicated by the intermittent availability of the cropland to receive the waste, therefore storage will be required until the land is available. Another complication may be the percent recovery of the nutrients by the crop. If recoveries are low, there exists the potential of surface and groundwater contamination due to the nutrient residuals. The degree of contamination which may result will depend on the geology and hydrology of the disposal area. Contamination of runoff could be reduced by plowing the disposal site after manure applications.

Another alternative for the disposal of the accumulated solids would be that of application to land without regard for nutrient recovery. Such practice calls for heavy applications of the manure to the land and has the potential of both surface and groundwater contamination if the site is not selected or managed properly. The same practices used in the site selection and management of sanitary landfills can reduce the pollution potential.

As indicated by Dague[10] an ideal sight would be one where surface runoff from surrounding areas does not flow across the disposal area; where underlying soils are tight, to minimize the percolation of water through the deposited manure and into the ground water; where deep aquifers are protected by aquicludes from pollution due to nitrogen and other chemical forms; where the area is relatively isolated from human habitation, to reduce problems based on esthetics; and where sufficient soil is available for use as a cover material for the deposits of manure. Essentially, what is proposed is the operation of a sanitary landfill for disposal of cattle waste solids.

Composting of the manure might be considered. However, the additional work may be great for a small volume reduction. There is also the aspect of ultimate disposal of the residue. This may be essentially as big a problem or work load as that originally. Some natural composting will occur if the solids are held on the lot surface.

Other chemical and biological treatment processes might be considered. However, it is questionable whether they would be economical.

The Liquid Runoff

Regarding management of the liquid portion of the waste, several basic procedures have been postulated by Dague[10]. These are: 1) uncontrolled release of the runoff to a stream, 2) controlled release to a stream following a period of retention in a pond, 3) release to the land after a period of retention in a pond, and 4) biological treatment followed by release to the land or to the stream. Each feedlot should be treated individually and the best management scheme fitting the treatment requirements applied.

Uncontrolled Release to a Stream.

Uncontrolled release of the runoff to the stream is not necessarily the least desirable alternative. Feedlot runoff occurs at the same time that runoff from adjacent areas occurs. Depending upon the relative magnitude of the runoff from adjacent areas, the dilution available may be enough to reduce the "slug" effect of the feedlot runoff. The available dilution is directly related to stream flow. However, if the organic load in the stream is beyond the tolerable level it is not desirable to further deplete the oxygen level. In such case a retention facility could be used to retain the runoff for later release at more desirable stream conditions. The decision to use a retention facility should be made only after it is shown that uncontrolled release of the runoff is an impairment to the water quality for some legitimate downstream water use.

Controlled Release Following a Retention Period.

Controlled release of the runoff to the stream following a period of retention, is another well-founded control procedure. Such practice results in a reduced load on the stream rather than the slug load resulting from uncontrolled discharge. The oxygen demand is extended and averaged over a week, month, quarter, or annual period depending upon stream conditions and assimilation capacity. Collection of the runoff in a retention pond will result in a suspended solids and BOD reduction as a result of plain settling. In research at Kansas State University, Dague[11] observed COD reductions ranging from 25 to 45 percent as a result of solids removal by plain settling for periods ranging from 2 to 24 hours. A significant reduction in the strength of the waste can be obtained by plain settling, however the solids must be removed for disposal. The fixed portion of the solids removed will probably be quite high and, therefore, even with a 50 percent volatile solids reduction through anaerobic digestion, the total solids remaining for disposal may be as high as 75 percent of the original. Probably the best disposal method is to dispose of the settleable solids along with the feedlot manure accumulation.

Retention ponds used for collection of feedlot runoff can become filled with solids if some method is not used to prevent it. In Kansas, some retention ponds designed to hold three inches of runoff were filled with solids within three years after construction. Removal of the muck from a filled retention pond may be more costly than the original excavation. Good management dictates some scheme for creating quiescent conditions for the runoff prior to entering the retention pond. One feedlot in Kansas utilizes a long, flat-sloped ditch to transport the runoff from the feedlot to the retention ponds. The reduced flow velocities allow the solids to settle out in the bottom of the ditches where they can be removed for disposal.

After the solids have been removed the problem of disposal of the liquid remains. One alternative is the controlled release of the liquid waste to the stream. Spreading the liquid on the land is another possibility. Another method is further stabilization of the liquid by biological treatment followed by release to the land or to the stream.

Controlled release to the stream is probably the simplest method for disposing of the pre-settled liquid. Such practice will, in many cases, provide the necessary degree of waste control. Pre-settling will remove the suspended solids, reduce the strength of the liquid, and prevent the build-up of sludge banks at the discharge point. By controlling the rate of discharge, shock loading will be avoided. Utilizing available water quality and stream flow data, a discharge rate may be determined to maintain acceptable stream conditions throughout the entire year. If recreation and municipal use of the stream is demanded, it may be desirable not to release during months of the year when such activity is prevalent. Such consideration may require storage for the entire period during which the use exists. Storage requirements may be determined by utilizing the mass diagram technique to balance influent and discharge quantities. It may be necessary to withhold discharge to the stream during periods of ice cover. Again, the mass diagram may be utilized to determine storage requirements for such periods. Thus, this relatively simple runoff control practice can accomplish a great deal in preventing stream pollution and maintaining acceptable conditions for all legitimate downstream water demands throughout the entire year.

Release to the Land.

Application of pre-settled feedlot runoff to the land is another possible method of disposal. Such practice may be concerned with recovery of the fertilizer elements or utilization of the liquid for moisture to supplement natural rainfall. On the other hand, the major concern might be disposal only. The amount of storage necessary will depend on how the liquid is to be utilized.

Land disposal refers to the discharge of liquid effluents to a receiving soil. The waste stabilization is achieved by two means (1) soil filtration and exchange and (2) aerobic biochemical reduction by soil bacteria.

In addition to waste stabilization, land application affords a source of fertilizing elements such as nitrogen, phosphorus, and potassium, trace elements, organic matter, and additional water for the soil and soil organisms as well as the vegetation it supports.

Experiences from sewage farms throughout the United States have shown that the cover crops, grasses, clover, and alfalfa, are best for irrigation because of their absorption characteristics and the reduced potential of runoff from such crops. The crops also serve the function of maintenance by using the available nutrients, balancing the biological system, and keeping the soil loose for good percolation.

Basically there are two types of land disposal, spray irrigation and ridge-and-furrow irrigation. Spray irrigation is best adopted to areas where the terrain is rolling. Ridge-and-furrow irrigation is practiced in flat areas.

Nuisance free land disposal normally requires intermittent application of effluents so that the percolating liquid moves through the air-containing soil interstices drawing air behind it. When the soil becomes saturated, further application of effluent may exhaust the available oxygen, causing anaerobic conditions and its associated septic odors.

The efficiency of land disposal can be attributed to the availability of oxygen in the soil and the enormous surface area available on the soil particles for biochemical activity. In addition, the soil provides an optimum biological population and environment. To maintain efficiency, it is necessary to consider loadings in terms permeability of the soil, oxygen demand of the waste, and the concentrations of other chemical constituents in the waste.

Stone[12], in a review of land disposal of sewage and industrial wastes based on observations in temperate climates, composed a table of effluent application for various soil types. He lists a volumetric loading rate of 1,000 to 10,000 gpd/acre for effluents with BOD greater than 100 p.p.m. This application range is for natural soils of the following types: very fine sands; organic and inorganic silts; mixtures of sand, silt, and clay; glacial till; and stratified clay deposits. In a review of ridge-and-furrow irrigation for industrial waste disposal, Schraufnagel[13] reported volumetric loadings exceeding 50,000 gpd/acre and BOD loadings greater than 1000 lb./day/acre. His review disclosed a variety of wastes being disposed of by this method without adverse effects.

An ideal irrigation site is characterized by crop cover or soil types capable of removing chemical elements to levels below those set by public health standards. If this is not the case, there is need for an aquiclude to prevent leaching of the elements into the groundwater. Proper site selection should be based on an analysis of the ground water geology and the assimilation capacity of the soil and vegetation. Ground water quality monitoring may be necessary to evaluate the efficiency of the disposal area.

Biological Treatment.

Biological treatment followed by release to the stream or land is another possibility for management of the liquid feedlot waste. However, one of the primary requirements of biological treatment processes is the avoidance of hydraulic and organic surge loads. In this regard an equalization pond would be necessary to enable treatment on a continuous basis. A runoff retention pond could be operated to serve that purpose.

Biological treatment schemes have been proposed[6], but the efficiency and economic feasibility applied to feedlot runoff is uncertain. The costs of biological treatment, both first cost and operating costs, are quite extensive and beyond the scope of simple operation. Although biological treatment can accomplish satisfactory stabilization it seems best to avoid this practice if possible.

THE STUDY AREA

Selection Basis

The Iowa River Basin was chosen as the area of study on the basis of the variety of data available for use in this research. Available data consisted of U.S. Geological Survey surface water records, Iowa State Climatological Survey meteorologic records, U.S. Army Corps of Engineers water quality data from the Coralville Reservoir Project, and numerous theses written on various aspects of the Iowa River.

The flow records of the Iowa River at Marshalltown were selected for a stream flow analysis because of their length and nonsuceptibility to fluctuations due to power or industrial water demands. On the assumption of meteorologic homogeneity, the meterologic data for Cedar Rapids, Iowa, was selected for a precipitation analysis because of the length of record available and its availability on computer punch cards. Data on water quality from the files of the Coralville Project were the only data of such type in existence covering any appreciable length of water quality monitoring on the Iowa River. The purpose of the Coralville Project is to determine the effects of the Coralville Reservoir on the water quality downstream. Samples are taken at one station upstream, at two stations within the reservoir, and at two stations downstream.

The water quality data used in this research are from samples taken upstream from the reservoir.

Description

Geographic Location

The Iowa River Basin is located in the eastern half of the State of Iowa (Figure 3). The river rises from two separate branches in Hancock County, in North-Central Iowa. Crystal Lake is the source of the West Branch and the East Branch begins as a small stream northwest of Garner. Just above Belmond, in Wright County, the two branches join together and flow in a southeasterly direction for three hundred and twenty-seven miles before joining the Mississippi River about twenty miles below Muscatine.

The drainage area of the Iowa River at its confluence with the Cedar is 4,770 square miles. Before entering the Mississippi the Iowa-Cedar River Basin represents a drainage area of 12,640 square miles.

Municipal, Industrial, and Agricultural Characteristics

The Iowa River basin is composed primarily of an agricultural area having only two large cities on the basin, Marshalltown and Iowa City. A domestic and industrial waste survey from a 1963 thesis by Butts[14] yielded the industries and cities listed in Tables 8 and 9 and shown in Figure 4 as those discharging wastes into the Iowa River.

Data from a 1964 U.S. Census of Agriculture in Iowa[15]

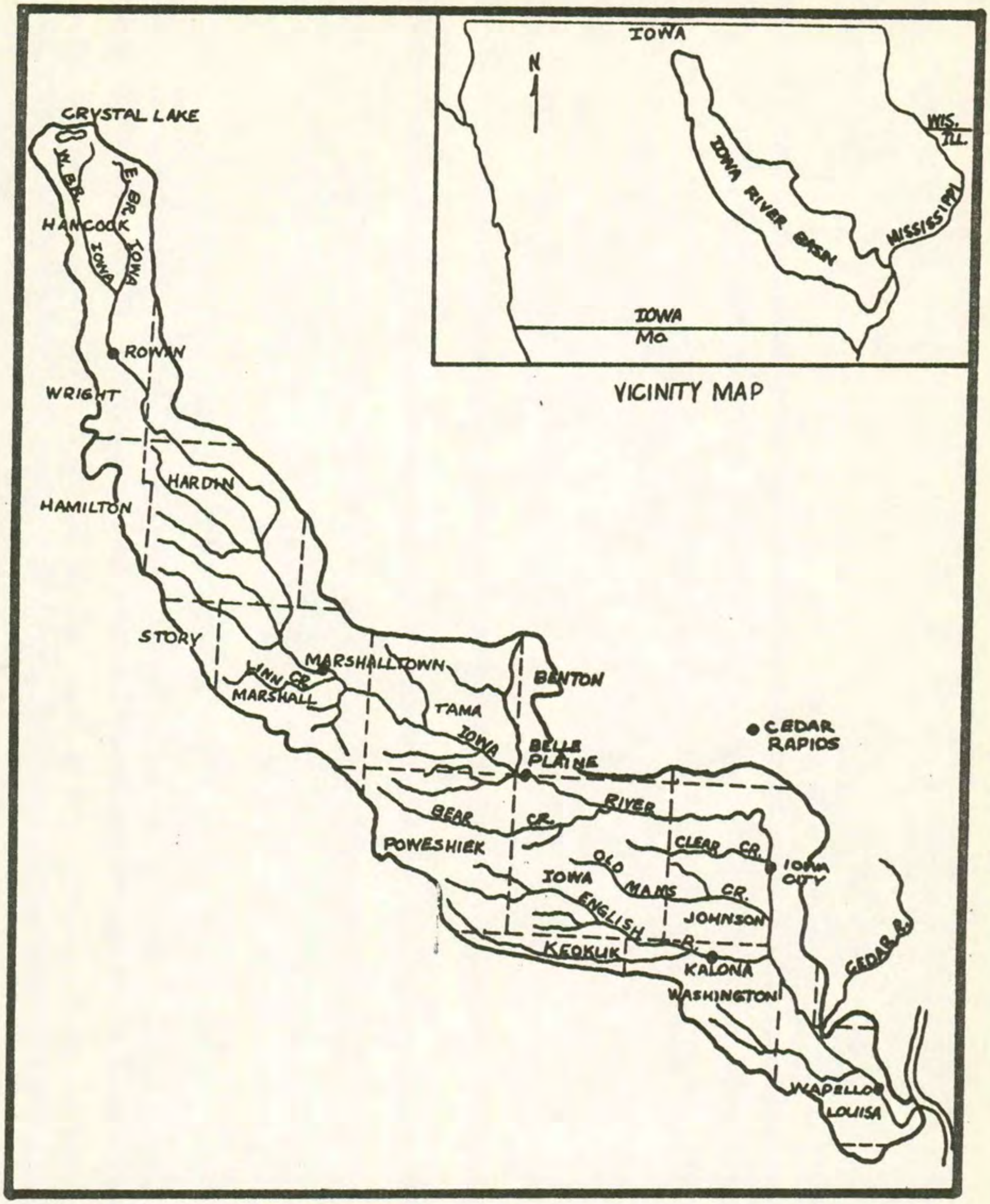

Fig. 3. Vicinity Map and River Gaging Station Location.

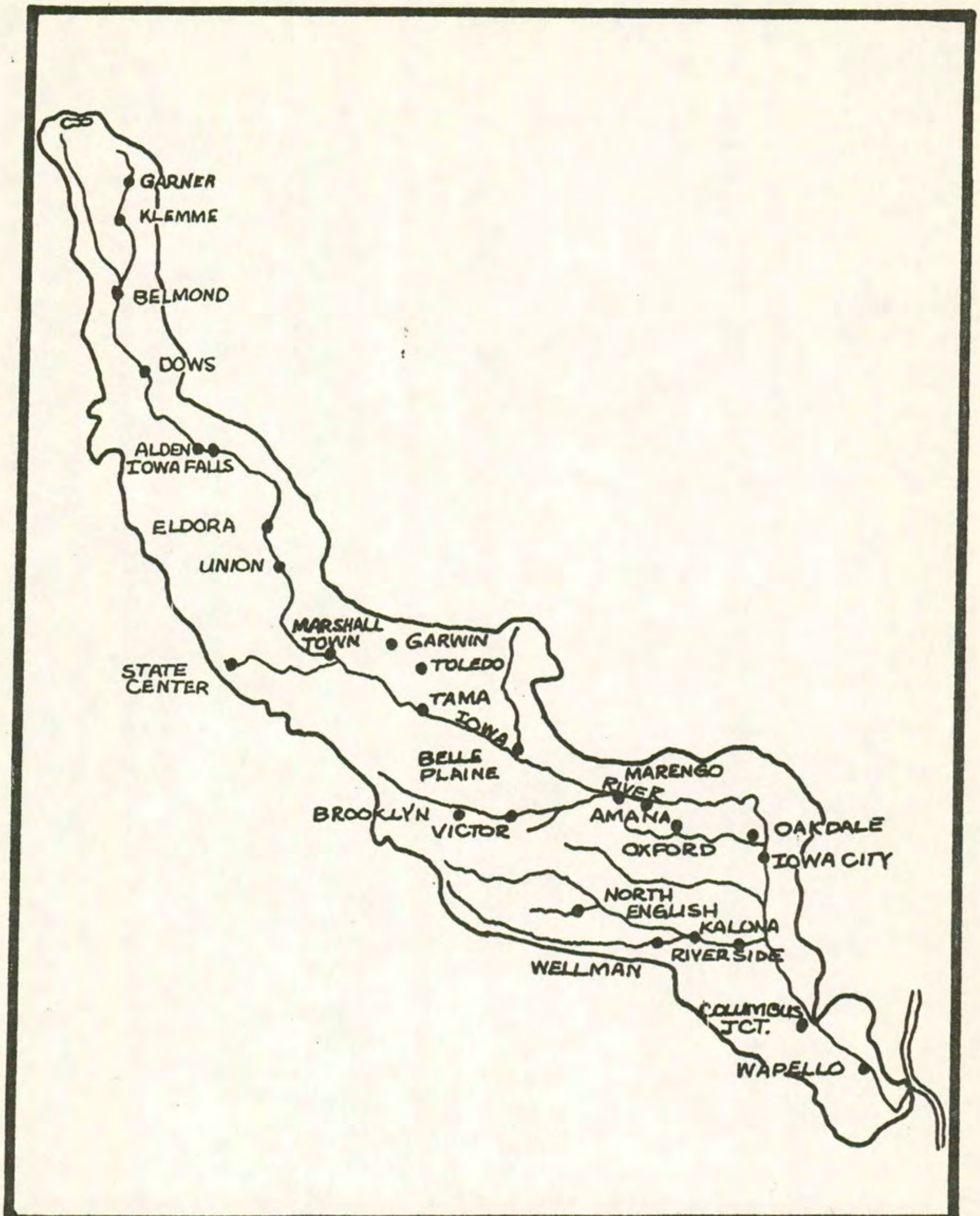

Fig. 4. Communities and Industries Discharging Wastes into the Iowa River.

showed the cropped-farmland in the basin to be 33 percent corn, 14 percent soybeans, 7 percent oats, 9 percent hay, and the remaining 37 percent of the farmland to be pasture, grasslands, and wooded areas. The same census showed the major farm animal categories to consist of; 21 percent cattle, calves, steers, and bulls; 10 percent milk cows, and heifers; 2.5 percent sheep and lambs; 27 percent hogs and pigs; and the remaining 39.5 percent chickens, turkeys, and miscellaneous poultry. For the major meat classifications (excluding poultry), the numbers of animals marketed were 19 percent beef, 75 percent pork, and 6 percent mutton.

Table 8. Industries Discharging Wastes into the Iowa River.

	Industry	Location	Treatment	Effluent 5-day 20° BOD (PE)
1.	General Mills	Belmond	None	400
2.	Soybean Plant	Belmond	Skimming	3,800
3.	Alden Creamery	Alden	None	200
4.	Central Fibre Products Co.	Tama	None	6,200
5.	Amana Refrigeration and Amana Society	Amana	None	4,000[1/]

1/ Determined by Butts from a field analysis.

Basic Regimen

The Iowa River Basin is long and rather narrow as indicated by Figure 3. Actions of various glacial periods have given the basin

Table 9. Communities Discharging Municipal Wastes into the Iowa River.

	Community	Population 1960	Population Sewerd	Degree of Treatment	Effluent PE4/
1.	Garner	1,990	1,500	Sec.1/	550
2.	Belmond	2,506	2,000	Sec.	400
3.	Klemme	615		Sec.	70
4.	Dows	882	760	Sec.	500
5.	Alden	838	660	Sec.	100
6.	Iowa Falls	5,565	4,000	Sec.	800
7.	Eldora	3,225	2,790	Sec.	525
8.	Eldora Training School	790	790	Sec.	125
9.	Union	534	380	Pri.1/	300
10.	Marshalltown	22,521	18,000	Sec.	4,500
11.	State Center2/	1,142	900	Sec.	250
12.	Tama	2,925	2,100	Sec.	300
13.	Garwin2/	546	350	Pri.	150
14.	Toledo2/	2,850	1,600	Sec.	1,200
15.	Dysart2/	800		Sec.	150
16.	Belle Plaine	2,923	2,500	Sec.	400
17.	Marengo	2,264	1,800	Lagoon	1,0003/
18.	Brooklyn	1,415	1,080	Sec.	600
19.	Victor2/	870	700	Sec.	100

Table 9. Cont.

	Community	Population 1960	Population Sewerd	Degree of Treatment	Efflyent PE[4/]
20.	Solon[2/]	604	527	Sec.	100
21.	Oakdale TB Sanitarium		750	Sec.	60
22.	Oxford	633	633	Imhoff	400[3/]
23.	Iowa City	33,443	30,000	Sec.	3,250
24.	Williamsburg[2/]	1,342	1,100	Sec.	400
25.	North English[2/]	1,004	700	Sec.	200
26.	Wellman[2/]	1,085	950	Sec.	830
27.	Riverside[2/]	656	500	None	500
28.	Columbus Junction	1,123	600	None	700
29.	Wapello	1,745	1,290	None	1,300

[1/] Sec. = Secondary Treatment; Pri. = Primary Treatment

[2/] Indicates waste discharged into a tributary

[3/] Indicates personal estimate by Butts

[4/] Based on BOD (5 day, $20^{o}C$)

a variety of topographic features characteristic of each glacial period. Its topography ranges from wide, poorly-drained valleys and gentle undulations in the upper reaches to a channel carved from solid limestone in the Iowa Falls area and again to wide alluvial flood plains in the lower reaches below Iowa City.

The upper reaches of the basin are generally flat to slightly undulating and natural drainage is poor. The natural drainage has been supplemented by artificial drainage by using tile systems and drainage ditches. Most of the lower basin is characterized by well developed natural drainage as is characteristic of the Kansan drift and wind-blown loess deposits.

There are few large tributaries which contribute flow to the Iowa River. With the exclusion of the Cedar River, the only one of significant size is the English River having a length of eighty-five miles and a drainage area of 645 square miles.

Hydrology

A great variety of flows characterize the Iowa River. In the spring, flooding occurs where the stream is not controlled by levees or the Coralville dam. Flows during the warm months of July, August, September, and some winter months can be extremely low. It is during the time of low flows that waste discharges can be critical because of the low dilution capacity available. Waste discharge at low flow can be even more critical if dissolved oxygen levels are low because of higher temperatures or ice cover.

METHOD AND PROCEDURE

Precipitation Data Analysis

From a letter written to the Weather Bureau Office in Des Moines it was learned that precipitation data for three stations in Iowa was available on computer punch cards. The stations listed were Cedar Rapids, Fairfield, and Iowa City. Cedar Rapids and Fairfield were listed as being on punch card from 1900 through 1965 whereas Iowa City was available only from 1937 to 1962. On the basis of the length of record and the location, Cedar Rapids data was selected for use in this research. A storage tape copy of this data was requested and received.

The primary interest in this research is the control of feedlot runoff. Since runoff is a function of rainfall, the questions asked were: when does it rain?, and how much?. A computer programmer was employed to write a program to analyze the data and print out only the days on which precipitation occurred. This program produced a printout about one-third the size of the raw data and in a more legible form. Available computer time for the project was very limited and it was decided to save it for a later program; therefore a hand analysis of the reduced data was necessary. The hand analysis was conducted as follows:

1. Classification of precipitation events

   a. A class system for magnitudes of precipitation events was set up as follows:

Class	Magnitude in inches
1	.01 or greater
2	.25 or greater
3	.50 or greater
4	1.0 or greater
5	1.5 or greater
6	2.0 or greater

   b. For rainfall only the reduced data was searched and each event put in its respective class.

2. Number of events in each class on a monthly basis.

   a. For each month of each year the number of events in each class was tabulated.

   b. The average number of events for each month in each class was computed by dividing the summation of the particular event by the 66 year length of record.

   c. The results were tabulated as shown in Table 10 and plotted as shown in Appendix A.

3. Number of events in each class on a yearly basis.

   a. The number of events in each class on an annual basis was computed by summing up the monthly

Table 10. Number of Days of Rainfall Accumulations of Various Magnitudes (66 Year Average).

Month	.01 or More	.25 or More	.50 or More	1.0 or More	1.5	2.0 or More
January	2.06	0.59	0.24	0.03	.01	0.01
February	2.16	0.73	0.29	0.04	.01	0.00
March	4.82	1.88	1.01	0.21	.08	0.03
April	8.72	3.45	1.92	0.64	.18	0.03
May	11.16	4.61	2.70	0.85	.30	0.12
June	10.22	4.64	2.91	1.30	.56	0.27
July	8.75	3.92	2.44	1.04	.52	0.26
August	8.22	3.70	2.44	1.04	.45	0.18
September	8.48	4.32	2.77	1.09	.58	0.26
October	6.62	2.85	1.65	0.48	.23	0.09
November	4.75	1.99	1.08	0.35	.15	0.07
December	2.25	0.80	0.42	0.12	.03	0.00
Year Total	78.21	33.48	19.87	7.19	3.10	1.32

values as computed in part 2.b.

b. This data is also shown in Table 10 and plotted as shown in Appendix A.

The number of events in each class on a quarterly basis was not determined. However all one need do is sum the monthly values for each month of the quarter if it is desirable to have the information.

To answer the question of how much precipitation might be expected in a given period of time was the next task undertaken. A computer programmer was employed to write a program analyzing the raw data to compute weekly, bimonthly, monthly, and annual precipitation accumulations for each year of record. The procedure used was as follows:

1. Weekly precipitation accumulations.
   a. For each month of the year the accumulations for the first seven, second seven, second to last seven and last seven days were calculated and stored giving a total of four values for each year.
   b. The values for the 66 year record obtained in part (a) were rank-ordered and plotted on a probability basis as shown in Appendix A.
2. Bimonthly precipitation accumulation.
   a. For each month of the year, except February, the summation of precipitation for the first fifteen and last fifteen days was computed and stored.

b. February was handled by taking the first fourteen and last fourteen day accumulations.

c. The values obtained in parts (a) and (b) were rank-ordered and plotted as probabilities as shown in Appendix A.

3. Monthly precipitation accumulations.

   a. The total precipitation for each month of the year was determined and stored.

   b. Precipitation totals from part (a) were rank-ordered and plotted on a recurrence interval basis as shown in Appendix A.

4. Quarterly precipitation summations.

   a. The monthly totals for each year as determined in part 3(a) were summed for each quarter and stored.

   b. Values determined in part (a) were rank-ordered and plotted on a recurrence interval basis as shown in Appendix A.

5. Annual precipitation accumulations.

   a. Monthly totals determined in part 3(a) were summed for each year and stored.

   b. The yearly totals from part (a) were rank-ordered and plotted on a recurrence interval basis.

6. Percentage each monthly total was of the respective annual total.

The values determined in part 3(a) were divided by the values determined in 5(a) and the resulting answer multiplied by 100% for each year.

The program previously described completely exhausted the available computer time and necessitated manual analysis of the remainder of the output.

7. Average percentage each monthly summation was of the annual summation.
   a. The values obtained in part 6 were summed and divided by the length of record to yield the average percentage.
   b. A check on part (a) was determined by summing up all the accumulations for a particular month and dividing the result by the summation of the annual accumulations. The procedure was repeated for a few months until confident that the values obtained in part (a) were correct.
   c. The results were tabulated as shown in Table 11.
8. Average monthly and annual rainfall.
   a. The summation of annual rainfalls was divided by the length of record to determine the average annual rainfall.
   b. Average monthly rainfalls were determined by multiplying the results of part 7(b) by the value obtained in part 8(a). See Table 11.

c. A manual check of part (b) showed the results to be correct.

Table 11. Precipitation Averages: Monthly Percentage of Annual; Monthly; and Annual.

Month	Average % of Annual	Precipitation Inches
January	3.8	1.27
February	3.5	1.17
March	6.4	2.13
April	9.0	3.00
May	11.9	3.97
June	13.8	4.60
July	11.8	3.93
August	11.2	3.73
September	12.3	4.10
October	7.0	2.33
November	5.5	1.83
December	3.8	1.27
Annual	100.0	33.33

Surface Water Flow Analysis

One alternative for managing the runoff from cattle feedlots is that of holding it in a retention pond. The retained runoff is then released to the stream on a controlled basis or applied to the land. Allowable release rates to the stream are related to the stream flow and its water quality at the time of release. Surface water records were obtained from the U.S. Geological Survey for an analysis of stream discharges. The flow records for the gaging station at Marshalltown were used in the analysis. These records were selected on the basis of length and non-susceptibility to fluctuations due to draughts or impoundments.

Published data listed average daily flows for each month on record. Daily flows for each month were available from water year 1940 to water year 1967. An analysis of the stream flow data was conducted in a manner as follows.

1. Low monthly flow analysis.
    a. The lowest daily discharges for each month of the year were tabulated for the 27 year record.
    b. For each year of record the lowest monthly discharges for each month were rank-ordered and plotted on a recurrence interval basis as shown in Appendix B.
2. Average monthly flow analysis
    a. Average monthly discharges for each month of the year were tabulated for the 49 year record.

b. The monthly discharges for each month of each year were rank-ordered and plotted on a recurrence interval basis as shown in Appendix B.

3. Flow values for selected recurrence intervals were taken from both the lowest daily and average daily recurrence interval plots. The values are shown in Tables 12 and 13.

Water Quality Data

In the previous discussion it was mentioned that allowable discharge from a retention facility was a function of stream quality at the time of release. The two major water quality parameters which characterize stream conditions are DO and BOD. Water quality data for the Iowa River were obtained from Dr. D. B. McDonald. Dr. McDonald has been in charge of the Coralville Project since its beginning in 1964.

The data from the project covered only four years of water quality monitoring. At the time of this research it was the only data being collected continuously on the Iowa River. The data were analyzed as follows:

1. Dissolved Oxygen

   a. The dissolved oxygen values for each month of each year were tabulated and rank-ordered.

   b. Rank-ordered values from part (a) were plotted on a probability of exceedance basis as shown

Table 12. Discharge, cfs, for Selected Recurrence Intervals of Lowest Daily Flow for the Iowa River at Marshalltown, Iowa.

	Recurrence Interval, Years				
Month	1.575	2	5	10	20
January	93	67	47	31	23
February	128	90	47	33	24
March	420	232	94	58	37
April	630	450	155	110	85
May	520	380	146	93	72
June	580	430	147	74	38
July	300	233	107	64	39
August	147	120	63	42	28
September	135	101	42	27	22
October	190	126	55	38	26
November	150	100	62	45	34
December	115	88	47	38	32

Table 13. Discharge, cfs, for Selected Recurrence Intervals of Average Daily Flow for the Iowa River at Marshalltown, Iowa.

	Recurrence Interval, Years				
Month	1.575	2	5	10	20
January	250	163	64	43	29
February	600	400	110	58	37
March	1850	1200	440	230	152
April	1130	890	420	255	160
May	1170	830	275	183	138
June	1700	1080	365	177	90
July	660	480	182	120	92
August	302	180	106	76	54
September	370	220	93	63	44
October	345	205	82	65	52
November	325	210	100	68	55
December	232	168	59	47	42

in Appendix C.

2. Biochemical Oxygen Demand

   The procedure for BOD analysis was the same as that described for DO analysis in parts 1 (a) and (b).

3. Average Water Temperature

   Temperature values for each month were added for the length of record and the arithmetic mean found and entered in Table 14.

4. Dissolved oxygen and BOD values for the 50 percentile positions were selected from the probability plots and are listed in Table 14.

Allowable Stream Loading

In regard to steam sanitation work, H. W. Streeter and E. B. Phelps[16] were true pioneers. Their classical studies on the Ohio River evolved in a mathematical description of the net rate of change in the dissolved-oxygen (DO) deficit of a stream.

They used two theories in deriving their now well-known "oxygen sag-curve" formula. The first theory is that the rate at which water is reaerated under constant temperature and turbulent mixing conditions is directly proportional to the existing oxygen saturation deficit. Secondly, the rate of biochemical oxidation of organic matter is directly proportional to the remaining concentration of unoxidized substance (BOD). The first assumption states in the absence of BOD:

Table 14. Water Quality Data

Month	Avg. Temp °C	DO/mg/l 50%	BOD_5mg/l 50%
January	1	8.9	3.0
February	1	9.8	4.5
March	6	10.1	8.0
April	11	9.9	3.7
May	15	9.3	5.5
June	22.6	7.1	2.7
July	26.7	7.2	4.7
August	24	8.5	5.0
September	18	7.6	3.8
October	12.5	10.1	3.5
November	5.6	11.4	3.4
December	2	11.7	2.9

$$\frac{dD}{dt} = -K_2 D \tag{4}$$

while the second one states in the absence of reaeration:

$$\frac{dD}{dt} = K_1(L_a - L_t) \tag{5}$$

where

$\frac{dD}{dt}$ = The rate at which oxygen is absorbed from the air or is used up biologically.

L_a = The ultimate first stage biochemical oxygen demand (BOD).

L_t = The BOD at any given time later.

K_1 = The coefficient of deoxygenation to the base"e".

K_2 = The coefficient of reoxygenation to the base"e".

D = The dissolved oxygen defecit after any time "t".

The two formulas when combined yield a linear, first order, differential equation which when integrated between the limits D_a at the point of pollution, or reference point (t=o, $(L_a-L_t) = L_a$), and D at any point distant a time of flow t from the reference point yields the oxygen sag formula:

$$D = \frac{K_1 L_a}{K_2-K_1}(e^{-K_1 t} - e^{-K_2 t}) + D_a e^{-K_2 t} \tag{6}$$

where

D_a = The initial dissolved oxygen deficit.

t = The incubation time in days.

If the ratio between the rates of reaeration and deoxygenation K_2/K_1, which may be termed the oxygen-recovery or self purification ratio, f, of the particular stream, is used in the oxygen sag formula, the expression becomes

$$D = \frac{La}{f-1} e^{-K_1 t}(1-e^{-(f-1)K_1 t}(1-(f-1)\frac{D_a}{L_a})). \qquad (6\text{-}1)$$

Inspection of the above expression shows that the allowable pollutional load L_a for a given receiving water is determined by the magnitudes of the following parameters: (1) the deoxygenation constant K_1, (2) the self purification ratio $f = {}^{K_2}/K_1$, (3) the critical deficit D_c, and (4) the initial deficit D_a.

The sag curve has two characteristic points: (1) a critical point, with coordinates D_c and t_c, where the deficit is maximum and (2) a point of maximum rate of recovery, with coordinates D_i and t_i. The critical point is defined mathematically by ${}^{dD}/dt = 0$ and ${}^{d^2D}/dt^2 < 0$. Differentiation of the oxygen sag expression and simplification yield the following expressions for the critical and inflection times t_c and t_i and their associated deficits D_c and D_i:

$$t_c = \frac{2.3}{K_1(f-1)} \log (f(1-(f-1)(D_a/L_a))) \qquad (7)$$

$$D_c = \frac{L_a}{f(f(1-(f-1)(D_a/L_a)))}^{1/(f-1)} \qquad (8)$$

and

$$t_i = \frac{2.3}{K_1(f-1)} \log (f^2(1-(f-1)(D_a/L_a))) \qquad (9)$$

$$D_i = \frac{(f+1)La}{f^2(f^2(1-(f-1)(D_a/L_a)))^{1/(f-1)}} \tag{10}$$

These two sets of coordinates in addition to the reference coordinates ($t=o$, $D=D_a$) completely define the oxygen sag curve.

For given valves of K_1, K_2/K_1, and D_c, the initial deficit D_a establishes two boundary values for the maximum allowable loading on a receiving stream: an upper bound associated with zero initial deficit or full DO saturation ($D_a=0$), and a lower bound associated with an initial deficit equal to the critical deficit ($D_a=D_c$). These boundary conditions result in the following sets of coordinates of the characteristic points of the oxygen sag curve:

For $D_a=0$ and D_c less than saturation DO

$t'_c = \frac{2.3(\log f)}{K_1(f-1)}$............Upper Boundary Conditions

$L'_a/D_c=f^{f/(f-1)}$

For $D_a=D_c$ and D_a less than saturation DO

$t''_c=0$

$L''_a/D_c=f$ ....Lower Boundary Conditions

These boundary conditions indicate that allowable loading L_a is a function of the self purification constant, f, when the loading is expressed in terms of the critical deficit D_c. The important parameters of the sag curve can be generalized and represented graphically such as the loading curves shown in Figure 5 which is a reprint of that presented in Fair, Geyer, and Okun[17].

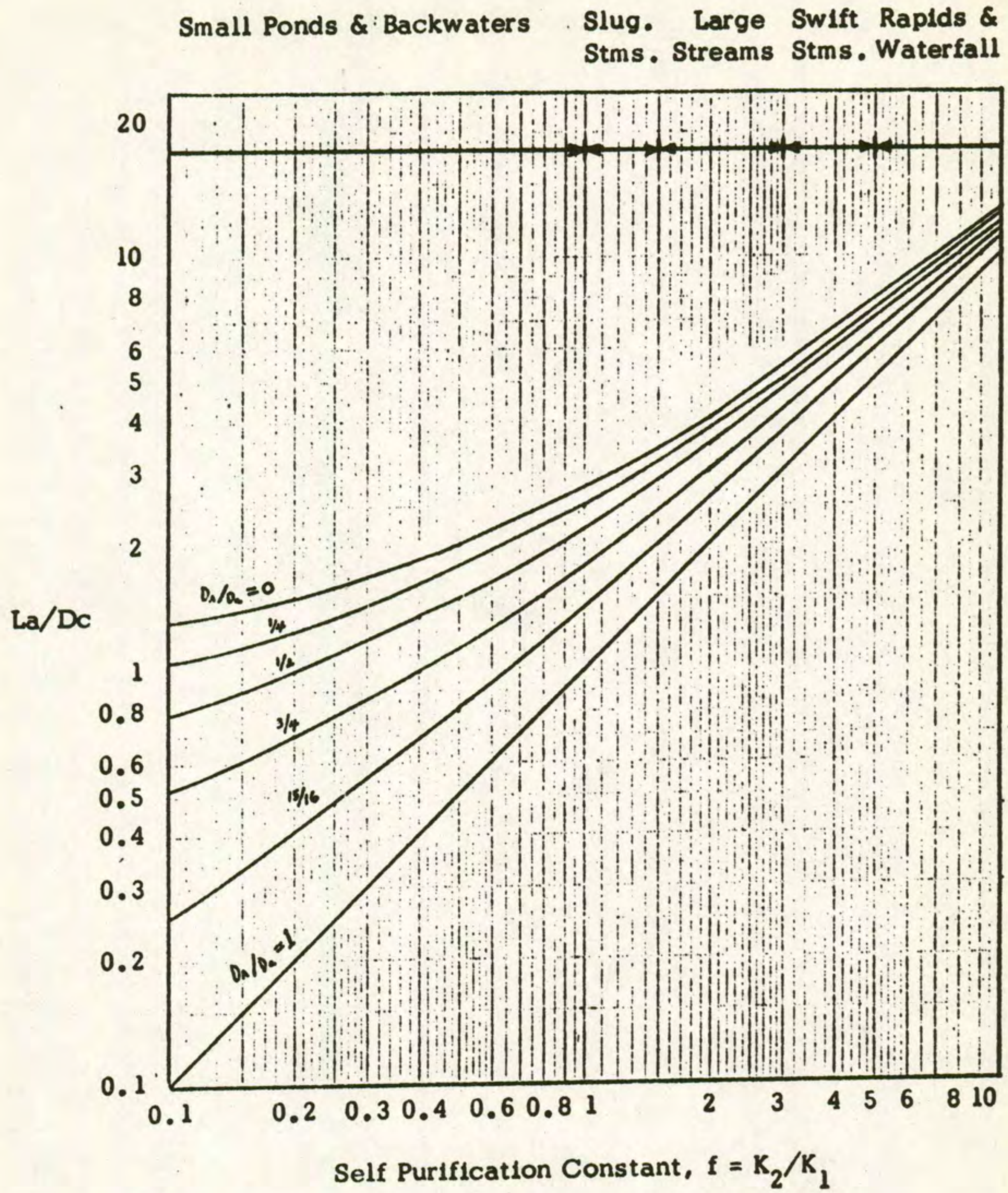

Fig. 5. Allowable Loading of Receiving Waters.

APPLICATION

Various methods have been cited for management and disposal of the liquid portion of cattle feedlot wastes. Two of the disposal methods, controlled release to a stream and release to the land, will be presented in the form of a typical design. The management aspect considered is that of a retention pond designed to hold the feedlot runoff until it can be released.

Controlled Release to a Stream

Controlled release to a stream can be referred to as "disposal by dilution". The waste is released at a rate such that established water quality criteria are met. The objective is to not exceed a limiting BOD discharge rate established by the assimilative capacity of the receiving stream. For release to a stream, the critical time is during low flows. At low flow, a stream has a low dilution capacity. An overload might result in adverse effects to aquatic life. As an example, the 10-year recurrence interval low daily flow for each month will be used along with the water quality for that month to determine retention pond discharge rates. Stream discharge and water quality data for each month are shown in Table 15.

On the assumption that the average BOD in the runoff

Table 15. Stream Flow and Water Quality Data (From Appendices B and C).

Month	Discharge[1/] cfs	Temperature Average C	Dissolved[2/] Oxygen mg/l	BOD_5[3/] mg/l
January	31	1	8.9	3.0
February	33	1	9.8	4.5
March	58	6	10.1	8.0
April	110	11	9.9	3.7
May	93	15	9.3	5.5
June	74	23	7.1	2.7
July	64	27	7.2	4.7
August	42	24	8.3	5.0
September	27	18	7.6	3.8
October	38	12	10.1	3.5
November	45	6	11.4	3.4
December	38	2	11.7	2.9

1/ 10 Year recurrence interval for the Iowa River at Marshalltown.

2/ 50 percentile value, i.e., 50 percent of observed values were less

3/ 50 percentile value, i.e., 50 percent of observed values were less (equation 2-1) is 1080 mg/l and that quiescent conditions in the retention pond will reduce the BOD by 35 percent, the average BOD of the pond effluent will be 720 mg/l. The only BOD exertion rate constant (k) available in technical publications was the value of 0.089 reported by Witzel et al.[6] If this value is used, the projected ultimate BOD of the retention pond effluent will average 1120 mg/l. The ultimate BOD of the stream depends upon its BOD exertion rate constant. For the data from the Coralville Project, the BOD exertion rate constant at 20° C is 0.1. The ultimate BOD is given by:

$$L = \frac{BOD_5}{(1 - 10^{-5k})} \qquad (11)$$

where

L = Ultimate BOD, mg/l

BOD_5 = 5 day, 20°C BOD, mg/l

K = BOD exertion rate constant at 20°C, $^1/$time.

(K = 0.1 for the Coralville Project data).

Figure 5 can be used to determine the allowable ultimate BOD, L_a, of the stream. To use the figure, the stream purification factor, $f = k_2/k_1$, and the ratio of the initial deficit to the critical deficit, D_a/D_c, must be known. The stream purification factor, f, also varies with temperature. Its variation with temperature is shown by[17]:

$$f_T = f_{20}\, e^{-0.022(T-20)} \qquad (12)$$

where

f_T = stream purification capacity at temperature T.

f_{20} = stream purification capacity at 20^oC
(f_{20} = 2.0 for this analysis)

T = temperature, ^oC.

The initial deficit, D_a, is equal to the dissolved oxygen saturation value at the corresponding temperature minus the observed dissolved oxygen. Critical deficit, D_c, is equal to the saturation value minus the allowable minimum dissolved oxygen. The minimum dissolved oxygen allowed in this analysis will be 7.0 mg/l. This value is above most water quality standards for streams in Iowa. The dissolved oxygen standard for warm water areas in Iowa is: not less than 5.0 mg/l during at least 16 hours of any 24-hour period and not less than 4.0 mg/l at any time during the 24-hour period. For cold water areas in Iowa, the dissolved oxygen standard is: not less than 7.0 mg/l during at least 16 hours of any 24-hour period and not less than 5.0 mg/l at any time during the 24-hour period. The use of 7.0 mg/l adds a factor of safety to compensate for other uses of the stream as receiving waters.

Table 16 gives the allowable loading, L_a, as a ratio to the critical deficit. The allowable ultimate BOD is the product of the critical deficit and this ratio. These values are shown in Table 17. L_a is the allowable ultimate BOD after the stream flow and retention pond discharge have merged. This relationship is shown

Table 16. Allowable Ultimate BOD for the Receiving Stream.

Month	Dissolved Oxygen at Saturation[1/] mg/l	Initial Deficit D_a mg/l	Critical Deficit D_c mg/l	D_a/D_c	f	L_a/D_c[2/]
January	14.3	5.4	7.3	.74	3.0	4.2
February	14.3	4.5	7.3	.62	3.0	4.5
March	12.5	2.4	5.5	.44	2.7	4.4
April	11.0	1.1	4.0	.27	2.4	4.3
May	10.0	0.7	3.0	.23	2.2	4.1
June	8.5	1.4	1.5	.93	1.9	2.5
July	7.9	0.7	0.9	.78	1.7	2.6
August	8.3	0	1.3	0	1.8	3.8
September	9.4	1.8	2.4	.75	2.1	3.2
October	10.8	0.7	3.8	.18	2.4	4.4
November	12.5	1.1	5.5	.20	2.7	4.8
December	13.9	2.2	6.9	.32	3.0	4.9

1/ At corresponding temperatures shown in Table 1.

2/ From Figure 5.

Table 17. Solution for Retention Pond Discharges

Month	L_a mg/l	L_s mg/l	L_p mg/l	Q_s cfs	Q_p cfs	Q_s/Q_p
January	30.7	4.4	1120	31	1/	--
February	32.8	6.6	1120	33	1/	--
March	24.2	11.7	1120	58	0.659	88
April	17.2	5.4	1120	110	1.183	93
May	12.3	8.1	1120	93	0.352	264
June	3.7	4.0	1120	74	2/	--
July	2.3	6.9	1120	64	2/	--
August	4.9	7.3	1120	42	2/	--
September	7.7	5.6	1120	27	0.051	530
October	16.7	5.1	1120	38	0.400	95
November	26.4	5.0	1120	45	0.882	51
December	33.8	4.2	1120	38	1.027 3/	37

1/ No discharge allowed due to possible ice cover.

2/ Stream water quality will not permit pond discharge.

3/ Discharge during only the first half of this month will be allowed because of possible ice cover.

by the equation:

$$L_a(Q_s+Q_p) = L_sQ_s + L_pQ_p \quad (13)$$

where

L_a = Allowable ultimate BOD in the stream; mg/l

L_s = Ultimate BOD of the stream, mg/l.

L_p = Ultimate BOD of the pond effluent, mg/l.

Q_s = Stream flow, cfs.

Q_p = Retention pond discharge, cfs.

Equation 13 yields:

$$Q_p = Q_s \frac{L_a-L_s}{L_p-L_a} \quad (13a)$$

Table 17 shows the factors and solution to equation 13a.

The ratio of stream discharge to retention pond discharge is a dilution factor. It is the dilution factor required to maintain acceptable dissolved oxygen levels in the stream during any flow. If the dissolved oxygen and BOD relationships are the same for the entire basin, the same dilution factors will apply throughout the basin. However, this may not be the case. Variations in yield, cropping practice, and background pollution will affect the dilution factors. Also, there may be a difference in the stream flow - water quality correlations from one area to another.

The pond discharge values shown in Table 17 are for the 10-Year recurrence interval low monthly flow for the Iowa River at

Marshalltown. Retention pond discharge rates for other selected recurrence intervals of both low and average daily flow are shown in Table 18. Only those months during which the stream is capable of handling pond discharge are shown.

If the yield, in cfs per square mile, is constant for the entire basin the flow at any point within the basin is equal to the drainage area times the yield. This assumption will likely be true for larger drainage basins. However, drainage basins in which the streams are intermittent may be exceptions. The basin size below which the streams are intermittent depends upon groundwater hydrology. It was the opinion of U.S.G.S. personnel that basins with areas less than 50 square miles might be expected to be intermittent.

If the yield for basins larger than 50 square miles is constant and the dilution factors from Table 17 apply to the entire basin, then the pond discharge values in Table 18 can be used after adjustment to drainage area. The values in Table 18 are for a drainage area of 1564 square miles. If they are divided by 1564 they yield a unit retention pond discharge rate. Multiplying the unit discharge rate by the drainage area at the point of discharge yields the allowable retention pond discharge rate at that point.

For basins with a drainage area of less than 50 square miles, the best time to discharge from a retention facility would be when the stream is flowing. This might be during or following a rainfall. The runoff from adjacent areas would be used to provide natural dilution for the retention pond discharge. For example if

Table 18. Retention Pond Discharge Rates for Selected Recurrence Intervals of Flow for the Iowa River at Marshalltown.

Month	Recurrence Interval, Years				
	1.575 (Most Probable)	2	5	10	20
	Low Daily Flow, cfs				
March	4.773	2.636	1.068	0.659	0.420
April	6.774	4.839	1.666	1.183	0.914
May	1.969	1.439	0.553	0.352	0.273
September	0.255	0.190	0.079	0.051	0.041
October	2.000	1.326	0.579	0.400	0.273
November	2.941	1.961	1.215	0.882	0.667
December	3.108	2.378	1.270	1.027	0.865
	Average Daily Flow, cfs				
March	21.023	13.636	5.000	2.613	1.727
April	12.150	9.570	4.516	2.742	1.720
May	4.432	3.144	1.041	0.693	0.523
September	0.698	0.415	0.175	0.119	0.083
October	3.631	2.158	0.863	0.684	0.547
November	6.372	4.117	1.961	1.333	1.078
December	6.270	4.540	1.594	1.270	1.135

the runoff from an adjacent area was 1,000 acre-feet while 10 acre-feet of storage was released, the dilution factor would be about 100. The true dilution would depend upon the strength of the runoff from the contributing area.

In design, the recurrence interval and flow value used, i.e. low or average, is at the discretion of the engineer. As the tolerable level of damage to aquatic life decreases, lower flows and longer recurrence intervals are used. Each case should be considered separately and sound engineering principles applied.

Typical Design.

A 10 acre feedlot, containing 1,500 cattle, is located in a small drainage basin at a point above which the drainage area is only 75 square miles. The question is: How much storage will be required to retain runoff equal to the 10-year recurrence interval rainfall value?

Precipitation data.

From Appendix A the 10-year precipitation is 41.0 inches. Table 19 shows the distribution in terms of average monthly percentages.

Discharge data.

It has been decided to discharge according to the most probable low daily flow. This corresponds to a recurrence interval of 1.575 years in Table 18. The discharge rates from Table 18 have been adjusted to the drainage area and are shown in Table 20.

Table 19. Monthly Precipitation Distribution, 10-Year Recurrence Intervals

Month	Percent of Annual	Precipitation Inches	Summation Inches
January	3.8	1.56	1.56
February	3.5	1.43	2.99
March	6.4	2.62	5.61
April	9.0	3.69	9.30
May	11.9	4.88	14.18
June	13.8	5.66	19.84
July	11.8	4.84	24.68
August	11.2	4.60	29.28
Sept.	12.3	5.04	34.32
October	7.0	2.87	37.19
November	5.5	2.25	39.44
December	3.8	1.56	41.00

Storage

Utilizing a mass diagram (Figure 6) the storage in acre-feet per acre of feedlot is given by the length of ordinate "a" divided by 12. For the 10 acre feedlot the storage required is 12.6 acre-feet. At a depth of 10 feet, the retention pond area would be 1.26 acres.

Cost

Excavation:

Retention pond	
20,500 cubic yards @ $0.35	$7,200
Terraces	
4,000 lft @ $0.20	800
Total	$8,000
Miscellaneous Costs (piping, valves, etc)	$1,000
Total First Cost	$9,000

Annual operating and maintenance costs

Cleaning terraces and retention pond	$ 800
Loading and hauling solids to the land	200
Total Annual Operating Cost	$1,000

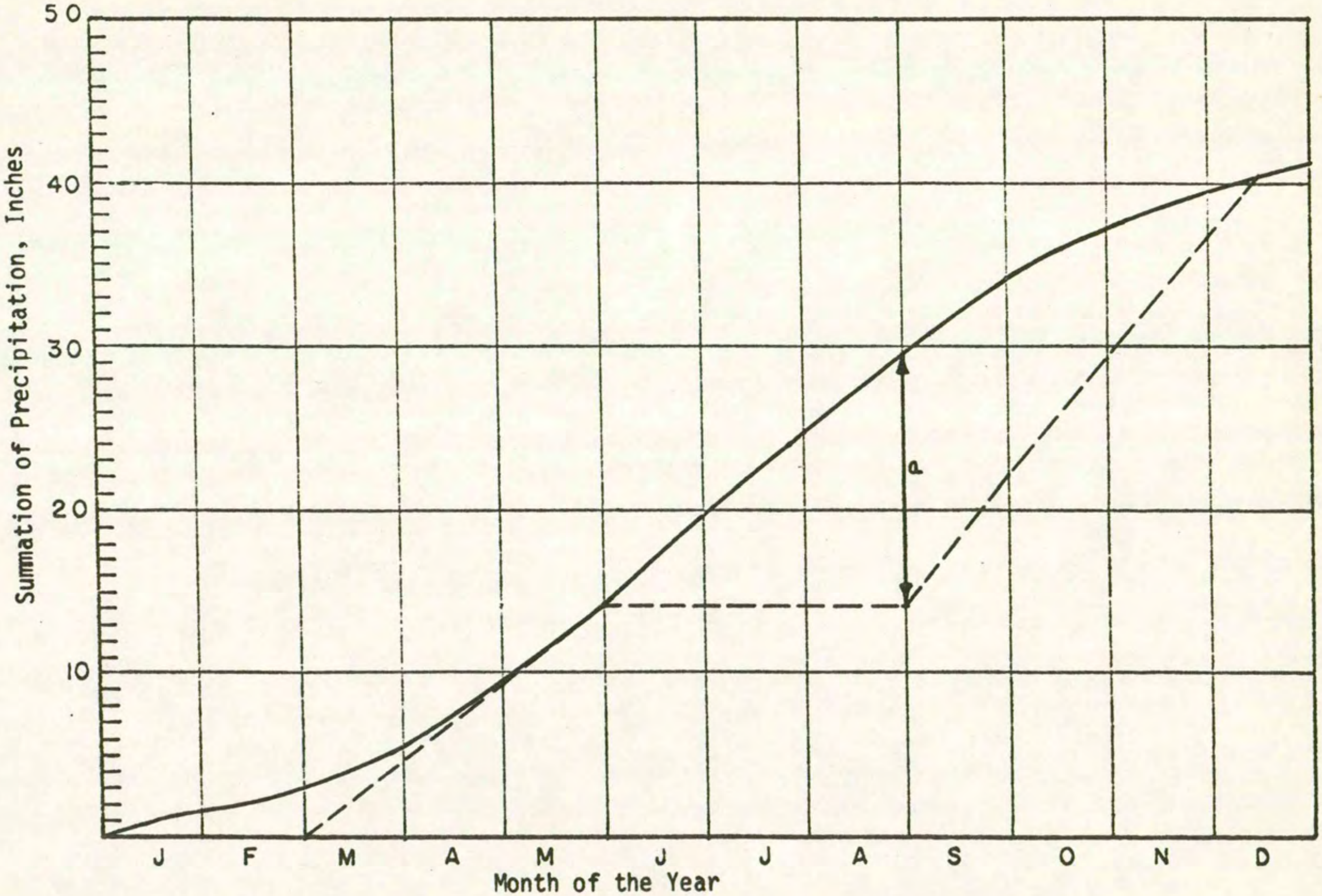

Fig. 6. Mass Diagram for Determination of Lagoon Storage Requirements for Controlled Release to the Stream.

Table 20. Retention Pond Discharge.

Month	Discharge Days	Discharge Rate cfs	Discharge Rate Acre-in./day[1/]	Discharge Acre-in.
March	31	0.229	5.45	168.95
April	30	0.325	7.73	231.90
May	31	0.094	2.24	69.44
September	30	0.012	0.28	8.40
October	31	0.096	2.28	70.68
November	30	0.141	3.35	100.50
December	15	0.149	3.54	53.10

1/ 1 cfs = 23.8 acre-in./day.

The capitalized cost is given by:

$$C.C. = F.C. + \frac{O.C.}{r} + \frac{R.C.}{nr} \tag{14}$$

where

C.C. = Capitalized cost, dollars.

F.C. = First cost, dollars.

O.C. = Annual operating cost, dollars.

r = Interest rate per period.

R.C. = Replacement cost, dollars.

n = Number of periods.

Assuming that by maintaining the facilities there will be no replacement cost (R.C.), the capitalized cost at an interest rate of 7% is:

$$C.C. = \$9{,}000 + \frac{\$1{,}000}{0.07}$$

$$C.C. = \$23{,}286.$$

The annual cost (A.C.) is equal to the capitalized cost times the interest rate. That is:

$$A.C. = \$23{,}286 \times 0.07$$

$$A.C. = \$1{,}630.$$

The cost per head of cattle is about $1.09. For a 1,000 lb. live weight animal, the annual cost of waste control facilities would be about $0.001 per pound.

Release to the Land

Application of retention pond storage to the land has several benefits. Among these are provision of nutrients for vegetation and organic material for building soil structure. It also provides irrigation as well as a means of liquid disposal.

The rate at which the liquid may be applied depends upon many factors. Some of these are the type of cover crop, the season of the year, the percolation capacity of the soil, and the slope of the spreading area. Another significant factor is the strength of the waste in terms of BOD. This is important because of the necessity to maintain aerobic conditions in the soil. It is also important to give the spreading area sufficient time to recover before subsequent applications are made. Lysimeter tests or pilot scale studies should be used to determine the optimum cycle of loading and resting.

Each land disposal system should be evaluated separately and the appropriate tests conducted to determine its capabilities.

Typical Design

For a 10 acre feedlot, containing 1,500 cattle, how much storage will be required to retain runoff equal to the 10-year recurrence interval rainfall (Table 19)?

Let us assume that:

1. The retention pond effluent can be spread on the land during the period April 1 to November 30.

2. Percolation tests have determined the time for a 1 inch drop to be 60 minutes.
3. Lysimeter tests have shown the optimum cycle for a 1 inch application to be 6 days for the months of April, May, September, October, and November and 5 days for the remaining months. June July August
4. The spreading area will be seeded with a mixture of blue grass, brome, and timothy.
5. An application rate of 1 inch per acre per week will be used.

Storage

From the mass diagram in Figure 7, the storage in acre-feet required per acre of feedlot is equal to "a" plus "b" divided by 12. For the 10 acre feedlot the storage required is 6 acre-feet. The surface area would be 0.6 acres at a retention pond depth of 10 feet.

Area for spreading

As shown in Figure 7, a total of 41 inches of storage are spread for each acre of feedlot. The spreading is conducted over a period of 244 days. This results in the application of 1.17 inches per week. The area required for spreading at a rate of 1 inch per acre per week would be about 1.2 acres per acre of feedlot. For the 10 acre feedlot, 12 acres are required to dispose of the liquid. To provide flexibility, twice as much area might be used for the spreading

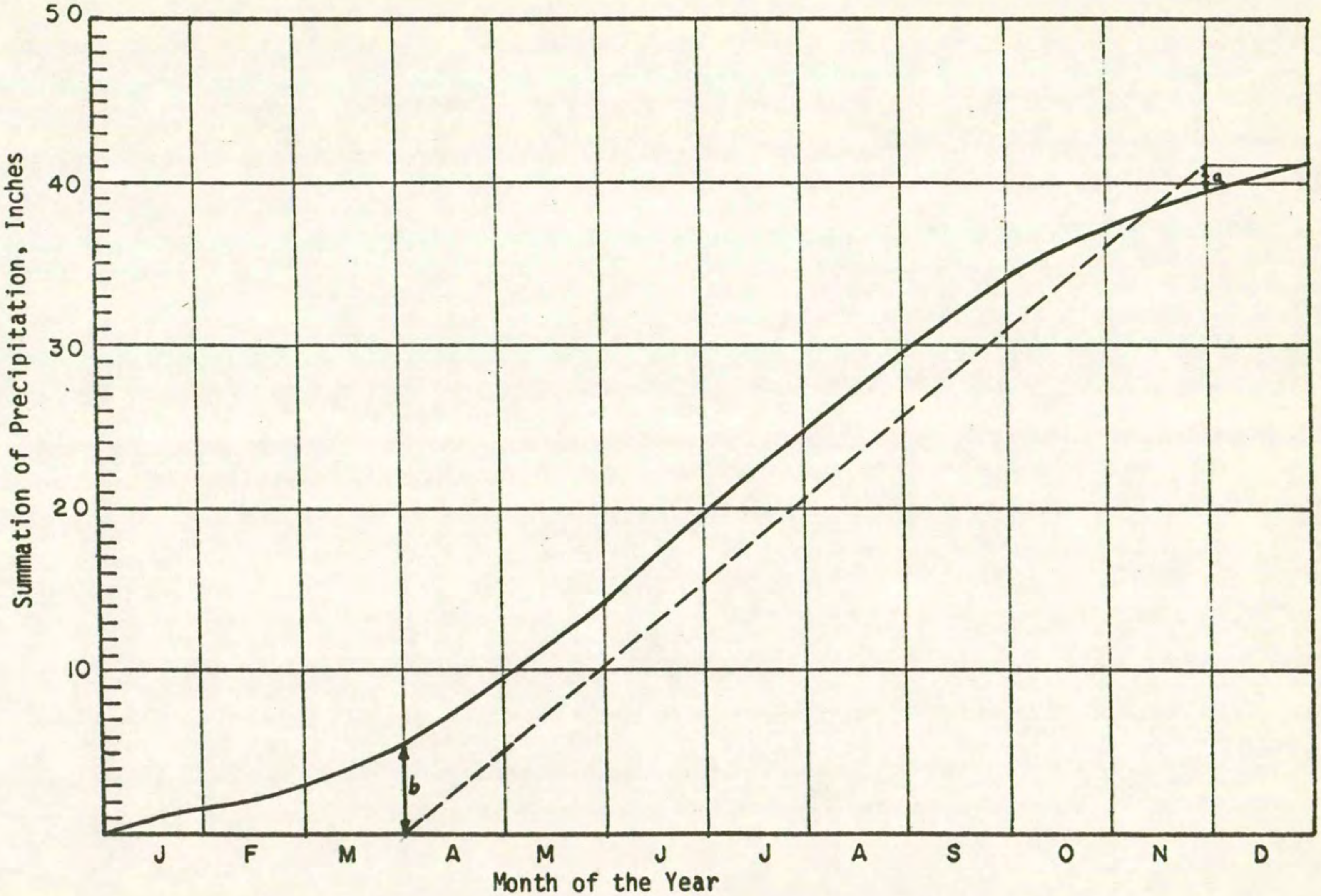

Fig. 7. Mass Diagram for Determination of Lagoon Storage Requirements for Release to the Land.

operation.

Cost (exclusive of irrigation system)

Excavation

Retention pond	
9,700 cubic yards @ $0.35	$3,400
Terraces	
4,000 lft. @ $0.20	$ 800
Total	$4,200
Miscellaneous Costs (piping, valves, etc)	$1,000
Total First Cost	$5,200

Annual operating and maintenance costs

Cleaning terraces and retention pond	$ 420
Loading and hauling solids to the land	$ 200
Total Annual Operating Costs	$ 620

Let us assume that by maintaining the facilities, the replacement cost (R.C.) will be avoided. The capitalized cost at an interest rate of 7% is:

$$C.C. = \$5,200 + \frac{\$620}{0.07}$$

$$C.C. = \$14,057.$$

The annual cost (A.C.) is:

$$A.C. = \$14,057 \times 0.07$$

$$A.C. = \$984.$$

The cost per head of cattle is about $0.66 exclusive of the irrigation system. The annual cost per pound of live weight for a 1,000 lb. animal would be about $0.00066.

Combination

A combined system, release to the stream-application to land, is another possibility for liquid disposal. The system would take advantage of whichever method was possible for any particular month. This combination would allow disposal of the liquid on land during the summer months when discharge to streams is not possible.

Typical Design

Let us assume that a 10 acre feedlot containing 1,500 cattle is located in a small drainage basin at a point above which the drainage area is only 75 square miles. The owner has considered using a combined stream-land disposal system. The question is: How much storage will be required to retain runoff equal to the 10-year recurrence interval rainfall (Table 19)?

Discharge data for release to the stream

Let us assume that discharge from the retention pond will be limited by the most probable low daily flow for each month. Since the drainage area is 75 square miles, the discharge rates in Table 20 can be used. Because the discharge rate is low, it might be assumed that releases to the stream during the month of September will not be made.

Application to land

For release to the land, let us assume that:

1. The retention pond effluent will be spread on the land during those months for which it is not possible

to release it to the stream.

2. Percolation tests have determined the time for a 1 inch drop to be 60 minutes.
3. Lysimeter tests have determined the time for a 1 inch application to be 6 days for the month of September and 5 days for the months of June, July, and August.
4. The spreading area will be seeded with a mixture of blue grass, brome, and timothy.
5. An application rate of 1 inch per acre per week will be used.

Storage

From the mass diagram in Figure 8, the storage in acre-feet required per acre of feedlot is the ordinate "a" divided by 12. For the 10 acre feedlot, the storage required is 2.5 acre-feet.

Area for spreading

As shown in Figure 8, a total of 20.2 inches are spread during the period June 1 to September 30. This results in the application of 1.16 inches per week. Since the design application rate is 1 inch per acre per week, the area required for spreading is about 1.2 acres per acre of feedlot. For spreading, the 10 acre feedlot requires about 12 acres. However, twice the area might be provided to enable flexibility in the spreading operation.

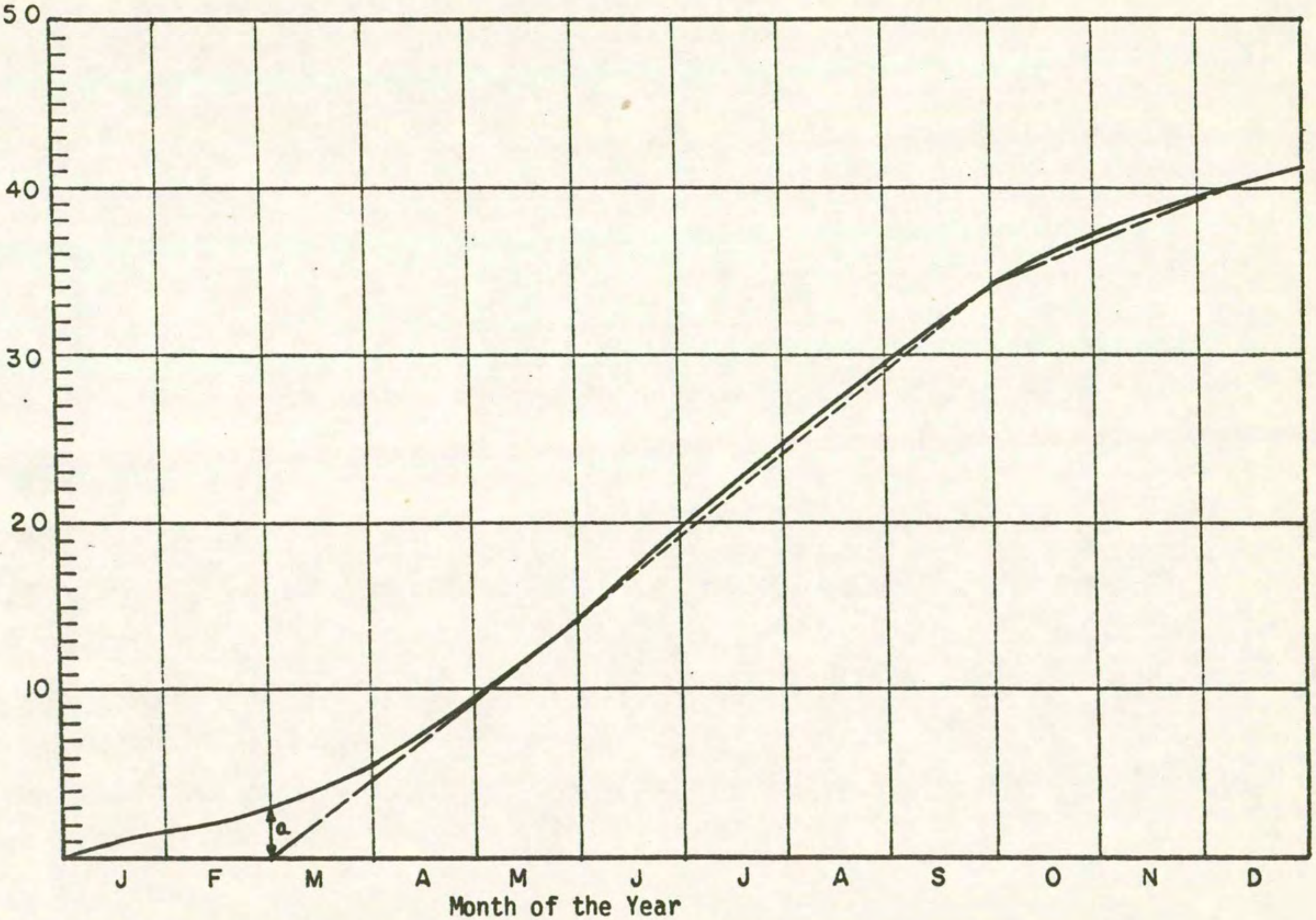

Fig. 8. Mass Diagram for Determination of Lagoon Storage Requirements for Combination Stream-Land Release.

Cost (exclusive of irrigation system)

Excavation	
Retention pond	
4,150 cubic yards @ $0.35	$1,450
Terraces	
4.000 lft. @ $0.20	$ 800
Total	$2,250
Miscellaneous costs (piping, valves, etc.)	$1,000
Total First Cost	$3,250
Annual operating and maintenance costs	
Cleaning terraces and retention pond	$ 200
Loading and hauling solids to the land	$ 200
Total Annual Operating Costs	$ 400

Assuming that maintenance will eliminate the replacement cost (R.C.), the capitalized cost at an interest rate of 7% is:

$$C.C. = \$3,250 + \frac{\$400}{0.07}$$

$$C.C. = \$8,965.$$

The annual cost (A.C.) is:

$$A.C. = \$8,965 \times 0.07$$

$$A.C. = \$628.$$

The cost per head of cattle is about $0.42 exclusive of the irrigation system. For a 1,000 lb. live weight animal, the annual cost of waste control facilities would be about $0.00042 per pound.

DISCUSSION

Typical designs were used to demonstrate the use of hydrologic and water quality data in applying various management schemes to cattle feedlot runoff. In all cases, terraces and retention ponds were used as minimums for controlling runoff. The methods considered for liquid disposal were release to a stream and application to land. Feedlot manure accumulations were disposed of by hauling to the land.

Terracing feedlot surfaces will help to minimize the transport of both organic and inorganic suspended solids from the lot. Most of the soil and manure solids washed from the lot will become entrapped in the terraces. This will require cleaning the terraces so that they can continually serve their function. The solids cleaned from the terraces can be either hauled to the land for disposal or put back on the feedlot surface. If terraces are cleaned and maintained, the need to replace them will be avoided.

In addition to reducing the transport of solids, terraces can also reduce the volume of runoff. The runoff held by terraces can subsequently evaporate or infiltrate. However, infiltration is expected to be minimal because of the soil being plugged by the solids washed from the lot.

Terrace spacing depends upon the feedlot slope and surface conditions. Feedlots with steep slopes or sandy surfaces would require closer spacings as the terraces might be expected to fill more rapidly. For the typical designs, the terrace spacing used was 100 feet. The method of terracing considered was the parallel method since this type might lend itself to easier feedlot cleaning. A typical profile of the feedlot terracing is shown in Figure 9.

In some areas, perhaps only terraces may be needed to control cattle feedlot runoff. Whether or not more runoff control is needed depends upon the amount of rainfall typical of the area and, to some extent, on the slope of the feedlot. The magnitude and frequency of rainfall events is also an important consideration in determining whether more control is needed. The methods of feedlot runoff control for a given feedlot should be based on its physical characteristics and the hydrology of the area.

In most cases, terraces will not completely eliminate runoff. Therefore, runoff retention ponds will be necessary. Runoff equal to the 10-year recurrence interval precipitation was used to determine the storage requirements. This value was used because, in spite of control methods, solids will accumulate in the retention facility. The additional storage resulting in the use of the 10-year precipitation will accommodate the solids.

Solids in a retention pond can arise from several sources. Terraces, although designed to control solids transport, will not eliminate siltation. In addition, finely divided particulate matter present in the runoff may flocculate and settle out under the

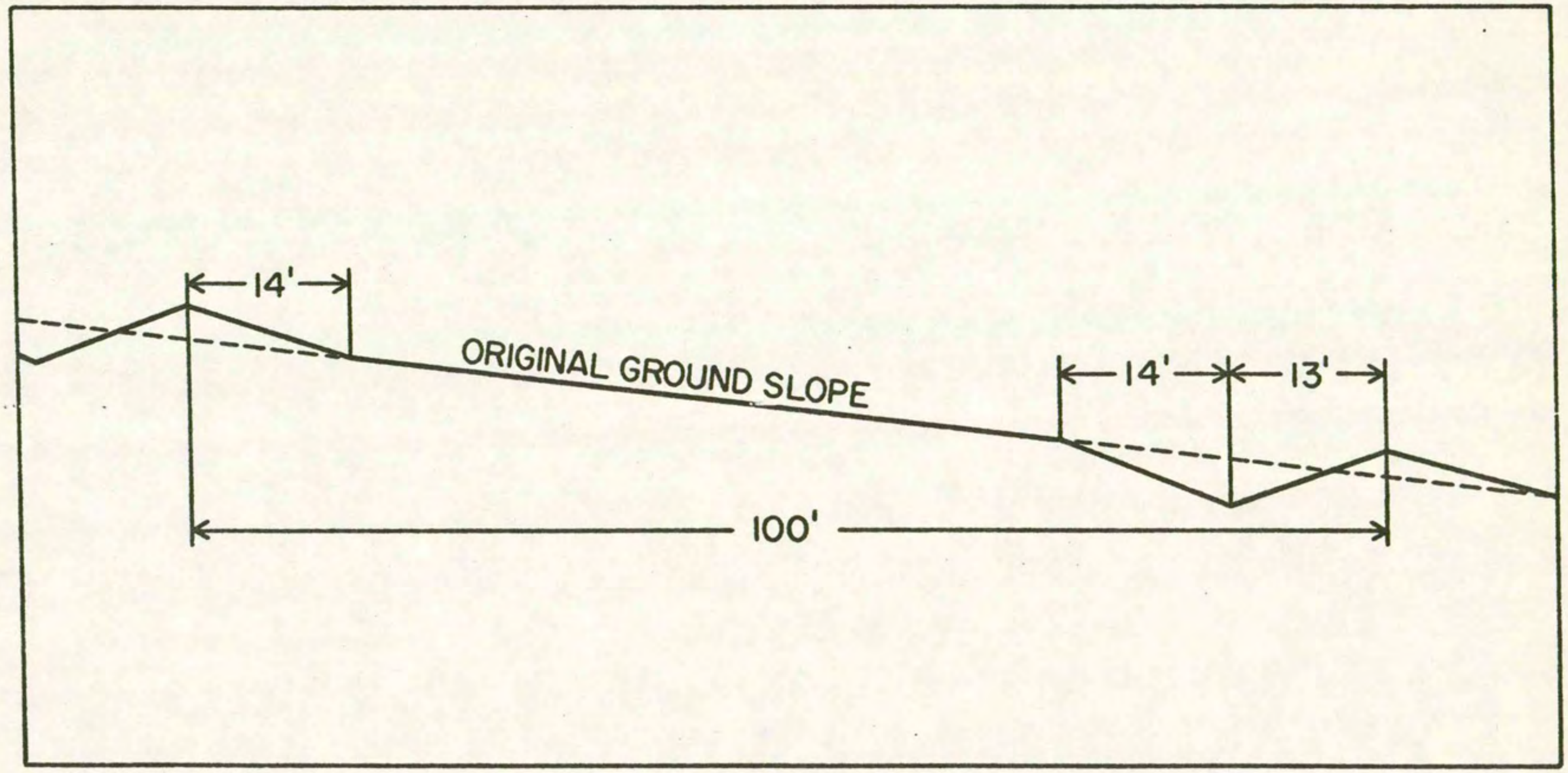

Fig. 9. Typical Profile of Feedlot Terracing.

quiescent conditions of the retention pond. There is also the aspect of siltation and the erosion of the slopes of the pond.

No account was made for that precipitation falling directly on the surface of the retention pond. This would amount to an additional 41 inches minus the evaporation per unit of surface area. It was hoped that by designing for runoff equal to the 10-year precipitation the storage would be adequate to account for surface precipitation and solids accumulation. For safer designs, one might sum the 10-year monthly precipitations for the months during which release is not possible. This will result in greater storage requirements and additional allowance for surface precipitation and solids accumulation.

In spite of control measures, retention ponds will accumulate solids. To facilitate cleaning, the retention ponds might be diked into sections, each section being small enough so that a dragline can easily be used for cleaning. An alternate method might be two retention ponds operated in parallel. One of these can be drained and cleaned while the other is used for runoff collection.

The solids resulting from retention pond cleaning might be disposed of by hauling to the land. On the other hand, if there is a considerable soil content, they might be used to dress up the slopes of the retention pond or as fill material. The choice of disposal methods is left to the feedlot owner as he should know for what purposes the material is best suited.

Hauling the manure accumulations to the land is the most common method of disposal. This may be complicated by the availability of land for disposal or the availability at the time of solids removal. It may be necessary to stockpile the manure until it can be hauled when land is available for spreading. Manure stockpiles should be carefully located so that they do not contribute to the strength of runoff. They should not be located in low areas and if necessary should be covered to control pollution of runoff.

When the land is available, the solids can be hauled and spread. After land application, the manure should be plowed-down as soon as possible to prevent the pollution of runoff waters from the disposal site. Plowing also mixes the solids with the soil and keeps the nutrient losses at a minimum. Proper management of the solids disposal site, as well as its selection, is of major importance. Poor management might result in an increase of both surface and groundwater pollution.

One method of liquid disposal considered in the typical designs was that of spreading on the land. The method of land application could be either ridge-and-furrow irrigation or spray irrigation. Ridge-and-furrow irrigation is best adapted to flat terrain. Also, cropping under conditions of ridge-and-furrow irrigation is more complicated. For these reasons, the method of land application intended was that of spray irrigation. Spray irrigation might be applied to land in the Federal soil conservation reserve program. However, permission must be obtained from the local program office.

If the liquid can be applied to land in the soil conservation program a means of further improving the soil would be provided. The liquid might also be applied to crops such as corn or soybeans. In addition to providing nutrients for the crops, this method would also supply supplemental water during the most critical time.

Areas for spreading the liquid should be carefully selected and managed. Perhaps monitoring groundwater quality may be necessary to protect against the pollution of shallow aquifers. The spreading area should be capable of handling the liquid at the selected application rates. Application rates should be based on the appropriate soil tests to protect against rates which are too high. If the rates are excessive, runoff may occur. Poor selection and management of spreading areas may result in increased pollution of both surface and ground waters.

For the spray irrigation system considered in the typical design, a cost analysis was omitted. The cost of a spray irrigation system is dependent upon a number of factors. Among these are the application rate, the distance to the spreading area, and the pumping requirements. There are also the aspects of nozzle type, screening devices, pipe size and type, and whether the system is to be movable or fixed. In addition, the cost of land may be involved. It was the opinion of the writer that a cost analysis might be misleading and therefore was purposely disregarded.

The water quality data of the river used for determining retention pond discharge rates was from a sampling point some 100 river miles downstream. The data was used only to demonstrate a method and was not intended to be that characteristic of the point of discharge. To be more correct, water quality data should be taken at the point of discharge and a correlation made between the two sets of data. This would enable one to use the data from the Coralville Project to determine retention pond discharge rates at the sampling point.

A minimum dissolved oxygen allowance of 7.0 mg/l was used in the typical designs. This value is greater than the minimum dissolved oxygen set by most water quality standards. The use of 7.0 mg/l was felt necessary to compensate for other uses of the water as a receiving stream.

The quality of the effluent from the retention facilities was based on research by Miner et.al.[8] Reduction in BOD resulting from quiescent conditions in the retention ponds was based on research at Kansas State University reported by Dague.[11] In a similar manner, the projection of BOD_5 to ultimate BOD was made using a BOD exertion rate constant reported by Witzel et.al.[6] These data were not intended to represent the ultimate in data but were used for illustrative purposes only.

Data from Miner et.al.[8] was for a feedlot stocked at a cattle density of 200 head per acre. The runoff was produced as a result of artificial rainfall. Animal density may affect the strength of feedlot runoff. However, lower animal densities mean more freedom of movement for the animals. This would result in lesser concentration of manure on the feedlot surfaces, but the surfaces are likely to be coated with manure. More research is needed in the area of runoff strength versus animal density. There is also need for research on runoff strength under natural rainfall conditions.

The BOD exertion rate constant reported by Witzel et al.[6] was for the cattle wastes as defecated mixed with an equal volume of water. Under the conditions of a retention pond the k value might be greatly different because of the more dilute mixture. More research is needed in the area of BOD exertion rate constants for cattle feedlot runoff. This research might also be conducted for various rainfall intensities and cattle densities.

Discharge rates for retention ponds were based on the most probable low monthly flows for the Iowa River at Marshalltown. Other recurrence intervals might have been used for the design. It is also possible to use the average monthly flow for determining retention pond discharge rates. As the tolerable level of damage gets lower, longer recurrence intervals are used and the tendency is toward the use of low flows. The choice of flow and recurrence interval for design purposes is left to the designing engineer.

The major problems associated with pollution control for cattle feedlot runoff might arise in those basins already having large numbers of feedlots. In these basins, it may be impossible for some feedlot owners to dispose of runoff by controlled release to a stream. Others may have insufficient land to use the spreading technique.

Terracing and retention ponds will reduce pollution from feedlot runoff. At this point the amount of the reduction is not predictable. Perhaps, a retention pond will not provide the degree of treatment necessary to protect water quality. There are also the aspects of nutrients present in the discharge from retention ponds. Will it be necessary to provide more treatment beyond that of a retention pond? Will nutrient removal be necessary to protect against algal blooms and their associated taste and odor problems? These and other questions, hopefully, can be answered through further research.

Perhaps a systems approach can be applied to solve the problems associated with cattle feedlot runoff. Such an approach would look at the entire basin and prescribe the best method of treatment and disposal for each feedlot.

CONCLUSIONS AND RECOMMENDATIONS

General conclusions of the study of hydrologic aspects of feedlot waste control are as follows:

1. The hydrologic aspects, rainfall, runoff, and stream flow, are the primary factors to consider in managing cattle feedlot runoff. This is evidenced by the fact that the nature, volume, and rate of delivery of runoff is directly related to rainfall. Storage requirements for retention facilities depend upon the volume of runoff. In considering disposal by controlled release to a stream, the retention pond discharge rate is proportional to the flow in the stream.
2. Terraces and retention ponds will reduce the pollution from cattle feedlot runoff. Evidence of this is shown by the reduction in suspended solids, BOD, and COD as a result of settling. Terraces will reduce the transport of solids from the lot and to some degree the volume of runoff. Retention ponds will reduce the suspended solids which in turn will result in BOD and COD reductions.
3. Application to land appears to be the most practical method of disposal for both the solids and the liquid. When applied to agricultural land, the waste has some economic value. The value may exceed the cost of application if the operation is carried on where land is available. To be

economical, sufficient area must be available for crops to recover the plant nutrients from the waste.

4. Retention ponds may not remove sufficient amounts of suspended solids, BOD, COD, and nutrients to provide safe effluents for disposal to streams. It may be necessary to provide additional treatment and nutrient removal to protect water quality. The profit potential and the degree of concern of the feedlot owner for adequate waste treatment will dictate the type of treatment system that is practical and economical.

More research is needed to expand the areas of cattle feedlot runoff characteristics and management schemes. The following recommendations are made:

1. Additional data on the characteristics of runoff as a function of cattle density. Also data on feedlot runoff characteristics under conditions of natural rainfall.
2. A pilot study of an open feedlot to keep track of the various forms of nitrogen, phosphorous, and potassium. Also studies to determine the amount of precipitation that actually runs off.
3. Scale studies of retention ponds to determine whether additional physical and chemical principles can be economically and practically applied to improve the quality of the effluent.
4. A systems approach and mathematical modeling applied to a

basin to resolve the feedlot runoff problem.

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APPENDICES

APPENDIX A

PRECIPITATION DATA
FROM CEDAR RAPIDS, IOWA

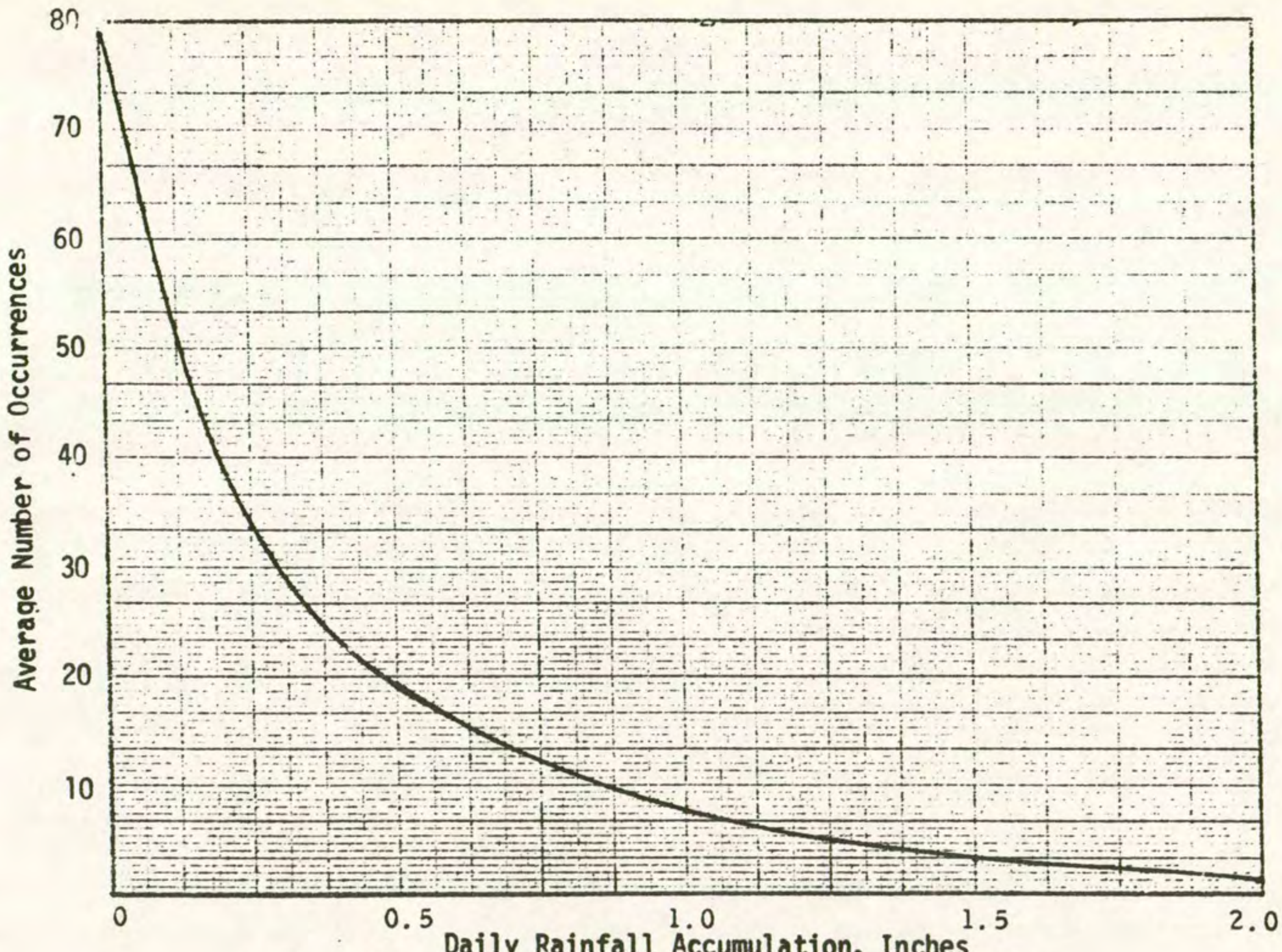


Fig. A-1. Variation in the Average Number of Daily Rainfall Events with Rainfall Accumulation (Annual).

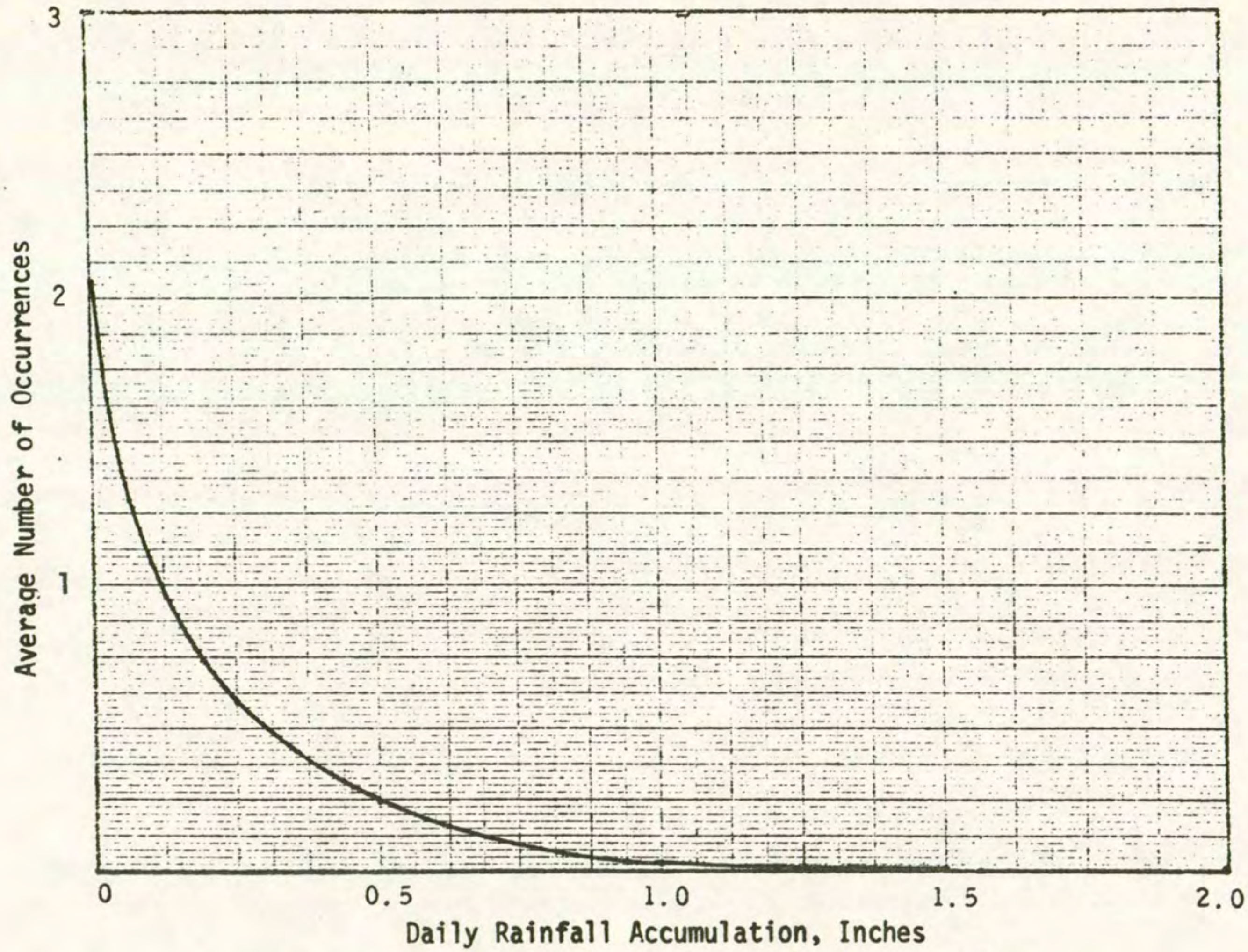


Fig. A-2. Variation in the Average Number of Daily Rainfall Events with Rainfall Accumulation (January).

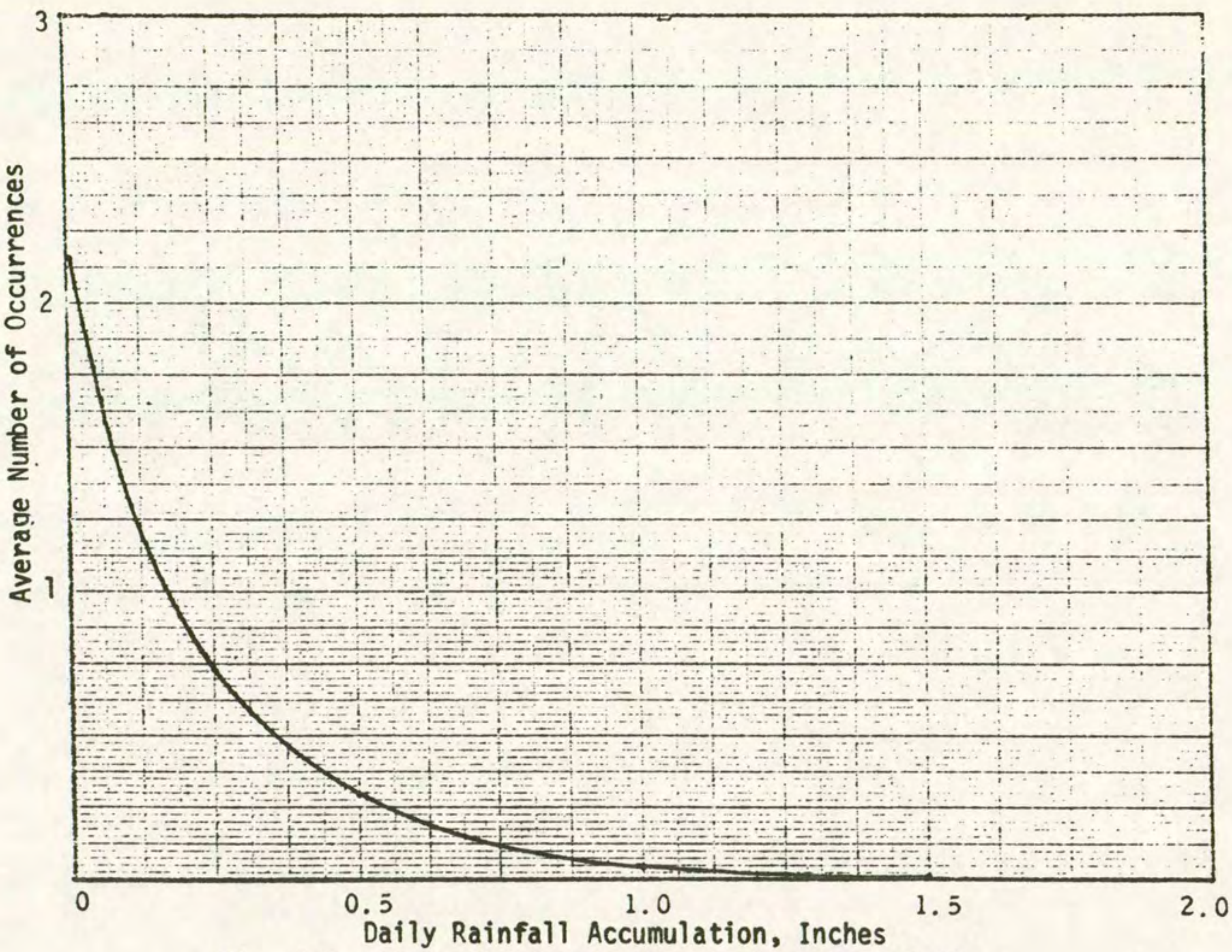


Fig. A-3. Variation in the Average Number of Daily Rainfall Events with Rainfall Accumulation (February).

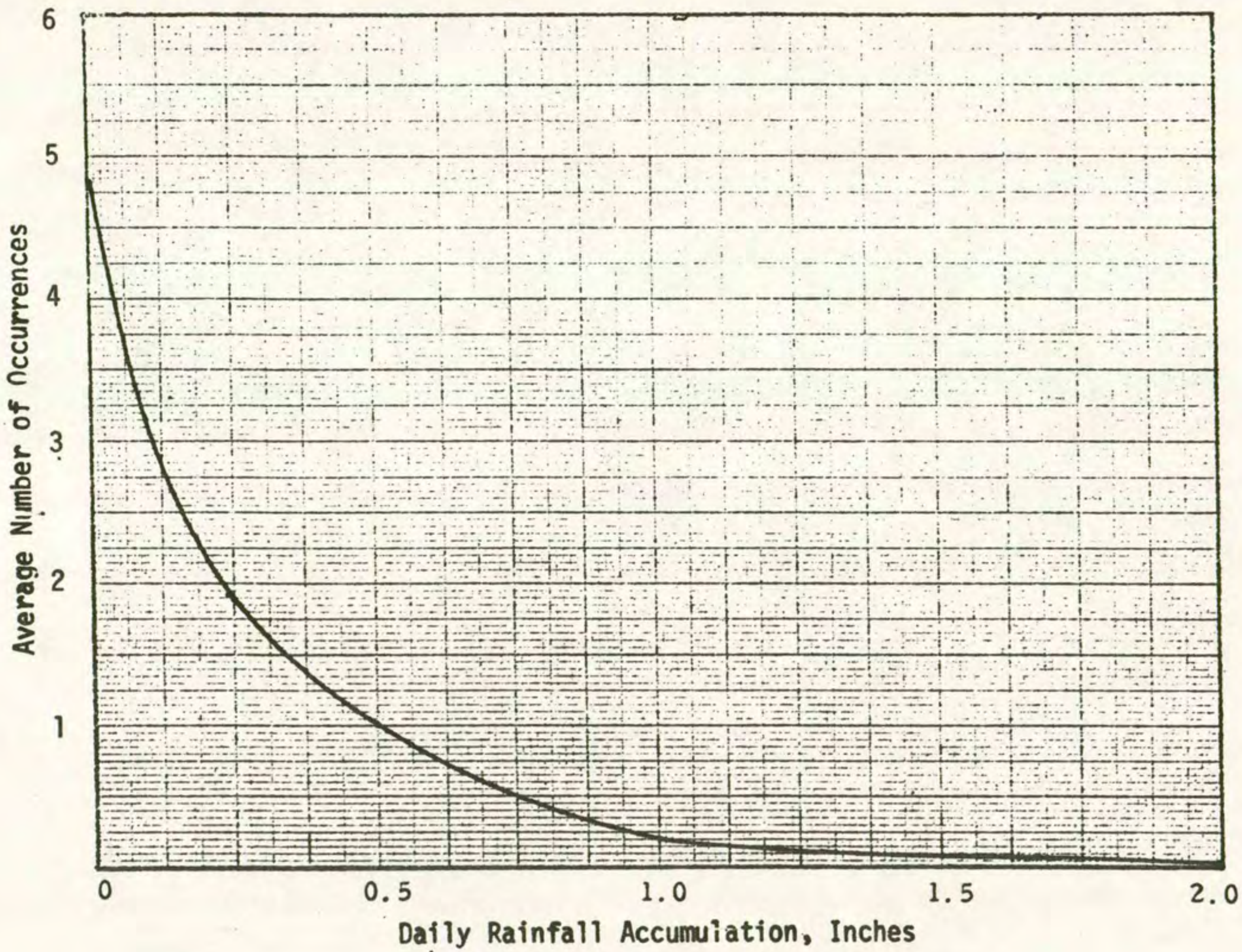


Fig. A-4. Variation in the Average Number of Daily Rainfall Events with Rainfall Accumulation (March).

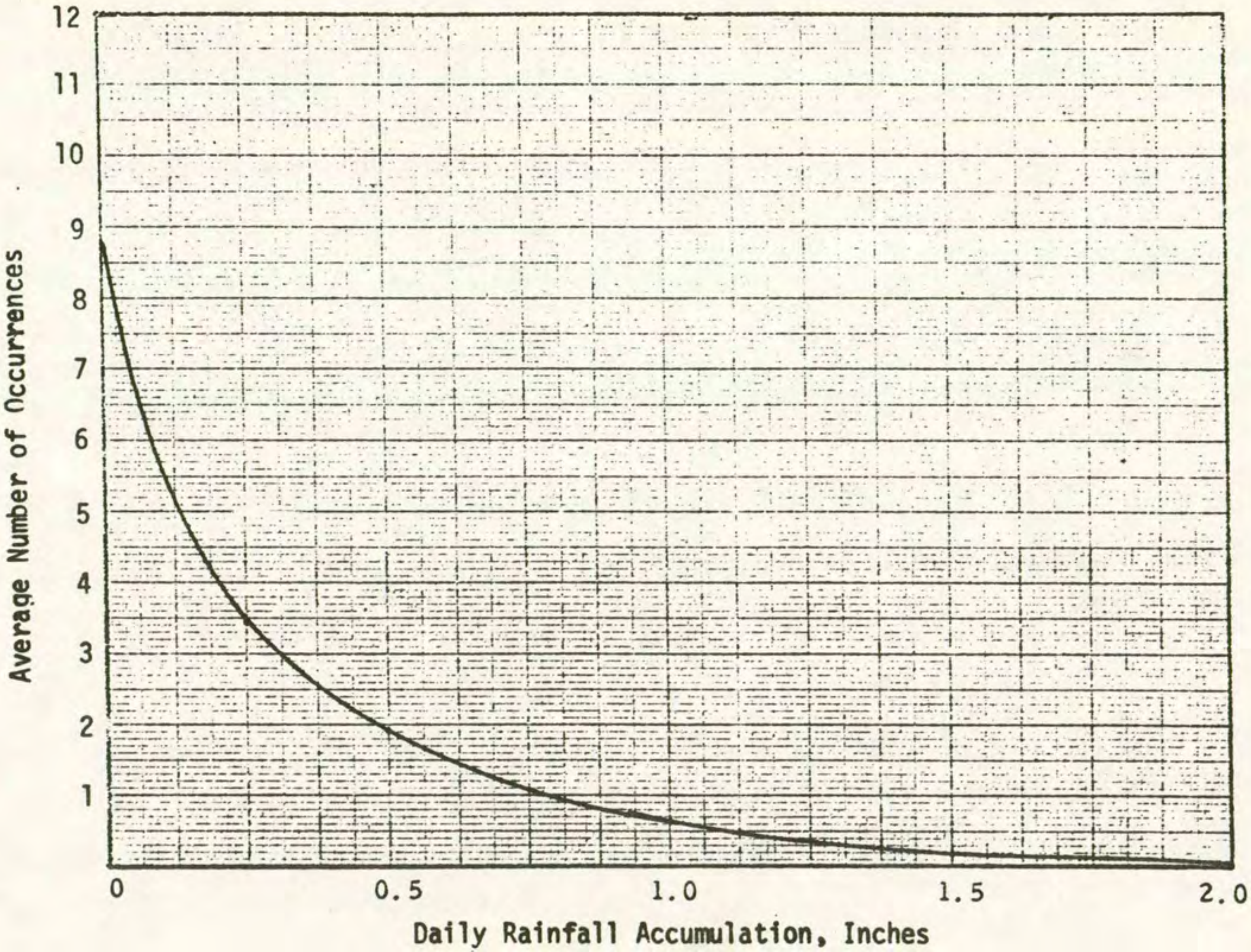


Fig. A-5. Variation in the Average Number of Daily Rainfall Events with Rainfall Accumulation (April).

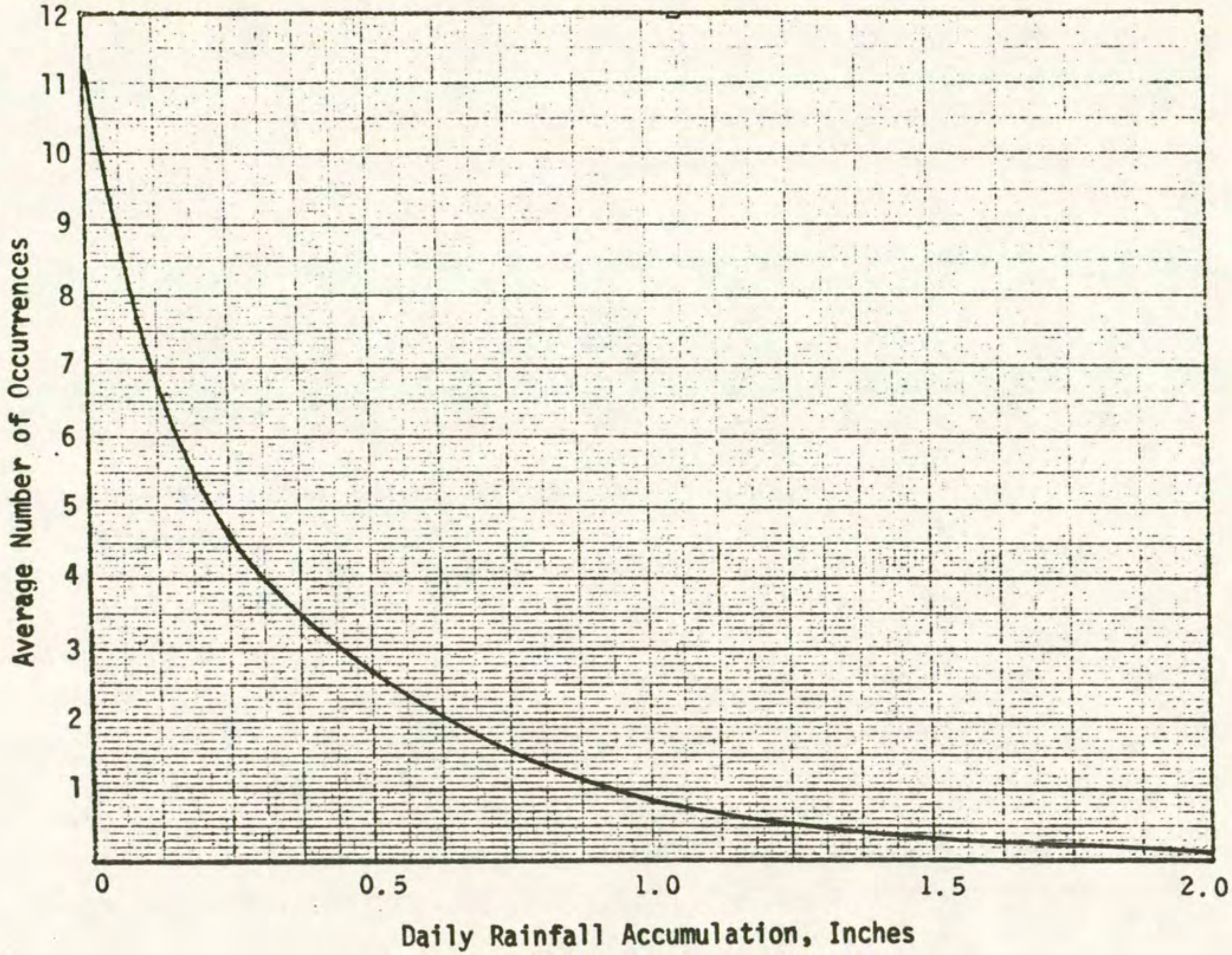


Fig. A-6. Variation in the Average Number of Daily Rainfall Events with Rainfall Accumulation (May).

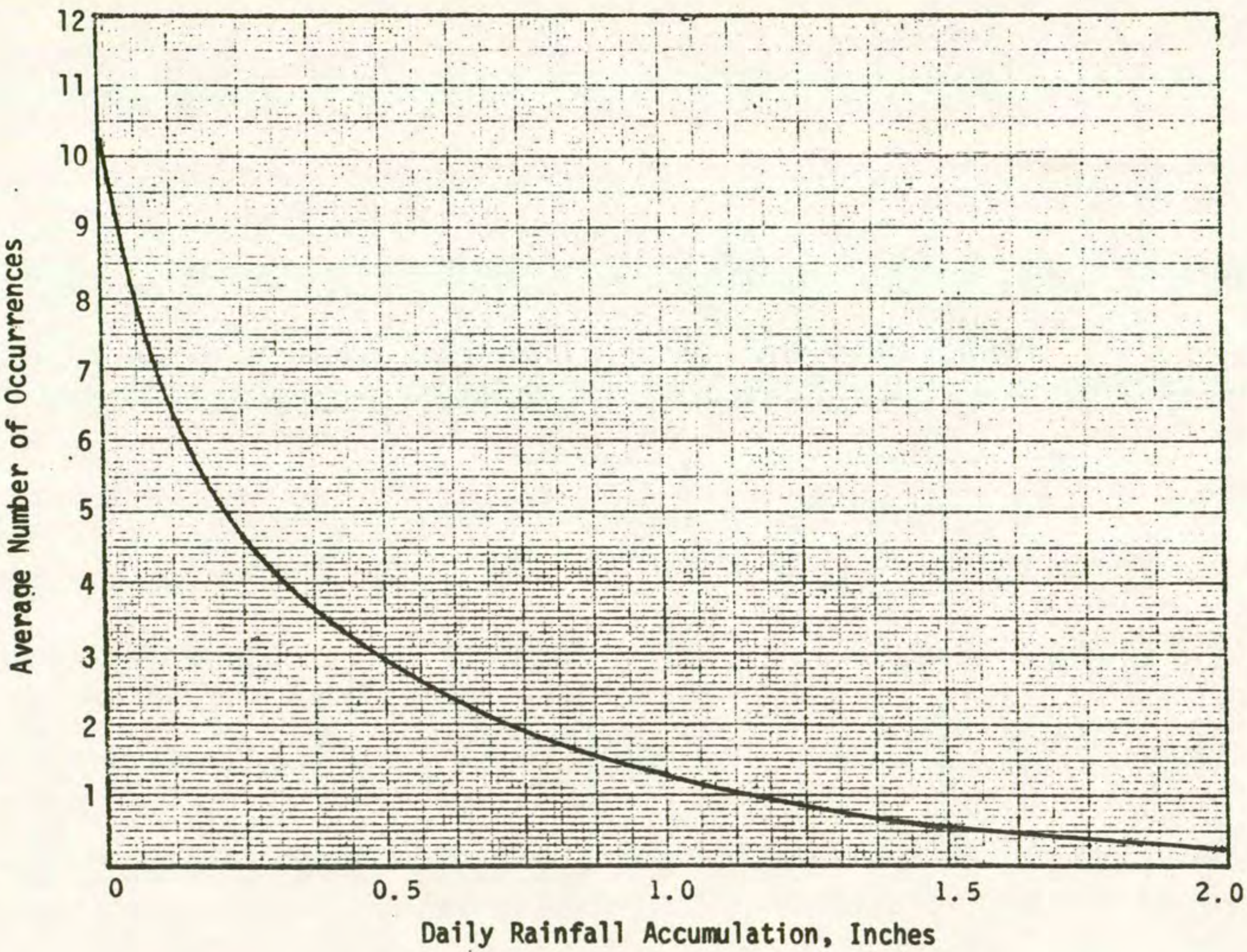


Fig. A-7. Variation in the Average Number of Daily Rainfall Events with Rainfall Accumulation (June).

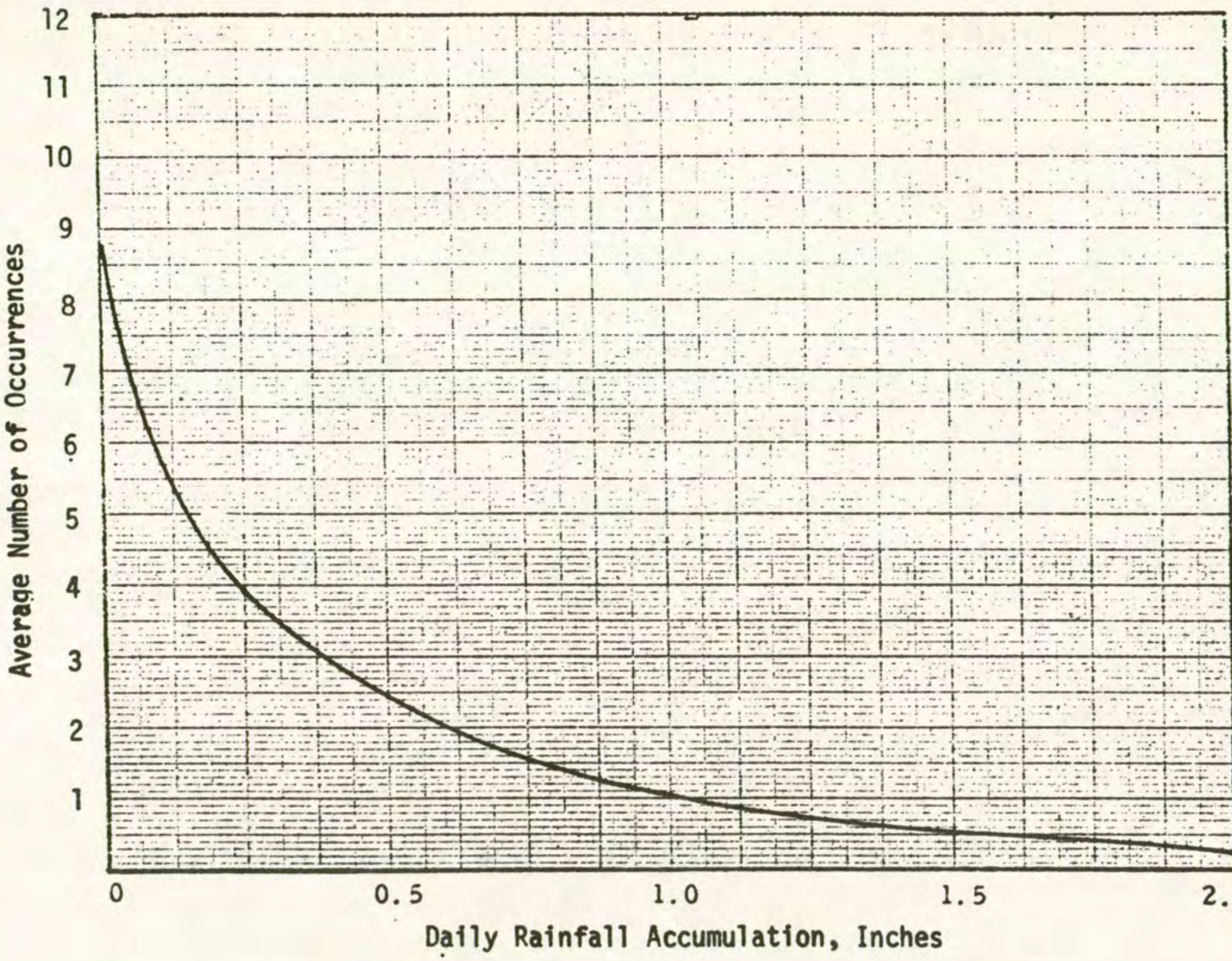


Fig. A-8. Variation in the Average Number of Daily Rainfall Events with Rainfall Accumulation (July).

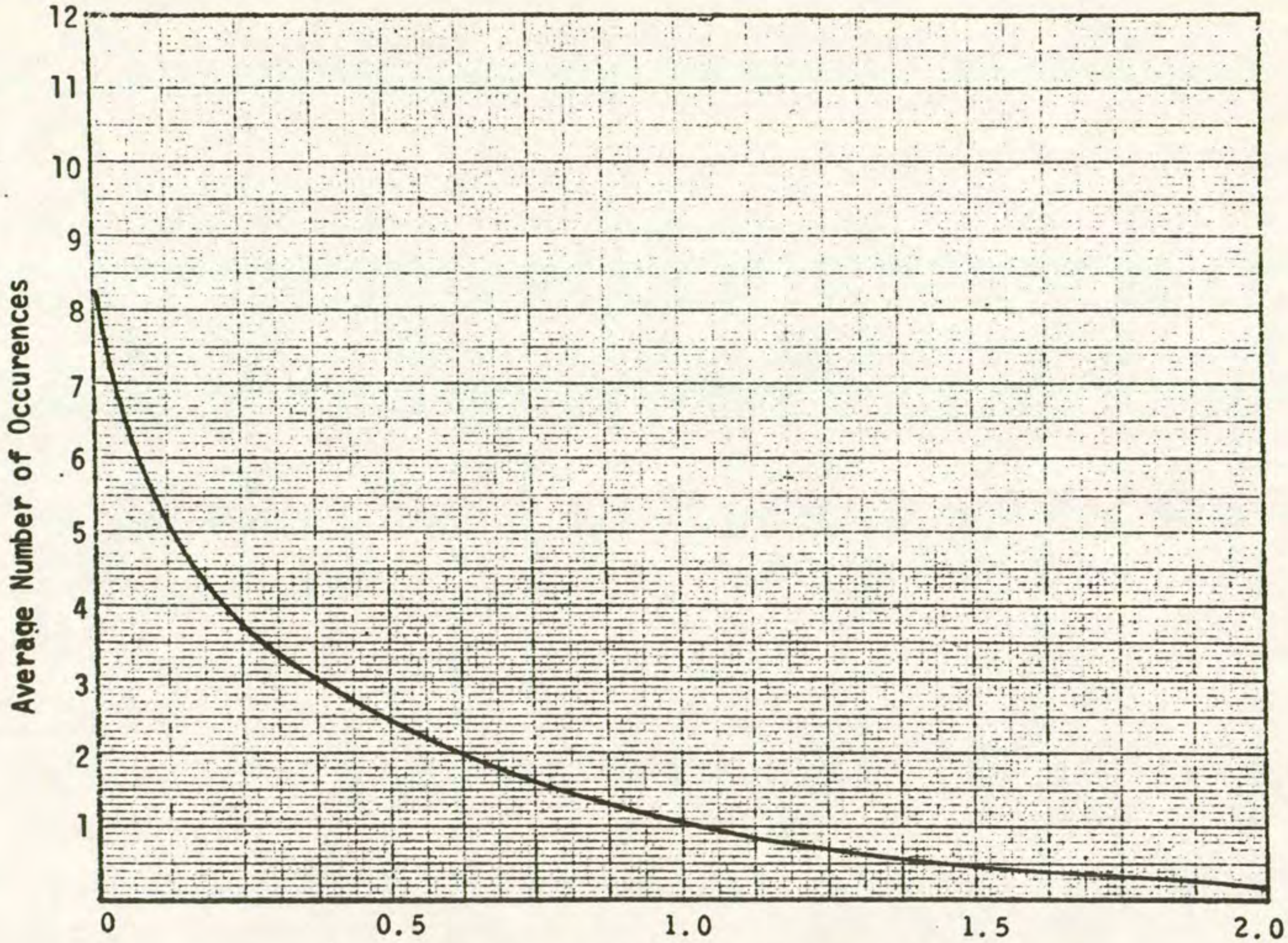


Fig. A-9. Variation in the Average Number of Daily Rainfall Events with Rainfall Accumulation (August).

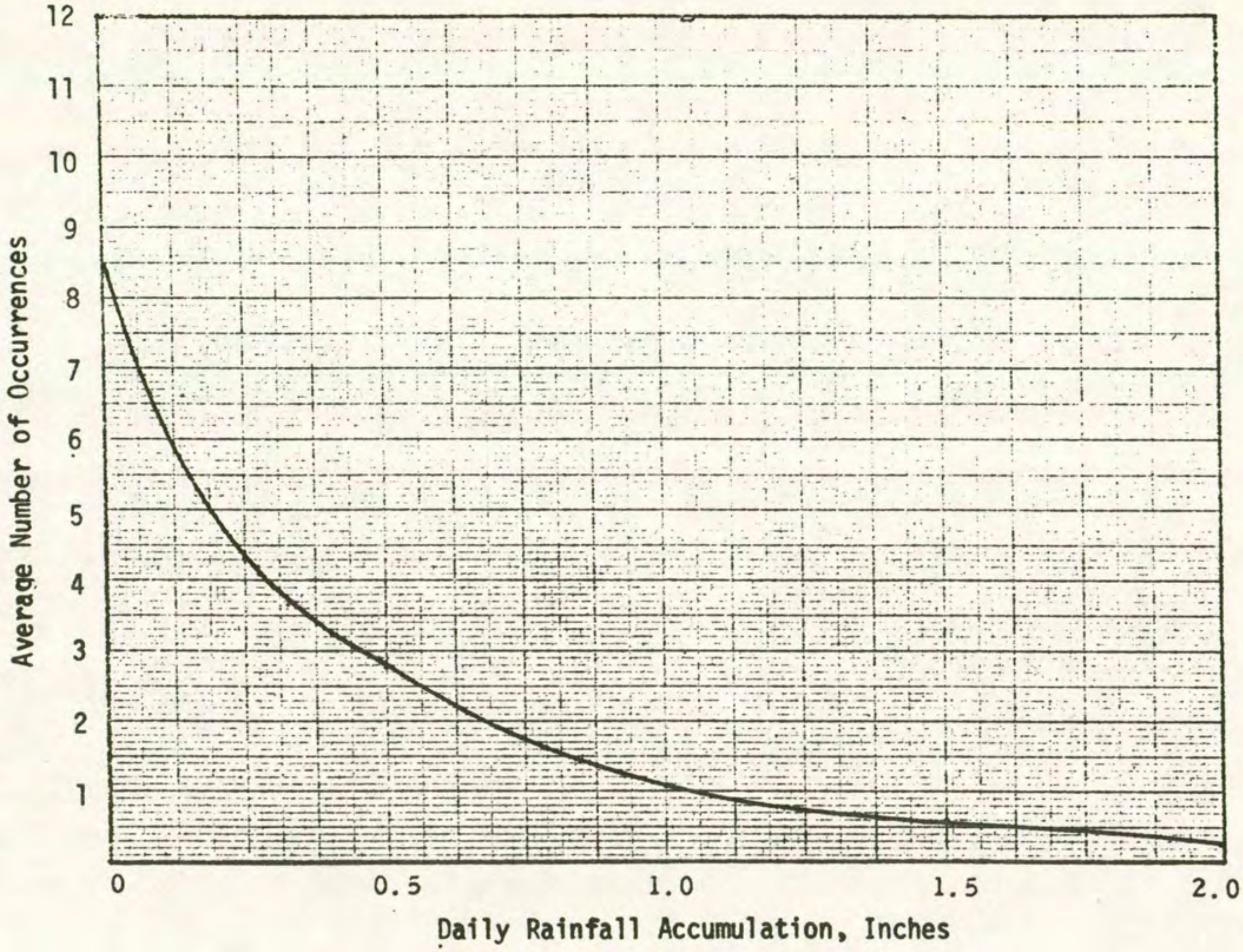


Fig. A-10. Variation in the Average Number of Daily Rainfall Events with Rainfall Accumulation (September).

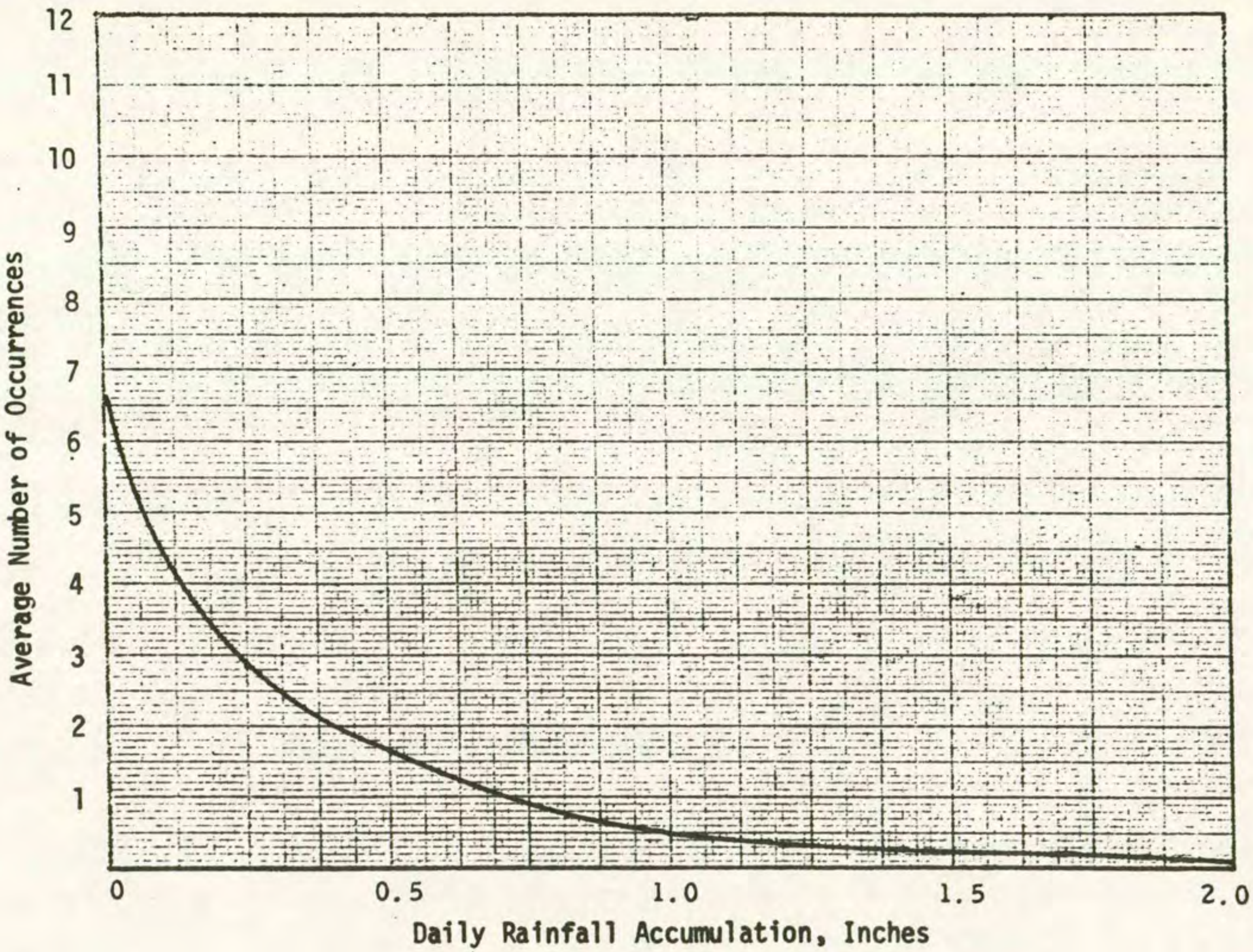


Fig. A-11. Variation in the Average Number of Daily Rainfall Events with Rainfall Accumulation (October).

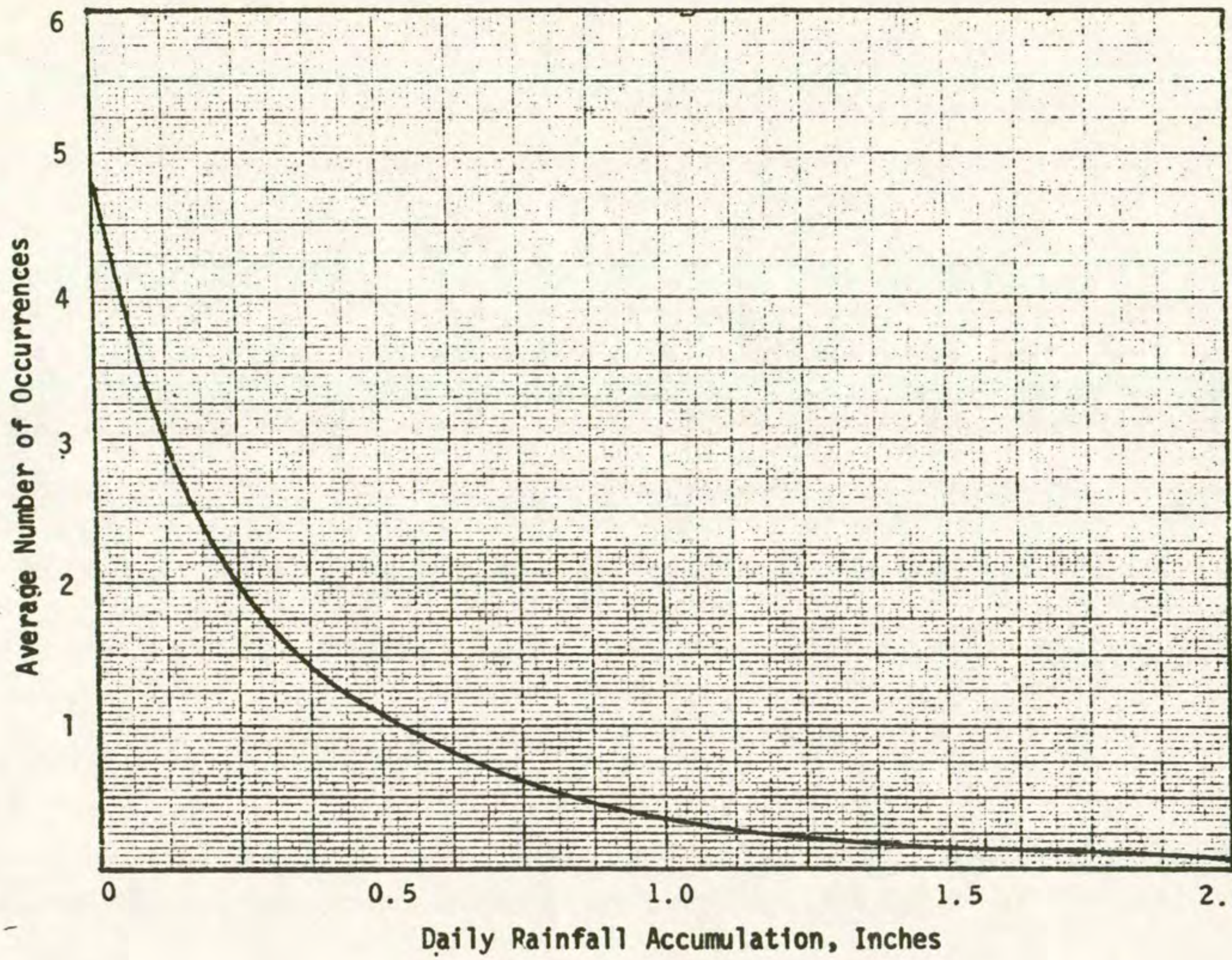


Fig. A-12. Variation in the Average Number of Daily Rainfall Events with Rainfall Accumulation (November).

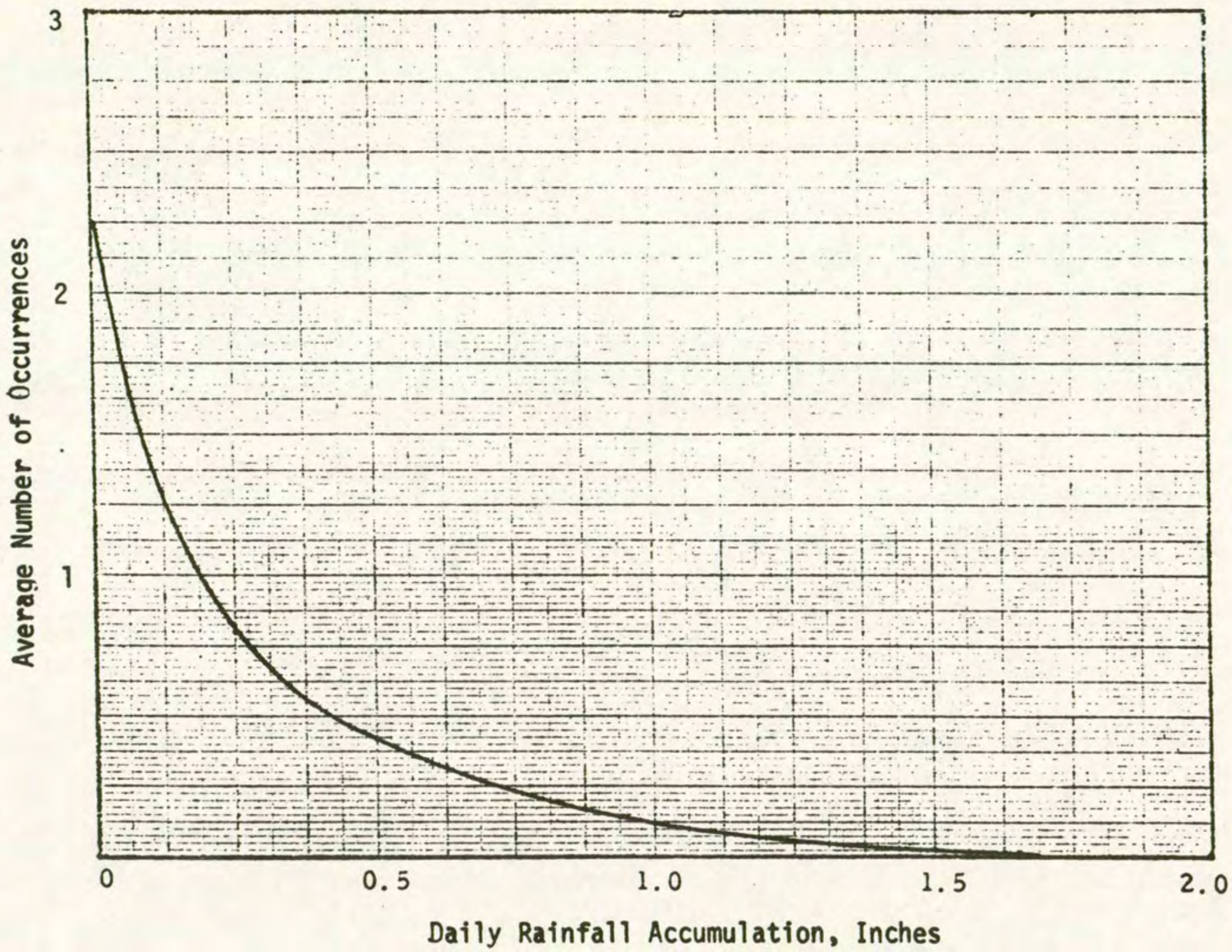


Fig. A-13. Variation in the Average Number of Daily Rainfall Events with Rainfall Accumulation (December).

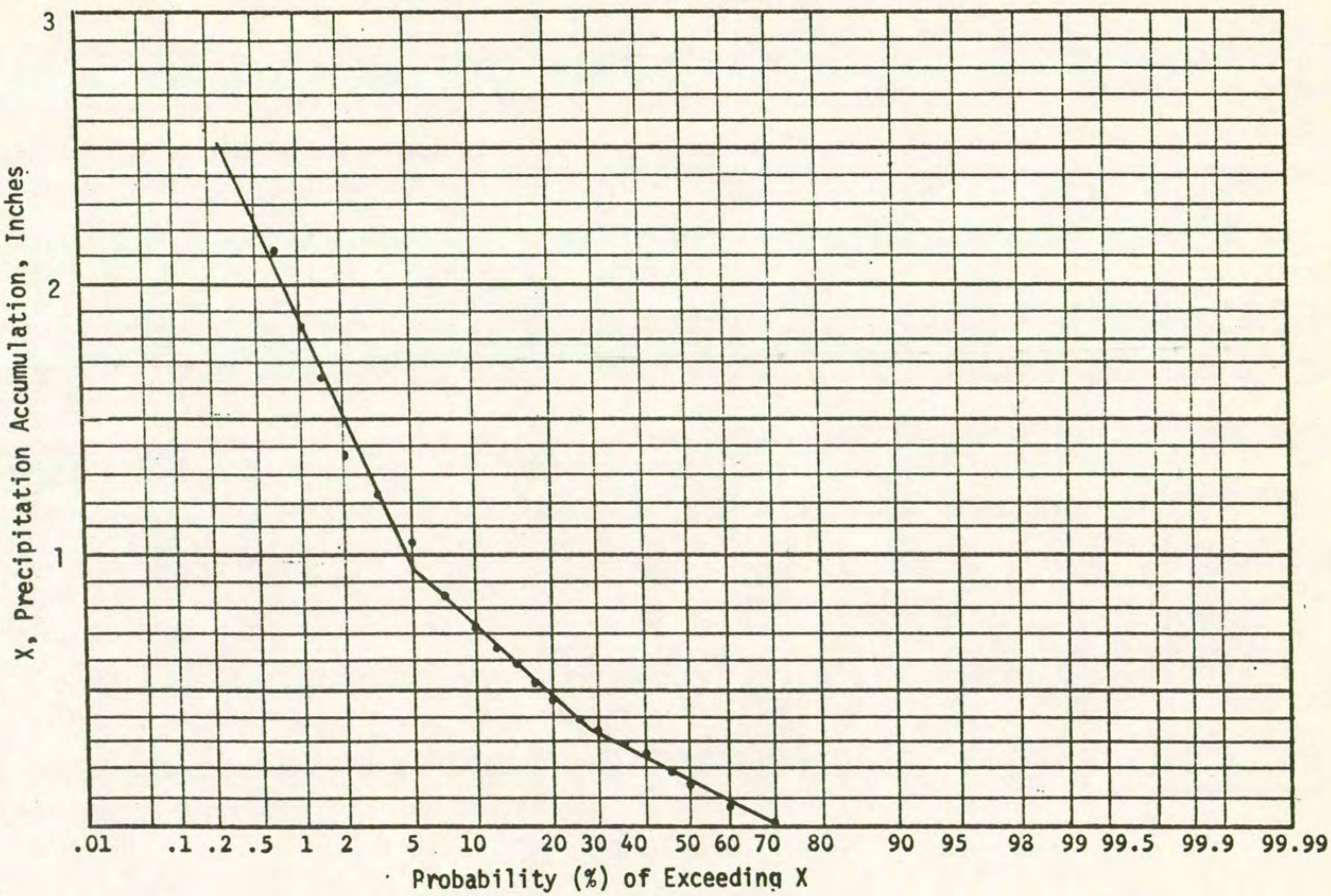


Fig. A-14. Probability of Exceeding Various Weekly Precipitation Accumulations (January).

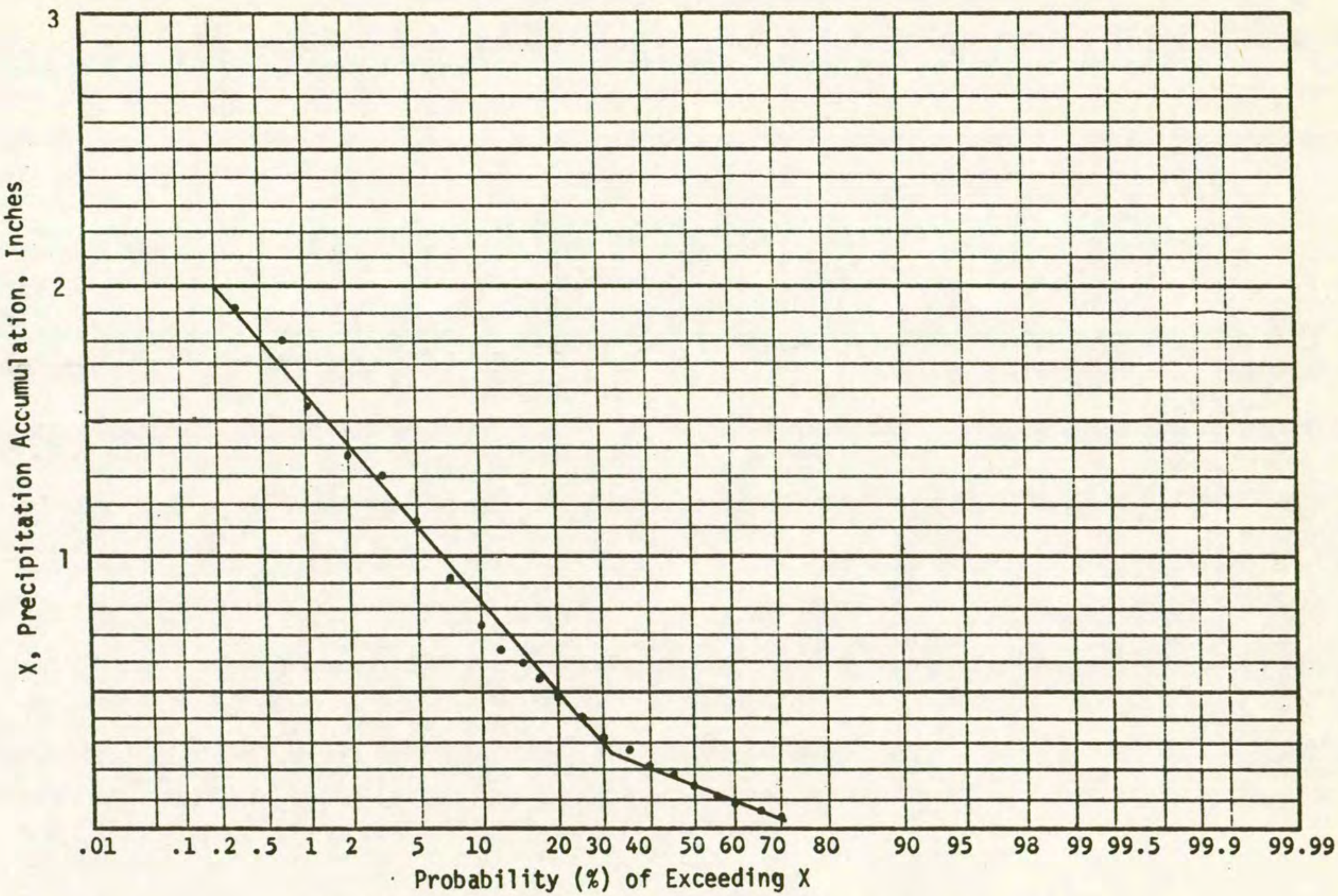


Fig. A-15. Probability of Exceeding Various Weekly Precipitation Accumulations (February).

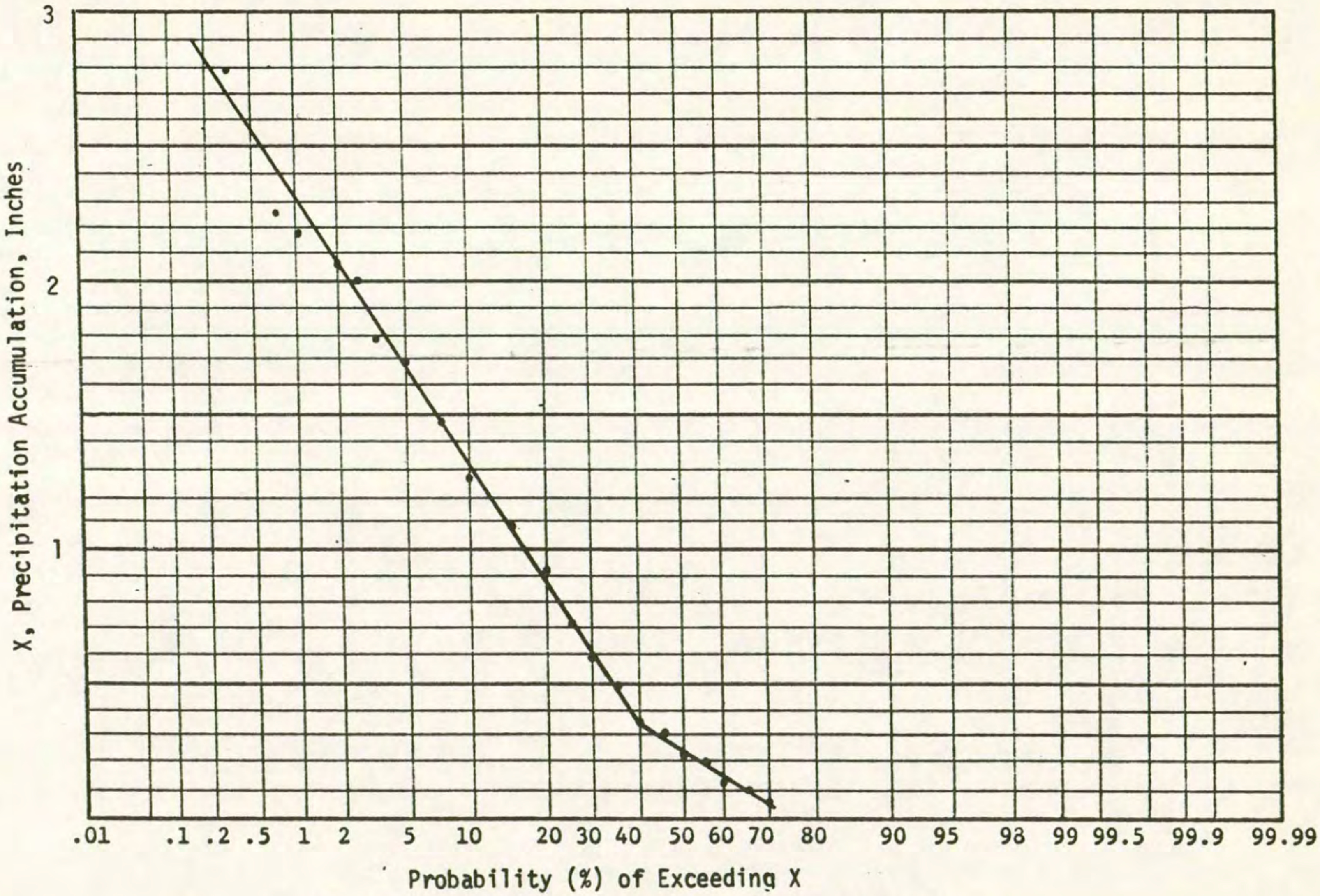


Fig. A-16. Probability of Exceeding Various Weekly Precipitation Accumulations (March).

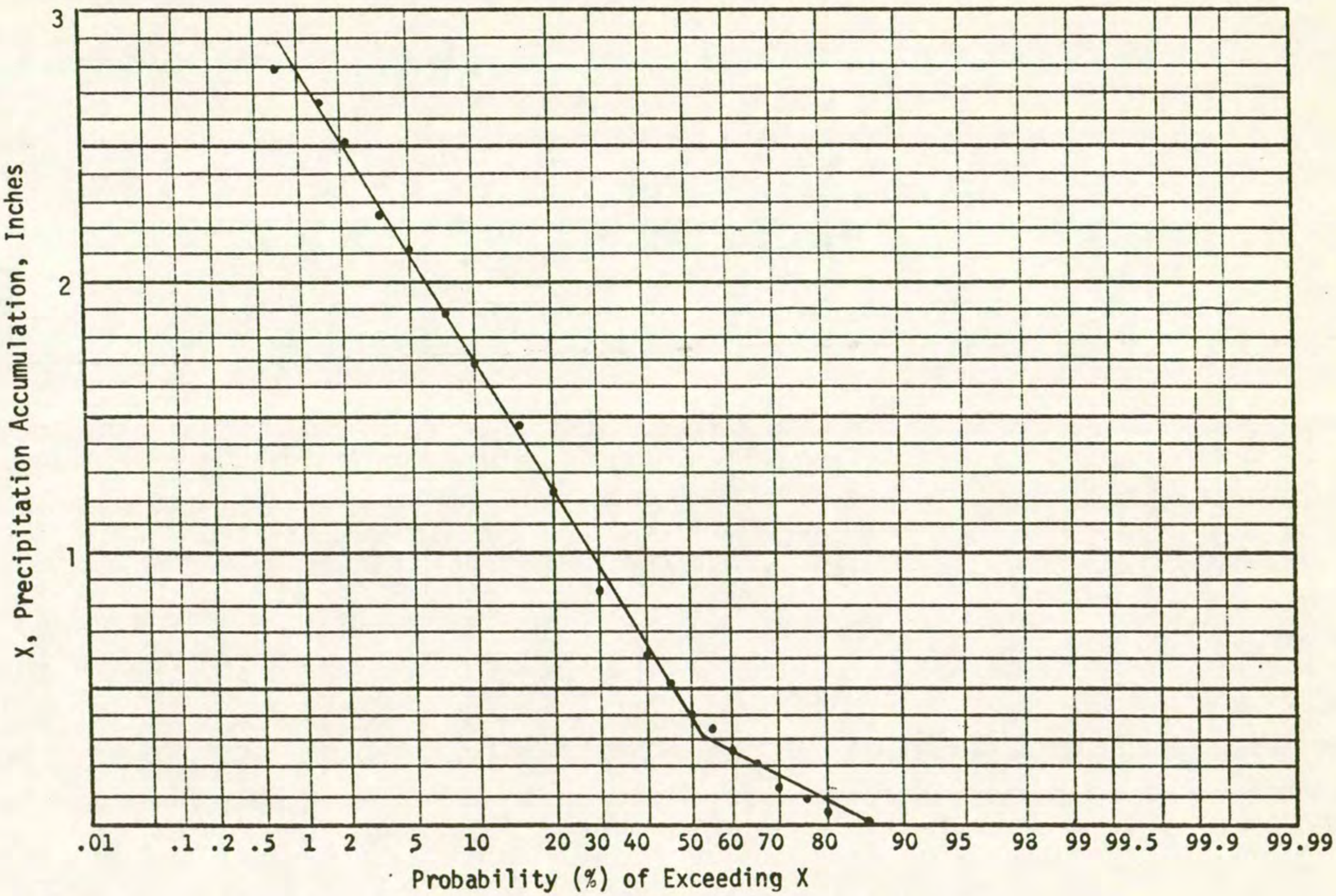


Fig. A-17. Probability of Exceeding Various Weekly Precipitation Accumulations (April).

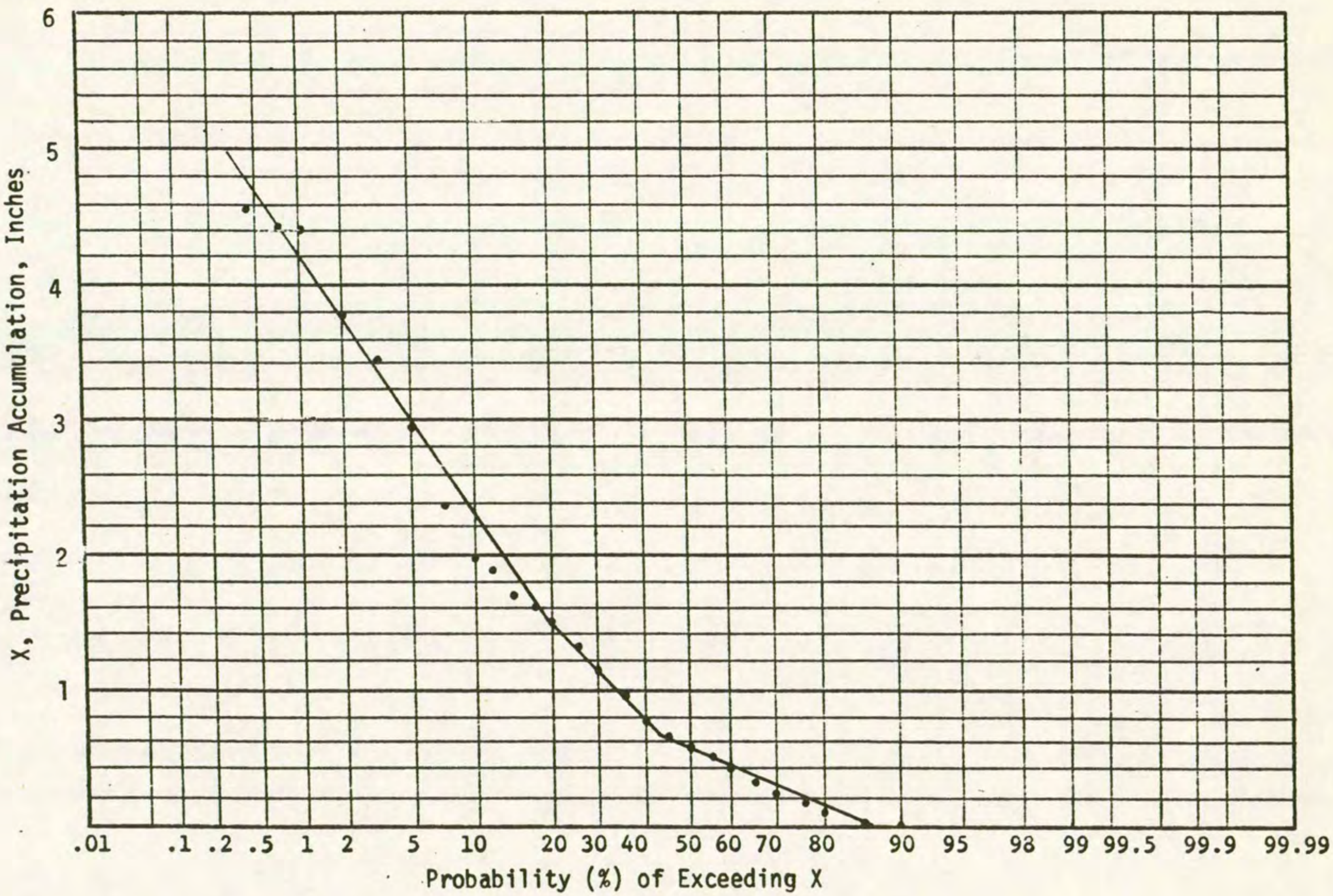


Fig. A-18. Probability of Exceeding Various Weekly Precipitation Accumulations (May).

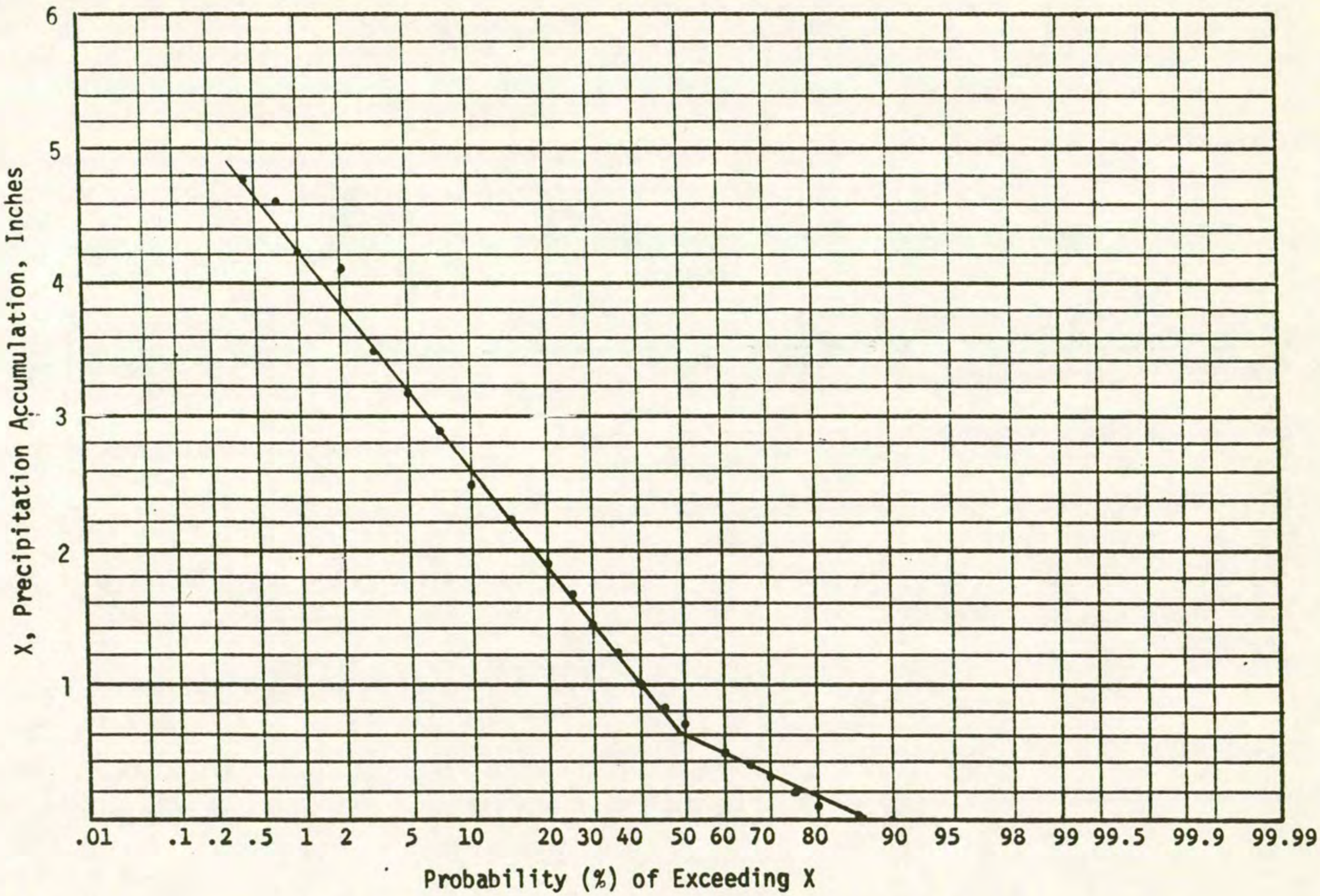


Fig. A-19. Probability of Exceeding Various Weekly Precipitation Accumulations (June).

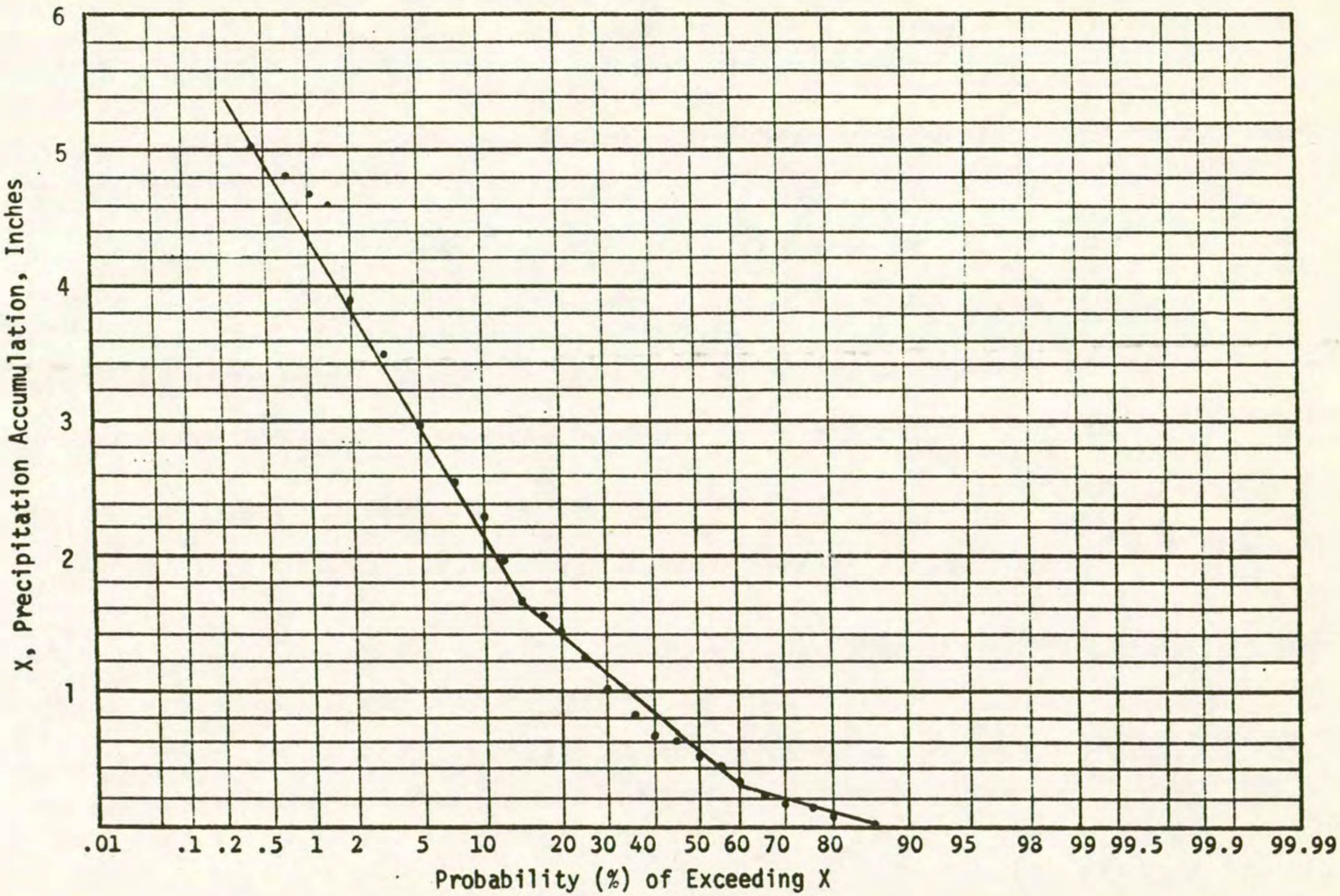


Fig. A-20. Probability of Exceeding Various Weekly Precipitation Accumulations (July).

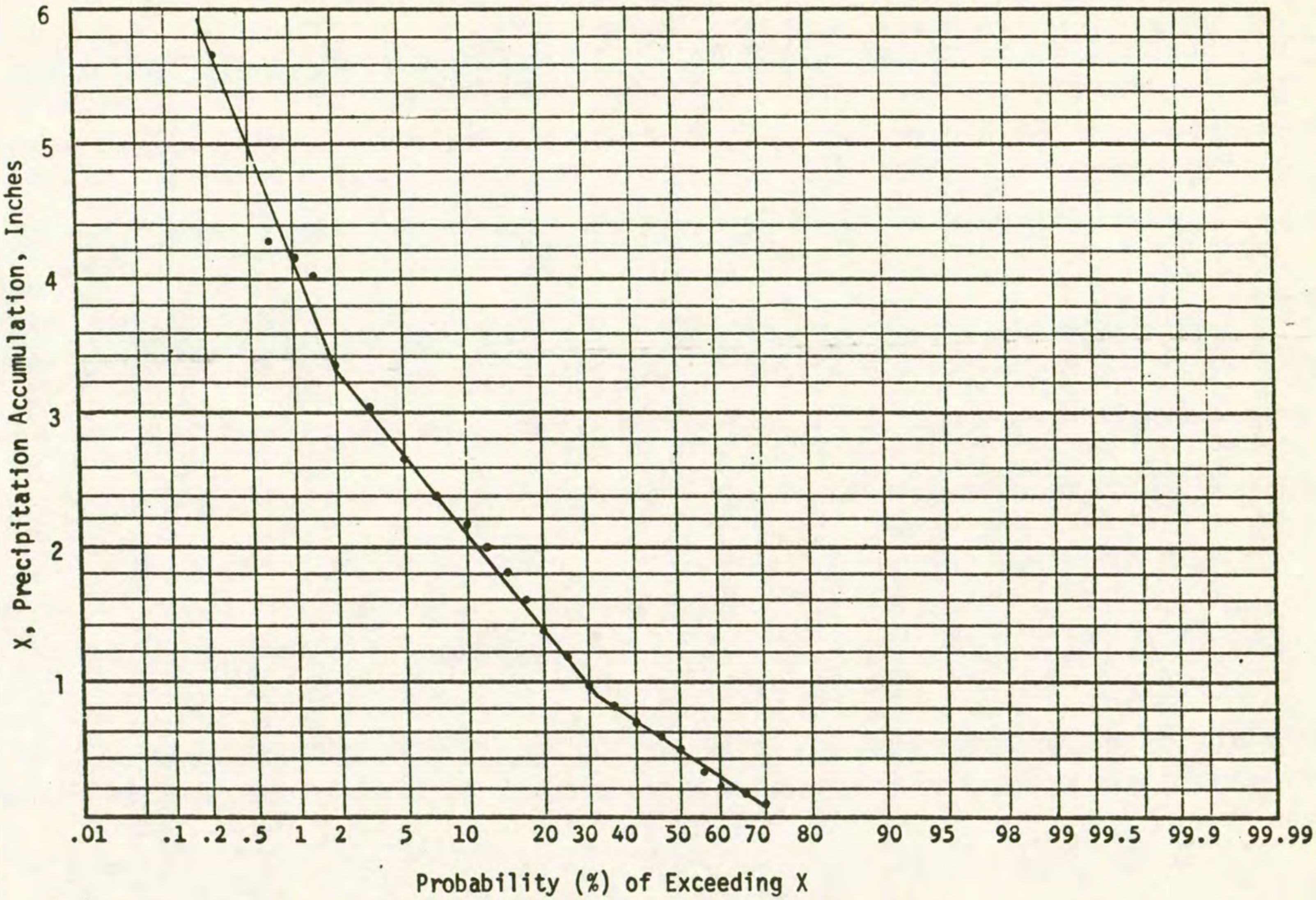


Fig. A-21. Probability of Exceeding Various Weekly Precipitation Accumulations (August).

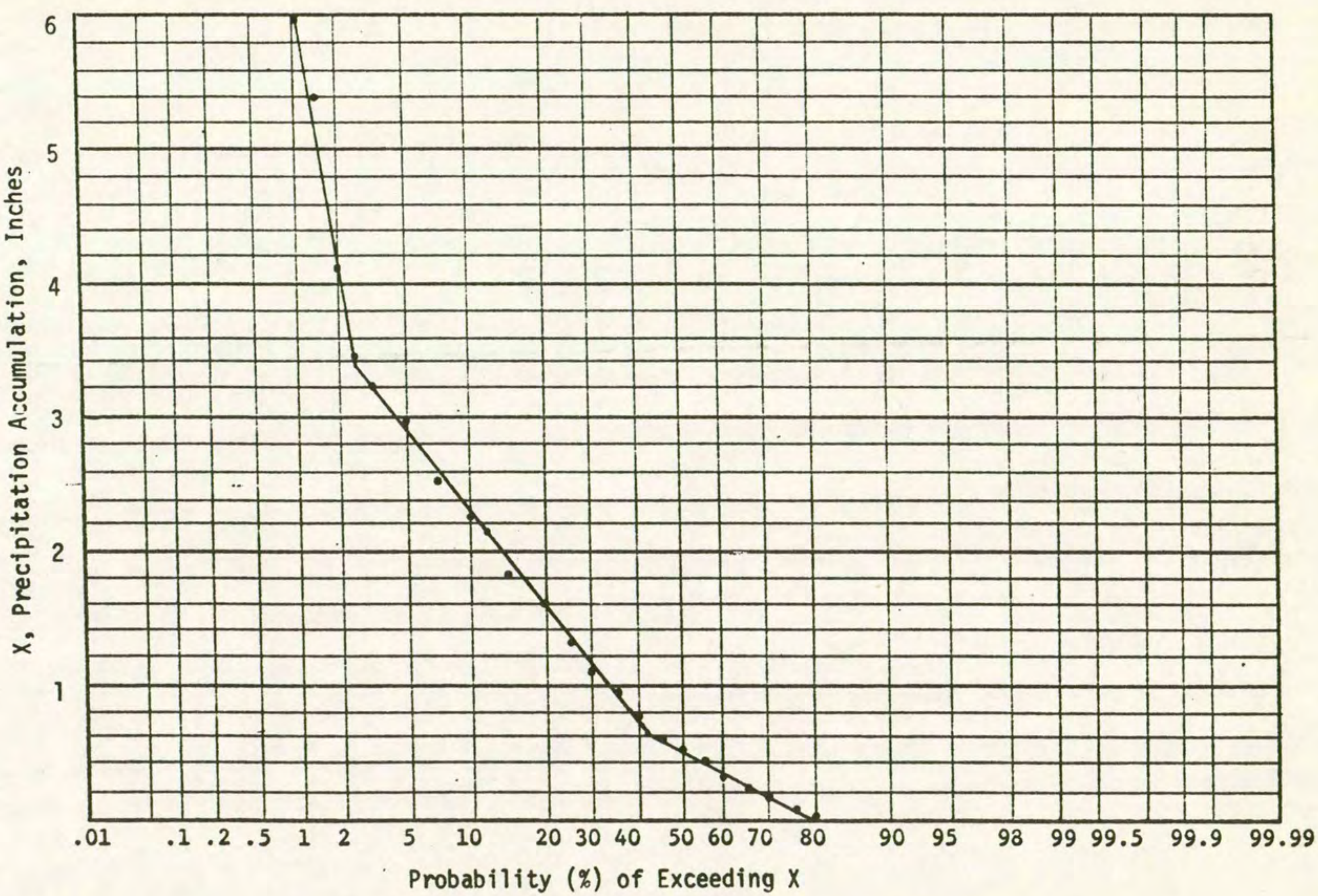


Fig. A-22. Probability of Exceeding Various Weekly Precipitation Accumulations (September).

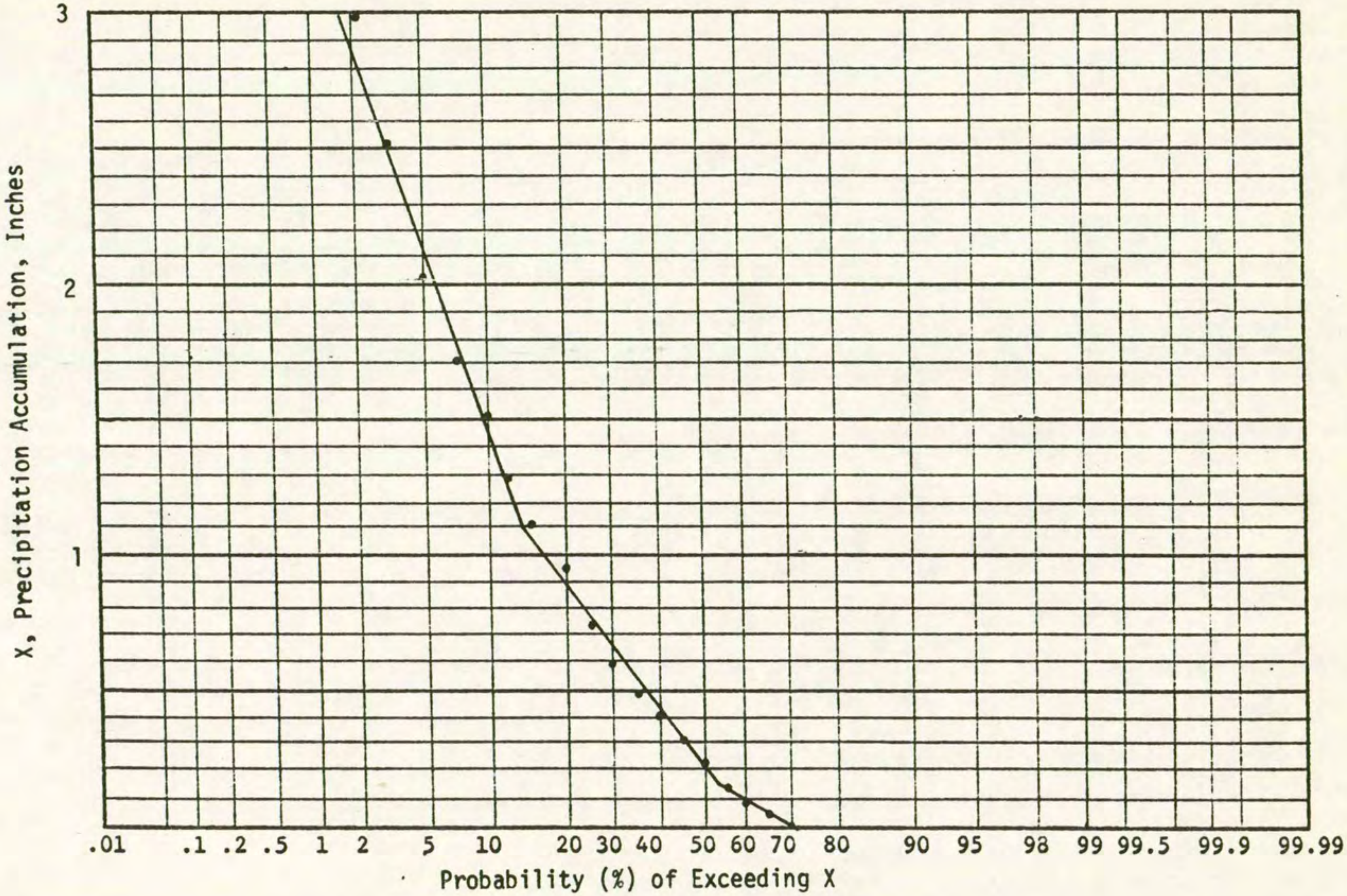


Fig. A-23. Probability of Exceeding Various Weekly Precipitation Accumulations (October).

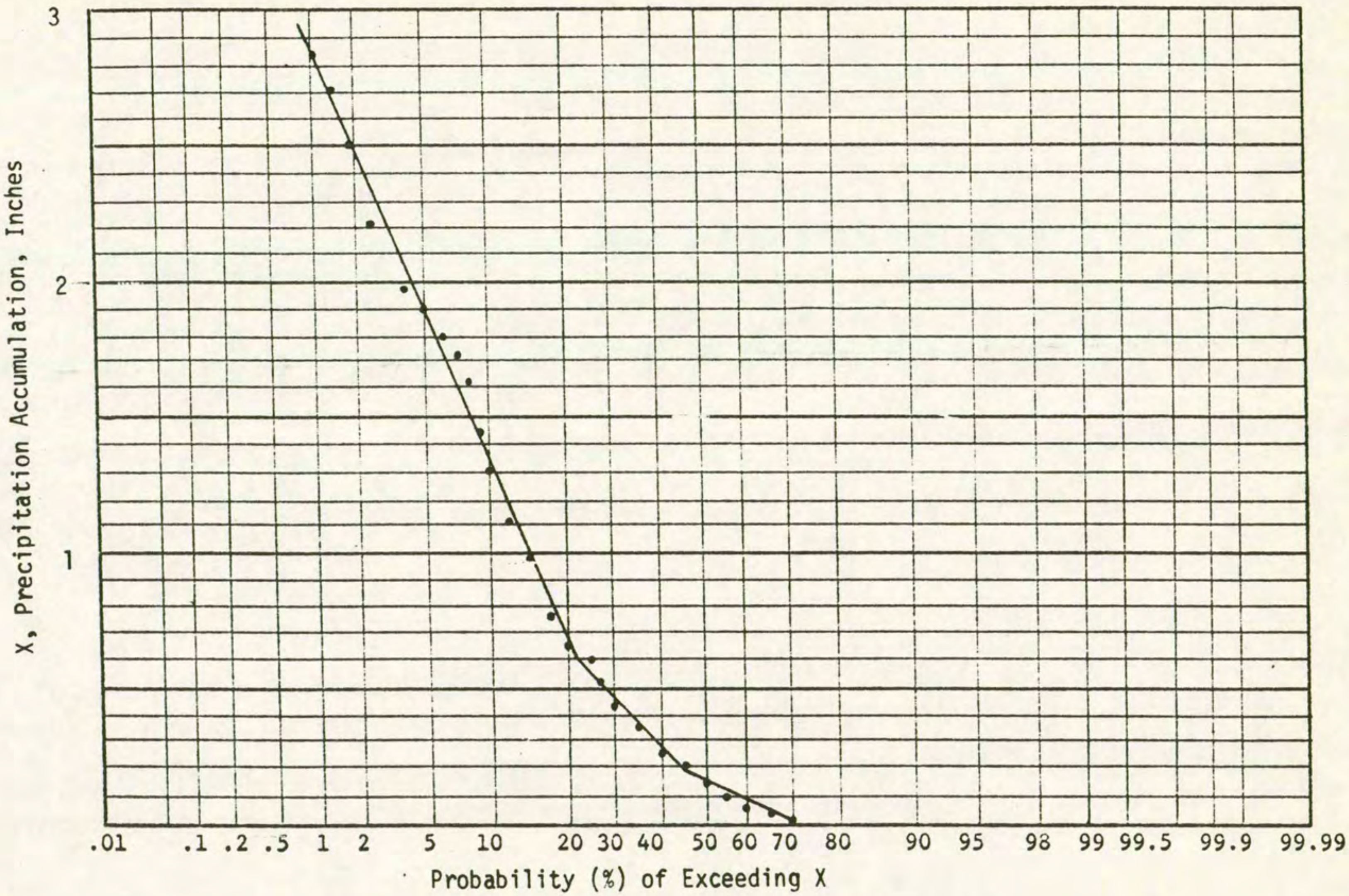


Fig. A-24. Probability of Exceeding Various Weekly Precipitation Accumulations (November).

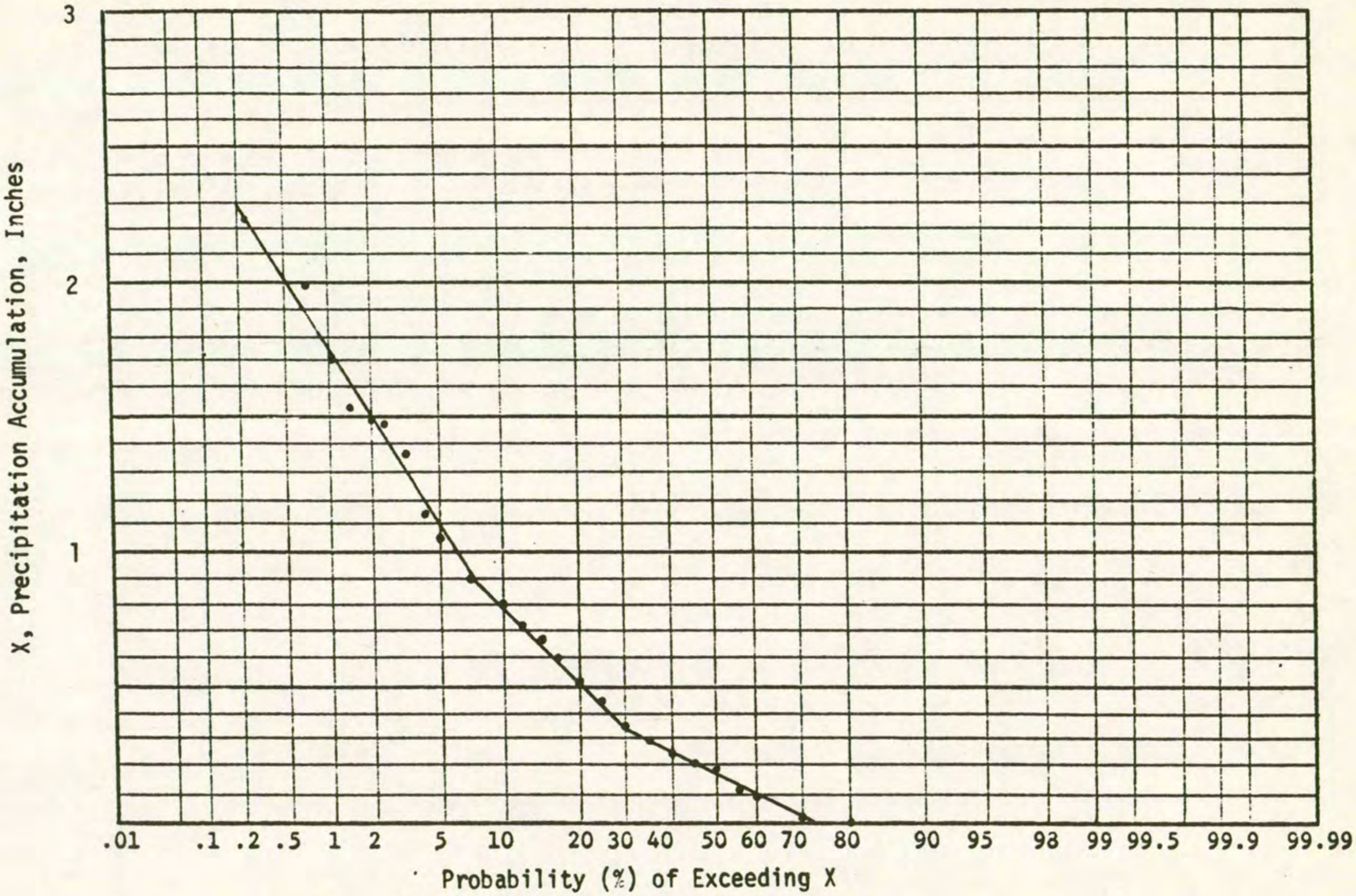


Fig. A-25. Probability of Exceeding Various Weekly Precipitation Accumulations (December).

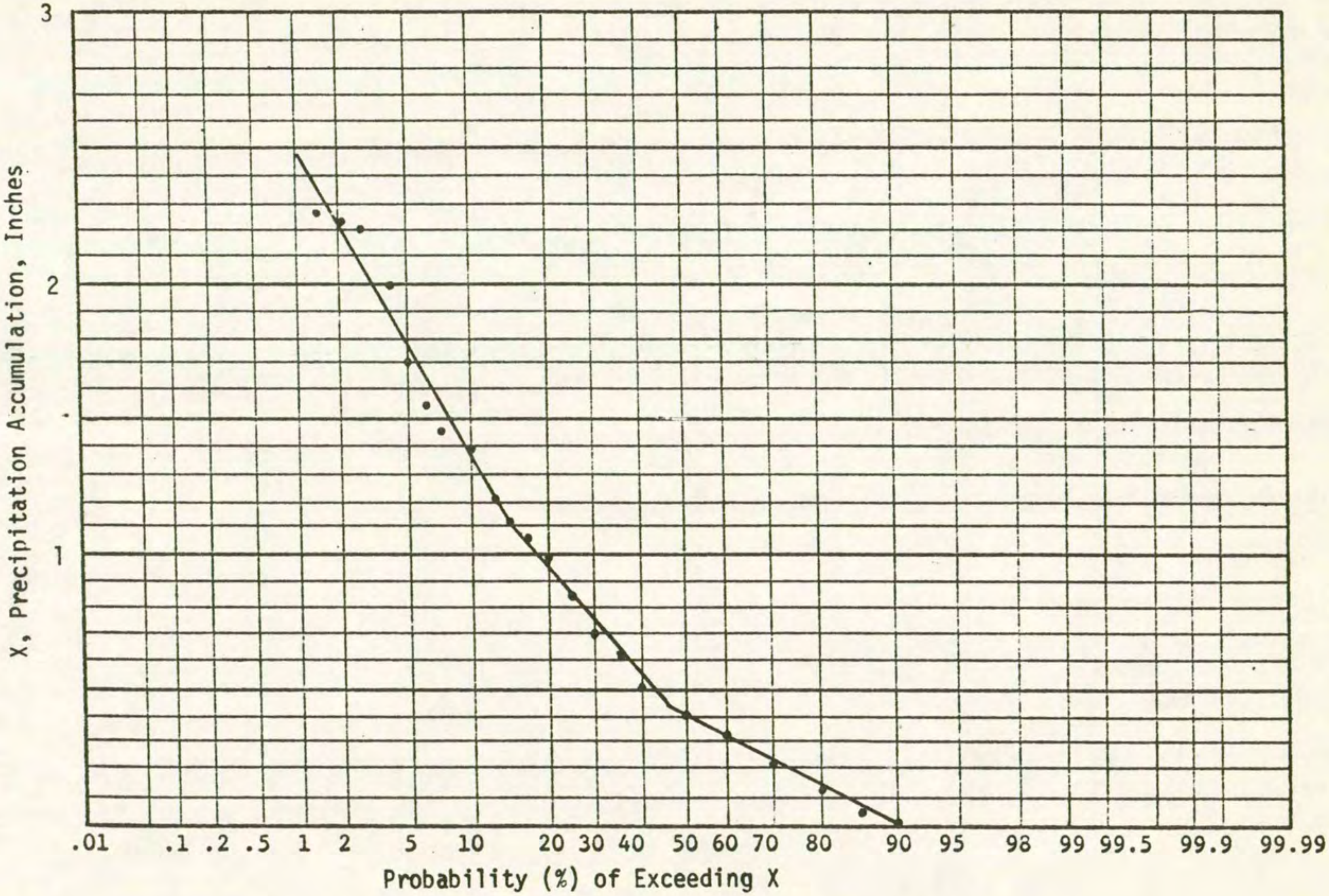


Fig. A-26. Probability of Exceeding Various Bimonthly Precipitation Accumulations (January).

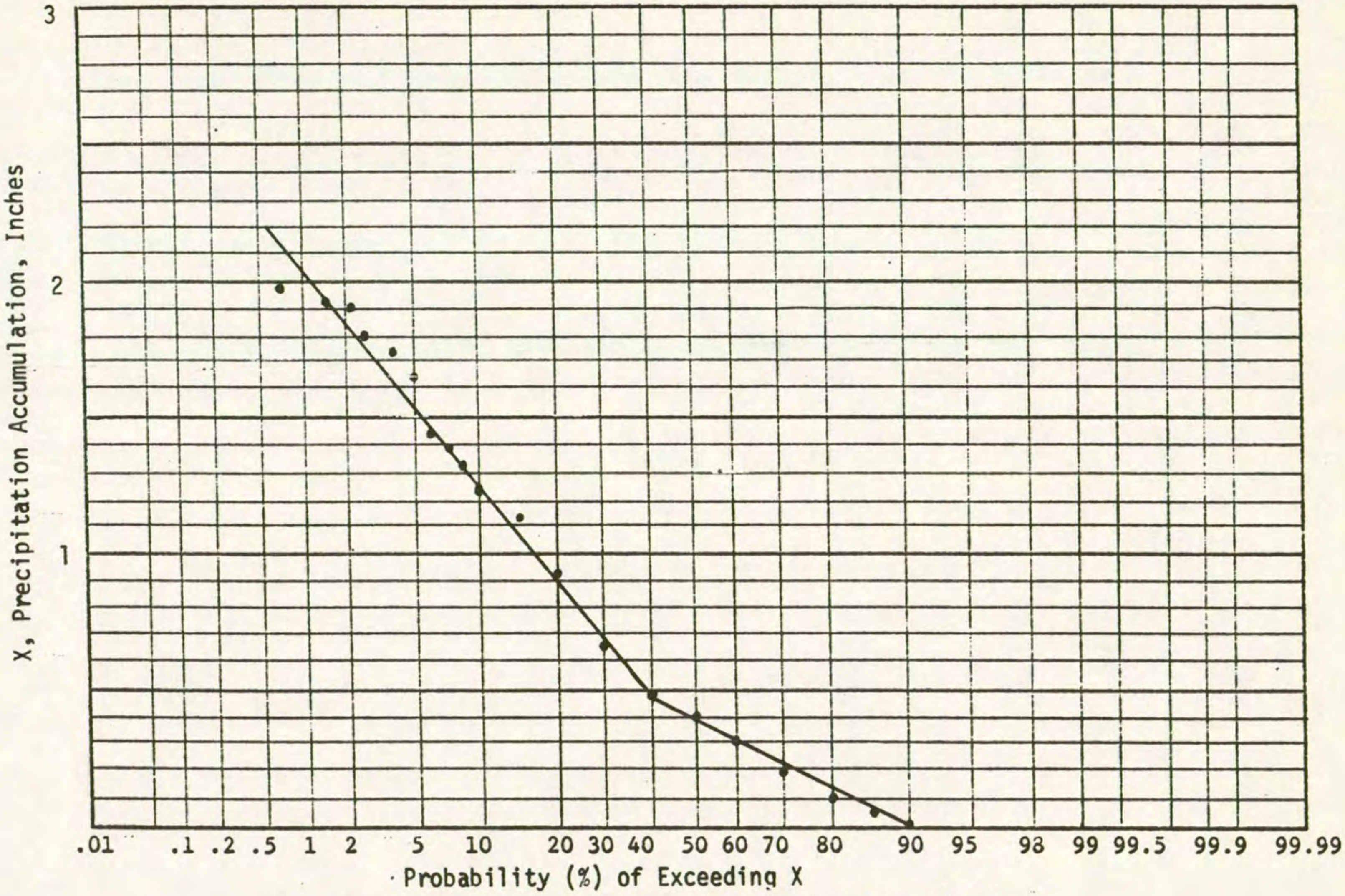
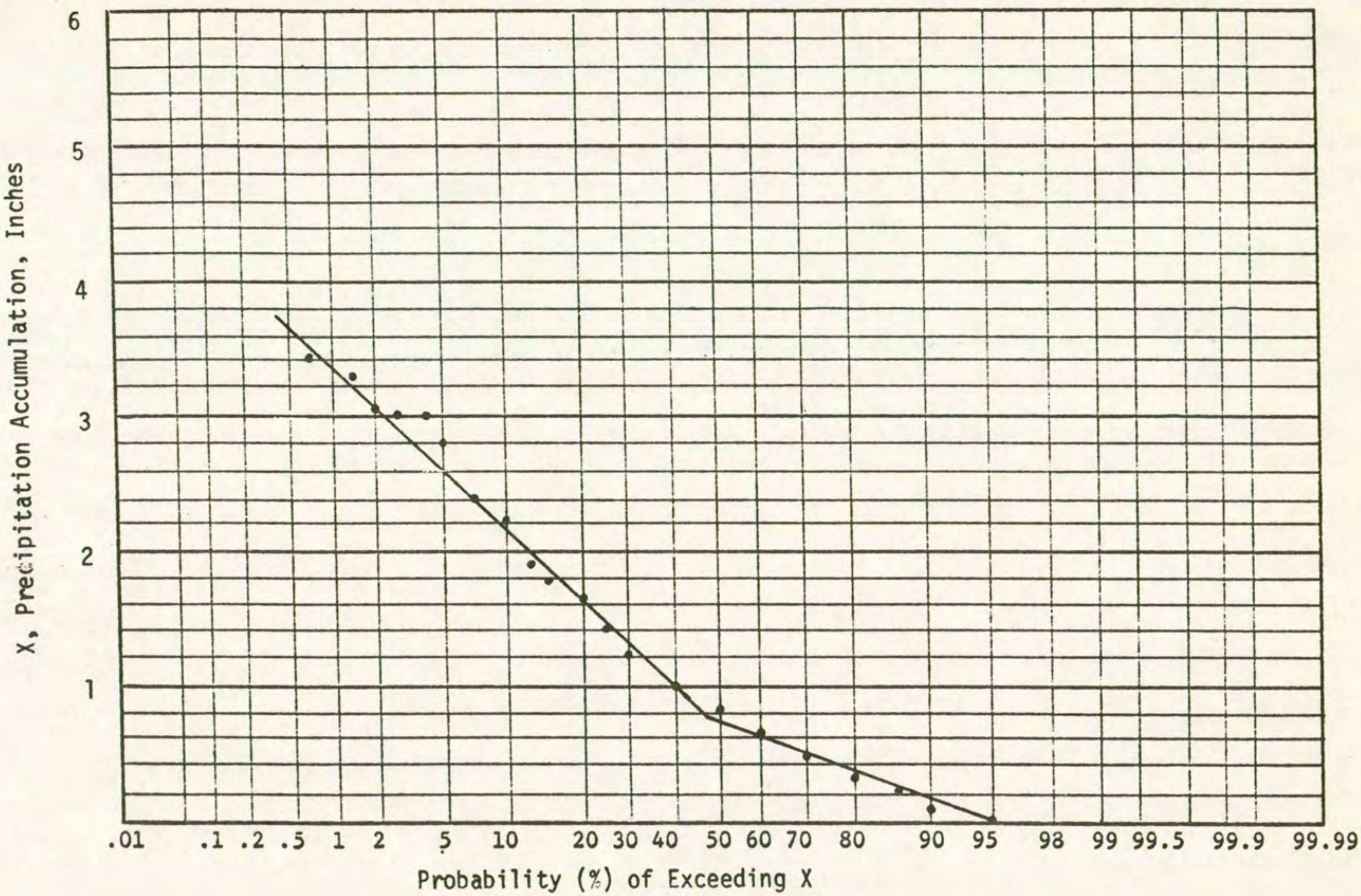


Fig. A-27. Probability of Exceeding Various Bimonthly Precipitation Accumulations (February).



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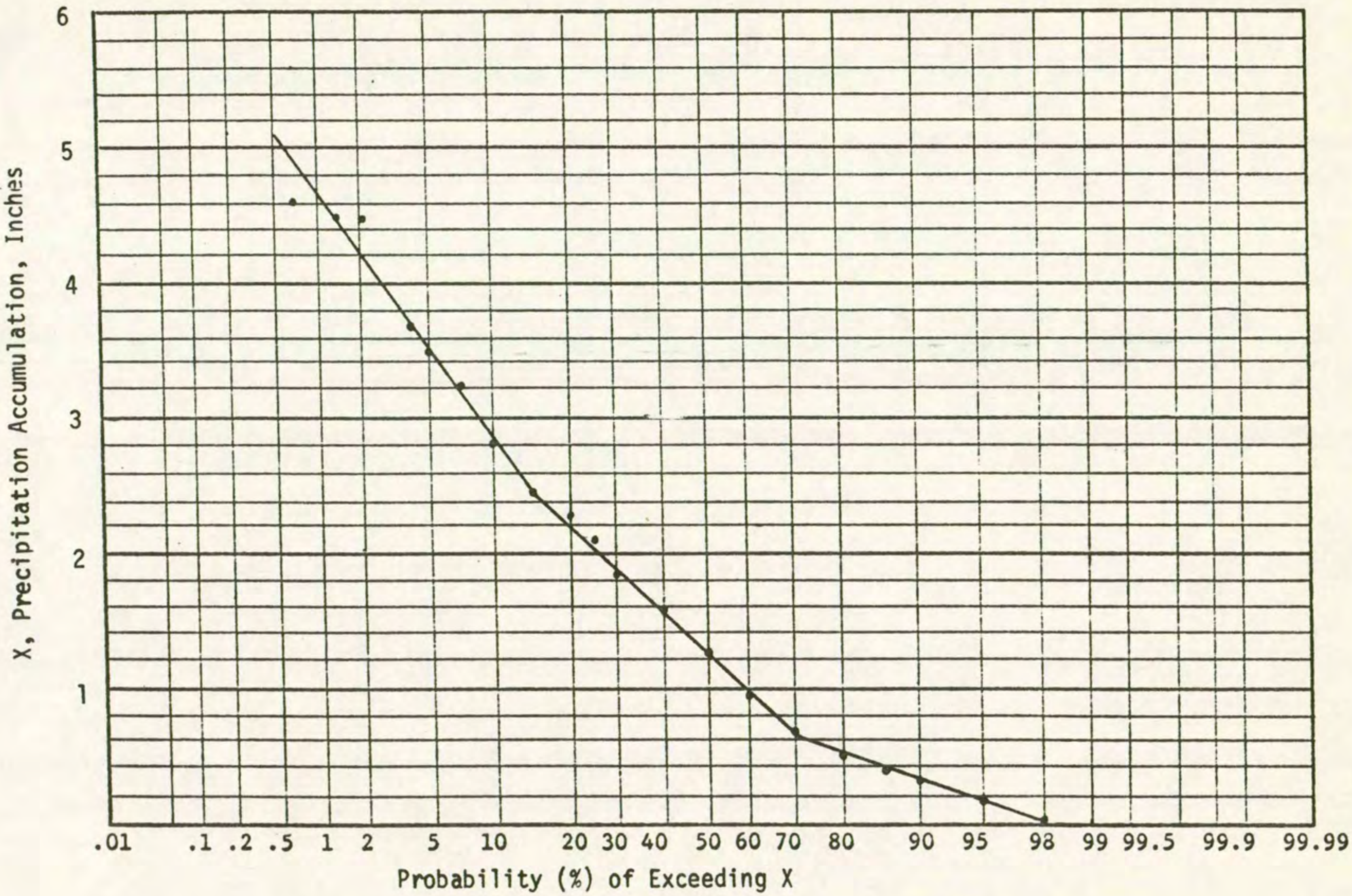


Fig. A-29. Probability of Exceeding Various Bimonthly Precipitation Accumulations (April).

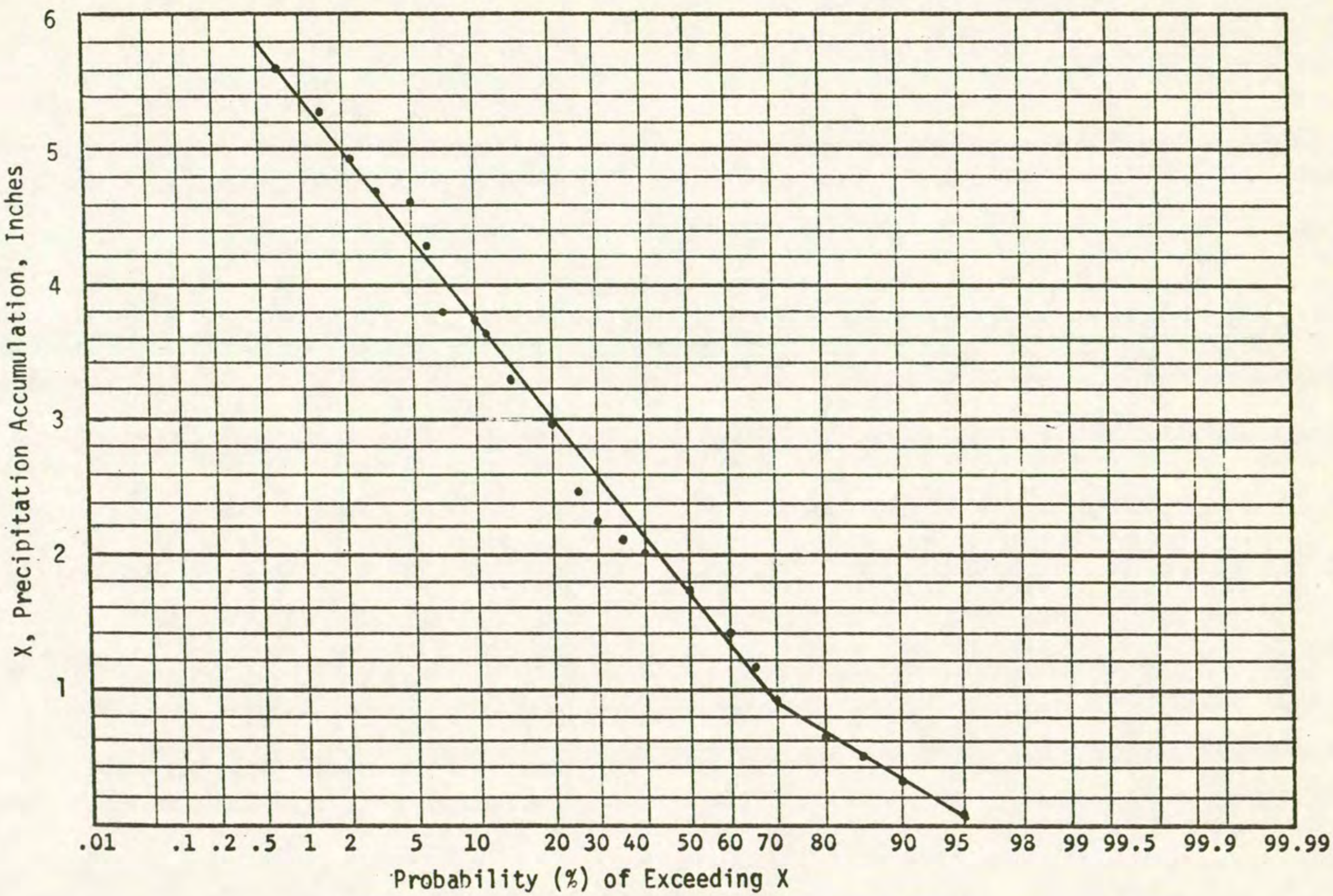
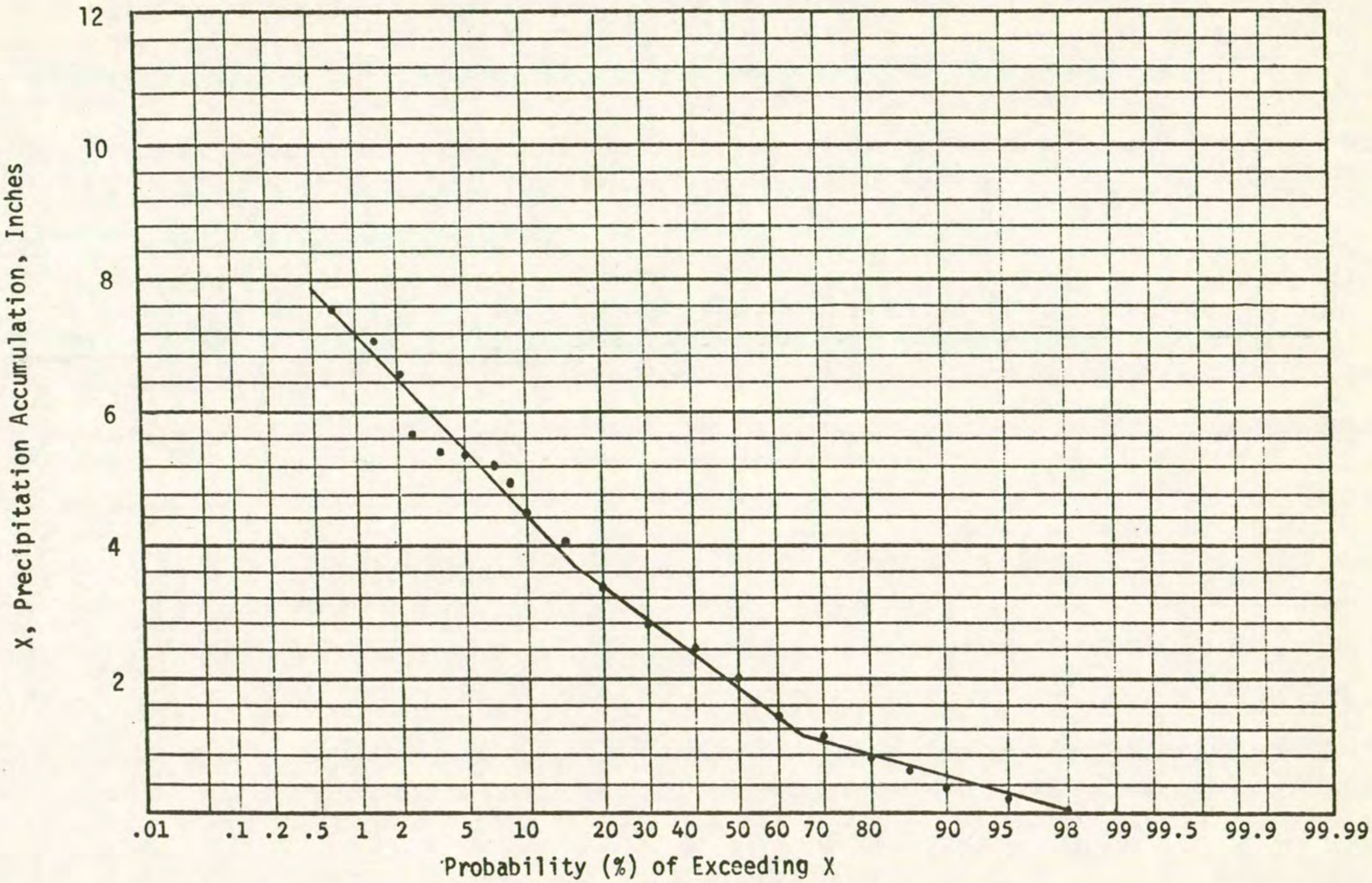


Fig. A-30. Probability of Exceeding Various Bimonthly Precipitation Accumulations (May).



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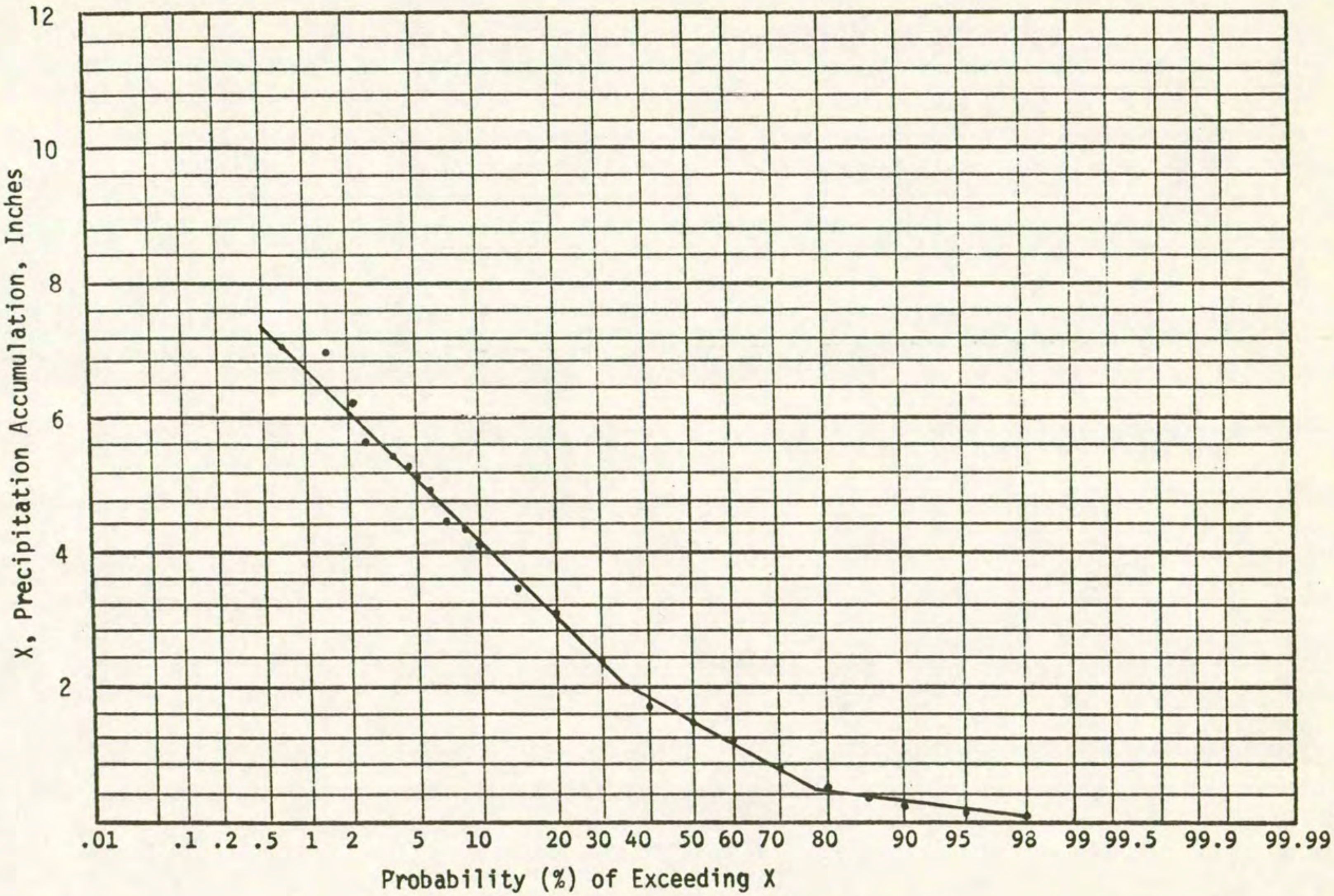

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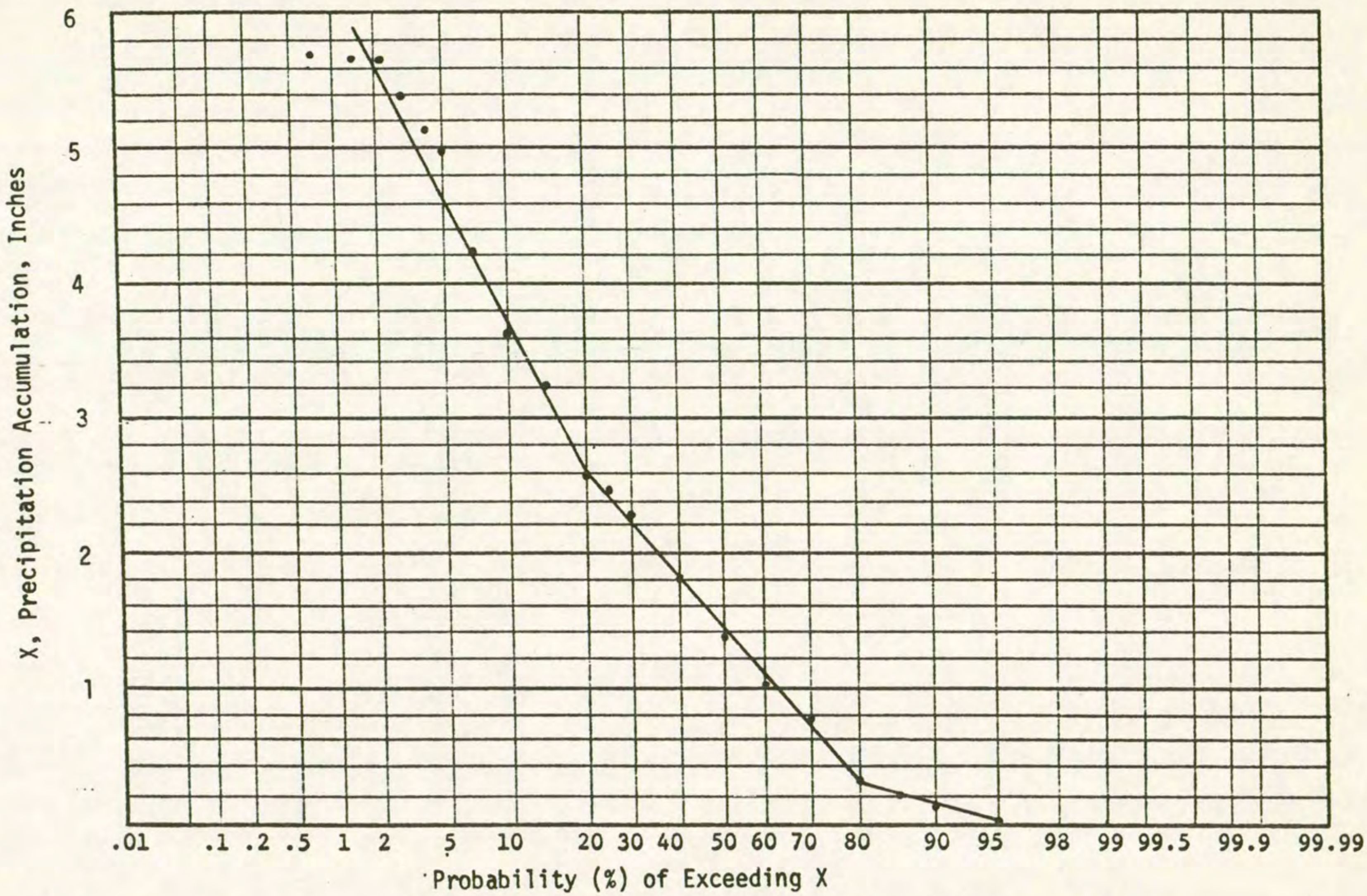

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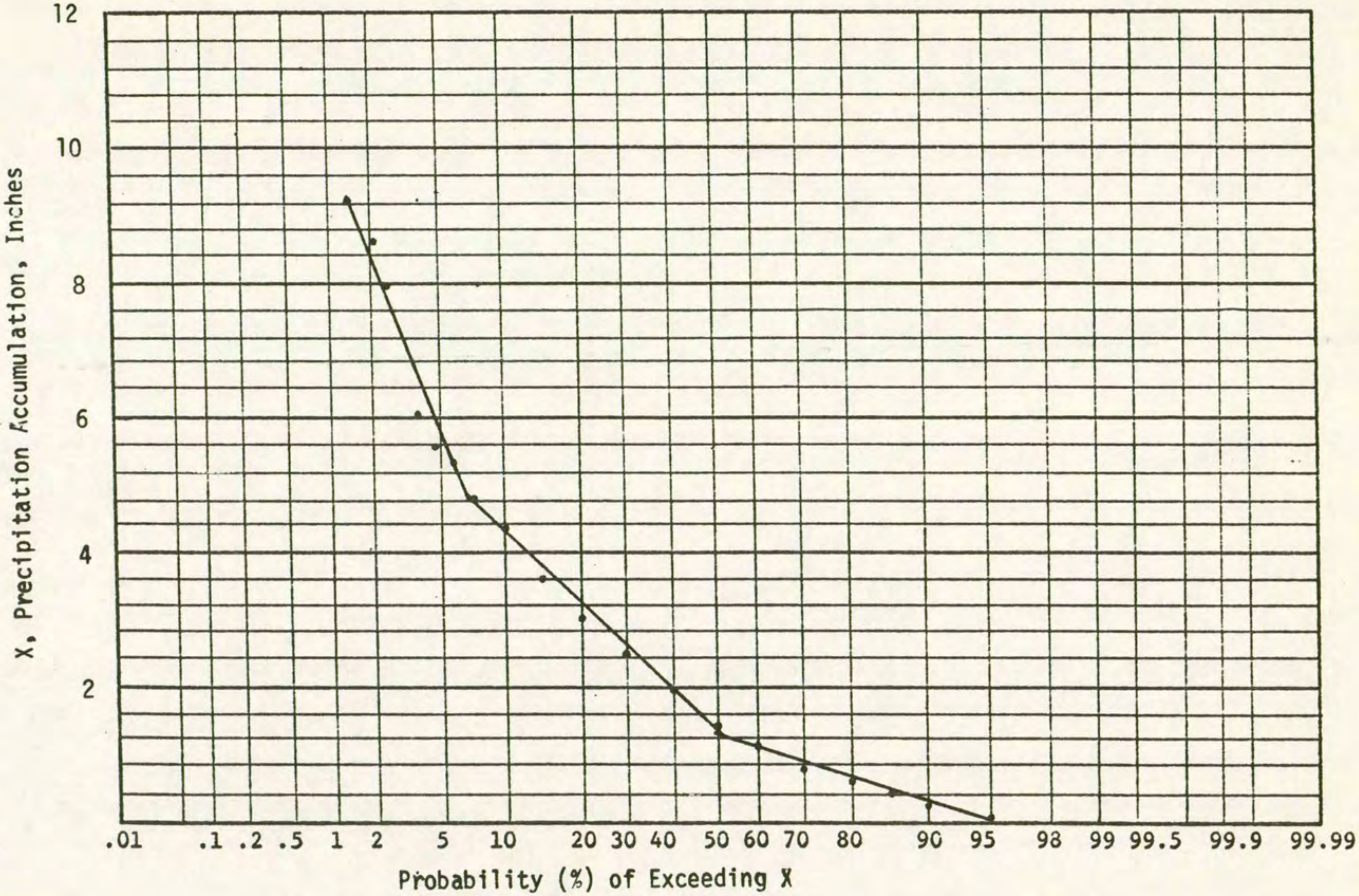

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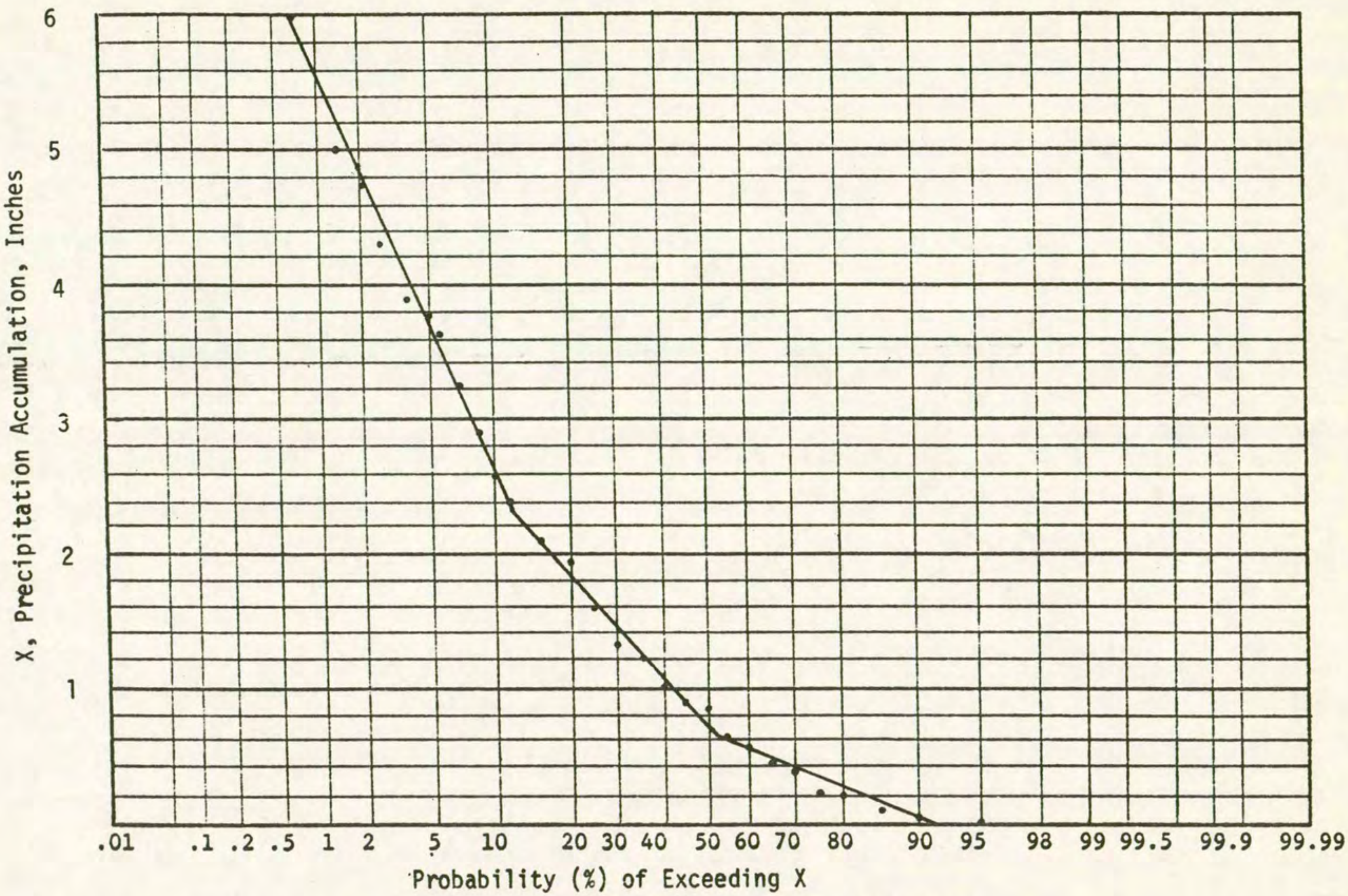

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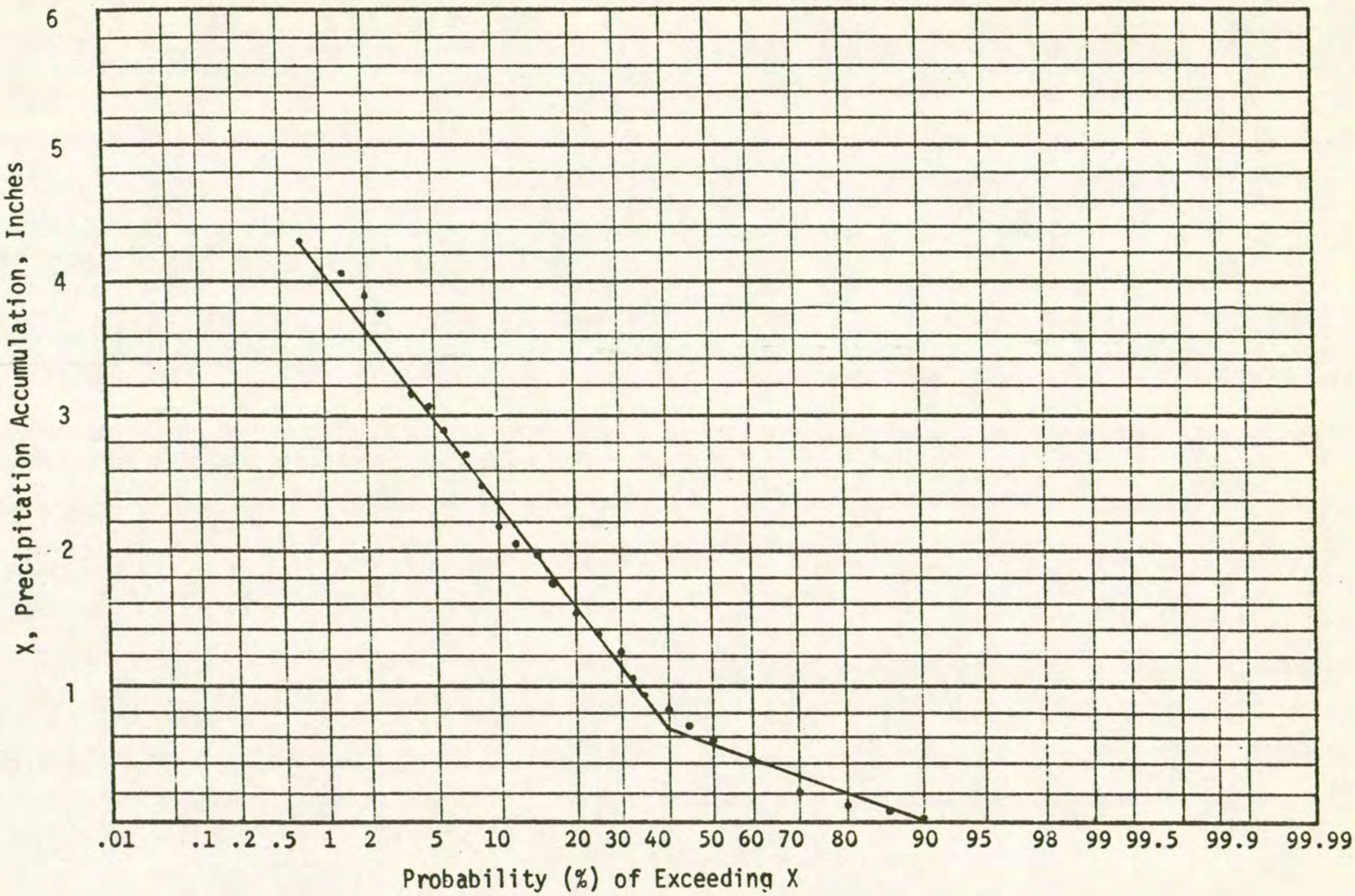

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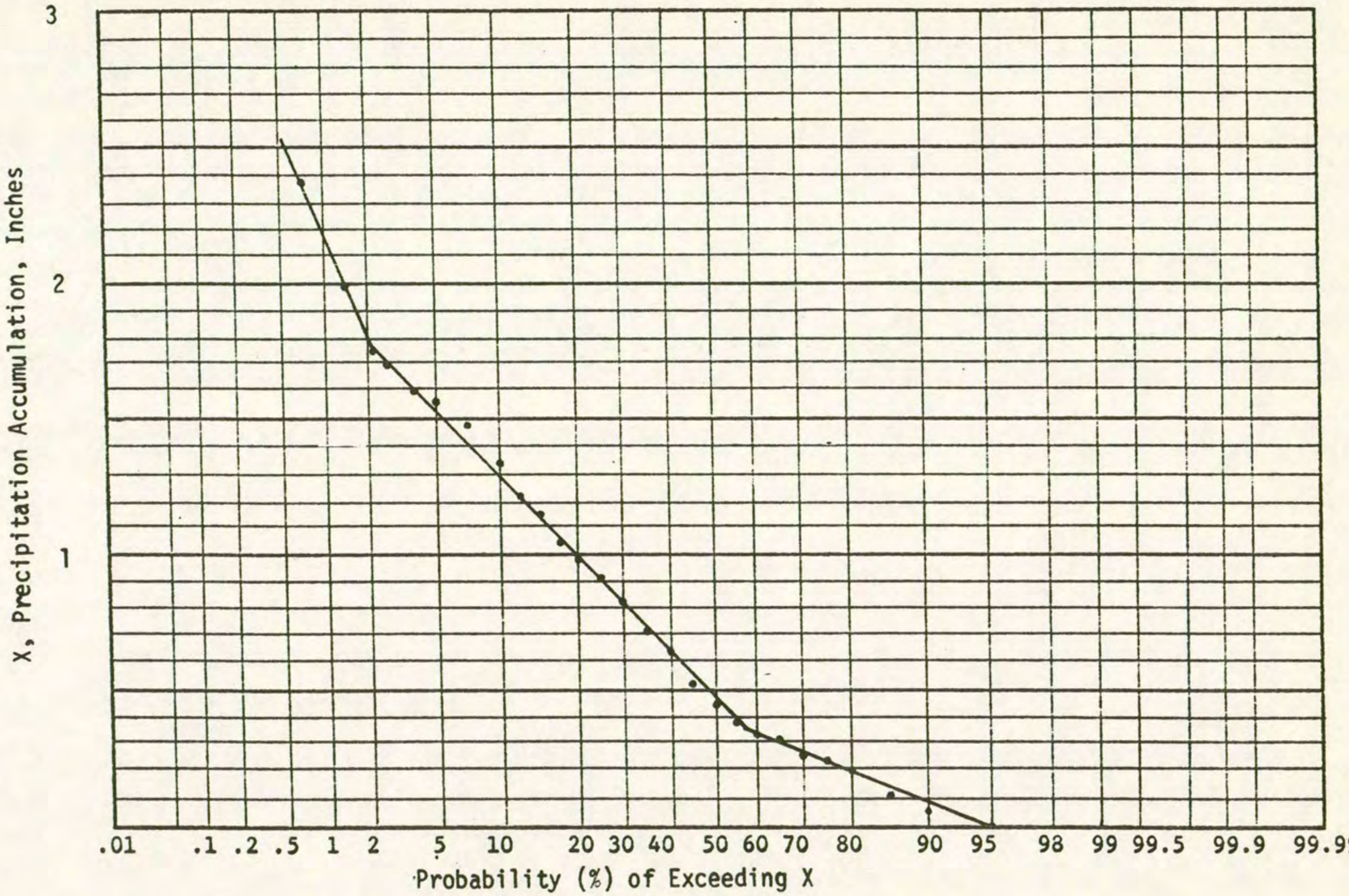

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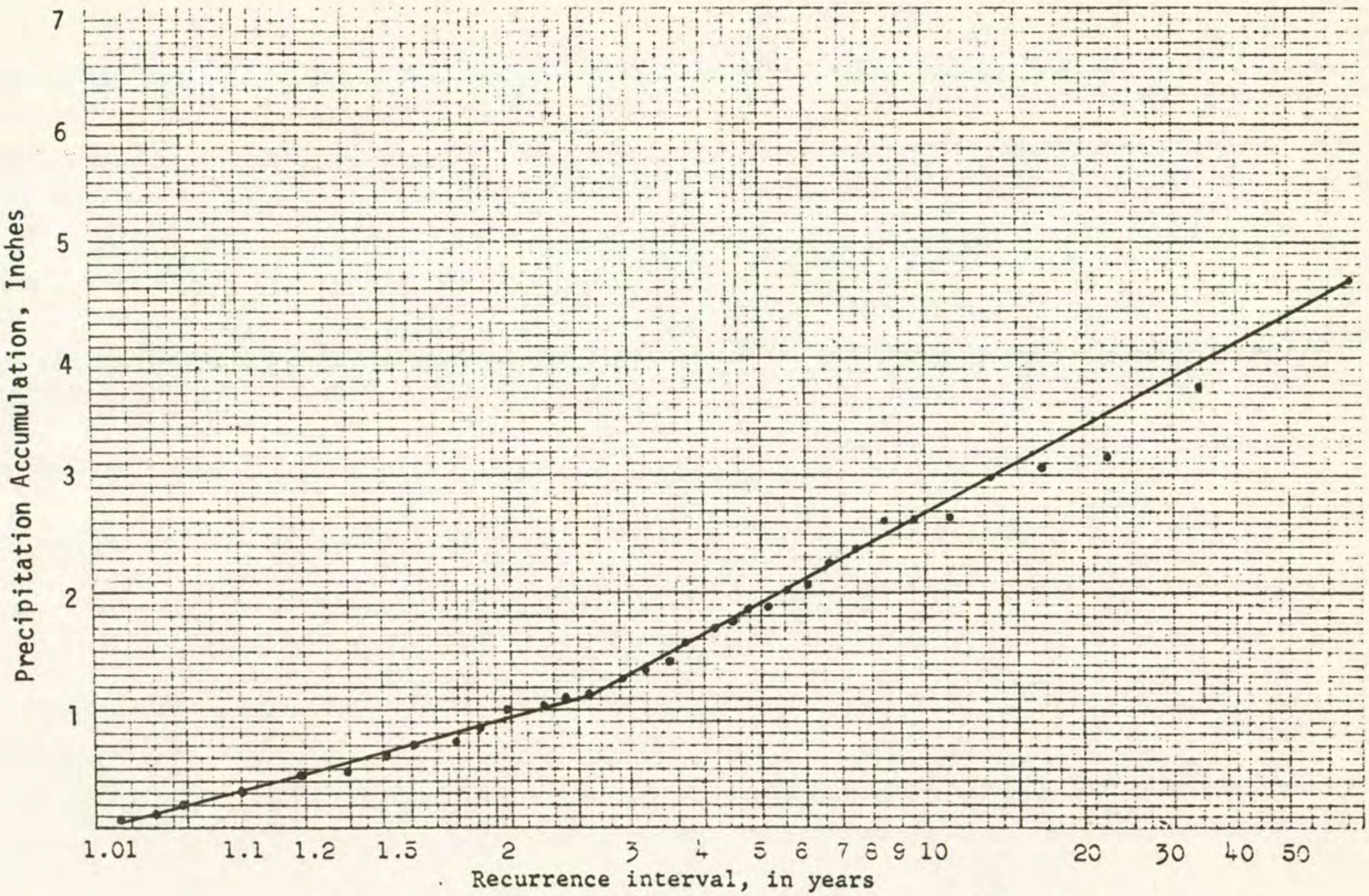


Fig. A-38. Recurrence Interval of Various Monthly Precipitation Accumulations (January).

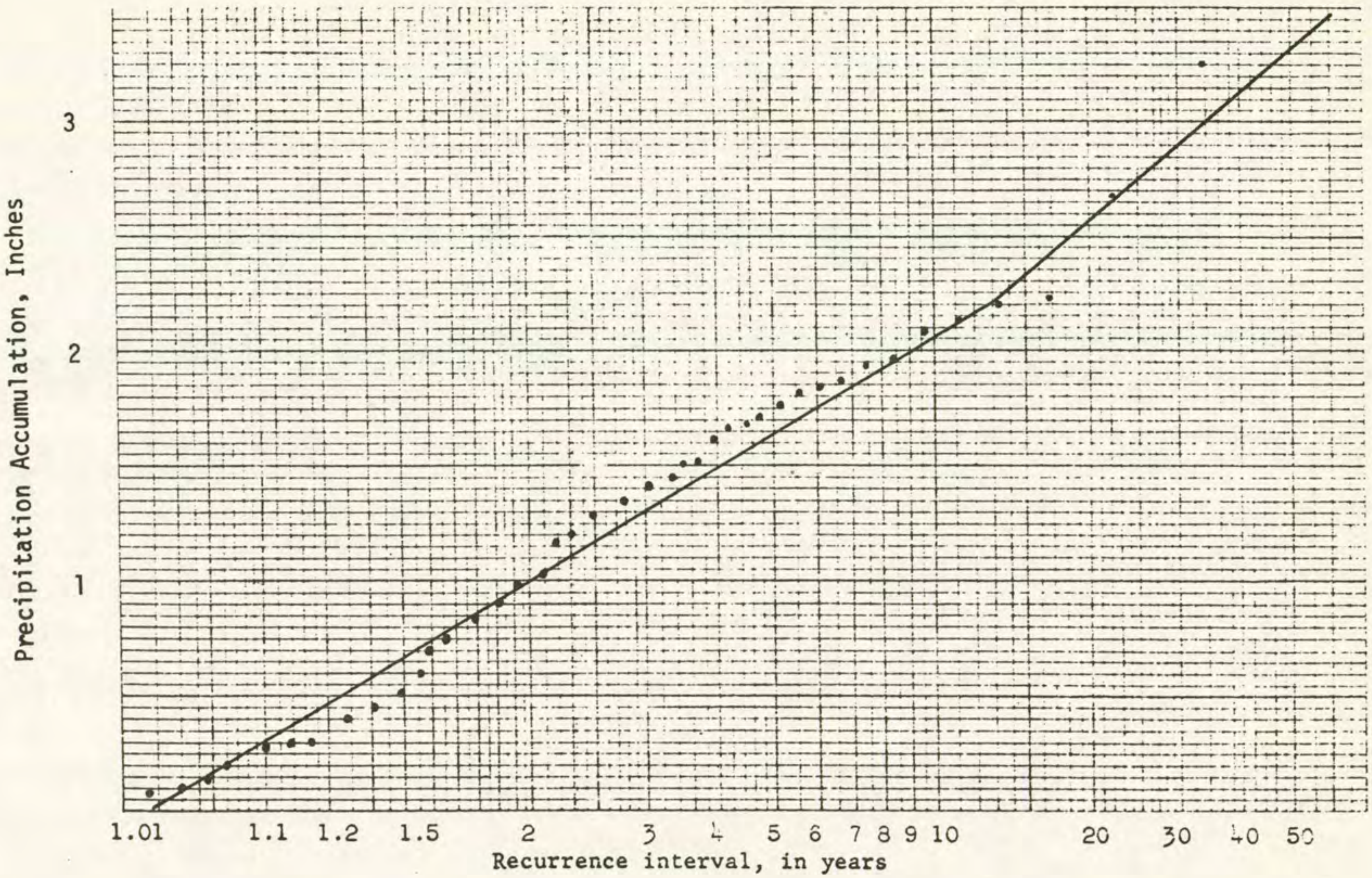


Fig. A-39. Recurrence Interval of Various Monthly Precipitation Accumulations (February)

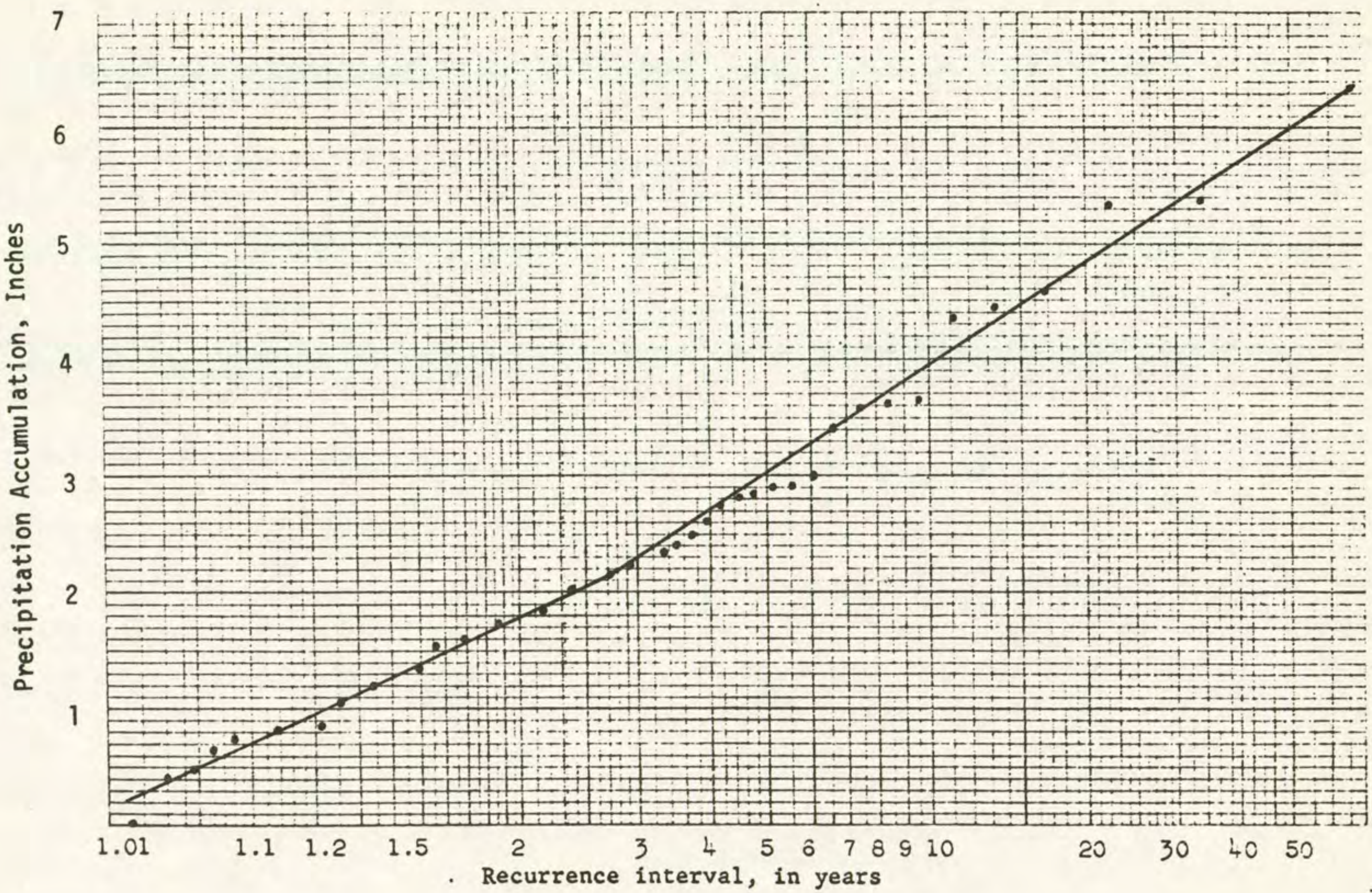


Fig. A-40. Recurrence Interval of Various Monthly Precipitation Accumulations (March).

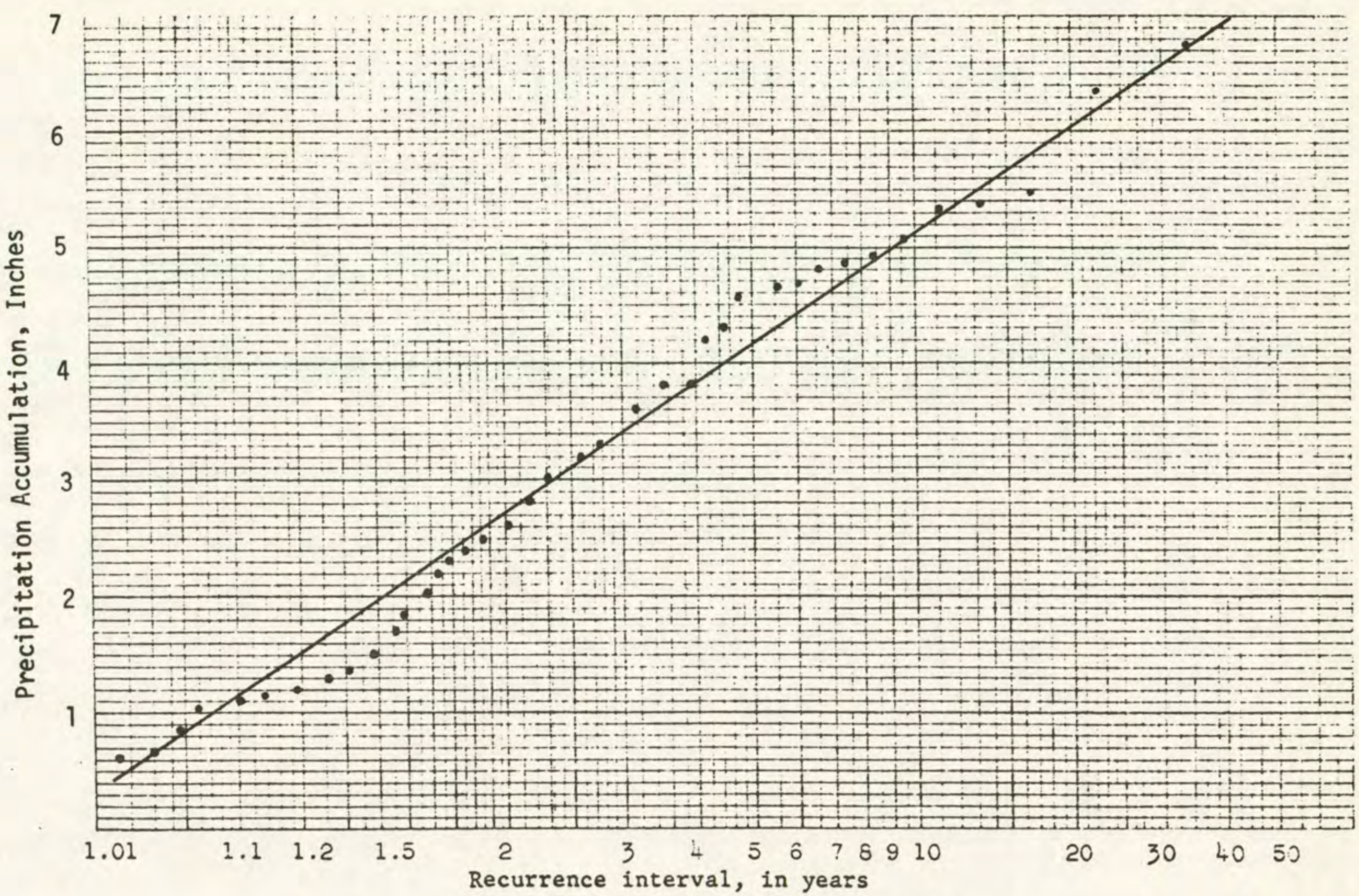


Fig. A-41. Recurrence Interval of Various Monthly Precipitation Accumulations (April).

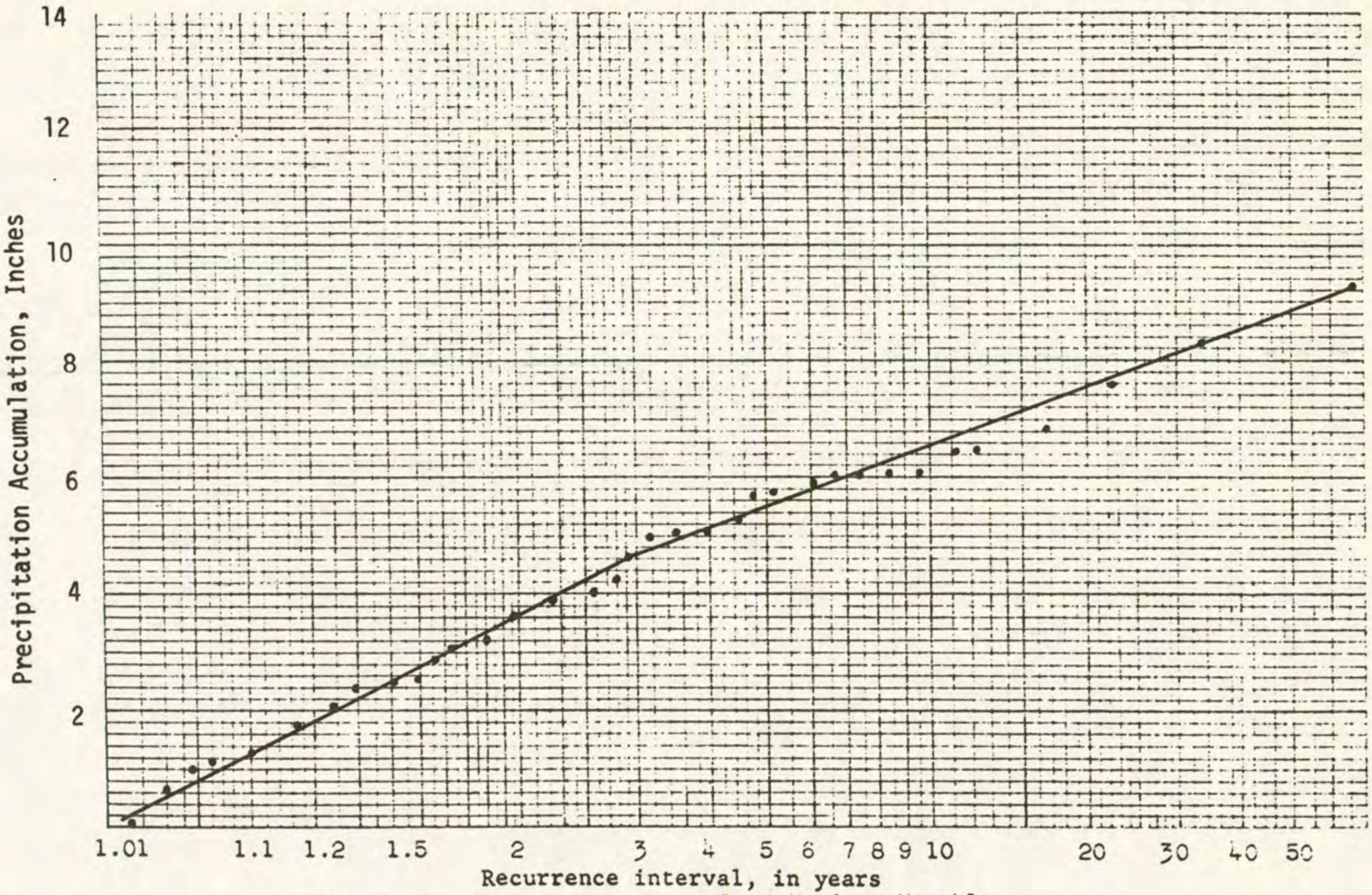


Fig. A-42. Recurrence Interval of Various Monthly Precipitation Accumulations (May).

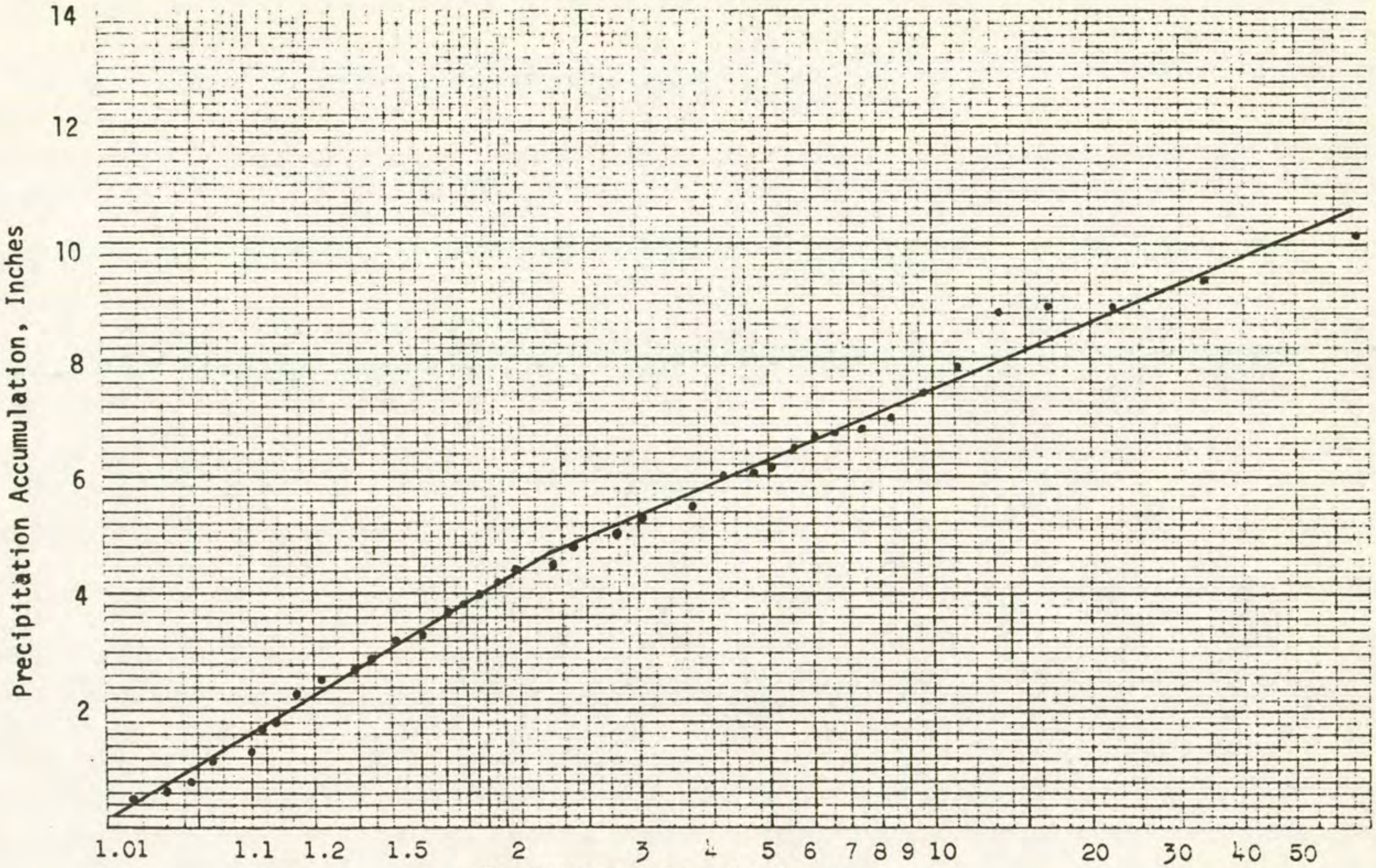


Fig. A-43. Recurrence Interval of Various Monthly Precipitation Accumulations (June)

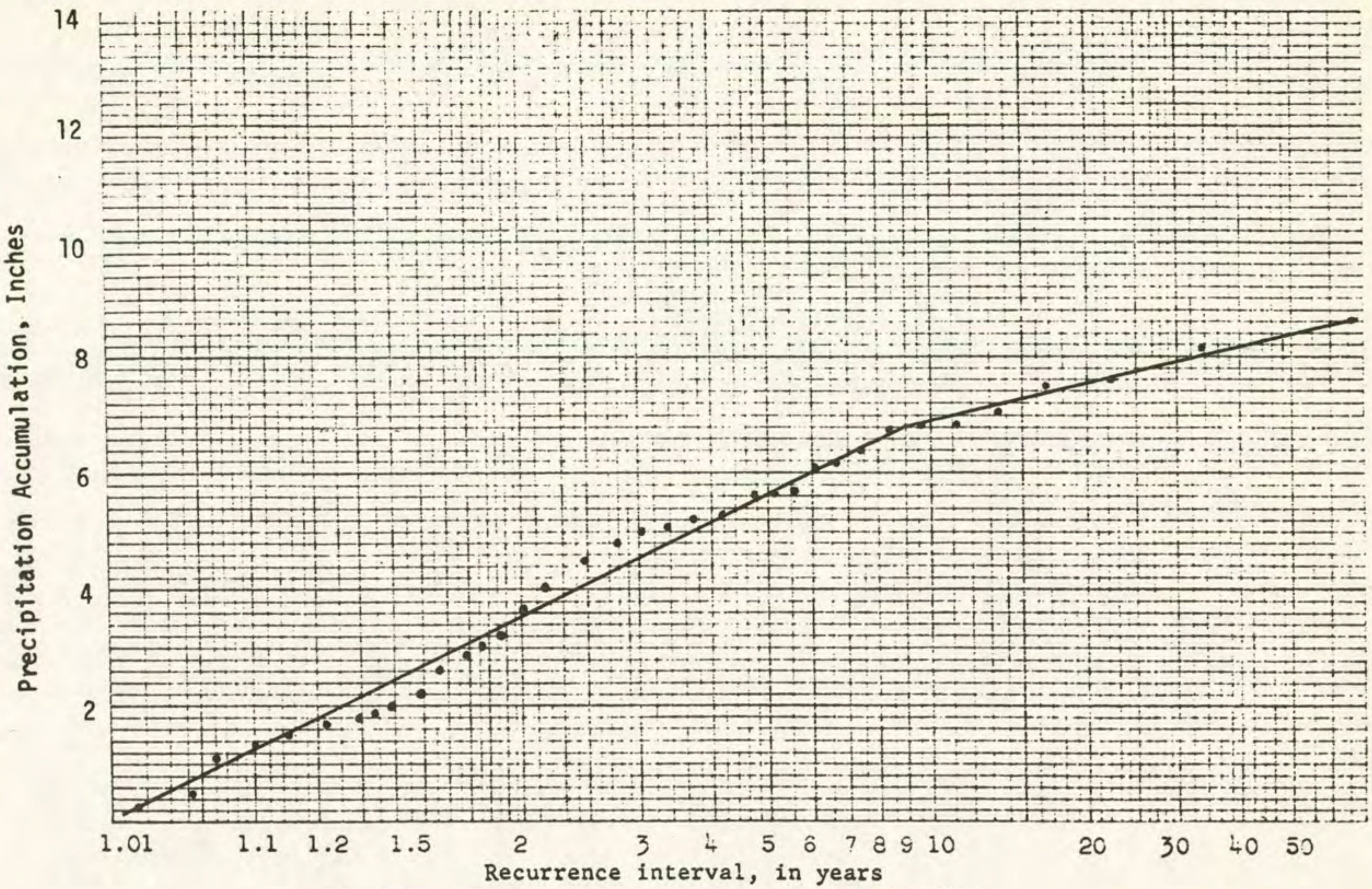


Fig. A-44. Recurrence Interval of Various Monthly Precipitation Accumulations (July)

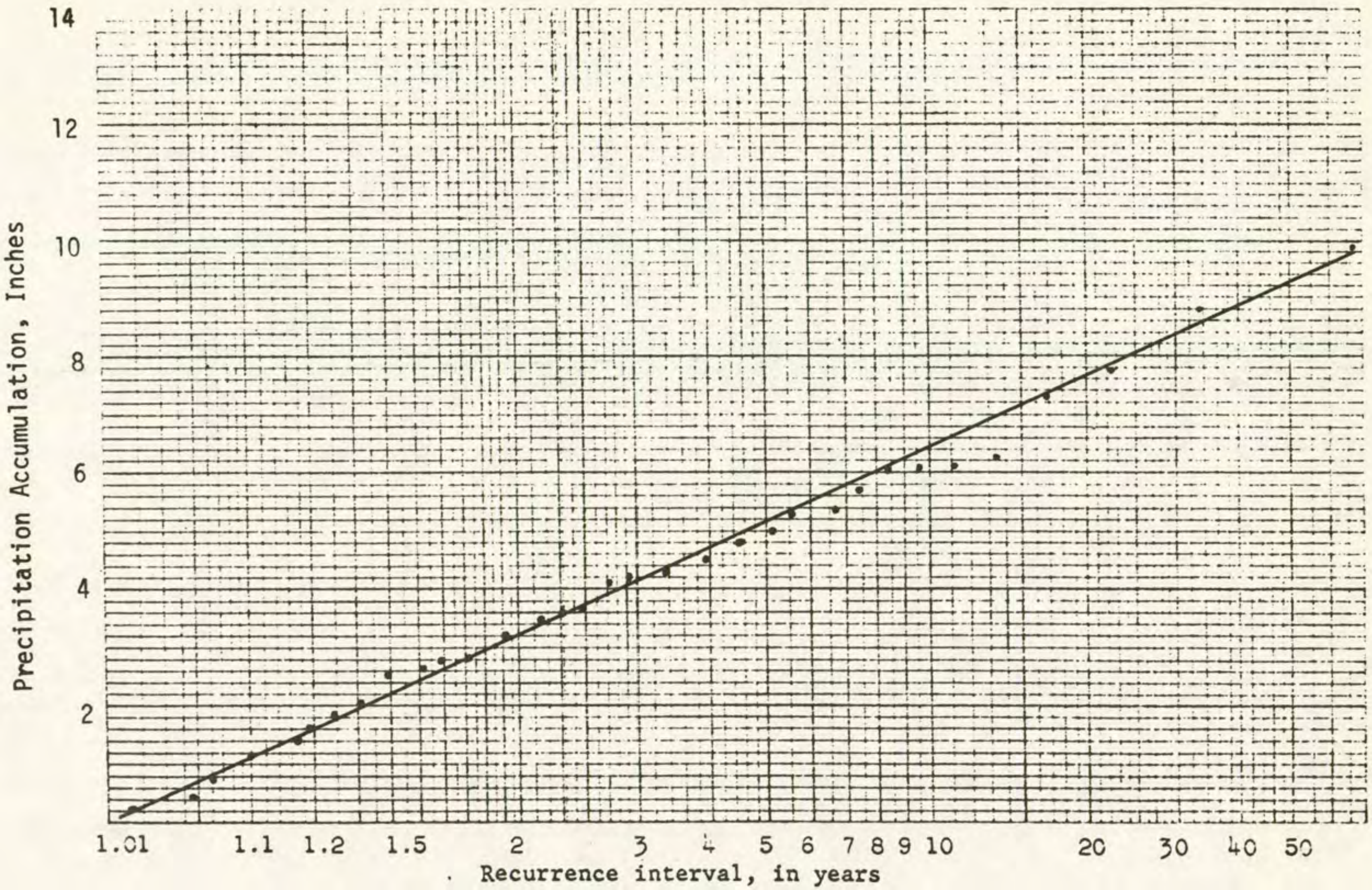


Fig. A-45. Recurrence Interval of Various Monthly Precipitation Accumulations (August).

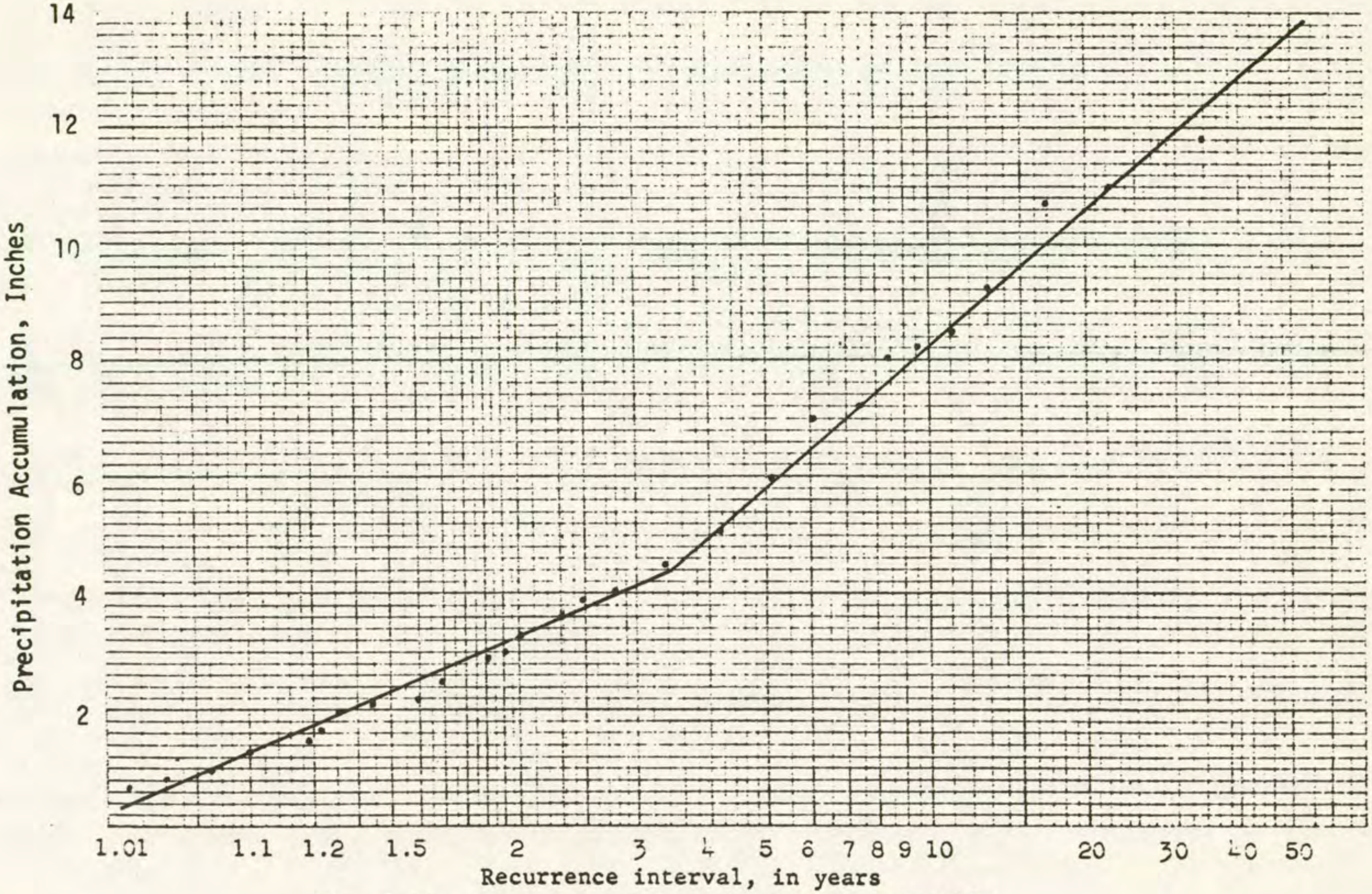


Fig. A-46. Recurrence Interval of Various Monthly Precipitation Accumulations (September).

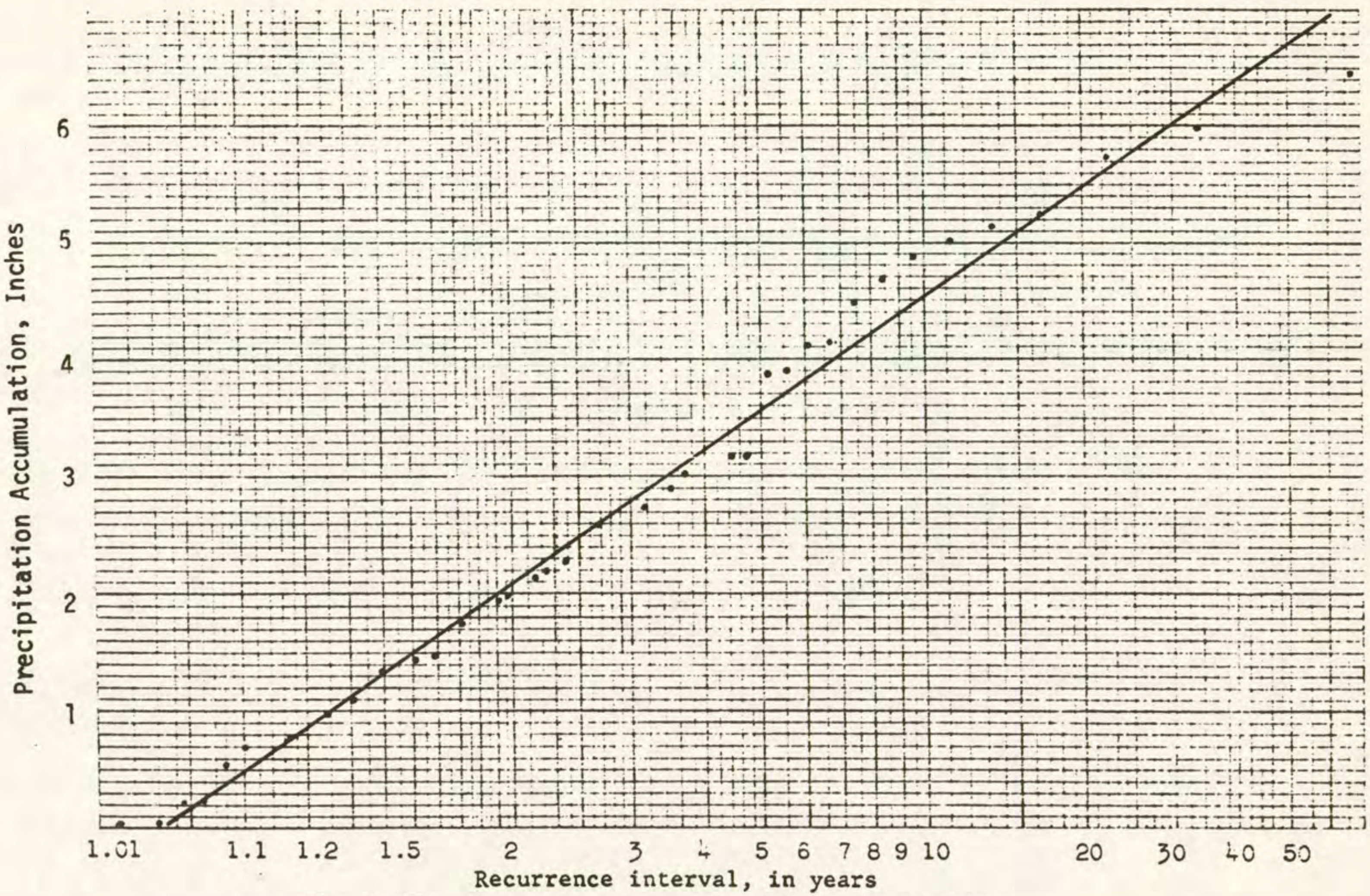


Fig. A-47. Recurrence Interval of Various Monthly Precipitation Accumulations (October).

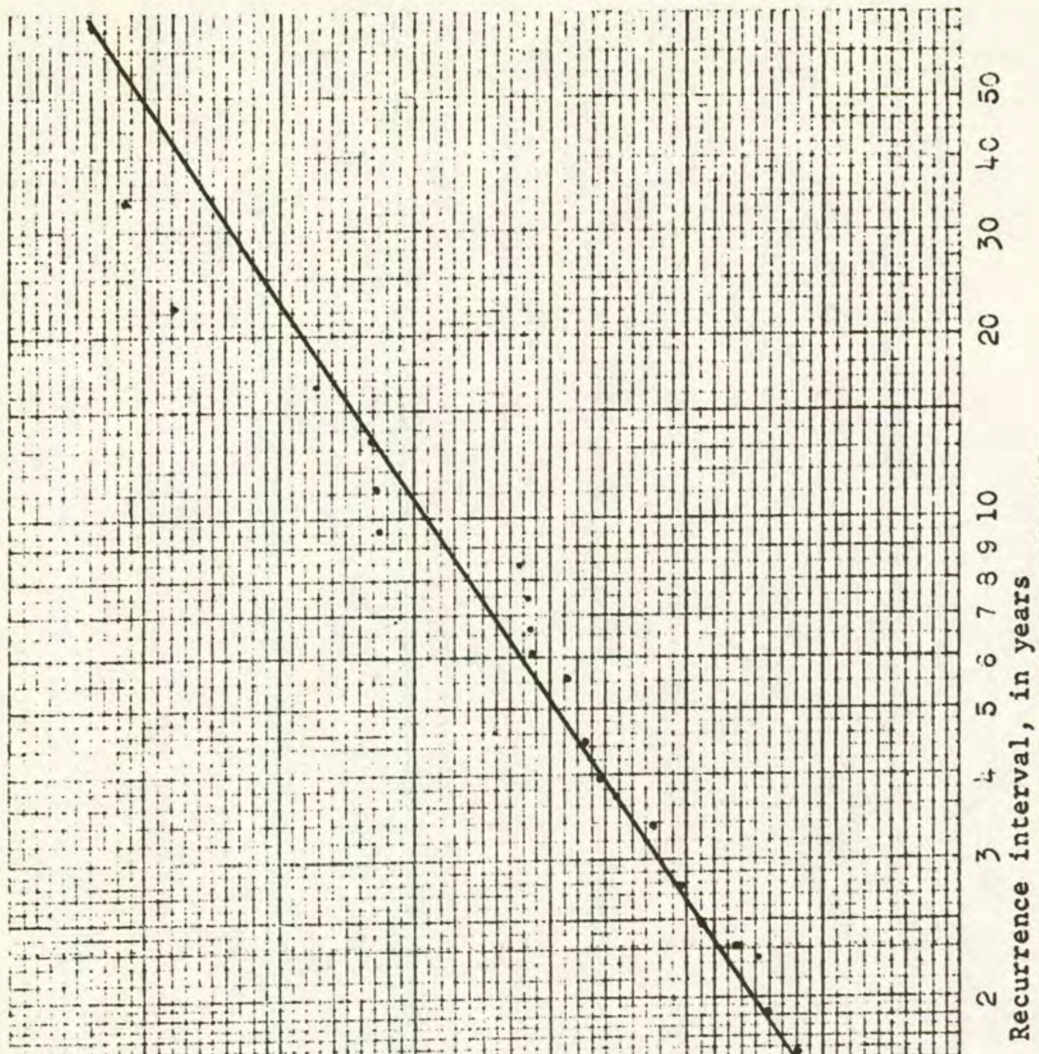


Fig. A-48. Recurrence Interval of Various Monthly Precipitation Accumulations (November).

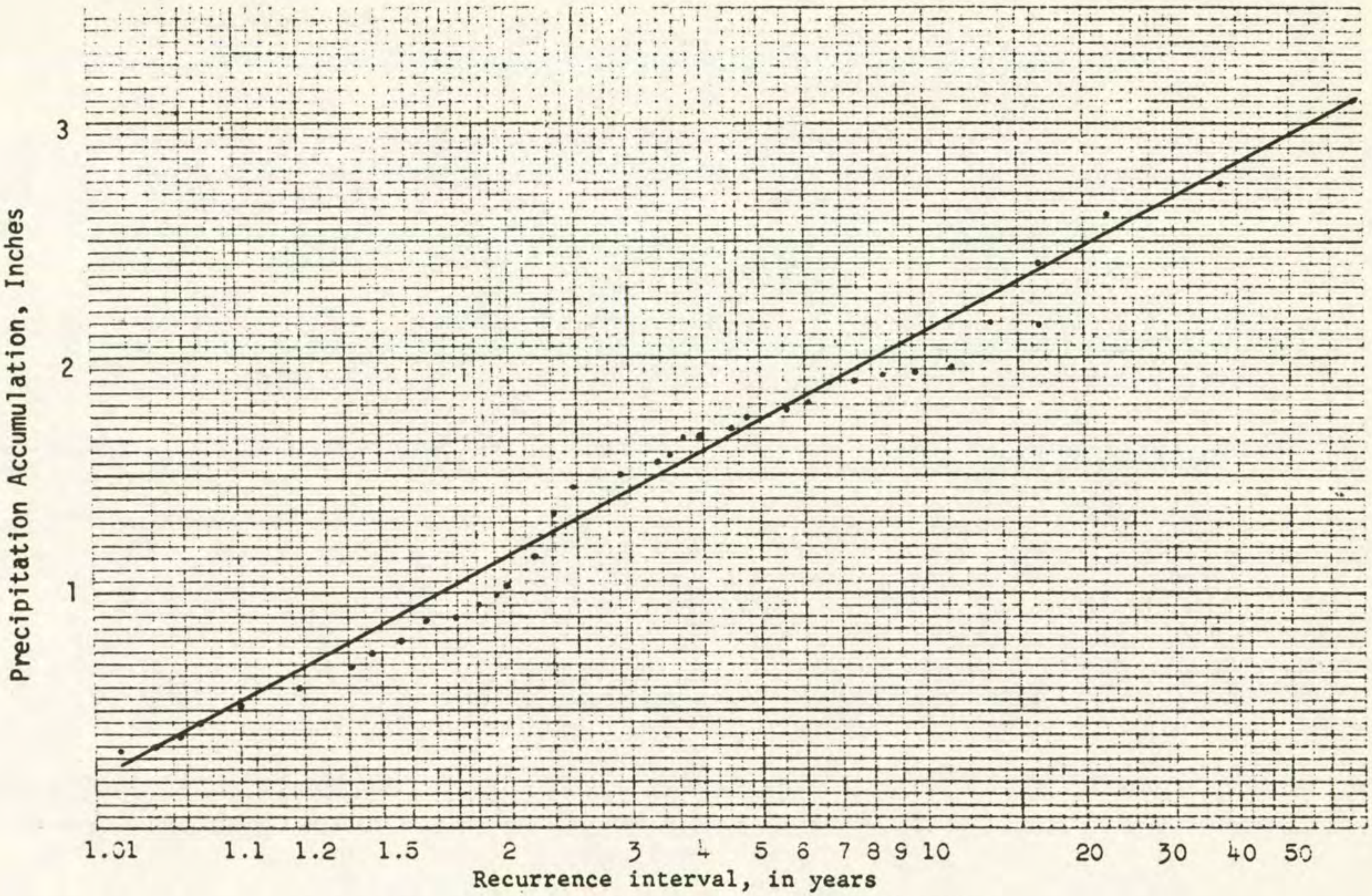


Fig. A-49. Recurrence Interval of Various Monthly Precipitation Accumulations (December).

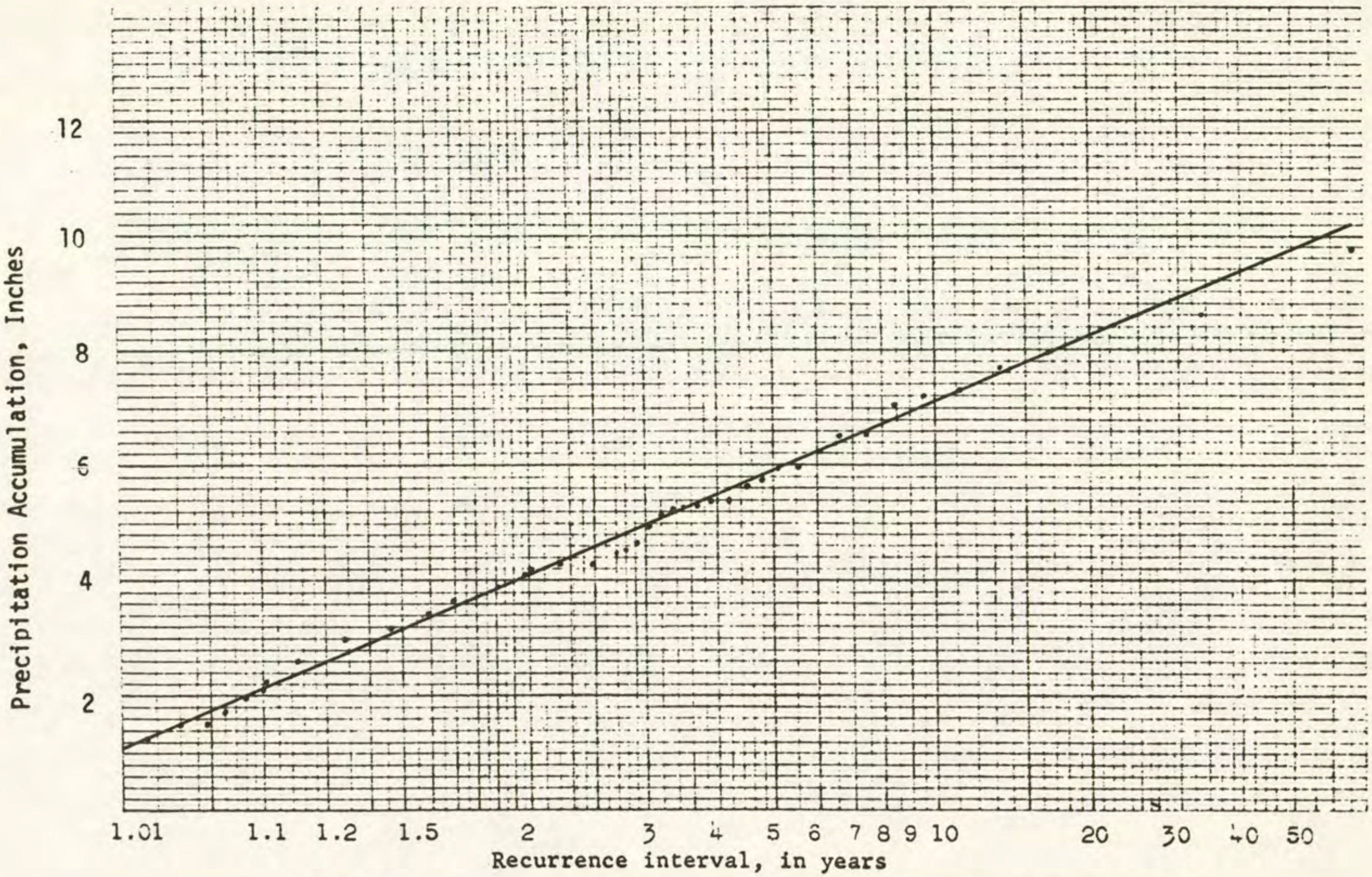


Fig. A-50. Recurrence Interval of Various Quarterly Precipitation Accumulations (January, February, March).

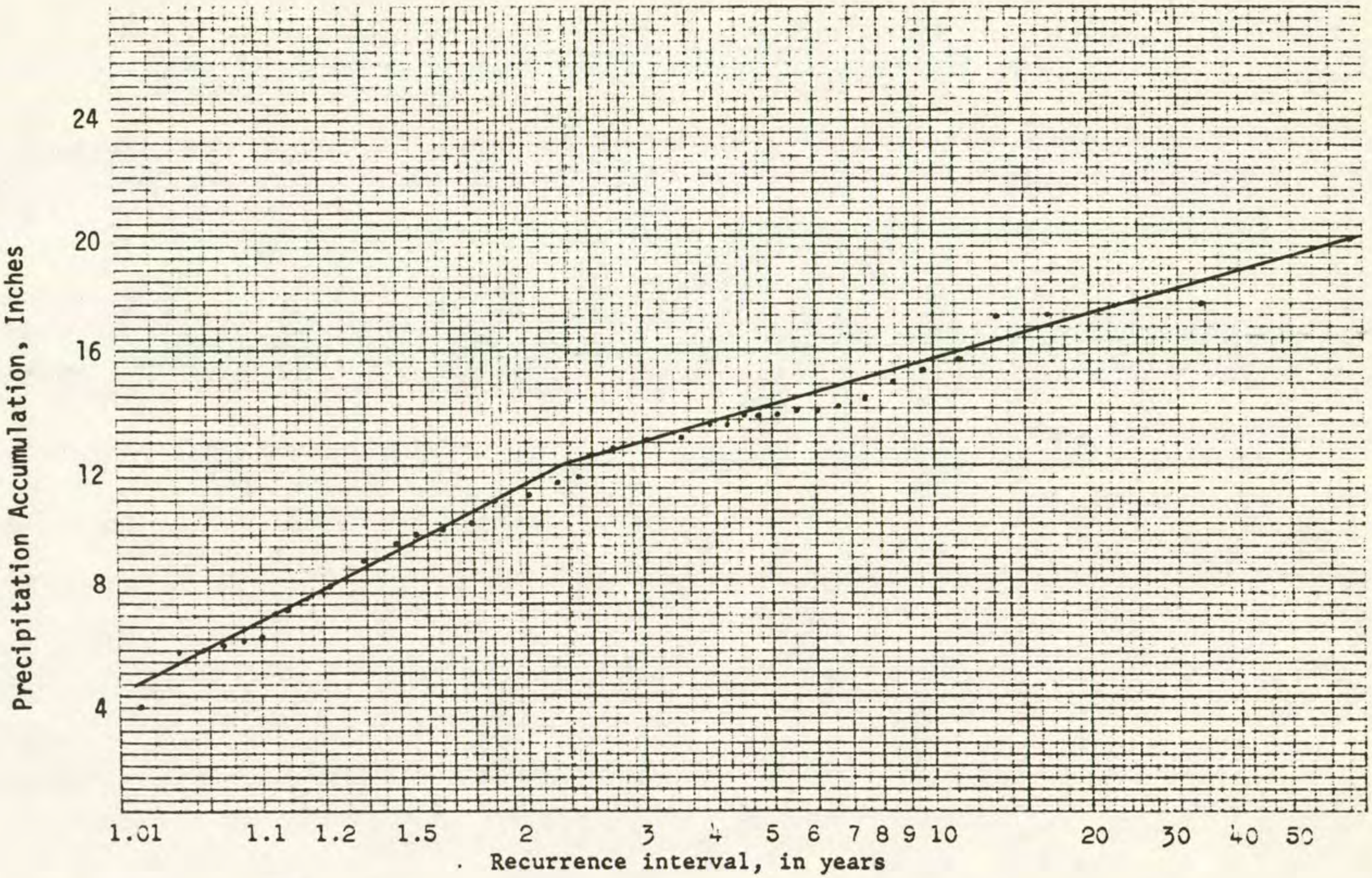


Fig. A-51. Recurrence Interval of Various Quarterly Precipitation Accumulations (April, May, June).

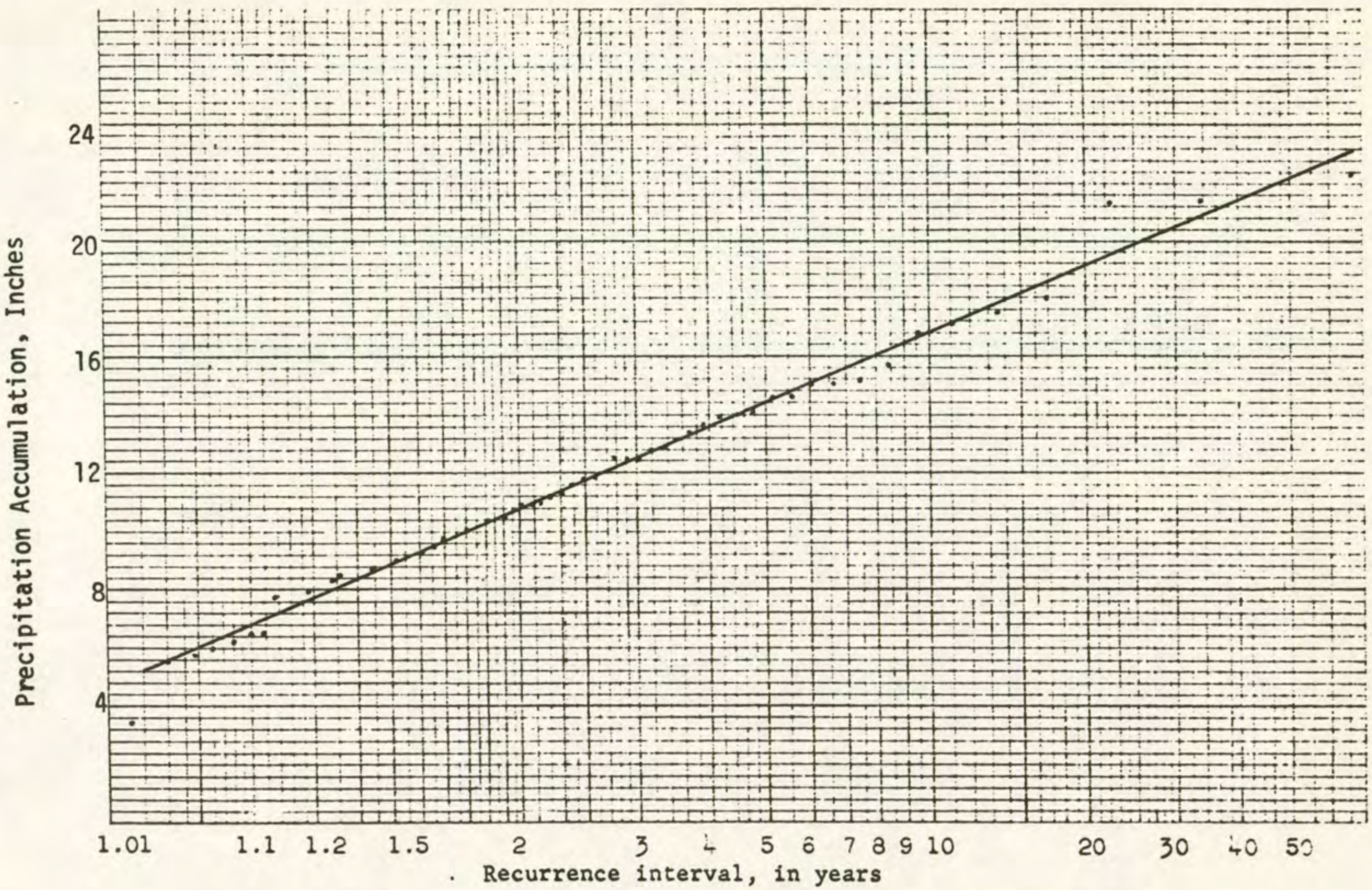


Fig. A-52. Recurrence Interval of Various Quarterly Precipitation Accumulations (July, August, September).

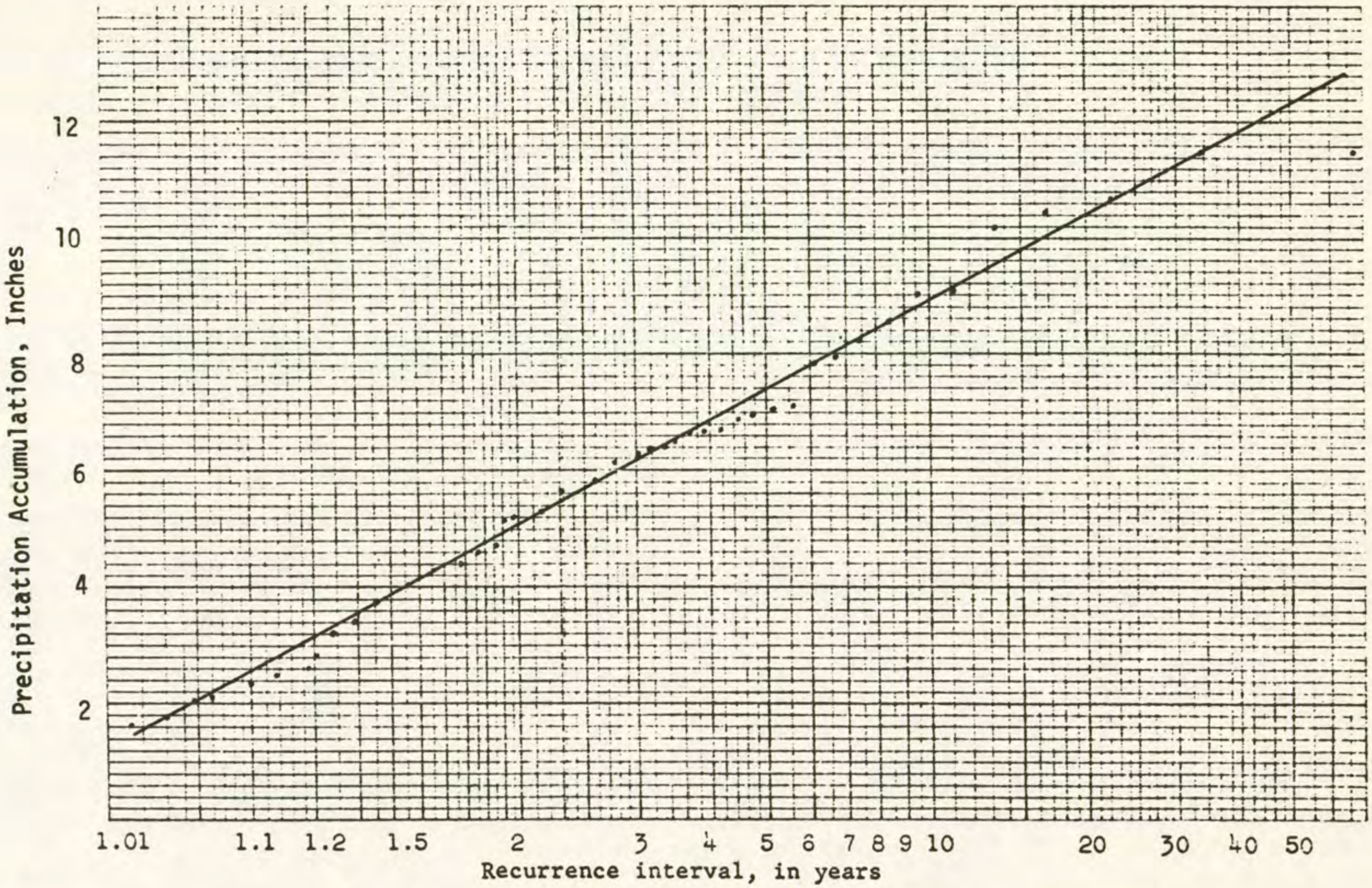
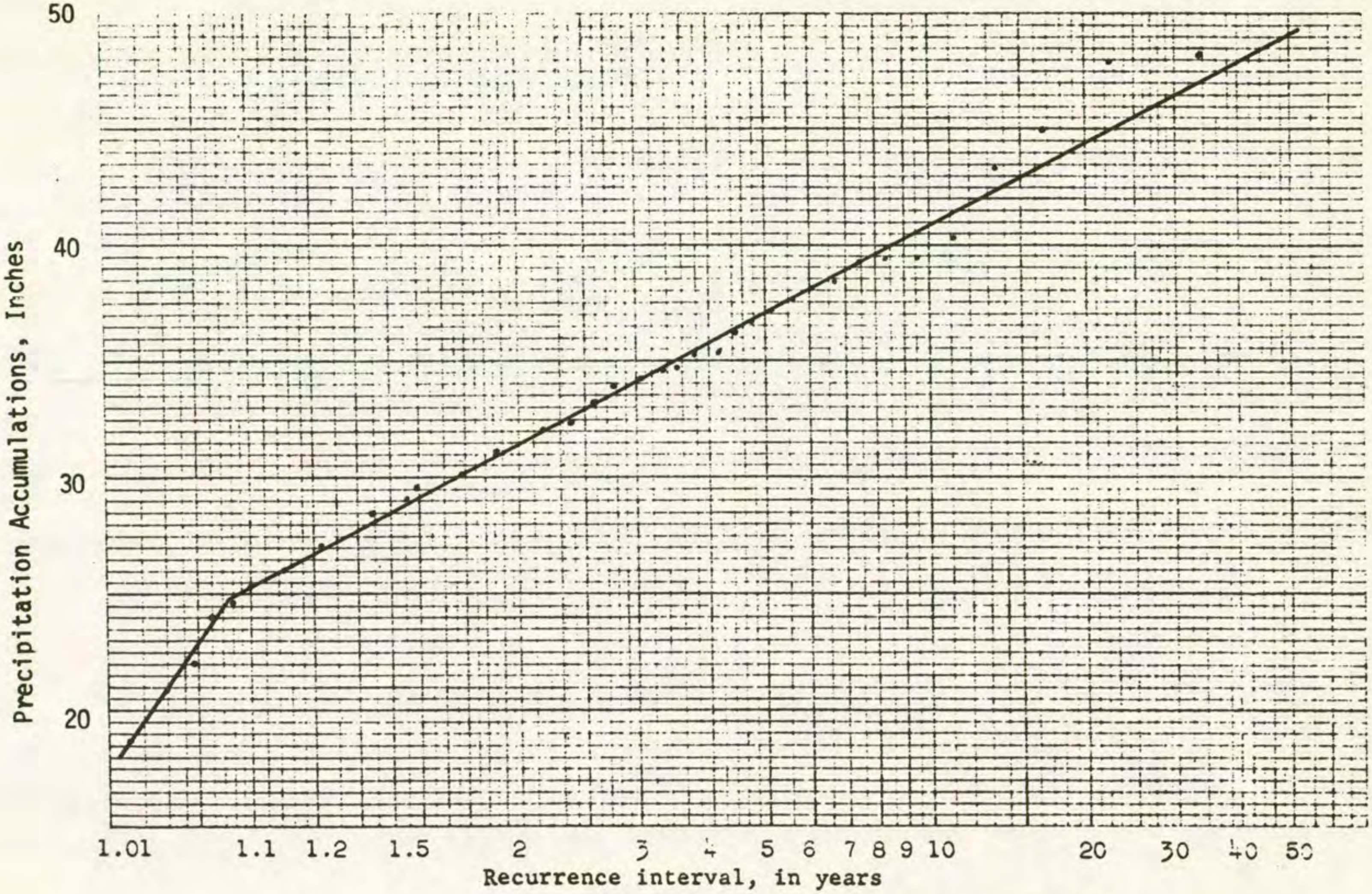


Fig. A-53. Recurrence Interval of Various Quarterly Precipitation Accumulations (October, November, December).



Fia. A-54. Recurrence Interval of Various Annual Precipitation Accumulations.

APPENDIX B

STREAM FLOW DATA
FOR THE IOWA RIVER
AT MARSHALLTOWN, IOWA

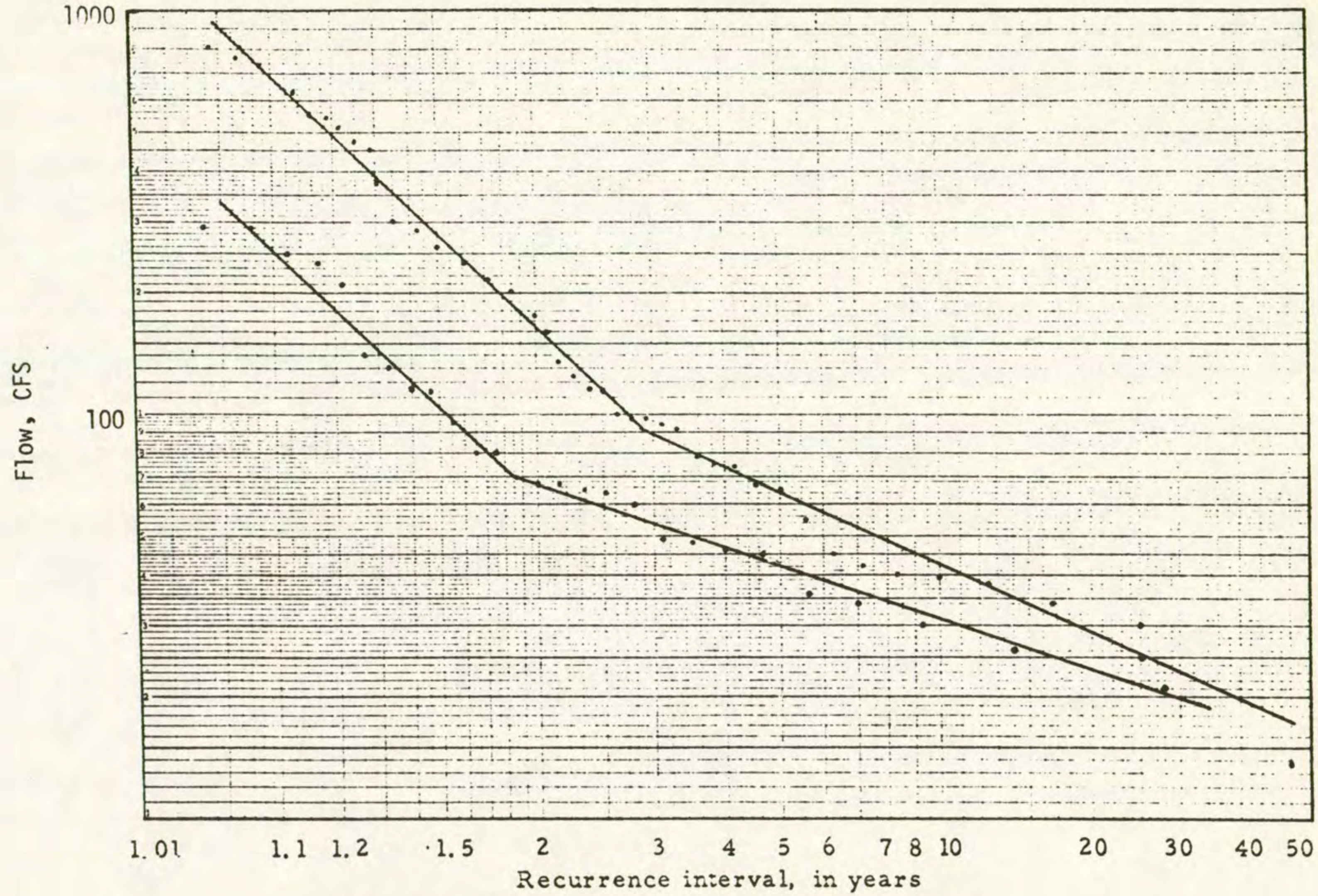


Fig. B-1. Recurrence Interval of Low and Average Daily Flow (January).

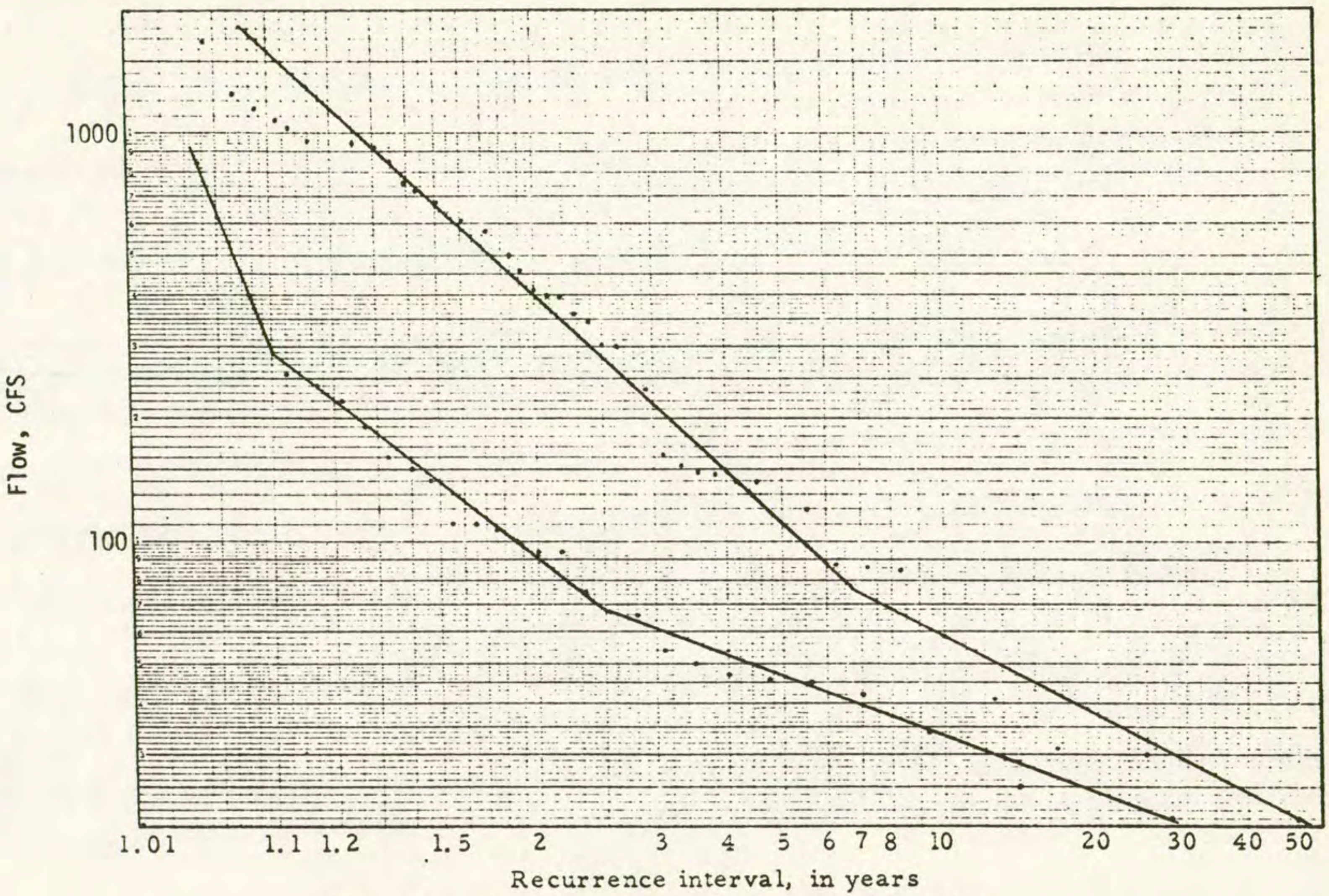


Fig. B-2. Recurrence Interval of Low and Average Daily Flow (February).

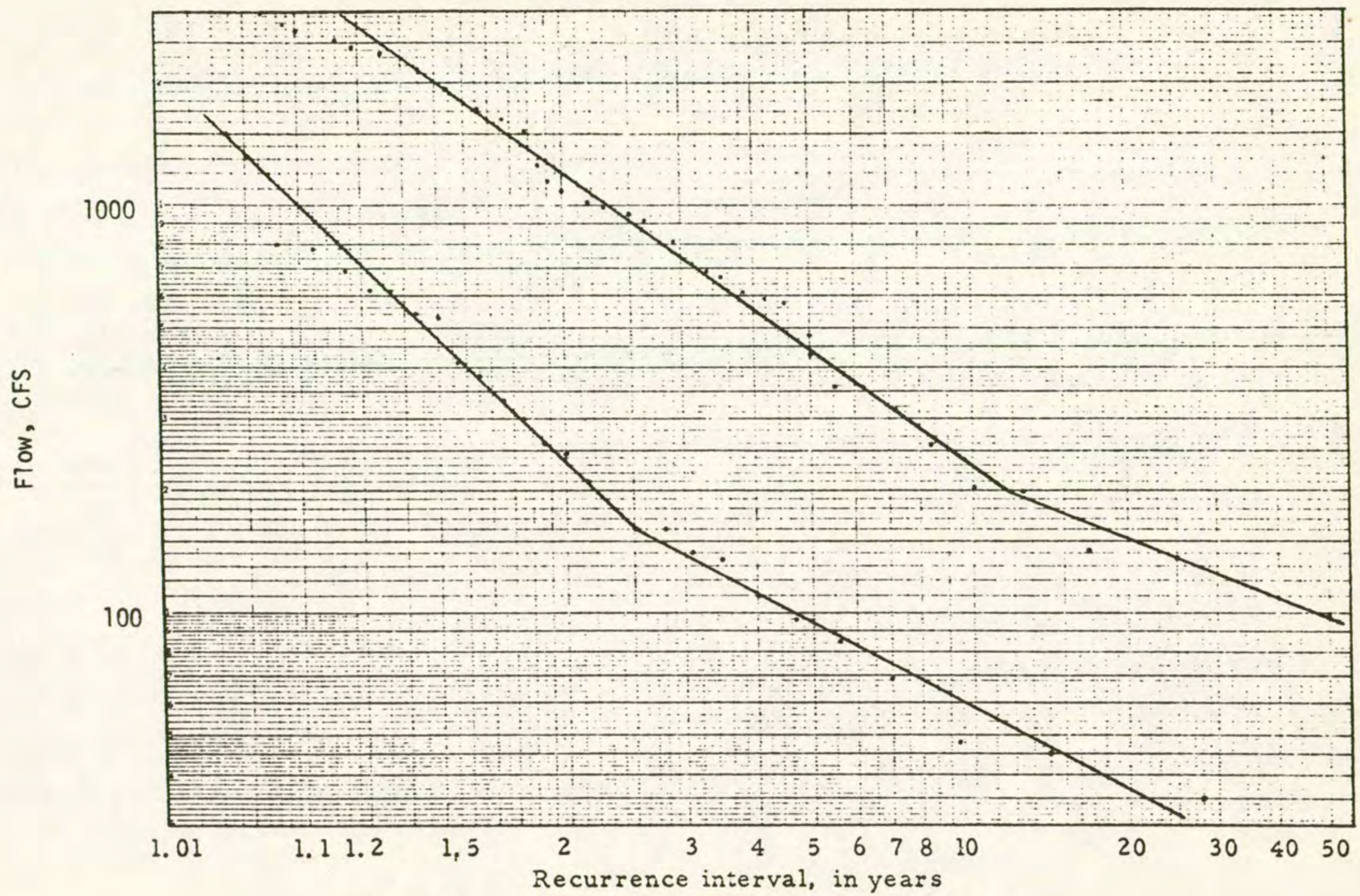


Fig. B-3. Recurrence Interval of Low and Average Daily Flow (March).

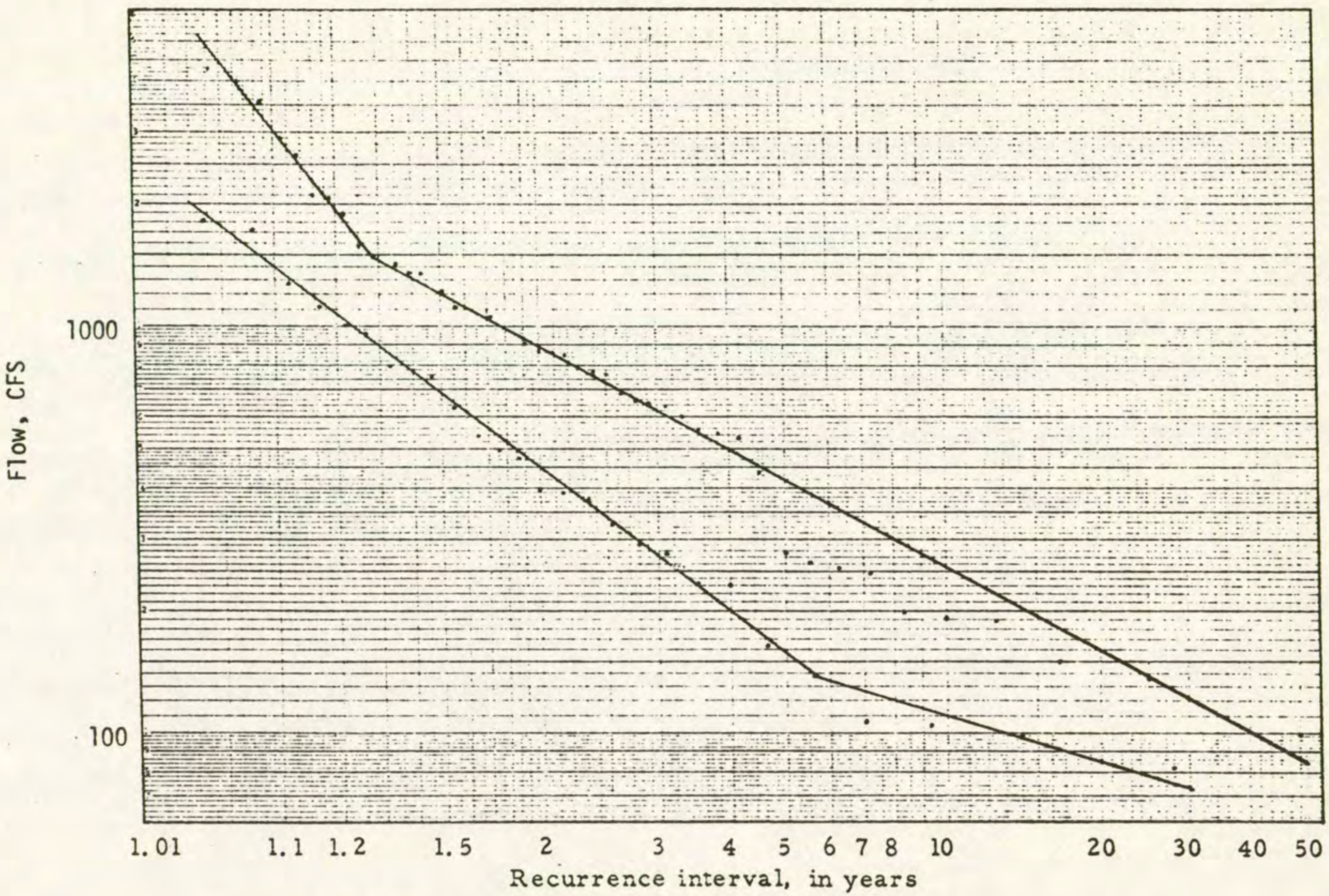


Fig. B-4. Recurrence Interval of Low and Average Daily Flow (April).

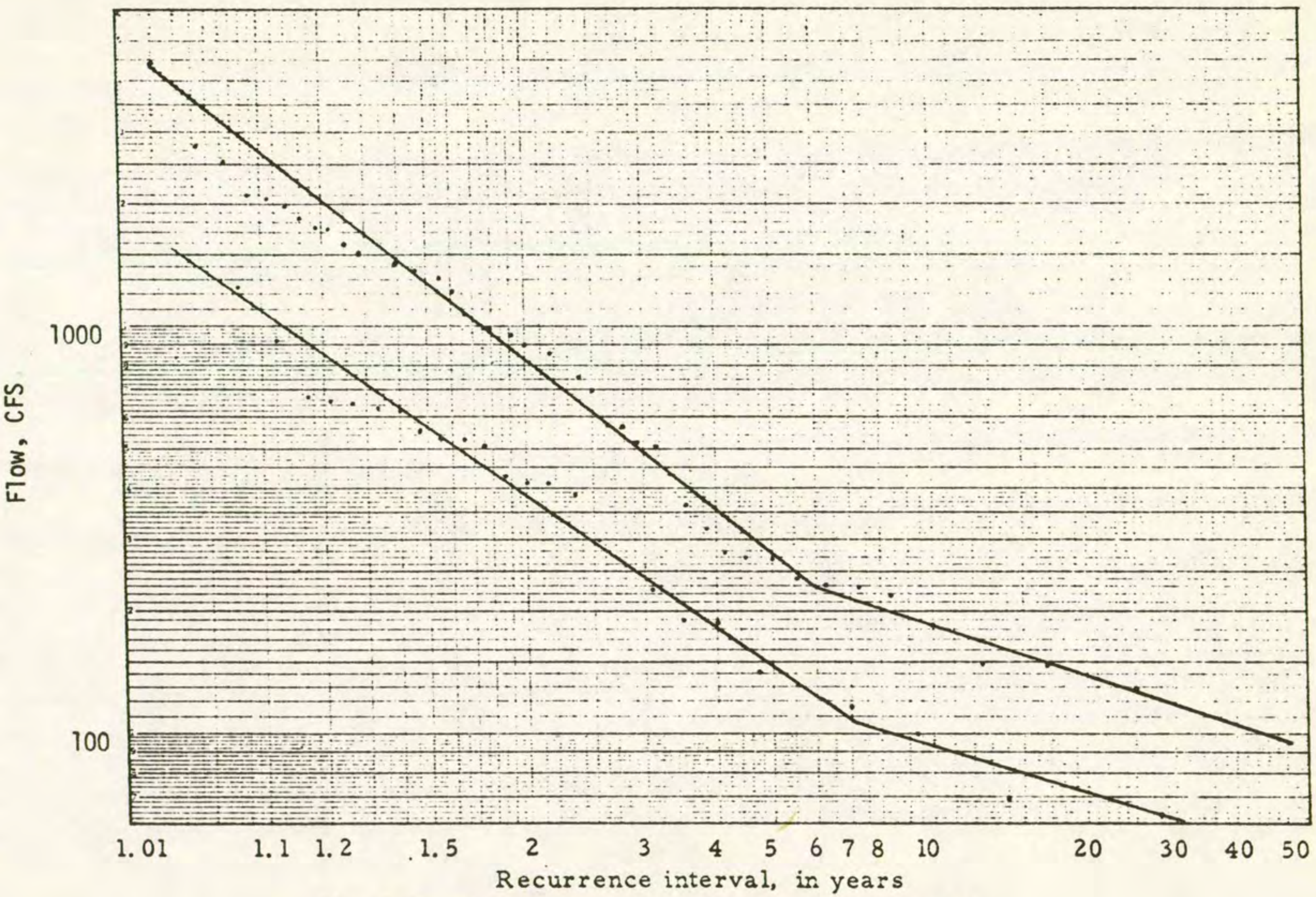


Fig. B-5. Recurrence Interval of Low and Average Daily Flow (May).

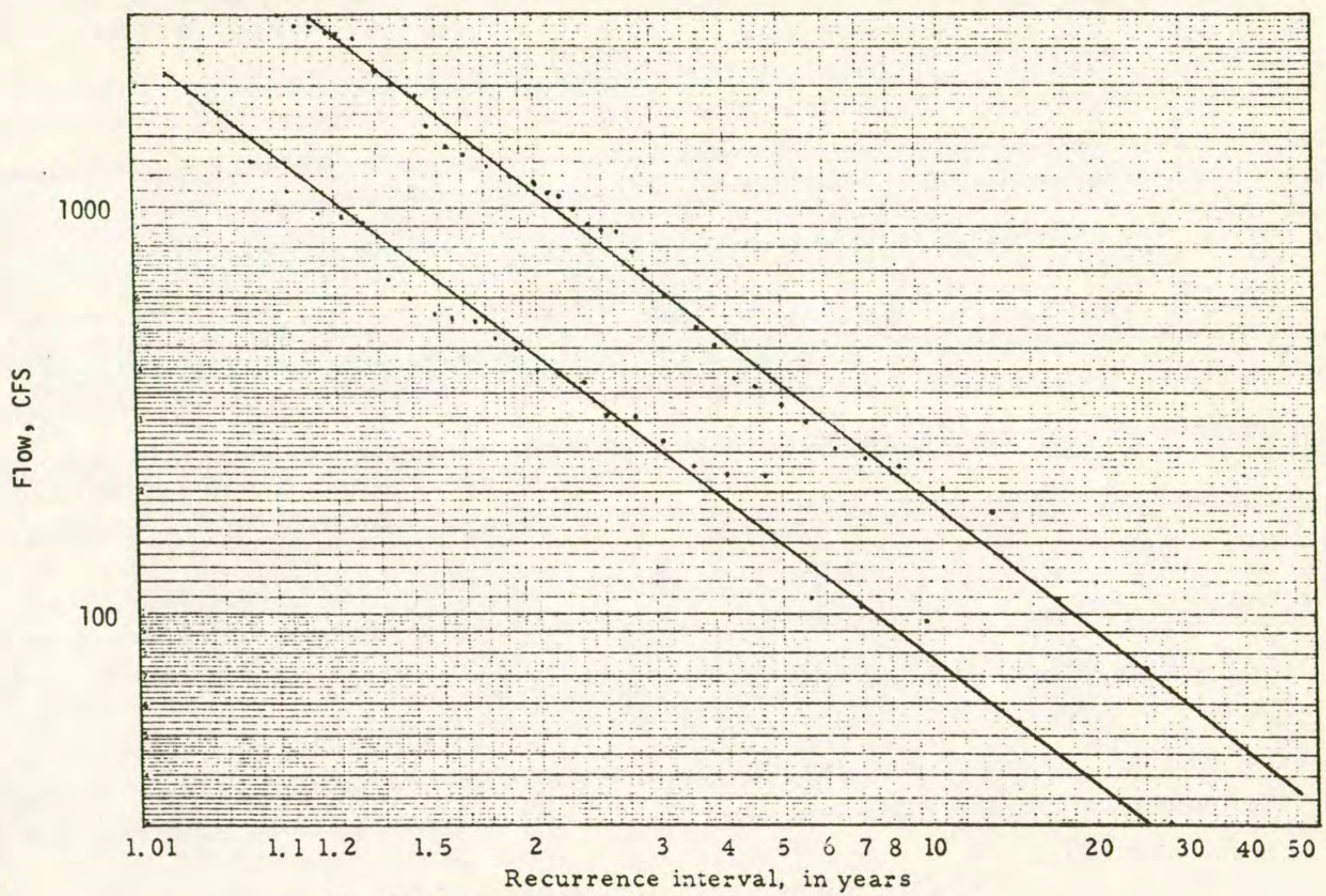


Fig. B-6. Recurrence Interval of Low and Average Daily Flow (June).

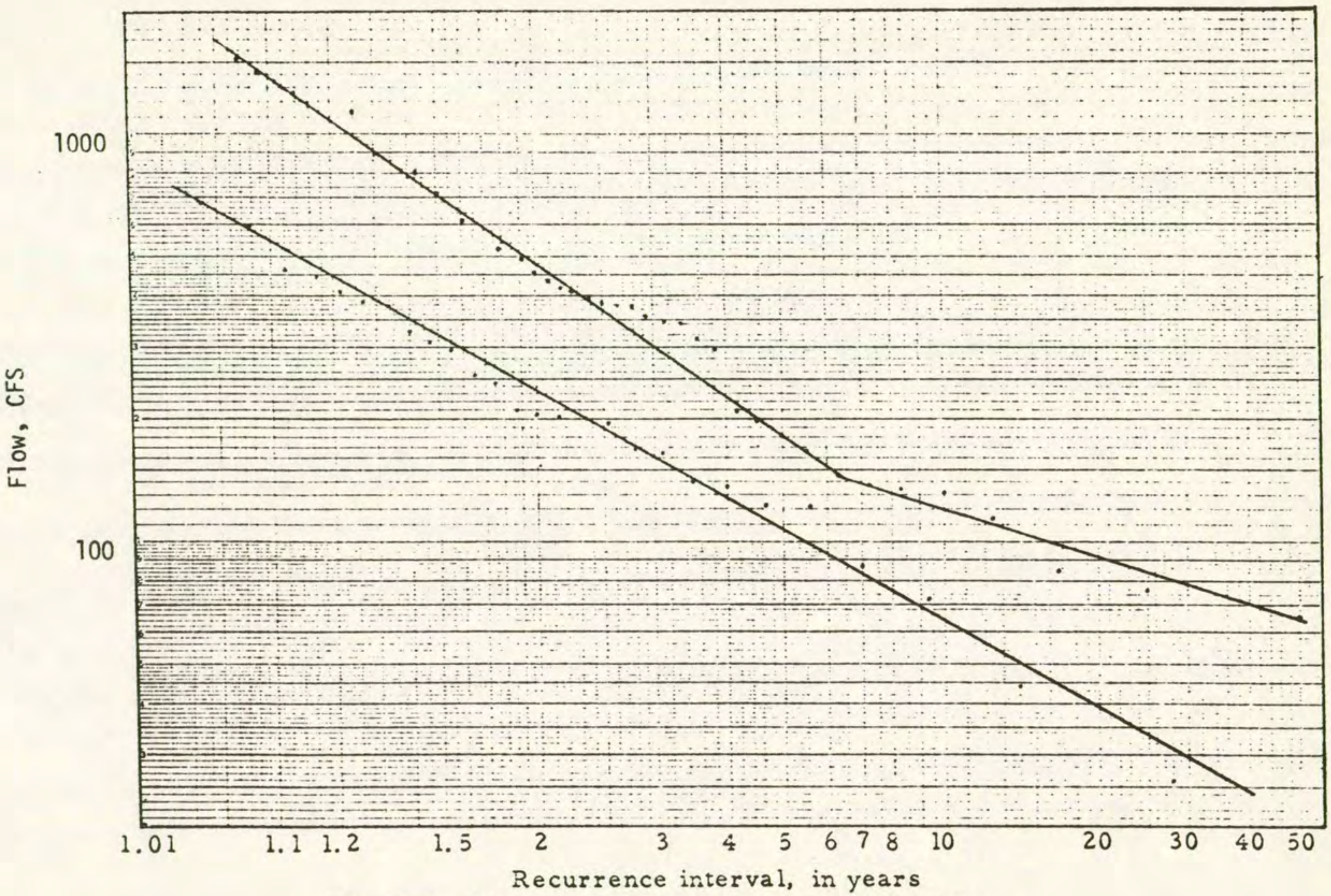


Fig. B-7. Recurrence Interval of Low and Average Daily Flow (July).

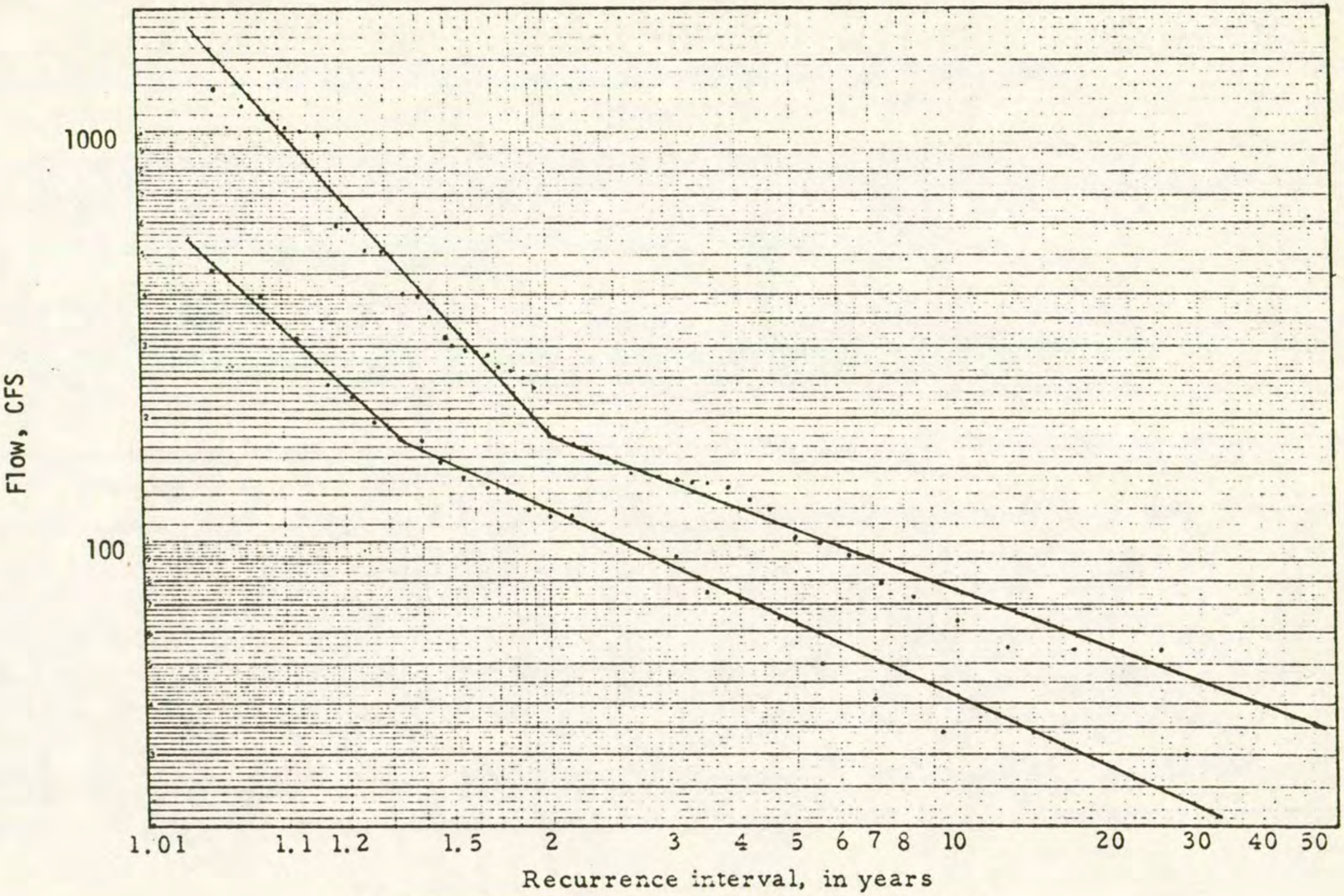


Fig. B-8. Recurrence Interval of Low and Average Daily Flow (August).

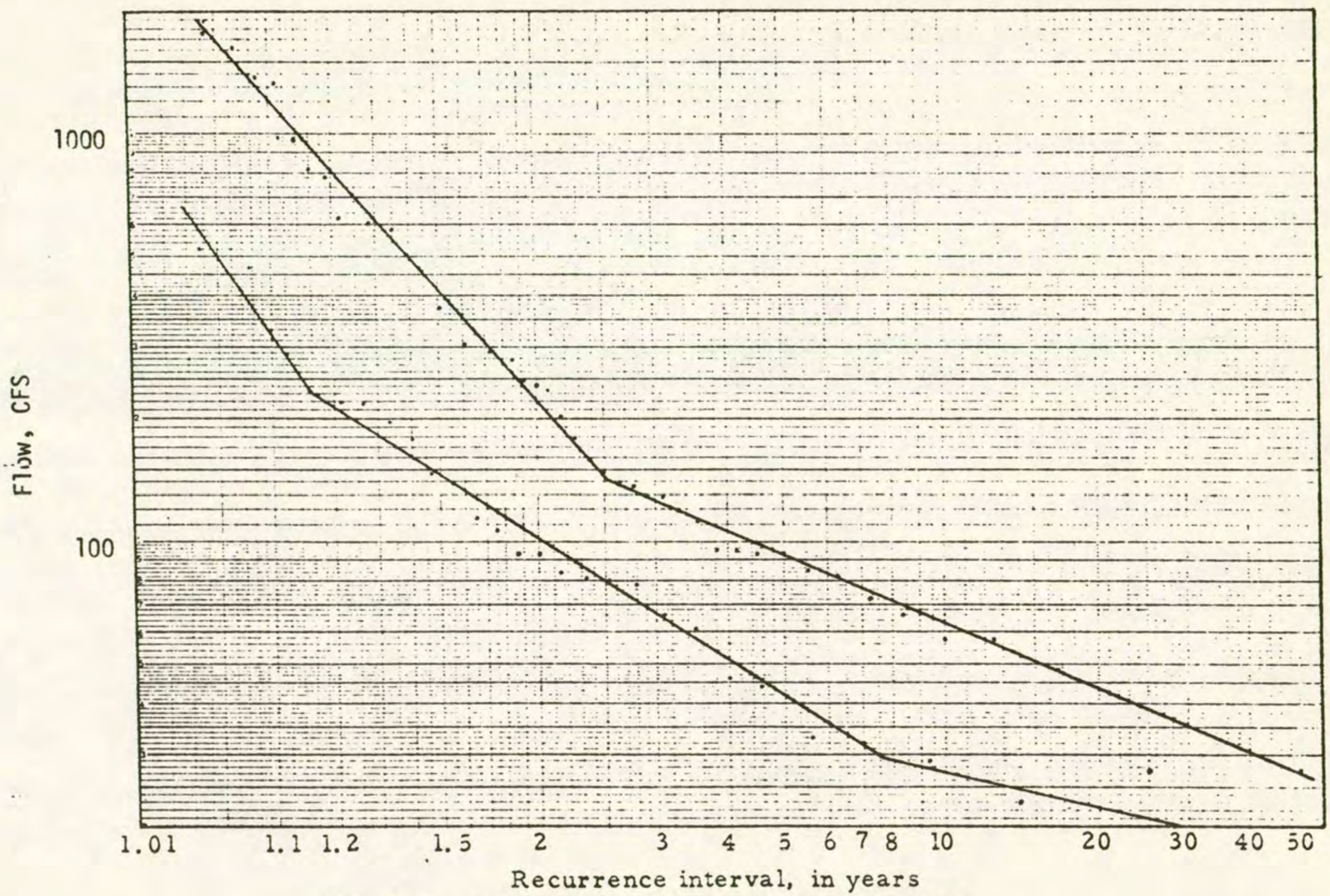


Fig. B-9. Recurrence Interval of Low and Average Daily Flow (September).

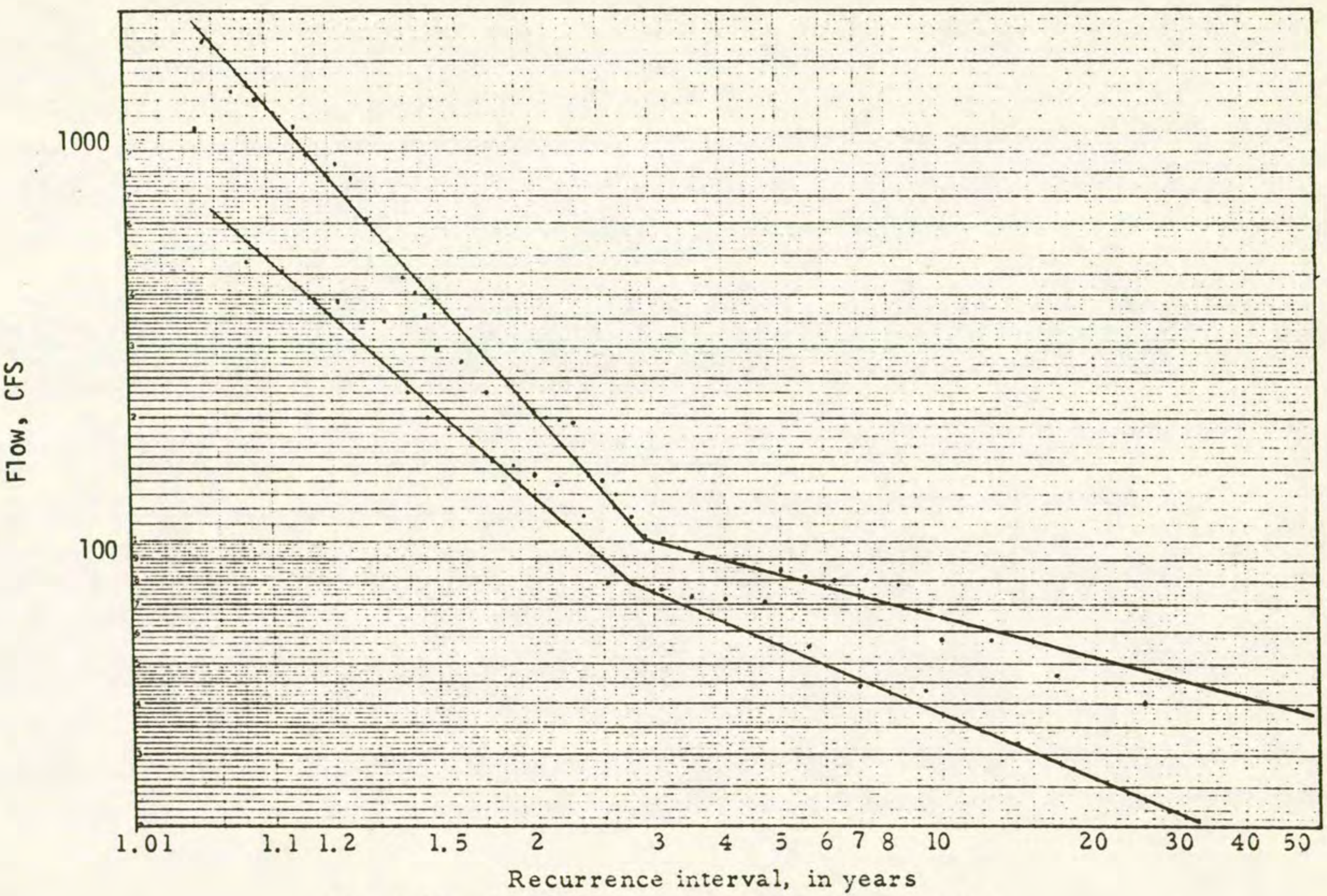


Fig. B-10. Recurrence Interval of Low and Average Daily Flow (October).

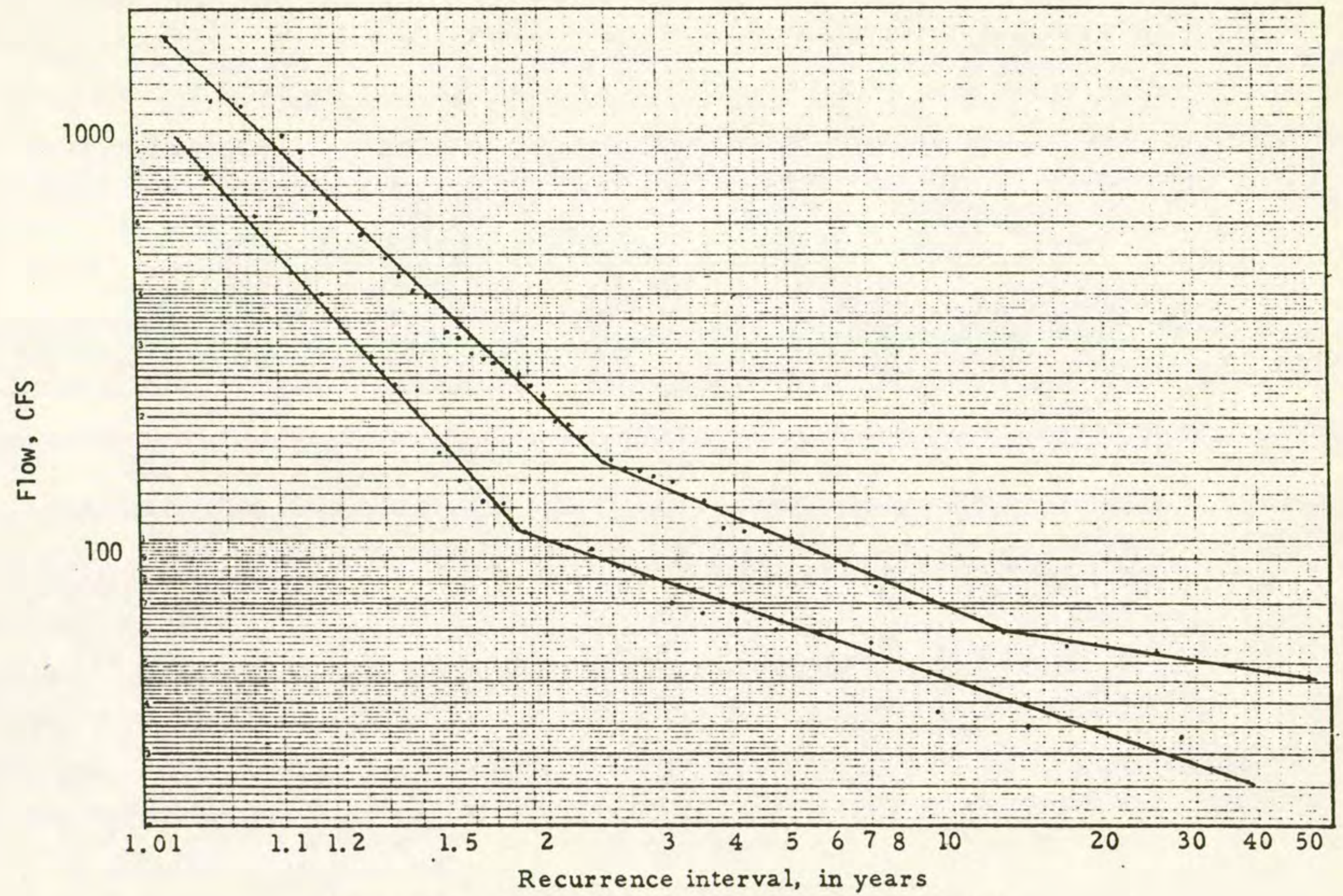


Fig. B-11. Recurrence Interval of Low and Average Daily Flow (November).

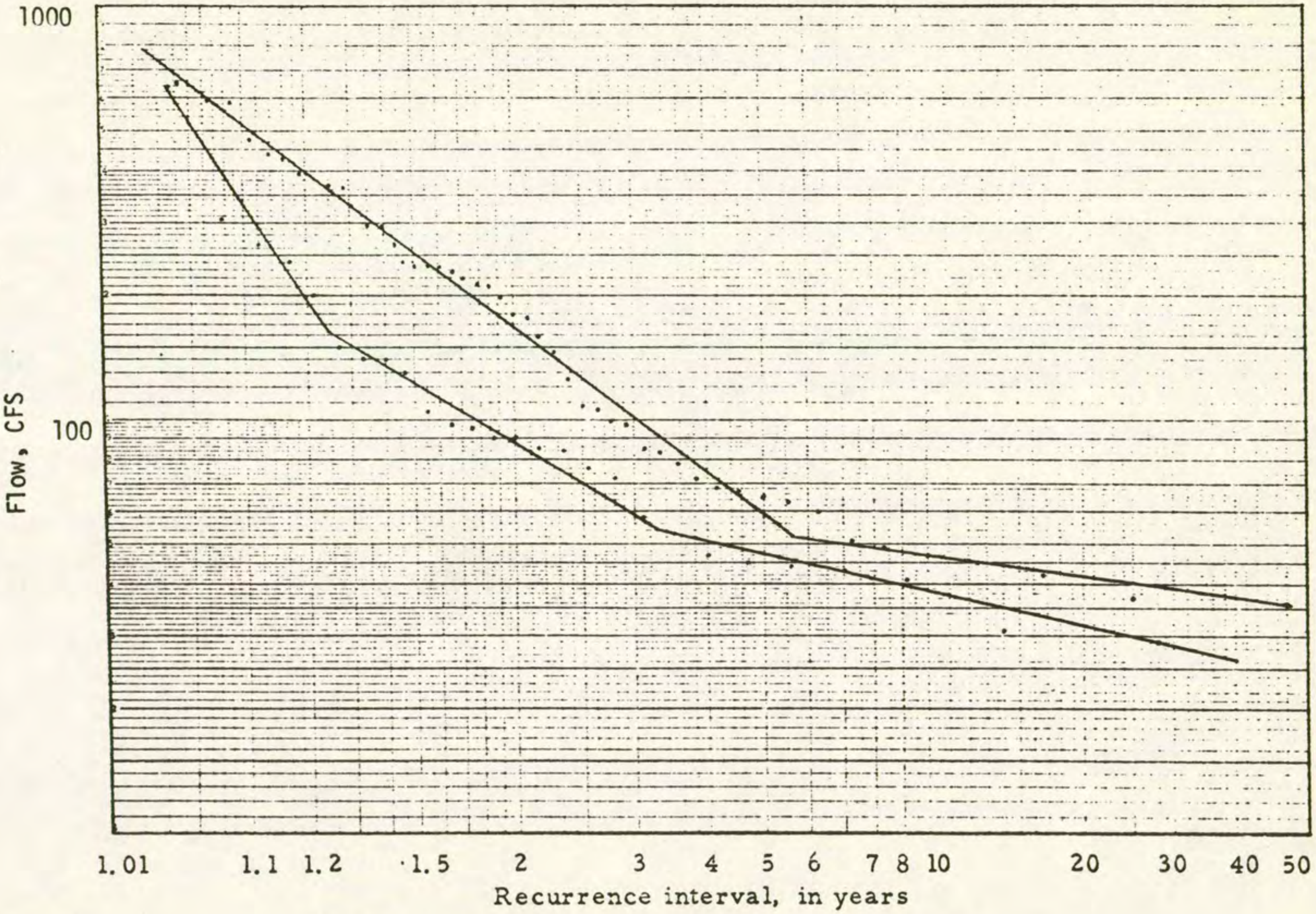


Fig. B-12. Recurrence Interval of Low and Average Daily Flow (December)

APPENDIX C

WATER QUALITY DATA IMMEDIATELY UPSTREAM FROM THE CORALVILLE RESERVOIR

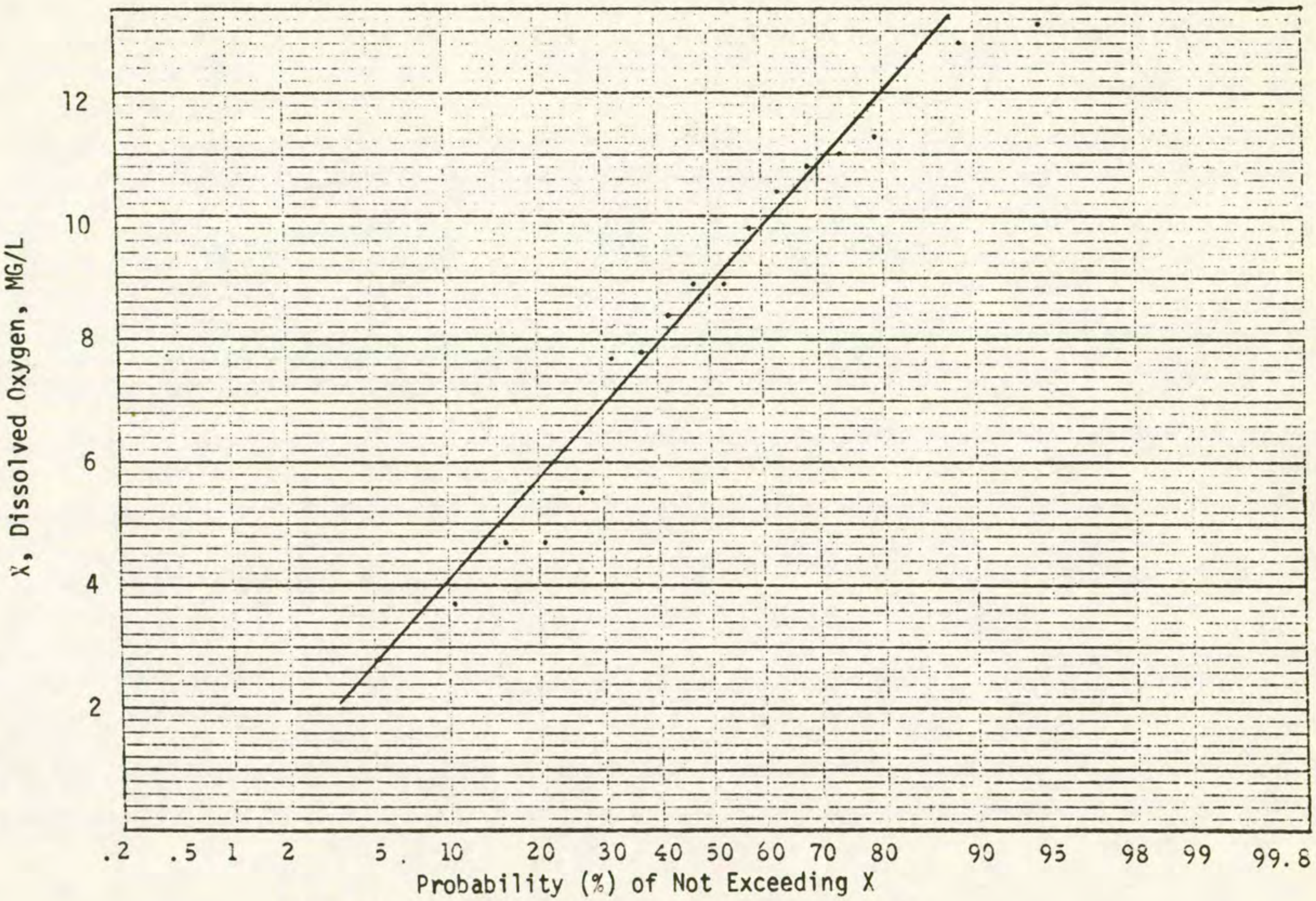


Fig. C-1. Probability of Not Exceeding Various Dissolved Oxygen Levels (January).

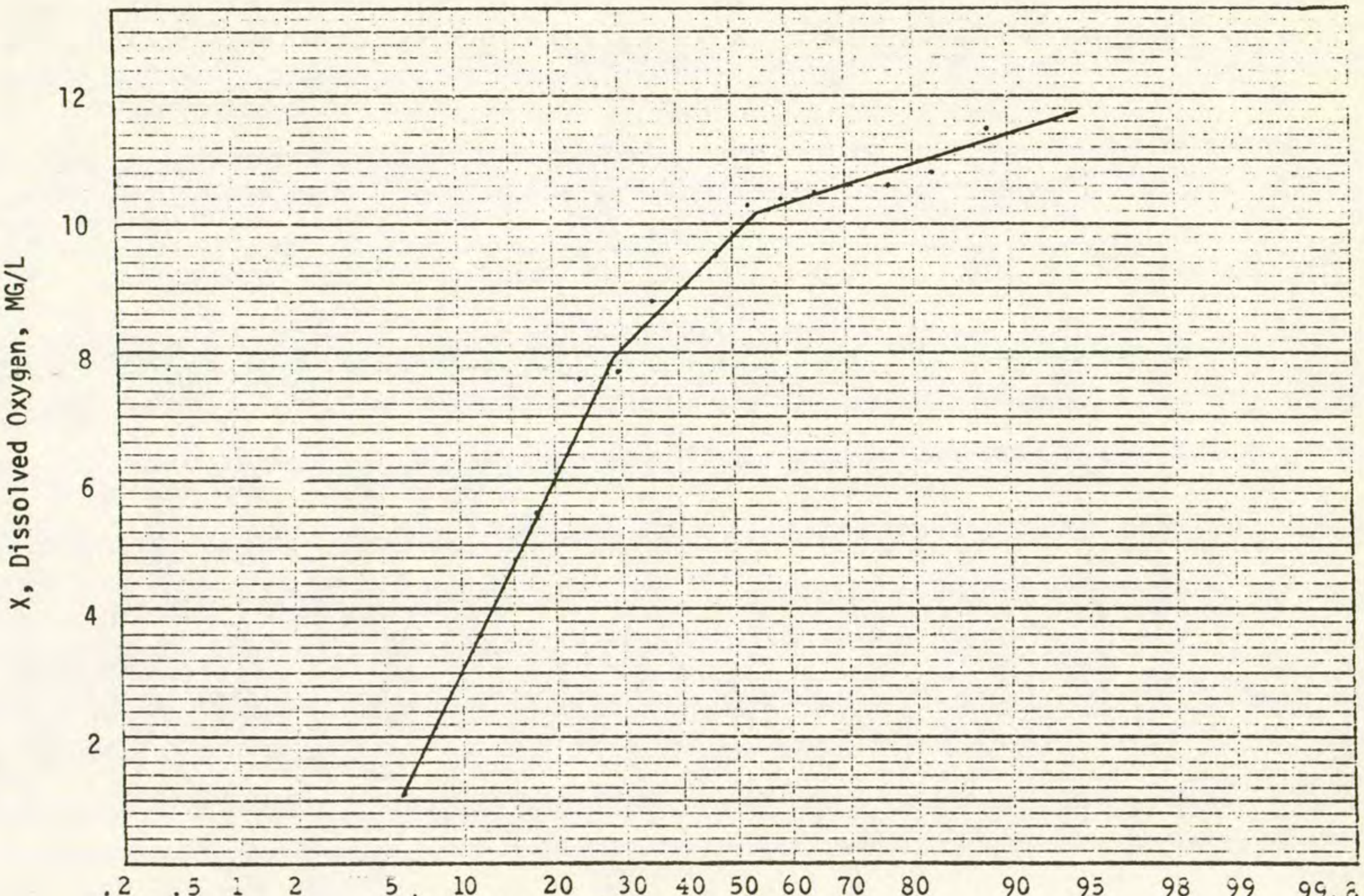


Fig. C-2. Probability of Not Exceeding Various Dissolved Oxygen Levels (February).

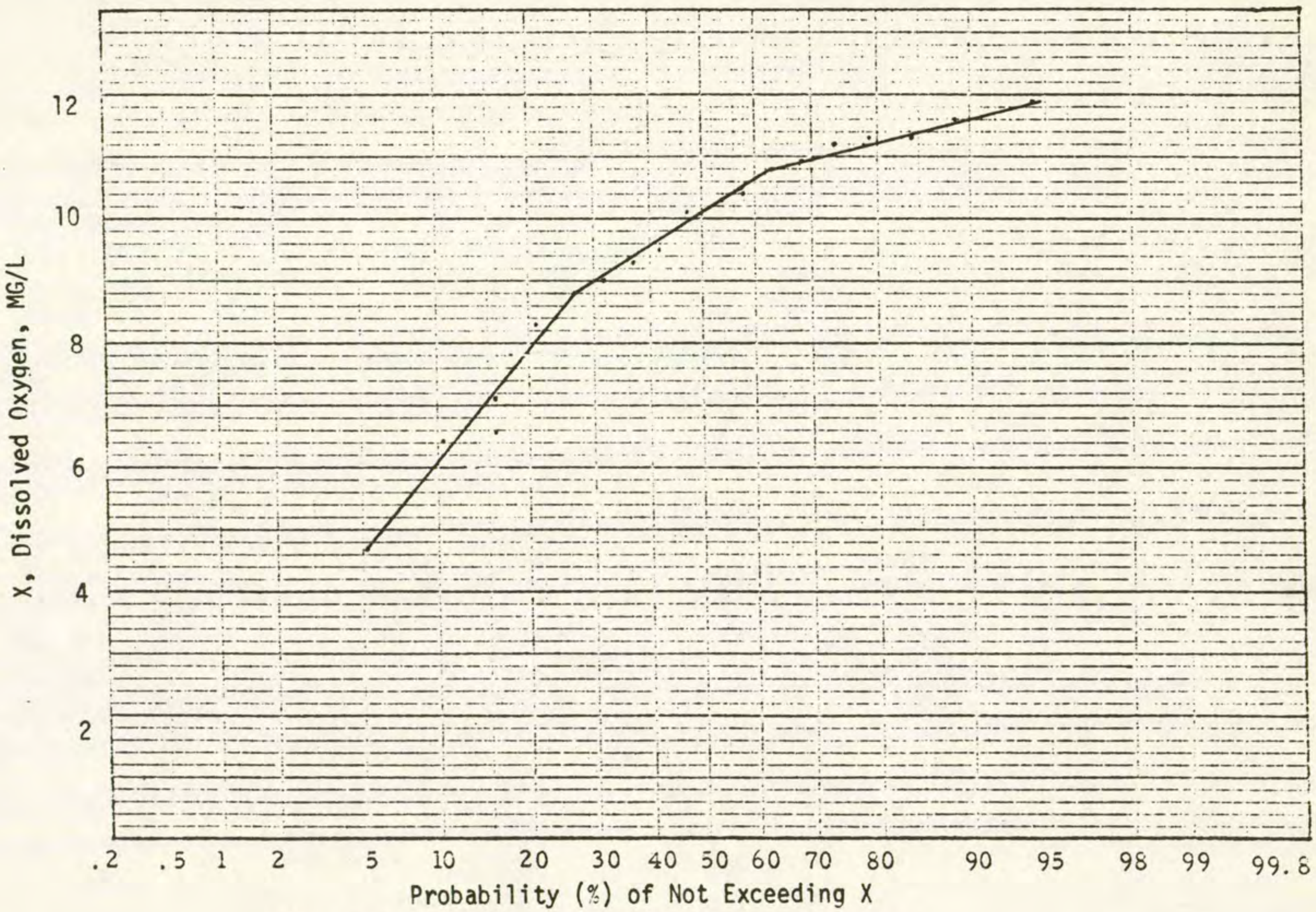


Fig. C-3. Probability of Not Exceeding Various Dissolved Oxygen Levels (March)

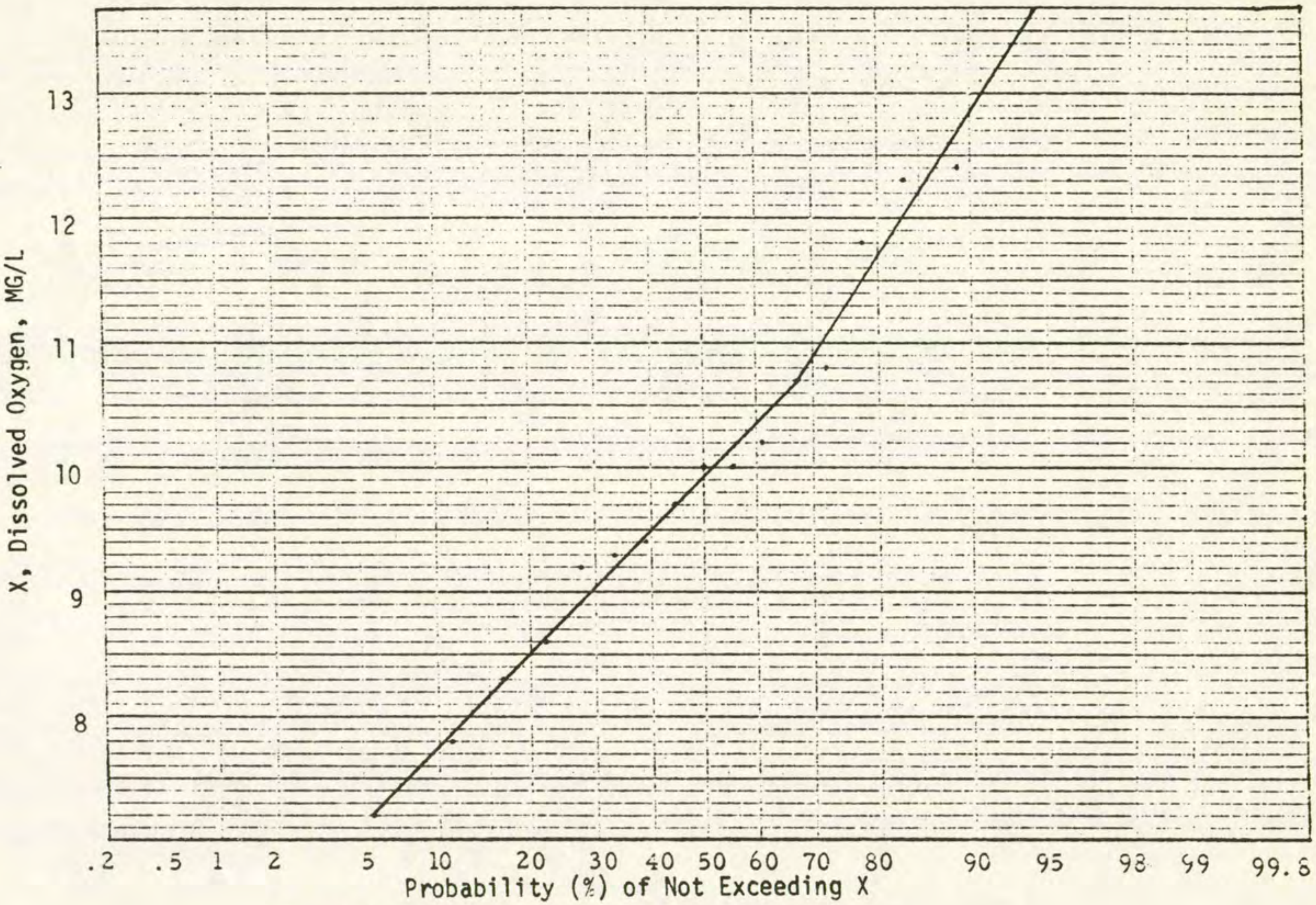


Fig. C-4. Probability of Not Exceeding Various Dissolved Oxygen Levels (April).

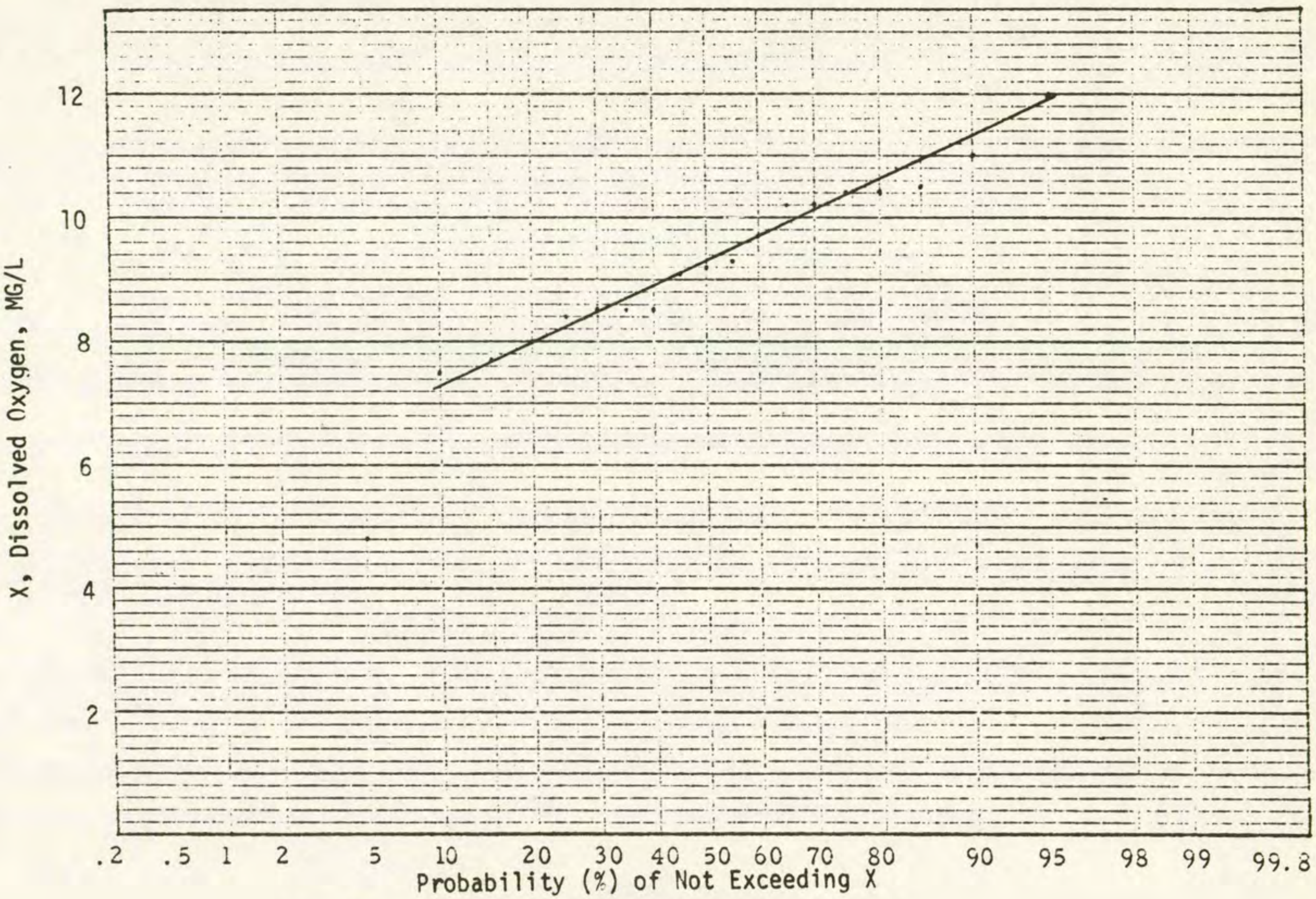


Fig. C-5. Probability of Not Exceeding Various Dissolved Oxygen Levels (May).

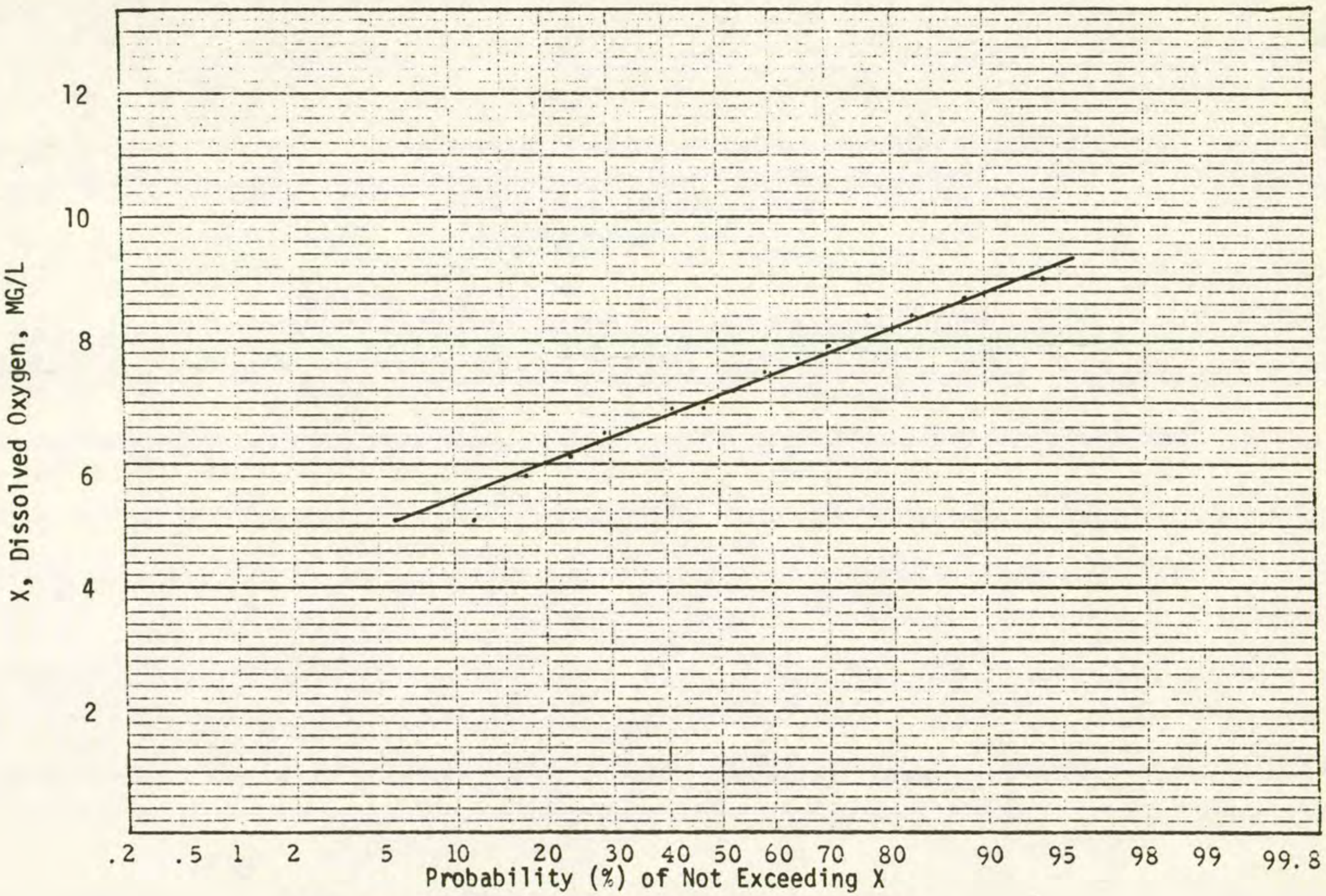


Fig. C-6. Probability of Not Exceeding Various Dissolved Oxygen Levels (June).

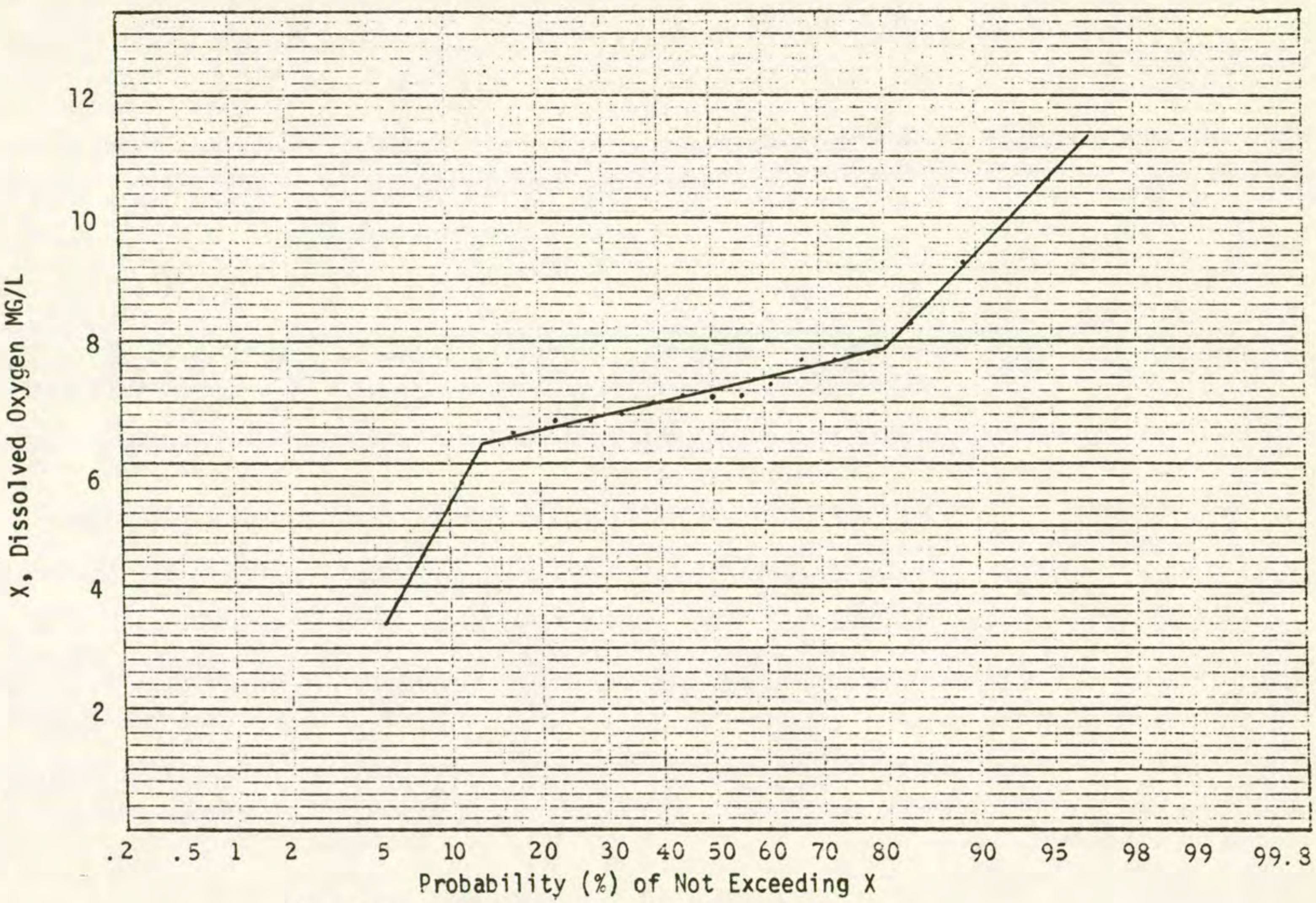


Fig. C-7. Probability of Not Exceeding Various Dissolved Oxygen Levels (July).

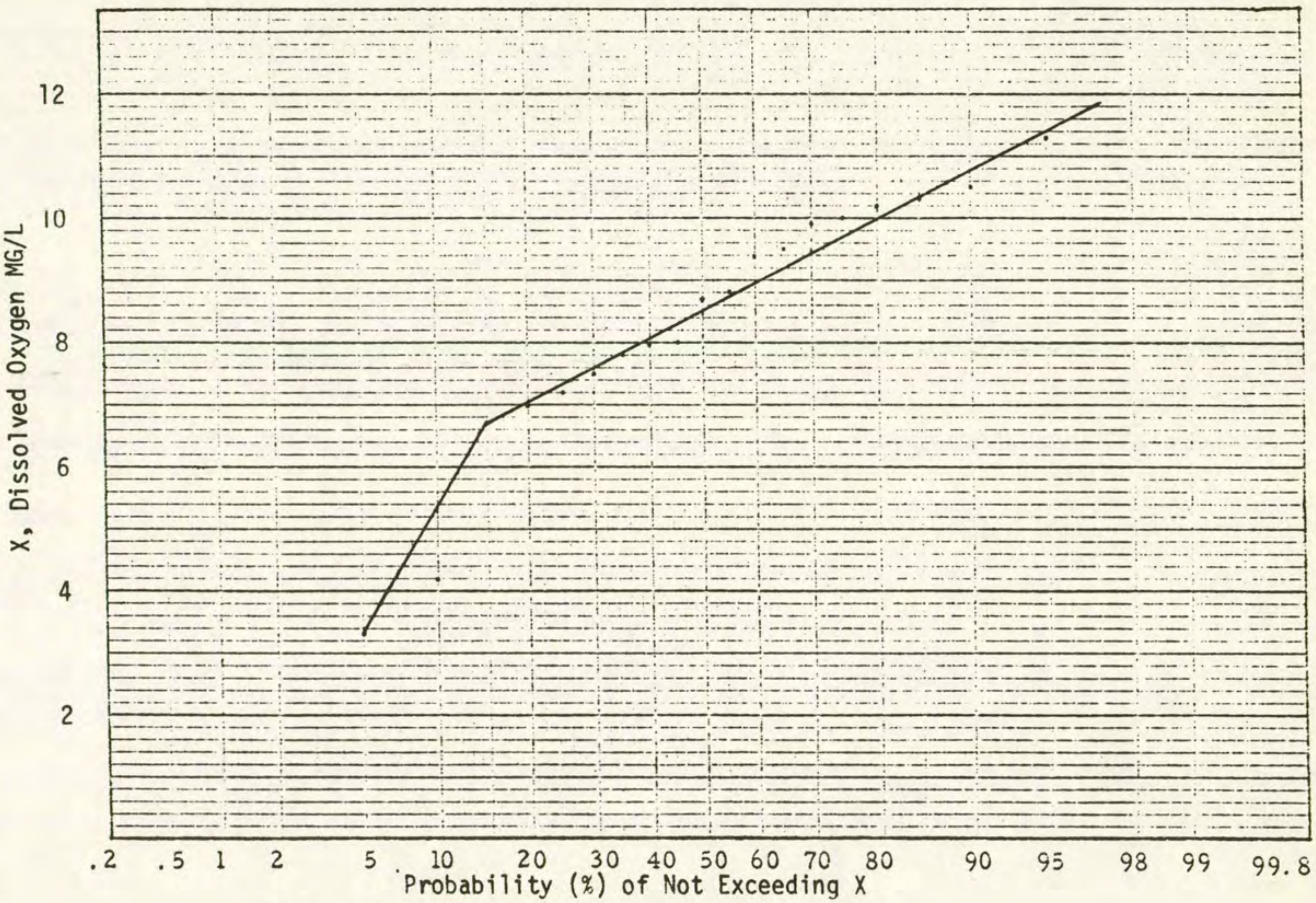


Fig. C-8. Probability of Not Exceeding Various Dissolved Oxygen Levels (August).

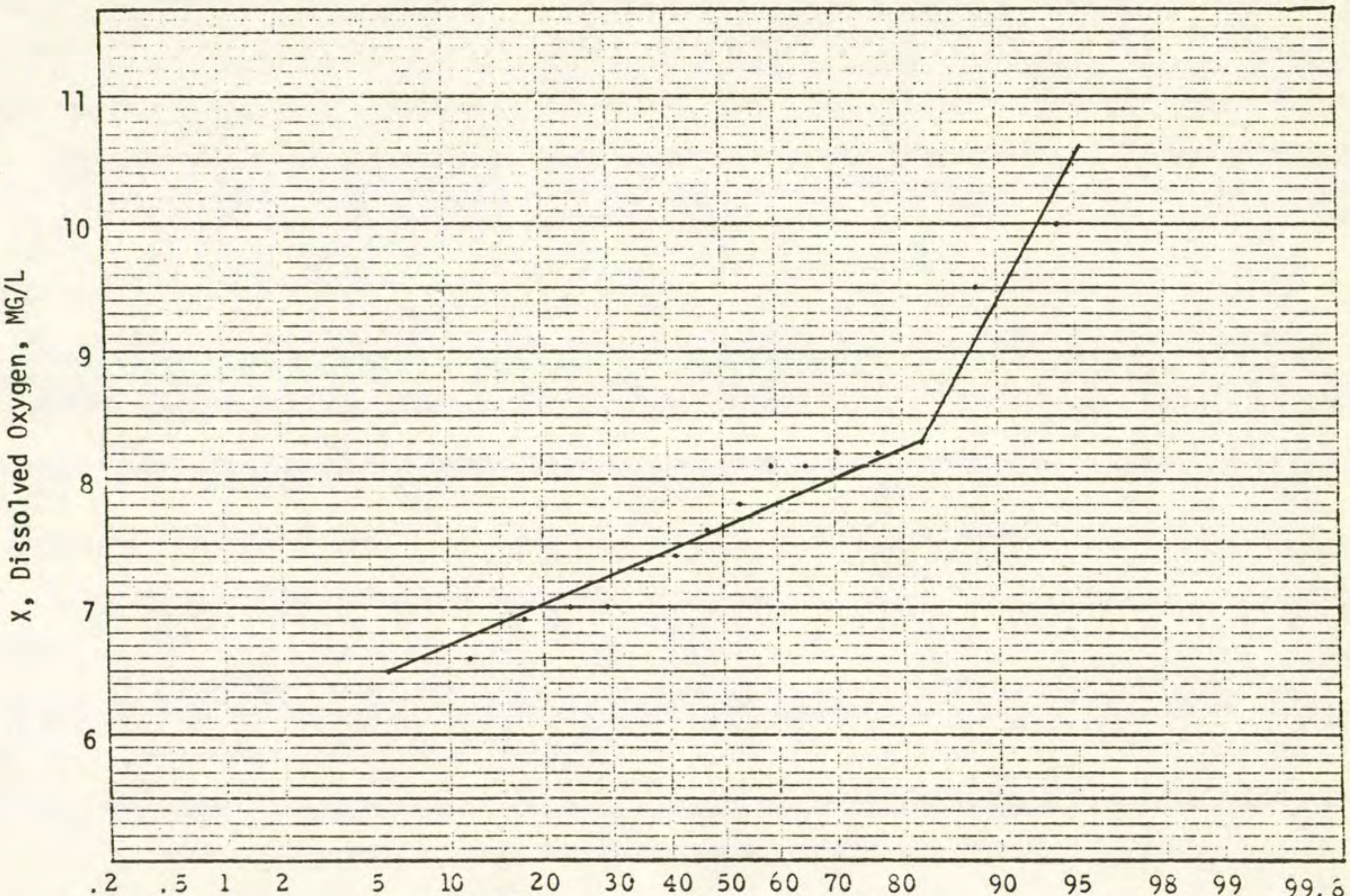


Fig. C-9. Probability of Not Exceeding Various Dissolved Oxygen Levels (September).

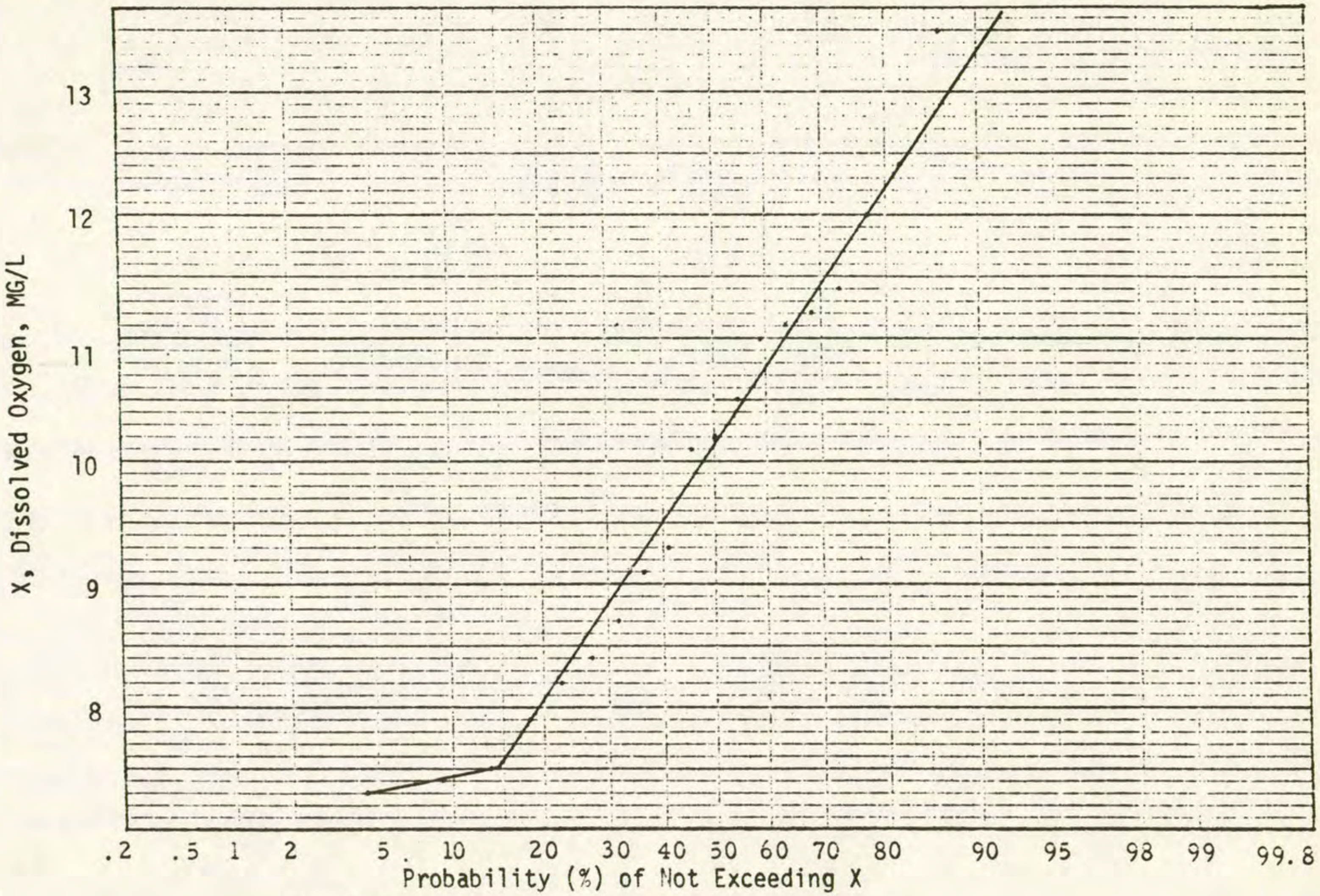


Fig. C-10. Probability of Not Exceeding Various Dissolved Oxygen Levels (October).

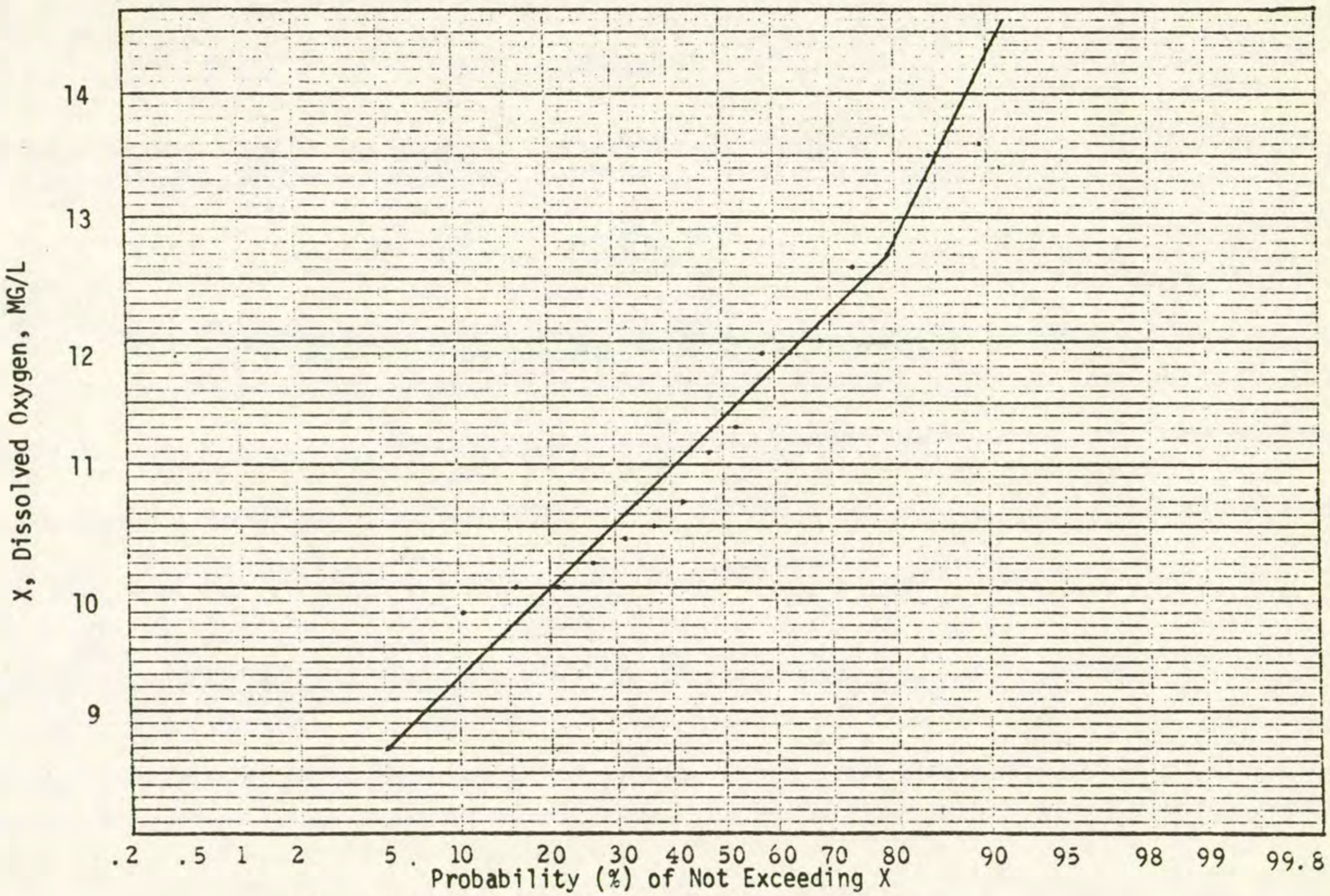


Fig. C-11. Probability of Not Exceeding Various Dissolved Oxygen Levels (November).

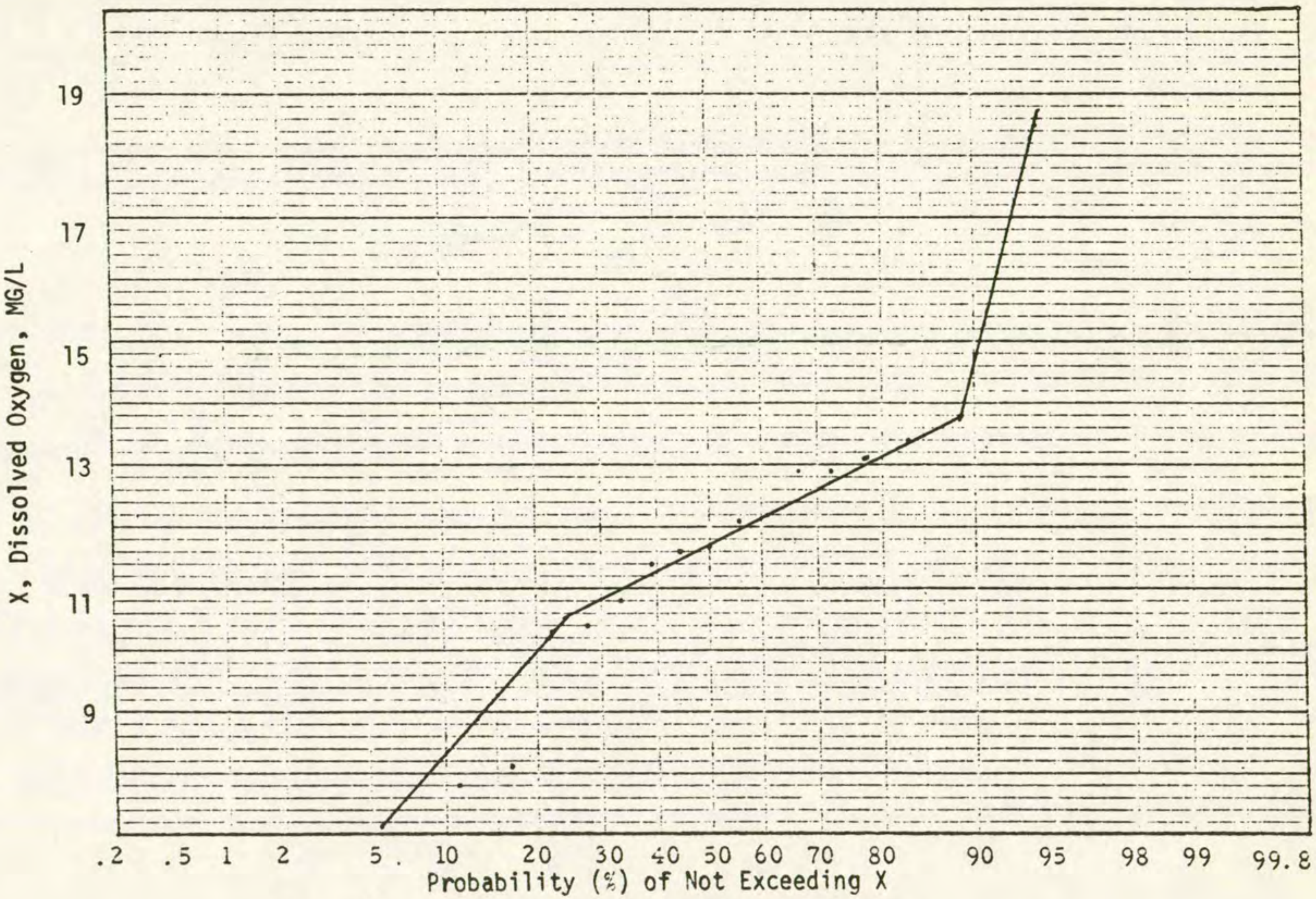


Fig. C-12. Probability of Not Exceeding Various Dissolved Oxygen Levels (December).

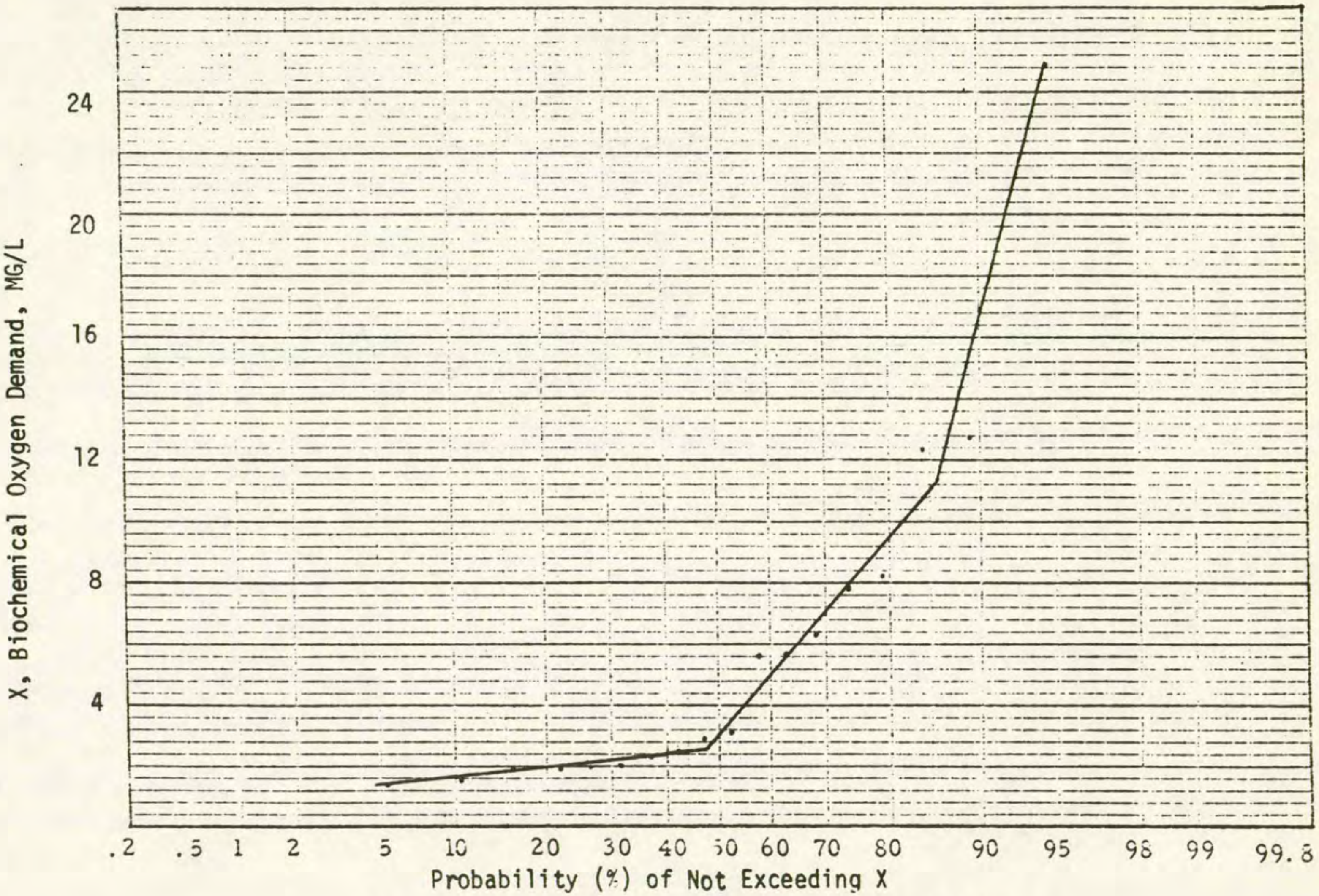


Fig. C-13. Probability of Not Exceeding Various Biochemical Oxygen Demands (January).

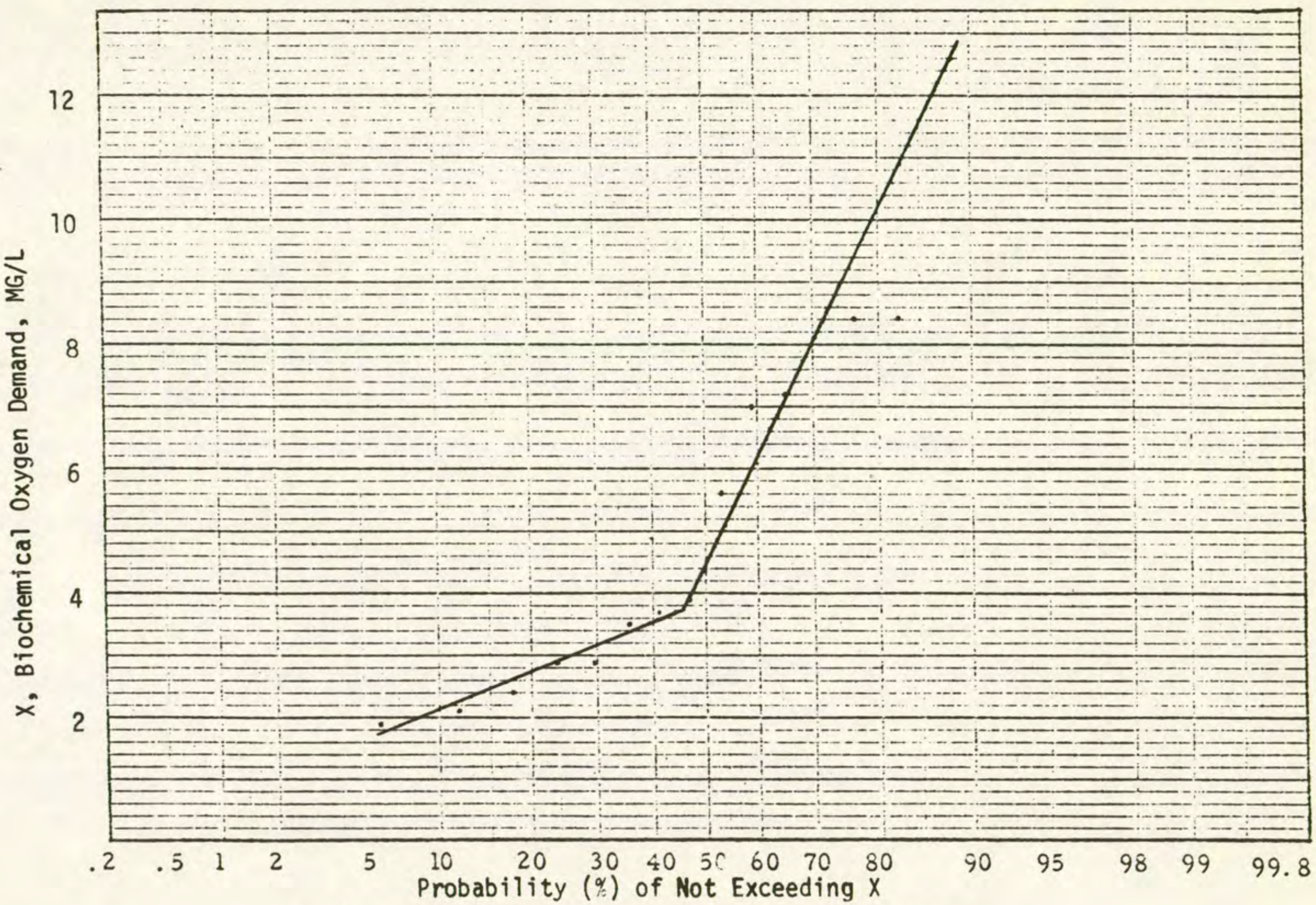


Fig. C-14. Probability of Not Exceeding Various Biochemical Oxygen Demands (February).

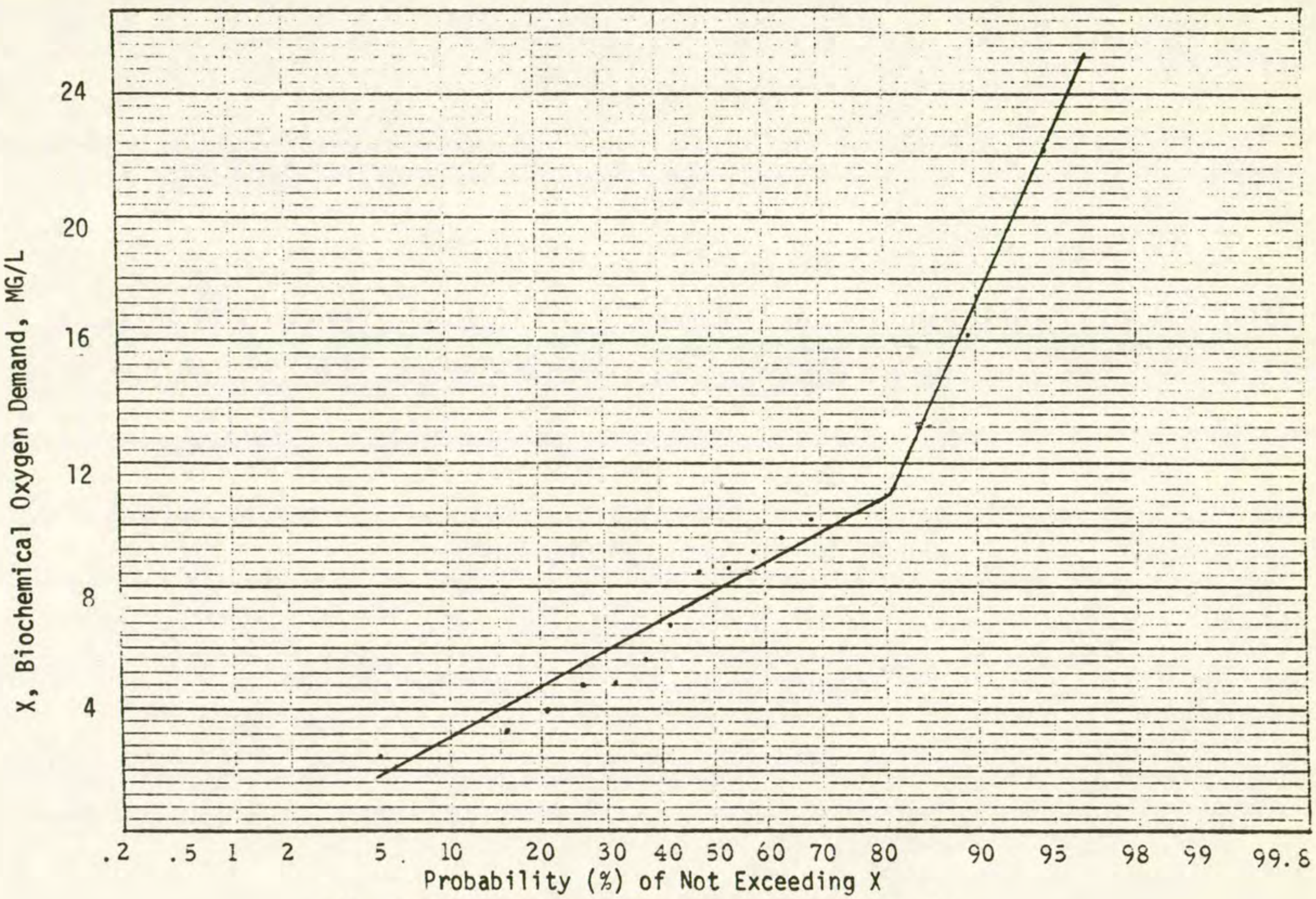


Fig. C-15. Probability of Not Exceeding Various Biochemical Oxygen Demands (March).

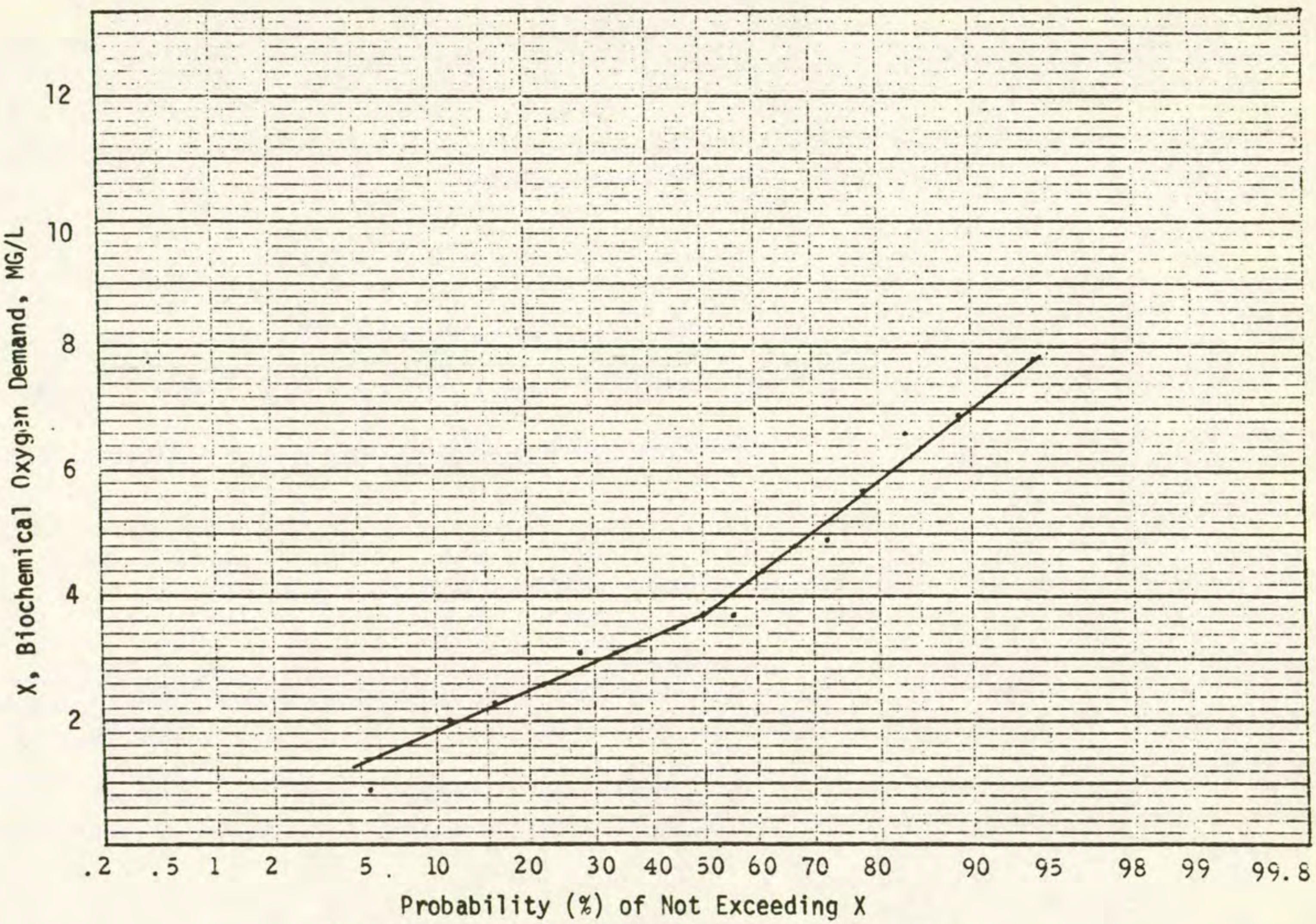


Fig. C-16. Probability of Not Exceeding Various Biochemical Oxygen Demands (April).

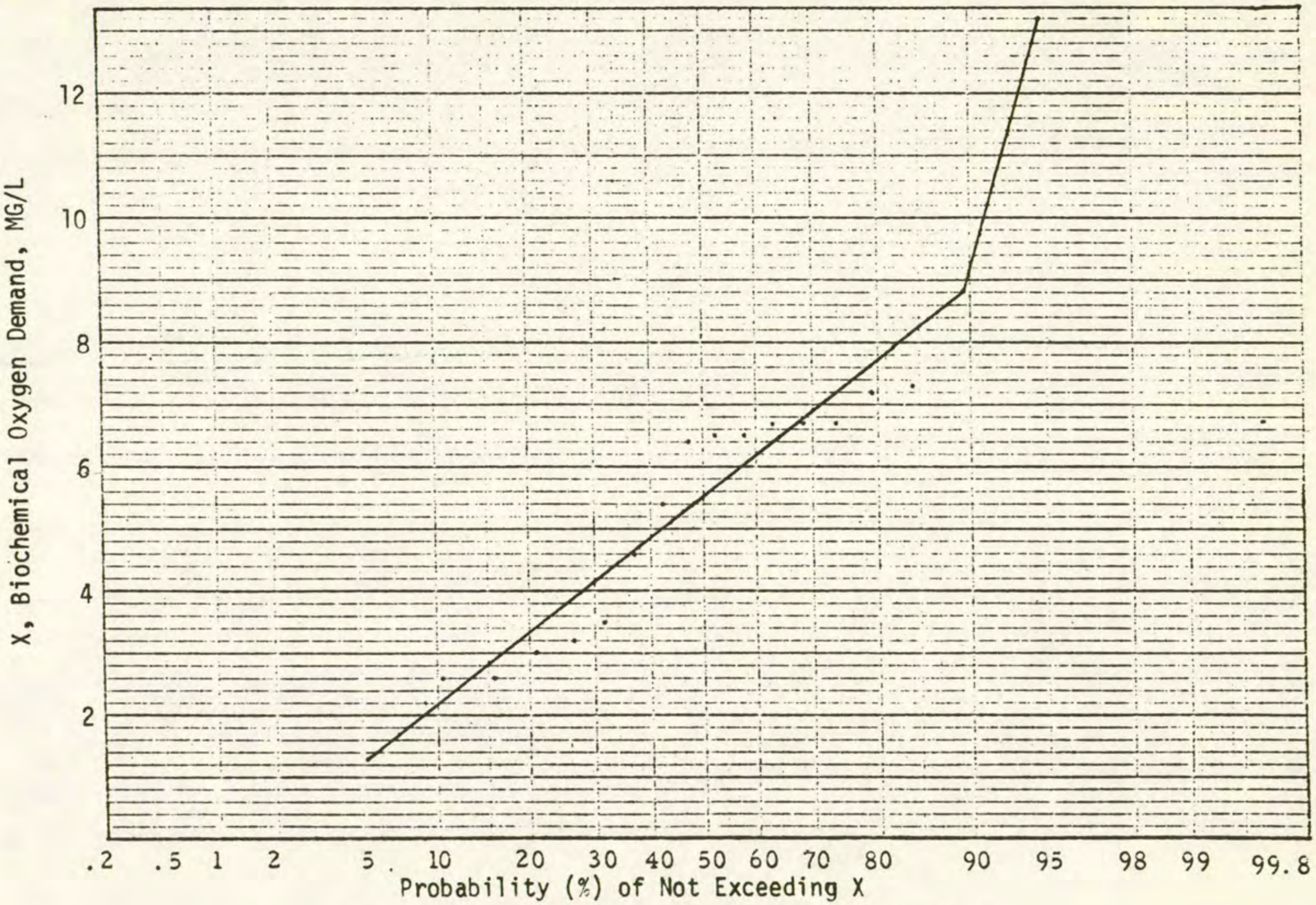


Fig. C-17. Probability of Not Exceeding Various Biochemical Oxygen Demands (May).

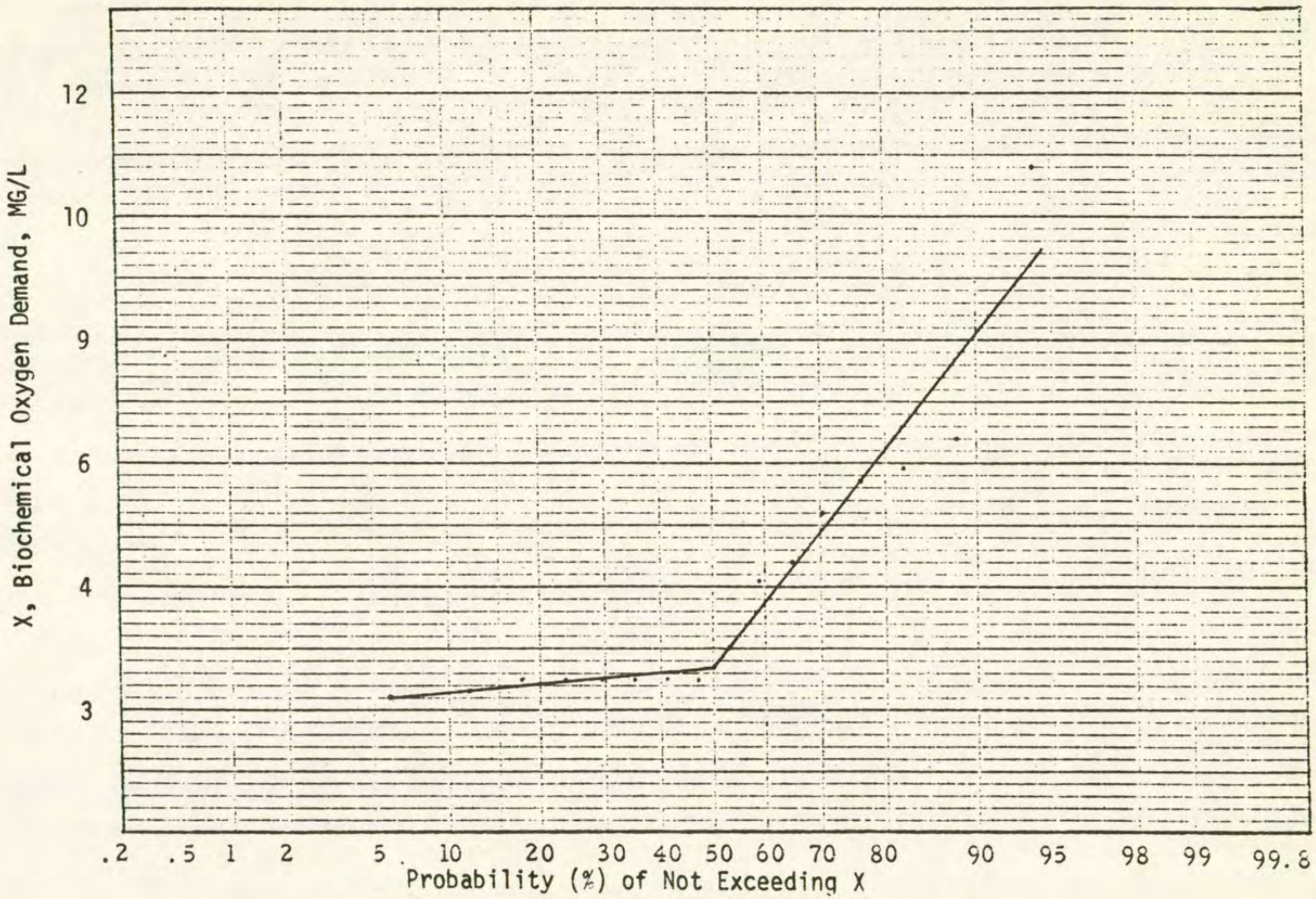


Fig. C-18. Probability of Not Exceeding Various Biochemical Oxygen Demands (June).

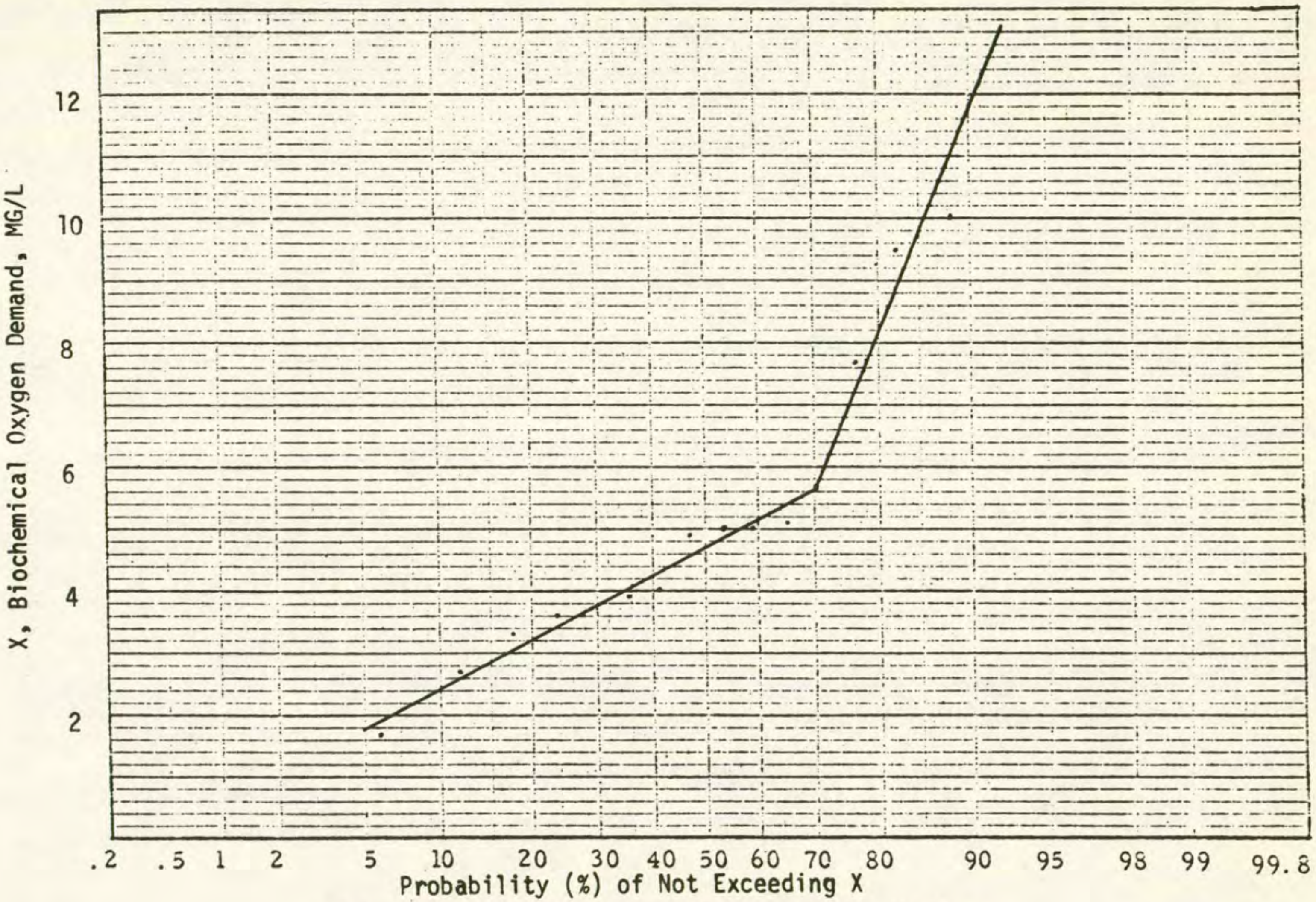


Fig. C-19. Probability of Not Exceeding Various Biochemical Oxygen Demands (July).

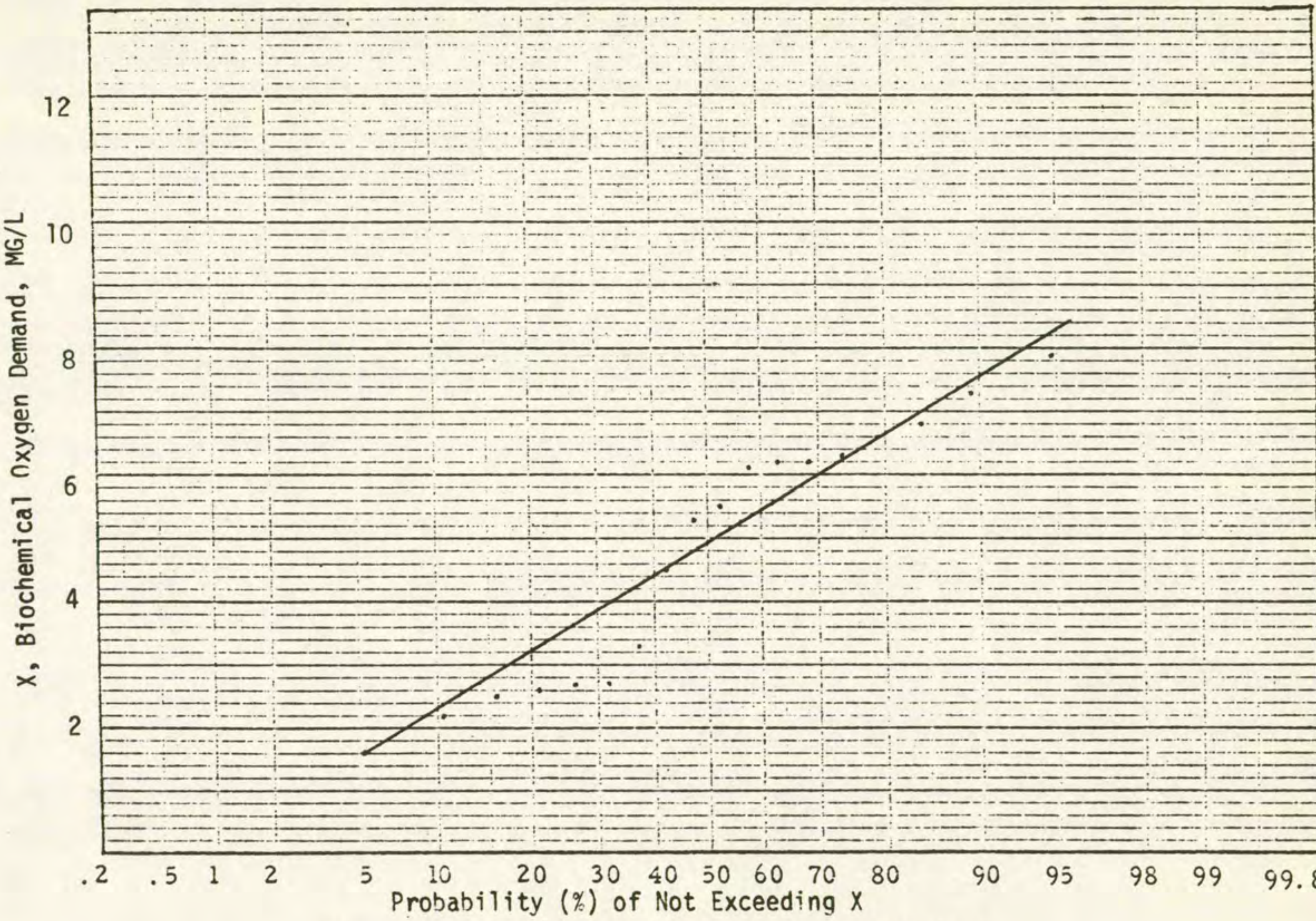


Fig. C-20. Probability of Not Exceeding Various Biochemical Oxygen Demands (August).

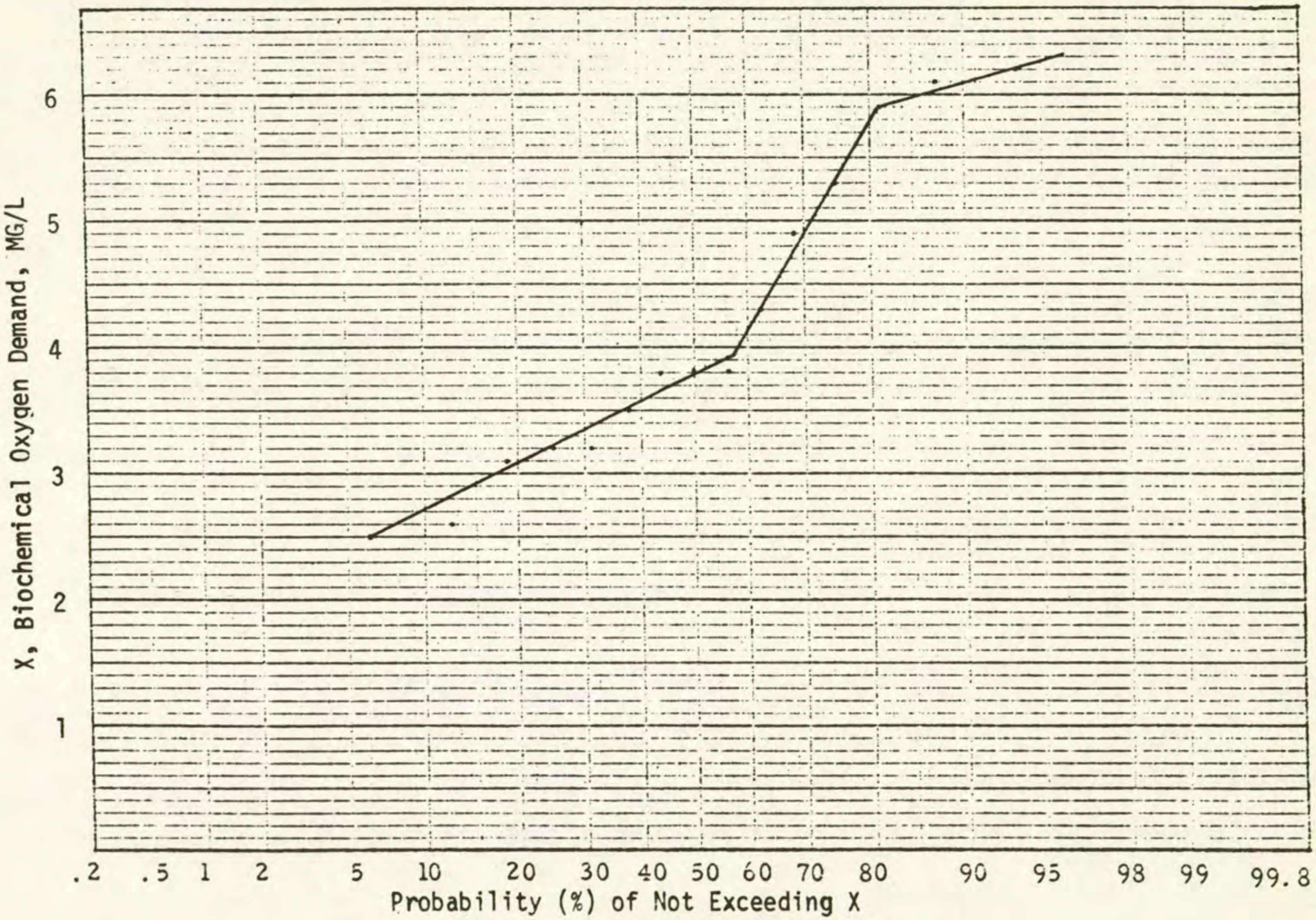


Fig. C-21. Probability of Not Exceeding Various Biochemical Oxygen Demands (September).

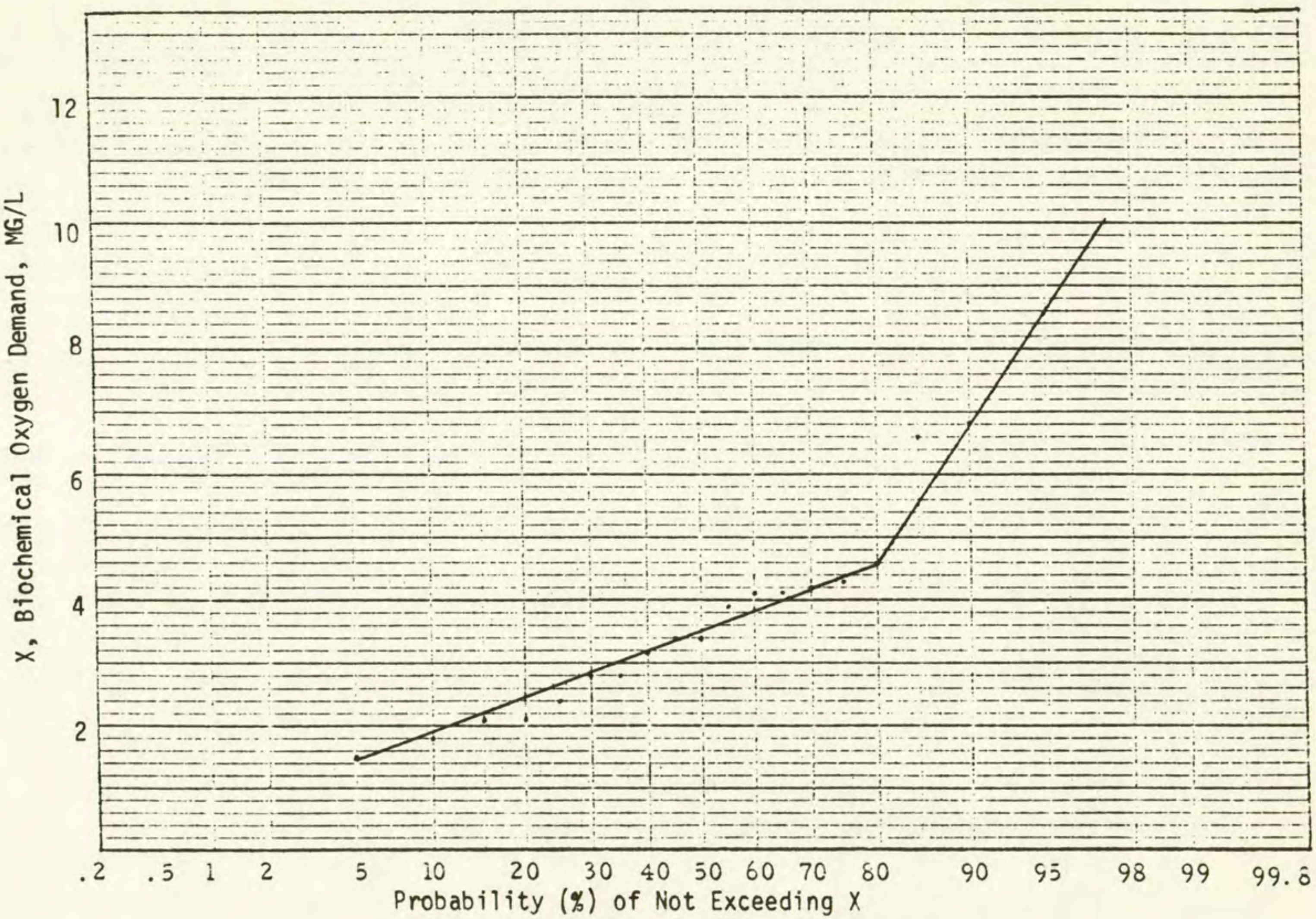


Fig. C-22. Probability of Not Exceeding Various Biochemical Oxygen Demands (October).

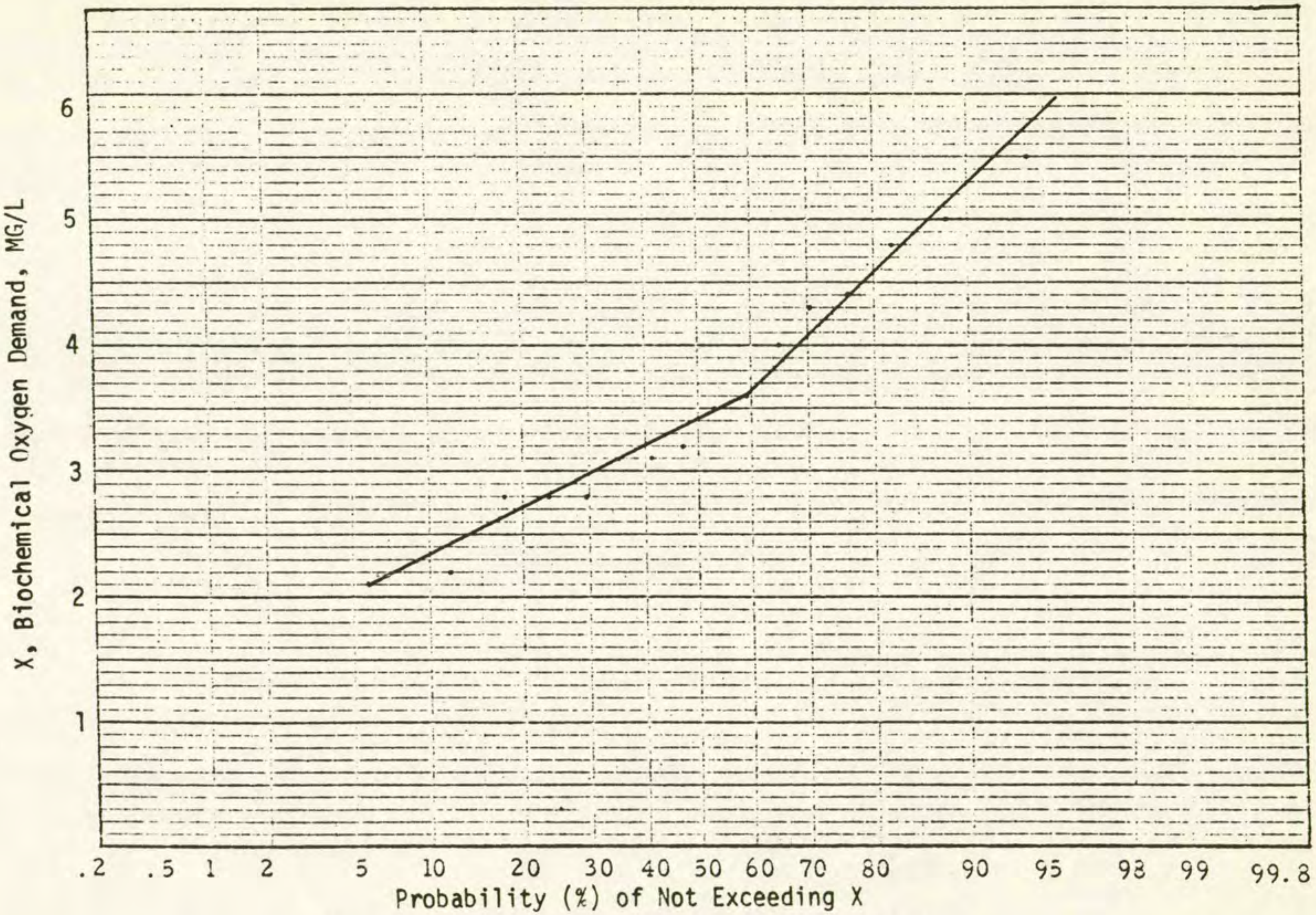


Fig. C-23. Probability of Not Exceeding Various Biochemical Oxygen Demands (November).

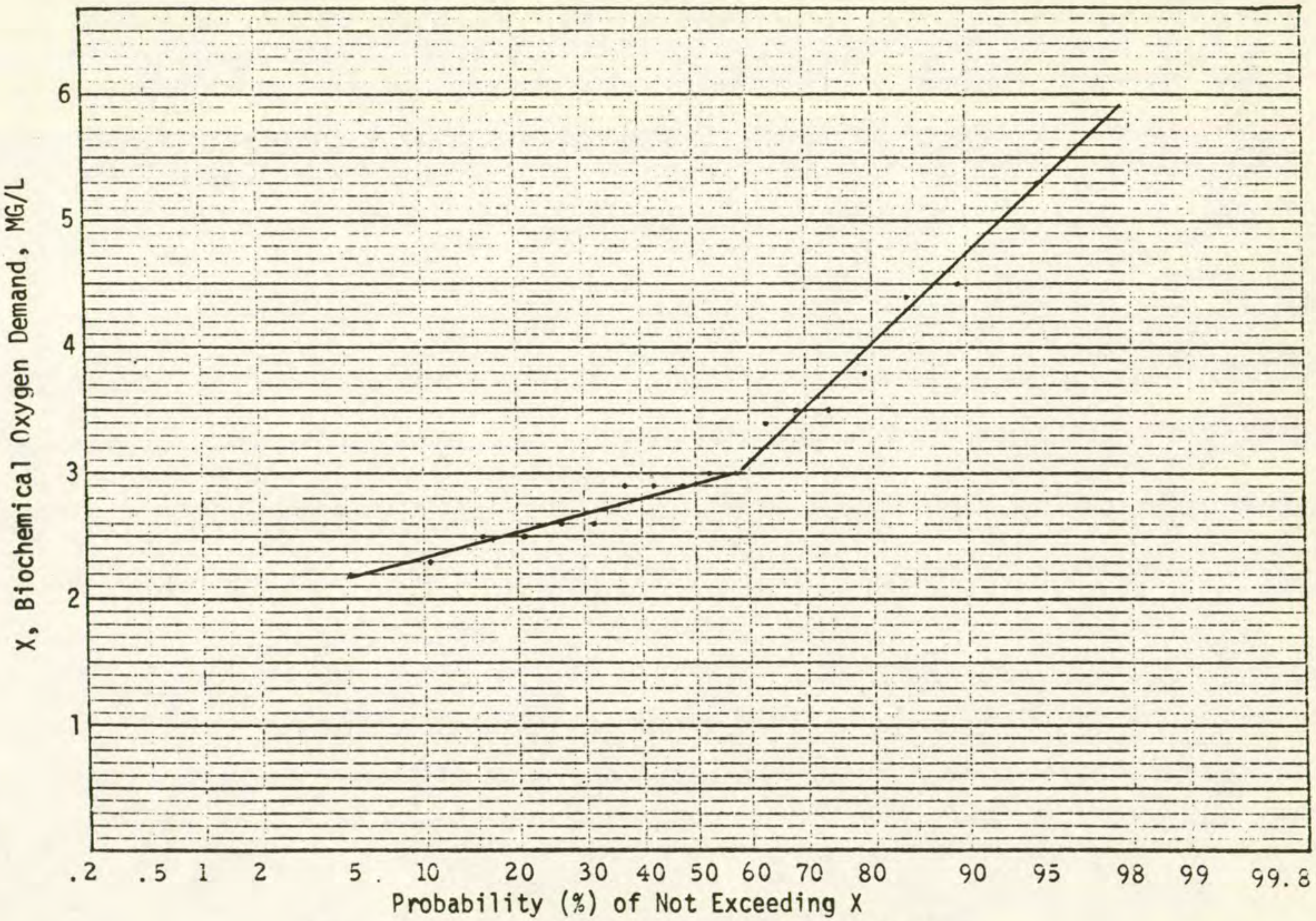


Fig. C-24. Probability of Not Exceeding Various Biochemical Oxygen Demands (December).

APPENDIX D

COMPUTER PROGRAMS

COMPUTER PROGRAM FOR PRECIPITATION DATA REDUCTION

```
      DIMENSION MOS(12)
      CALL ERRSET(215,256,-1,1,1)
      READ(5,901) (MOS(I),I=1,12),ZERO,BLANK
  901 FORMAT(12A4,2A3)
   10 READ(1,900,END=15) IYR,MO,IDAY,RAIN,SNOW
  900 FORMAT(4X,I4,2I2,T24,A3,1X,A2)
      ICK=IDAY + MO
      IF(ICK.GT.1) GO TO 25
      WRITE(6,906)
  906 FORMAT('1')
   25 CONTINUE
      IF(IDAY.NE.1) GO TO 57
      WRITE(6,902) MOS(MO),IYR
  902 FORMAT('0',T10,'PRECIPITATION BY DAY FOR ',A4,',',I5)
      WRITE(6,903)
   57 CONTINUE
  903 FORMAT('0',T10,'DAY',T20,'TOTAL PREC.'.T50,'SNOWFALL
     X(INCHES)'/)
      IF(RAIN.EQ.ZERO.OR.RAIN.EQ.BLANK) GO TO 10
      IF(SNOW.NE.ZERO) GO TO 11
      WRITE(6,904) IDAY,RAIN
  904 FORMAT(' ',T10,I3,T23,A3,T55,A2)
      GO TO 10
   11 WRITE(6,904) IDAY,RAIN,SNOW
      GO TO 10
   15 CONTINUE
      CALL EXIT
      END
```

COMPUTER PROGRAM FOR COMPUTATION OF WEEKLY, BIMONTHLY, MONTHLY, AND ANNUAL PRECIPITATION SUMMATIONS AND RANK-ORDER OF EACH

```
      DIMENSION MOS(12)
      DIMENSION QRT(66)
      DIMENSION IWK(12,31),IBMO(12,31),WK(66,48)
      DIMENSION BIMO(66,25),XMO(66,12)
      DIMENSION YR(66)
      DIMENSION XH(264),IH(264),IHJ(264),PROB(264)
      CALL ERRSET(215,256,-1,1,1)
      READ(5,925) (MOS(I),I=1,12)
  925 FORMAT(20A4)
      DO 20 I=1,12
   20 READ(5,905) (IWK(I,J),J=1,31)
      DO 25 I=1,12
   25 READ(5,905) (IBMO(I,J),J=1,31)
  905 FORMAT(40I2)
      DO 35 J=1,66
      DO 35 I=1,48
   35 WK(J,I)=0.0
      DO 40 I=1,66
      YR(I)=0.0
      DO 40 J=1,25
   40 BIMO(I,J)=0.0
      DO 45 I=1,66
      DO 45 J=1,12
   45 XMO(I,J)=0.0
   10 READ(1,900,END=15) IYR,MO,IDAY,RAIN
  900 FORMAT(6X,3I2,T23,F4.0)
      K=IYR + 1
      ID=IWK(MO,IDAY)
      ND=IBMO(MO,IDAY)
      IF(MO.EQ.02.AND.IDAY.EQ.15) XSAV=RAIN
      IF(MO.EQ.02.AND.IDAY.EQ.22) XSAV2=RAIN
      IF(MO.EQ.02.AND.IDAY.EQ.29) GO TO 54
      GO TO 56
   54 WK(K,7)=WK(K,7) + XSAV2 -XSAV
      WK(K,8)=WK(K,8) -XSAV2
      BIMO(K,4)=BIMO(K,4) -XSAV
   56 CONTINUE
      IF(ID.EQ.99) GO TO 50
      WK(K,ID)= WK(K,ID) + RAIN
   50 CONTINUE
      IF(ND.EQ.99) GO TO 55
      BIMO(K,ND)=BIMO(K,ND) + RAIN
   55 CONTINUE
      XMO(K,MO)=XMO(K,MO) + RAIN
      YR(K)=YR(K) + RAIN
      GO TO 10
   15 CONTINUE
```

```
      DO 600 I=1,66
      WRITE(6,710)
  710 FORMAT('1',T20,'MONTHLY PERCENT OF TOTAL ANNUAL PRECITATION'/)
      II=I + 1899
      WRITE(6,720) II
  720 FORMAT('0',T10,'YEAR=',I5,T30,'YEARLY TOTAL',T50,'MONTHLY
     XTOTAL', T70,'PERCENT'/)
      DO 601 L=1,12
      IF(XMO(I,L).LE.0.0) GO TO 601
      PCT=XMO(I,L)/YR(I)
      WRITE(6,730) MOS(L),YR(I),XMO(I,L),PCT
  730 FORMAT(' ',T12,A4,T25,F10.0,T45,F10.0,T70,F10.5)
  601 CONTINUE
  600 CONTINUE
      KK=0
      DO 115 M=1,48,4
      KK=KK + 1
      WRITE(6,930) MOS(KK)
  930 FORMAT('1',T20,'RANK-ORDER OF WEEKLY PRECIPITATION
     XACCUMULATION FOR ',A4/'0',T12,'YEAR',T22,'WEEK',T33,'TOTAL',
     XT48,'PROBABILITY'/)
      JI=M
      JK=M + 3
      DO 102 L=1,264
      BIG=0.0
      DO 100 J=JI,JK
      DO 100 I=1,66
      IF(WK(I,J).LT.BIG) GO TO 100
      BIG=WK(I,J)
      IT=I
      IJ=J
  100 CONTINUE
      IH(L)=IT + 1
      IHJ(L)=IJ
      WK(IT,IJ)=-99.0
  102 XH(L)=BIG
      DO 110 J=1,264
      XC=XH(J)
      IF(XH(J+1).LT.XC) GO TO 106
      WRITE(6,920) IH(J),IHJ(J),XH(J)
      GO TO 110
  106 DNOM=264.0
      DNUM=J
      PCT=DNUM/DNOM
      WRITE(6,920) IH(J),IHJ(J),XH(J),PCT
  920 FORMAT(' ',T10,I5,T20,I5,T30,F10.0,T50,F10.5)
  110 CONTINUE
  115 CONTINUE
      LL=0
      DO 200 M=1,24,2
```

```
      LL=LL + 1
      WRITE(6,940) MOS(LL)
  940 FORMAT('1',T20,'RANK-ORDER OF BI-MONTHLY PRECIPITATION
     XACCUMULATION FOR',1X,A4/'0',T12,'YEAR',T33,'TOTAL',T48,
     X'PROBABILITY'/)
      JI=M
      JJ=M + 1
      DO 201 L=1,132
      BIG=0.0
      DO 202 KN=JI,JJ
      DO 202 I=1,66
      IF(BIMO(I,KN).LT.BIG) GO TO 202
      BIG=BIMO(I,KN)
      II=I
      IR=KN
  202 CONTINUE
      IH(L)=II + 1
      IHJ(L)=IR
      BIMO(II,IR)=-99.0
  201 XH(L)=BIG
      DO 205 J=1,132
      XQ=XH(J)
      IF(XH(J+1).LT.XQ) GO TO 206
      WRITE(6,920) IH(J),IHJ(J),XH(J)
      GO TO 205
  206 DENOM=132.0
      DNUM=J
      PCT=DNUM/DENOM
      WRITE(6,920) IH(J),IHJ(J),XH(J),PCT
  205 CONTINUE
  200 CONTINUE
      DO 400 I=1,12,3
      II=I
      IM=I + 2
      WRITE(6,970) (MOS(J),J=II,IM)
  970 FORMAT('1',T20,'QUARTERLY PRECIPITATION ACCUMULATION.',
     X2X,3A4/'0',T12,'YEAR',T33.'TOTAL',T48,'PROBABILITY'/)
      DO 402 NM=1,66
      QRT(NM)=0.0
      DO 401 KL=II,IM
  401 QRT(NM)=QRT(NM) + XMO(NM,KL)
  402 CONTINUE
      DO 403 JB=1,66
      BIG=0.0
      DO 404 JA=1,66
      IF(QRT(JA).LT.BIG) GO TO 404
      BIG=QRT(JA)
      II=JA
  404 CONTINUE
      IH(JB)=II + 1
```

```
      XH(JB)=BIG
  403 QRT(II)=0.0
      DO 405 I=1,66
      XC=XH(I)
      IF(XH(I+1).LT.XC) GO TO 406
      WRITE (6,960)  IH(J),XH(J)
      GO TO 405
  406 DENOM=66.0
      DNUM=I
      PCT=DNUM/DENOM
      WRITE(6,960) IH(J),XH(J),PCT
  405 CONTINUE
  400 CONTINUE
      DO 300 I=1,12
      II=I
      WRITE(6,950) MOS(II)
  950 FORMAT('1',T20,'RANK-ORDER OF MONTHLY PRECIPITATION
     XACCUMULATION FOR',1X,A4/'0',T12,'YEAR',T33,'TOTAL',T48,
     X'PROBABILITY'/)
      DO 301 L=1,66
      BIG=0.0
      DO 302 J=1,66
      IF(XMO(J,I).LT.BIG) GO TO 302
      BIG=XMO(J,I)
      JJ=J
  302 CONTINUE
      XMO(JJ,I)=0.0
      XH(L)=BIG
  301 IH(L)=JJ + 1
      DO 305 J=1,66
      XT=XH(J)
      IF(XH(J+1).LT.XT) GO TO 306
      WRITE(6,960)  IH(J),XH(J)
  960 FORMAT(' ',T10,I5,T30,F10.5,T50,F10.5)
      GO TO 305
  306 DENOM=66.0
      DNUM=J
      PCT=DNUM/DENOM
      WRITE(6,960) IH(J),XH(J),PCT
  305 CONTINUE
  300 CONTINUE
      WRITE(6,980)
  980 FORMAT('1',T20,'ANNUAL PRECIPITATION ACCUMULATION BY
     XRANK-ORDER'/'0',T12,'YEAR'.T33,'TOTAL',T48,'PROBABILITY'/)
      DO 500 I=1,66
      BIG=0.0
      DO 501 J=1,66
      IF(YR(J).LT.BIG) GO TO 501
      BIG=YR(J)
      II=J
```

```
501 CONTINUE
    XH(I)=BIG
    YR(II)=0.0
    IH(I)=II + 1
500 CONTINUE
    DO 502 I=1,66
    XC=XH(I)
    IF(XH(I+1).LT.XC) GO TO 504
    WRITE(6,960)  IH(I),XH(I)
    GO TO 502
504 DENOM=66.0
    DNUM=1
    PCT=DNUM/DENOM
    WRITE(6,960) IH(I),XH(I),PCT
502 CONTINUE
    CALL EXIT
    END
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