INSTITUTE OF HYDROLOGY

Report No. 9

May 1971

RIVER LEVEL SAMPLING PERIODS

by

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A Report to the Water Resources Board

CONTENTS

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ABSTRACT

The loss in accuracy of stream flow measurement caused by a reduction in the stream level sampling frequency has been calculated for a sample of British catchments. An attempt has been made to describe the necessary sampling frequency for a given error level in terms of easily measureable catchment characteristics. Equations for predicting the necessary sampling frequency for other catchments are given, together with a statistical description of their reliability.

1. INTRODUCTION

The Water Resources Board is now collecting large quantities of stream flow data, in particular the 16 and 5 track outputs from digital stage recorders installed throughout the country as part of the hydrometric schemes. These punched tape recorders (Fischer and Porter, and Ott) record stage continuously at 15 minute intervals on paper tape which is bulky and inconvenient to use in large quantities. When considering transferring data to archival storage on magnetic tape, the Water Resources Board discussed with various interested bodies the possibility of retaining only hourly stage readings instead of transferring every 15 minutes reading to magnetic tape. The Institute of Hydrology at their request undertook the following study to examine the additional errors in computed discharge introduced by increasing the river level sampling period to, say, 1 hour from 15 minutes. The results of this study are to assist the Water Resources Board in deciding:

a. whether to transfer to magnetic tape 15 minute water levels from all stations or only from selected stations,

b. the sampling time interval for data to be transferred to magnetic tape and the corresponding error in discharge computation,

c. the most suitable sampling interval for ungauged catchments.

2. DISCUSSION OF ERRORS IN DISCHARGE COMPUTATION

2.1 Errors in calculating mean discharges from natural hydrographs

One of the most important statistics used in water resources is the daily mean discharge at a gauging station, which is calculated by taking the mean of the instantaneous discharges recorded throughout the day. The most accurate method of calculating the daily mean discharge would obviously be to find the area under the daily discharge hydrograph, but the arithmetic method is much simpler. However, the arithmetic method does have the disadvantage of making the assumption of linear interpolation between readings, which although insignificant at short time intervals, could introduce quite large errors over longer time intervals.

This error arises from two sources as shown in Figure 1. In the first case the error is due to the peak stage occurring between two stage measurements. This is a random error depending on whether or not the peak happens to occur at a time when the level is being measured. These errors can be very variable and usually tend to underestimate mean flows.

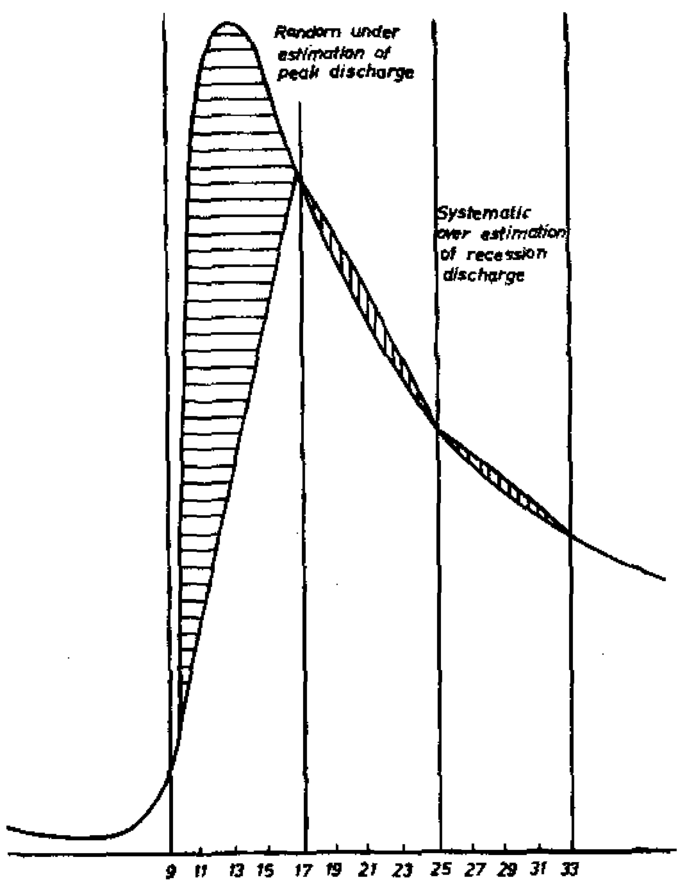
The second source of error is due to assuming straight line interpolation instead of a curve during the hydrograph recession. These are systematic errors, dependent on the sampling interval and the shape of the recession curve.

These errors tend to cancel themselves out, especially if the mean discharges are taken over a longer time period, for instance monthly or annual mean discharge.

2.2 Errors due to artificial surges

Many rivers in the United Kingdom are subject to artificial controls which can produce short but abrupt hydrograph changes. Some have locks or sluices upstream of the gauging station and others have effluent discharge or abstractions and these are noted in the description of the catchments.

FIGURE 1



TYPICAL ERRORS DUE TO 8 HOUR SAMPLING INTERVAL

FIG 1

In the final quality control of the data, sequences of stages were found that suggested surges of this type. These were retained as being characteristic of the flow being measured at that point. However there were other sequences which on closer inspection were considered to be caused by the malfunctioning of the recorder punch. The best example of that is from station 32/2 (Willow Brook) in April 1967, when sequences such as these were found:-

192	192	192	192	191	191	191	191	190	190	190	190
<u>181</u>	<u>181</u>	<u>181</u>	<u>181</u>	<u>180</u>	<u>180</u>	<u>180</u>	<u>180</u>	187	187	187	187
186	186	185	185	184	184	184	183	183	182	182	182
181	181	181	180	180	180	<u>171</u>	<u>171</u>	<u>171</u>	<u>170</u>	<u>170</u>	<u>170</u>
177	177	177	176	176	176	175	175	175	174	174	174

etc.

3. GENERAL APPROACH TO STUDY

To give a wide variety of characteristics twelve catchments have been selected from a list of suitable gauging stations supplied by the Water Resources Board. For each station stream flow data has been collected to give in most cases two years of uninterrupted data from October 1966 to September 1968 inclusive. In order to carry out the study properly it has been necessary to have 96 correct values of stage each day. This has involved collecting charts from the River Authorities and considerable editing and quality control of the Fischer and Porter punched tape data. This aspect of the study is discussed in the section on data processing and was by far the most time consuming part of the study.

The daily mean discharge is calculated, first for a 15 minute sampling interval, then for the longer periods of 30 minutes, 1, 2, 4 and 8 hours. The daily mean discharge calculated from each of the longer periods is compared with the 15 minute daily mean discharge and expressed in terms of the difference as a percentage of the 15 minute daily mean discharge. This is called a "departure" and is printed out as either positive or negative, depending on whether it is greater or less than the true daily mean discharge.

The departures found for each sampling interval are analysed over each month and year to find their mean and standard deviation. For each catchment a regression equation was found for the relationship between the sampling interval and the observed standard deviation of departure. Three values of standard deviation were selected as giving a range of permissible errors. The corresponding sampling intervals for each station were found from the sampling interval - standard deviation regression. These were then correlated with three catchment characteristics, area, rainfall and infiltration by multiple regression analysis, and prediction equations were found for estimating the required sampling interval for a given error level and catchment characteristics. Finally the prediction equations were tested by comparing the observed and predicted sampling interval using a simple error function.

4. DESCRIPTION OF GAUGING SITES AND CATCHMENTS

The following details of the gauging sites are summarised from the Surface Water Year Book of 1965.

22/3 <u>Usway Burn of Shillmoor</u>

Sharp edged weir just upstream of confluence of the River Coquet and Usway Burn.

23/1 River Tyne at Bywell

River section 2 km upstream of Bywell Bridge. Low flow measurement has been affected by removal of gravel from river downstream and re-calibration is in hand; meanwhile such flows are estimated. Pumping station upstream at Barrasford. Four reservoirs in the catchment area.

23/3 River North Tyne at Reaverhill

River section near Barrasford. One reservoir in catchment area.

28/4 River Tame at Lee Marston

River section downstream of road bridge.

28/9 River Trent at Colwick

River section, 0.8 km downstream of Holme Sluices, Colwick.

28/12 River Trent at Yoxall

River section, 24 m downstream of road bridge.

32/2 Willow Brook at Fotheringhay

Standing wave flume (Rectangular). Abstractions to industry and effluents from Corby New Town discharged into Brook. Flows over 7.4 m^3/s by-pass flume.

39/17 River Ray at Grendon Underwood

Critical depth flume (trapezoidal). Limit of measurement 5.7 m^3/s.

43/5 River Avon at Amesbury (Queens Falls)

Crump weir. About 0.05 m^3/s by-passes the station via a drainage channel. Considerable groundwater abstractions from this chalk catchment.

52/10 River Brue at Lovington

Low flows measured by Crump type triangular cross section weir; high flows by rated river section. Summer floods outside the capacity of the weir are affected by weed growth downstream of the station.

55/14 River Lugg at Byton

River section downstream of road bridge. Limit of measurement 45 m^3/s.

71/1 River Ribble at Salmesbury

River section about 1 km upstream of motorway bridge.

72/1 River Lune at Halton

River section about 50 m downstream of bridge. This station is subject to tidal influence by some spring tides. Flows above 280 m^3/s are estimated. Abstractions upstream.

Details of the catchment characteristics are given in Table I.

TABLE NO. 1

CATCHMENT CHARACTERISTICS

Station No.	Station	I.H. No.	Area km^2	Stream length km	Station level m above OD	Highest point m above OD	Mean annual catchment Rainfall* (1) 66-67 mm	(2) 67-68 mm	(3) 1916-50 mm	Infiltration Index ** mm/hr
22/3	Usway Burn at Shillmoor	101	21	13.7	207	776	1254	1211	1130	2.60
23/1	River Tyne at Bywell	102	2180	91.7	16	893	1172	1250	1044	2.21
23/3	River North Tyne at Reaverhill	103	1010	64.4	65	600	1163	1243	1062	2.26
28/4	River Tame at Lea Marston	104	795	38.6	70	389	771	876	734	4.76
28/9	River Trent at Colwick	105	7490	140.8	17	636	808	898	785	
28/12	River Trent at Yoxall	106	1230	60.3	57	318	831	869	775	3.78
32/2	Willow Brook at Fotheringhay	107	90	24.1	15	140	642	806	603	4.92
39/17	River Ray at Grendon Underwood	002	19	7.2	67	189	719	808	660	2.10
43/5	River Avon at Amesbury (Queens Falls)	108	337	37.8	67	293	901	860	795	6.80
52/10	River Brue at Lovington	109	135	20.9	20	244	1039	975	909	5.86
55/14	River Lugg at Byton	110	371	28.2	124	660	1161	1142	1023	6.61
71/1	River Ribble at Salmesbury	111	1140	111.0	8	680	1416	1686	1323	2.10
72/1	River Lune at Halton	112	995	67.6	5	737	1776	1841	1577	2.10

* As supplied by Surface Water Year Book and Meteorological Office

** Average catchment infiltration from "Hydrological Classification of soils in England and Wales" by R B Painter

TABLE NO. 2

SAMPLING INTERVAL

Month	30 min	1 hour	2 hours	4 hours	8 hours
10.66	0	1	2	4	7
11.66	0	0	0	0	1
12.66	0	1	1	4	5
1.67	0	0	0	0	3
2.67	0	1	3	3	6
3.67	0	0	0	1	1
4.67	0	0	0	0	0
5.67	0	0	0	1	1
6.67	0	0	0	0	1
7.67	0	0	0	0	1
8.67	0	0	0	0	0
9.67	0	0	0	0	0
10.67	0	0	0	1	2
11.67	0	0	0	1	2
12.67	0	0	0	2	3
1.68	1	1	1	4	4
2.68	0	0	0	0	1
3.68	0	0	0	0	0
4.68	0	0	0	0	2

Grendon Underwood

Number of days per month when daily maximum instantaneous discharge at the given sampling intervals differs from the maximum at 15 min sampling interval by more than $0.1 m^3/s$.

5. DATA PROCESSING

5.1 Preliminary program development - Grendon Underwood data

The first step taken was to prepare a program that would process the Institute's own Grendon Underwood data.

The Institute has six years of data for this station, readily accessible on magnetic tape, which has also been subjected to thorough quality control. As the data is abstracted from charts it is recorded on the basis of change in stage, rather than at regular time intervals. In order to obtain a complete set of 96 readings at 15 minute intervals for each day, intermediate readings were filled in by a cubic interpolation program. The time intervals between stage readings is only increased on very flat parts of the hydrograph, so no additional errors are introduced.

In the original program discharges were calculated at the increasing sampling intervals and for each month a linear regression was fitted by least squares to the monthly set of daily mean discharges calculated at each increasing sampling interval. The monthly mean discharge calculated at the larger sampling intervals are expressed as a percentage of the monthly mean discharge calculated from the 15 minute readings.

A short subroutine was also included which printed out the daily maximum instantaneous discharge found for each sampling interval. This indicates how often peak discharges are 'lost' with larger intervals. Having made the arbitrary assumption that an error of 0.01 m^3/s (approximately $\frac{1}{3}$ ft^3/s) is significant in the maximum instantaneous discharge, the number of occasions when that error occurs has been counted for the period October 1966 to April 1968. These are tabulated in Table 2. On these results it was not considered worthwhile running that subroutine with other stations, although this could easily be done if there was a specific need for an analysis of the errors in maximum discharges at longer sampling intervals.

5.2 Preliminary program development - Water Resources Board data

The Water Resources Board data being used is derived from Fischer and Porter punched tape recorders in the form of 5-track paper tape in Ferranti code. This allows the efficient handling of data with programs written in machine language, but does not facilitate the use of more sophisticated programming languages. As the Water Resources Board did not have programming time available to re-write the Institute of Hydrology's Fortran program, and the Institute of Hydrology's programmers have not had experience of Ferranti code, alternative measures had to be taken. Initially an attempt was made to write a PLAN subroutine which enables the 5-track Ferranti code data to be read into a Fortran program. However, neither the Water Resources Board nor Institute of Hydrology programmers were successful in this and it was abandoned. Some preliminary results were obtained by slightly modifying the Institute of Hydrology's Fortran program to run on the Water Resources Board computer and running it with selected error free data which had been previously translated from 5-track to 8-track paper tape. This was obviously a laborious exercise and the Water Resources Board Computing Section did not feel able to spend further computing time on the translation of tapes. Another major problem was that it was not possible to edit and correct at the Water Resources Board the many months of paper tape that were not perfect. Alternative methods of data processing were developed which avoided imposing a further load on the Water Resources Board Computer.

5.3 Preliminary Quality Control

The first step in assessing the quality of the data was to examine the monthly summary print out sheets from the computer. In the first instance the summaries that were examined did not have the error code messages or number of daily values listed. The sheets were annotated, however, in cases where more than four readings per day were incorrect. To find further details of errors the master files were then examined and photocopies taken of all monthly summaries for the 288 station months under consideration. Twelve suitable stations, over the water years 1966-1968, were selected on the grounds that earlier records would require even closer scrutiny.

The errors or omissions for the 288 station months, as shown by the master copies of the monthly summary sheets, were then examined. 118 out of the 288 months had at least one day with less than 96 readings or other anomalies requiring clarification. To examine these in greater detail, listings of the 5-track stage tapes were obtained for every month containing errors and these were examined by eye. The types and number of errors found are summarised in Table No. 3. It became clear, however, that a far more detailed quality control was required for all data and that a considerable amount of editing would have to be done.

5.4 Errors found by preliminary quality control

The errors found in the stage listings were of the following types. The code letters refer to the table of errors.

Description	Code
1. An obviously artificially induced flow caused by abstraction, blocking of stream or float sticking	Art
2. Discontinuity between readings	
e.g. 1234 1235 1211 1212	S
3. Discontinuity between readings and between days	SD
4. Discontinuity between readings and between months	SM

e.g. 0123 0123 0123 0123 0123 0123 0123 0123 0123 0123

0123 0124 0124 0124 0125 0125 0125 0126 0126 0126

End of month

New month

0051 0051 0052 0052 0052 0053 0053 0054 0054 0054

0054 0055 0055 0054 0054 0053 0053 0053 0053 0053

Description	Code
5. Several obviously wrong readings giving a 'trough'. Often due to last two digits mispunched, usually as zeros	
e.g. 3467 3468 3400 3400 3400 3472	ZT
6. One reading obviously wrong or out of place	
e.g. 0179 0178 0019 0174 etc.	Z

TABLE NO. 3

ERRORS FOUND IN 118 STATION MONTHS OF STREAM FLOW RECORDS EXAMINED

Station		22/3	23/1	23/3	28/4	28/9	28/12	32/2	43/5	52/10	55/14	71/1	72/1	Total
Probable source of Error	Code													
External: abstraction or discharge; float sticking	Art	1						4						5
External or F & P mispunching	S,SM,SD,	2		5	1	1			1		2	2	2	16
	ZT	2	8	1								2		13
														34
Fischer and Porter mispunching	Z	18	11			1		3	1					34
	EV			1		4	5			2	2			14
														48
Fischer and Porter mispunching or d-mac translation error (misreading, mispunching)	ZO	7	4	8	4	7	3	10	3	6	20	13	6	91
	X,Y	2	3	5	15	14	8	10	5	7	1	18	5	93
	D	1	2	3	15	4	4	2	3	6	1	3		44
														228
Processing program misreading	NL	6	3	6	6	2	5	2	5	5	1	3	7	51
Miscellaneous			1	6				3	1	1	3	1		16
														67
Total Errors		39	32	35	41	33	25	34	19	27	30	42	20	377
Missing data														
No. of days missing in monthly data at WRB			5	6	12	12		21				44		100
No. of months completely missing from WRB				1		10	5			1				17

		Code
7.	Whole months of data with the last digit in each number being even due to the omit punch on the F & P not operating	EV
	e.g. 0178 0178 0176 0176 0174 0174 0172 0172	
8.	A single reading of four zero's	ZO
	e.g. 0123 0133 <u>0000</u> 0134	
9.	More than 96 readings in one day	X
10.	Less than 96 readings in one day	Y
11.	Row of figures displaced often caused by omission of one digit	D
12.	An error recorded by processing program but not found in stage listings	NL
13.	Miscellaneous errors include:	

(i) Several days of meaningless readings

(ii) Several lines of stage data repeated later in the day or month

(iii) No blank lines between days

(iv) Wrong number of days in the month

(v) Stage readings read as station number, etc.

The type and numbers of errors found in each station have been tabulated in Table No. 3. But it must be emphasised again that these were the errors found only in the months for which listings were obtained from WRB. Although the 118 months of data examined were all those that contained errors as found by the WRB quality control program, it was not verified that the remaining data were in fact perfect.

A monthly count has also been made of the errors listed by the WRB quality control program in the master copy of the monthly summaries. The number of days containing these errors has been tabulated for each month and station in Table No. 4.

5.5 Final program development

A major decision was taken in October 1969 to transfer all Water Resources Board data to be used in the study on to magnetic tape to be processed on Atlas. The reasons for this decision were as follows:

(i) A careful examination of the data has shown that there were far more errors and missing data than originally anticipated.

(ii) The nature of the study demands 96 values of perfect data each day and so a much more sophisticated form of quality control is needed than is usually required for water resources purposes. IH already has good quality control programs and these were amended to handle WRB data.

TABLE NO. 4

NUMBER OF DAYS CONTAINING ONE OR MORE ERRORS AS LISTED BY WRB QUALITY CONTROL

Station Number	22/3	23/1	23/3	28/4	28/9	28/12	32/2	39/69	43/5	52/10	55/14	71/1	72/1
Month and Year													
10/66	1	1			1		1			1			1
11	1			1						3	9		
12	1		1	1		1	6		1	2		11	
1/67	1			3	2	5	1				2	13	
2	1			1			5		8	1		3	
3				3					8				
4	1			4		1						1	3
5			2	2	11	1	3					2	
6					1								
7			3		1		7		1	1			
8				1							2		1
9		1		3					1	1			
10		2	3	6			1		2		1		
11			1	4	4 Data ends					1			1
12			1	1								2	
1/68	3	9	1									1	2
2		1				1	1						
3		3	3			1	1			4			
4		4	5	1		1				1			
5				1		Data ends	2					1	
6	4		1	3						1		24	2
7	1	14	1	2							1	9	2
8		1	2	1						1		19	4
9		3	3				20				1	1	
TOTAL	14	26	27	38	20	11	41		21	17	16	87	16

(iii) At the time (October 1969) no facilities existed at WRB for large scale editing of paper tapes and there were no spare staff to do the job. In any case the paper tapes in their existing format would be very difficult to edit.

(iv) With the formation of the Floods Studies Team at IH interest has developed in countrywide streamflow data and it was decided that it would be useful to have the WRB data on magnetic tape, as part of our data bank.

(v) IH's data processing system was about to be improved by the addition of a program which would allow easy editing of raw data on magnetic tape. (Previously all raw data was punched on cards and quality control run using card input; data was only transferred to magnetic tape when perfect). This would considerably facilitate the editing procedure.

(vi) Data on magnetic tape would enable the final program to be run on Atlas which is much more convenient for IH, as well as WRB whose computer has little spare time available.

(vii) Inspection of the data showed that about 35 charts would have to be obtained from River Authorities to fill in gaps caused by missing data. The easiest way of doing this is to digitise the charts using the Institute's chart follower, which outputs in a format acceptable by Atlas.

Preliminary data assembly involved collecting copies of the 5-track tapes of stage from the WRB archives. Consecutive months were spliced together by WRB into eight month reels, which greatly helped IH, although there was some confusion on the odd occasions when tapes were spliced in the wrong order or back to front. Also some 35 stage charts of varied types were collected from five River Authorities and digitised using the d-mac chart follower.

The programs that were subsequently used to handle all these data have been developed as an integral part of the Institute's data processing system. As efficient data handling is the foundation to all water resources research and management, much effort has been put into developing a unified processing system for all hydrological data. It is hoped that a comprehensive data processing manual will be published by the Institute in the near future. Briefly, however, the system accepts data of any input type (cards, 5 or 8 track paper tape or magnetic tape) at any sampling frequency and outputs at any required frequency, having processed and quality controlled the data and put it on magnetic tape files.

So that the method of quality control analysis and output format can be easily understood some notes are given on the program's uses and the problems encountered with the data. Figure 4 gives a flow diagram of the various stages involved in the data collection, processing and analysis.

5.5.1 Flow preprocessing program

This program accepts both the Water Resources Board data on 5-track paper tape and the output from the d-mac on 8-track paper tape. The 5-track tapes almost all have 96 readings of stage each day (at 15 minute sampling intervals) and where there are 288 readings (5 minute intervals) only every third value is used. All the stage recorder charts are digitised at time intervals sufficiently close to define the hydrograph accurately and the program then uses a cubic interpolation program between these values to give the required 96 readings per day.

The main routine of the flow preprocessing program controls the transfer of data day by day. The Lead and Control cards are read and written on to the magnetic tape at the beginning of every month. The input frequency index on the control card gives the number of readings per day that are to be written on to tape and the data form card which follows directs subsequent data to one of two subroutines:

a. Water Resources Board Tape

This subroutine transfers the 5-track tapes from Water Resources Board on to magnetic tape and its development has presented one of the most difficult problems encountered in the data processing system. The Water Resources Board tapes when perfect have the format of 96 uninterrupted readings of stage with end of line characters only at the end of each day, i.e. after about 480 characters. Unfortunately the Atlas input buffer accepts only 159 characters at a time, so that the last 67% of each day's data is lost. The solution to this problem was eventually found by reading the 5-track tape a character at a time, using the Atlas library subroutine Tape 5. This subroutine is, in turn, controlled by another subroutine, Track 5.

Considerable development of Track 5 was required to overcome all the possible mispunchings of the Water Resources Board tapes. One of the most difficult problems was to find a suitable method of ignoring accidentally punched letter-shift characters, which causes all subsequent punchings to be coded alphabetically rather than numerically. In such a case when a letter-shift character has been encountered and subsequent alphabetic codes are indicated by punchings which could also be for the numbers 0 - 9, the Tracks subroutine interprets the code as the corresponding number.

Another difficulty arises in identifying the end of days and months, which are indicated by the line feed and carriage return, line feed symbols respectively. Line feeds are frequently either omitted or inserted in the wrong place. If a line feed has been omitted then the day is assumed to have ended after 106 readings and a new day is begun. Where a superfluous line feed appears in the data this must be positively identified and read as the end of the day, because input data can have any number of daily readings. All subsequent days are then written a day later and there is an extra day's data at the end of the month. This fault can be corrected during editing by an updating subroutine which changes the dates of the data.

The end of a month is far more difficult to recognise correctly. As the end of the month is transmitted by a "shift to outer set" code, which is also transmitted by any other outer set character accidentally punched, such as the frequent rub-out symbol, a more complex sequence of characters is used to signal the end of a month when it is not expected. When the main routine expects the end of a month after 28, 29, 30 or 31 days it calls subroutine WRBFIN. This finds the end of the month signal and counts any additional stray characters before the month end. If the end of month symbol has been omitted, WRBFIN accepts a sequence of 40 blank characters as adequate justification for assuming the end of the month's data.

b. Cubint

This subroutine will either deal with card or 8-track input. The output from the d-mac is in the form of a list of readings of time with corresponding readings of stage. A Fortran Library subroutine TB03A is used to fit the best cubic curve to sets of three points at a time using end gradients to ensure continuity. Using the centre portion of the curves to define the hydrograph, Cubint locates the required time points and its corresponding stage and the data is written on to tape.

c. Preprocessing quality control

The preprocessing program does some basic quality control, which is usually sufficient to indicate the main bulk of editing required. The number of readings recorded for each day of the month is printed, together with the number of extra stray characters found at the end of the month.

5.5.2 Editing program

The preprocessing program writes the stage data on to magnetic tape in lines of twelve readings with eight lines to a day. Each line is identified by a line number and has details of the catchment number and date as well as the various indices required in the programs. This enables the data to be edited line by line as required. The three operations possible are deletion, amendment and insertion of any numbered line of data. The original data is numbered so as to allow the insertion of up to nine lines of additional data. The amendments are punched on cards, each line requiring a card with the line number and edit instruction code and second card with the revised line of data. A deck of these amendments is then run with the edit program.

To reduce the quantities of cards punched a subroutine has been developed which will alter the date on any line of data. This is very useful where extra line feeds appear in the data which are read as end of day signals thus writing the rest of the months data a day late.

5.5.3 Quality Control Program

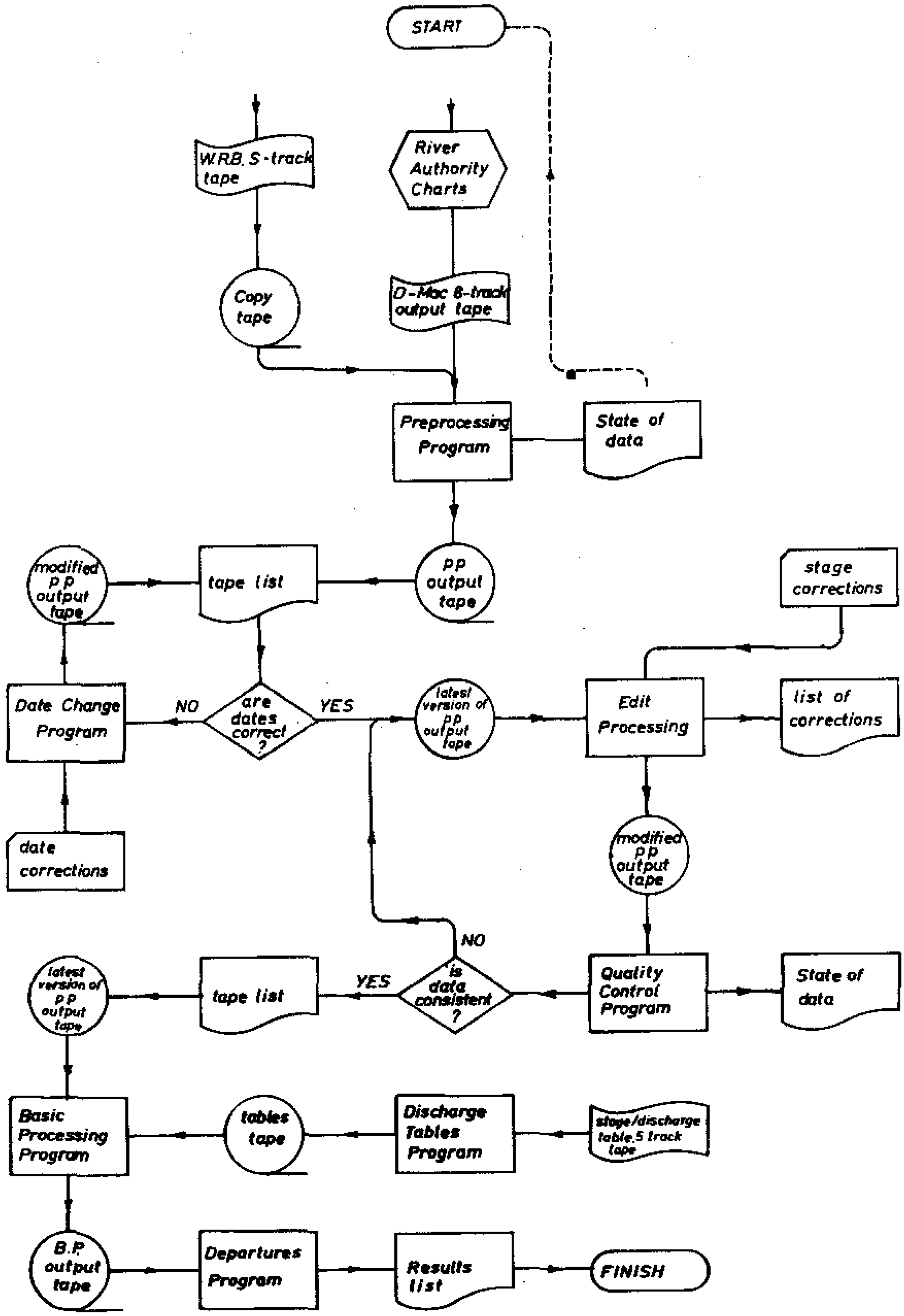
The quality control program used is basically the standard program used by the Institute for its own flow data, but with a number of additional features to deal with River Authority data. The suspected errors are listed, giving the date, type of error and reading number in the day. The program used is rather more sensitive than is really necessary, querying sequences that were in fact correct, but this can be seen quickly on inspection of the listings.

The program checks for stages exceeding the maximum stage given on the control card at the beginning of the month. The first and last three readings of each month are printed to check for inconsistencies between months. In particular the program spots marked sharp discontinuities within a days reading, which could be caused by the recorder punch only partially operating. It also looks for troughs with flat bottoms and peaks with flat tops. In all these cases each reading is compared with the three readings before and after it. Figure 2 gives a flow diagram of the data processing system.

5.6 Stage-discharge Tables

The stage-discharge 'look up' tables provided by WRB are again on 5-track

FIGURE 2



DATA PROCESSING FLOW DIAGRAM

FIG 2

paper tape and consist of a list of discharge values in ft^3/s for increments of one hundredths of a foot of stage. Thus the 109th discharge in the list gives the flow for a stage of 1.09 ft. The tables have been mounted on magnetic tape using metric units, which has necessitated some interpolation. Some of the tables needed quality control and editing to correct punching or translation errors.

5.7 Analysis Program

The program computes and prints daily mean discharge in mm, using 97 values of stage and the trapezoidal rule:

$$Q = \left(\frac{Q_1}{2} + Q_2 + \ldots . Q_{96} + \frac{Q_{97}}{2}\right)$$

$$\bar{Q} = Q/96$$

The daily mean discharge calculated from the 97 values of stage at 15 minute intervals is regarded as the "time" daily mean discharge. The daily mean discharge is then calculated again using longer sampling intervals:

Sampling in interval	No. of Stages
15 min	97
30 min	49
1 hour	25
2 hours	13
4 hours	7
8 hours	4

The daily mean discharges calculated at these intervals were then expressed in terms of "departures" from the "true" daily mean discharge e.g.

$$D_{30} = \frac{(Q_{30} - Q_{15})}{Q_{15}} \quad 100\%$$

Where: D_{30} is the departure from the dmd in % of the dmd.

Q_{30} is the dmd calculated at 30 minute sampling interval

Q_{15} is the dmd calculated at 15 minute sampling interval

The departures are printed with a negative sign when less than the daily mean discharge.

The departures thus obtained are analysed over three time periods:

(i) Monthly

(ii) Annually (water years used)

(iii) The two years October '66-September '68, or the maximum period for which records are available during this time.

The means and standard deviations of the departures over these periods have been calculated and analysed statistically.

6. DISCUSSION OF RESULTS

6.1 Analysis of means of departures

The departures are expressed as a percentage of the daily mean discharge calculated from 97 instantaneous values of discharge. The means of the departures were calculated for each sampling interval over monthly and annual periods. These are shown in Tables 5-20 (see Appendix I).

At a 30 minute sampling interval the largest monthly mean departure was 0.134% (Lune at Halton) and practically all the remaining monthly means were below 0.05%, with a large proportion below 0.005%.

At a 2 hour sampling interval the largest monthly mean departure was 0.787% (Lune at Halton), with all other monthly means below 0.375%. Four stations had all their monthly means below 0.1% (Trent at Yoxall, Willow Brook at Fotheringhay, Avon at Amesbury, Lugg at Byton).

At an 8 hour sampling interval, the largest monthly mean departure was 4.76% (Usway Burn at Shillmoor). Three stations had monthly mean departures less than 1% (Trent at Yoxall, Willow Brook at Fotheringhay, Lugg at Byton).

The monthly means were given as either positive (over-estimate) or negative (under-estimate). It was thought that over-estimates would tend to occur in dry months with recessions predominant and that under-estimates would occur in wet months with flashy hydrographs. However, it was not possible to see any significant trends when comparing the monthly mean departures with monthly rainfall.

When comparing the means at the five intervals for a given station and month, there is no marked relationship between them. A large mean departure at 30 minutes does not necessarily mean a large mean departure at 2 hours or even 8 hours. For a given month the largest mean departure is not necessarily found at the 8 hour sampling interval. However, it is generally found that the monthly means of departure increase with the sampling interval.

The means of departures were also calculated over the two water years 1966-1967 and 1967-1968; these are shown in Tables 18-20. It should be noted that not all stations have complete data and the annual means are not shown for these stations. As would be expected the means are much smaller when taken over a longer period of time.

At a 30 minute sampling interval, the largest mean annual departure found was 0.009% (Usway Burn, 67/68), with all remaining stations falling below 0.05%.

At a 2 hour sampling interval, the largest mean annual departure found was 0.139% (Usway Burn, 67/68) with all remaining stations falling below 0.05%.
At an 8 hour sampling interval, the largest mean annual departure found was 0.768% (Usway Burn, 67/68), with only four station years falling below 0.1%

(Trent at Colwick, 66/67, Willow Brook at Fotheringhay, 66/67 and 67/68, Lugg at Byton, 67/68).

Analysis of the mean departures shows that if one is only concerned with annual volumes of flow, these can be estimated with considerable accuracy (about $\pm \frac{1}{2}$%) using an 8 hour sampling interval. For most practical purposes these small mean departures can be regarded as zero and neglected.

6.2 Analysis of standard deviation of departures

As analysis of the mean annual departures has shown them to be effectively zero, daily variations throughout the year are given by the standard deviation of the departures. When dealing with daily mean discharge this will give an index of the mean error likely in any one day, as a percentage of the daily mean discharge.

Tables 21-33 give the standard deviations of departures (as % of dmd) by months for the five sampling intervals.

The standard deviations increase with the larger sampling intervals approximately linearly when plotted on log-log paper. For comparison these curves of the months having the greatest and least standard deviation have been plotted for each station. These are shown in Figures 3-14; the mean values for the period of records are shown in Figures 15-16 (see Appendix II).

The months having the greatest standard deviations at each station are given at three sampling intervals and are shown in Table 37.

TABLE NO. 37

MAXIMUM STANDARD DEVIATIONS ON RECORD

Station	Month	30 minute	2 hours	8 hours
22/3	6/68	0.405	5.155	32.021
23/1	10/67	0.086	0.866	12.885
23/3	5/67	0.051	1.610	16.432
28/4	6/68	0.020	0.707	7.766
28/9	7/67	0.115	0.477	4.044
28/12	7/67	0.031	0.114	2.150
32/2	6/68	0.042	0.136	5.948
43/5	10/66	0.053	0.201	1.091
52/10	10/66	0.069	0.431	7.880
55/14	7/67	0.034	0.252	2.607
71/1	3/68	0.033	0.797	9.040
72/1	3/68	0.224	3.579	11.942
39/17	6/66	0.05	0.82	11.28
"	7/67	0.07	0.65	13.28

At a 30 minute sampling interval all the stations have a standard deviation of departure below 0.5% and ten of the thirteen stations are below 0.1%.

At a 2 hour sampling interval all the stations have standard deviations below 5.2% and ten of the thirteen are below 1%.

At an 8 hour sampling interval all stations have standard deviation below 32%; five stations are in the range 10-16% and seven between 1 and 10%.

Although adjacent basins often have the largest standard deviations on the same months these are not usually the wettest (or the driest) months in the two year record. There seemed no obvious correlation with rainfall.

6.3 Regression of Standard Deviation of Departure and Sampling Interval

For each data batch the relationship between the standard deviation of departures from daily mean discharge and sampling interval was found. In about 50% of cases this relationship could be best expressed as a straight line. It is clear, however, that the relationships cannot be described by one parameter alone, and in the cases where a straight line is not applicable, even two parameters are insufficient (see Table 38 for data batch 1).

The intercepts of each curve at three representative error levels were therefore taken as being the most satisfactory way of describing the curves. The error levels chosen were:-

Standard deviation of departure, $Y1 = 0.10\%$
Standard deviation of departure, $Y2 = 0.50\%$
Standard deviation of departure, $Y3 = 1.00\%$

Tables 40 and 41 give these data for each data batch with the associated catchment characteristics.

6.4 Data Batches Used

1. Tables 5 to 20 show that there are some months in the two water years selected when it has not been possible to obtain data. These are summarised below:-

Station	Missing Months
22/3	Complete
23/1	1/68-9/68 inclusive
23/3	8/68, 9/68
28/4	Complete
(28/9	12/67-9/68 inclusive)
28/12	Complete
32/2	Complete
43/5	Complete
52/10	8/68
55/14	Complete
71/1	9/68
72/1	11/66, 12/66, 9/68

With the exception of station 28/9, this list comprises the first batch of data - 252 station months out of a possible total of 268. Station 28/9 was rejected at this stage because it was found that the derived sampling intervals

TABLE NO. 40

BATCH 1 DATA FOR MULTIPLE REGRESSION

Station	X_1 Hr	X_2 Hr	X_3 Hr	Area Km^2	Rain mm	Infiltration mm/hr
22/3	0.26	0.81	1.33	21	1130	2.60
23/1	0.72	1.72	2.51	2180	1044	2.21
23/3	0.64	1.58	2.33	1010	1062	2.26
28/4	0.98	2.37	3.46	795	734	4.76
28/12	1.17	4.90	9.06	1230	775	3.78
32/2	1.10	3.30	5.31	90	603	4.92
43/5	1.27	5.82	11.22	324	795	6.80
52/10	0.50	1.71	2.88	135	909	5.86
55/14	1.32	4.57	7.80	203	1023	6.61
71/1	0.65	1.87	2.95	1140	1323	2.10
72/1	0.26	0.91	1.55	995	1577	2.10

TABLE NO. 41

BATCH 2 DATA FOR MULTIPLE REGRESSION

Station	Year	X_1 Hr	X_2 Hr	X_3 Hr	Area Km^2	Rain mm	Infiltration mm/hr
39/17	64/65	1.00	2.50	3.70	19	614	2.10
39/17	65/66	1.09	2.39	3.34	19	719	2.10
39/17	66/67	0.74	2.02	3.11	19	715	2.10
39/17	67/68	1.00	2.40	3.50	19	758	2.10
22/3	66/67	0.36	0.96	1.46	21	1254	2.60
22/3	67/68	0.25	0.74	1.18	21	1211	2.60
23/1	66/67	0.70	1.59	2.32	2180	1172	2.21
23/3	66/67	0.61	1.46	2.12	1010	1163	2.26
28/4	66/67	1.00	2.42	3.56	795	771	4.76
28/4	67/68	0.98	2.34	3.40	795	876	4.76
28/12	66/67	1.26	5.02	7.53	1230	831	3.78
28/12	67/68	1.34	5.30	7.80	1230	896	3.78
32/2	66/67	1.27	3.38	5.13	90	642	4.92
32/2	67/68	1.26	3.50	5.24	90	806	4.92
43/5	66/67	1.40	6.18	11.70	324	901	6.80
43/5	67/68	1.17	5.60	8.63	324	860	6.80
52/10	66/67	0.49	1.76	2.95	135	1039	5.86
52/10	67/68	0.46	2.38	3.64	135	975	5.86
55/14	66/67	1.33	4.27	7.05	203	1161	6.61
55/14	67/68	1.62	5.20	8.05	203	1142	6.61
71/1	66/67	0.54	1.72	2.85	1140	1416	2.10
71/1	67/68	0.88	2.13	3.12	1140	1686	2.10
72/1	67/68	0.28	0.94	1.59	995	1841	2.10

were very small due to the proximity to the artificial control of Holme Sluices. This batch utilises the most station record data available but the missing months could introduce bias. This batch should provide the best estimate of the observed sampling intervals, X1, X2, X3, corresponding to the selected standard deviations, Y1, Y2, Y3. In the multiple regression of X values with catchment characteristics, the 1915-1950 mean annual rainfall has been used to avoid exaggerating the bias caused by missing months. These data are summarised in Table 40.

2. Batch 1 only provided 11 sets of data for correlation with catchment characteristics. It was thought desirable to increase the sample size by using all available data from Grendon Underwood and using complete station years of record which would be correlated with annual rainfall, area and infiltration. This batch comprised 23 complete station years and is summarised in Table 41.

6.5 Multiple Regression with Catchment Characteristics

The regression analysis was carried out using a standard statistical package (A Statistical Computing Procedure by B E Cooper) on the Atlas Computer at Harwell. The output gave the values of the regression coefficients, their variance and co-variance, analysis of variance of fit, summary of input data and a correlation matrix for input data. The program also plotted the observed and calculated values of sampling interval for each equation and these are shown in Figures 18-29. The data used for these plots are found in Tables 51 and 52. (See Appendix II).

The two batches of data listed in Tables 40 and 41 were fed into the regression analysis package. On each batch of data two multiple regressions were tried:-

(i) Observed sampling intervals X_1, X_2, X_3 with catchment characteristics area and rainfall.

(ii) Observed sampling intervals X_1, X_2, X_3 with catchment characteristics area, rainfall and infiltration.

(a) Data batch 1: 11 station records

The data was tested for internal correlations and the results are as follows:-

TABLE NO. 42

COEFFICIENTS OF CORRELATION BETWEEN SAMPLING INTERVALS

	X_1	X_2	X_3
X_1	1.00	0.92	0.87
X_2	0.92	1.00	0.99
X_3	0.87	0.99	1.00

TABLE NO. 43

COEFFICIENTS OF CORRELATION BETWEEN CATCHMENT CHARACTERISTICS

	Area	Rain	Infiltration
Area	1.00	0.28	- 0.62
Rain	0.28	1.00	- 0.62
Infiltration	- 0.62	- 0.62	1.00

TABLE NO. 44

COEFFICIENTS OF CORRELATION BETWEEN SAMPLING INTERVAL AND CATCHMENT CHARACTERISTICS

	X_1	X_2	X_3
Area	- 0.10	-0.19	- 0.20
Rain	- 0.69	-0.59	- 0.54
Infiltration	0.69	0.72	0.70

(b) Data batch 2; 23 station years

The internal correlation results are as follows:-

TABLE NO. 45

COEFFICIENTS OF CORRELATION BETWEEN SAMPLING INTERVALS

	X_1	X_2	X_3
X_1	1.00	0.87	0.82
X_2	0.87	1.00	0.99
X_3	0.82	0.99	1.00

TABLE NO. 46

COEFFICIENTS OF CORRELATION BETWEEN CATCHMENT CHARACTERISTICS

	Area	Rain	Infiltration
Area	1.00	0.41	- 0.28
Rain	0.41	1.00	- 0.25
Infiltration	- 0.28	- 0.25	1.00

TABLE NO. 47

COEFFICIENTS OF CORRELATION BETWEEN SAMPLING INTERVAL AND CATCHMENT CHARACTERISTICS

	X_1	X_2	X_3
Area	- 0.08	-0.05	- 0.07
Rain	- 0.50	-0.38	- 0.34
Infiltration	0.52	0.68	0.71

Tables 42 and 45 show a high degree of correlation between the sampling intervals, as is to be expected.

Tables 43 and 46 show varying degrees of correlation between the catchment characteristics. This makes it difficult to assess the importance of individual parameters. Batch 2 data shows less internal correlation in Table 46 which is probably due to the influence of the four years of Grendon data (small area, low rainfall, low infiltration) over the other stations which have only one or two years of data. In batch 1 data the catchment characteristics for each station carry equal weight.

Tables 44 and 47 show a fair correlation between infiltration and sampling interval but this is inevitably linked with rainfall. However, it can be seen that area is the least important of the three catchment characteristics considered. It should also be noted that there is a significantly better correlation between the sampling interval and the long term mean annual rainfall in batch 1 than with the mean annual rainfall used in batch 2. This is due to the smoothing effect of the long term average and results in better coefficients of correlation for batch 1 data.

The basic statistics of the input data are shown in Table 48.

TABLE NO. 48

	Batch 1		Batch 2	
	Mean	St.dev.	Mean	St.dev.
X_1	0.806	0.384	0.914	0.394
X_2	2.687	1.709	2.878	1.619
X_3	4.581	3.331	4.476	2.721
Area	738.5	661.9	727.6	587.6
Rain	997.6	281.2	1018.3	318.6
Infiltration	4.00	1.87	3.91	1.84

The sampling intervals have slightly smaller variances in the batch 2 data, but the annual rainfall data of batch 2 has a standard deviation 13% greater than in batch 1.

6.6 Multiple regression prediction equations

The equations derived are of the form:-

$$\text{Log } X = \text{Log } K + a \text{ Log Area} + b \text{ Log Rain} \quad \text{and}$$

$$\text{Log } X = \text{Log } K + a \text{ Log Area} + b \text{ Log Rain} + c \text{ Log Infiltration}$$

Table 49 gives the results of the regression analysis, the first six equations being for batch 1 data, the second six for batch 2 data. The constants K, a, b, c, are given as natural numbers but the variances are given as logarithms. The residual variance calculated is unbiased estimate, which is adjusted for the correct number of degrees of freedom. This is necessary because of the small sample size:-

$$\text{Biased estimate of variance} = \frac{S.S.}{N}$$

$$\text{Unbiased estimate of variance} = \frac{S.S.}{D.F.}$$

S.S. = Sum of squares of deviations from regression line

N = Sample size

D.F. = Degrees of freedom, N - m

m = Number of parameters

The coefficients of determination and correlation were both calculated using the logarithms of the unbiased estimates of variance:-

$$r^2 = 1 - \frac{\text{Residual variance}}{\text{Original variance}}$$

The standard factorial error of estimate given is calculated as:-

$$s\ f\ e\ e = \text{antilog } (\sqrt{\text{Residual variance}})$$

When the logarithm of a quantity x has a variance of σ^2 the standard error of log x is σ, this corresponds to a multiplying or dividing error in x of antilog σ(67% confidence limits) or antilog 2σ (95% confidence limits).

i.e. upper limit $x \times \text{antilog } \sigma$

lower limit $x \div \text{antilog } \sigma$

If the confidence limits are required as a percentage of x, the procedure is as follows:-

Upper limit: find antilog σ (or 2σ)
subtract 1 and express as percentage

e.g. $\sigma = 0.1$ $\quad 2\sigma = 0.2$

antilog 0.2 = 1.585

1.585 - 1 = 0.585 = 58.5%

TABLE NO. 49

RESULTS OF MULTIPLE REGRESSIONS

EQ.No.	Dependent Variable	k	a	b	c	Original Variance	Unbiased Residual Variance	Unbiased Coeff.of Corr. r	Unbiased Coeff.of Det. r^2	Factorial Standard Error of Estimate
1.1.1	Log X_1	26,260.0	0.1654	- 1.676	-	0.06464	0.02820	0.751	0.564	1.47
1.1.2	X_2	80.2	0.2180	- 0.9949	0.6206	0.06464	0.02087	0.823	0.677	1.39
1.2.1	X_2	137,000.0	0.1333	- 1.721	-	0.08164	0.04922	0.630	0.367	1.66
1.2.2	X_2	16.7	0.2151	- 0.6612	0.9656	0.08164	0.02874	0.805	0.648	1.48
1.3.1	X_3	282,900.0	0.1185	- 1.742	-	0.09437	0.06463	0.561	0.315	1.79
1.3.2	X_3	9.15	0.2124	- 0.5260	1.108	0.09437	0.03764	0.775	0.601	1.56
2.1.1	Log X_1	5,764.0	0.1470	- 1.401	-	0.05389	0.03058	0.658	0.433	1.49
2.1.2	X_1	1,656.0	0.1240	- 1.251	0.2671	0.05389	0.02902	0.679	0.461	1.48
2.2.1	X_2	15,930.0	0.1768	- 1.411	-	0.06631	0.04206	0.605	0.366	1.59
2.2.2	X_2	971.0	0.1252	- 1.074	0.5990	0.06631	0.02834	0.757	0.573	1.47
2.3.1	X_3	13,800.0	0.1733	- 1.325	-	0.06820	0.04722	0.555	0.308	1.65
2.3.2	X_3	603.0	0.1156	- 0.948	0.6704	0.06820	0.02974	0.751	0.564	1.49

Lower limit: find antilog (1 -) (or 2)
subtract __from__ 1 and express as percentage

e.g. 2σ = 0.2

antilog (1 - 0.2) = 0.63

1 - 0.63 = 0.37 = 37%

The variances of the individual regression parameters are given in Table 50. There is little difference between the variances of the two and three parameter models at each sampling interval. However the variances increase with sampling time and those in data batch 2 are much smaller than those for data batch 1.

From Table 49 it can be seen that slightly better correlations are obtained with batch 1 data and that the inclusion of the infiltration parameter improves the correlation, such that 60 - 68% of the variance is accounted for. The residual variances and factorial standard error of estimate increase as the sampling time (X_1, X_2, X_3) increase. There is not a great deal of difference between the standard errors in each data batch, although batch 2 tends to have slightly lower standard errors, due to the larger sample size.

Taking into consideration the results given in Tables 49 and 50, it is suggested that the following prediction equations be used:-

EQ.2.1.2 $\text{Log } X_1 = \text{Log } 1656.0 + 0.1240 \text{ Log Area} - 1.251 \text{ Log Rain} + 0.2671 \text{ Log Infiltration}$

EQ.2.2.2 $\text{Log } X_2 = \text{Log } 971.0 + 0.1252 \text{ Log Area} - 1.074 \text{ Log Rain} + 0.5990 \text{ Log Infiltration}$

EQ.2.3.2 $\text{Log } X_3 = \text{Log } 603.0 + 0.1156 \text{ Log Area} - 0.948 \text{ Log Rain} + 0.6704 \text{ Log Infiltration}$

The reasons for choosing these equations from batch 2 data instead of batch 1 data are:-

(i) The batch 2 regression line coefficients have much smaller variances (by about one third) than batch 1 regression lines. See Table 50. In other words the regression lines themselves are more reliable.

(ii) The original variances of batch 2 data are smaller than those for batch 1.

(iii) The values of residual variances for X_2 and X_3 are slightly smaller in batch 2 than batch 1.

(iv) Although the coefficients of correlation and determination are rather better for batch 1 data, the standard error of estimates are slightly better for the X_2 and X_3 equations in batch 2.

6.7 Use of Results

(i) General approach

If it is not thought necessary to choose sampling intervals for each catchment individually or by groups and the sample of 12 catchments

TABLE NO. 50

VARIANCE OF REGRESSION COEFFICIENTS

EQ.No.		a	b	c
1.1.1	X_1	0.0079	0.2039	-
1.1.2		0.0065	0.2726	0.1010
1.2.1	X_2	0.0137	0.3559	-
1.2.2		0.0090	0.3755	0.1391
1.3.1	X_3	0.0180	0.4673	-
1.3.2		0.0118	0.4918	0.1822
2.1.1	X_1	0.0033	0.1077	-
2.1.2		0.0034	0.1132	0.0344
2.2.1	X_2	0.0045	0.1482	-
2.2.2		0.0033	0.1105	0.0336
2.3.1	X_3	0.0050	0.1664	-
2.3.2		0.0034	0.1160	0.0353

examined is considered to be representative and containing the extremes in flashy catchments, then Figure 30 can be used to choose an overall sampling interval for an acceptable error level (standard) deviation of departure).

Figure 30 is plotted from the values of observed sampling intervals found for the three levels of standard deviation, 0.1%, 0.5% and 1.0% of daily mean discharge given in Tables 53 and 54 which were obtained from the regression equations of observed sampling times and standard deviations.

If the errors due to sampling interval at <u>all</u> stations are to be kept within the prescribed limits then the sample intervals would be:-

Error in d.m.d

1 standard deviation	= 0.1%	0.5%	1.0%
Sampling interval	= 0.25 hrs.	0.75 hrs.	1.25 hrs.

If a slight increase in errors at stations 22/3 and 72/1 over the rest is acceptable then the sampling intervals would be:-

Error in d.m.d

1 standard deviation	= 0.1%	0.5%	1.0%
Sampling interval	= 0.50 hrs.	1.50 hrs.	2.25 hrs.

(ii) Using the prediction equations

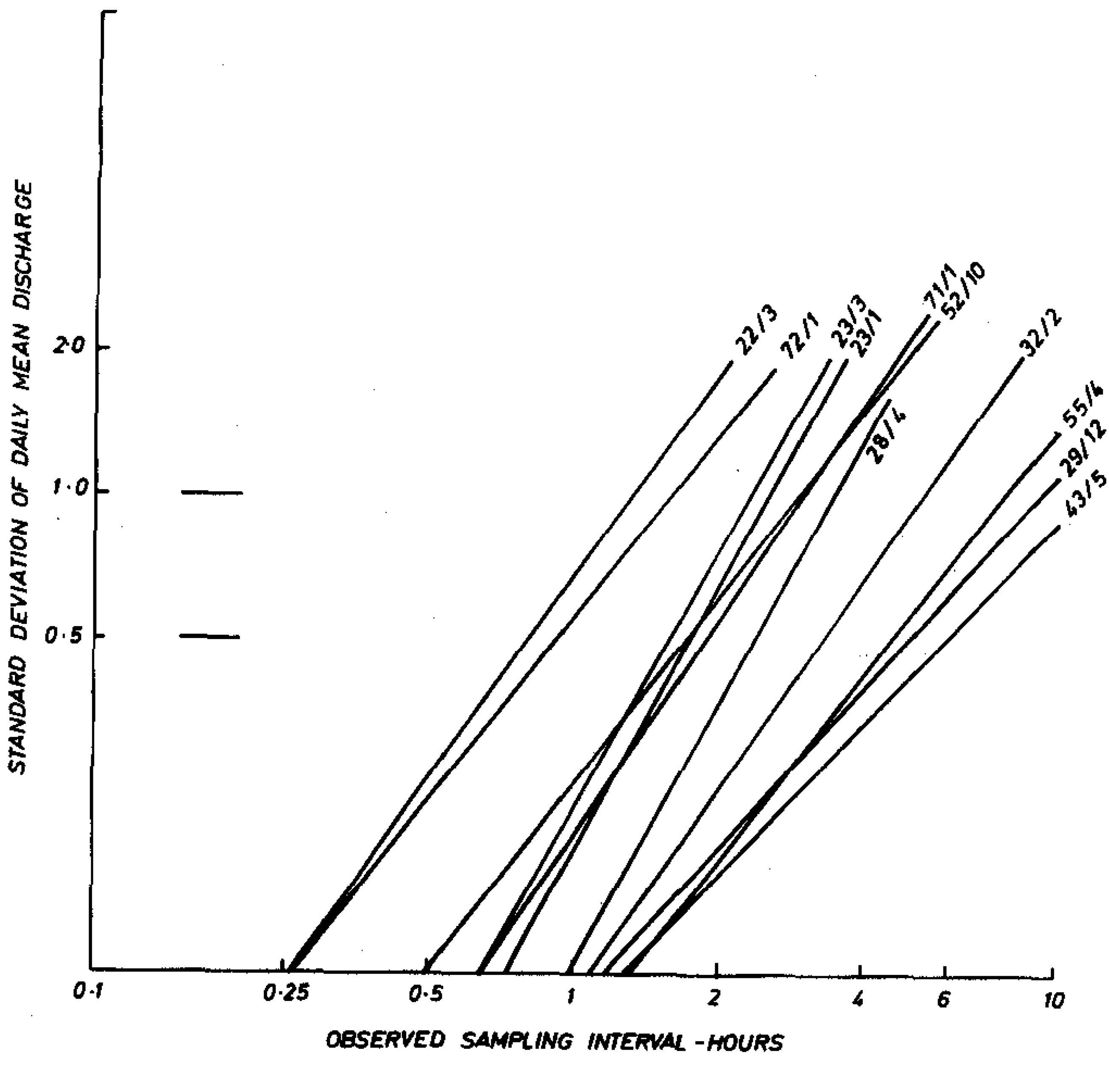
The prediction equations can be used if it is required to choose sampling intervals for individual catchments. Using EQ. 2.3.2 with the catchment area in km^2, annual rainfall over the catchment in mm, and an areal infiltration factor derived from Figure 32 in mm, the values of sampling interval X_1, X_2, X_3 can be found. These should be plotted on log - log paper against the standard deviation $Y_1 = 0.1\%$, $Y_2 = 0.5\%$, $Y_3 = 1.0\%$. Table 49 gives the standard factorial error of estimate, S_1, for X in hours and if this is plotted the corresponding range in the value of standard deviation of departures can be found.

Example:

Area	1000 km^2	Log: 3.0
Rain	1000 mm	3.0
Infiltration	3 mm	0.47712

EQ.2.1.2 $\text{Log } X_1 = \text{Log } 1656.0 + 0.1240 \text{ Log } 1000 - 1.251$
$\text{Log } 1000 + 0.2671 \text{ Log } 3.0$

$X_1 = 0.923$ hours   s f e e = 1.48



OBSERVED SAMPLING INTERVALS PLOTTED FOR THREE LEVELS OF STANDARD DEVIATION FROM TABLE 40

FIG 30

TABLE NO. 53

VALUES OF GENERAL RAINFALL IN MILLIMETRES

Station		Year	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Total
Shillmoor	22/3	1966-1967	151	127	151	75	111	67	73	167	59	105	81	87	1254
		1967-1968	166	174	60	47	76	106	74	82	62	147	77	140	1211
Bywell	23/1	1966-1967	116	102	125	63	117	76	52	131	59	105	127	99	1172
		1967-1968	223	101	71	77	60	152	67	72	84	103	64	176	1250
Reaverhill	23/3	1966-1967	105	105	115	72	109	79	43	134	62	107	131	101	1163
		1967-1968	229	97	63	81	59	165	68	71	71	99	67	173	1243
Lea Marston	28/4	1966-1967	106	52	95	46	62	51	27	154	21	36	52	69	771
		1967-1968	135	47	63	69	40	26	65	99	84	98	48	102	876
Colwick	28/9	1966-1967	106	66	105	43	66	49	37	143	24	42	55	72	808
		1967-1968	139	55	59	74	41	37	62	81	73	103	56	118	898
Yoxall	28/12	1966-1967	100	65	129	45	59	50	30	148	18	57	49	81	831
		1967-1968	131	53	67	89	41	38	55	82	76	91	39	107	869
Fotheringhay	32/2	1966-1967	87	55	75	24	52	34	59	112	24	27	52	41	642
		1967-1968	108	40	44	46	86	18	62	53	63	115	103	118	806
Grendon	39/17	1966-1967	120	40	77	33	58	30	43	106	32	92	37	51	719
Underwood		1967-1968	122	35	61	54	18	26	49	65	65	127	69	117	808
Amesbury	43/5	1966-1967	161	55	81	70	87	64	27	121	39	35	50	111	901
Lovington	52/10	1966-1967	126	107	109	74	88	65	48	145	24	57	66	130	1039
		1967-1968	178	48	77	77	49	35	60	71	105	87	63	125	975
Byton	55/14	1966-1967	135	137	118	68	132	66	27	145	38	63	78	154	1161
		1967-1968	187	55	98	113	42	79	80	94	92	125	49	128	1142
Samlesbury	71/1	1966-1967	128	126	194	80	125	75	48	178	96	104	94	168	1416
		1967-1968	304	117	106	166	47	164	91	126	129	96	63	277	1686
Halton	72/1	1966-1967	121	148	198	100	181	116	57	178	89	177	214	198	1776
		1967-1968	402	103	127	172	53	246	93	112	114	92	65	262	1841

TABLE NO. 54

Monthly Rainfall

Grendon Underwood

Month	1963	1964	1965	1966	1967	1968
January		13.5	57.7	29.1	33.0	54.7
February		20.3	7.1	77.6	59.1	16.8
March		80.3	49.0	15.3	30.0	25.7
April		56.1	49.8	84.4	104.7	
May		41.1	67.8	66.2	43.6	
June		81.3	62.2	65.7	32.5	
July		62.0	92.3	64.6	88.2	
August		15.7	54.9	102.0	37.0	
September		19.8	80.3	45.7	51.2	
October	36.8	18.3	12.7	118.1	116.1	
November	115.3	20.3	52.2	41.5	34.3	
December	13.2	41.4	103.6	76.1	59.0	
TOTAL		470.1	689.6	786.3	688.7	

$$\text{EQ.2.2.2} \quad \text{Log } X_1 = \begin{array}{l}\text{Log } 971.0 + 0.1252 \text{ Log } 1000 - 1.074 \\ \text{Log } 1000 + 0.5990 \text{ Log } 3.0\end{array}$$

X_2 = 2.67 hours   s f e e = 1.47

$$\text{EQ.2.3.2} \quad \text{Log } X_3 = \begin{array}{l}\text{Log } 630.0 + 0.1156 \text{ Log } 1000 - 0.948 \\ \text{Log } 1000 + 0.6704 \text{ Log } 3.0\end{array}$$

X_3 = 4.01 hours   s f e e = 1.49

1 standard error (67% confidence)

		x hrs.	
Y_1%	X_1 hrs.	Upper	Lower
0.1	0.92	1.36	0.63
0.5	2.67	3.92	1.82
1.0	4.01	5.97	2.70

These points are plotted in Figure 31, from which it can be seen that if an error of 0.5% in the daily mean discharge is chosen giving a sampling interval of 2.6 hours, and this sampling interval was used, then the standard error of estimate indicates a possible error of 0.95% of the daily mean discharge at the 67% confidence level.

7. CONCLUSIONS

Analysis of the mean departures showed negligible errors over monthly or annual periods, even at 8 hour sampling intervals. Mean annual or monthly mean flows, which might be used, for example, in reservoir yield studies, can therefore be calculated accurately using only three stage readings daily.

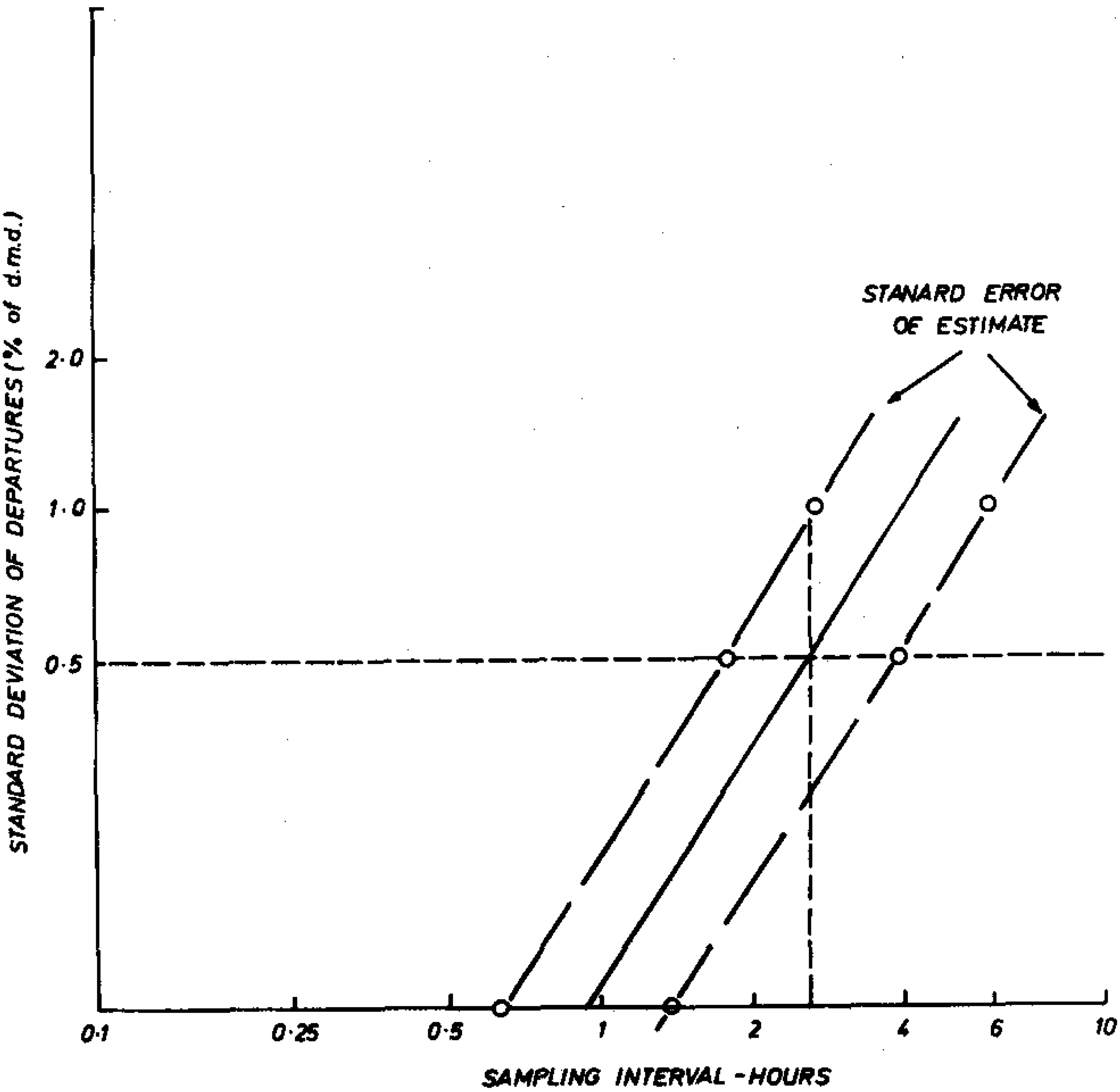
Analysis of the standard deviation of departures shows (Figures 16, 17 and 30) that use of the present 15 minute sampling interval introduces an insignificant error (up to 0.1% at 1 standard deviation) in daily mean discharge and this is unnecessarily accurate when considering the errors in stream-flow measurement from other sources.

All stations could be sampled at 30 minute intervals with an error standard deviation of only 0.25% in dmd and the vast majority could be sampled at 1 hour intervals for the same error.

Selection of the permissible error level should be made with regard to the errors from other sources. It is suggested that the following figures are representative of the possible errors in instantaneous discharge:-

	Type of Measurement	Measurement Error		Allowable Computation Error (st dev)
		Range	Mean	
(i)	River section - shifting control	7-13%	10%	1.0%
(ii)	River section - stable control and hydraulic structure (weir, flume etc.)	3-7%	5%	0.5%

FIGURE 31



EXAMPLE OF USE OF PREDICTION EQUATION

FIG 31

For (i) the errors are due to errors in the discharge measurement and the scatter of the rating curve. For (ii) the errors are due to the errors in the discharge measurement, and the dimensional tolerances of the structure and the method of calibration of a structure (theoretical or model). In all cases, errors in low flow estimates are more sensitive to errors in stage measurement. The suggested allowable computation error or standard deviation of departures from daily mean discharge have been included for each classification.

In the regression analysis it was found that area was not so significant a catchment characteristic as was rainfall and infiltration.

It might be expected that 'flashiness' would decrease with an increase in catchment area and therefore that area would be a very significant parameter. In the sample of catchments used in this study, area varied about 100 fold which is a modest range when compared with the two-fold range of rainfall. The latter covers the range of rainfall over most areas of the United Kingdom, whereas the former is small in comparison with the range between small experimental catchments (say, $1 km^2$) and large river basins (say, $10,000 km^2$). In view of this, one should not necessarily expect the same reaction to similar proportional change in rainfall and area.

The sensitivity of a parameter is a measure of the change in response for a given proportional change in the parameter. The insensitivity of the catchment area parameter leads to the low statistical significance of this parameter in the sample used. Further, the sample of catchments used is slightly biased in that two of the largest catchments were also two of the flashiest because of high rainfall and low infiltration. The abandoning of the data from the very large, slow responding catchment of the Trent above Colwick was the cause of this bias, and its inclusion (had the data been satisfactory) would have led to a more balanced sample of British catchments.

The high significance of the rainfall parameter is not only a result of its high sensitivity, but also, perhaps, a consequence of the high correlation between land slope and rainfall in the United Kingdom (Nash 1965).

Two data batches were used in an attempt to increase the sample size for the regressions. The first data batch contained station records of 1-2 years and used the 1916-1950 long term mean annual catchment rainfall as supplied by the Meteorological Office and had 11 values. The second batch of data used 23 values of station year records including actual mean annual rainfall. It was found that batch 1 data gave better correlations than for batch 2; but although batch 2 regressions accounted for less variance they had less original and residual variance and much less variance in the regression coefficients. It is suggested therefore that the prediction equations using mean annual rainfall and infiltration will give the best results.

Sampling intervals can be derived for individual catchments by using the following multiple regression prediction equations:-

2.1.2 $$X_1 = 1656.0 \times \text{Area}^{0.1240} \times \text{Rain}^{-1.251} \times \text{Infiltration}^{0.2671}$$

2.2.2 $$X_2 = 971.0 \times \text{Area}^{0.1252} \times \text{Rain}^{-1.074} \times \text{Infiltration}^{0.5990}$$

2.3.2 $$X_3 = 603.0 \times \text{Area}^{0.1156} \times \text{Rain}^{-0.9480} \times \text{Infiltration}^{0.6704}$$

Where X_1, X_2 and X_3 are the sampling intervals (in hours) which will give error distributions with means approximately zero and standard deviations of 0.1%, 0.5% and 1.0% respectively.

By using the mean annual rainfall and infiltration parameters 46-57% of the variance of the observed values can be accounted for. In using the prediction equations, the standard error of estimate at the 95% confidence level will be found to be large, although at 67% confidence level quite small.

TABLE NO. 5

MONTHLY MEANS OF DEPARTURES (% of d.m.d.)

MONTH	30	1	2	4	8
10.66	-0.014	0.027	-0.006	1.488	-2.883
11.66	-0.008	0.038	0.145	0.572	1.329
12.66	0.007	0.087	-0.009	-0.381	-0.598
1.67	0.026	0.007	-0.073	-0.490	0.158
2.67	-0.007	-0.002	-0.007	0.303	1.293
3.67	0.014	-0.013	-0.066	-0.334	-0.902
4.67	0.000	0.044	0.123	0.315	0.109
5.67	0.054	-0.013	-0.204	-0.356	2.963
6.67	-0.005	-0.107	-0.265	0.037	0.635
7.67	0.002	-0.104	0.674	2.490	0.892
8.67	-0.064	-0.127	-0.175	0.728	1.849
9.67	0.047	0.087	-0.074	-0.819	0.156
10.67	-0.044	-0.008	0.206	0.368	1.641
11.67	0.009	0.171	0.173	-0.002	-0.223
12.67	0.055	0.139	-0.010	0.149	1.326
1.68	-0.018	0.253	0.018	-0.393	1.987
2.68	0.021	0.002	0.016	0.100	1.456
3.68	0.004	-0.009	0.141	0.030	-1.108
4.68	-0.008	-0.046	-0.175	0.923	-2.020
5.68	-0.009	0.159	0.593	0.199	1.607
6.68	0.055	0.273	0.609	1.601	4.755
7.68	0.035	0.013	-0.285	-1.166	-3.695
8.68	0.002	-0.010	0.006	0.241	-0.370
9.68	0.010	0.005	0.377	1.563	3.997

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TABLE NO. 6

MONTHLY MEANS OF DEPARTURES (% of d.m.d.)

MONTH	30	1	2	4	8
10.66	-0.004	0.012	0.118	0.064	0.376
11.66	0.010	0.043	0.097	0.216	-0.509
12.66	0.001	0.019	0.143	0.274	2.150
1.67	-0.007	-0.022	-0.038	0.049	0.637
2.67	-0.002	0.023	0.127	0.376	0.643
3.67	-0.003	-0.012	-0.047	0.213	-0.544
4.67	0.006	-0.002	-0.161	0.152	1.345
5.67	0.001	0.014	-0.013	-0.016	0.858
6,67	-0.006	0.067	0.015	-1.116	1.043
7.67	0.004	0.025	0.137	0.297	-0.916
8.67	-0.006	-0.006	-0.125	-0.551	-2.332
9.67	-0.000	-0.086	-0.161	-0.406	1.804
10.67	0.011	-0.002	0.280	-0.039	-1.127
11.67	0.003	0.004	-0.005	0.236	0.792
12.67	0.014	0.012	0.029	0.049	-0.067

TABLE NO. 7

MONTHLY MEANS OF DEPARTURES (% of d.m.d.)

MONTH	30	1	2	4	8
10.66	0.003	0.040	0.040	0.293	1.319
11.66	-0.000	-0.012	0.040	0.364	1.554
12.66	-0.000	-0.009	-0.061	0.211	2.654
1.67	-0.003	-0.014	0.008	0.103	0.104
2.67	0.004	0.016	-0.016	-0.221	-0.636
3.67	0.003	0.006	-0.010	0.360	0.823
4.67	-0.003	-0.004	-0.039	0.078	-0.760
5.67	0.012	0.080	0.345	0.499	1.527
6.67	-0.006	0.065	-0.165	-0.636	-1.485
7.67	-0.000	-0.054	0.083	0.339	0.157
8.67	-0.006	0.069	0.017	-0.101	1.651
9.67	0.060	0.118	-0.043	0.325	-0.793
10.67	0.006	0.073	0.320	0.240	1.359
11.67	-0.000	0.016	0.051	0.169	0.184
12.67	0.004	-0.008	-0.014	0.026	1.735
1.68	0.002	0.025	0.035	0.025	0.815
2.68	0.001	0.002	0.024	0.116	0.018
3.68	0.016	0.066	0.091	-0.078	-0.194
4.68	0.001	0.014	-0.048	0.425	2.183
5.68	0.016	-0.013	0.019	-0.023	-1.294
6.68	0.013	0.012	0.336	0.988	2.664
7.68	-0.006	-0.068	0.007	-0.502	-0.694

TABLE NO. 8

MONTHLY MEANS OF DEPARTURES (% of d.m.d.)

MONTH	30	1	2	4	8
10.66	0.005	-0.005	0.003	-0.092	-0.331
11.66	0.007	0.014	0.098	-0.059	0.307
12.66	0.004	0.014	0.077	0.342	0.600
1.67	-0.001	0.011	0.108	0.376	0.965
2.67	0.004	0.015	-0.013	0.224	0.027
3.67	-0.004	-0.004	-0.052	-0.403	-0.166
4.67	0.005	-0.006	-0.033	-0.078	-0.509
5.67	-0.005	-0.010	-0.084	-0.402	-0.785
6.67	-0.003	-0.015	0.016	-0.649	-1.711
7.67	-0.003	-0.019	-0.114	-0.407	-1.096
8.67	-0.009	-0.006	0.012	-0.580	-1.606
9.67	0.007	0.014	0.014	-0.524	-1.205
10.67	0.001	-0.004	-0.051	-0.524	-2.369
11.67	-0.002	-0.018	-0.004	0.214	-0.353
12.67	-0.003	0.003	-0.006	9.123	-0.787
1.68	-0.006	-0.019	-0.006	0.205	0.492
2.68	-0.004	-0.018	0.007	-0.468	-0.713
3.68	-0.007	-0.028	-0.106	-0.449	-0.876
4.68	0.012	0.006	0.233	0.045	0.742
5.68	-0.001	-0.030	0.044	-0.152	-0.448
6.68	0.000	-0.029	-0.121	-0.726	-0.867
7.68	-0.007	-0.023	0.013	-0.543	-0.802
8.68	0.002	0.012	0.044	-0.211	-0.349
9.68	-0.001	-0.001	0.021	0.098	-1.102

TABLE NO. 9

MONTHLY MEANS OF DEPARTURES (% of d.m.d.)

MONTH	30	1	2	4	8
10.66	0.011	0.033	0.094	0.472	0.708
11.66	0.006	0.035	-0.005	-0.235	-0.594
12.66	0.009	0.016	0.060	0.228	0.164
1.67	0.006	0.054	0.152	0.058	0.379
2.67	-0.019	0.053	0.112	0.070	-0.177
3.67	0.008	0.008	-0.011	-0.199	-0.007
4.67	-0.030	-0.085	-0.042	0.262	0.541
5.67	-0.004	-0.014	-0.028	-0.108	-0.058
6.67	0.015	0.059	0.092	0.374	0.706
7.67	0.004	0.018	-0.094	0.182	-0.928
8.67	0.006	0.051	0.026	-0.096	-0.986
9.67	0.025	-0.063	0.064	0.062	-0.207
10.67	-0.049	-0.008	0.045	0.184	1.068
11.67	0.005	0.004	0.034	-0.014	0.459

TABLE NO. 10

MONTHLY MEANS OF DEPARTURE (% of d.m.d.)

MONTH	30	1	2	4	8
10.66	-0.005	0.004	0.015	0.078	0.184
11.66	0.020	0.015	0.052	0.096	0.160
12.66	-0.005	0.001	0.001	-0.059	0.065
1.67	-0.005	-0.013	-0.043	-0.030	-0.040
2.67	0.002	0.017	0.021	0.013	0.088
3.67	0.005	-0.004	0.017	0.027	0.331
4.67	-0.002	-0.006	-0.023	-0.080	0.040
5.67	-0.004	0.001	-0.004	0.021	0.366
6.67	-0.011	-0.015	-0.021	-0.077	0.240
7.67	-0.001	-0.002	0.007	0.095	0.350
8.67	0.010	0.017	0.014	0.081	0.279
9.67	0.004	-0.007	0.046	0.005	-0.249
10.67	-0.012	-0.004	-0.018	0.030	0.191
11.67	0.009	0.031	0.021	0.075	0.192
12.67	0.021	0.020	0.029	0.133	0.393
1.68	-0.005	-0.011	-0.042	-0 013	0.403
2.68	-0.005	-0.015	0.008	-0.071	-0.091
3.68	-0.006	-0.007	-0.029	-0.088	-0.159
4.68	0.005	-0.005	0.010	-0.019	0.128
5.68	0.001	-0.002	0.011	0.035	0.241
6.68	-0.004	-0.007	-0.007	-0.023	0.101
7.68	-0.006	-0.011	-0.007	-0.006	-0.020
8.68	-0.000	0.007	-0.003	-0.004	-0.009
9.68	0.000	0.004	0.007	0.032	0.143

TABLE NO. 11

MONTHLY MEANS OF DEPARTURE (%of d.m.d.)

MONTH	30	1	2	4	8
10.66	0.001	-0.002	0.017	-0.014	-0.114
11.66	0.010	0.006	-0.010	0.009	0.082
12.66	-0.003	-0.005	-0.010	-0.074	-0.350
1.67	-0.005	-0.003	-0.047	-0.099	0.132
2.67	-0.001	-0.015	-0.031	-0.037	-0.444
3.67	-0.011	0.021	0.073	0.209	0.348
4.67	-0.003	-0.009	0.061	0.249	0.543
5.67	-0.005	0.006	0.078	-0.037	0.440
6.67	-0.006	-0.008	-0.037	-0.077	-0.125
7.67	0.004	0.004	0.002	-0.043	-0.070
8.67	0.005	-0.013	-0.012	-0.007	-0.040
9.67	0.007	-0.021	0.016	-0.045	-0.048
10.67	-0.002	-0.004	-0.026	-0.017	0.009
11.67	0.012	0.001	0.021	0.051	0.269
12.67	0.004	0.009	0.013	0.055	0.141
1.68	0.007	0.016	0.031	0.127	0.044
2.68	0.003	0.006	0.012	0.012	0.099
3.68	-0.002	-0.010	-0.012	-0.040	-0.361
4.68	-0.003	0.008	0.019	0.000	0.088
5.68	0.005	0.005	0.045	-0.166	-0.066
6.68	-0.005	0.041	0.034	0.312	0.786
7.68	0.002	0.001	0.007	-0.054	-0.023
8.68	0.010	0.010	-0.043	-0.074	-0.085
9.68	-0.003	-0.008	0.010	0.056	0.279

TABLE NO. 12

MONTHLY MEANS OF DEPARTURE (% of d.m.d.)

MONTH	30	1	2	4	8
10.66	-0.004	-0.009	0.015	0.048	-0.931
11.66	-0.002	0.005	-0.007	-0.005	-0.001
12.66	-0.001	0.004	-0.001	-0.082	0.025
1.67	0.005	0.005	-0.019	-0.032	0.008
2.67	0.001	-0.000	0.003	-0.013	0.057
3.67	0.006	0.030	0.061	-0.041	-0.083
4.67	-0.002	-0.006	0.001	-0.023	-0.028
5.67	0.001	-0.006	-0.023	0.006	-0.159
6.67	-0.005	-0.010	0.003	-0.054	-0.093
7.67	0.000	-0.017	-0.059	-0.068	-0.452
8.67	-0.006	-0.014	-0.001	0.014	-0.145
9.67	0.023	0.026	-0.007	-0.051	-0.498
10.67	-0.006	-0.014	-0.054	0.036	-0.627
11.67	0.005	0.004	0.021	0.018	-0.029
12.67	0.005	0.010	0.004	0.015	0.051
1.68	0.007	0.011	-0.004	-0.008	-0.009
2.68	-0.003	-0.007	0.007	0.004	0.007
3.68	-0.004	-0.005	-0.011	0.050	0.271
4.68	-0.000	-0.024	0.000	0.030	0.055
5.68	0.001	-0.005	-0.029	-0.040	-0.036
6.68	-0.002	-0.009	-0.040	0.037	-0.277
7.68	0.006	0.012	0.010	0.030	-0.067
8.68	0.009	0.026	0.082	-0.022	-0.644
9.68	0.012	0.017	0.003	-0.198	-1.931

TABLE NO. 13

MONTHLY MEANS OF DEPARTURE (% of d.m.d.)

MONTH	30	1	2	4	8
10.66	0.005	0.013	0.027	0.036	0.973
11.66	0.001	-0.004	-0.015	-0.052	0.395
12.66	0.012	0.011	0.041	0.003	0.280
1.67	-0.015	-0.017	-0.017	-0.185	0.392
2.67	0.002	0.025	0.018	-0.102	-0.106
3.67	-0.006	0.009	0.051	0.112	0.281
4.67	0.018	0.127	0.375	0.158	0.357
5.67	-0.015	-0.067	-0.023	-0.107	0.340
6.67	-0.004	-0.026	-0.023	-0.410	-1.246
7.67	0.009	0.003	0.108	-0.193	1.814
8.67	0.006	-0.024	-0.032	0.245	2.031
9.67	0.017	-0.010	0.058	0.228	2.684
10.67	-0.007	-0.032	-0.177	-0.289	0.138
11.67	-0.006	-0.014	0.024	-0.104	-0.454
12.67	-0.013	-0.003	-0.053	0.003	0.007
1.68	-0.005	-0.032	0.012	0.095	0.802
2.68	0.014	0.007	0.004	0.033	-0.170
3.68	-0.004	0.026	0.024	-0.386	0.749
4.68	-0.037	-0.066	-0.128	0.259	2.139
5.68	-0.013	-0.019	-0.008	-0.448	-0.397
6.68	0.025	0.096	0.157	0.490	2.607
7.68	0.042	0.032	0.068	-0.283	-0.049
8.68					
9.68	0.000	-0.061	-0.043	0.231	-0.228

TABLE NO. 14

MONTHLY MEANS OF DEPARTURE (% of d.m.d.)

MONTH	30	1	2	4	8
10.66	-0.002	0.008	0.058	0.110	0.386
11.66	-0.000	-0.014	-0.019	0.008	0.281
12.66	-0.001	0.006	0.016	0.021	0.141
1.67	0.001	-0.007	0.002	-0.004	0.063
2.67	-0.007	-0.020	-0.038	-0.027	-0.119
3.67	-0.003	-0.004	-0.001	0.072	0.373
4.67	-0.002	-0.001	0.019	0.051	-0.287
5.67	0.002	0.004	0.018	-0.026	0.034
6.67	-0.010	-0.021	-0.010	0.028	0.050
7.67	0.008	-0.002	0.063	-0.069	0.729
8.67	0.008	0.004	-0.006	-0.048	0.051
9.67	-0.003	0.005	-0.002	0.067	0.311
10.67	0.002	-0.009	-0.042	-0.124	-0.027
11.67	-0.002	-0.008	-0.005	-0.037	-0.086
12.67	0.001	0.003	-0.003	0.009	-0.050
1.68	0.002	0.002	0.014	0.048	0.046
2.68	-0.007	-0.006	-0.022	-0.025	-0.024
3.68	-0.010	-0.021	-0.041	-0.021	0.017
4.68	-0.002	0.001	0.018	-0.018	0.056
5.68	-0.001	0.011	0.017	0.003	-0.274
6.68	-0.003	0.006	-0.024	-0.059	-0.005
7.68	0.000	0.012	0.019	0.099	0.425
8.68	0.000	0.006	0.013	0.007	0.074
9.68	-0.006	-0.003	0.013	0.181	0.443

TABLE NO. 15

MONTHLY MEANS OF DEPARTURE (% of d.m.d.)

MONTH	30	1	2	4	8
10.66	-0.005	-0.007	-0.010	0.066	-0.090
11.66	-0.023	-0.070	-0.133	-0.313	0.077
12.66	0.009	0.008	0.025	0.001	1.001
1.67	0.002	0.009	0.031	0.195	0.661
2.67	0.004	-0.013	-0.025	-0.035	-0.442
3.67	0.007	0.009	0.013	0.033	-0.334
4.67	-0.041	-0.122	0.042	0.119	0.180
5.67	0.001	0.017	0.042	0.061	1.245
6.67	0.005	0.021	0.015	0.090	-0.856
7.67	-0.004	-0.004	0.015	0.249	0.297
8.67	-0.007	-0.049	0.062	0.214	3.225
9.67	-0.001	-0.004	-0.062	0.137	0.524
10.67	-0.007	-0.016	0.079	-0.215	0.075
11.67	0.006	0.014	0.065	0.176	0.638
12.67	-0.008	0.006	0.039	0.226	0.623
1.68	-0.001	0.020	0.001	-0.171	-0.695
2.68	-0.010	-0.020	-0.004	0.028	0.213
3.68	-0.000	0.004	0.105	0.681	2.546
4.68	0.010	-0.014	-0.147	0.227	-0.020
5.68	0.011	0.008	-0.038	-0.287	-0.038
6.68	0.000	0.003	-0.050	0.277	0.306
7.68	-0.008	0.004	0.053	0.310	-0.022
8.68	-0.002	-0.006	-0.058	-0.220	-1.064

TABLE NO. 16

Sta.72/1

MONTHLY MEANS OF DEPARTURES (% of d.m.d.)

MONTH	30	1	2	4	8
10.66	0.074	-0.017	0.300	0.666	-0.062
11.66					
12.66					
1.67	0.062	0.108	0.051	0.102	0.283
2.67	0.032	-0.016	0.170	1.225	-0.300
3.67	0.027	0.141	0.123	2.290	0.233
4.67	0.134	0.273	0.150	1.177	0.459
5.67	0.008	0.017	0.031	0.311	1.124
6.67	0.040	0.034	0.092	0.276	-1.124
7.67	-0.023	-0.023	-0.168	0.186	-1.672
8.67	-0.014	0.024	-0.088	0.263	0.716
9.67	-0.026	0.015	-0.087	-0.080	-0.312
10.67	0.016	0.038	0.251	1.725	2.815
11.67	-0.057	-0.030	0.024	0.936	0.851
12.67	-0.024	-0.040	-0.071	-0.066	-0.380
1.68	0.026	0.017	0.019	-0.004	-0.564
2.68	-0.015	-0.072	-0.083	-0.024	-0.241
3.68	0.046	-0.152	0.041	-2.313	-2.073
4.68	0.015	0.073	-0.787	-0.611	-0.737
5.68	0.012	0.023	0.076	0.047	0.173
6.68	-0.015	-0.061	0.033	0.331	-0.095
7.68	0.009	0.016	-0.033	0.182	0.269
8.68	0.071	0.154	0.194	0.711	1.158

TABLE NO. 17

Sta. 39/7
Grendon Underwood

MONTHLY MEANS OF DEPARTURES (% of d.m.d.)

MONTH	30	1	2	4	8
10.63	0.00	0.00	0.00	0.07	0.11
11.63	0.01	0.02	0.09	0.27	1.48
12.63	0.01	0.01	0.00	-0.13	0.43
1.64	0.00	0.01	0.04	0.13	0.26
2.64	0.00	0.00	0.01	0.01	-0.04
3.64	0.01	0.03	0.13	0.53	1.71
4.64	0.01	0.03	0.09	0.22	0.87
5.64	0.01	0.01	-0.02	0.23	0.61
6.64	0.00	0.00	0.09	0.26	-0.50
7.64	0.01	0.04	0.06	0.12	1.05
8.64	0.00	0.01	0.02	-0.08	1.41
9.64					
10.64	0.00	0.01	-0.02	0.00	0.17
11.64	0.00	0.00	0.05	0.08	-0.18
12.64	0.00	0.00	-0.01	-0.29	0.39
1.65	0.00	0.00	0.02	0.11	0.21
2.65	0.00	0.00	0.00	-0.02	-0.17
3.65	0.00	-0.03	-0.08	0.16	0.62
4.65	0.01	0.02	-0.01	0.15	-0.52
5.65	0.00	0.00	-0.02	0.09	0.29
6.65	0.01	-0.01	-0.01	0.70	0.62
7.65	0.00	0.01	0.01	0.41	-0.19
8.65	0.00	0.02	0.05	0.11	-0.40
9.65	0.00	0.00	-0.02	0.09	0.28
10.65	0.00	0.00	0.00	0.02	-0.09
11.65	0.01	0.02	0.05	0.30	1.86
12.65	0.01	0.02	0.14	0.35	2.07
1.66	0.00	0.01	0.04	0.12	0.33
2.66	0.01	0.03	0.07	0.16	1.45
3.66	0.00	0.00	0.00	0.02	0.02
4.66	0.01	0.01	0.05	0.08	-0.51
5.66	0.00	0.01	0.01	-0.07	-0.37
6.66	0.01	0.03	0.11	0.57	2.29
7.66	0.00	0.00	-0.02	-0.42	-0.58
8.66	0.00	0.00	0.16	-0.10	2.20
9.66	0.00	0.01	0.05	0.15	0.59

TABLE NO. 17 (continued)

MONTHLY MEANS OF DEPARTURES (% of d.m.d.)

MONTH	30	1	2	4	8
10.66	0.00	0.02	0.06	0.33	1.69
11.66	0.01	0.02	0.10	0.64	0.81
12.66	0.01	0.03	0.13	0.14	2.54
1.67	-0.01	-0.01	0.01	0.16	0.79
2.67	0.00	0.01	0.06	0.26	0.39
3.67	0.00	0.01	0.01	0.01	0.55
4.67	0.00	0.01	0.04	0.03	0.00
5.67	0.00	0.02	-0.03	0.37	0.46
6.67	0.00	0.00	-0.06	-0.32	-0.14
7.67	0.01	0.01	-0.01	-0.13	2.51
8.67	0.00	0.01	0.04	0.19	0.76
9.67	-0.03	0.03	0.08	0.00	0.18
10.67	-0.02	-0.01	0.00	0.03	0.76
11.67	0.00	0.00	0.00	0.07	0.33
12.67	0.01	0.03	0.12	0.22	1.81
1.68	0.00	0.02	0.08	0.50	1.88
2.68	0.00	0.00	0.03	-0.09	-0.31
3.68	0.01	0.02	-0.03	0.00	-0.14
4.68	0.01	0.01	0.01	-0.03	0.04
5.68	0.00	0.00	0.05	0.22	1.28
6.68	0.00	-0.01	-0.02	-0.29	-1.51
7.68	0.01	0.02	0.17	0.18	0.73
8.68	0.00	0.03	-0.01	-0.18	0.36
9.68	0.01	0.02	0.06	0.57	1.62

TABLE NO. 18

MEANS OF DEPARTURES, WATER YEAR 1966/67 (%of d.m.d.)

STA.NO.	30	1	2	4	8
22/3	0.004	-0.007	0.006	0.265	0.408
23/1	-0.000	0.006	0.007	-0.038	0.371
23/3	0.005	0.025	0.018	0.138	0.529
28/4	0.000	0.000	0.002	-0.189	-0.542
28/9	0.003	0.014	0.035	0.090	-0.039
28/12	0.000	0.000	0.007	0.014	0.153
32/2	-0.001	-0.003	0.009	0.004	0.036
43/5	0.001	0.001	-0.003	-0.025	-0.194
52/10	0.002	0.003	0.047	-0.022	0.691
55/14	-0.001	-0.003	0.009	0.015	0.171
71/1	-0.004	-0.017	0.002	0.070	0.470
72/1					

TABLE NO. 19

MEANS OF DEPARTURES : WATER YEAR 1967/68 (% of d.m.d.)

STA.NO.	30	1	2	4	8
22/3	0.009	0.079	0.139	0.295	0.768
23/1					
23/3					
28/4	-0.001	-0.013	0.005	-0.199	-0.623
28/9					
28/12	-0.000	0.000	-0.002	0.007	0.127
32/2	0.002	0.006	0.009	0.021	0.096
43/5	0.002	0.001	-0.001	-0.004	-0.269
52/10	0.000	-0.003	-0.003	-0.038	0.372
55/14	-0.002	-0.000	-0.004	0.005	0.050
71/1	-0.001	0.000	0.004	0.093	0.226
72/1	0.009	-0.001	-0.033	0.069	0.119

TABLE NO. 20

MEANS OF DEPARTURES OVER TWO YEARS 66 - 68 (% of d.m.d.)

Sta.No.	30	1	2	4	8
22/3	0.007	0.036	0.072	0.280	0.587
*23/1	0.002	0.006	0.026	-0.014	0.268
*23/3	0.005	0.019	0.047	0.137	0.594
28/4	0.000	-0.006	0.004	-0.194	-0.582
*28/9	0.000	0.012	0.035	0.090	0.074
28/12	0.000	0.000	0.002	0.011	0.140
32/2	0.001	0.002	0.009	0.012	0.066
43/5	0.002	0.001	-0.002	-0.014	-0.231
*52/10	0.001	-0.001	0.019	-0.030	0.583
55/14	-0.001	-0.002	0.003	0.010	0.110
*71/1	-0.003	-0.009	0.003	0.081	0.356
*72/1	0.019	0.025	0.012	0.348	0.054

* Incomplete record

TABLE NO. 21

Sta.22/3

MONTHLY STANDARD DEVIATION OF DEPARTURES

MONTH	30	1	2	4	8
10.66	0.095	0.808	2.772	4.206	10.536
11.66	0.086	0.339	1.121	2.387	7.236
12.66	0.130	0.263	0.616	3.187	9.358
1.67	0.093	0.169	0.774	2.627	3.114
2.67	0.061	0.212	0.689	1.469	6.183
3.67	0.067	0.078	0.547	1.417	4.321
4.67	0.056	0.186	0.597	2.155	2.059
5.67	0.208	0.333	1.913	6.155	5.766
6.67	0.065	0.496	1.359	0.531	2.603
7.67	0.152	0.953	2.384	9.441	13.023
8.67	0.450	0.931	2.679	4.153	12.195
9.67	0.170	0.533	1.632	5.395	10.867
10.67	0.196	0.441	1.551	2.048	13.697
11.67	0.114	0.590	1.004	5.502	15.866
12.67	0.294	1.167	0.745	3.620	8.231
1.68	0.717	0.975	3.326	5.759	10.530
2.68	0.085	0.193	0.439	0.816	2.690
3.68	0.093	0.294	0.685	0.992	5.778
4.68	0.095	0.258	0.938	3.926	9.303
5.68	0.287	0.561	2.316	2.968	6.075
6.68	0.405	1.816	5.155	12.738	32.021
7.68	0.202	0.674	2.374	4.459	10.771
8.68	0.048	0.096	0.406	1.668	2.408
9.68	0.142	0.717	2.360	8.358	14.905

TABLE NO. 22

Sta.23/1

MONTHLY STANDARD DEVIATION OF DEPARTURES

MONTH	30	1	2	4	8
10.66	0.029	0.116	0.276	0.791	3.557
11.66	0.045	0.145	0.769	2.649	11.062
12.66	0.037	0.120	0.832	3.789	11.250
1.67	0.026	0.065	0.322	0.864	3.577
2.67	0.052	0.285	0.993	2.428	5.892
3.67	0.022	0.039	0.187	1.464	3.877
4.67	0.026	0.059	0.721	1.822	6.638
5.67	0.018	0.070	0.377	1.706	4.414
6.67	0.034	0.492	0.866	5.045	4.077
7.67	0.020	0.085	0.372	1.136	6.298
8.67	0.020	0.108	0.635	2.601	8.000
9.67	0.074	0.522	1.560	4.711	8.373
10.67	0.086	0.298	0.866	2.963	12.885
11.67	0.023	0.054	0.251	1.262	4.606
12.67	0.037	0.080	0.315	1.347	4.834

TABLE NO. 23

Sta.23/3

MONTHLY STANDARD DEVIATION OF DEPARTURES

MONTH	30	1	2	4	8
10.66	0.024	0.109	0.497	1.318	6.404
11.66	0.022	0.073	0.253	1.204	4.395
12.66	0.019	0.116	0.629	1.545	8.085
1.67	0.029	0.065	0.163	1.154	3.883
2.67	0.019	0.068	0.140	1.357	4.654
3.67	0.038	0.084	0.093	1.897	6.364
4.67	0.026	0.137	0.199	0.817	5.078
5.67	0.051	0.263	1.610	6.664	16.432
6.67	0.125	0.473	1.942	5.402	11.167
7.67	0.072	0.343	0.314	2.058	5.767
8.67	0.040	0.202	1.068	2.545	8.720
9.67	0.168	0.468	1.340	4.695	9.329
10.67	0.077	0.336	1.478	3.459	11.181
11.67	0.026	0.118	0.378	1.228	5.656
12.67	0.032	0.071	0.416	0.715	4.591
1.68	0.027	0.132	0.226	1.160	6.037
2.68	0.028	0.043	0.130	0.451	2.071
3.68	0.044	0.144	0.291	2.337	7.587
4.68	0.023	0.119	0.496	1.470	8.817
5.68	0.069	0.106	0.104	0.378	6.916
6.68	0.057	0.038	1.702	5.087	11.896
7.68	0.027	0.384	0.666	2.216	6.356

TABLE NO. 24

Sta.28/4

MONTHLY STANDARD DEVIATION OF DEPARTURES

MONTH	30	1	2	4	8
10.66	0.043	0.141	0.469	1.738	4.639
11.66	0.029	0.061	0.267	1.102	1.888
12.66	0.026	0.059	0.214	1.058	4.174
1.67	0.024	0.061	0.241	1.336	3.496
2.67	0.027	0.066	0.212	0.902	2.918
3.67	0.023	0.052	0.282	1.216	2.238
4.67	0.028	0.058	0.292	1.093	2.821
5.67	0.026	0.066	0.329	1.499	3.849
6.67	0.027	0.063	0.237	0.866	3.872
7.67	0.036	0.095	0.268	1.673	3.905
8.67	0.038	0.116	0.479	2.279	4.671
9.67	0.039	0.124	0.515	2.704	5.504
10.67	0.026	0.067	0.405	1.807	4.475
11.67	0.027	0.068	0.157	0.514	1.606
12.67	0.024	0.048	0.204	1.102	2.947
1.68	0.023	0.049	0.173	0.539	1.446
2.68	0.026	0.064	0.238	0.794	1.451
3.68	0.026	0.078	0.307	0.997	3.221
4.68	0.049	0.141	0.710	2.231	6.531
5.68	0.040	0.108	0.399	2.222	5.495
6.68	0.020	0.102	0.707	2.198	7.766
7.68	0.020	0.066	0.225	0.846	3.873
8.68	0.037	0.150	0.590	2.005	3.980
9.68	0.033	0.057	0.379	1.498	4.770

TABLE NO. 25

Sta.28/9

MONTHLY STANDARD DEVIATION OF DEPARTURES

MONTH	30	1	2	4	8
10.66	0.064	0.228	0.398	1.455	1.976
11.66	0.065	0.157	0.451	0.971	2.086
12.66	0.039	0.077	0.209	0.514	0.867
1.67	0.051	0.098	0.329	0.868	1.433
2.67	0.077	0.203	0.508	1.205	2.570
3.67	0.069	0.160	0.347	0.751	1.997
4.67	0.071	0.234	0.437	1.183	3.380
5.67	0.060	0.167	0.361	0.781	1.568
6.67	0.106	0.177	0.373	1.167	3.248
7.67	0.115	0.207	0.477	1.462	4.044
8.67	0.125	0.277	0.575	1.658	3.411
9.67	0.138	0.301	0.571	1.557	3.825
10.67	0.110	0.170	0.330	1.531	3.158
11.67	0.068	0.110	0.304	0.728	1.907

TABLE NO. 26

STATION NO. 106 Sta.28/12

MONTHLY STANDARD DEVIATION OF DEPARTURES (% of d.m.d.)

MONTH	30	1	2	4	8
10.66	0.041	0.059	0.112	0.240	0.738
11.66	0.042	0.087	0.149	0.302	0.872
12.66	0.078	0.121	0.193	0.410	1.131
1.67	0.057	0.087	0.180	0.261	0.734
2.67	0.076	0.117	0.197	0.322	1.054
3.67	0.067	0.106	0.157	0.278	0.777
4.67	0.038	0.073	0.127	0.209	0.726
5.67	0.056	0.090	0.157	0.454	1.500
6.67	0.045	0.079	0.154	0.345	0.857
7.67	0.031	0.066	0.114	0.480	2.150
8.67	0.028	0.051	0.101	0.268	0.706
9.67	0.040	0.072	0.139	0.368	1.282
10.67	0.043	0.057	0.119	0.230	0.982
11.67	0.061	0.091	0.132	0.253	0.692
12.67	0.065	0.117	0.198	0.403	1.090
1.68	0.061	0.125	0.215	0.524	1.853
2.68	0.049	0.088	0.153	0.199	0.444
3.68	0.035	0.092	0.161	0.217	0.440
4.68	0.027	0.065	0.133	0.313	1.016
5.68	0.021	0.039	0.081	0.590	1.410
6.68	0.019	0.027	0.074	0.197	0.747
7.68	0.019	0.040	0.080	0.251	0.858
8.68	0.012	0.025	0.052	0.114	0.600
9.68	0.017	0.043	0.094	0.489	1.957

TABLE NO. 27

STATION NO. 107

MONTHLY STANDARD DEVIATION OF DEPARTURES (%of d.m.d.)

MONTH	30	1	2	4	8
10.66	0.029	0.057	0.096	0.569	2.398
11.66	0.033	0.053	0.106	0.158	0.280
12.66	0.022	0.045	0.098	0.811	2.628
1.67	0.029	0.056	0.241	0.712	1.313
2.67	0.036	0.066	0.350	1.560	3.171
3.67	0.108	0.132	0.327	1.120	1.808
4.67	0.021	0.054	0.319	1.105	2.696
5.67	0.029	0.077	0.288	0.685	2.216
6.67	0.026	0.040	0.094	0.170	0.356
7.67	0.043	0.054	0.096	0.194	0.340
8.67	0.030	0.063	0.091	0.155	0.276
9.67	0.044	0.075	0.136	0.310	0.688
10.67	0.036	0.087	0.137	0.274	0.949
11.67	0.056	0.072	0.129	0.359	0.957
12.67	0.030	0.055	0.078	0.215	0.444
1.68	0.021	0.046	0.086	0.273	0.700
2.68	0.025	0.052	0.067	0.152	0.559
3.68	0.029	0.058	0.125	0.216	1.959
4.68	0.026	0.050	0.063	0.184	0.504
5.68	0.023	0.067	0.468	0.760	2.083
6.68	0.042	0.147	0.136	1.764	5.948
7.68	0.035	0.067	0.096	0.362	1.289
8.68	0.034	0.093	0.333	0.831	2.294
9.68	0.025	0.041	0.147	0.447	1.084

TABLE NO. 28

STATION NO. 108 43/5

MONTHLY STANDARD DEVIATION OF DEPARTURES (% of d.m.d.)

MONTH	30	1	2	3	4
10.66	0.041	0.091	0.162	0.449	1.441
11.66	0.012	0.023	0.047	0.131	0.277
12.66	0.027	0.049	0.069	0.227	0.319
1.67	0.025	0.049	0.078	0.116	0.335
2.67	0.018	0.035	0.079	0.205	0.560
3.67	0.022	0.113	0.303	0.334	0.406
4.67	0.014	0.032	0.085	0.169	0.300
5.67	0.025	0.046	0.127	0.247	0.542
6.67	0.022	0.053	0.141	0.226	0.532
7.67	0.053	0.102	0.172	0.233	0.751
8.67	0.053	0.099	0.164	0.231	0.522
9.67	0.043	0.100	0.220	0.396	0.495
10.67	0.053	0.086	0.201	0.440	1.091
11.67	0.018	0.051	0.082	0.184	0.321
12.67	0.017	0.043	0.083	0.211	0.358
1.68	0.018	0.053	0.089	0.276	0.369
2.68	0.015	0.045	0.069	0.137	0.352
3.68	0.022	0.047	0.073	0.199	0.666
4.68	0.025	0.060	0.109	0.189	0.489
5.68	0.023	0.044	0.108	0.260	0.519
6.68	0.053	0.109	0.205	0.375	0.901
7.68	0.053	0.095	0.153	0.240	0.641
8.68	0.073	0.124	0.175	0.311	0.663
9.68	0.069	0.186	0.332	0.640	1.101

TABLE NO. 29

STATION NO. 109 52/10

MONTHLY STANDARD DEVIATION OF DEPARTURES (% of d.m.d.

MONTH	30	1	2	4	8
10.66	0.069	0.134	0.431	2.275	7.880
11.66	0.038	0.089	0.219	0.517	2.643
12.66	0.035	0.057	0.238	1.074	3.426
1.67	0.050	0.131	0.422	1.430	4.147
2.67	0.043	0.096	0.175	0.543	4.623
3.67	0.034	0.085	0.328	1.212	5.693
4.67	0.247	0.557	1.434	2.855	3.591
5.67	0.127	0.328	0.832	1.806	6.469
6.67	0.086	0.168	0.291	1.149	2.505
7.67	0.091	0.223	0.351	1.084	2.540
8.67	0.109	0.169	0.421	1.226	4.967
9.67	0.092	0.312	0.692	1.930	5.882
10.67	0.125	0.294	0.847	1.996	5.670
11.67	0.048	0.078	0.231	0.612	1.446
12.67	0.062	0.136	0.291	0.940	3.141
1.68	0.025	0.065	0.187	0.721	3.437
2.68	0.053	0.113	0.166	0.737	2.623
3.68	0.069	0.143	0.292	0.711	2.548
4.68	0.102	0.189	0.445	0.957	5.354
5.68	0.082	0.169	0.259	1.078	2.819
6.68	0.186	0.360	0.632	1.964	5.412
7.68	0.186	0.227	0.408	1.544	3.883
8.68					
9.68	0.097	0.193	0.370	1.412	6.356

TABLE NO. 30

STATION NO. 110 55/14

MONTHLY STANDARD DEVIATION OF DEPARTURES (% of d.m.d.)

MONTH	30	1	2	4	8
10.66	0.026	0.071	0.133	0.403	1.279
11.66	0.016	0.052	0.107	0.294	1.393
12.66	0.022	0.043	0.095	0.229	0.705
1.67	0.024	0.043	0.090	0.164	0.592
2.67	0.034	0.054	0.107	0.279	1.492
3.67	0.017	0.028	0.052	0.253	0.858
4.67	0.017	0.031	0.165	0.308	0.939
5.67	0.037	0.069	0.190	0.371	1.241
6.67	0.023	0.046	0.081	0.186	0.324
7.67	0.034	0.163	0.252	1.412	2.607
8.67	0.037	0.063	0.104	0.283	0.866
9.67	0.055	0.091	0.180	0.434	1.130
10.67	0.053	0.091	0.158	0.294	0.611
11.67	0.035	0.078	0.074	0.238	0.580
12.67	0.037	0.052	0.130	0.287	0.843
1.68	0.022	0.064	0.151	0.230	0.647
2.68	0.018	0.035	0.064	0.157	0.242
3.68	0.015	0.043	0.103	0.237	0.608
4.68	0.023	0.059	0.113	0.350	0.720
5.68	0.019	0.045	0.112	0.338	1.322
6.68	0.032	0.044	0.094	0.492	0.922
7.68	0.038	0.115	0.137	0.583	1.824
8.68	0.024	0.044	0.089	0.182	0.527
9.68	0.042	0.130	0.231	0.553	1.663

TABLE NO. 31

STATION NO. 111 71/1

MONTHLY STANDARD DEVIATION (% of d.m.d.)

MONTH	30	1	2	4	8
10.66	0.018	0.047	0.113	0.990	2.741
11.66	0.192	0.587	1.241	2.880	2.470
12.66	0.041	0.079	0.193	1.032	5.179
1.67	0.025	0.055	0.326	1.296	4.161
2.67	0.023	0.067	0.215	1.466	6.216
3.67	0.025	0.059	0.136	0.470	1.657
4.67	0.223	0.659	0.281	0.770	2.134
5.67	0.029	0.089	0.274	1.033	3.047
6.67	0.030	0.055	0.158	0.780	5.535
7.67	0.027	0.067	0.264	0.947	3.601
8.67	0.057	0.346	0.675	1.988	9.039
9.67	0.030	0.052	0.362	1.712	5.754
10.67	0.047	0.100	0.403	1.358	7.025
11.67	0.025	0.058	0.250	0.804	4.248
12.67	0.038	0.050	0.150	0.639	3.116
1.68	0.029	0.082	0.247	1.144	5.905
2.68	0.027	0.032	0.082	0.214	1.001
3.68	0.033	0.066	0.797	3.177	9.040
4.68	0.037	0.161	1.249	1.569	7.182
5.68	0.029	0.062	0.193	1.509	3.618
6.68	0.036	0.076	0.226	1.580	4.926
7.68	0.043	0.141	0.307	1.486	2.425
8.68	0.047	0.105	0.340	1.390	4.691

TABLE NO. 32

Sta.72/1

MONTHLY STANDARD DEVIATION OF DEPARTURES

MONTH	30	1	2	4	8
10.66	0.290	0.550	2.436	5.997	9.330
11.66					
12.66					
1.67	0.153	0.218	0.816	1.493	4.757
2.67	0.123	0.378	1.300	4.982	6.140
3.67	0.294	0.859	2.933	10.779	10.691
4.67	0.487	0.872	2.545	5.152	3.367
5.67	0.111	0.190	0.353	2.228	6.581
6.67	0.212	0.339	0.653	1.737	5.709
7.67	0.168	0.188	0.450	1.099	5.429
8.67	0.066	0.145	0.493	1.107	3.891
9.67	0.101	0.203	0.508	1.932	6.051
10.67	0.100	0.165	2.556	6.927	11.198
11.67	0.169	0.505	1.034	3.636	6.934
12.67	0.068	0.162	0.314	0.959	2.471
1.68	0.078	0.168	0.337	1.112	4.460
2.68	0.142	0.239	0.321	0.665	1.058
3.68	0.224	0.861	3.579	7.372	11.942
4.68	0.568	0.476	4.116	6.042	9.628
5.68	0.105	0.234	0.495	0.879	3.076
6.68	0.169	0.373	0.519	1.293	3.044
7.68	0.119	0.276	0.606	1.306	2.639
8.68	0.247	0.434	1.094	3.944	6.307
9.68					

TABLE NO. 33

Sta.39/17

STANDARD DEVIATION OF DEPARTURES (%of dmd)

MONTH	30	1	2	4	8
10.63	0.01	0.02	0.09	0.17	2.15
11.63	0.02	0.05	0.26	0.84	5.28
12.63	0.02	0.06	0.05	0.90	1.83
1.64	0.01	0.04	0.15	0.65	2.25
2.64	0.00	0.01	0.05	0.19	0.99
3.64	0.04	0.17	0.68	2.67	8.00
4.64	0.02	0.07	0.29	1.02	3.78
5.64	0.01	0.03	0.31	0.66	4.73
6.64	0.01	0.03	0.26	0.51	4.55
7.64	0.05	0.14	0.55	2.93	9.43
8.64	0.01	0.03	0.29	1.29	3.77
9.64					
10.64	0.04	0.07	0.23	0.56	2.22
11.64	0.01	0.03	0.12	0.43	2.76
12.64	0.01	0.04	0.23	0.94	3.24
1.65	0.01	0.02	0.13	0.40	1.46
2.65	0.00	0.01	0.02	0.24	0.74
3.65	0.03	0.18	0.95	1.54	4.45
4.65	0.02	0.09	0.22	0.72	3.07
5.65	0.02	0.05	0.28	1.49	2.31
6.65	0.06	0.19	0.30	1.62	8.01
7.65	0.03	0.07	0.35	1.06	6.96
8.65	0.03	0.08	0.36	0.84	4.75
9.65	0.03	0.06	0.22	1.28	5.09
10.65	0.00	0.01	0.03	0.12	0.67
11.65	0.02	0.08	0.25	1.41	8.22
12.65	0.02	0.06	0.29	1.27	5.90
1.66	0.02	0.06	0.19	0.81	3.12
2.66	0.03	0.08	0.24	1.12	6.76
3.66	0.00	0.00	0.02	0.08	0.45
4.66	0.02	0.06	0.13	0.69	4.56
5.66	0.01	0.03	0.18	1.02	7.32
6.66	0.05	0.18	0.82	4.05	11.28
7.66	0.01	0.03	0.15	1.80	3.76
88.66	0.01	0.07	0.73	1.71	9.21
9.66	0.01	0.03	0.14	0.60	3.47

TABLE NO. 33 (continued)

Sta.39/17

STANDARD DEVIATION OF DEPARTURES (% of d.m.d.)

MONTH	30	1	2	4	8
10.66	0.01	0.03	0.20	0.94	3.65
11.66	0.05	0.15	0.33	2.26	4.87
12.66	0.03	0.10	0.39	1.32	7.50
1.67	0.02	0.05	0.21	0.89	4.19
2.67	0.02	0.05	0.23	0.99	3.48
3.67	0.02	0.05	0.08	0.44	2.89
4.67	0.01	0.04	0.22	0.68	1.64
5.67	0.03	0.10	0.69	1.95	8.71
6.67	0.01	0.02	0.22	1.27	1.99
7.67	0.07	0.04	0.65	1.26	13.28
8.67	0.02	0.07	0.47	1.30	4.51
9.67	0.23	0.39	0.79	1.49	5.07
10.67	0.05	0.09	0.34	0.81	3.93
11.67	0.01	0.02	0.07	0.23	1.13
12.67	0.03	0.07	0.47	1.03	7.57
1.68	0.02	0.09	0.39	1.81	7.98
2.68	0.02	0.04	0.11	0.56	3.91
3.68	0.03	0.15	0.19	0.58	1.42
4.68	0.02	0.04	0.20	0.83	2.77
5.68	0.02	0.04	0.14	0.59	3.68
6.68	0.03	0.11	0.41	2.13	5.13
7.68	0.05	0.23	0.56	2.24	7.01
8.68	0.04	0.18	0.27	2.10	4.43
9.68	0.04	0.08	0.33	1.85	7.27

TABLE NO. 34

STANDARD DEVIATION OF DEPARTURES, WATER YEAR 1966/67 (% of d.m.d.)

STA.NO.	30	1	2	4	8
22/3	0.173	0.529	1.636	4.373	8.187
23/1	0.039	0.235	0.748	2.758	6.939
23/3	0.070	0.248	0.916	3.126	8.255
28/4	0.031	0.085	0.336	1.571	3.850
28/9	0.087	0.202	0.430	1.183	2.731
28/12	0.052	0.086	0.151	0.339	1.121
32/2	0.044	0.068	0.213	0.751	1.805
43/5	0.033	0.074	0.155	0.264	0.673
52/10	0.101	0.239	0.593	1.559	4.861
55/14	0.043	0.072	0.141	0.498	1.257
71/1	0.089	0.276	0.458	1.408	4.770
72/1					

TABLE NO. 35

STANDARD DEVIATION OF DEPARTURES : WATER YEAR 1967/68 (% of d.m.d.)

STA.NO.					
22/3	0.286	0.793	2.216	5.437	13.350
23/1					
23/3					
28/4	0.030	0.089	0.422	1.551	4.402
28/9					
28/12	0.041	0.075	0.133	0.347	1.115
32/2	0.033	0.075	0.194	0.653	2.115
43/5	0.042	0.089	0.160	0.320	0.874
52/10	0.105	0.195	0.402	1.213	4.051
55/14	0.032	0.072	0.129	0.358	0.997
71/1	0.037	0.092	0.501	1.536	5.321
72/1	0.215	0.394	1.811	3.905	6.674

TABLE NO. 36

STANDARD DEVIATION OF DEPARTURES OVER YEARS 66 - 68 (% of d.m.d.)

Sta. No.	30	1	2	4	8
22/3	0.236	0.675	1.946	4.927	11.060
23/1	0.041	0.224	0.715	2.622	7.239
23/3	0.060	0.223	0.860	2.785	7.973
28/4	0.031	0.087	0.381	1.559	4.130
28/9	0.088	0.195	0.416	1.187	2.731
28/12	0.047	0.080	0.142	0.343	1.117
32/2	0.039	0.072	0.204	0.705	1.969
43/5	0.038	0.081	0.157	0.293	0.780
52/10	0.104	0.221	0.520	1.424	4.560
55/14	0.031	0.072	0.135	0.433	1.134
71/1	0.069	0.210	0.480	1.473	5.050
72/1	0.230	0.443	1.743	4.378	6.663

TABLE NO. 38

LINEAR REGRESSION OF 2-YEAR STANDARD DEVIATION OF DEPARTURES V SAMPLING INTERVAL 1966-1968

Station No.	a*	b*	So	S	R
22/3	1.428	1.397	0.01	0.043	0.999
23/1	0.415	1.848	0.03	0.091	0.996
23/3	0.572	1.775	0.01	0.049	0.999
28/4	0.186	1.828	0.02	0.071	0.998
28/9	1.044	1.252	0.01	0.038	0.999
28/12	0.800	1.124	0.04	0.110	0.985
32/2	0.480	1.461	0.02	0.086	0.994
43/5	0.833	1.057	0.01	0.046	0.997
52/10	1.073	1.320	0.02	0.084	0.993
55/14	0.546	1.297	0.02	0.069	0.996
71/1	0.766	1.520	0.01	0.053	0.998
72/1	1.449	1.302	0.04	0.119	0.987

a* best estimate of parameter a

b* best estimate of parameter b

So residual sum of squares

S estimate of standard error of individual measurements

R regression coefficient

TABLE NO. 51

A COMPARISON BETWEEN NECESSARY SAMPLING INTERVAL AND THE SAMPLING INTERVAL PREDICTED WITH AND WITHOUT THE USE OF AN INFILTRATION TERM (UNITS - HRS)

Station	OBS	X_1 $PRED_1$ (without I)	$PRED_2$ (with I)	OBS	X_2 $PRED_1$ (without I)	$PRED_2$ (with I)	OBS	X_3 $PRED_1$ (without I)	$PRED_2$ (with I)
22/3	0.26	0.33	0.26	0.81	1.14	0.77	1.33	1.94	1.25
23/1	0.72	0.82	0.70	1.72	2.43	1.89	2.51	3.87	2.91
23/3	0.64	0.70	0.59	1.58	2.13	1.62	2.33	3.43	2.51
23/4	0.98	1.25	1.28	2.37	3.89	4.03	3.46	6.34	6.62
28/12	1.17	1.22	1.15	4.90	3.75	3.42	9.06	6.08	5.46
32/2	1.10	1.21	0.99	3.30	4.09	2.97	5.31	6.92	4.80
43/5	1.27	0.94	1.21	5.82	3.01	4.45	11.22	4.96	7.78
52/10	0.50	0.65	0.80	1.71	1.12	2.92	2.88	3.54	5.11
55/14	1.32	0.57	0.83	4.57	1.88	3.32	7.80	3.03	5.98
71/1	0.65	0.49	0.46	1.87	1.48	1.34	2.95	2.37	2.12
72/1	0.26	0.36	0.38	0.91	1.07	1.16	1.55	1.72	1.87

TABLE NO. 52

AND, THE CORRESPONDING TABLE FOR 23 STATION YEARS

Station	OBS	X_1 PRED$_1$ (without I)	PRED$_2$ (with I)	OBS	X_2 PRED$_1$ (without I)	PRED$_2$ (with I)	OBS	X_3 PRED$_1$ (without I)	PRED$_2$ (with I)
39/17	1.00	1.10	0.94	2.50	3.10	2.21	3.70	4.62	3.16
39/17	1.09	0.88	0.77	2.39	2.48	1.86	3.34	3.75	2.72
39/17	0.74	0.89	0.78	2.02	2.50	1.88	3.11	3.78	2.74
39/17	1.00	0.82	0.72	2.40	2.30	1.76	3.50	3.50	2.59
22/3	0.36	0.41	0.42	0.96	1.16	1.18	1.46	1.83	1.88
22/3	0.25	0.43	0.43	0.74	1.22	1.23	1.18	1.92	1.94
23/1	0.70	0.89	0.77	1.59	2.89	1.06	2.32	4.48	3.07
23/3	0.61	0.81	0.71	1.46	2.55	1.92	2.12	3.96	2.88
28/4	1.00	1.39	1.41	2.42	4.37	4.52	3.56	6.56	6.80
28/4	0.98	1.16	1.20	2.34	3.65	3.94	3.40	5.53	6.02
28/12	1.26	1.33	1.27	5.02	4.25	3.83	7.53	6.40	5.71
28/12	1.34	1.25	1.20	5.30	3.99	3.65	7.80	6.03	5.47
32/2	1.27	1.30	1.36	3.38	3.85	4.27	5.13	5.73	6.43
32/2	1.26	0.95	1.02	3.50	2.79	3.34	5.24	4.24	5.19
43/5	1.40	0.98	1.14	6.18	2.99	4.23	11.70	4.56	6.72
43/5	1.17	1.04	1.21	5.60	3.20	4.45	8.63	4.85	7.02
52/10	0.49	0.70	0.82	1.76	2.10	2.97	2.95	3.25	4.80
52/10	0.46	0.77	0.89	2.38	2.29	3.18	3.64	3.53	5.10
55/14	1.33	0.64	0.78	4.27	1.93	2.99	7.05	3.01	4.91
55/14	1.62	0.65	0.79	5.20	1.97	3.04	8.05	3.07	4.99
71/1	0.54	0.62	0.55	1.72	1.97	1.51	2.85	3.12	2.30
71/1	0.88	0.49	0.44	2.13	1.54	1.25	3.12	2.47	1.95
72/1	0.28	0.42	0.39	0.94	1.33	1.12	1.59	2.15	1.77

REPORTS OF INSTITUTE OF HYDROLOGY

INSTITUTE OF HYDROLOGY

Report No. 1	1970	"Publications Handbook. Guide to preparation of manuscripts for publication. Papers for submission to external journals. Institute of Hydrology Reports", by B.C. Kennedy

HYDROLOGICAL RESEARCH UNIT

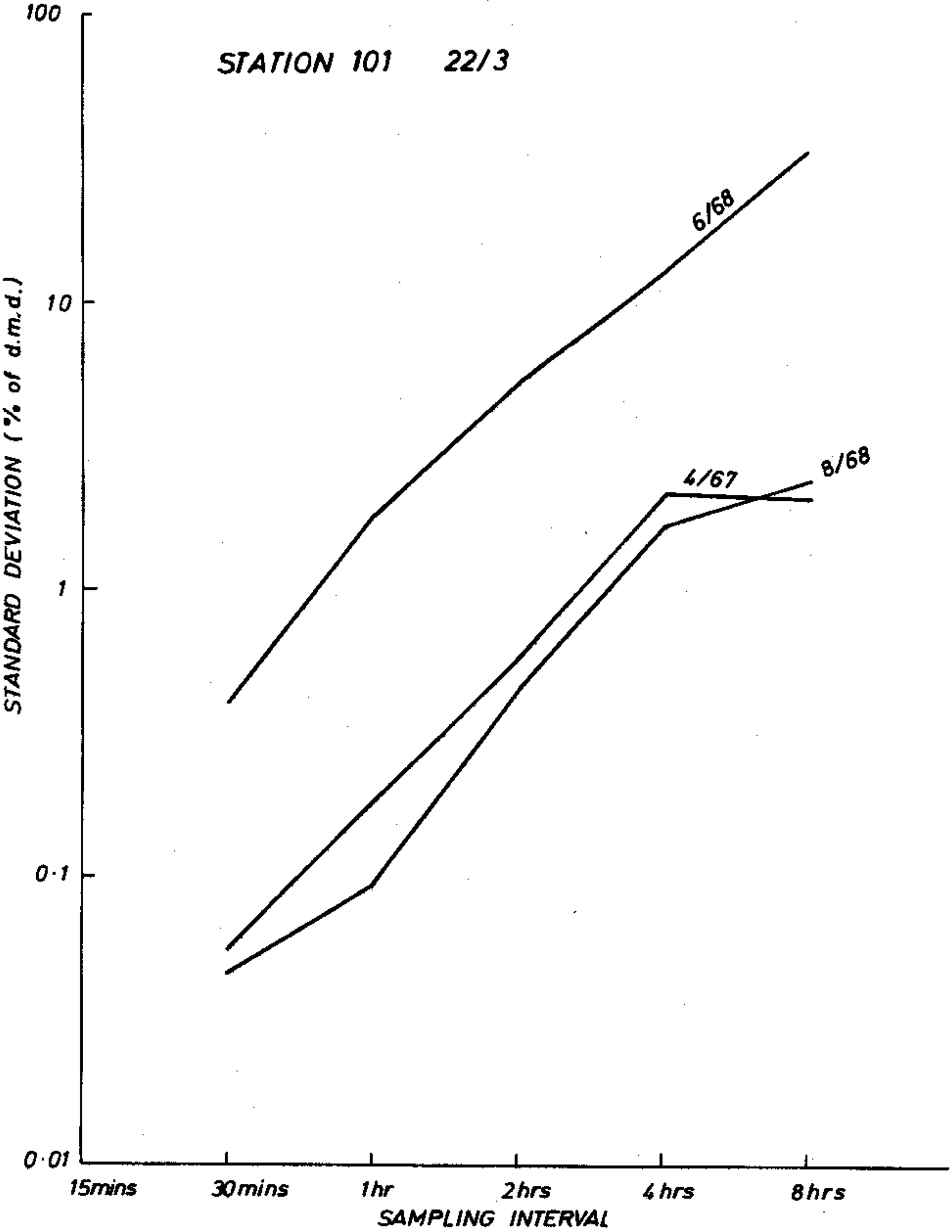
Report No. 2	1967	"Snow in Great Britain", by P.C. Rowe
Report No. 3 *	1968	"Evaporation from forests", by J.B. Stewart
Report No. 4 *	1968	"Design of steep stream gauging structures for the Plynlimon Experimental Catchments, by P.W. Herbertson

INSTITUTE OF HYDROLOGY

Report No. 5	1969	"Processing errors in the Analysis of Catchment data", by A.N. Mandeville, D.T. Plinston and Miss A. Hill

* *Out of print*

Report No. 6	1969	"A feasibility study and development programme for continuous dilution gauging", by P.H. Hosegood, M.K. Bridle and P.W. Herbertson
Report No. 7	1969	"Installation of access tubes and calibration of neutron moisture meters", by C.W.O. Eeles
Report No. 8	(in press)	"The Soil Hydrology of the Plynlimon experimental catchments", by J.P. Bell
Report No. 9	1971	"River Level Sampling Periods", by P.W. Herbertson, J.R. Douglas and Miss A. Hill
Report No. 10	1971	"User's Testing Schedule for the Wallingford Probe System", by P.M. Holdsworth



STATION 101 22/3
6/68
4/67
8/68
100
10
1
0·1
0·01
STANDARD DEVIATION (% of d.m.d.)
15mins
30mins
1hr
2hrs
4hrs
8hrs
SAMPLING INTERVAL

FIG 3

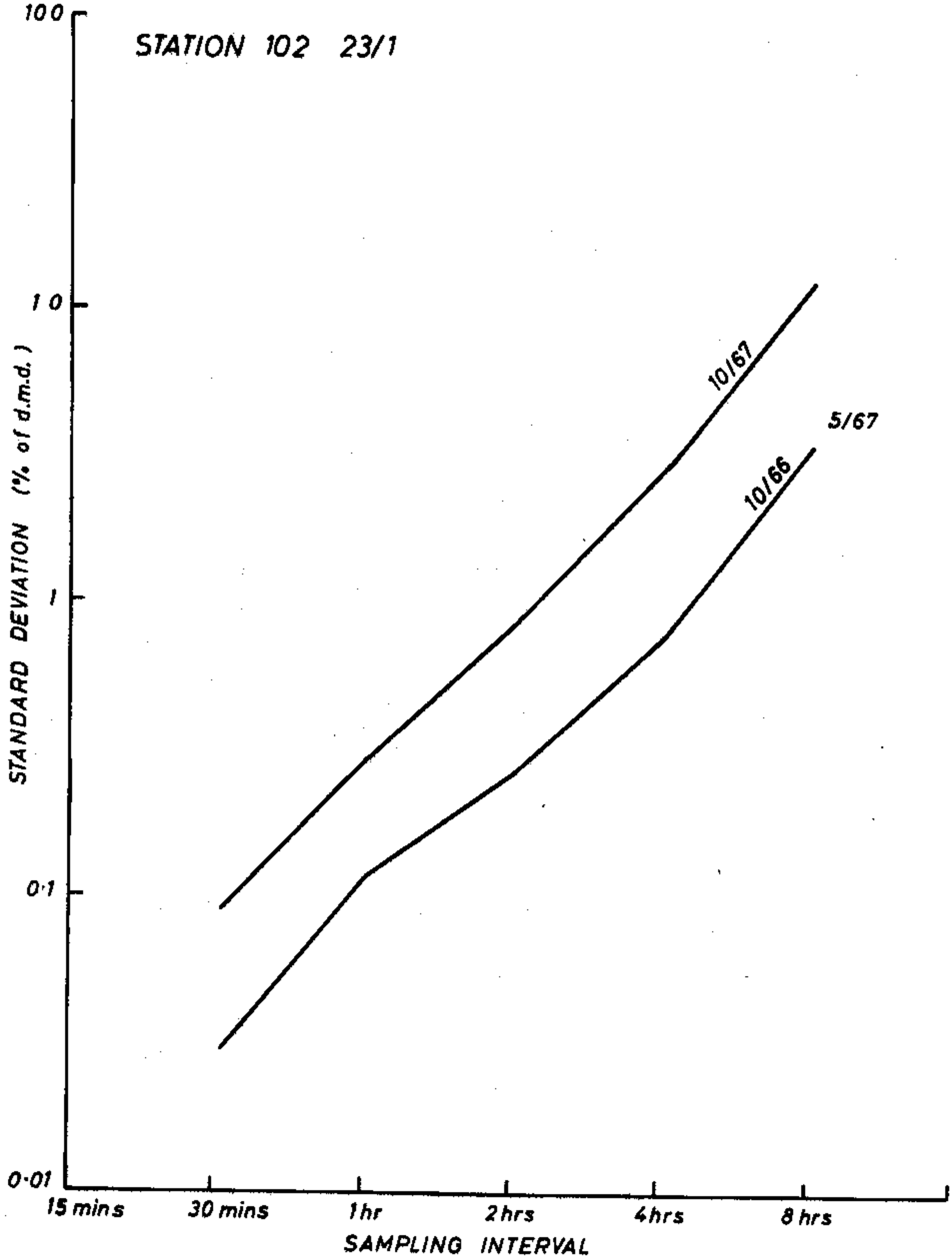
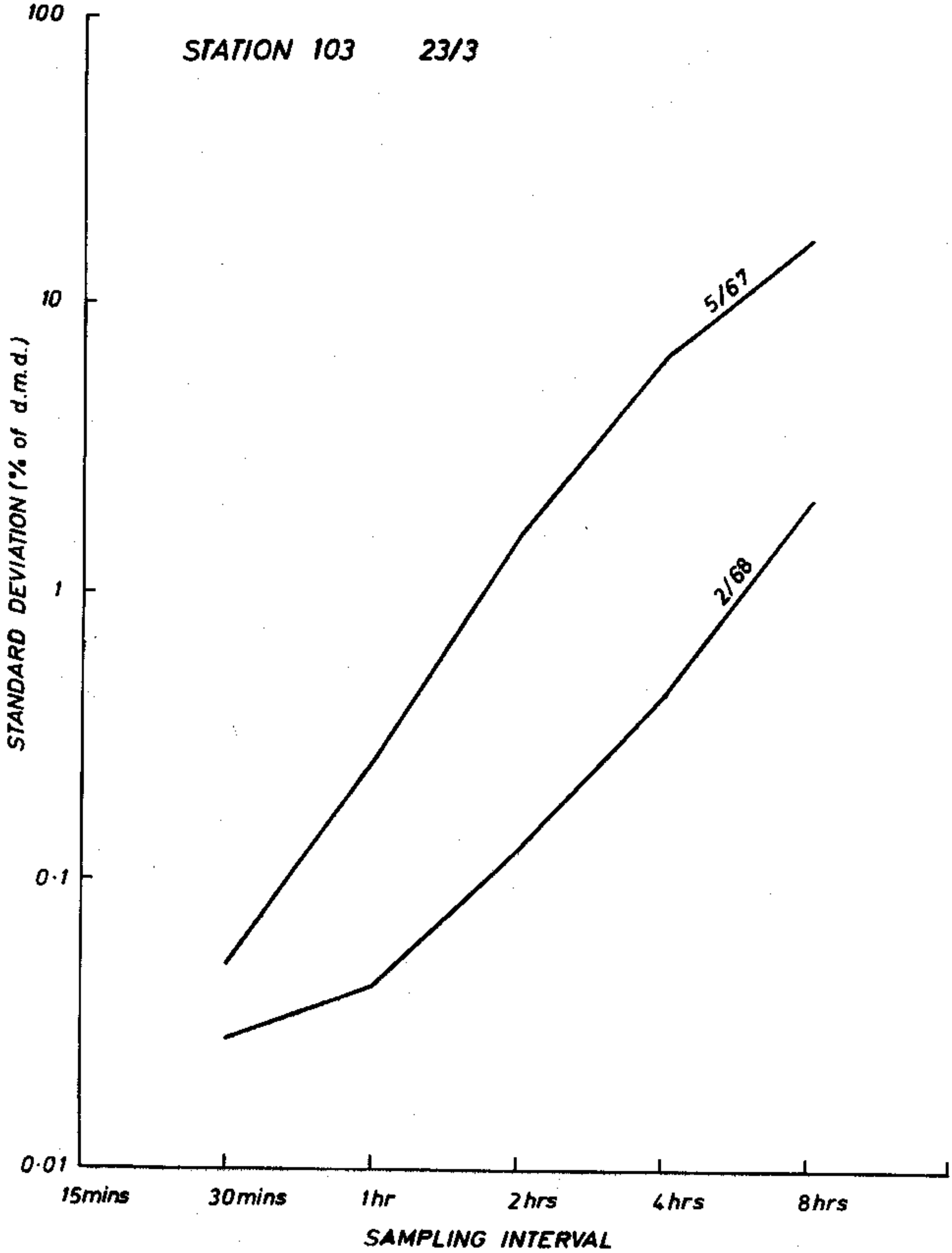

STATION 102 23/1
100
10
1
0·1
0·01
STANDARD DEVIATION (% of d.m.d.)
10/67
5/67
10/66
15 mins
30 mins
1hr
2hrs
4hrs
8 hrs
SAMPLING INTERVAL

FIG 4



STATION 103 23/3
100
10
1
0·1
0·01
STANDARD DEVIATION (% of d.m.d.)
5/67
2/68
15mins
30mins
1hr
2hrs
4hrs
8hrs
SAMPLING INTERVAL

FIG 5

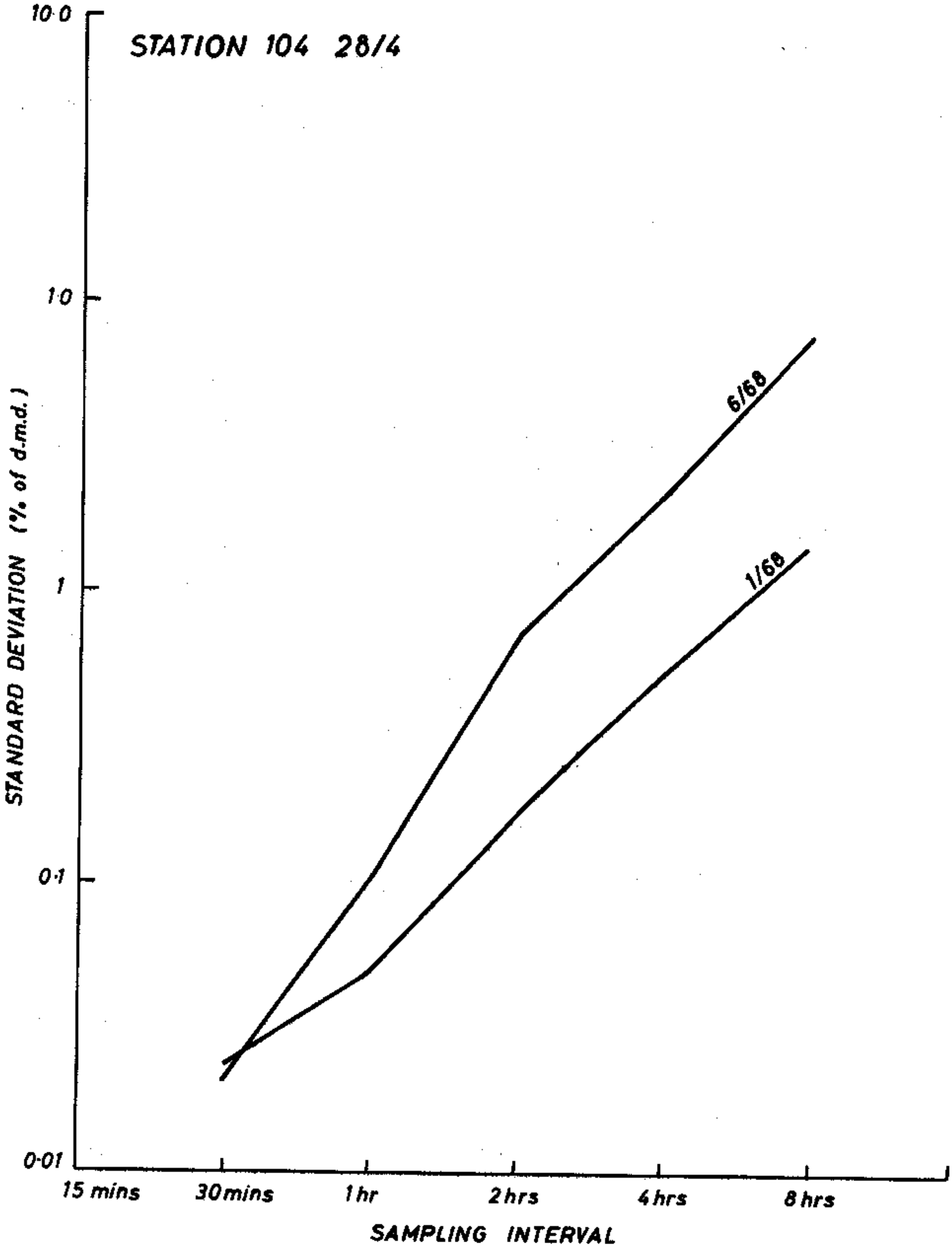
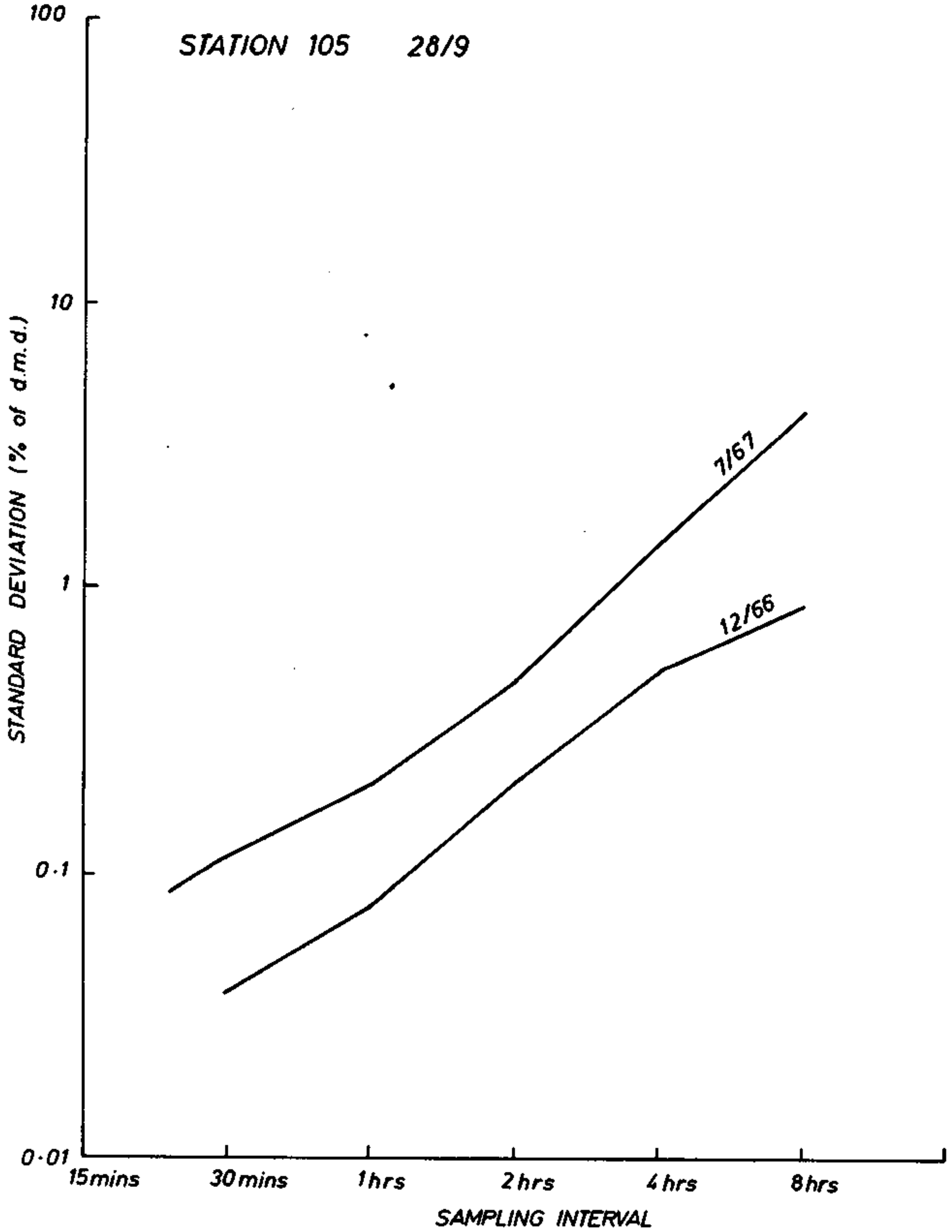

STATION 104 28/4
10·0
1·0
1
0·1
0·01
STANDARD DEVIATION (% of d.m.d.)
6/68
1/68
15 mins
30 mins
1 hr
2 hrs
4 hrs
8 hrs
SAMPLING INTERVAL

FIG 6



STATION 105 28/9
100
10
1
0·1
0·01
STANDARD DEVIATION (% of d.m.d.)
7/67
12/66
15mins
30mins
1hrs
2hrs
4hrs
8hrs
SAMPLING INTERVAL

FIG 7

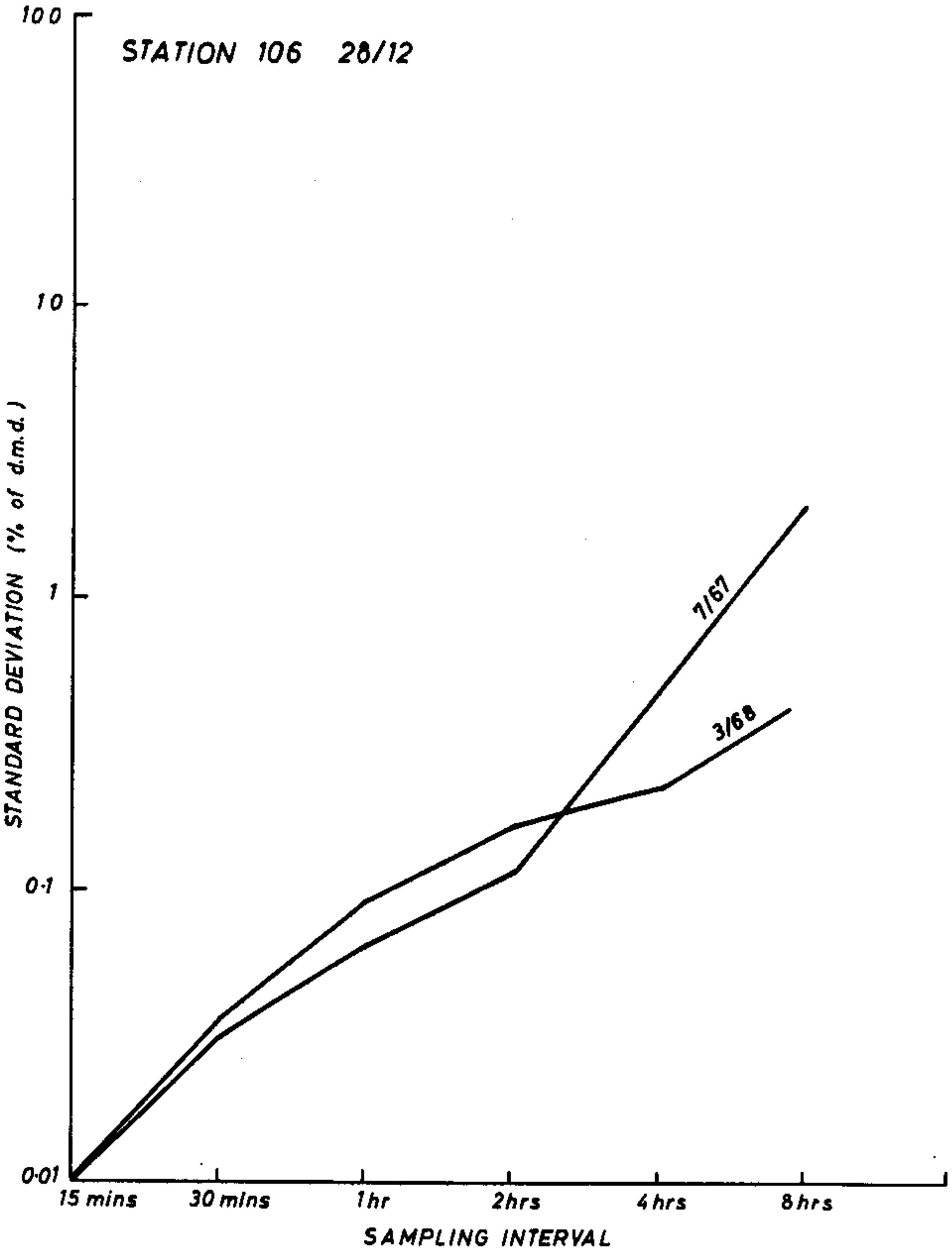

STATION 106 28/12
10.0
1.0
1
0·1
0·01
STANDARD DEVIATION (% of d.m.d.)
7/67
3/68
15 mins
30 mins
1hr
2hrs
4hrs
8hrs
SAMPLING INTERVAL

FIG 8

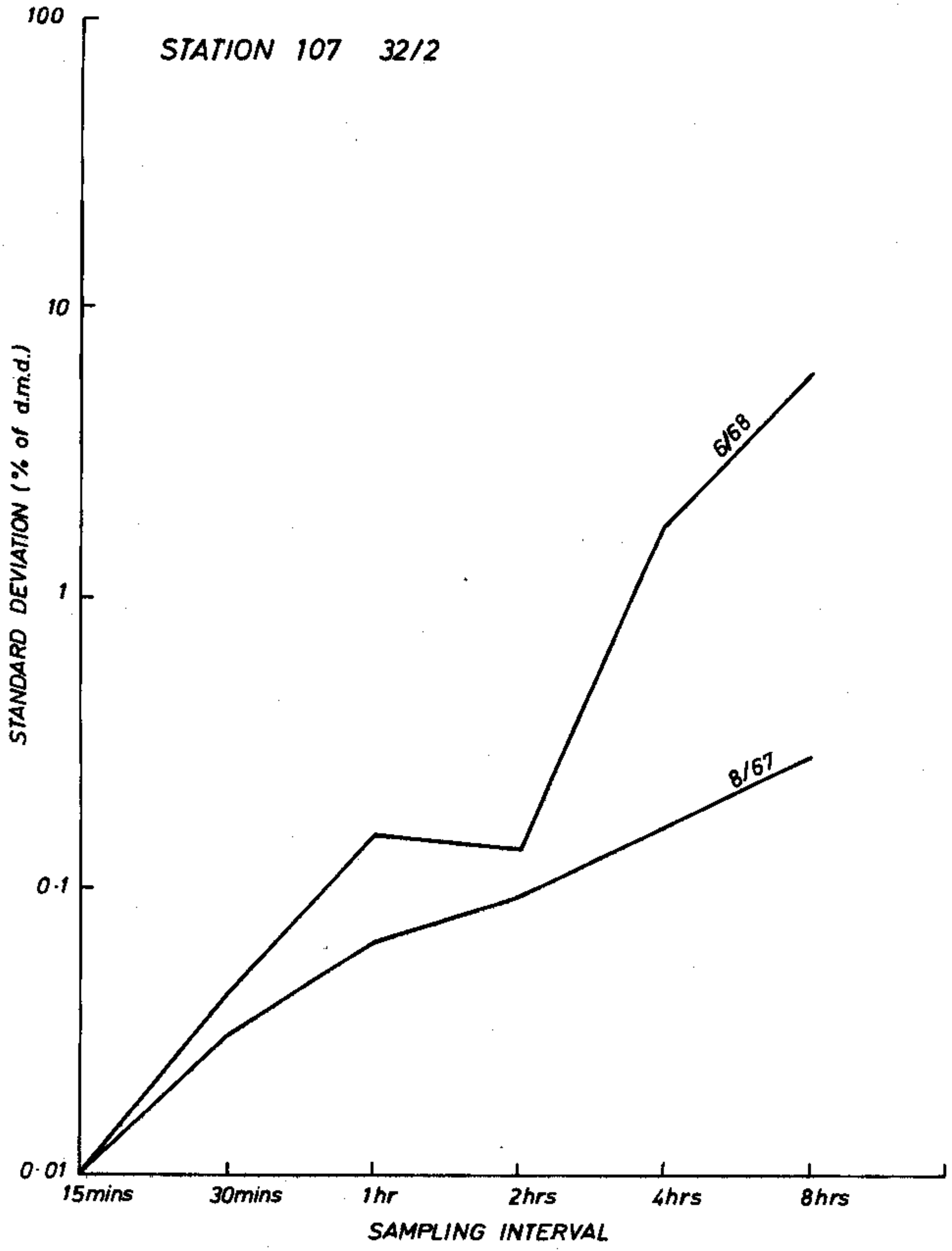
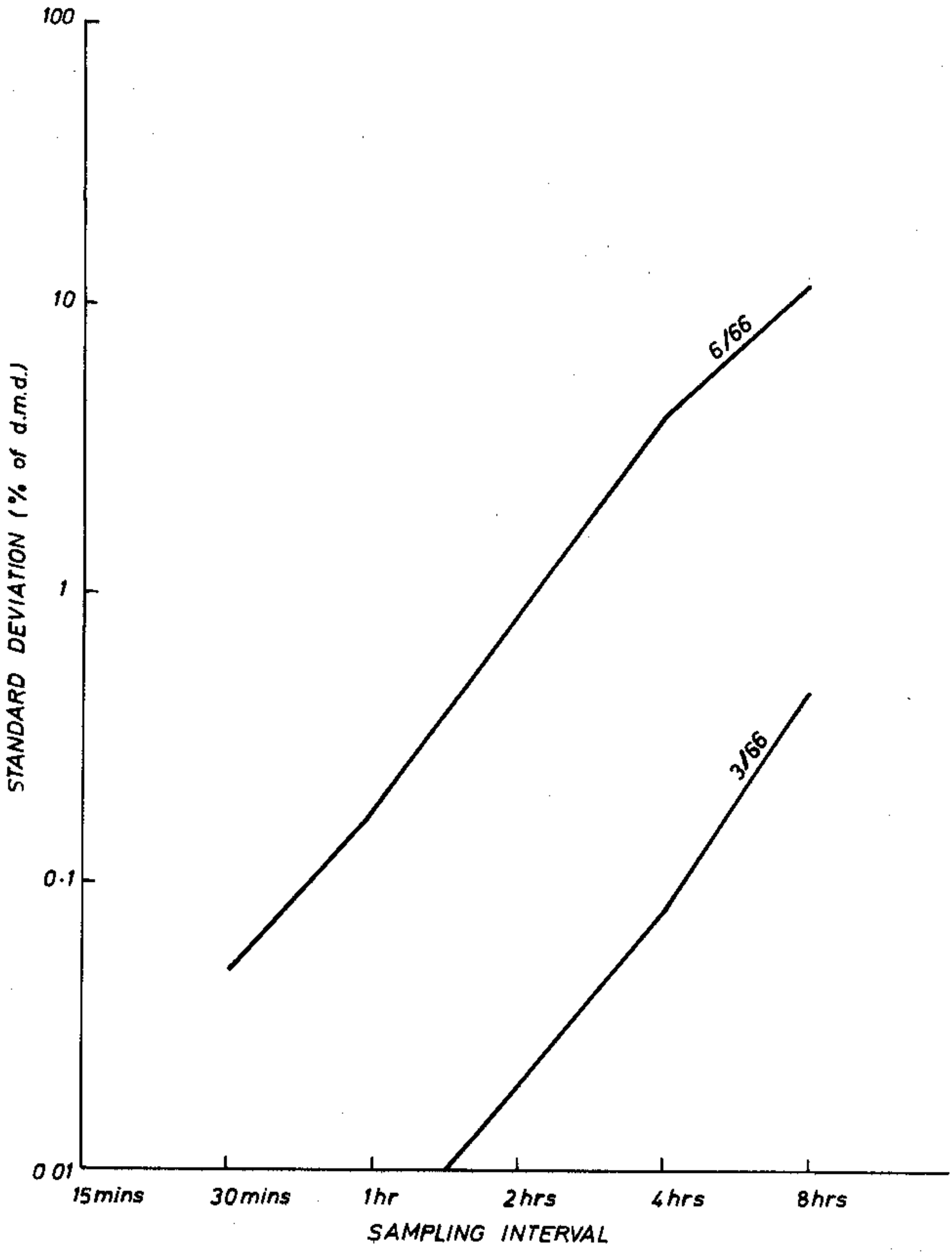

STATION 107 32/2
100
10
1
0·1
0·01
STANDARD DEVIATION (% of d.m.d.)
6/68
8/67
15mins
30mins
1hr
2hrs
4hrs
8hrs
SAMPLING INTERVAL

FIG 9



100
10
1
0·1
0 01
STANDARD DEVIATION (% of d.m.d.)
6/66
3/66
15mins
30mins
1hr
2hrs
4hrs
8hrs
SAMPLING INTERVAL

FIG 10

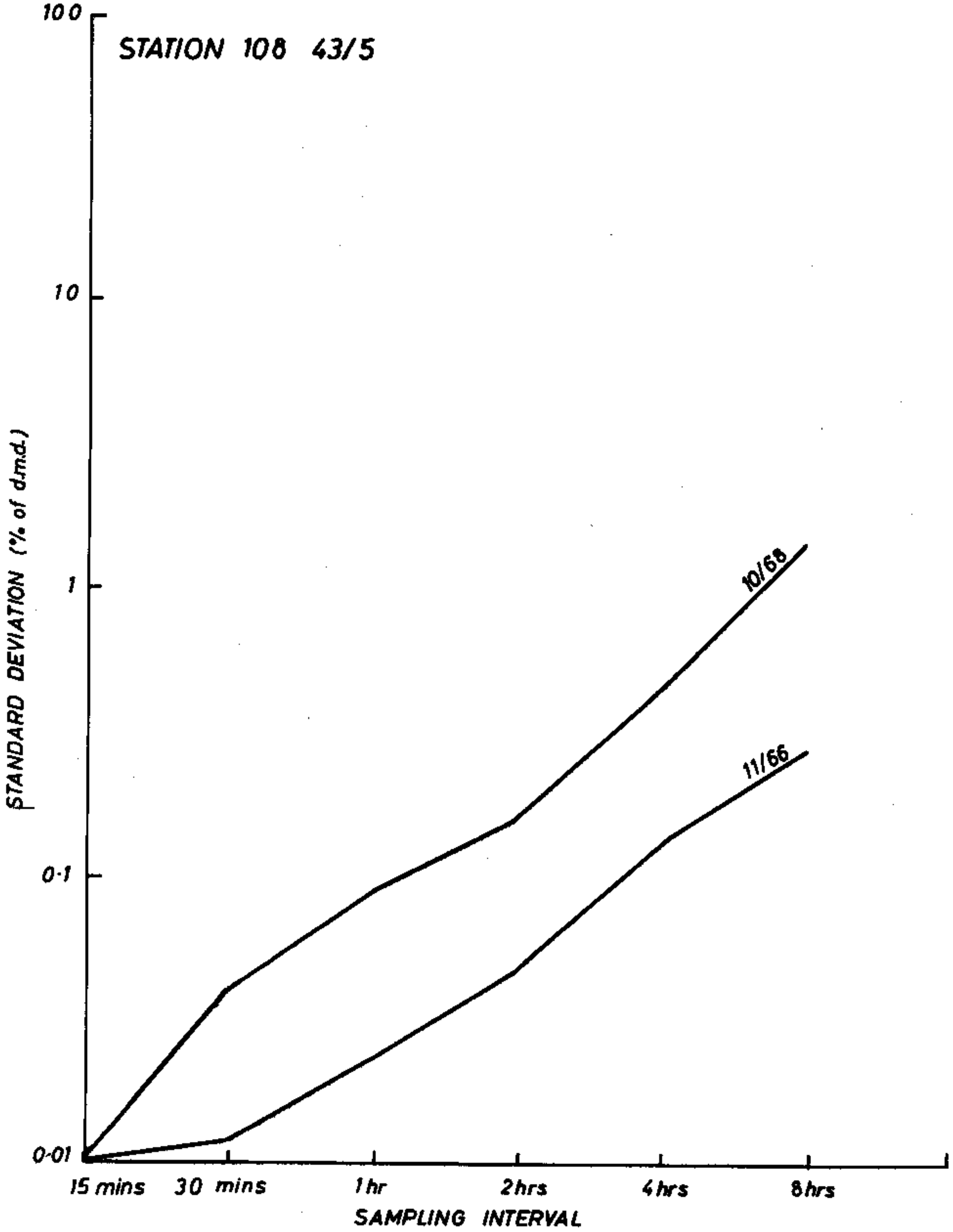
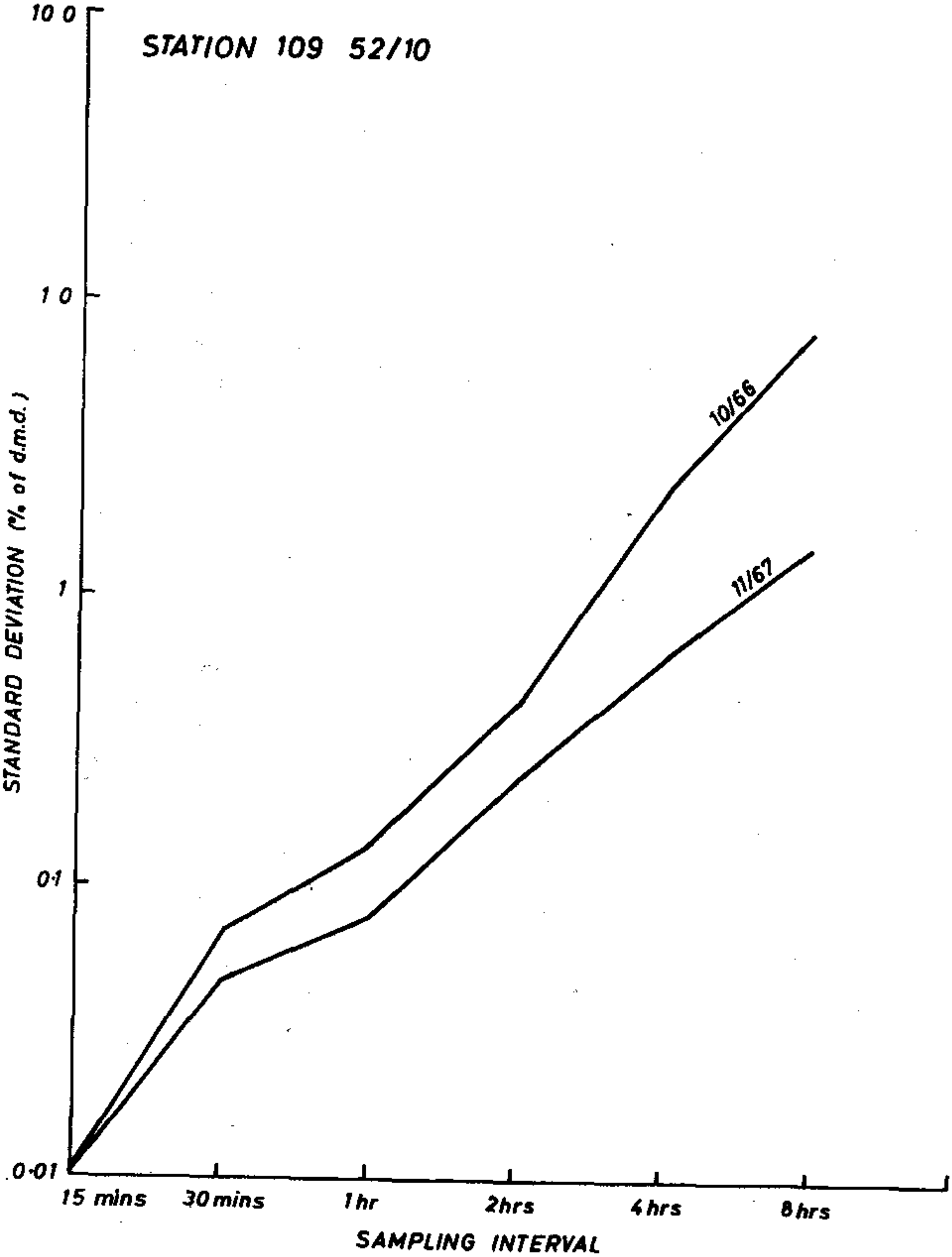

STATION 108 43/5
100
10
1
0·1
0·01
STANDARD DEVIATION (% of d.m.d.)
10/68
11/66
15 mins
30 mins
1 hr
2 hrs
4 hrs
8 hrs
SAMPLING INTERVAL

FIG 11



STATION 109 52/10
10 0
1 0
1
0·1
0·01
STANDARD DEVIATION (% of d.m.d.)
10/66
11/67
15 mins
30 mins
1 hr
2hrs
4 hrs
8 hrs
SAMPLING INTERVAL

FIG 12

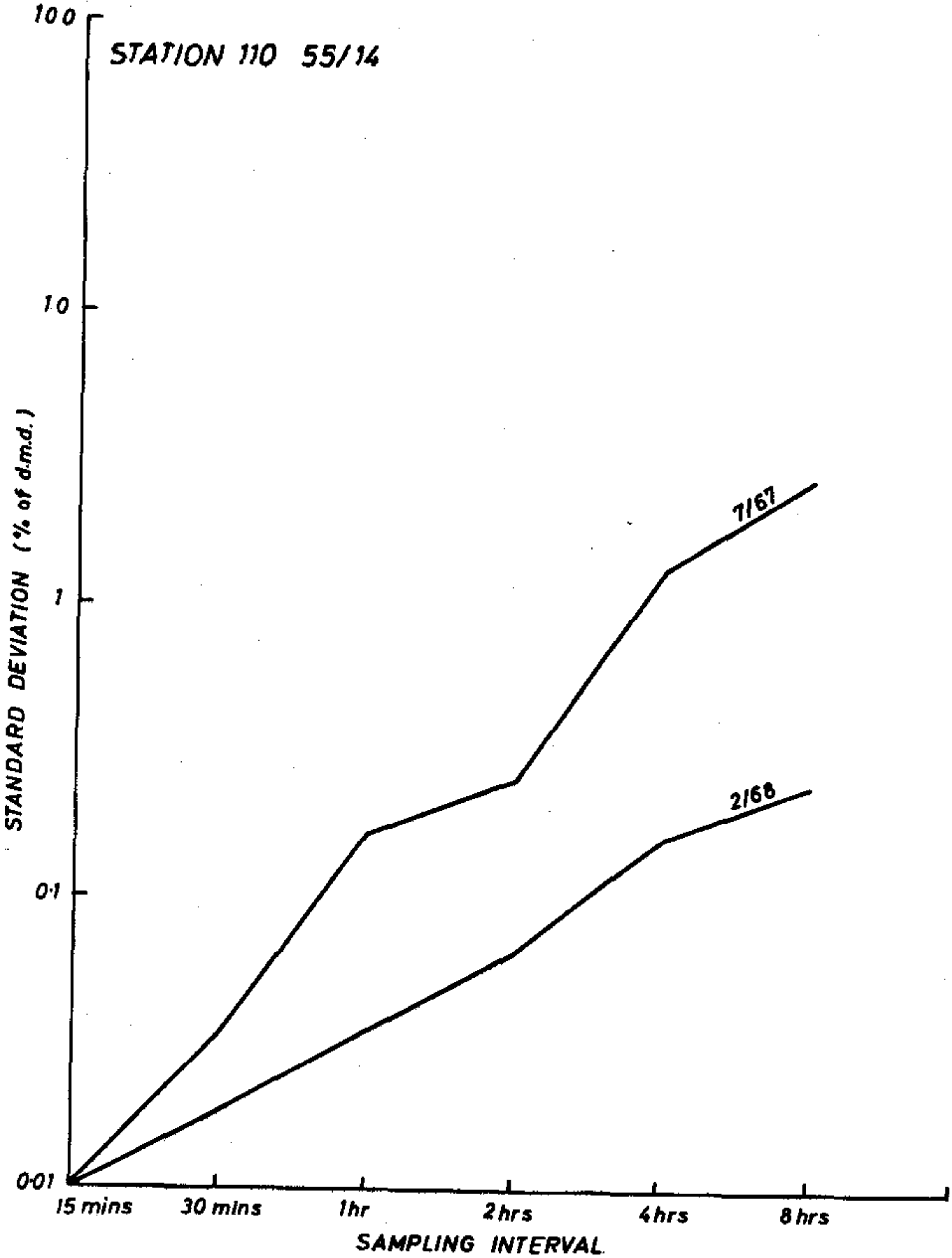
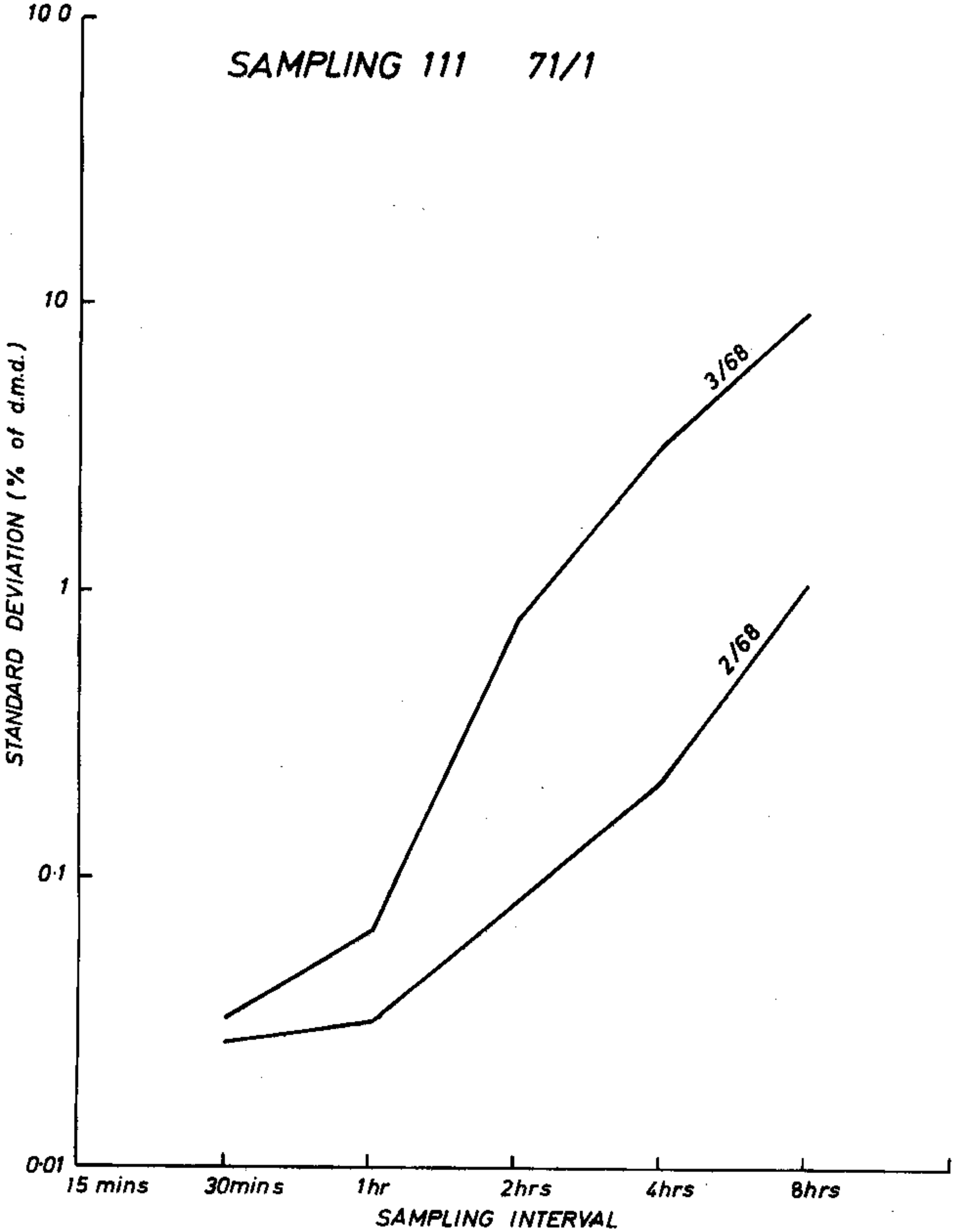
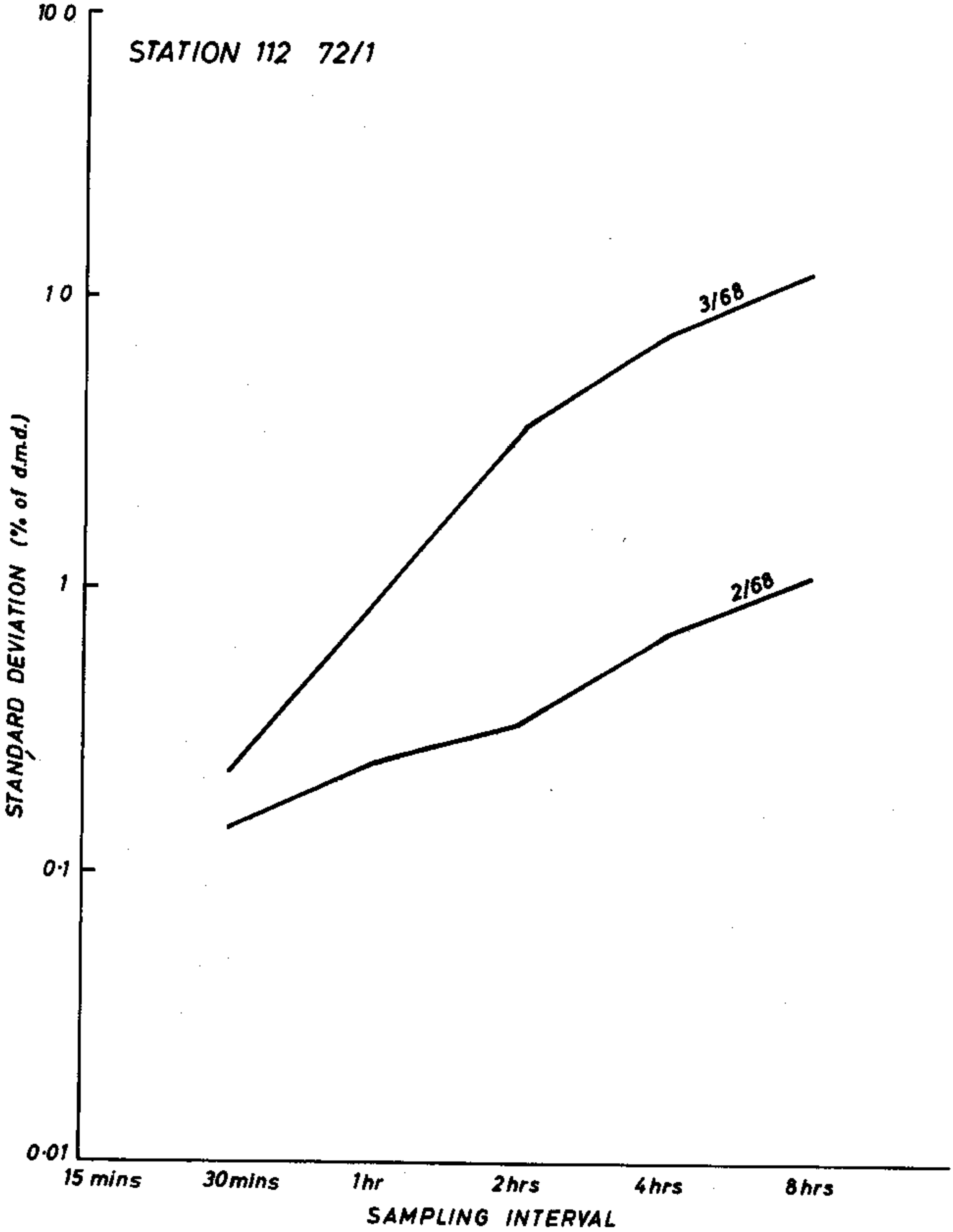

STATION 110 55/14
10.0
1.0
1
0·1
0·01
STANDARD DEVIATION (% of d.m.d.)
7/67
2/68
15 mins
30 mins
1hr
2 hrs
4 hrs
8 hrs
SAMPLING INTERVAL

FIG 13



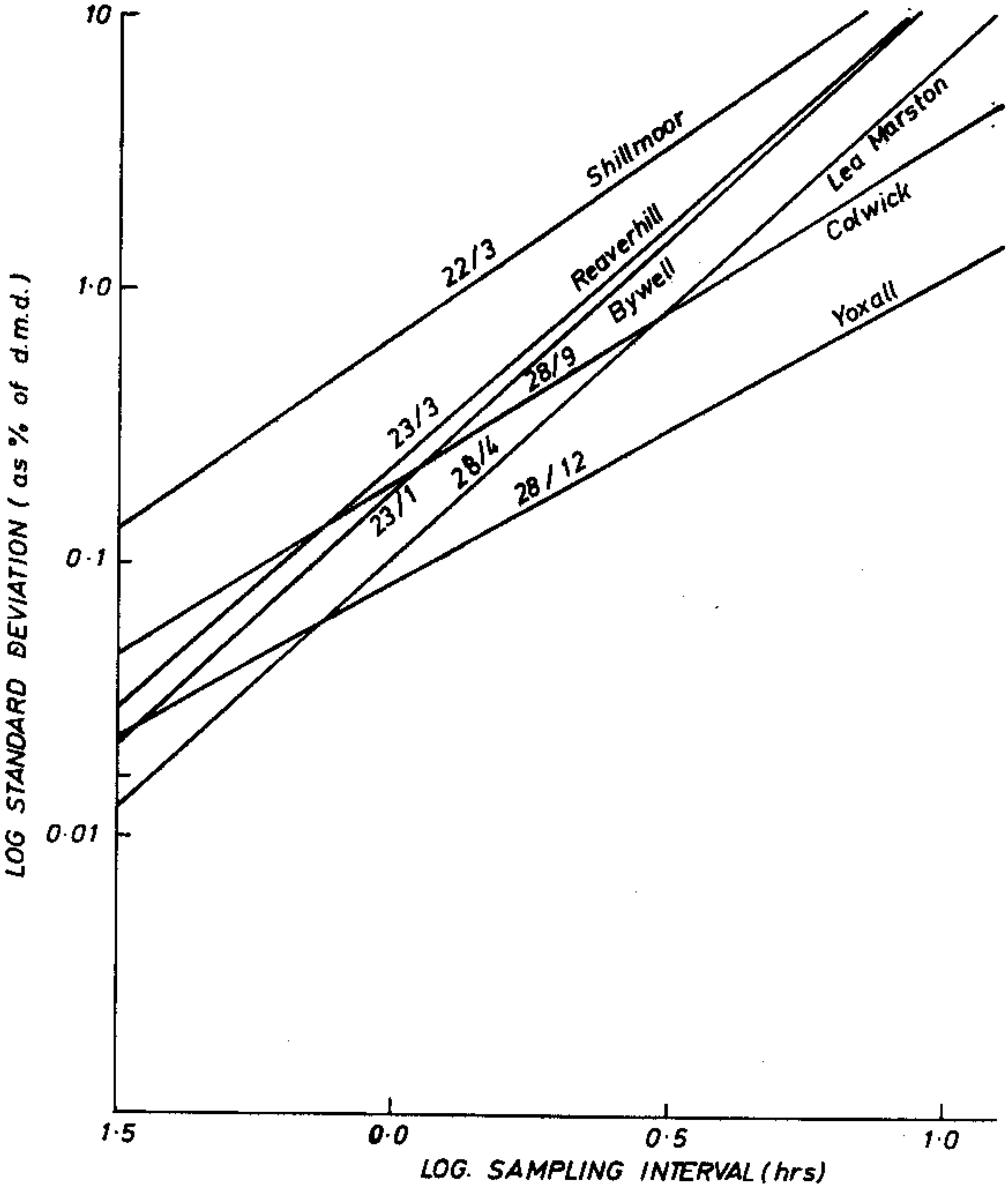
SAMPLING 111   71/1
STANDARD DEVIATION (% of d.m.d.)
10 0
10
1
0·1
0·01
3/68
2/68
15 mins
30mins
1hr
2hrs
4hrs
8hrs
SAMPLING INTERVAL

FIG 14



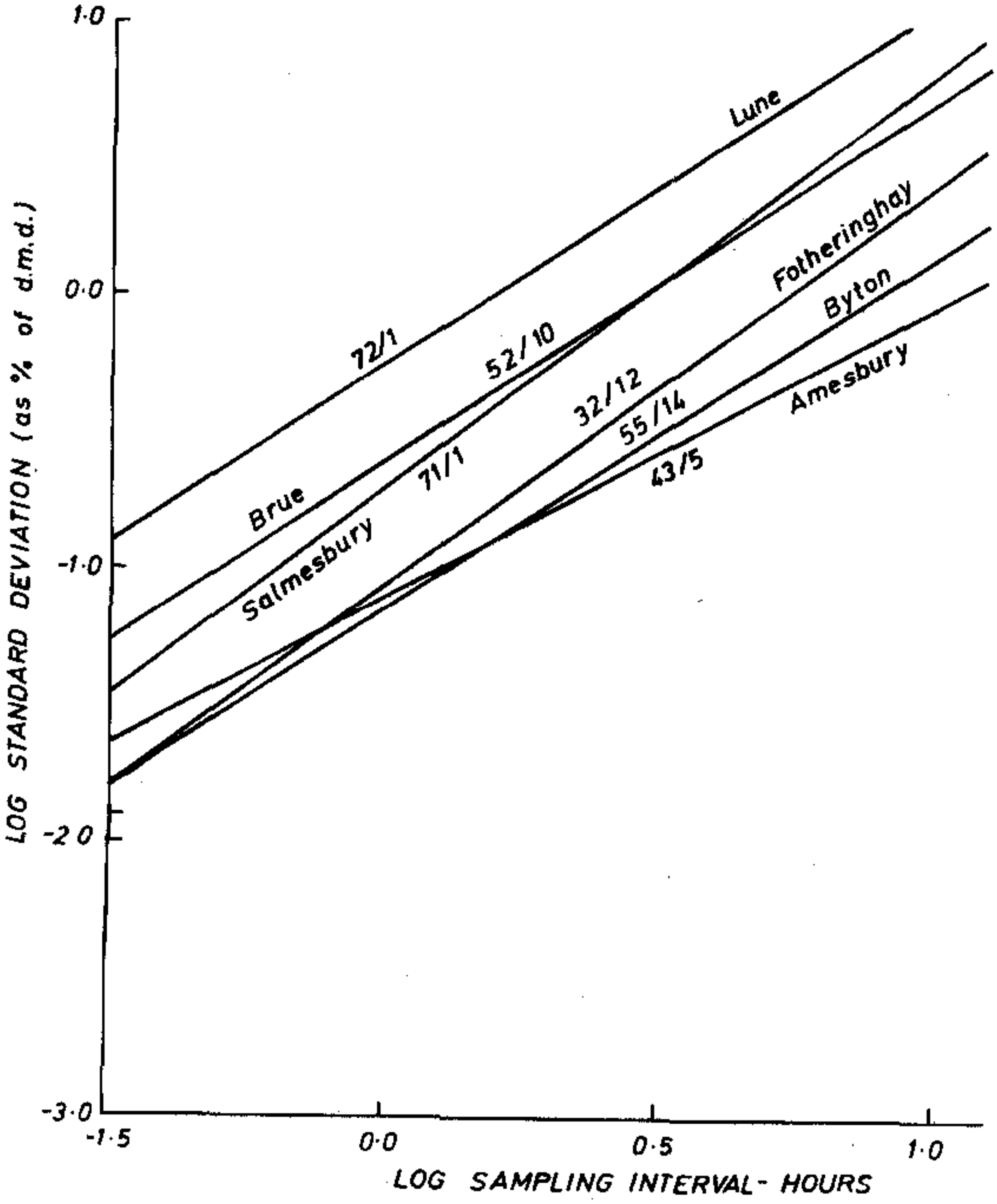
STATION 112 72/1
STANDARD DEVIATION (% of d.m.d.)
10 0
1 0
1
0·1
0·01
3/68
2/68
15 mins
30mins
1hr
2hrs
4hrs
8hrs
SAMPLING INTERVAL

FIG 15



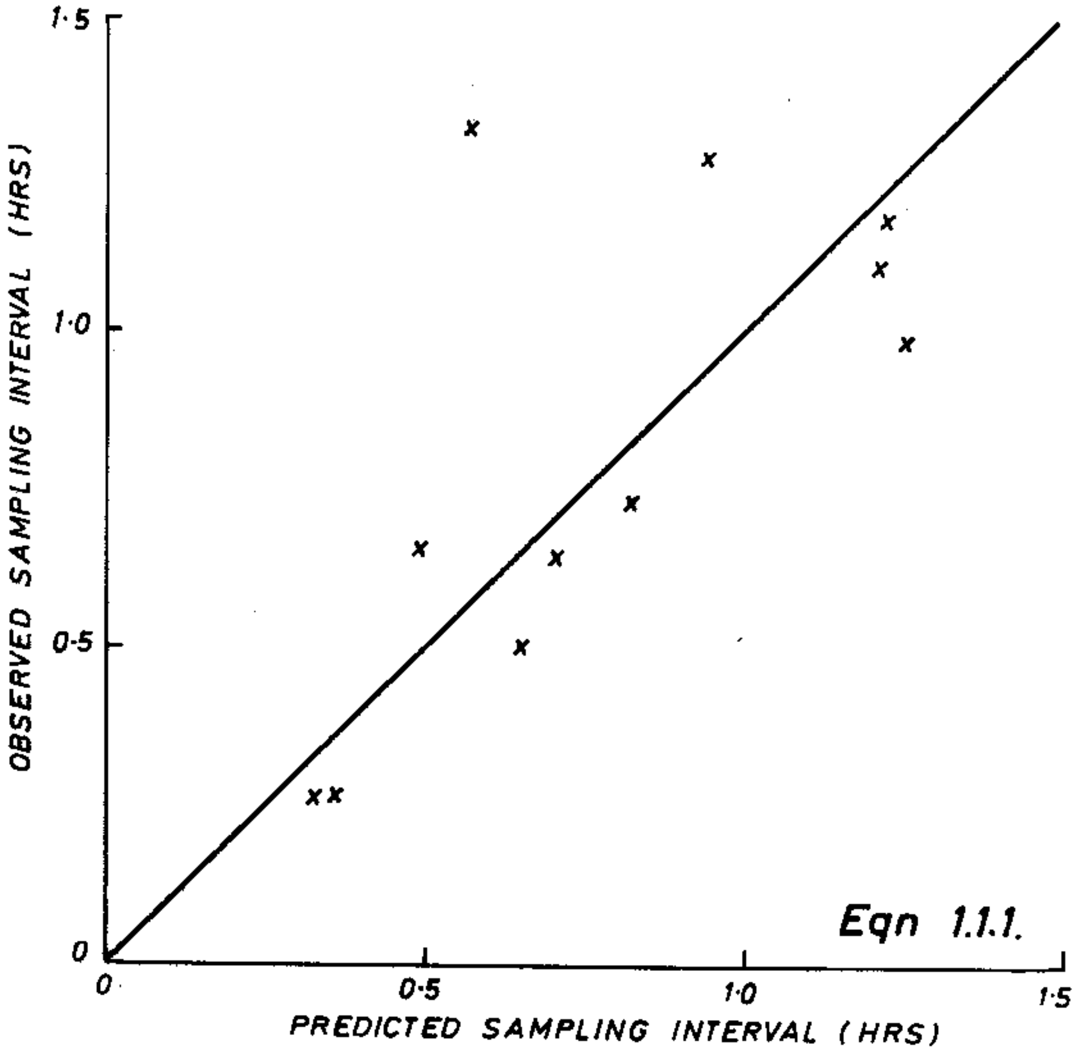
OBSERVED STANDARD DEVIATION AND SAMPLING INTERVAL FOR 6 STATION RECORDS (1966 -1968)

FIG 16



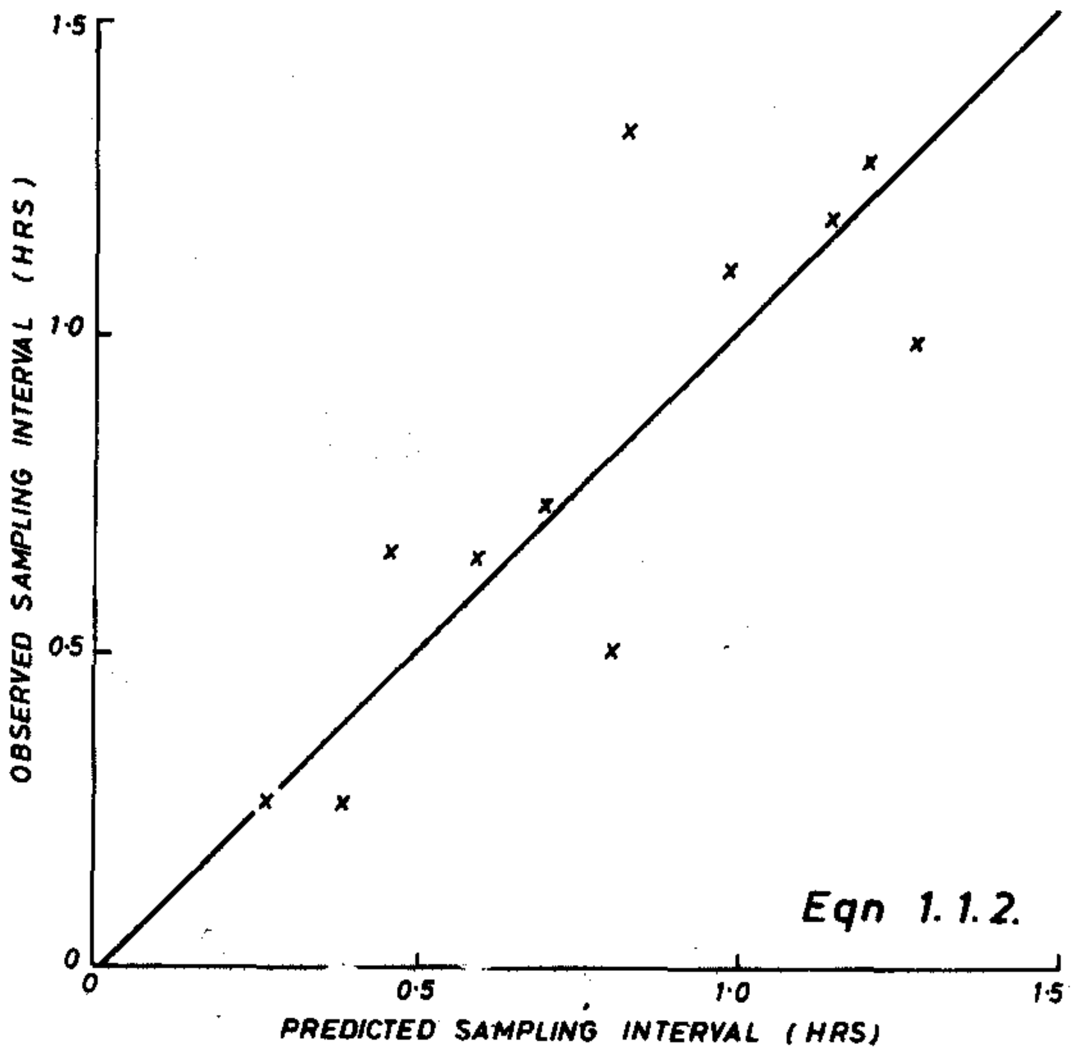
OBSERVED STANDARD DEVIATION AND SAMPLING INTERVAL FOR 6 STATION RECORDS (1966 - 1968)

FIG 17



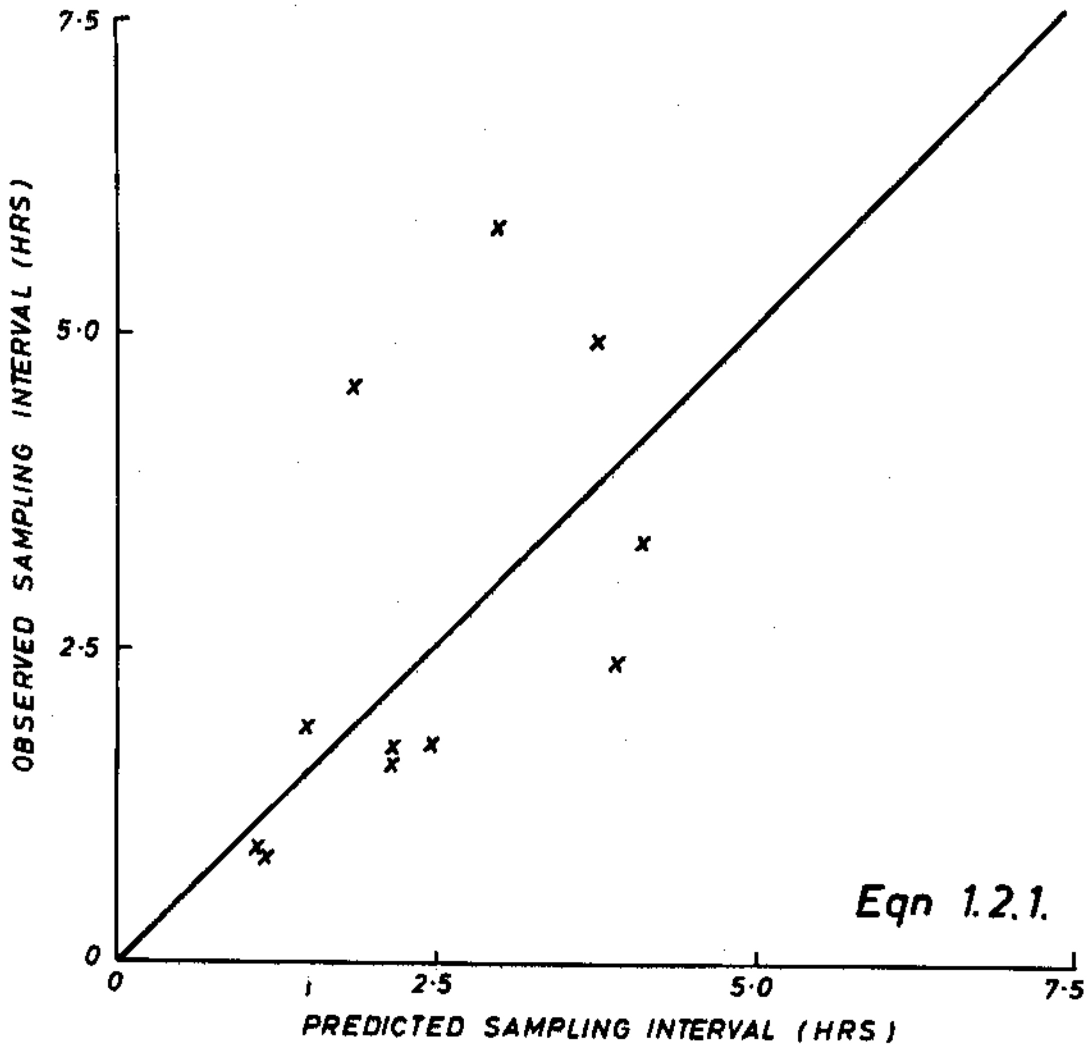
OBSERVED AND PREDICTED SAMPLING INTERVALS

FIG 18



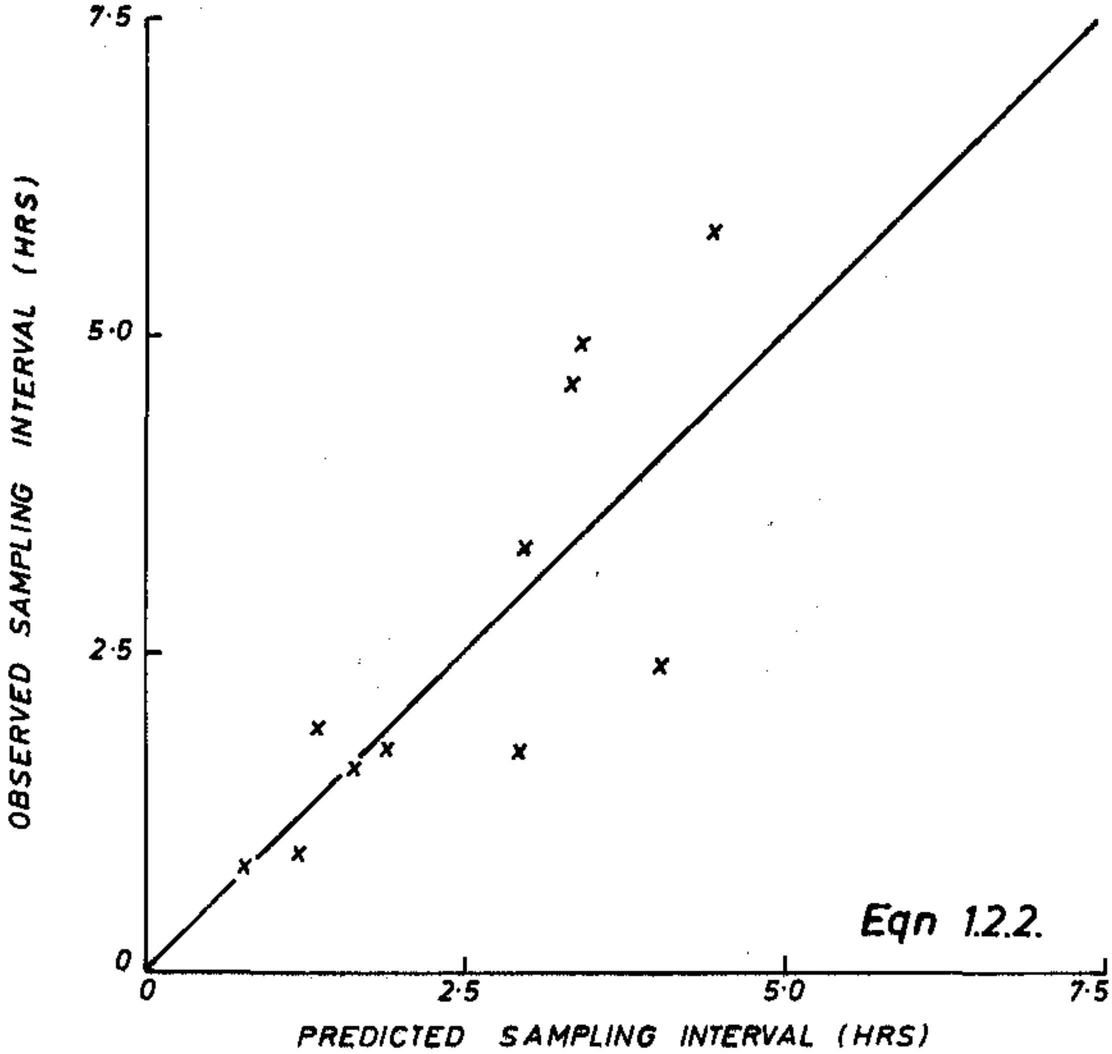
OBSERVED AND PREDICTED SAMPLING INTERVALS

FIG 19



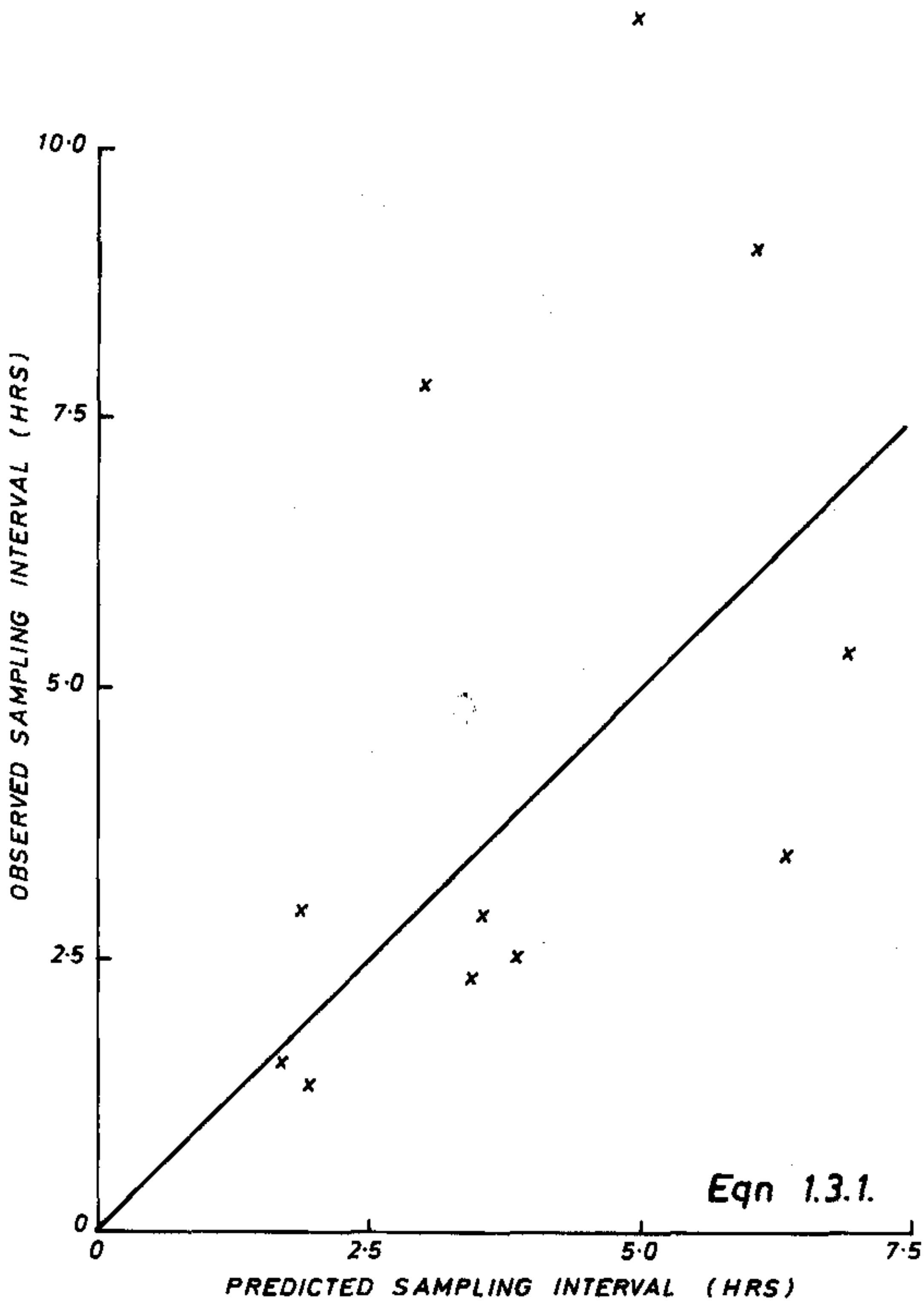
OBSERVED AND PREDICTED SAMPLING INTERVALS

FIG 20



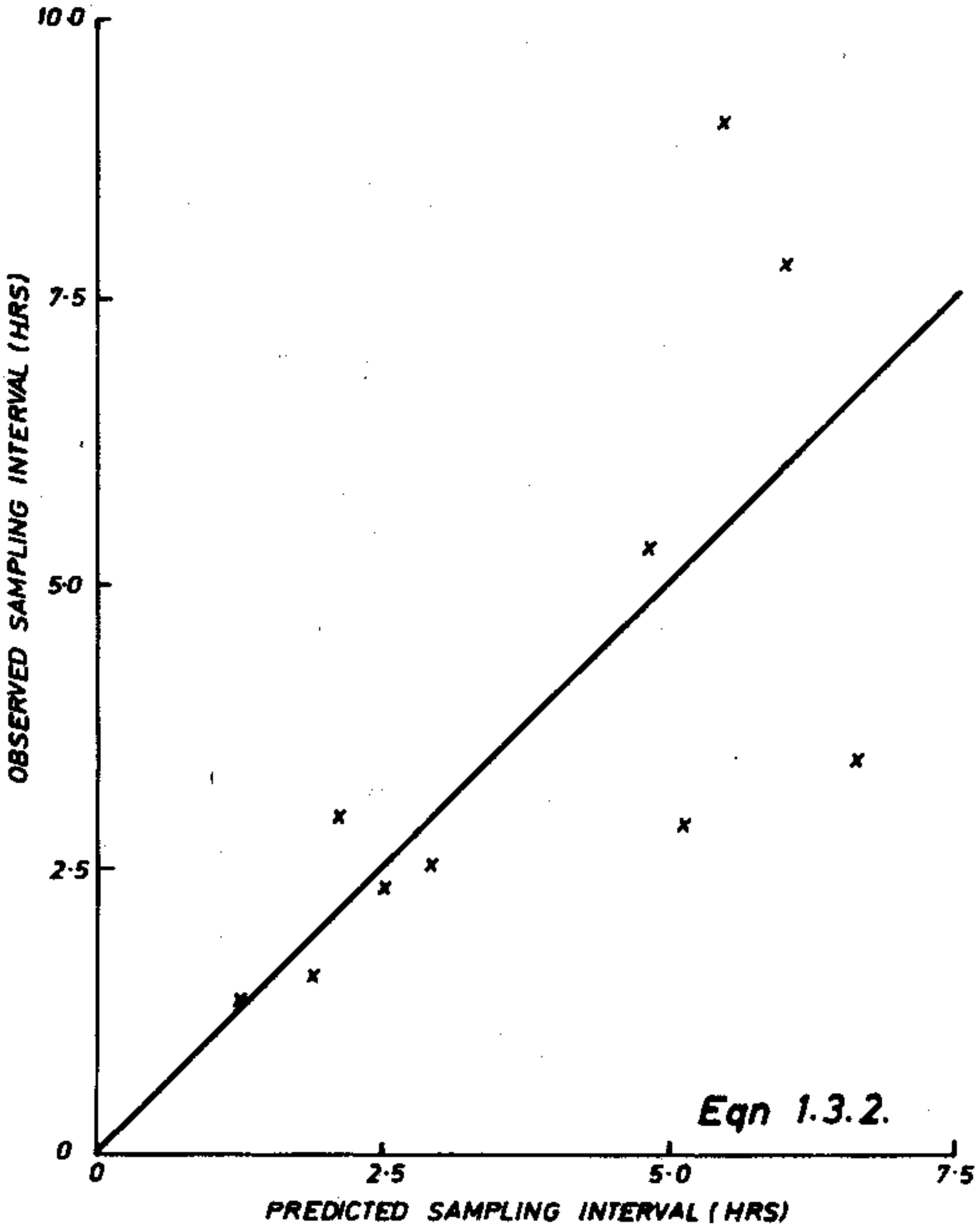
OBSERVED AND PREDICTED SAMPLING INTERVALS

FIG 21



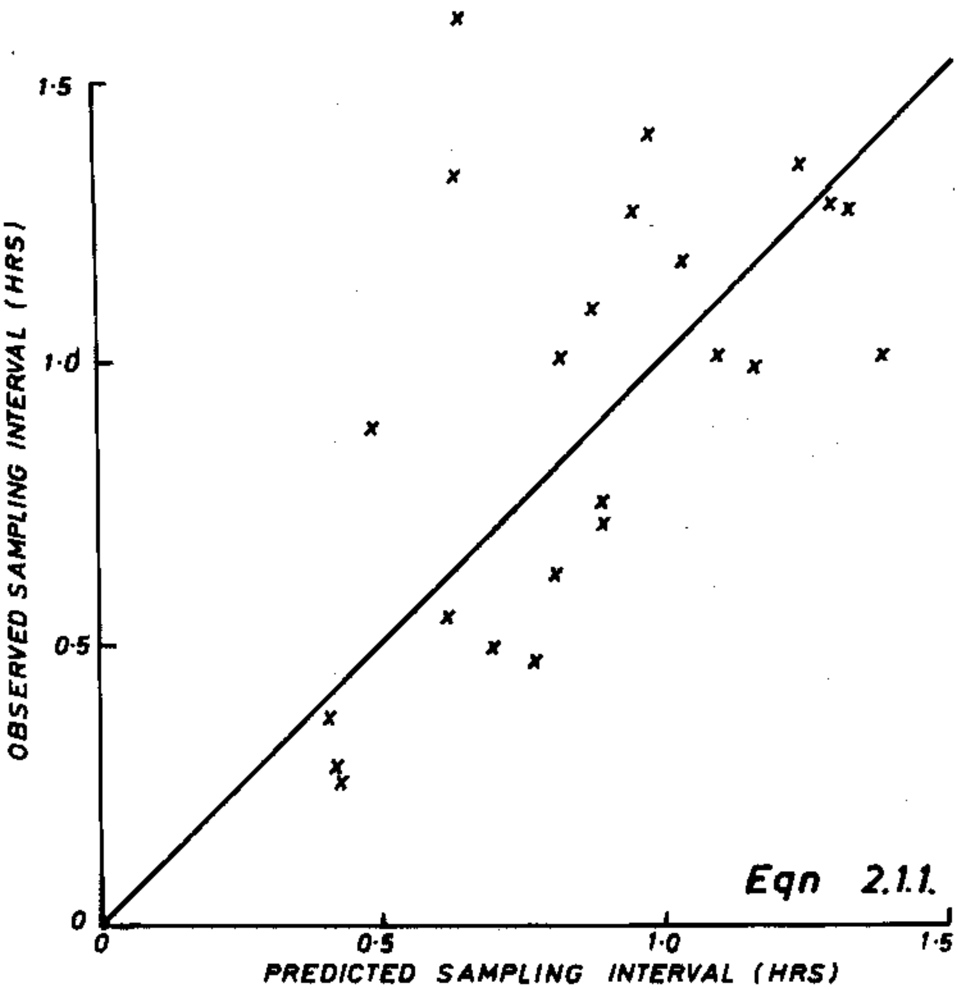
OBSERVED AND PREDICTED SAMPLING INTERVALS

FIG 22



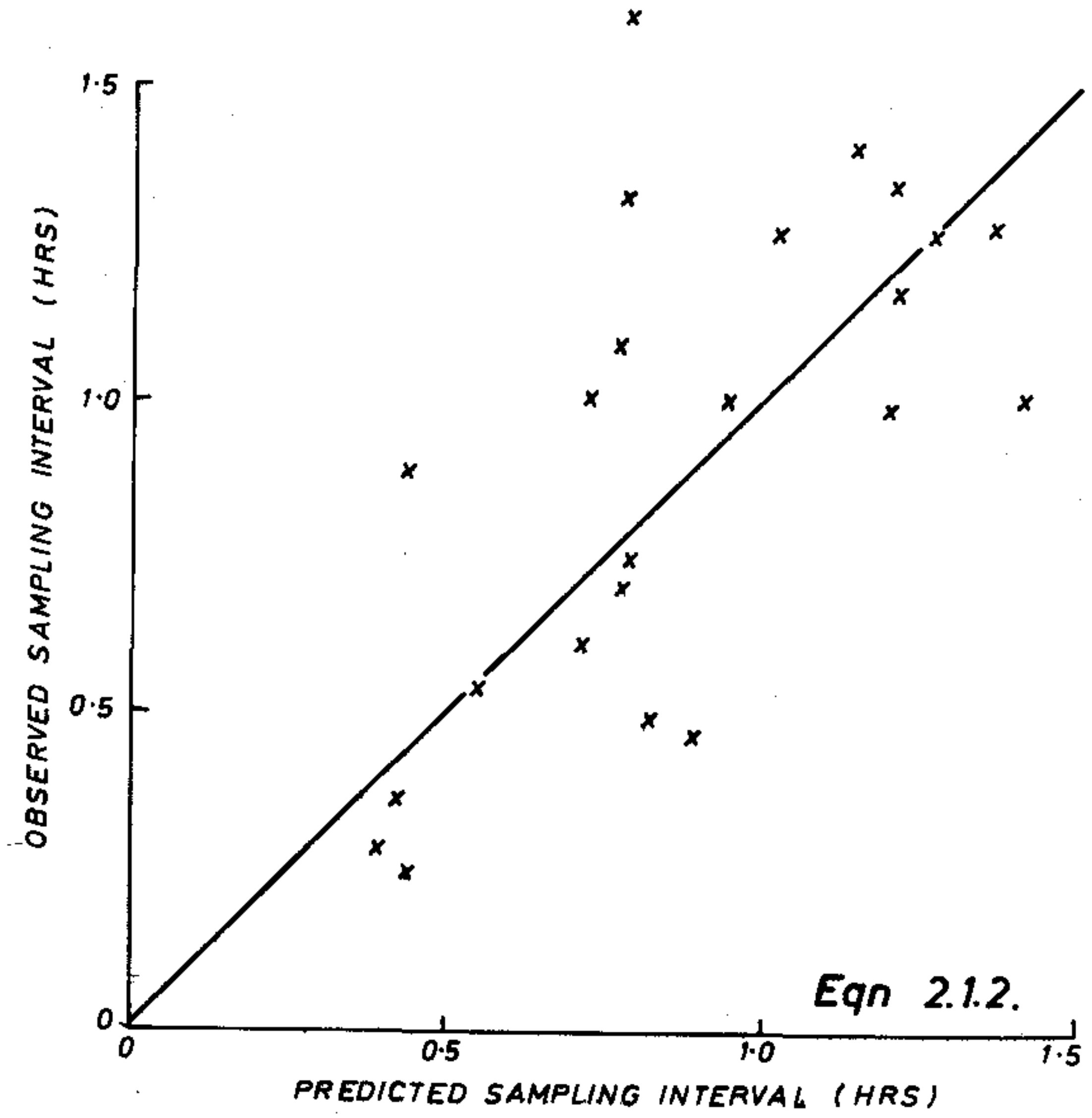
OBSERVED AND PREDICTED SAMPLING INTERVALS

FIG 23



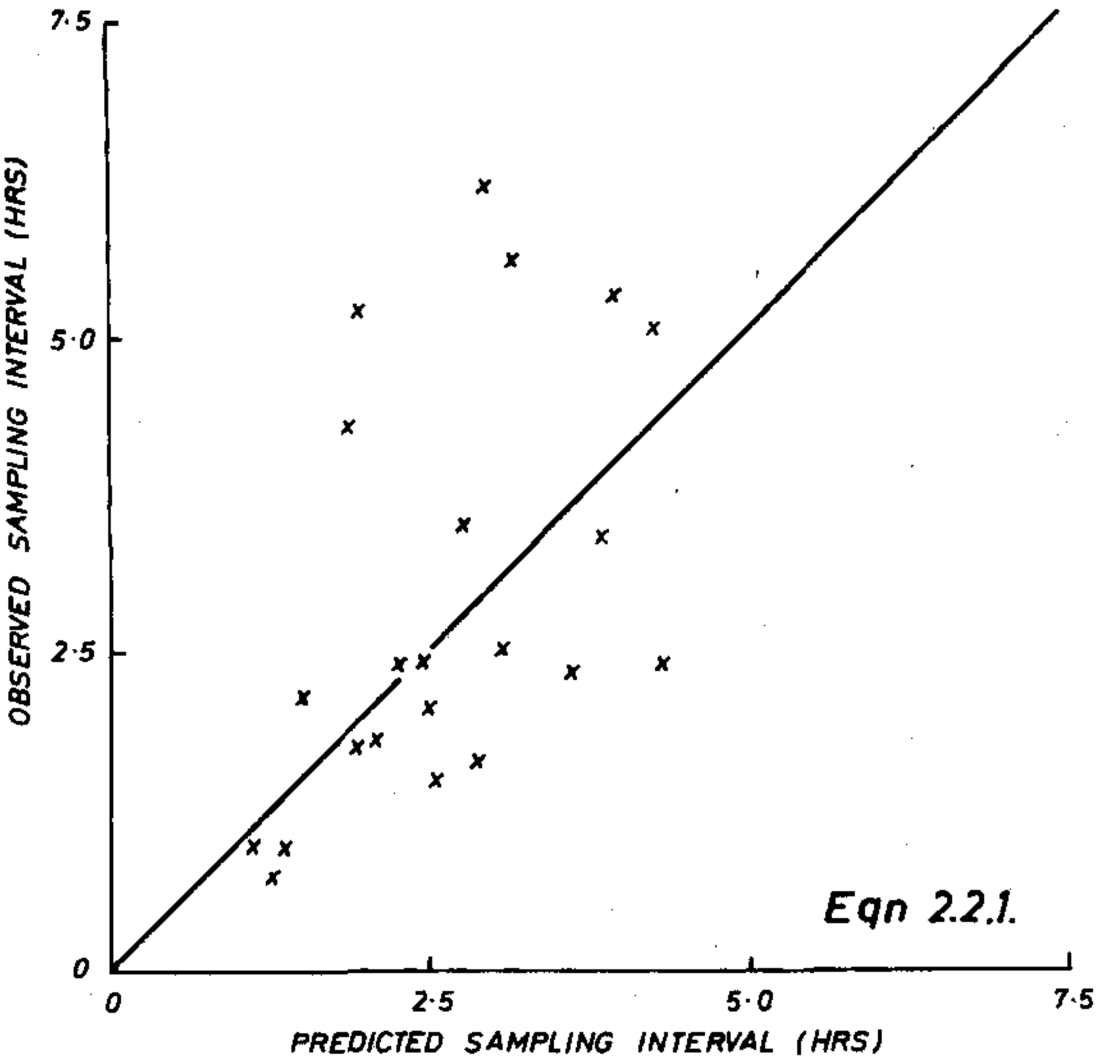
OBSERVED AND PREDICTED SAMPLING INTERVALS

FIG 24



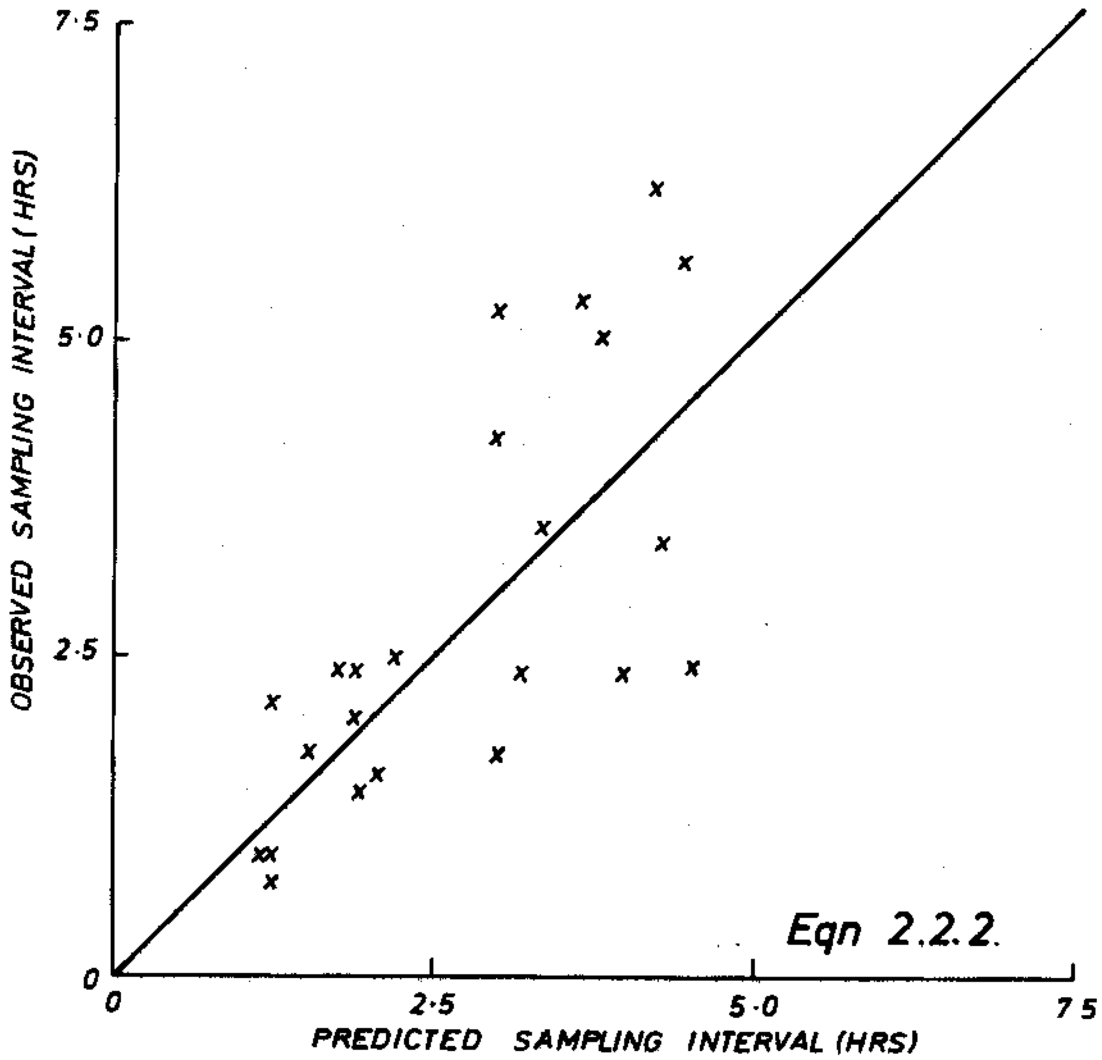
OBSERVED AND PREDICTED SAMPLING INTERVALS

FIG 25



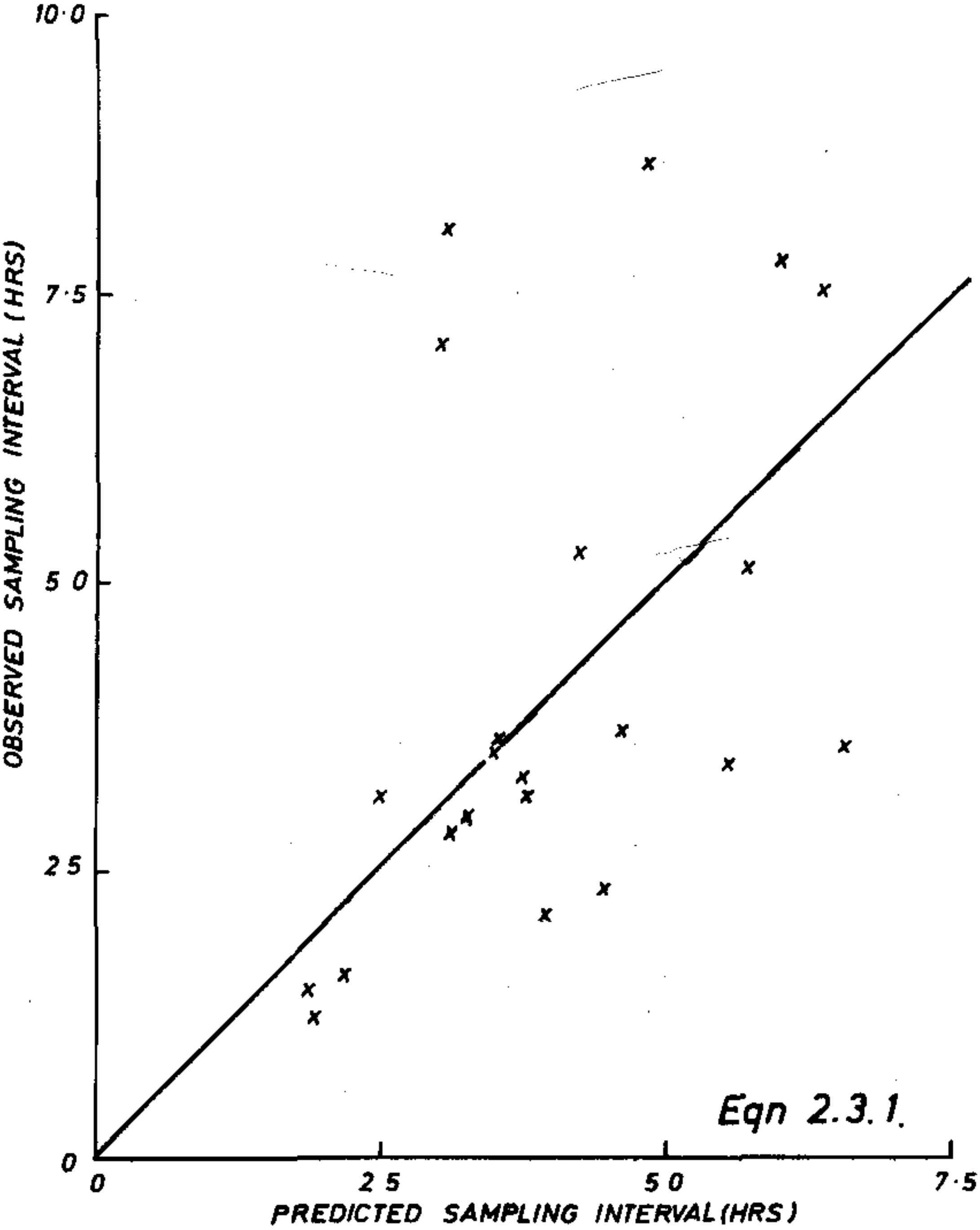
OBSERVED AND PREDICTED SAMPLING INTERVALS

FIG 26



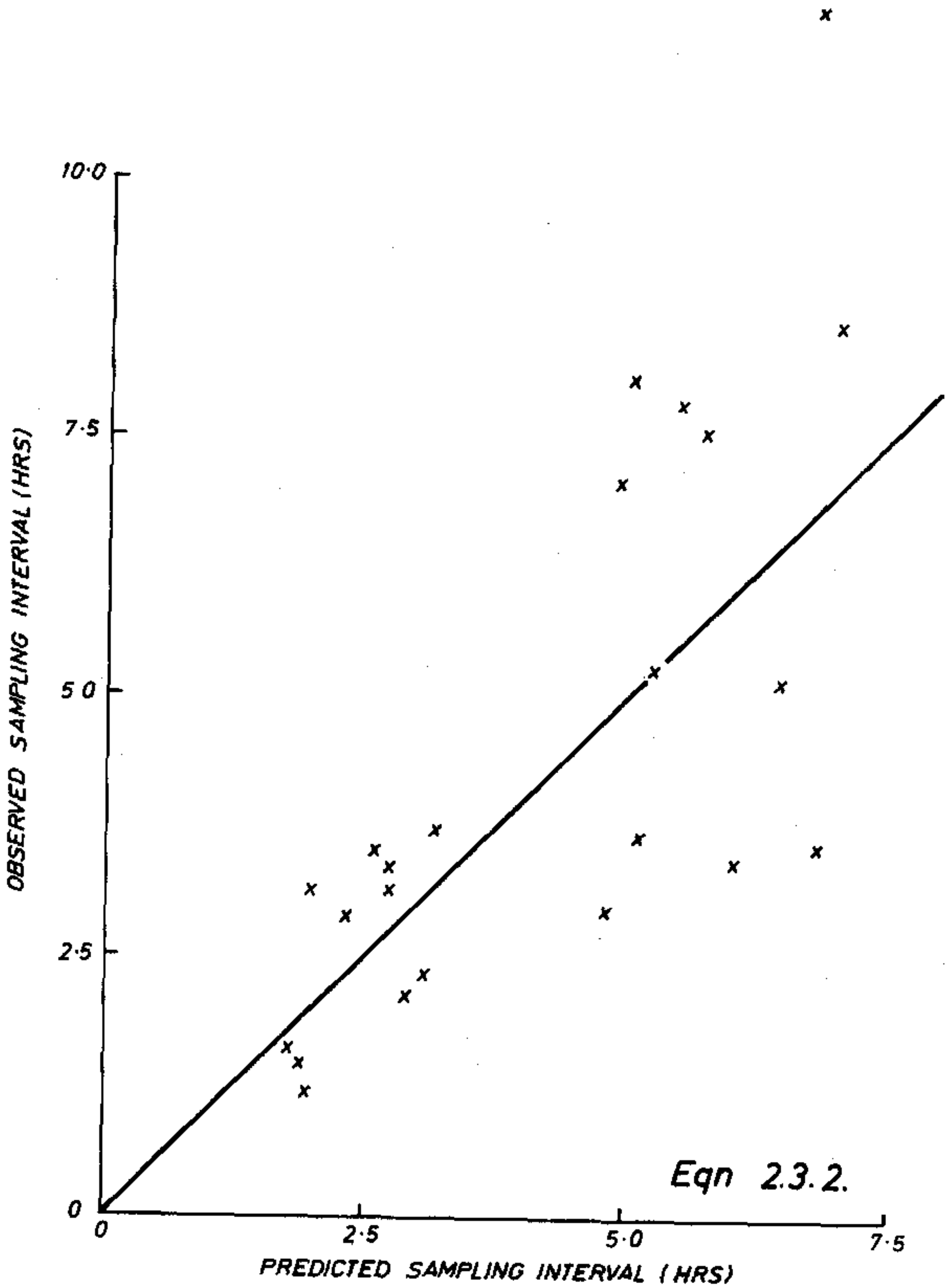
OBSERVED AND PREDICTED SAMPLING INTERVALS

FIG 27



OBSERVED AND PREDICTED SAMPING INTERVALS

FIG 28



OBSERVED AND PREDICTED SAMPLING INTERVALS

FIG 29

HYDROLOGICAL CLASSIFICATION OF SOILS IN ENGLAND AND WALES

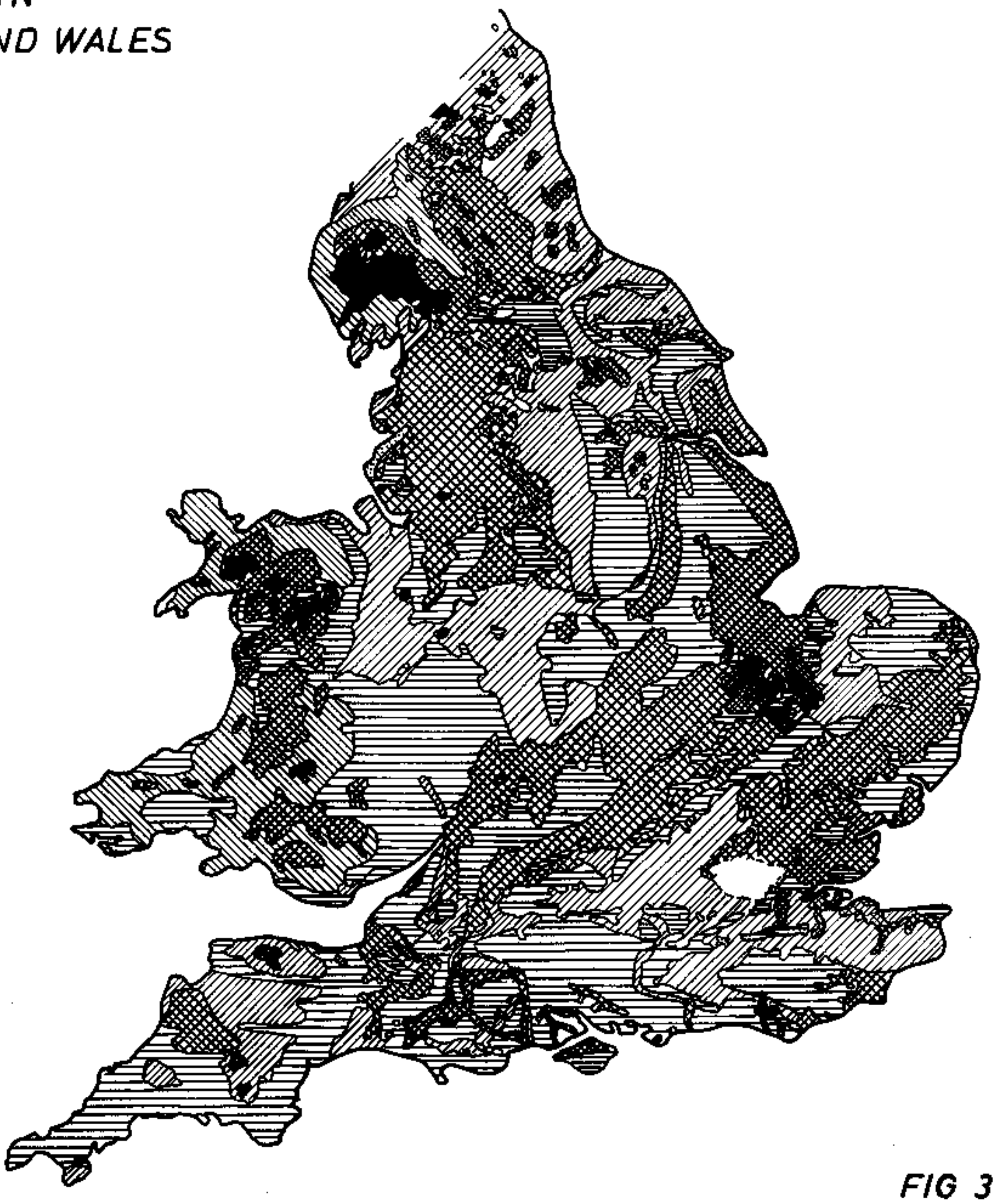


FIG 32