Technical Memorandum 1

Transport of Trace Metals in the Magela Creek System, Northern Territory

I. Concentrations and loads of iron, manganese, cadmium, copper, lead and zinc during flood periods in the 1978–1979 wet season

B. T. Hart, S. H. R. Davies and P. A. Thomas

Supervising Scientist for
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SUMMARY

Five major floods occurred in Magela Creek during the 1978-79 tropical wet season and floodwaters were sampled for conductivity, suspended solids and the trace metals, iron, manganese, cadmium, copper, lead and zinc. All concentrations were found to be very low, as were the denudation rates for trace metals and suspended materials. These results are as expected, since the catchment is highly weathered and is relatively undisturbed by man. The variations in conductivity, suspended solids and trace metal concentrations during individual flood events are also discussed.

1 INTRODUCTION

In order that realistic effluent standards may be established for the Ranger Uranium operations at Jabiru, Northern Territory, it is necessary that there be a clear and detailed knowledge of the pre-mining levels of trace metals and of their behaviour within the Magela Creek system.

This report details the results of a survey of the concentrations and loads of Fe, Mn, Cd, Cu, Pb and Zn transported past Jabiru, January-March 1978-79, during the wet season. A particular aim of the study was to determine the concentrations and loads during high flow periods. This was done to test the hypothesis that the bulk of heavy metals carried by this stream are transported during periods of high flow.

2 STUDY DETAILS

2.1 Sampling

The sampling point chosen for this study was situated in the main channel of Magela Creek at a point just above the confluence with Djalkmara Creek (Fig. 1). This point was selected for its accessibility during the wet season and its close proximity to the gauging station GS821009 (approximately 4.5 km downstream) and the proposed effluent release point from the Ranger operation. At this point Magela Creek is essentially confined to two channels - the sampling point was situated in the major channel.

Metal concentration data collected during this study, and water flow data at GS821009 supplied by Water Division, Northern Territory Department of Transport and Works, have permitted the calculation of total annual loads of trace metals delivered to the flood plain.

Water samples were collected during five of the eight major flood events that occurred during the study period (23 January to 3 March 1979). The sampling periods are shown as the shaded areas on Figure 2. An attempt was made to sample more frequently on the rising stage of the flood hydrograph, since it has been reported (Whipple et al. 1976) that higher trace metal concentrations occur at these times. Additionally, a number of samples were taken during lower flow periods so that base flow loads could be calculated.

Water samples were collected from the creek in polythene bottles held just below the surface. Bottles for trace metal samples were cleaned by soaking in 2M HNO_3 for three days, and those for determinations of conductivity and suspended solids with a strong detergent solution (Extran, Merck). All bottles were rinsed three times with ultrapure water (Milli-Q) after cleaning and were subsequently rinsed three times with creek water before the final sample was taken.

The samples for total trace metal analysis were preserved with 5 ml concentrated nitric acid per litre. Those for filterable metal analysis were vacuum filtered through a Sartorius 0.45 μ m membrane filter and acidified with 5 ml concentrated nitric acid per litre. The polycarbonate filter units and filters were soaked in 1M nitric acid. Immediately before use the filter units were rinsed with 0.5M nitric acid and about 50 ml of this acid was drawn through the filter. This procedure was repeated twice with 50 mL de-ionised water. The first 50 mL of the filtered sample was discarded.

2.2 Analytical Methods

Iron was determined by flame atomic absorption spectrophotometry (AAS). Cadmium, copper, lead, manganese and zinc were determined by flameless AAS using a Varian Techtron CRA-90 atomiser. Manganese and zinc were determined on the samples without pre-treatment; copper, cadmium and lead were determined on the samples after pre-concentration using the method described by Danielsson et al. (1978). Calibration was achieved using standards prepared in a composite sample of Magela Creek water.

Procedural precision for the six metals measured in this study is given in Table 1. Procedural precision is defined here as including both sampling and analytical reproducibility, and was obtained by the analysis of replicate samples.

Conductivity was determined using a Townson laboratory conductivity meter. Typically the precision was ± 0.5 µS/cm.

Suspended solids were determined by filtration of a 500 mL aliquot of the sample through a 0.45 µm filter. At 24 mg/L the precision was ± 2 mg/L and at 5 mg/L the precision was ± 0.5 mg/L.

3 RESULTS AND DISCUSSION

All analytical results together with the water flow at the time of sampling are recorded in the Appendix. To assist interpretation, certain of these data have also been presented graphically and will be discussed in the appropriate sections.

3.1 Flows

The hydrograph (at gauging station GS821009) for the 1978-79 water year is shown in Figure 2. The sampling periods are also shown on this diagram.

The flows at the sampling point were obtained from a 'rating curve' (Fig. 3) constructed from the gauge height readings at the sampling point, and flow records from the nearby gauging station GS821009, the latter provided by the Water Division, Northern Territory Department of Transport and Works. An average transit time of 2.5 h was used for water travelling between the sampling point and GS821009. This was estimated from the transit times between GS821008 and GS821009.

From Figure 2 it can be seen that no large floods occurred during the study period. The largest sampled was that between 23-28 January 1979, when a peak discharge of 164 m^3/s occurred. To place this flood in perspective, it has been estimated (Uranium Province Hydrology 1979) that a flood with a peak discharge (at GS821009) of 500 m^3/s could occur, on average, once every two years. We estimate that some 25% of the total volume of water to flow past GS821009 in the 1978-79 wet season (1 December 1978 to 31 March 1979) flowed past the sampling point in the five floods studied. The flood hydrographs sampled are shown in more detail in Figure 4.

3.2 Conductivity

Conductivity was generally very low, ranging from a minimum of 10.3 µS/cm to a maximum of 21.3 µS/cm. This confirms other studies showing the waters of Magela Creek to contain very low levels of dissolved salts. The low concentrations of dissolved salts are a consequence of the highly weathered nature of the soils in this area, the large areas of sandstone escarpment in the catchment and the high rate of runoff that allows minimal contact with soils when leaching could occur.

The general trend apparent from both the detailed flood profiles (Fig. 4) and the scatter diagram (Fig. 5) is one of lower conductivities at higher flows. This would be the result of dilution. It would appear that the rain falling on this catchment would have a conductivity of around 12 µS/cm.

3.3 Suspended Solids

The data plotted in Figure 4 show a similar trend for suspended solids levels during each flood event. There was a rapid increase in suspended solids during the early stages of each flood, followed by a reduction to levels not significantly different from those found during the low flow periods. The 'flushing' of sediment during the initial stages of the flood might be due to either scour from the stream bed of material deposited during low flow periods, or to accelerated erosion during the initial stages of runoff. From the limited data available, it appears that the increase in suspended sediment concentrations during the initial stages of runoff is related to antecedent conditions. For example, the highest suspended solids concentrations were found in the two floods that were preceded by the longest periods of low flow. The data also suggest that peak suspended solids concentrations are related to storm intensity (peak discharge).

Studies in other catchments have generally found an increase in suspended solids with discharge (Walling 1977). This trend is also apparent in the Magela Creek (see Fig. 5), although there is a large amount of scatter in the data. The fact that the highest levels of suspended solids were found in the initial runoff, together with the generally low levels transported, suggest that the supply of sediment in the catchment is rather limited.

From the data collected during the five floods studied, it has been possible, using the method outlined in the next section, to calculate that 2940 tonnes of suspended material was transported past the sampling position during the 1978-79 wet season. In an 'average' year the amount would be 5300 tonnes.

3.4 Trace Metals

3.4.1 Metal Concentrations

The trace metal concentrations found in Magela Creek are low (Table 2). Morley (1979) has also reported very low trace metal levels in waters taken at Jabiluka on the flood plain during the wet season. The low metal concentrations are not surprising considering the undisturbed nature of the catchment, the low suspended load and the low conductivity of the waters.

3.4.2 Speciation

There were major differences in the speciation of the trace metals determined. Iron appeared to be transported almost entirely in particulate forms. In contrast, almost all the Cd and approximately 70% of the Mn, Cu and Zn were transported in filterable (<0.45 µm) forms. It is not possible to comment upon the Pb speciation at this stage, since the total levels were at or below the analytical detection limit.

3.4.3 Particulate Metal Fractions

The particulate metal concentrations were generally quite variable (Table 3), but appeared to be correlated with the suspended solids levels. Thus scatter diagrams for Fe, Mn and Zn (Fig. 6) indicate a trend towards higher levels of particulate metal with increasing concentrations of suspended solids. This trend is to be expected. The large scatter in the data may reflect differing particulate distributions at differing rates of stream discharge. Figure 4 shows that, in a number of flow events, but not all, the particulate metal levels were highest on the rising stage of the flood hydrograph. This 'flushing effect' reflects closely the behaviour of the suspended solids. The effect was not noticeable during the third flood (18-21 February), but this could have been due to the flush having occurred in the period between 1330 h on 19 February and 1115 h on 20 February, a period when no samples were taken.

Using the available data, the trace metal concentrations (in µg/g) in the particulate matter were calculated (Table 3). In the case of Fe, there was a trend towards lower levels at higher discharges (Fig. 7). This may reflect increased amounts of low Fe-containing material (SiO_2) being transported at the higher discharge rates. The trend was not discernible for the other metals as the scatter of data was far too great.

It is noticeable that the mean trace metal concentrations in the suspended matter were considerably higher than corresponding levels in billabong sediments and flood plains soils (see Table 3).

3.4.4 Filterable Metal Fractions

It was previously noted that the major fraction of the Mn, Cd, Cu and Zn was in filterable forms. The data plotted in Figure 4, and in the scatter plots (Fig. 8), indicate there is little discernible change in filterable metal concentrations with discharge. In this respect the trace metals appear to behave somewhat differently from the major cations which, as reflected by the conductivity, decrease in concentration with increased discharge. Other studies (e.g. Grimshaw et al. 1976; Whipple et al. 1976) have pointed to the significance of the relationship between discharge and metal concentration.

One observation worthy of further study is the behaviour shown by Zn and, to a lesser extent, by Mn, Cu and Cd. During the latter stages of the first flood studied (23-27 January), the filterable Zn was found almost to double in concentration. This may have been caused by delayed flushing of trace metals from the soil profile during the latter stages of the flood, when rainwater had had time to percolate into the soil. It is unlikely that this amount of trace metal would contribute significantly to the total load transported; however, it could be important when decisions are taken on the optimum times at which effluent discharges should be permitted.

3.4.5 Trace Metal Loads

The variations in the amounts or loads of suspended solids and trace metals transported past the sampling point during the first flood (23-27 January 1979) are illustrated in Figure 9. It is clear that the loads transported by Magela Creek during high flow periods can be more than an order of magnitude higher than those carried during low flow periods.

The total load transported annually has been estimated from the data using the storm loading technique described by Whipple et al. (1976). The amount transported during each flood is estimated by integration of the load hydrograph, and the total annual load calculated from the equation:

$$\text{Total annual load} = \text{Load carried during floods sampled} \times \frac{\text{Total annual discharge}}{\text{Total discharge during floods sampled.}}$$

The results of these calculations for the water year 1978-79 are given in Table 4. These data indicate that the major amounts of the trace metals, Mn, Zn, Cu and Cd are transported in filterable forms. Almost all the Fe is transported in particulate forms. The results also indicate that considerable variation in loads transported could be expected from year to year, as a result of the variations in annual discharge.

It must be pointed out that only comparatively small flood events were sampled during this present study, and any extrapolation to larger flood events must be done with caution.

4 CONCLUSIONS

1. Five of the eight flood peaks occurring in Magela Creek during the 1978-79 wet season were sampled for trace metals, conductivity and suspended solids at a site 4.5 km upstream of the gauging station GS821009. Samples were taken on a total of 42 occasions. The floods sampled represented approximately 25% of the total water volume that flowed past the sample point during the wet season.

2. The conductivity was found to be low (10-21 µS/cm) and was reduced at high flows.

3. The suspended solids levels were also found to be low (5-46 mg/L). The highest levels occurred during the early stages of each flood event and appeared to be related to the length of the period between floods. During the 1978-79 wet season an estimated 2940 tonnes of suspended solids were transported past the sample point. In an 'average' year this could rise to 5300 tonnes.

4. Trace metal concentrations in Magela Creek are very low.

5. There were major differences in the speciation of the trace metals determined. Iron existed almost entirely in particulate forms. In contrast, almost all the Cd and approximately 70% of the Mn, Zn and Cu were in filterable forms.

6. There was no noticeable change in filterable metal concentrations with increasing stream discharge.

7. The particulate trace metal concentrations were variable but generally correlated with the suspended solids levels, increasing with increasing concentrations of suspended solids.

8. The total annual trace metal loads transported past the sampling point were estimated both for the 1978-79 wet season, and for an 'average' year in which the annual water discharge was 500 million m^3.

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APPENDIX ANALYTICAL DATA FROM SAMPLING SITE GIVING SAMPLING TIMES, WATER FLOW, SUSPENDED SOLIDS, CONDUCTIVITY AND TRACE METAL CONCENTRATIONS

Sample No.	Date 1979 (Time h)	Flow (m^3/s)	Suspended Solids (mg/L)	Conductivity (µS/cm)	Trace Metal Concentrations (µg/L) Fe		Mn		Zn		Cu		Cd		Pb	
					tot	filt	tot	filt	tot	filt	tot	filt	tot	filt	tot	filt
	January															
06	23 (0940)	12	4.9	21.3	370	15	8.9	3.7	2.7	1.7	0.33	0.20	0.04	0.03	<0.5	nd
07	24 (0850)	27	16.6	21.0	455	15	8.4	3.6	3.1	1.5	0.27	0.25	0.04	0.04	<0.5	nd
08	24 (1155)	44	46.0	16.6	770	15	21.4	5.2	5.2	1.9	0.73	0.42	0.04	0.02	<0.5	nd
09	24 (1600)	127	21.2	14.0	405	15	8.9	7.9	2.9	1.6	0.31	0.22	0.03	0.03	<0.5	nd
10	24 (1600)	127	25.3	14.2	405	35	8.5	7.3	3.0	1.8	0.23	0.28	0.04	0.04	<0.5	nd
11	24 (1600)	127	24.4	14.9	420	25	9.3	7.4	2.8	1.7	0.27	0.30	0.02	0.03	0.8	nd
12	24 (2315)	150	7.0	12.9	185	30	7.3	5.1	2.7	1.5	0.31	0.23	0.04	0.04	<0.5	nd
13	25 (1215)	88	9.2	14.7	210	25	9.6	3.7	2.0	1.7	0.31	0.26	0.04	0.02	<0.5	nd
14	26 (1155)	27	7.6	18.4	240	15	9.6	4.3	3.2	2.6	0.37	0.23	0.05	0.05	<0.5	nd
15	27 (1225)	17	6.1	19.5	270	5	8.4	5.6	3.7	2.9	nd	nd	0.05	0.05	0.7	nd
	February															
28	13 (1650)	34	29.1	15.5	590	<10	13.9	8.2	2.8	1.7	0.64	0.27	0.05	0.02	0.8	nd
29	13 (2000)	49	14.2	15.6	330	<10	9.1	7.3	2.9	1.5	0.34	0.37	0.03	0.03	<0.5	nd
30	14 (0700)	57	9.5	14.9	230	<10	4.9	4.6	2.7	1.9	0.46	0.37	0.06	0.03	<0.5	nd
31	14 (1700)	37	5.8	15.2	205	<10	4.2	2.5	2.1	2.0	0.31	0.17	0.03	0.02	<0.5	nd
32	15 (1800)	15	8.5	17.3	265	<10	8.7	2.8	3.2	2.3	0.32	0.31	0.02	0.03	<0.5	nd

nd = not determined

APPENDIX (ctd)

Sample No.	Date 1979 (Time h)	Flow (m^3/s)	Suspended Solids (mg/L)	Conductivity (μS/cm)	Trace Metal Concentrations (μg/L)											
					Fe		Mn		Zn		Cu		Cd		Pb	
					tot	filt	tot	filt	tot	filt	tot	filt	tot	filt	tot	filt
	February															
33	16 (0730)	42	12.4	20.2	375	<10	10.7	3.9	2.6	2.6	0.32	0.40	0.05	0.05	<0.5	nd
34	16 (1030)	48	16.8	14.2	380	<10	10.1	5.7	2.8	2.3	0.31	0.30	0.04	0.06	<0.5	nd
35	16 (1405)	64	19.5	12.9	390	<10	15.4	6.4	4.3	2.2	0.47	0.42	0.08	0.02	<0.5	nd
36	16 (1815)	80	9.2	12.5	200	<10	7.5	5.6	3.4	2.1	0.45	0.37	0.04	0.01	<0.5	nd
37	16 (1815)	80	9.2	13.8	195	<10	6.2	4.2	3.3	2.3	0.40	0.45	0.04	0.01	<0.5	nd
38	17 (0900)	41	6.5	15.6	195	<10	5.5	4.6	2.8	2.5	0.42	0.27	0.02	0.02	<0.5	nd
39	18 (1245)	30	7.0	15.8	260	<10	6.0	5.2	2.4	1.9	0.29	0.28	0.04	0.04	<0.5	nd
40	19 (0730)	40	10.4	13.6	275	<10	7.7	3.8	2.8	1.6	0.51	0.29	0.07	0.05	<0.5	nd
41	19 (1030)	52	12.7	12.8	225	<10	6.4	4.9	2.9	1.5	0.46	0.16	0.03	0.05	<0.5	nd
42	19 (1330)	64	9.5	11.9	170	<10	5.7	5.9	2.2	1.8	0.69	0.43	0.05	0.05	0.7	nd
43	20 (1115)	97	17.4	12.2	290	<10	9.0	7.0	2.2	2.2	0.64	0.40	0.07	0.04	<0.5	nd
44	20 (1530)	111	8.0	11.9	190	<10	4.6	2.8	3.4	1.7	0.43	0.38	0.02	0.02	0.6	nd
45	21 (1045)	41	8.8	15.6	130	<10	8.4	6.0	2.3	1.8	0.49	0.47	0.07	0.03	<0.5	nd
46	23 (0900)	21	6.1	17.9	270	<10	4.0	2.8	3.2	1.9	0.42	0.26	0.04	0.05	<0.5	nd
47	26 (0745)	27	6.4	16.2	250	<10	3.1	2.6	2.1	1.6	0.41	0.25	0.08	0.06	<0.5	nd
48	26 (2300)	43	8.2	15.2	230	<10	3.6	3.1	2.0	1.6	0.22	0.16	0.05	0.07	<0.5	nd

nd = not determined

APPENDIX (ctd)

Sample No.	Date 1979 (Time h)	Flow (m^3/s)	Suspended Solids (mg/L)	Conductivity (µS/cm)	Trace Metal Concentrations (µg/L)											
					Fe		Mn		Zn		Cu		Cd		Pb	
					tot	filt	tot	filt	tot	filt	tot	filt	tot	filt	tot	filt
	February															
49	27 (0630)	51	9.7	17.4	290	<10	7.3	4.3	2.3	1.9	0.22	0.20	0.07	0.06	0.8	nd
50	27 (1120)	65	15.5	14.6	345	<10	8.4	3.6	4.0	1.5	0.39	0.33	0.06	0.04	<0.5	nd
51	27 (1500)	88	9.6	12.6	230	<10	5.9	3.1	2.3	1.8	0.23	0.17	0.06	0.04	<0.5	nd
52	27 (1900)	103	7.7	10.3	175	<10	5.1	3.8	2.5	2.0	0.73	0.35	0.03	0.02	<0.5	nd
53	27 (1900)	103	7.2	12.4	175	<10	5.0	3.4	2.0	1.6	0.75	0.41	0.02	0.03	<0.5	nd
54	27 (1900)	103	8.0	11.4	165	<10	5.4	2.8	2.4	2.1	0.78	0.33	0.02	0.02	<0.5	nd
55	28 (0950)	51	7.3	14.6	210	nd	4.4	nd	2.6	nd	0.45	nd	0.05	nd	<0.5	nd
57	28 (1900)	59	9.0	13.2	205	<10	8.0	3.2	2.6	1.8	0.13	0.17	0.04	0.03	<0.5	nd
	March															
58	1 (1010)	84	nd	nd	210	nd	7.4	nd	2.3	nd	0.36	nd	0.04	nd	<0.5	nd
59	1 (1800)	51	7.6	nd	215	<10	8.2	4.0	1.8	1.3	0.42	0.27	0.06	0.04	<0.5	nd
60	2 (1730)	37	7.5	nd	230	<10	8.7	6.1	2.0	1.3	0.24	0.25	0.03	0.03	<0.5	nd

nd = not determined

TABLE 1 PROCEDURAL PRECISION FOR TRACE METAL ANALYSES

Trace Metal	Unfiltered Samples (μg/L)	Filtered Samples
Fe	10	10
Mn	0.5	0.6
Zn	0.2	0.2
Cu	0.03	0.05
Cd	0.01	0.01
Pb	0.3	-

Note: Precision was estimated from four separate sets of triplicate analyses.

TABLE 2 SUMMARY OF TRACE METAL CONCENTRATIONS IN MAGELA CREEK

	Metal Concentration (μg/L)				
	This Study				
Metal	Total (42 samples)	Filterable (40 samples)	Weighted mean[a] Total	Weighted mean[a] Filterable	Morley (1979)
Fe range	130-770	<10-35			
mean ± S.E.	281 ± 122		260		
Mn	3.1-21.4	2.5-8.2			2.0-30.0
	7.8 ± 3.3	4.7 ± 1.6	7.6	5.2	15.0
Zn	1.8-5.2	1.3-2.9			0.5-3.5
	2.8 ± 0.7	1.9 ± 0.4	2.8	2.0	1.0
Cu	0.13-0.78	0.16-0.45			0.2-1.0
	0.41 ± 0.16	0.30 ± 0.09	0.42	0.30	0.8
Cd	0.02-0.08	0.01-0.07			0.03-0.25
	0.04 ± 0.02	0.04 ± 0.01	0.04	0.04	0.05
Pb	<0.5-0.8	-			0.2-1.0
			<0.5	-	0.5

[a] Weighted mean = annual mass transported/annual mass water transported (see Table 4 for data).

TABLE 3 TRACE METAL CONCENTRATIONS IN SUSPENDED SOLIDS, SEDIMENTS AND FLOOD PLAIN SOILS

(Values given in μg/g)

Metal	Suspended Solids	Flood Plain Billabong Sediments[a]	Flood Plain Soils (Morley 1979)	Billabong Sediments (Morley 1979)
Fe	13 600-72 400 (25 500)	32 600-43 300 (38 100)	-	-
Mn	32-1061 (294)	87-186 (129)	17.0-56.0 (32)	7.0-3000 (200)
Zn	30-213 (90)	28-32 (30)	1.6-14.0 (6.9)	7.0-37.0 (20.0)
Cu	1-61 (16)	15-19 (16)	0.5-15.2 (3.0)	3.0-15.0 (7.0)
Cd	-	<0.2	<0.01-0.10 (0.02)	<0.5
Pb	<10-115	6-8 (7)	3.0-14.0 (6.4)	5.0-15.0 (9.0)

[a] <20 μm fraction.

Figures in brackets are mean concentrations.

TABLE 4 TOTAL ANNUAL LOADS ESTIMATED FROM 1978-79 DATA USING FLOOD LOADING TECHNIQUE

Flood Sampled 1979	Sample Nos	Mass Transported: Water (x 10^6 tonnes)	Susp. Solids (tonnes)	Fe (tonnes)	Mn Total (kg)	Mn Filt (kg)	Zn Total (kg)	Zn Filt (kg)	Cu Total (kg)	Cu Filt (kg)	Cd Total (kg)	Cd Filt (kg)	Pb (kg)
23-27 Jan.	06-15	19.3	225	5.3	175	91	52	35	6.0	4.7	0.75	0.67	<10
13-18 Feb.	28-39	17.3	166	4.3	123	106	49	37	6.5	5.4	0.72	0.49	<9
19-21 Feb.	40-45	16.4	187	3.7	106	83	44	31	9.0	6.3	0.82	0.66	<8
26-27 Feb.	47-60	16.1	148	4.4	128	77	45	30	8.1	5.0	0.77	0.64	<8
Total for floods		69.1	726	17.7	532	358	190	133	29.6	21.4	3.06	2.46	<35
Annual load for 'average' year		500[a]	5300	130	3800	2600	1400	1000	210	150	20	20	<250
Total for 1978-79 wet season		280	2940	70	2160	1450	770	540	120	90	12	10	<140

[a] Mean annual discharge at GS821009

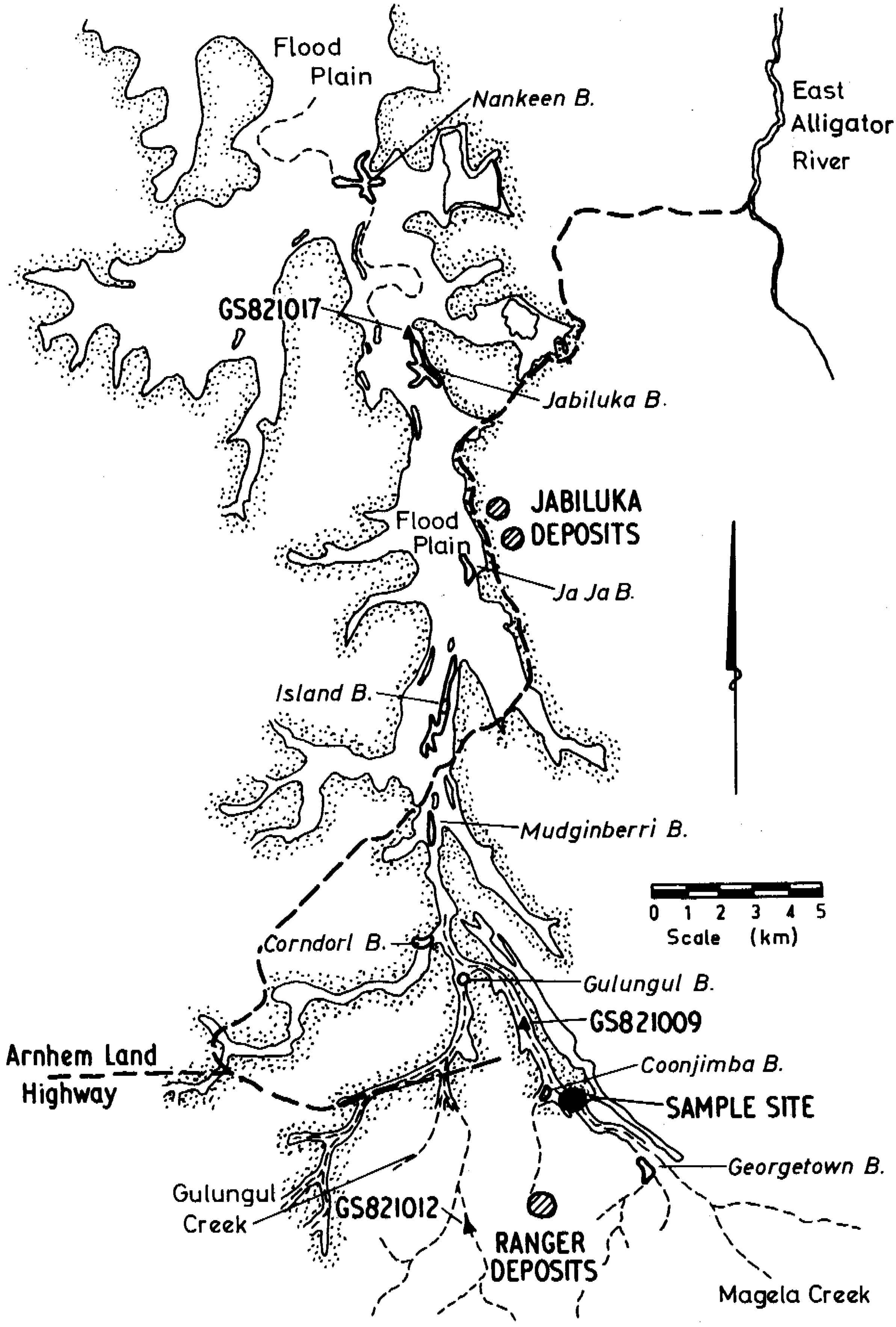


FIG. 1 STUDY AREA SHOWING LOCATION OF SAMPLING SITE

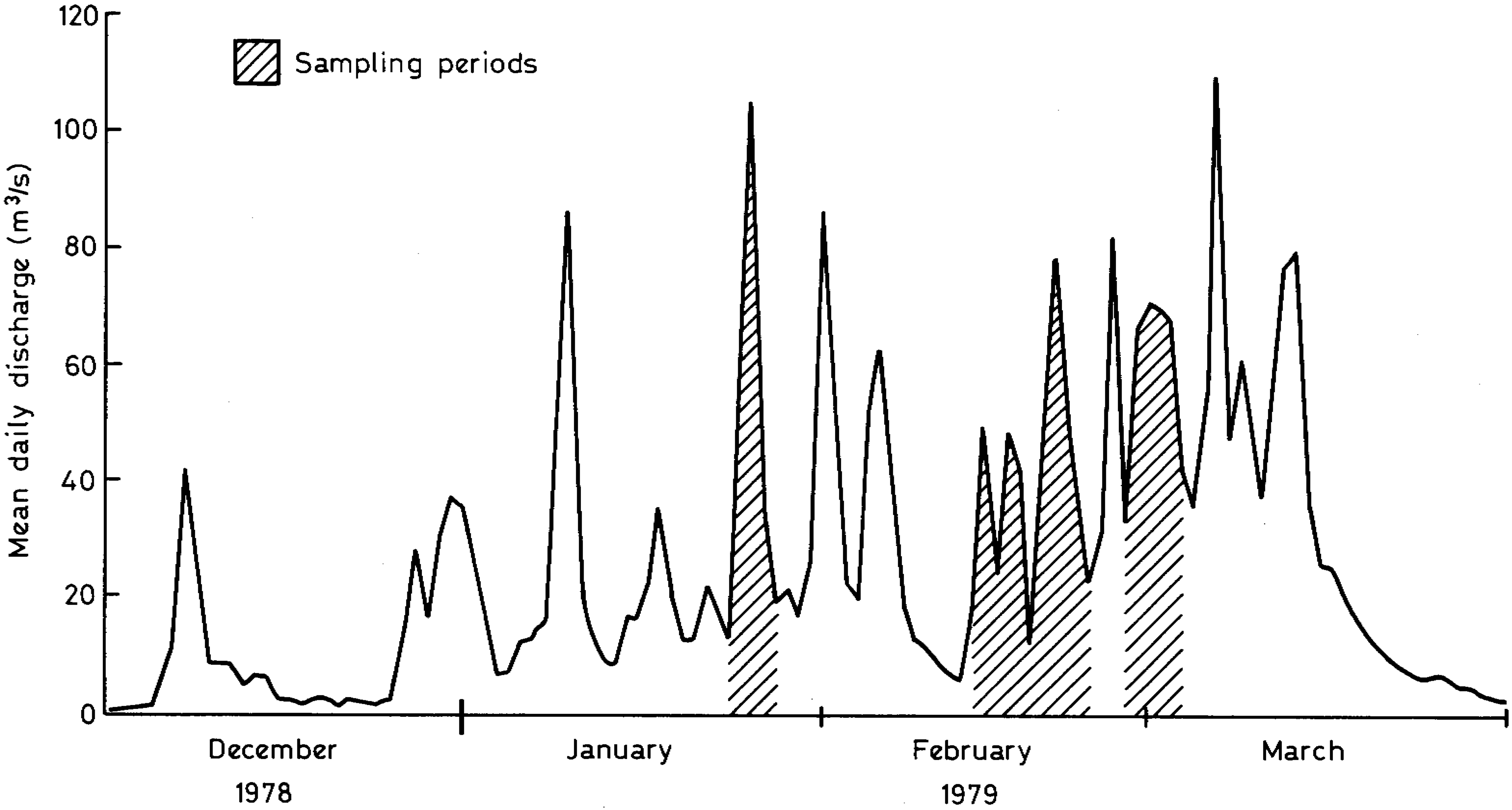


FIG. 2 HYDROGRAPH SHOWING MEAN DAILY DISCHARGE FOR 1978-79 WATER YEAR (Samples from gauging station GS821009)

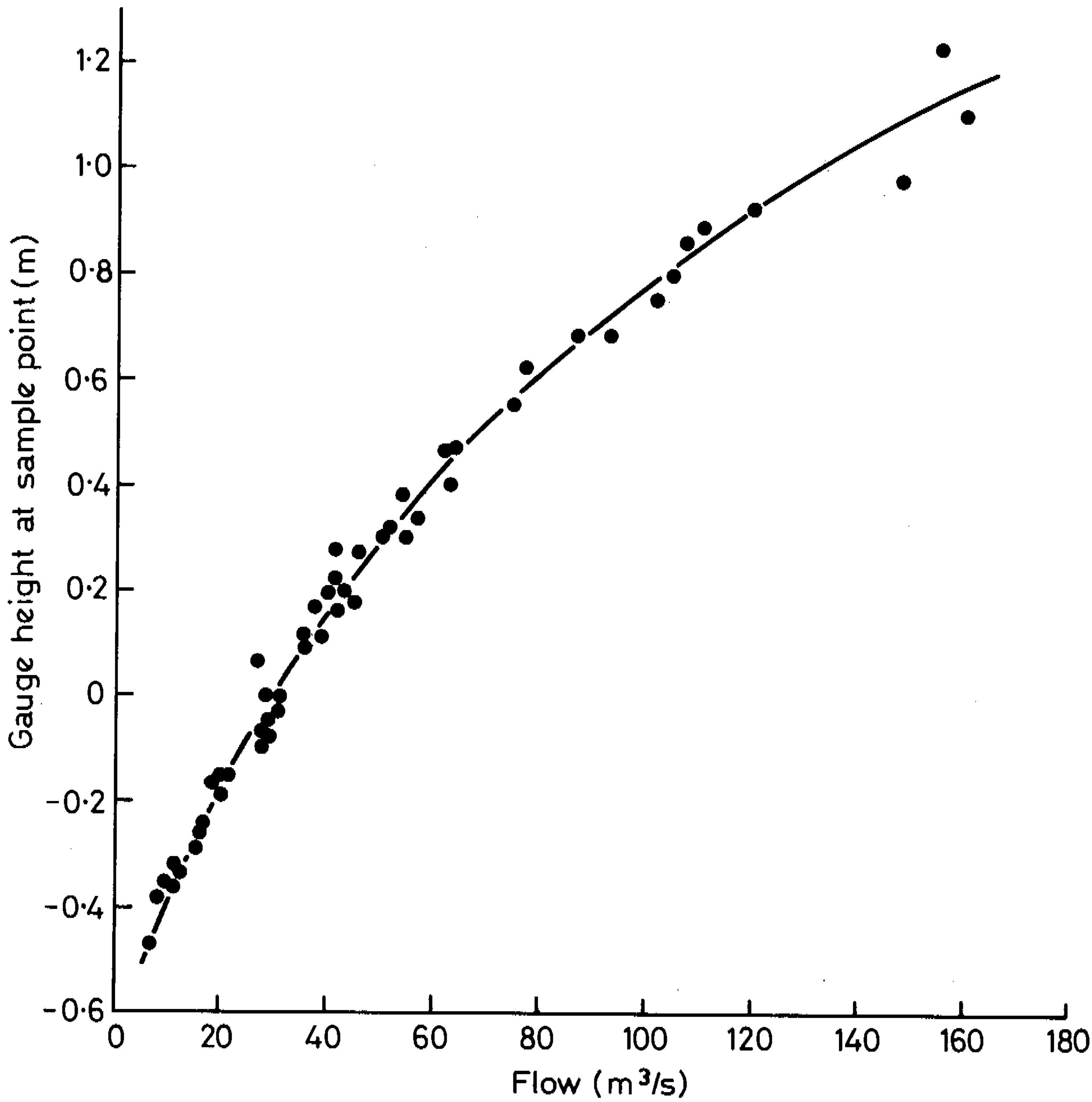


FIG. 3 DERIVED RATING CURVE FOR WATER FLOWS IN MAGELA CREEK AT SAMPLING SITE
(Flows estimated from those at GS821009, assuming a delay time of 2.5 h)

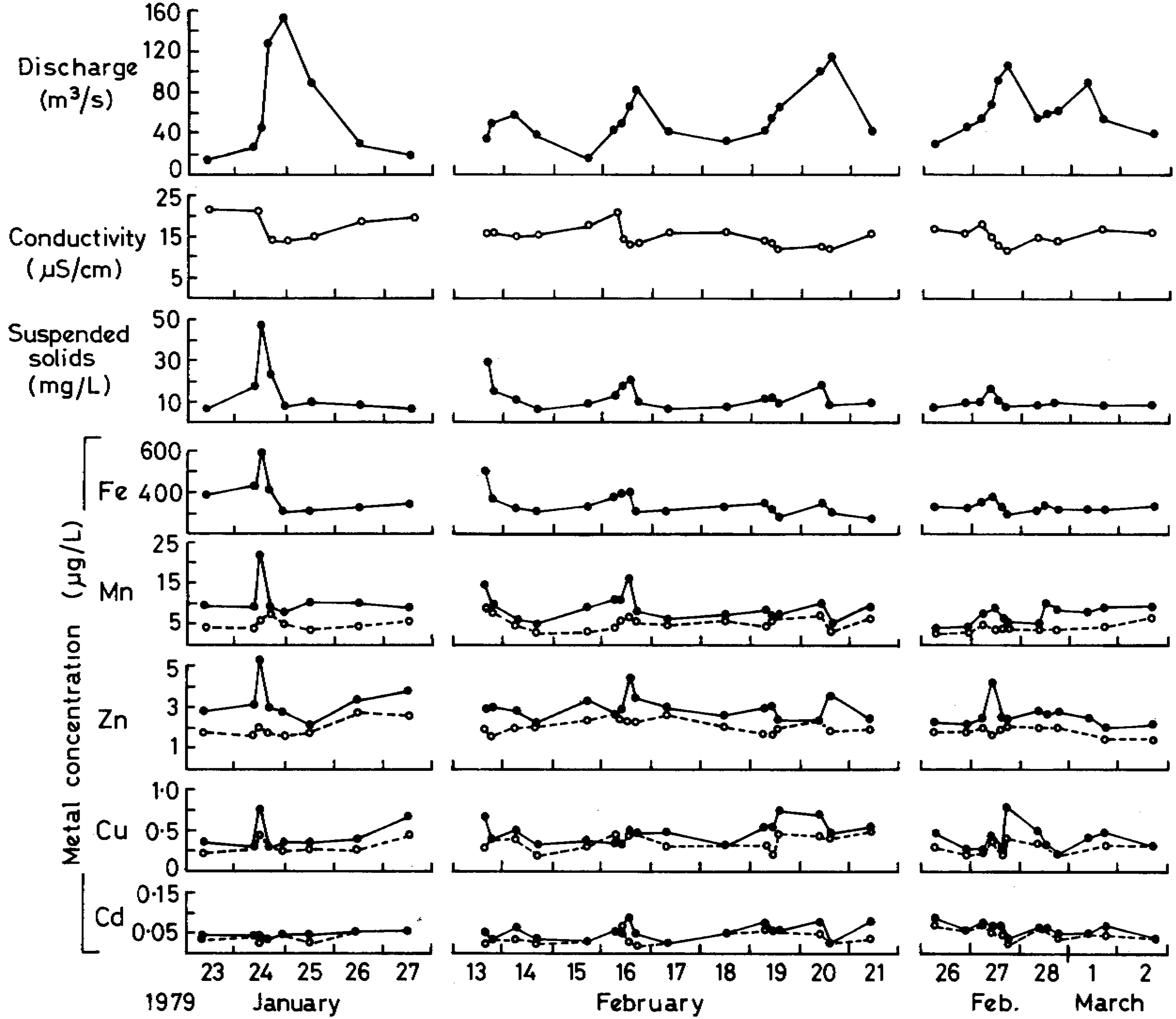
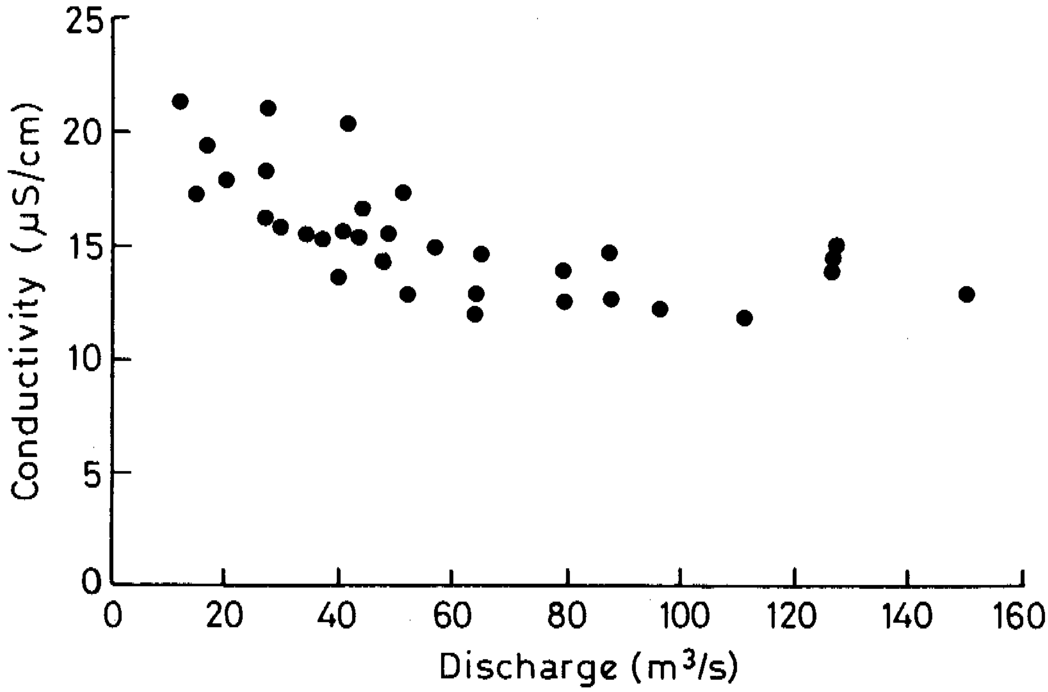


FIG. 4 VARIATIONS OVER THE STUDY PERIOD, IN DISCHARGE, CONDUCTIVITY, SUSPENDED SOLIDS, AND TOTAL AND FILTERABLE CONCENTRATIONS OF Fe, Mn, Cu AND Cd (● total, o filterable)



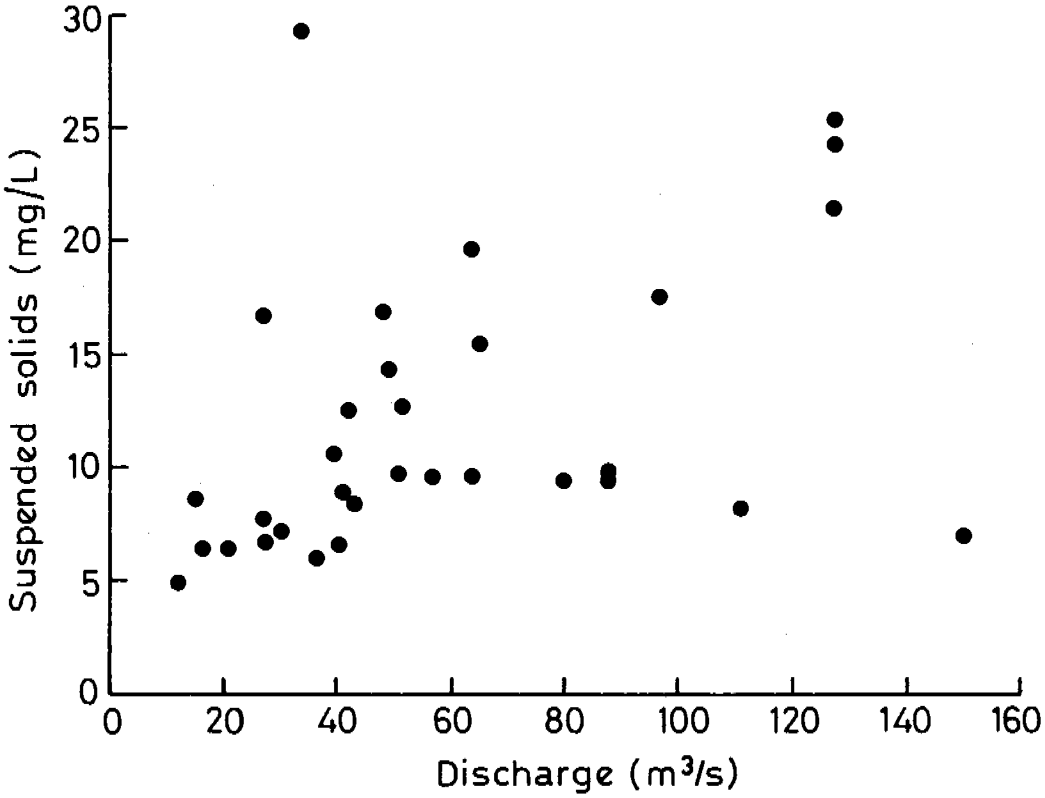


FIG. 5 SCATTER DIAGRAMS SHOWING (a) CONDUCTIVITY vs DISCHARGE, AND (b) SUSPENDED SOLIDS vs DISCHARGE IN MAGELA CREEK

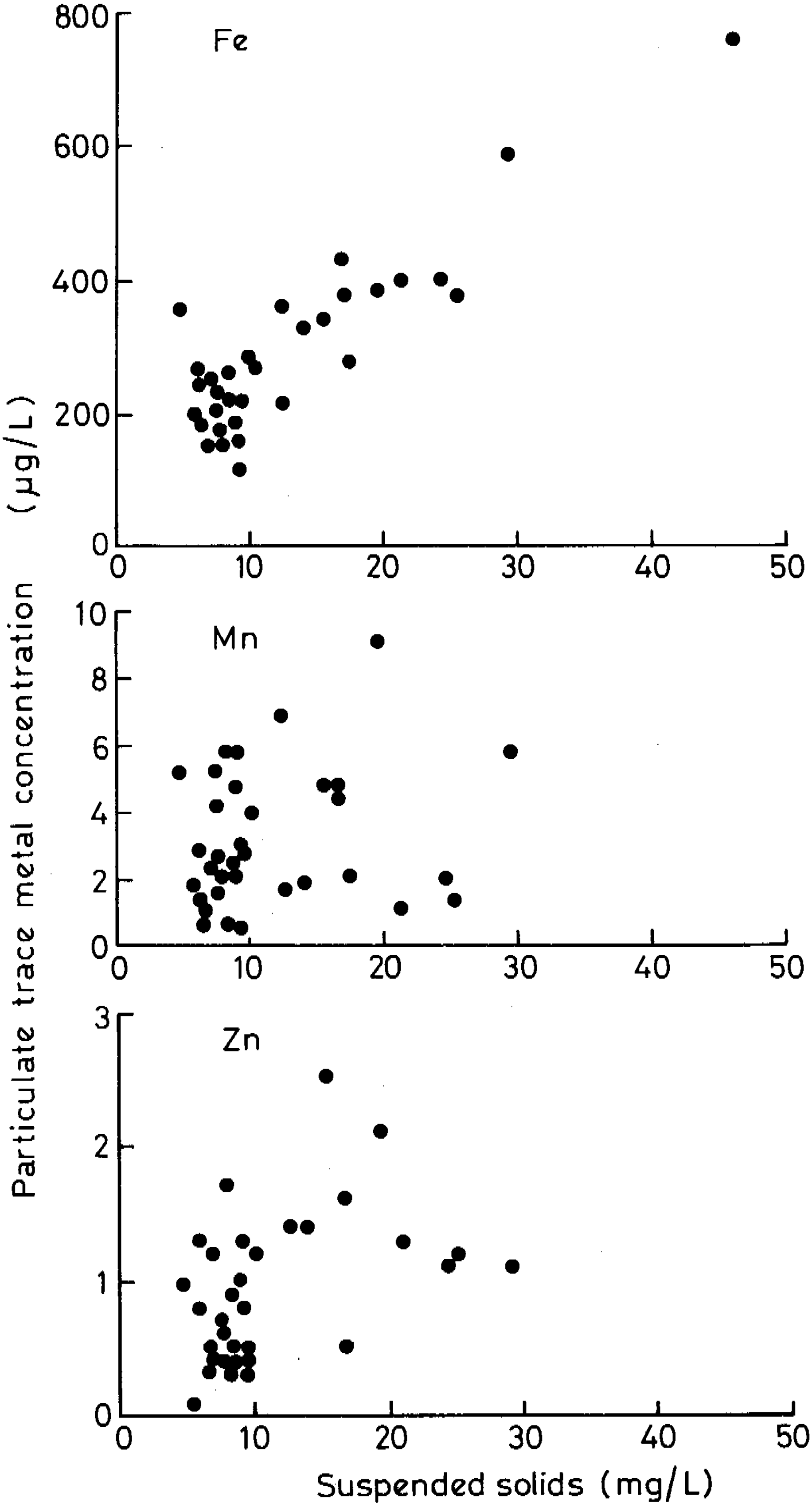


FIG. 6 SCATTER DIAGRAMS SHOWING SUSPENDED SOLIDS CONCENTRATIONS vs PARTICULATE Fe, Mn AND Zn CONCENTRATIONS

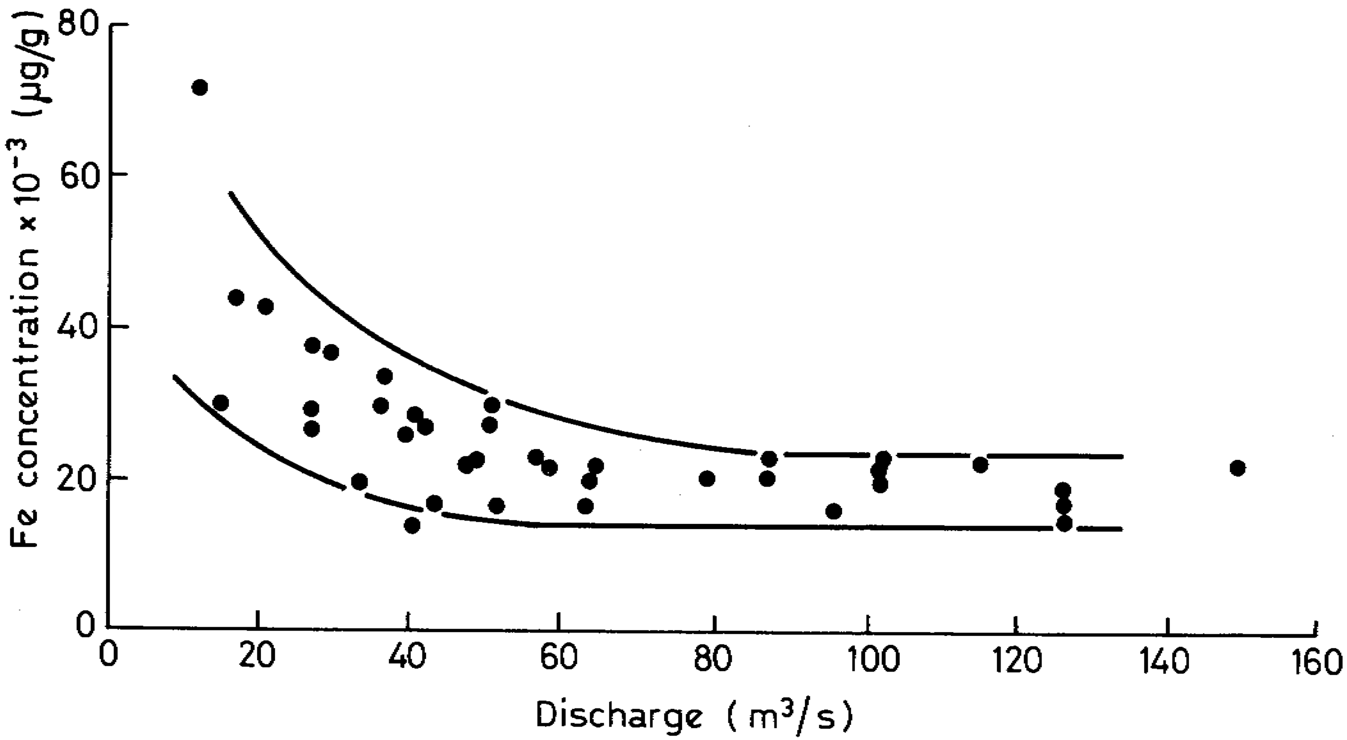


FIG. 7 SCATTER DIAGRAM FOR Fe CONCENTRATION IN PARTICULATE MATTER vs WATER DISCHARGE

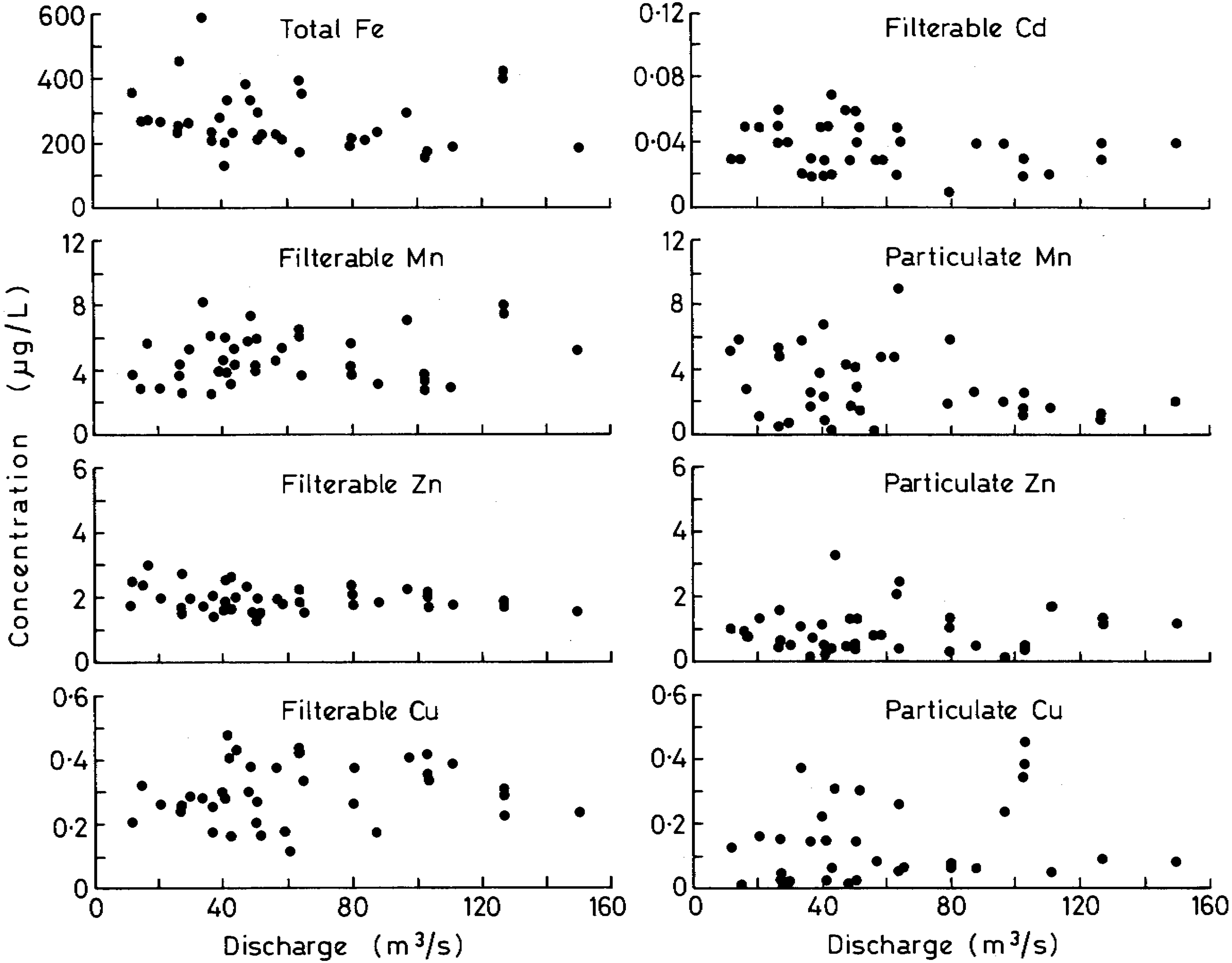


FIG. 8 SCATTER DIAGRAMS SHOWING CONCENTRATIONS OF TRACE METALS PLOTTED AGAINST DISCHARGE (a) Total Fe (b) Filterable Cd (c) Filterable Mn (d) Particulate Mn (e) Filterable Zn (f) Particulate Zn (g) Filterable Cu (h) Particulate Cu

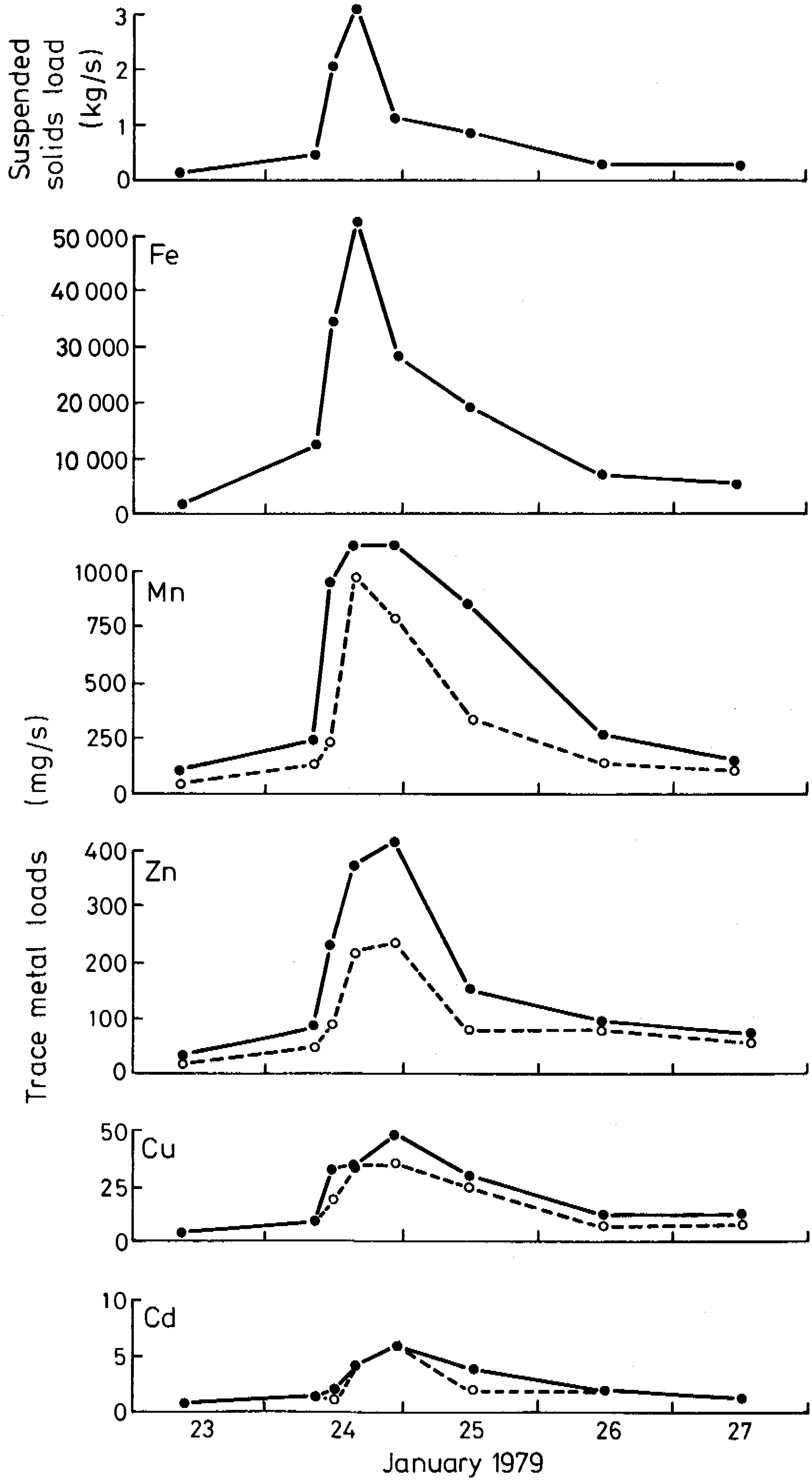


FIG. 9 LOAD HYDROGRAPHS OVER THE FIRST FLOOD PERIOD (23-27 JANUARY 1979) FOR SUSPENDED SOLIDS, AND TOTAL AND FILTERABLE Fe, Mn, Zn, Cu AND Cd (● total, o filterable)