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16. Summary/Notes

The objective of this research was to verify the usefulness of LANDSAT MSS IMAGE-100 classified data to monitor the dispersion of suspended sediments in artificial reservoir and to estimate their concentrations in surface waters. Two different seasons (dry/wet) were analyzed, using values for MSS grey tones and Secchi Depth measurements, to produce semi-quantitative maps of sediment dispersion. In a correlation analysis, MSS channels were significantly correlated and inversely proportional to Secchi Depth measurements. It was observed that the rainy season was the most optimal period to discriminate grey tones for analysis and MSS channel 4 presented the least error in the estimation of means.

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TRÊS MARIAS RESERVOIR, MINAS GERAIS STATE: STUDY OF THE DISPERSION OF SUSPENDED SEDIMENTS IN SURFACE WATERS USING ORBITAL IMAGERY

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ABSTRACT

The objective of this research was to verify the usefulness of LANDSAT MSS IMAGE-100 classified data to monitor the dispersion of suspended sediments in artificial reservoir and to estimate their concentrations in surface waters. Two different seasons (dry/wet) were analyzed, using values for MSS grey tones and Secchi Depth measurements, to produce semi-quantitative maps of sediment dispersion. In a correlation analysis, MSS channels were significantly correlated and inversely proportional to Secchi Depth measurements. It was observed that the rainy season was the most optimal period to discriminate grey tones for analysis and MSS channel 4 presented the least error in the estimation of means.

1. INTRODUCTION

One of the principal factors which threaten the longevity of artificial reservoirs in the accumulation of silt, aided by the transport of suspended soli particles, into the major water body.

According to studies by Ritchie et al. (1976), Yarger and McCauley (1975) and Trexler (1975), reflectance data furnished by LANDSAT MSS imagery in differe electromagnetic spectral bands, have high correlations with the quantity of suspended sediments. The objective of this study was to verify the usefulness of LANDSAT MSS imagery to monitor the dispersion of suspended sediments in reservoi and to estimate surface water sediment concentrations.

The present study is part of a research project being developed in cooperation with the Companhia de Desenvolvimento do Vale do São Francisco (CODEVASF) and INPE/CNPq.

2. MATERIALS AND METHODS

The Três Marias reservoir is located in the central part of Minas Gerais State and inundates an area of over 1,102 km^2.

LANDSAT CCT's, corresponding to path 164, row 25 passes of April 5 and August 27, 1978, were used to compartmentalize the reservoir according to respec tive grey level spectral response. Interactive and automatic, supervised classification, was executed on the IMAGE-100 system.

To complement spectral response data, Secchi Depth measurements were used. Field data were collected along 25 sampling points, on the reservoir and tributaries, during the periods March/April and August/September, 1978 (Figure 1).

The methods used for the above data analyses are as follows:

1) scale enlargement (to 1:450,000) of the imaged area corresponding to the reservoir;
2) delimitation (using channel 7) of the surface area of the reservoir;
3) scale enlargement (to 1:50,000) of areas with sampling points on the reservoir;
4) "single-pixel" extraction of grey tone values (in 4 channels) of the sampling points;
5) thematic classification of the image by means of a MAXVER program

(Velasco et al., 1978) using values of grey tones as training areas;
6) ranking of classes according to Secchi Depth base data;
7) acquisition of maps with the results of the thematic classification, and
8) correlation analysis (Pearson correlation coefficients) between grey tone and Secchi Depth values (Steel and Torrie, 1960).

3. RESULTS

The results of the analyses of all of the data obtained are described in this section.

3.1 LANDSAT PASS OF APRIL 5, 1978

This pass coincides with the region's rainy season and the period when field work was first carried out. A 70% cloud cover over the region during the orbital pass prejudiced somewhat the automatic analysis (several of the reservoirs tributaries having been obscured). The reservoir's surface waters, however, presented various workable grey tones.

During the field period, Secchi Depth values were collected at 24 sampling points. Table I shows values for grey tones extracted by "single pixel" method and Secchi Depth measurements. It was not possible to obtain values for 5 sample points owing to cloud cover and CCT noise.

From the April 5, 1978 pass, grey tone values for each sample point on the training area of the MAXVER analysis, combined with the corresponding Secchi Depth values, made it possible to produce a semi-quantitative classification of the dispersion of suspended sediments.

Twelve sediment dispersion classes were obtained. Table II presents the mean values and a matrix of covariance of these classes as well as the corresponding Secchi Depth values.

Table III shows the matrix of correct classification of the semi-quantitative classification derived from the April 5, 1978 pass.

Figures 2a and 2b illustrate the thematic map of different grey tone classes, produced on the IMAGE-100 alphanumeric output unit. The map was produced in two separate parts as to Image-100 system accommodates only 8 themes in its output mode.

For MAXVER thematic classification, CCT channel 7 was not used due to the fact that high surface water absorption, in this channel, presented null values in the matrix of covariance.

3.2 LANDSAT AND SECCHI DEPTH CORRELATIONS (WET SEASON)

A Pearson correlation analysis between the "single pixel" for MSS channels classification and Secchi Depth values produced the following r values ($p=.05$): -0.89 (MSS 4/Secchi), - 0.84 (MSS 5/Secchi), -0.77 (MSS 6/Secchi), and -0.71 (MSS 7/Secchi).

Figure 3 graphically illustrates the simple regression between mean values for MSS channel 4 and the Secchi Depth value, both having been obtained during the rainy season.

3.3 LANDSAT PASS OF AUGUST 27, 1978

In contrast to the wet season orbital pass, the dry season pass of August 27 was during a period when the reservoir's surface waters are considerably homogeneous. This particular scene presented a cloud cover of 30%, which created some problems in the automatic interpretation. The analyses procedures were the same as that of the dry season. Grey tone values in four MSS LANDSAT channels and dry season Secchi Depth measurements at 25 sampling points of the Três Marias Reservoir were analyzed. One extra sample point was required to augment the information of one of the reservoir's tributaries, which is fed by the Borrachudo River (site of sample point).

Table IV provides grey tone and Secchi Depth measurements for 25 points on the reservoir.

Using the same procedures for automatic analysis of the wet season pass, it was possible to obtain 8 different classes of suspended sediment dispersion. Table V presents the mean values of 8 classes and the matrix of covariance and the corresponding Secchi Depth measurements.

Table VI presents the matrix of correct classification for the semiquantitative classification of the 8 dry season classes.

3.4 LANDSAT AND SECCHI DEPTH CORRELATIONS (DRY SEASON)

A correlation analysis between grey tone and Secchi Depth values was also executed for the dry season pass. The coefficient correlations obtained for 24 sample points (3A omitted) were: -0.70 (MSS 4/Secchi), -0.96 (MSS 5/Secchi), -0.74 (MSS 6/Secchi), and -0.63 (MSS 7/Secchi).

Figure 4 presents a graph of the simple regression for the dry season MSS 5 and Secchi Depth values.

4. CONCLUSION

From the simple correlation analysis and graphic representation, it can be verified that grey tone levels are inversely proportional to Secchi Depth values. As Secchi Depth is related to a coefficient of water attenuation and the quantity of solid particles in suspension, it can be observed that the higher the quantity of suspended sediments, the higher the grey tone and smaller the Secchi Depth.

It was also observed that the most favorable period to conduct an analysis of this type is during the rainy season. This is owing to the fact that greater discharge of sediments into the reservoir facilitates the discrimination of different grey tones. In the rainy season correlation analysis, MSS channel 4 presented the least error in the estimation of means.

In the two seasons analyzed, MSS channel 4 comprised the largest intervals of Secchi Depth values; 0.50 to 3.50 meters (rainy season) and 0.25 to 6.0 meters (dry season).

MSS channel 5 was observed to present high sensitivity to variations in grey tones. A small variations Secchi Depth values created a large corresponding variation in channel 5.

MSS channel 6 and 7 were swited to the detection of extremely turbid areas of water. However, the probability of error in class separation is greater in the dry season when a tendency exists for the confusion of turbid waters with adjacent areas of the reservoir (e.g. shoreline soils and vegetation).

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Table I. Grey Tone Values in Four LANDSAT MSS Channels and Secchi Depth Measurements at 24 Sampling Points of Três Marias Reservoir

Sample Points	MSS 4	MSS 5	MSS 6	MSS 7	Secchi Depth (m)
1A	17	7	1	1	2,75
1B	21	10	2	1	2,75
1C	27	17	4	1	1,25
2A	15	6	1	1	4,0
2B	14	7	3	2	3,50
2C	14	6	1	1	4,0
3A	21	10	3	2	2,25
3B	25	12	3,5	1,5	2,00
3C	21	12	4	1,5	1,75
4A	27	16	4	2	1,50
4B	18	12	6	4	1,75
4C	20	12	5	2	1,25
5A	-	-	-	-	-
5B	-	-	-	-	-
5C	-	-	-	-	-
6A	30	32	7	4	0,80
6B	27	36	14	4	0,50
6C	28	41	20	5	0,25
7A	-	-	-	-	-
7B	28	27	9	2	1,00
7C	30	37	16	5	0,75
8A	24	18	7	3	1,50
8B	24	20	8	3	1,25
8C	-	-	-	-	-

Points 5A, 5B, 5C, 7A and 8C were obscured by cloud cover and were not included.

Table II. Mean Values and Matrix of Covariances of Grey Tone Classes (April 5, 1978 pass) and Secchi Depth Values

Classes	Means			Matrix of Covariance			Secchi Depth (m)
	MSS 4	MSS 5	MSS 6				
1	57.26	83.11	40.80	7.56	1.16	-1.26	0.25
				1.16	2.27	1.49	
				-1.26	1.49	3.17	
2	54.89	74.19	29.70	3.35	2.32	-0.02	0.50
				2.32	2.99	-1.48	
				-0.02	-1.48	2.62	
3	61.39	67.88	28.74	1.95	0.09	-1.85	0.75
				0.09	3.07	-0.34	
				-1.85	-0.34	9.24	
4	57.88	53.32	17.85	7.10	0.51	0.74	1.0
				0.51	5.17	0.25	
				0.74	0.25	1.67	
5	54.07	37.06	11.75	21.20	19.21	3.88	1,25
				19.21	19.87	3.04	
				3.88	3.04	4.10	
6	56.14	35.52	9.96	3.57	-0.57	3.59	1,50
				-0.57	4.33	0.13	
				3.59	0.13	8.04	
7	43.68	23.71	7.96	2.61	-0.26	0.07	1,75
				-0.26	1.59	1.13	
				-0.07	1.13	5.60	
8	45.27	20.80	4.88	6.12	-0.42	0.64	2,00
				-0.42	1.69	1.07	
				0.64	1.07	2.23	
9	38.24	19.19	5.93	8.79	2.40	0.40	2,25
				2.40	1.79	0.40	
				0.40	0.40	0.88	
10	35.27	14.46	3.05	1.71	0.01	-0.51	2,75
				0.01	1.13	-0.19	
				0.51	0.19	1.70	
11	26.43	13.72	4.40	4.68	1.08	-0.98	3,50
				1.08	3.82	-0.82	
				-0.98	-0.82	2.26	
12	28.93	11.94	3.19	12.85	2.17	-0.52	4,0
				2.17	2.67	0.34	
				-0.52	0.34	1.86	

of Correct Classification for 12 Grey Tone Classe

3	4	5	6	7	8	9	10	11	1
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
0.0	0.0	84.8	11.6	3.6	0.0	0.0	0.0	0.0	0
0.0	0.0	19.3	80.7	0.0	0.0	0.0	0.0	0.0	0
0.0	0.0	0.0	0.0	87.1	12.9	0.0	0.0	0.0	0
0.0	0.0	0.0	0.0	8.7	91.3	0.0	0.0	0.0	0
0.0	0.0	0.0	0.0	0.0	7.3	90.4	2.4	0.0	0
0.0	0.0	0.0	0.0	0.0	0.0	3.0	97.0	0.0	0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	80.0	20
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.4	73

Table IV. Gray Tone and Secchi Depth Values of the Três Marias Reservoir.

Sample Points	MSS 4	MSS 5	MSS 6	MSS 7	Secchi Depth (m)
1A	15	8	5	3	6,0
1B	12	6	3	1	6,0
1C	16	8	4	2	2,0
2A	16.5	8	5	3	3,75
2B	15	8	3	2	4,5
2C	15	7	4	1	4,5
3A	-	-	-	-	-
3B	16	7	4	2	4,5
3C	16	9	5	3	3,0
4A	16	8	4	2	4,5
4B	16	8	5	3	3,0
4C	16	9	5	3	4,0
5A	17	9	5	3	2,5
5B	16	11	6	4	1,5
5B	16	11	6	4	1,5
5C	16	10	6	3	1,5
5C	16	10	6	3	1,5
6A	16	8	3	2	4,0
6B	18	12	7	5	2,0
6C	17	18	10	7	0,25
7A	15	8,5	4	3	4,0
7B	16	8	5	3	3,0
7C	22	18	9	4	0,30
8A	14	12	9	6,5	2,5
8B	18	14	7,5	9	2,0
8C	17	13	11	8	2,0
9A	14	7	3	0,75	5,0

Point 3A was obscured by cloud cover and was not includ

Table III. Values for Grey Tone Means and Covariances (LANDSAT Pass of Aug.27, 1978) and Secchi Depth

Classes	Means			Matrix of Covariance			Secchi Depth (m)
	MSS 4	MSS 5	MSS 6				
1	34.50	35.31	21.87	3.97	0.29	-0.19	0,25
				0.29	2,02	0.71	
				-0.19	0.71	2.85	
2	32.80	22.78	12.83	3.10	0.22	-1.23	1,50
				0.22	4.01	1.50	
				-1.23	1.50	2.85	
3	29.23	15.48	8.54	4.52	0.64	-0.44	2,00
				0.64	2.09	0.63	
				-0.44	0.63	2.33	
4	28.09	17.08	9.36	3.75	1.27	1.36	2,50
				1.27	2.98	1.98	
				1.36	1.98	4.86	
5	30.67	17.90	10.77	1.57	-0.25	-0.16	3,00
				+0.25	0.80	0.03	
				-0.16	0.03	1.02	
6	31.97	17.38	8.58	1.50	0.00	0.30	4,00
				0.00	2.02	-0.16	
				0.30	-0.16	4.59	
7	25.83	14.84	6.66	0.78	-0.07	-0.52	4,50
				-0.07	3.33	0.31	
				0.52	0.31	1.42	
8	24.87	13.24	5.38	1.84	-0.22	-0.25	6,00
				-0.22	0.55	0.70	
				-0.25	0.70	2.63	

Table VI. Matrix of Correct Classification for 8 Grey Tone Classes (Aug. 27, 1978)

LIMIAR = 5.00

	N	1	2	3	4	5	6	7	8
1) 0.25	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2) 1.50	0.0	0.0	93.9	0.0	1.1	5.0	0.0	0.0	0.0
3) 2.00	0.0	0.0	0.0	53.4	25.6	0.0	18.1	3.0	0.0
4) 2.50	0.0	0.0	17.5	7.0	40.4	35.1	0.0	0.0	0.0
5) 3.00	0.0	0.0	0.0	0.0	8.8	77.4	13.9	0.0	0.0
6) 4.00	0.0	0.0	0.0	6.4	2.6	8.4	82.7	0.0	0.0
7) 4.50	0.0	0.0	0.0	0.0	16.7	0.0	0.0	62.2	21.0
8) 6.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.6	89.4

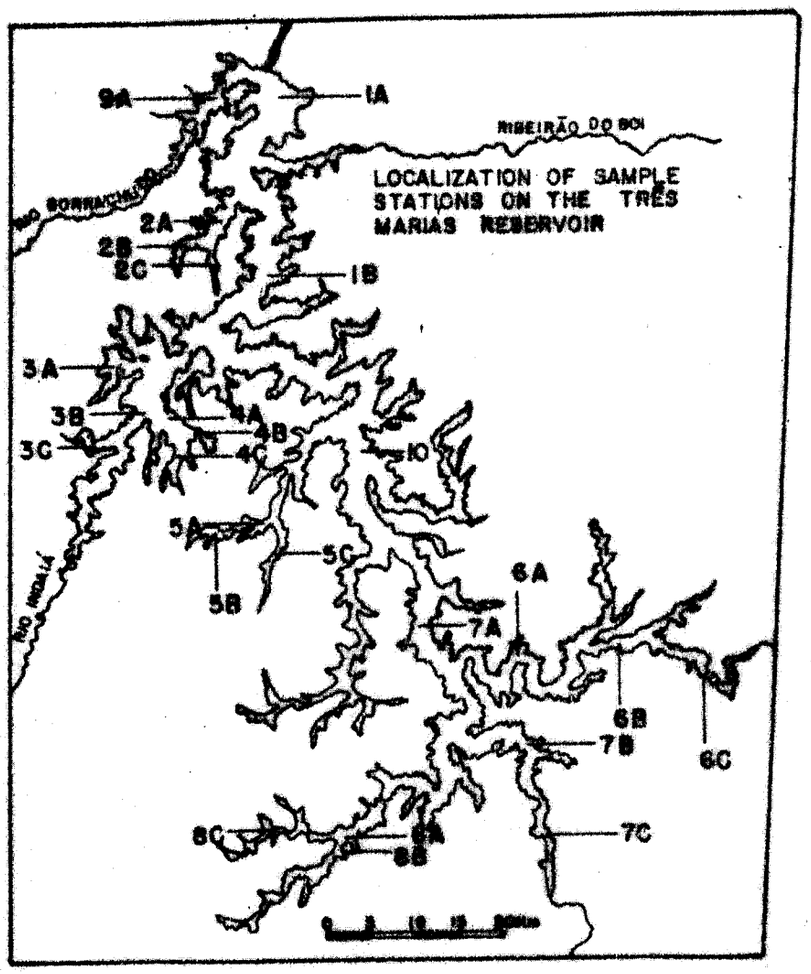

Figure 1. Localization of Sample Stations on the Três Marias Reservoir.

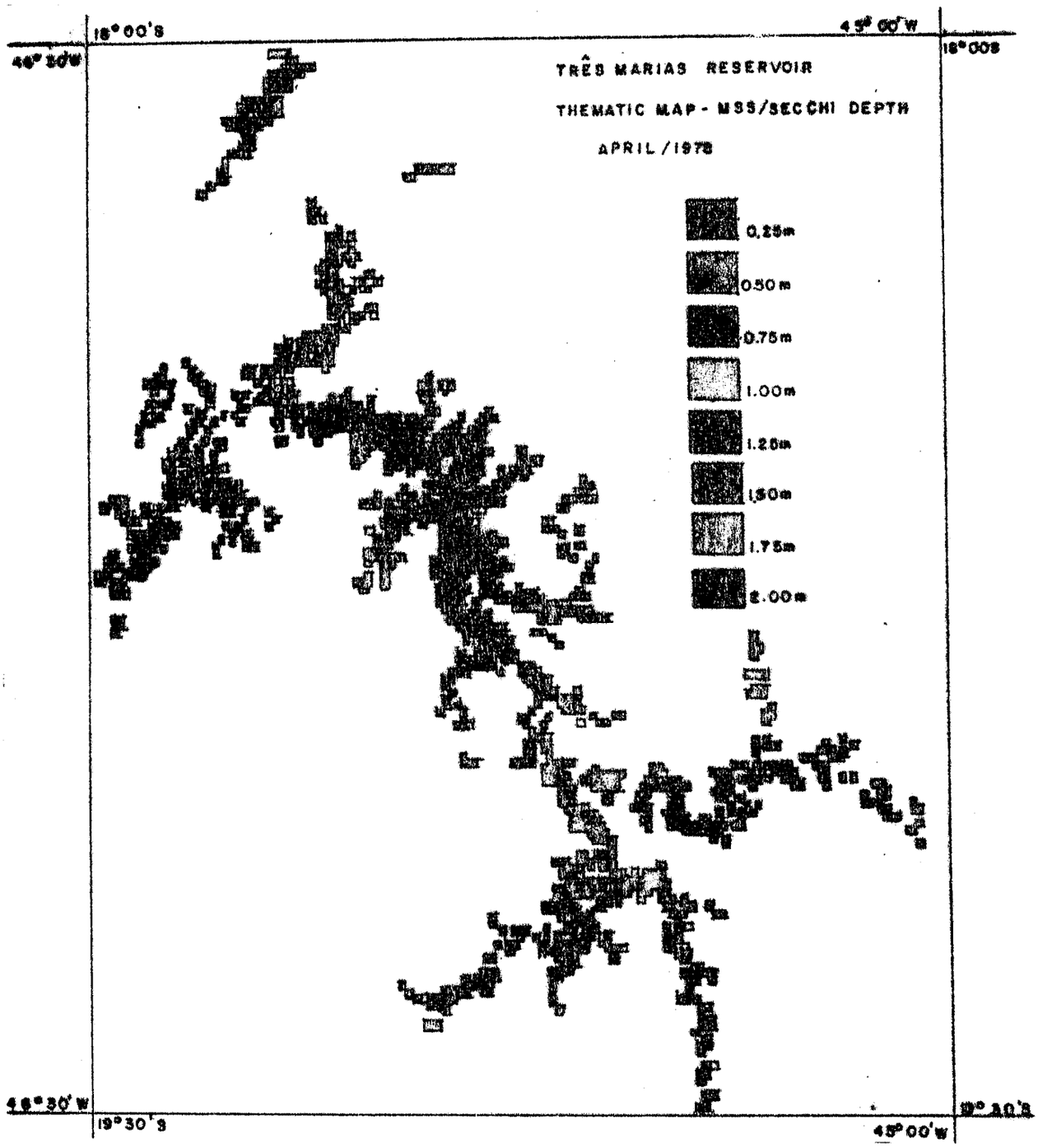

Figure 2a. Três Marias Reservoir - Thematic Map - MSS/Secchi Depth - April, 1978.

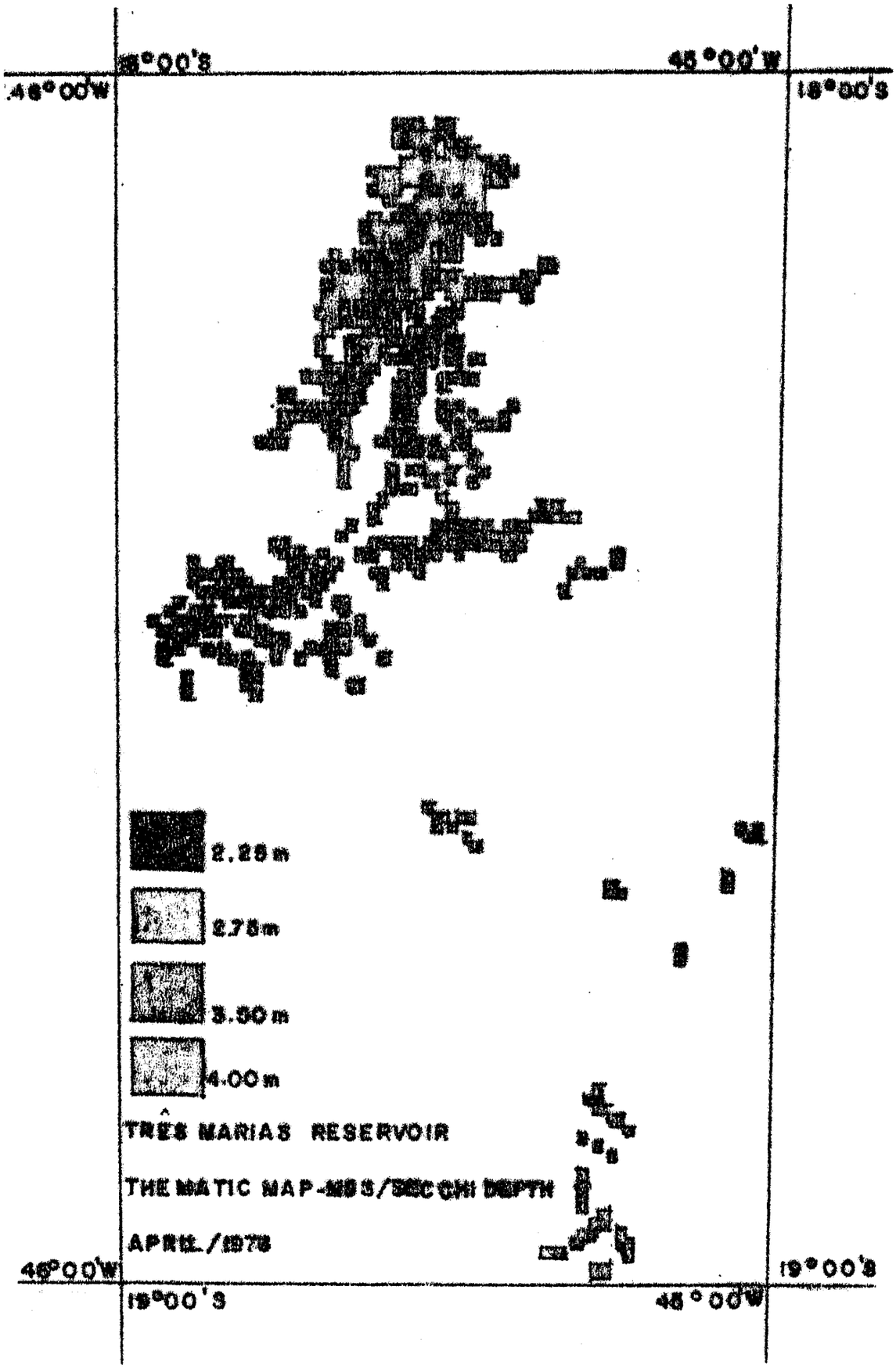

Figure 2b. Três Marias Reservoir - Thematic Map - MSS/Se Depth - April 1978.

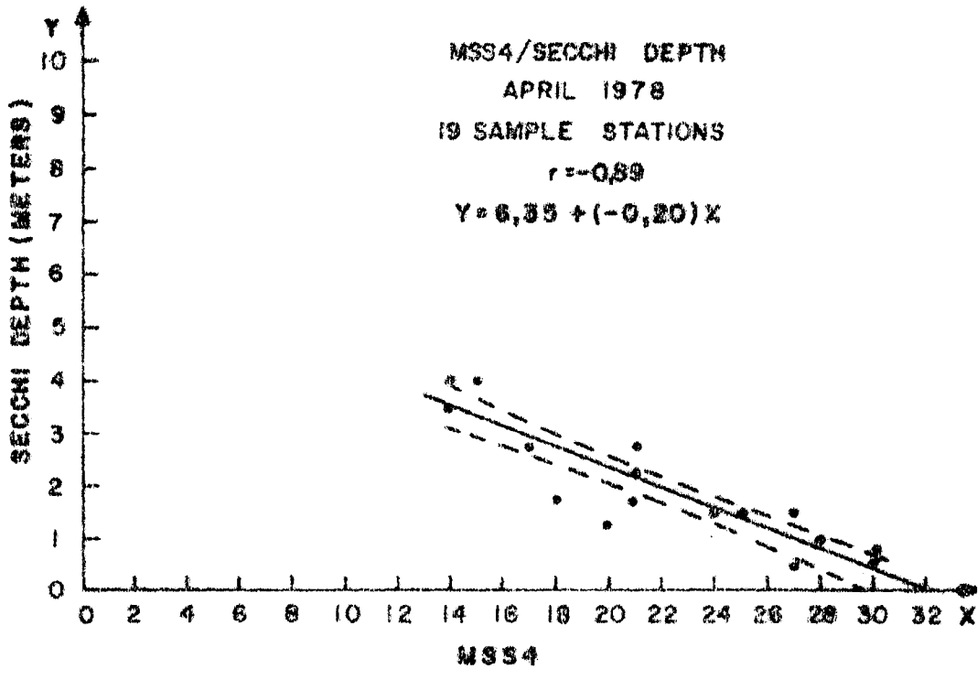

Figure 3. MSS4/Secchi Depth - April 1978
19 Sample Stations.

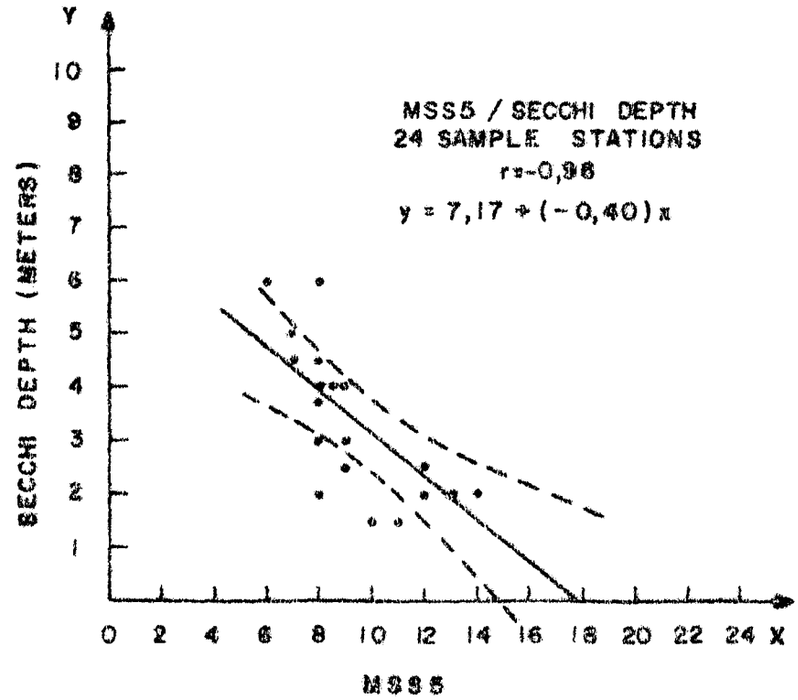

Figure 4. MSS 5/Secchi Depth
24 Sample Stations.