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MULTISPECTRAL ANALYSIS OF OCEAN DUMPED MATERIALS

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ABSTRACT

Experiments conducted in the Atlantic coastal zone indicate that plumes resulting from ocean dumping of acid wastes and sewage sludge have unique spectral characteristics. Remotely sensed wide area synoptic coverage provides information on these pollution features that is not readily available from other sources. Aircraft remotely sensed photographic and multispectral scanner data were interpreted by two methods. First, qualitative analyses in which pollution features are located, mapped, and identified without concurrent sea truth and, second, quantitative analyses in which concurrently collected sea truth is used to calibrate the remotely sensed data and to determine quantitative distributions of one or more parameters in a plume.

Location and mapping of pollution features in the coastal zone previously have been based on radiance differences between the plumes and receiving waters, using sea truth or other data for identification. As a result of the data analyses in these experiments, an in-scene calibration technique was developed that "normalizes" atmospheric effects, thereby potentially providing a means of plume identification that is independent of the specific scene and the multispectral scanner used. The in-scene calibration technique is based on ratio values in each band of a multispectral scanner where the ratios are radiance values in the pollutant plume divided by radiance values of ocean water in the same scene. Application of this technique to data from several experiments indicates that plumes resulting from acid wastes and sewage sludge have distinctive spectral characteristics over a range of environmental conditions and for two multispectral scanners flown at altitudes of 3.0 and 19.7 kilometers.

In addition to qualitative analyses that used the in-scene calibration, quantitative analysis techniques were applied to sewage sludge dump plumes. Results indicated that quantitative relationships exist between suspended solids in the plumes and remotely sensed radiance values. The calibrated regression equation that used Modular Multispectral Scanner bands 4 (540-580 nanometers (nm)) and 9 (760-860 nm) had a correlation coefficient of 0.961 and a standard error of estimate of 4.11 mg/ℓ for a measured range from 1.11 to 32.20 mg/ℓ. The calibrated regression equation was applied to map quantitative distributions of suspended solids in two plumes in the remotely sensed scene.

Additional experiments will be required to more fully define the role of remote sensing for monitoring ocean dumping and for determining plume characteristics, such as dispersion coefficients.

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1. INTRODUCTION

Pollution features in coastal zones include plumes from ocean dumping of waste materials, such as sewage sludge and acid wastes. It is of interest to environmental managers to locate these plumes and determine the pollutant dispersion characteristics. Remotely sensed wide area synoptic coverage provides information on features in the coastal zone that is not readily available by other means. Remotely sensed data may be interpreted by two approaches. The first approach is qualitative in nature and has been used to map features, such as river plumes, without concurrent sea-truth measurements. Photographic and multispectral scanner imagery or digital data have been used in conjunction with other available data, following photoanalysis techniques. The second approach is quantitative analyses in which sea truth collected at a limited number of locations is used to calibrate remotely sensed digital data and to extend the results to the remotely sensed scene. Results of the quantitative analyses, calibrated regression equations, have been used to develop maps showing quantitative distributions of one or more water quality parameters, such as suspended solids or chlorophyll a.

Aerial photographs have been analyzed by Scherz (ref. 1) to locate and trace pollutant plumes and their dispersion characteristics. Klemas, et al. (ref. 2) have analyzed Landsat and Skylab multispectral scanner imagery and/or photographs to study sediment distributions, acid waste plume persistance, and other characteristics of coastal zone pollution features. Yarger, et al. (ref. 3), Williamson and Grabau (ref. 4), Klemas, et al. (ref. 5), Rogers, et al. (ref. 6), and Johnson (refs. 7, 8, and 9) have applied classification or regression techniques to calibrate Landsat and aircraft multispectral scanner data and to map distributions of water quality parameters in inland and estuarine systems.

More recently, experiments were conducted in the Atlantic coastal areas to determine the applicability of aircraft remote sensing systems to (1) locate, identify, and map plumes resulting from ocean dumping of acid waste and sewage sludge, and (2) evaluate previously developed quantitative analysis techniques for determining quantitative distributions of materials in sewage sludge dumps. These investigations include development of multispectral analysis techniques that may be used to identify ocean dumped materials over a range of environmental conditions.

It is the purpose of this paper to present results from these experiments and the associated data analysis investigations. Results of the qualitative analyses are applicable to the technology base that is required before a remotely sensed monitoring system can be developed, for areas such as the New York Bight. Results of the quantitative analyses may be used to evaluate plumes, their dispersion characteristics, and environmental effects.

2. EXPERIMENTS

Remotely sensed data were collected in conjunction with sea-truth measurements in three experiments in the New York Bight apex of the Atlantic coastal zone, figure 1. Sea truth measurements were made by the National Oceanic and Atmospheric Administration (NOAA) in these joint experiments. Pollution features of primary interest in these experiments were ocean dumped materials, such as sewage sludge and acid waste. In the first experiment in April, 1975, acid waste and sewage sludge plumes were evaluated. In the second experiment on September 22, 1975, plumes resulting from dumping of sewage sludge by two methods were analyzed. The first dumping method is a "line" dump in which the sewage sludge is dispersed over a 3 to 4 kilometer (km) track from a moving barge in a 30 to 45 minute period. The second dumping method is a "spot" dump in which the sewage sludge is discharged in one location in about 5 minutes. In the third experiment on July 15, 1976, remotely sensed data were collected during multiple passes over a sewage sludge spot dump to study temporal dispersion characteristics. In addition, in this third experiment, spectral data were collected over an "unknown" sewage sludge dump and an in-progress acid waste dump.

Two National Aeronautics and Space Administration (NASA) multispectral scanners were used in the experiments reported here. The first scanner, which was flown in April, 1975, is the Ocean Color Scanner (OCS) onboard a NASA Ames Research Center (ARC) U-2 aircraft from an altitude of 19.7 kilometers (km) (65,000 ft). Spectral and spatial characteristics of the OCS are listed in table I. Experiment operations are described in reference 10. The second scanner, a Modular Multispectral Scanner (M2S), was flown on the September 22, 1975, and July 15, 1976, experiments onboard a NASA Johnson Space Center (JSC) P-3A aircraft. Spectral and spatial characteristics of the M2S and the mapping camera for the 3.0 km (10,000 ft) flight altitude are shown in table II. Operations for the September 22, 1975, experiment are described in reference 11.

3. DATA ANALYSIS

Qualitative Analysis

Qualitative analysis of pollution features includes location, identification, and mapping their extent. In general, pollution features have radiance levels different from those of the background water in one or more spectral regions. In almost all cases, plumes in the coastal zone have higher radiances (than the background water) that are due to suspended materials in the plumes (e.g., refs. 3, 4). These differences have been observed in photographic and digital remotely sensed data. Identification of pollution features without concurrent sea-truth measurements requires consideration of atmospheric as well as pollutant spectral responses. One method of "normalizing" environmental effects (e.g., atmospheric and Sun angle) between scenes is to use an in-scene calibration. The approach used in the results reported here was to determine ratios of plume radiances to background (ocean) water for the same remotely sensed scene in each of the multispectral scanner bands. These ratio values as a function of wavelength indicate unique characteristics that may be used for identification of plumes resulting from ocean dumping of acid waste and sewage sludge. After the plumes have been located and identified, they may be mapped using radiance differences in one (density slicing techniques) or more (classification techniques) spectral bands.

Quantitative Analysis

The quantitative analysis used is based on previously developed multiple regression techniques (refs. 7, 8, and 9). Specifically, a stepwise regression analysis is applied in which only statistically significant spectral bands are included in regression equations that relate remotely sensed data to parameters in the water column. These calibrated regression equations have been used to map distributions of water quality parameters, such as suspended sediment and chlorophyll a (refs. 8, 9).

4. RESULTS

Qualitative Analysis

Qualitative analysis of remotely sensed data includes location, mapping, and identification of features without the requirement for concurrent sea-truth measurements. Photographic and scanner radiance measurements from the September 22, 1975, experiment will be used to demonstrate how remotely sensed data have been analyzed. Spectral data will then be compared from the April 1975 and July 1976 experiments to demonstrate that the in-scene calibration technique provides a means for identification of acid waste and sewage sludge plumes over a range of experimental conditions.

Photographic results showing plumes from two sewage sludge dumps are shown in figure 2 (taken from ref. 11). The photograph was taken by a Zeiss mapping camera from 3.0 km (10,000 ft) at 11:59 a.m. eastern daylight time (e.d.t.), about 1 hour after the dumps. As noted in figure 2 the line dump took place from 10:46 a.m. to 11:16 a.m. and the spot dump from 11 a.m. to 11:05 a.m. The spectral image of the plumes, shown in figure 3, was obtained by mapping contours at different radiance levels in M2S Band 9 (760-860 nanometers (nm)). The essential outline of the plume is adequately represented by either figure. Spectral responses using the in-scene calibration technique over the visible and near IR spectral ranges for the two plumes are shown in figure 4. Also shown are spectral responses for the two plumes about 5 hours after dumping, indicating lower radiance values with dispersion of the plume over time, as expected. Also note that these are no large spectral shifts with time.

Location of pollution features and their mapping by density slicing and/or classification techniques is well developed (e.g., refs. 2, 3, 4, and 6). Thus, only results related to identification of pollution features will be presented for the April 1975 and July 1976 experiments. Spectral responses for acid waste and sewage sludge plumes obtained on April 9 and 13, 1975, are shown in figure 5. Recall these data were obtained by the OCS at a flight altitude of 19.7 km.

Spectral responses from sewage sludge and acid waste dump plumes on July 15, 1976, are shown in figure 6. In this figure, three curves are shown for sewage sludge plumes, the fourth curve is for an acid waste dump. The multispectral scanner was the M2S flown at an altitude of 3.0 km (see table II).

Note the general similarity of sewage sludge response curves (figs. 5 and 6) with peak ratio values occurring at wavelengths of about 700 to 800 nm. On the other hand, the peaks for the acid waste plumes (figs. 5 and 6) occur at about 600 nm. Thus, the curves of figure 6 appear qualitatively typical of spectral responses for sewage sludge and acid waste plumes over a range of experimental conditions.

Quantitative Analysis

Quantitative distributions of suspended solids in sewage sludge dumps were determined in an experiment in the New York Bight on September 22, 1975, involving two methods of dumping sewage sludge. The multiple regression (e.g., stepwise regression) analysis techniques were used to analyze M2S data that had been collected concurrenlty with sea-truth measurements by NOAA and the State University of New York (SUNY). In this particular experiment, only five of the ten possible M2S bands provided useable data; however, the bands available (2, 3, 4, 7, and 9) appear to give adequate spectral coverage.

Ten surface water samples were taken within 20 minutes of the aircraft over-pass. Five of the samples were taken in the line dump plume and five taken in water adjacent to the plume. Measured values of suspended solids and chlorophyll _a_ along with radiance values at the corresponding locations are listed in table III.

Suspended solids and chlorophyll _a_ concentrations were analyzed quantitatively with remotely sensed data (see ref. 9 for a detailed description of the procedure used). The calibrated regression equation used radiance changes in M2S bands 4 and 9 for determining suspended solids concentration changes; however, there were no significant radiance changes with chlorophyll _a_ concentration changes. The linear regression equation for suspended solids had a correlation coefficient of 0.961 and a standard error of estimate of 4.11 mg/ℓ over the measured range from 1.11 to 32.2 mg/ℓ. Comparison of the estimated suspended solids, calculated from the linear regression equation, and measured values are shown in figure 7. Prior investigations (refs. 7 and 8) have indicated linear responses for suspended solids in this range of measurements.

Applying the suspended solids regression equation to radiance data in the remotely sensed scene, quantitative distributions of suspended solids were determined and a map developed using a computerized contour routine.

Quantitative distributions of suspended solids in the sewage sludge dumps are shown in figure 8. The sea-truth measurements in the spot dump were not included in the regression equation; however, estimated values of 14-18 mg/ℓ, from the linear multiple regression equation, compare favorably with the interpolated measured value of 12 mg/ℓ obtained in the spot dump.

5. CONCLUDING REMARKS

Results of field experiments conducted in the Atlantic Coastal Zone indicated that pollution features such as plumes resulting from ocean dumping of sewage sludge and acid waste, have unique spectral characteristics. These spectral characteristics indicate significant differences over a range of experimental conditions when an in-scene calibration technique is used. In this technique the radiance ratio of the pollution feature (i.e., sewage sludge or acid waste plume) to ocean water is determined. The resulting uniquely shaped curve as a function of wavelength may be used to identify the pollution feature. After identification, the extent of the pollution feature is mapped based on radiance differences between the plume and the background water. This approach may be used to locate, identify, and map their distributions, without concurrent sea truth. This technology base may be used for the development of a remote sensing monitoring system; for example, to monitor ocean dumping in the New York Bight.

Quantitative analysis approaches may be used when concurrent sea-truth measurements are made. Results of these analyses, calibrated regression equations, have been used to determine quantitative distributions of water quality parameters, such as suspended solids in plumes resulting from sewage sludge dumps. These numerical results provide information for determining dispersion coefficients and environmental effects. Sea truth measurements in the September 22, 1975, sewage sludge monitoring experiment included chlorophyll a; however, there was no statistically significant correlation between changes in chlorophyll a concentrations and radiance values.

Results of experiments to date indicate that primary features such as acid waste and sewage sludge plumes may be distinguished by multispectral analysis techniques. In addition, changes in suspended solids concentrations in sewage sludge plumes produce spectral variations that may be used to develop calibrated regression equations. This procedure may then be applied to extend sea-truth measurements at a limited number of stations to map distributions of suspended solids in the remotely sensed scene. Additional factors to be evaluated in future tests, include dumping and mixing rates, type of sewage sludge treatment, and composition of the material (e.g., acid wastes) being dumped. In addition, further studies and measurements of receiving waters will aid in interpretation of factors such as the application of in-scene calibration techniques.

6. REFERENCES

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	SPECTRAL	
RANGE	423 - 782 NANOMETERS (nm)	
BANDS	BAND	RANGE
	1	433 nm ± 10 nm
	2	471 nm ± 10 nm
	3	509 nm ± 10 nm
	4	547 nm ± 10 nm
	5	583 nm ± 10 nm
	6	620 nm ± 10 nm
	7	662 nm ± 10 nm
	8	698 nm ± 10 nm
	9*	733 nm ± 10 nm
	10*	772 nm ± 10 nm

*BANDS NOT IN ANALYSIS

SPATIAL	
FIELD OF VIEW	
WIDTH, M	25 000
LENGTH, M	CONTINUOUS
RESOLUTION, M	75

TABLE I. OCEAN COLOR SCANNER SPECTRAL AND SPATIAL CHARACTERISTICS AT 19.7 KILOMETERS (65,000 FT) ALTITUDE.

STATION	SEA TRUTH: SUSPENDED SOLIDS mg/l	SEA TRUTH: CHLOROPHYLL a mg/m^3	REMOTELY SENSED RADIANCES, mw/cm^2 - ster - µm, M2S BAND 2	3	4	7	9
1	1.53	1.0	3.00	3.07	2.92	0.93	0.37
2	1.26	1.0	2.90	2.85	2.01	0.78	0.32
3	27.00	1.5	3.02	2.95	2.06	1.07	0.48
4	1.60	1.2	2.60	2.99	2.15	0.86	0.34
5	30.10	1.9	2.99	2.89	2.00	1.02	0.46
6	1.70	1.1	2.95	2.98	2.15	0.87	0.33
7	32.20	1.8	3.11	3.09	2.19	1.17	0.54
8	1.11	1.2	3.14	3.15	2.25	0.96	0.40
9	13.26	1.5	3.27	3.26	2.28	1.21	0.50
10	13.36	1.5	3.28	3.27	2.30	1.04	0.41
SPOT*	12.0**	--	3.30	3.45	2.51	1.36	0.52

* AVERAGE NEAR SUNY SHIP ONRUST

** INTERPOLATED VALUE

TABLE III. SEA TRUTH MEASUREMENTS AND REMOTELY SENSED DATA IN SEWAGE SLUDGE PLUME ON SEPTEMBER 22, 1975.

I MODULAR MULTISPECTRAL SCANNER (M2S)

RANGE	380 - 1060 nm + THERMAL	
BANDS	BAND	RANGE
	1	380 - 440 nm
	2	440 - 490 nm
	3	495 - 535 nm
	4	540 - 580 nm
	5	580 - 620 nm
	6	620 - 660 nm
	7	660 - 700 nm
	8	700 - 740 nm
	9	760 - 860 nm
	10	970 - 1060 nm
	THERMAL	8000 - 13 000 nm

SPATIAL	
FIELD OF VIEW	
WIDTH, M	8500
LENGTH, M	CONTINUOUS
RESOLUTION, M	9

II ZEISS MAPPING CAMERA

SPECTRAL RANGE	FILM	RESOLUTION, M	FOOT PRINT, M
300 - 700 nm	2402 (B & W)	1.3	4550 × 4550

TABLE II. SPECTRAL AND SPATIAL CHARACTERISTICS OF REMOTE SENSORS (AT 3.0 KILOMETER ALTITUDE)

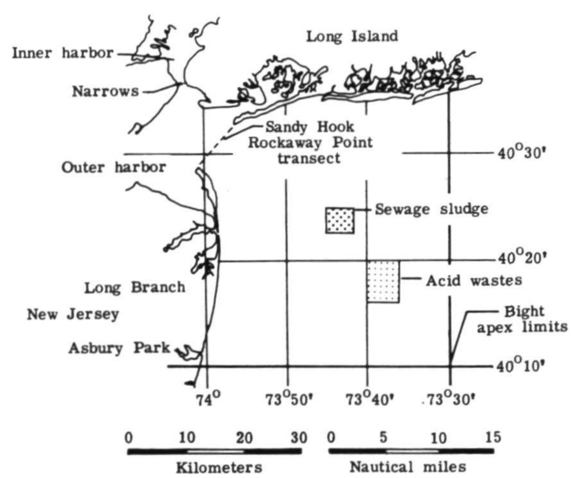

FIGURE 1. OCEAN DUMPSITES FOR SEWAGE SLUDGE AND ACID WASTES IN THE NEW YORK APEX.

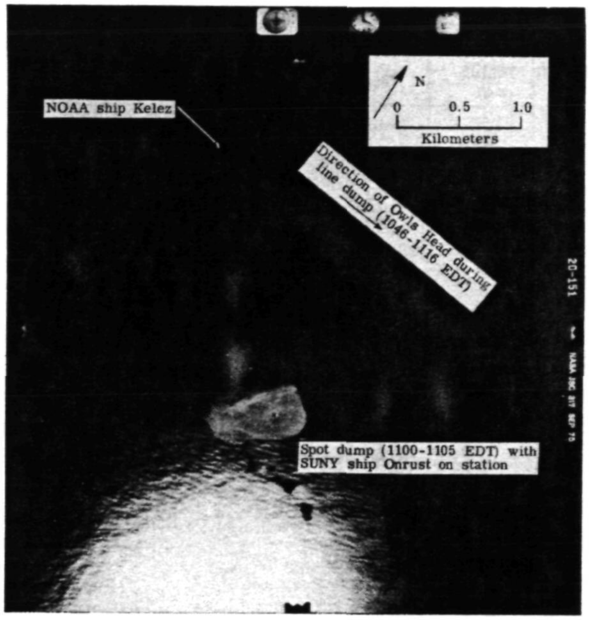

FIGURE 2. AERIAL PHOTOGRAPH AT 1159 EDT SHOWING LINE AND SPOT SEWAGE SLUDGE DUMP PLUMES ON SEPTEMBER 22, 1975.

FIGURE 3. QUALITATIVE MAPPING OF SEWAGE SLUDGE PLUMES OBTAINED BY "DENSITY SLICING" M2S BAND 9, SEPTEMBER 22, 1975.

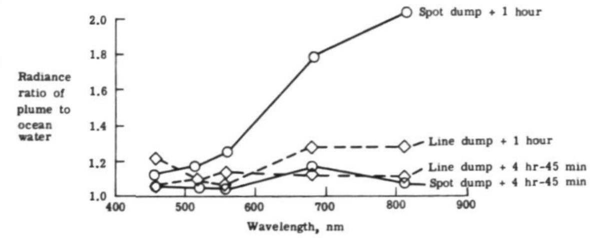

FIGURE 4. RADIANCE RATIOS OF PLUMES FROM LINE AND SPOT DUMPS OF SEWAGE SLUDGE ON SEPTEMBER 22, 1975.

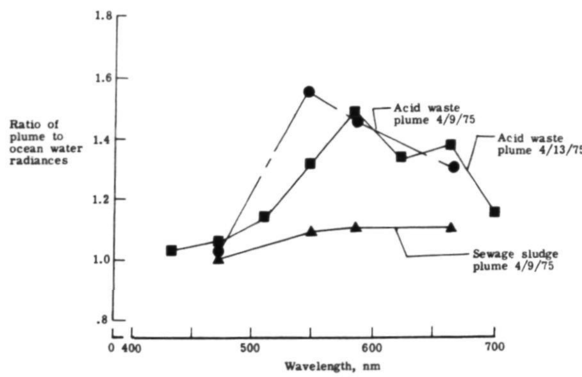

FIGURE 5. RADIANCE RATIOS OF ACID WASTE AND SEWAGE SLUDGE PLUMES ON APRIL 9 AND 13, 1975.

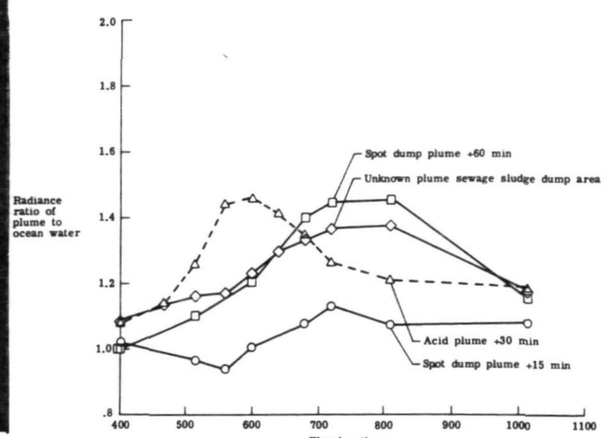

FIGURE 6. RADIANCE RATIOS OF ACID WASTE AND SEWAGE SLUDGE PLUMES ON JULY 15, 1976.

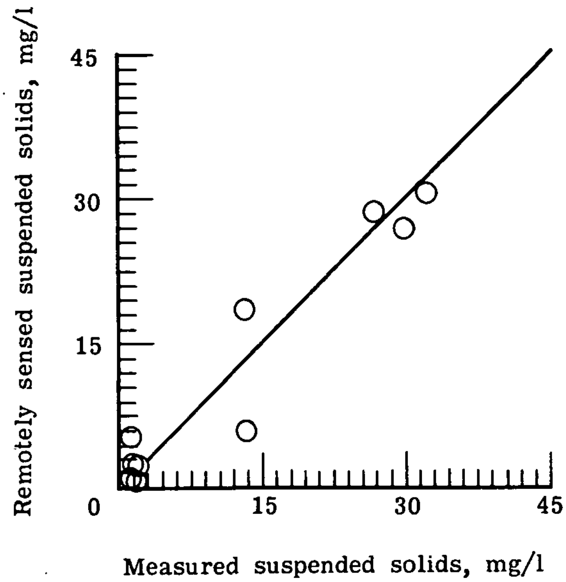

FIGURE 7. REMOTELY SENSED AND MEASURED VALUES OF SUSPENDED SOLIDS IN THE LINE DUMP PLUME ON SEPTEMBER 22, 1975.

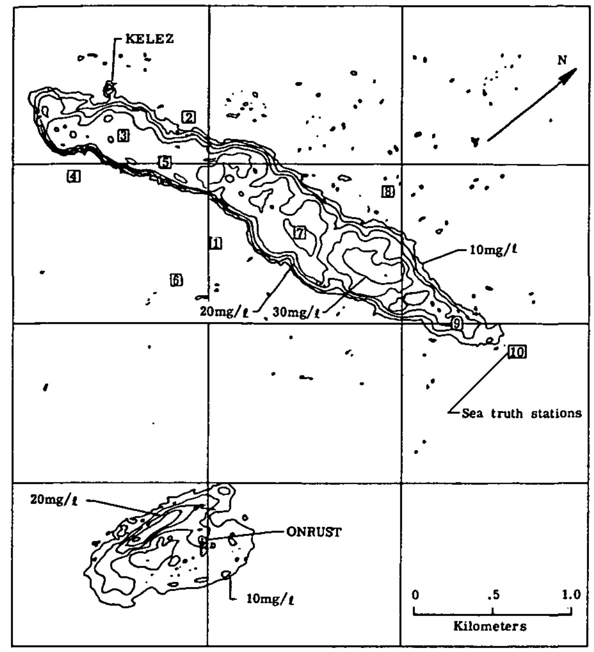

FIGURE 8. QUANTITATIVE DISTRIBUTIONS OF SUSPENDED SOLIDS IN THE LINE AND SPOT DUMP PLUMES ON SEPTEMBER 22, 1975

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