NOAA Data Report ERL GLERL-14

THE EFFECTS OF DREDGING ON THE CHEMICAL CHARACTERISTICS OF THE GRAND RIVER

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UNITED STATES DEPARTMENT OF COMMERCE
Philip M. Klutznick, Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Richard A. Frank, Administrator

Environmental Research Laboratories
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NOTICE

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During spring 1977, water was sampled in the Grand River, which runs through the State of Michigan, to estimate the increased loads of polluting and enriching substances caused by dredging the river channel near its mouth at Lake Michigan. Results indicate that sedimentary material disturbed during the dredging process is carried out to the lake. On an annual basis, the increase in loading is approximately 1 percent for all variables measured; however, during the period of dredging (about 1 week), the increases are approximately 30 percent. The effects of these events on the nearshore ecology are not known at present.

1. INTRODUCTION

As part of a continuing investigation of the influence of the Grand River on the nearshore of southeastern Lake Michigan, a Lagrangian study consisting of near-river-mouth samples collected adjacent to a moving drogue was conducted on April 6, 1977. During the period of sampling, the river was being dredged by the U.S. Army Corps of Engineers. The main objectives of the study were to determine the magnitude of the release of polluting and enriching substances during the dredging operation and to estimate their impact on the lake.

The Grand River, which flows 420 km through a drainage basin of approximately 14,000 km^2, empties into Lake Michigan at Grand Haven, Mich. (fig. 1). In terms of volume of flow, it is the largest river emptying into the lake. The harbor at Grand Haven has a minimum draft of 6.4 m to the railroad bridge. Above Spring Lake a 2.4 m deep channel extends 28 km upstream. The river outflow is channeled into Lake Michigan through a breakwater extending approximately 400 m offshore.

[1]GLERL Contribution No. 203.

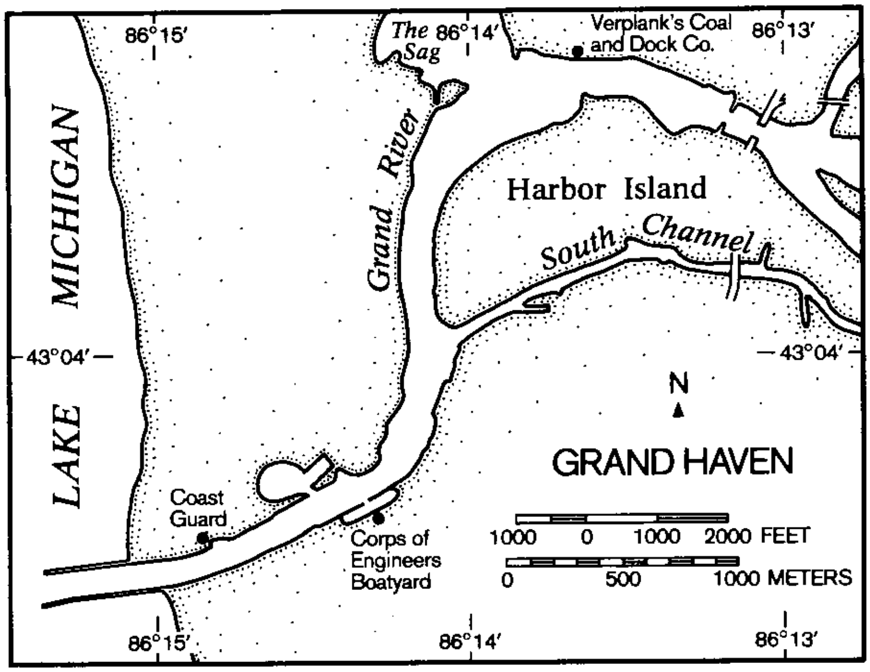

Figure 1.--*Grand River drainage basin.*

A record of flow measured at Grand Rapids, Mich., by the U.S. Geological Survey (1977) shows a 51-year mean of 100 m^3/s, with a range from 10.8 m^3/s to 1530 m^3/s from a total gaged area of 12,691 km^2. The flow during the 1977 water year ranged from 19 m^3/s to 240 m^3/s and averaged 63.7 m^3/s. Daily flows during the period of study are summarized in table 1. A consideration of the ratio of the total drainage area to the gaged area suggests that these flow values should be increased by a factor of 1.13 to arrive at a realistic value for the flow rate at Grand Haven. This approach is used by the Lake Hydrology Group of the Great Lakes Environmental Research Laboratory (GLERL) (R. N. Kelley, personal communication).

Table 1.--*Grand River daily flow at Grand Rapids, Mich., and adjusted daily flow at Grand Haven, Mich., 1977*

Date	Grand Rapids, m^3/s	Grand Haven, m^3/s	Date	Grand Rapids, m^3/s	Grand Haven, m^3/s
March 28	127.7	143.8	April 2	171.3	192.9
March 29	146.4	164.8	April 3	179.2	201.8
March 30	165.1	185.9	April 4	190.3	214.3
March 31	176.4	198.6	April 5	192.0	216.2
April 1	169.9	191.3	April 6	187.7	211.4

1.1 Dredging Operations

Dredging operations were conducted April 4-11, 1977, by the U.S. Army Corps of Engineers. Using the Hopper Dredge *Hains*, they cleared the navigation channel between the mouth of the south channel and the turning basin west of the railroad bridge. Spoils from this operation were pumped into a confined area north of the river near the Verplanks Coal and Dock Co. (fig. 2, table 2). Operation reports do not indicate any overflow-discharge from the hoppers during dredging (D. L. Billmeier, personal communication). This study was conducted on April 6 while the *Hains* was above the confluence of the north and south channels.

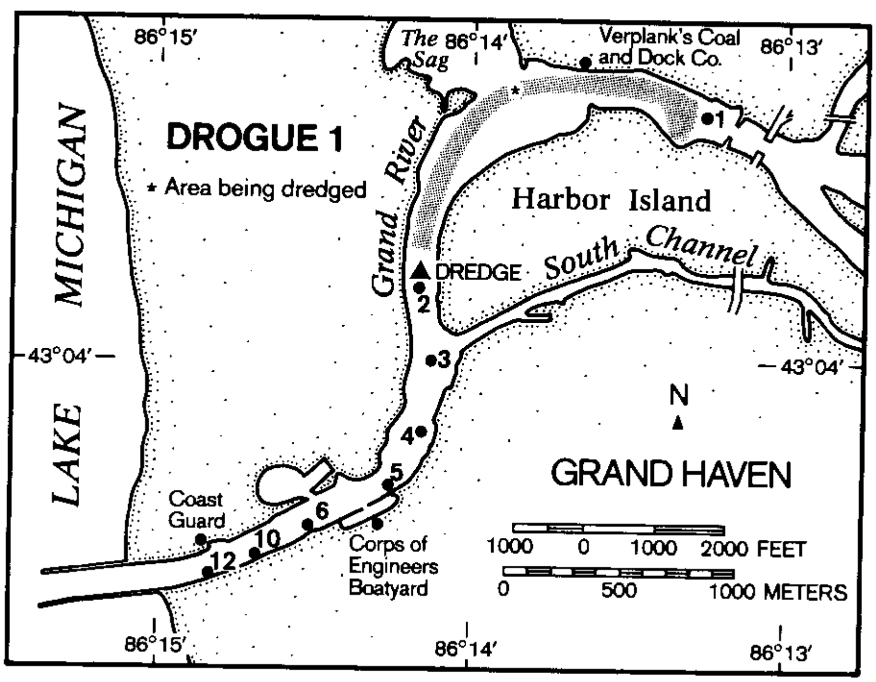

Figure 2.--*Station locations and position of dredge at start of drogue run.*

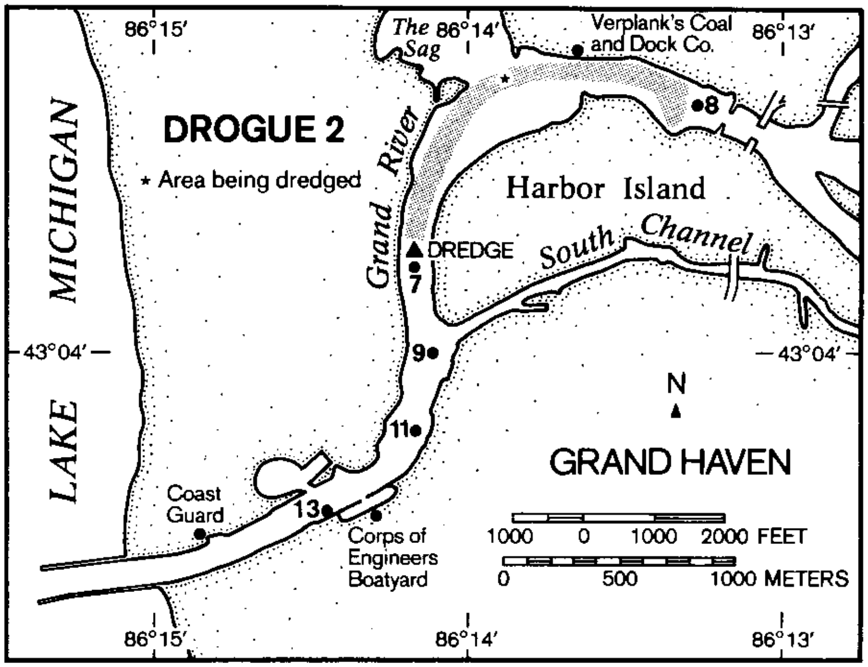

Figure 2.--*Station locations and position of dredge at start of drogue run (con.).*

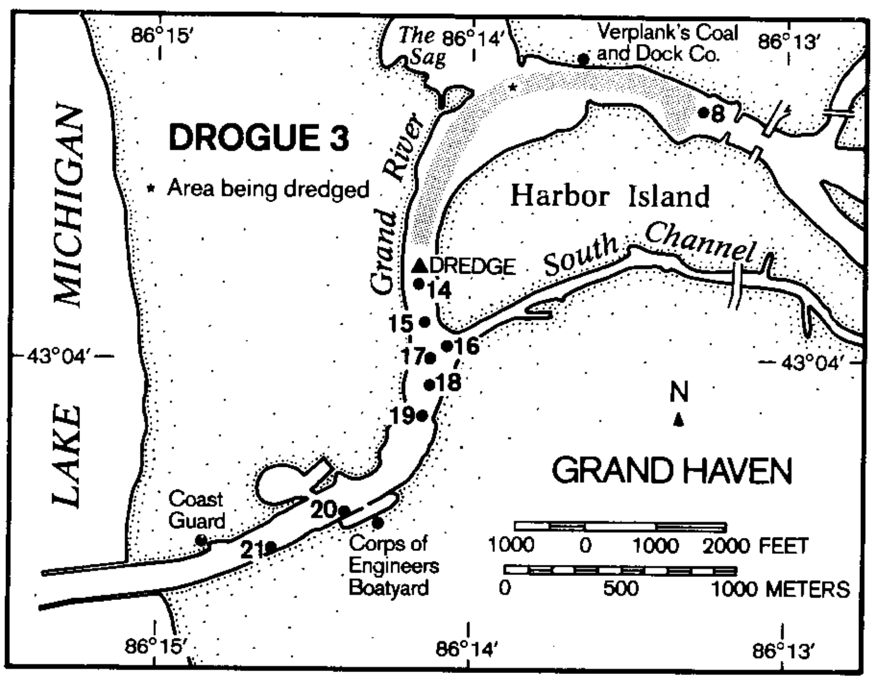

Figure 2.--*Station locations and position of dredge at start of drogue run (con.).*

Table 2.--*Station locations*

Cruise	Station	Latitude	Longitude	Cruise	Station	Latitude	Longitude
4	1-6,9	43.062°	86.237°	5	10	43.059°	86.245°
4	7	43.072°	86.236°	5	11	43.064°	86.236°
4	8	43.067°	86.235°	5	12	43.058°	86.247°
5	1	43.076°	86.221°	5	13	43.060°	86.242°
5	2	43.069°	86.236°	5	14	43.070°	86.236°
5	3	43.067°	86.235°	5	15	43.068°	86.236°
5	4	43.064°	86.236°	5	16	43.067°	86.235°
5	5	43.062°	86.238°	5	17	43.067°	86.235°
5	6	43.060°	86.242°	5	18	43.066°	86.235°
5	7	43.070°	86.236°	5	19	43.064°	86.236°
5	8	43.076°	86.221°	5	20	43.061°	86.240°
5	9	43.067°	86.235°	5	21	43.059°	86.245°

2. METHODS

A Lagrangian experiment was theoretically designed to sample from a moving parcel of water adjacent to a drogue. Small (40 cm x 80 cm) cruciform drogues set at 3 m to mid-vane were deployed one at a time approximately 50-m astern of the *Hains* while the dredge was moving upstream opposite the Power and Light Company plant. Periodic samples at each drogue were taken at the surface by bucket and at a depth of 5 m in 5-liter Niskin bottles while operating from a 6.7-m launch. The water samples were taken to a dockside laboratory for analysis within 1 h of collection. Surface temperatures were recorded with a bucket thermometer.

The samples were analyzed for soluble reactive, total dissolved, and total phosphorus, ammonia, nitrate, total dissolved and total Kjeldahl nitrogen, chloride, sulfate, silica, specific conductance, and total suspended materials (American PHA, 1971). Selected samples were analyzed for pH, Eh, alkalinity, and dissolved oxygen. Particle size analysis was performed on an HIAC, which measures numbers of particles in five size categories (2-4, 4-8, 8-16, 16-32, and 32-60 microns). These samples were prescreened at 60 microns. Samples vacuum filtered through Gelman A/E glass fiber filter pads, which retain materials greater than approximately 1 micron, were designated the "dissolved" fraction.

Turbidity measurements were performed with an HACH Turbidimeter, Model 2100A. The instrument was calibrated to HACH permanent latex turbidity standards and periodically rechecked for instrument drift. The results were reported in nephelometric turbidity units (NTU's). Total suspended materials were determined by vacuum filtering a measured volume (>500 ml) through preweighed Gelman A/E glass fiber, 47-mm diameter filters. Specific conductance was determined with an Industrial Instruments Conductivity Bridge, RC-19. Two separate analyses were made on each sample and the results expressed in micromhos at 25°C. Measurements of pH and Eh were made with Beckman and Orion digital meters. Phenolphthalein and total potentiometric alkalinity determinations were made by titrating 100-ml water samples with standard acid (H_2SO_4) to the endpoints of 8.2 and 4.5, respectively. Chloride concentrations were determined by standard addition and an Orion chloride specific ion electrode. Dissolved oxygen determinations were made by the Winkler method. Nitrogen and phosphorus forms were determined on a Technicon AutoAnalyzer II by the manufacturer's recommended procedures. Trace metals were measured by atomic absorption (graphite furnace equipped) and carbon by the Oceanography International wet oxidation process.

2.1 Confidence Limits

The precision achieved in measuring selected variables is shown in table 3.

2.2 Sediment Characteristics

The physical and chemical data summarized in tables 4 and 5 were provided by the U.S. Army Corps of Engineers, Detroit District (S. Jacek, personal communication). During our sampling period, dredging was being conducted between their stations A, B, and C (fig. 3), which are composed of fine-grained silts. The volume of material dredged from the channel and the location of its subsequent disposal is shown in table 6. Samples from the same regions were analyzed by the Environmental Protection Agency (EPA) (table 5). They were less than 30 percent solids and had very high concentrations of organics, nutrients, and iron.

Our Lagrangian experiments were designed to determine if the disturbance of these highly enriched sediments due to dredging increased the chemical load to the lake.

Table 3.--*Analytical precision (coefficient of variation, percent)*

Variable	Unit	Standards	Samples
Nitrate-nitrogen (NO_3-N)	PPB	4	5
Ammonia nitrogen (NH_3-N)	PPB	5	8
Total dissolved Kjeldahl nitrogen (TDKN)	PPB	5	--
Total Kjeldahl nitrogen (TKN)	PPB	5	7
Phosphate phosphorus (PO_4-P)	PPB	5	5
Dissolved total phosphorus (DTP)	PPB	2.5	--
Total phosphorus (TP)	PPB	2.5	4
Dissolved organic carbon (DOC)	PPB	3	5
Total organic carbon (TOC)	PPB	--	5
Sulfate (SO_4)	PPB	5	--
Silica (SiO_2)	PPB	3	--
Total alkalinity (TALK)	mg/l $CaCO_3$	2	2
Dissolved oxygen (D.O.)	mg/l	--	5
Dissolved oxygen	Percent sat.	--	5
Chloride (Cl)	mg/l	5	5
Specific conductance (S. Cond.)	Micromhos at 25°C	--	3
Dissolved iron (D Fe)	PPB	6	7
Total iron (T Fe)	PPB	--	7
Dissolved copper (D Cu)	PPB	5	9
Total copper (T Cu)	PPB	--	7
Dissolved lead (D Pb)	PPB	5	5
Total lead (T Pb)	PPB	--	4
Dissolved nickel (D Ni)	PPB	5	5
Total nickel (T Ni)	PPB	--	4
Dissolved manganese (D Mn)	PPB	2	2
Total manganese (T Mn)	PPB	--	4
Dissolved chromium (D Cr)	PPB	4	4
Total chromium (T Cr)	PPB	--	6
Particle counts	Counts/ml	--	5
Particle surface area	cm^2/l	--	5

Table 4.--*Physical characteristics of bottom sediment, March 16 and 17, 1977, provided by the Detroit District Corps of Engineers*

Station	Dist. from shoreline (m)	Description	Specific gravity	In place density (g/l)	Grain size (mm)* D20	D50	D80
A	4100	Silt, trace to some clay and fine sand	2.55	1205	0.005	0.021	0.069
C	1950	Silt, trace to some clay and fine sand	2.55	1120	0.003	0.019	0.072
D	200	Sand, fine	2.65	2118	0.25	0.25	0.28
E	0	Sand, medium to fine	2.66	1969	0.25	0.25	0.28

*Indicates maximum grain size at the 20th, 50th, and 80th percentile of the sample.

Table 5.--*Chemical characteristics of bottom sediment, 1972, (analyzed by EPA) provided by the Detroit District Corps of Engineers*

Region of station	Approx. dist. station from shoreline	T. solids (percent)	T. volatiles (percent)	C.O.D.* (mg/kg) dry	Phenol. (μg/kg) dry	TKN (mg/kg) dry	TP (mg/kg) dry	Oil and grease (mg/kg) dry	T. Fe (mg/kg) dry
A	12,000 (turning basin)	31.3	12.1	170,000	580	4,800	1,600	3,500	24,000
B	9,600	27.5	13.7	200,000	1,100	2,500	2,100	5,400	24,000
C	5,500	27.4	14.3	220,000	770	4,000	3,000	8,000	25,000
D	250	82.4	0.2	920	150	16	50	240	2,500
E	West end of south breakwater	84.0	0.3	21,000	110	20	55	240	2,600

*Chemical oxygen demand.

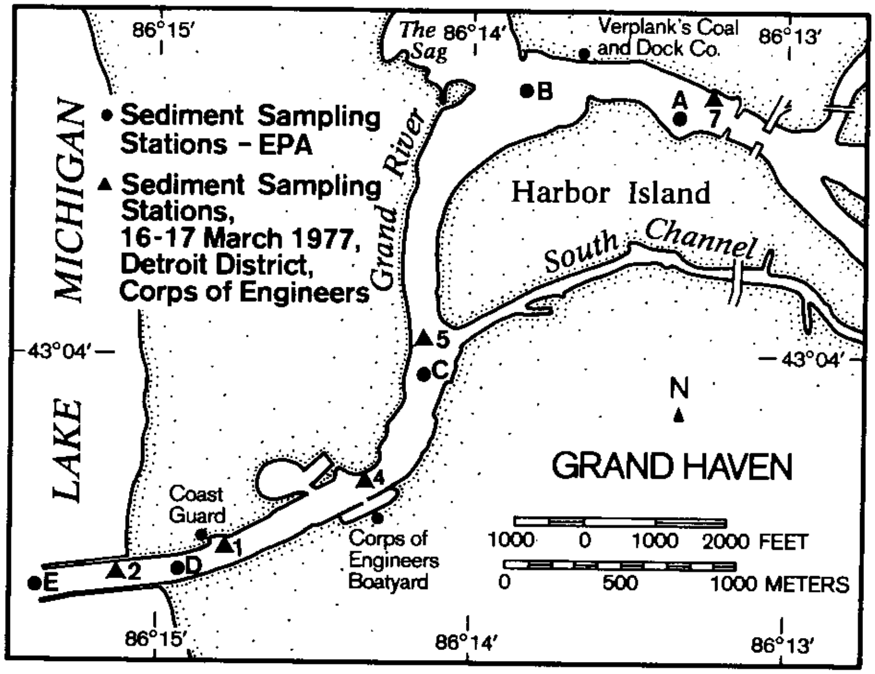

Figure 3.--*Bottom sediment sampling by EPA in 1972 and the U.S. Army Corps of Engineers in 1977.*

Table 6.--*Dredged volume (m^3) and disposal areas*

Disposal Area	April 1977	Average Annual
Open Lake	4,765	22,900
Confined	9,412	53,500
Total	14,177	76,400

3. RESULTS AND DISCUSSION

River current velocity, determined by timing drogues, varied from 53 cm/s behind the dredge to a minimum of 9 cm/s near the river mouth and averaged 22 cm/s for the three drogue experiments. The higher initial velocity was attributed to a combination of propeller thrust and increased flow through a somewhat restricted channel in the 0.4-km reach upriver from the mouth of the south channel.

Our three experiments were initiated within approximately 50 m of the dredge as it began its run upstream (fig. 2). The distance from drogue release to the river mouth was approximately 2,500 m. At a flow rate of 22 cm/s (∿800 m/h), materials disturbed by the dredging would reach the lake within 3 h.

The data for all three experiments are included (table 7). Our interpretation will deal primarily with the first drogue since results of the second and third experiments are similar to those of this first one.

To get an estimate of background (non-dredge influenced) variability, we analyzed the river for selected metals and nutrients for 10 days prior to the experiment. Figure 4 shows that the trace metal concentrations remained nearly constant as did the Kjeldahl nitrogen. Significant variability was noted in the phosphorus levels, especially the particulate fraction. On the day of the drogue experiments, two samples (stations 1, 8) were collected at the bridge, upriver of the dredge operations. This was done at the beginning of drogue runs 1 and 2.

3.1 Transport of Particulate Matter

The water was turbulent behind the dredge and fine particulates as well as plant fragments were brought to the surface. There was an increase in turbidity as expressed by both NTU and total suspended materials (TSM) in this area (fig. 5), peaking within 0.4 km of the dredge and approaching river background within 1 km. The same pattern holds for all three drogue experiments. Comparing these results with those in figure 6, which illustrates particulate surface area for the same samples, shows that the surface samples are much less perturbed than those taken at 5-m depth. (Approximate water depth is 8 m.) Both horizons recover rapidly, the surface returning to near background while the deeper region remains somewhat elevated in concentration.

Table 7.--*Data for three Lagrangian experiments*

Station	Depth (m)	Time from release (min)	Dist. below dredge (m)	NO_3-N (p/b)	NH_3-N (p/b)	TDKN (p/b)	TKN (p/b)	PO_4-P (p/b)	DTP (p/b)	TP (p/b)	DOC (p/m)	TOC (p/m)	SO_4 (mg/l)	SiO_2 (mg/l)	TALK (mg/l$CaCO_3$)	pH	Eh (volts)	D.O. (%)	Cl (mg/l)	S. Cond. (µmhrs)
								River Background												
1	0	Samp. @ 9.7 h	--	1750	115	850	1228	34	36.5	138	7.9	8.1	74	4.6	178	8.14	0.225	--	30.8	537
	5		--	1700	115	789	1331	35	43.2	--	--	8.6	74	5.4	176	8.08	0.219	--	30.5	537
8	0	Samp. @ 11.5 h	--	1520	114	--	760	30	--	87	--	6.8	--	--	--	--	--	--	--	545
	5		--	1700	117	--	880	36	--	115	--	8.0	--	--	--	--	--	86	--	546
								Drogue 1												
2	0	0	50	1700	145	865	1124	34	49.0	143	6.4	7.9	73	4.9	--	--	--	--	30.8	539
	5			1700	166	832	1405	34	42.0	202	6.3	8.3	75	5.2	--	--	--	--	30.6	539
3	0	10	370	1650	183	750	1255	32	45.0	153	5.0	8.5	76	4.2	--	--	--	--	31.3	546
	5			1750	213	940	1731	41	43.5	295	5.3	9.6	72	5.4	--	--	--	--	30.8	548
4	0	20	690	1750	157	905	1113	36	46.0	123	5.4	--	69	5.4	--	--	--	--	31.1	550
	5			1750	198	995	1335	38	47.0	143	6.3	--	68	5.4	--	--	--	--	31.4	550
5	0	30	965	1750	212	975	1260	42	47.5	150	6.4	7.0	68	5.4	--	--	--	--	32.2	550
	5			1750	210	985	1185	35	48.0	140	5.8	6.7	69	5.5	--	--	--	--	32.2	551
6	0	60	1362	1750	161	930	970	36	48.5	105	5.9	6.4	68	5.5	--	--	--	--	31.4	549
10	0	110	1637	1700	160	865	940	33	38.5	103	5.7	8.2	71	5.4	--	--	--	--	31.4	545
	5			1700	152	887	--	34	41.0	91	5.8	7.8	71	5.2	--	--	--	85	30.6	544
12	0	147	1850	1700	162	--	900	33	--	122	--	7.1	--	--	--	--	--	--	--	542
	5			1700	186	--	965	34	--	116	--	9.8	--	--	--	--	--	86	--	541
								Drogue 2												
7	0	0	50	1750	245	--	1295	28	--	163	--	15.0	--	--	--	--	--	--	--	551
9	0	27	440	1700	155	--	903	34	--	112	--	6.6	--	--	--	--	--	--	--	547
	5			1700	175	--	933	34	--	110	--	12.0	--	--	--	--	--	85	--	548
11	0	57	800	1700	156	--	900	34	--	102	--	8.3	--	--	--	--	--	--	--	541
	5			1700	172	--	983	34	--	135	--	--	--	--	--	--	--	87	--	541
13	0	90	1350	1700	152	--	830	32	--	95	--	6.9	--	--	--	--	--	--	--	542

Table 7.--*Data for three Lagrangian experiments (con.)*

Station	Depth (m)	Time from release (min)	Dist. below dredge (m)	NO_3-N (p/b)	NH_3-N (p/b)	TDKN (p/b)	TKN (p/b)	PO_4-P (p/b)	DTP (p/b)	TP (p/b)	DOC (p/m)	TOC (p/m)	SO_4 (mg/l)	SiO_2 (mg/l)	TALK (mg/l $CaCO_3$)	pH	Eh (volts)	D.O. (%)	Cl (mg/l)	S. Cond. (μmhrs)
Drogue 3																				
14	0	0	50	1570	272	810	1410	32	42.0	162	--	11.9	77	5.3	210	8.06	0.176	--	34.1	552
	5			1700	261	730	1130	31	35.0	202	--	11.3	74	5.6	201	8.14	0.188	87	34.3	550
15	0	10	218	1610	222	1005	1573	30	37.5	197	6.5	7.3	74	5.6	186	8.04	0.179	--	31.3	551
	5			1700	335	950	1870	30	30.0	335	5.7	12.1	80	5.4	191	7.97	0.187	85	32.2	551
16	0	17	340	1700	303	--	1335	30	--	413	--	6.8	--	--	177	8.00	0.149	--	--	563
	5			1700	285	--	1110	29	--	109	--	7.0	--	--	181	8.05	0.191	94	--	564
17	0	23	375	1650	164	--	1140	32	--	159	--	7.5	--	--	180	8.05	0.196	--	--	556
	5			1700	295	--	1398	30	--	178	--	10.3	--	--	185	7.97	0.201	86	--	556
18	0	35	526	1675	154	935	1130	34	50.0	192	6.4	7.5	75	5.2	179	8.07	0.202	--	32.4	557
	5			1650	216	995	1240	32	45.0	133	5.7	9.5	75	5.0	178	8.04	0.204	89	30.9	557
19	0	45	666	1675	167	935	--	32	41.5	108	6.3	6.9	71	4.1	180	8.06	0.203	--	31.1	556
	5			1650	198	960	1000	33	42.5	124	5.9	7.8	75	5.4	180	8.02	0.208	91	31.3	557
20	0	86	1244	1650	206	950	1250	34	37.0	116	6.1	7.4	71	4.6	180	8.02	0.209	--	30.9	554
	5			1650	198	945	1250	34	41.5	121	6.0	7.5	69	5.4	180	8.02	0.212	91	31.6	554
21	0	113	1605	1650	183	925	1025	34	40.5	79	6.2	--	70	5.3	180	8.08	0.210	--	31.1	550
	5			1650	192	935	1035	34	36.5	80	6.5	--	79	5.4	180	8.07	0.212	93	31.7	550

Table 7.--*Data for three Lagrangian experiments (con.)*

Station	Depth (m)	Time from release (min)	Dist. below dredge (m)	D[1] Fe (p/b)	T[2] Fe (p/b)	D Cu (p/b)	T Cu (p/b)	D Pb (p/b)	T Pb (p/b)	D Ni (p/b)	T Ni (p/b)	D Mn (p/b)	T Mn (p/b)	D Cr (p/b)	T Cr (p/b)
							River Background								
1	0	Samp. @ 9.7 h	--	1250	1900	5.0	6.4	1.1	3.6	9.4	13.0	44	110	4.0	9.9
	5		--	850	2100	13.0	13.0	3.7	5.0	10.0	12.0	53	100	3.5	11.0
8	0	Samp. @ 11.5 h	--	--	--	--	6.4	--	4.8	--	--	--	--	--	--
	5		--	--	--	--	8.4	--	4.8	--	--	--	--	--	--
							Drogue 1								
2	0	0	50	620	1500	3.3	8.3	1.7	4.0	8.4	12.0	52	93	6.3	11.0
	5			1500	2300	7.3	12.0	3.0	6.0	13.0	16.0	89	160	8.4	19.0
3	0	10	370	1500	1500	5.5	7.5	1.3	3.8	10.0	13.0	79	120	7.5	15.0
	5			2550	3300	9.8	22.0	2.7	6.4	19.0	20.0	110	210	12.0	35.0
4	0	20	690	940	1050	3.5	9.0	0.7	2.9	7.6	14.0	45	110	3.5	10.0
	5			1300	1700	7.1	13.0	2.1	4.2	10.0	19.0	72	150	6.4	19.0
5	0	30	965	525	1800	4.6	8.3	1.3	3.2	8.8	13.0	53	110	6.0	14.0
	5			1050	1700	4.0	6.5	1.6	3.2	8.0	12.0	53	100	8.4	12.0
6	0	60	1362	625	1250	3.7	7.0	1.6	3.8	9.4	12.0	66	120	7.0	11.0
	5			1200	1200	5.0	6.8	1.4	2.8	8.0	11.0	44	86	4.5	8.0
10	0	110	1637	500	2500	4.2	6.5	1.9	2.8	9.0	12.0	51	100	3.3	7.5
	5			900	1450	4.0	4.0	2.2	3.0	12.0	13.0	65	100	6.0	7.9
12	0	147	1850	--	1450	--	3.5	--	2.6	--	12.0	--	89	--	8.5
	5			--	2250	--	5.5	--	3.2	--	13.0	--	100	--	13.0
							Drogue 2								
7	0	0	50	--	--	--	14.0	--	10.0	--	--	--	--	--	--
9	0	27	440	--	--	--	10.0	--	7.2	--	--	--	--	--	--
	5			--	--	--	9.8	--	5.4	--	--	--	--	--	--
11	0	57	800	--	--	--	6.8	--	4.7	--	--	--	--	--	--
	5			--	--	--	8.8	--	5.6	--	--	--	--	--	--
13	0	90	1350	--	--	--	--	--	4.7	--	--	--	--	--	--

[1]Dissolved.

[2]Total.

Table 7.--*Data for three Lagrangian experiments (con.)*

Station	Depth (m)	Time from release (min)	Dist. below dredge (m)	D[1] Fe (p/b)	T[2] Pe (p/b)	D Cu (p/b)	T Cu (p/b)	D Pb (p/b)	T Pb (p/b)	D Ni (p/b)	T Ni (p/b)	D Mn (p/b)	T Mn (p/b)	D Cr (p/b)	T Cr (p/b)
							Drogue 3								
14	0	0	50	--	--	--	42.0	2.1	4.8	--	--	--	--	--	--
	5			--	--	--	21.0	1.5	10.0	--	--	--	--	--	--
15	0	10	218	--	--	--	17.0	2.1	5.4	--	--	--	--	--	--
	5			--	--	--	38.0	1.7	13.0	--	--	--	--	--	--
16	0	17	340	--	--	--	6.8	--	3.6	--	--	--	--	--	--
	5			--	--	--	6.8	--	3.6	--	--	--	--	--	--
17	0	23	375	--	--	--	7.2	--	4.1	--	--	--	--	--	--
	5			--	--	--	12.0	--	6.0	--	--	--	--	--	--
18	0	35	526	--	--	--	6.8	1.8	3.6	--	--	--	--	--	--
	5			--	--	--	8.4	2.6	8.4	--	--	--	--	--	--
19	0	45	666	--	--	--	--	1.5	4.8	--	--	--	--	--	--
	5			--	--	--	--	1.9	4.2	--	--	--	--	--	--
20	0	86	1244	--	--	--	--	2.8	4.8	--	--	--	--	--	--
	5			--	--	--	--	1.5	4.8	--	--	--	--	--	--
21	0	113	1605	--	--	--	--	2.1	4.8	--	--	--	--	--	--
	5			--	--	--	--	1.8	4.2	--	--	--	--	--	--

[1]Dissolved.
[2]Total.

Table 7.--*Data for three Lagrangian experiments (con.)*

Station	Depth (m)	Time from release (min)	Dist. below dredge (m)	Part.[3] C (p/m)	Part. P (p/b)	Part. N (p/b)	Part. Fe (p/b)	Part. Cu (p/b)	Part. Pb (p/b)	Part. Ni (p/b)	Part. Mn (p/b)	Part. Cr (p/b)	Surface area 2-4μ (cm^2/l)	4-8μ (cm^2/l)	8-16μ (cm^2/l)	16-32μ (cm^2/l)	32-63μ (cm^2/l)	TSM (mg/l)	Turb (NTU)
									River Background										
1	0	Samp. @ 9.7 h	--	0.2	101.5	378	650	1.4	2.5	3.6	66	5.9	3.0	12.5	21.9	87.9	42.3	31.5	16.5
	5		--	--	--	542	1250	0.0	1.3	2.0	47	7.5	2.9	12.4	22.2	92.0	49.9	28.0	19.0
8	0	Samp. @ 11.5 h	--	--	--	--	--	--	--	--	--	--	5.4	14.7	18.2	54.9	17.9	87.5	15.0
	5		--	--	--	--	--	--	--	--	--	--	5.1	16.9	25.1	93.9	40.9	--	18.0
									Drogue 1										
2	0	0	50	1.5	94.0	259	880	5.0	2.3	3.6	41	4.7	6.0	17.2	22.7	69.7	24.8	34.5	17.0
	5			2.0	160.0	573	800	4.7	3.0	3.0	71	10.6	4.7	21.3	37.3	144.5	71.2	47.0	21.0
3	0	10	370	3.5	108.0	505	0	2.0	2.5	3.0	41	7.5	5.4	21.0	33.7	115.4	40.4	47.5	26.0
	5			4.3	251.5	791	750	12.2	3.7	1.0	100	23.0	4.2	25.1	52.4	238.7	116.7	71.5	31.0
4	0	20	690	--	77.0	208	110	5.5	2.2	6.4	65	6.5	6.5	18.9	24.4	69.5	20.7	50.5	17.5
	5			--	96.0	340	400	5.9	2.1	9.0	78	12.6	5.0	22.2	39.1	145.9	61.7	59.0	24.0
5	0	30	965	0.6	102.5	285	1275	3.7	1.9	4.2	57	8.0	5.6	19.6	28.6	89.9	28.6	80.0	20.0
	5			0.9	92.0	200	650	2.5	1.6	4.0	47	3.6	5.6	18.3	25.3	83.1	29.5	41.0	20.0
6	0	60	1362	0.5	56.5	40	625	3.3	2.2	2.6	54	4.0	6.0	19.1	26.2	82.3	24.8	50.5	20.0
	5			1.6	53.0	50	0	1.8	1.4	3.0	42	3.5	6.1	18.1	23.0	66.9	19.3	49.5	17.5
10	0	110	1637	2.5	64.5	75	2000	2.3	0.9	3.0	49	4.2	6.1	20.1	25.7	72.6	17.9	81.0	18.5
	5			2.0	50.0	--	550	0.0	0.8	1.0	35	1.9	5.8	19.7	27.2	85.2	28.6	26.5	21.0
12	0	147	1850	--	--	--	--	--	--	--	--	--	6.5	20.1	23.9	60.3	14.7	--	18.5
	5			--	--	--	--	--	--	--	--	--	11.2	31.7	40.8	122.3	40.2	--	29.0
									Drogue 2										
7	0	0	50	--	--	--	--	--	--	--	--	--	20.7	95.9	167.7	571.4	185.9	--	46.0
9	0	27	440	--	--	--	--	--	--	--	--	--	5.6	20.6	30.4	98.9	35.1	--	23.0
	5			--	--	--	--	--	--	--	--	--	4.6	24.6	46.7	193.2	87.5	--	35.0
11	0	57	800	--	--	--	--	--	--	--	--	--	5.7	17.3	23.1	66.3	22.8	--	20.0
	5			--	--	--	--	--	--	--	--	--	5.3	23.5	38.9	130.7	44.5	--	29.0
13	0	90	1350										11.0	24.9	28.5	75.4	19.8		20.5

[3] All particulate fractions were calculated by subtracting the dissolved from the total concentration.

Table 7.--*Data for three Lagrangian experiments (con.)*

Station	Depth (m)	Time from release (min)	Dist. below dredge (m)	Part.[3] C (p/m)	Part. P (p/b)	Part. N (p/b)	Part. Fe (p/b)	Part. Cu (p/b)	Part. Pb (p/b)	Part. Ni (p/b)	Part. Mn (p/b)	Part. Cr (p/b)	Surface area 2-4μ (cm^2/l)	4-8μ (cm^2/l)	8-16μ (cm^2/l)	16-32μ (cm^2/l)	32-63μ (cm^2/l)	TSM (mg/l)	Turb (NTU)
									Drogue 3										
14	0	0		--	120.0	600	--	--	2.7	--	--	--	21.7	74.1	109.0	344.1	115.1	88.5	52.0
	5			--	167.0	400	--	--	8.5	--	--	--	21.3	73.2	108.6	338.3	104.7	154.0	51.5
15	0	10		0.8	159.5	568	--	--	3.3	--	--	--	11.7	42.4	62.7	184.5	56.9	86.5	39.5
	5			6.4	305.0	920	--	--	11.3	--	--	--	21.7	81.8	126.9	402.2	133.2	106.0	60.5
16	0	17		--	--	--	--	--	--	--	--	--	10.7	20.6	23.6	61.1	17.1	--	19.0
	5			--	--	--	--	--	--	--	--	--	17.0	23.2	25.1	64.3	16.6	--	18.5
17	0	23		--	--	--	--	--	--	--	--	--	10.7	21.9	27.3	75.8	21.2	--	21.0
	5			--	--	--	--	--	--	--	--	--	22.0	69.8	99.5	299.3	99.9	--	54.0
18	0	35		1.1	142.0	195	--	--	1.8	--	--	--	10.6	19.4	21.9	63.3	24.0	76.0	19.0
	5			3.8	88.0	245	--	--	5.8	--	--	--	20.4	39.6	47.5	141.7	39.5	64.5	34.0
19	0	45		0.6	66.5	--	--	--	3.3	--	--	--	11.4	24.1	28.4	79.4	27.7	30.0	20.0
	5			1.9	81.5	40	--	--	0.3	--	--	--	11.2	29.5	39.0	116.5	35.1	44.5	28.0
20	0	86		1.3	79.0	300	--	--	2.0	--	--	--	13.3	28.7	31.5	77.7	18.0	63.5	25.0
	5			1.5	79.5	305	--	--	3.3	--	--	--	22.2	30.6	30.0	73.3	19.4	44.0	21.5
21	0	113		--	38.5	100	--	--	2.7	--	--	--	12.0	21.5	23.0	59.3	13.9	38.5	21.5
	5			--	43.5	100	--	--	2.4	--	--	--	11.1	20.1	22.1	63.1	18.0	34.5	21.0

[3] All particulate fractions were calculated by subtracting the dissolved from the total concentration.

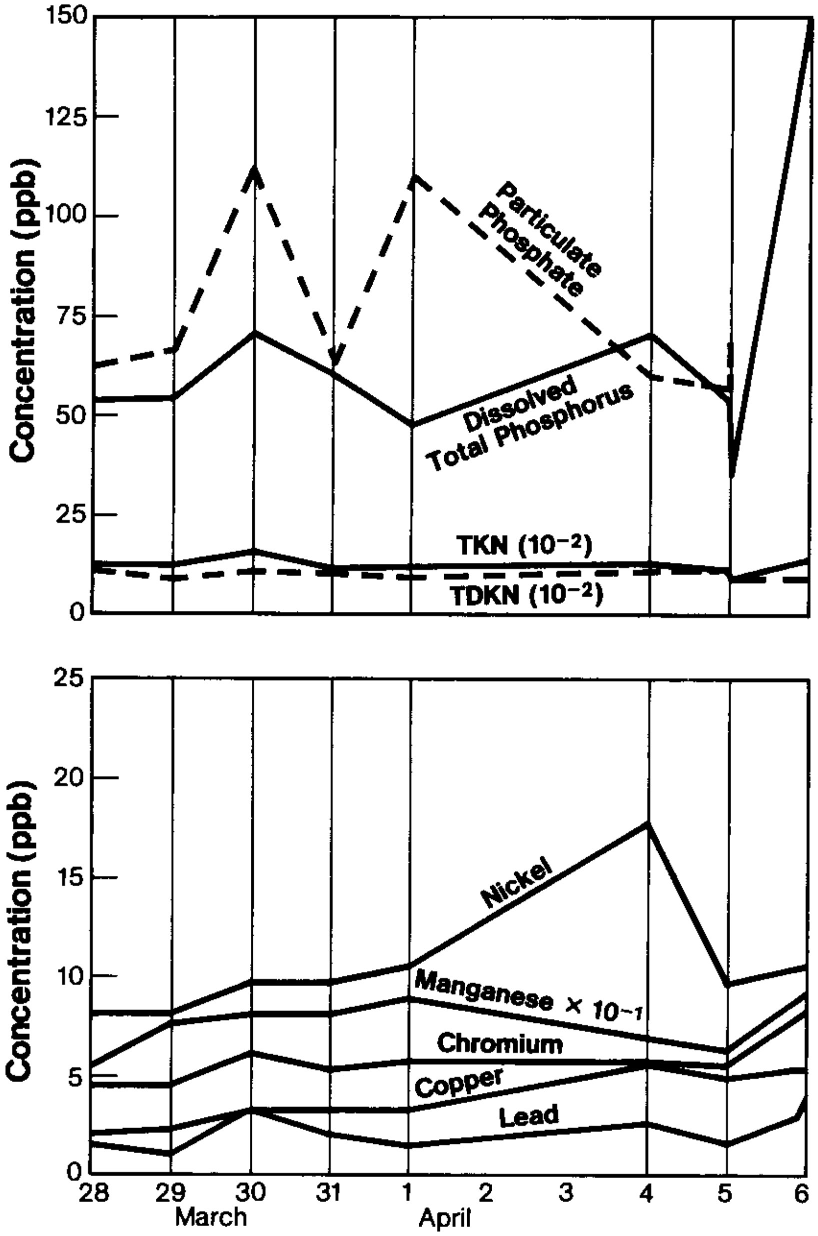

Figure 4.--*River water concentrations of total metals and nutrients in the week prior to the experiment.*

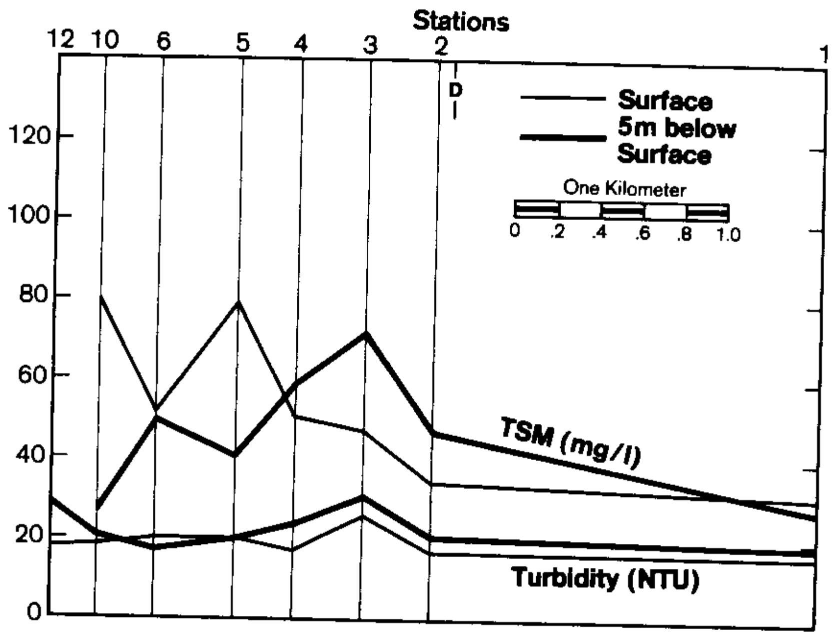

Figure 5.--*Total suspended matter and turbidity along the first drogue track.*

There are two explanations for concentration decrease of the particulate matter (or surface area) below the dredge: the first is loss through resettling and the second is dilution through lateral dispersion. Under these flow conditions (20 cm/s) the 2-4-micron fraction can be assumed to behave conservatively. Variables linearly correlated with a conservative substance are also behaving conservatively and this is the case for the less than 60-micron sized particles at the 5-m level, but the surface samples showed a concave (*in situ* loss) relationship. Based on these results, our conclusion is that the smaller amount of material driven to the surface during the dredging partially resettles and undergoes aggregation or in some other manner behaves nonconservatively, while the deeper material behaves conservatively, is diluted through lateral dispersion, but flows virtually intact into the lake. Because of the concentration differences, the material removed from the surface could be incorporated into the deeper layers with a marginal effect on that layer's conservative appearance.

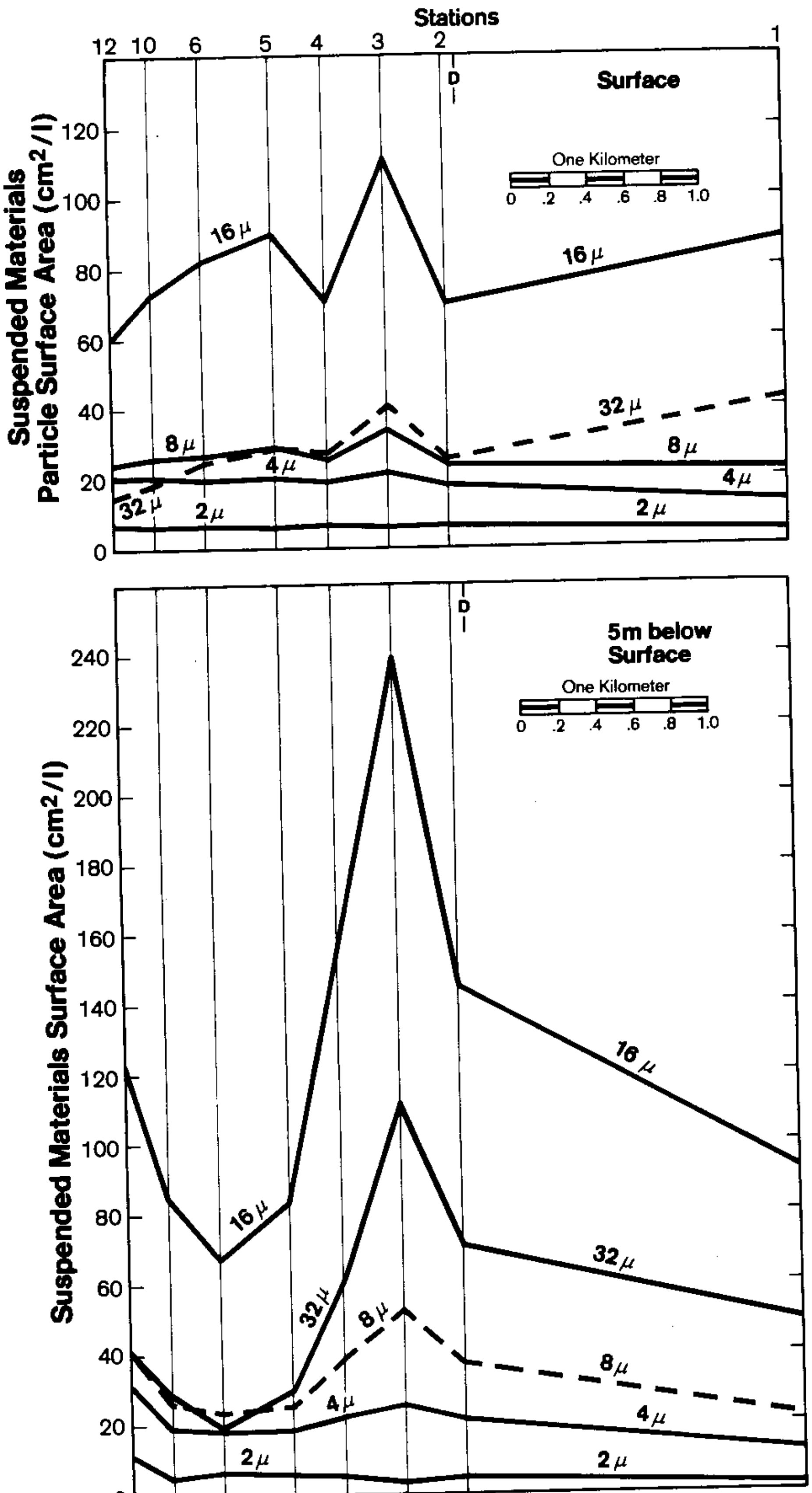

Figure 6.--*The particulate surface of five size categories (2-4, 4-8, 8-16, 16-32 and 32-60 microns) along the first drogue track (surface and 5 m).*

From the data we collected, we can only estimate the increased loading to the lake due to the portion of the dredging operation unassociated with disposal. Examining the TSM data at the stations 50 m astern of the dredge, it appears that the concentration of particulate material in the samples is approximately two to three times that above the dredge. We observed that at this point the visible plume is less than twice the dredge width (approximately 25-30 m). Then the range of the mass of particulate matter in a plane across the river (∿90 m width) is increased by 25/90 (28 percent) to 60/90 (67 percent). During an average annual dredging period of from 1 to 2 weeks, assuming the same flow conditions as during our experiment, the approximate range of loading increase of particulate material is calculated to be from 0.5 percent to 2.5 percent on an annual basis. Measurements near the river mouth indicate the number is near the low estimate. If the dredging were conducted under low flow conditions, even this small increase could be reduced.

3.2 Increased Chemical Loading

Nutrient content of the sediments in the region of dredging (table 6) are 1,600 to 3,000 p/m total phosphorus (TP) and 2,500 to 4,800 p/m total Kjeldahl nitrogen (TKN) and the concentrations in the suspended material at stations 1 and 8 (river background) averaged 3,200 p/m TP and 15,000 p/m TKN. There was a small apparent increase in dissolved TKN and TP (∿10 percent) below the dredge. It appears that an increased loading of 1 percent in the particulates (annual basis) would lead to a less than 1 percent increase in the loading of TP and TKN.

Figure 7 is a plot of the nitrogen and phosphorus data for one of the Lagrangian experiments. The major increase was in the particulate P and KN some 300 m below the dredge. There was a small (∿50 percent) increase in ammonia observed in the near bottom samples from bacterial decomposition of sedimentary organic material.

The region near the dredge showed a significant oxygen reduction of about 5 percent, but remained well above 80 percent saturated for all samples (fig. 8). Redox potential near the freshly released sedimentary material was also measurably lower. This was accompanied by a large injection of dissolved iron (fig. 9) as expected from the work of Lee *et al.* (1975). Manganese, nickel, copper, and chromium correlated significantly (α = .01) with iron in the bottom 5-m samples. Chromium concentrations are illustrated in figure 10. Although lead was not correlated with other metals, it was with nutrients and organic carbon.

None of the trace metals changed concentration at a higher ratio than the surface area of the particulates; therefore, the excess loading due to the dredging does not exceed the 1 percent estimate.

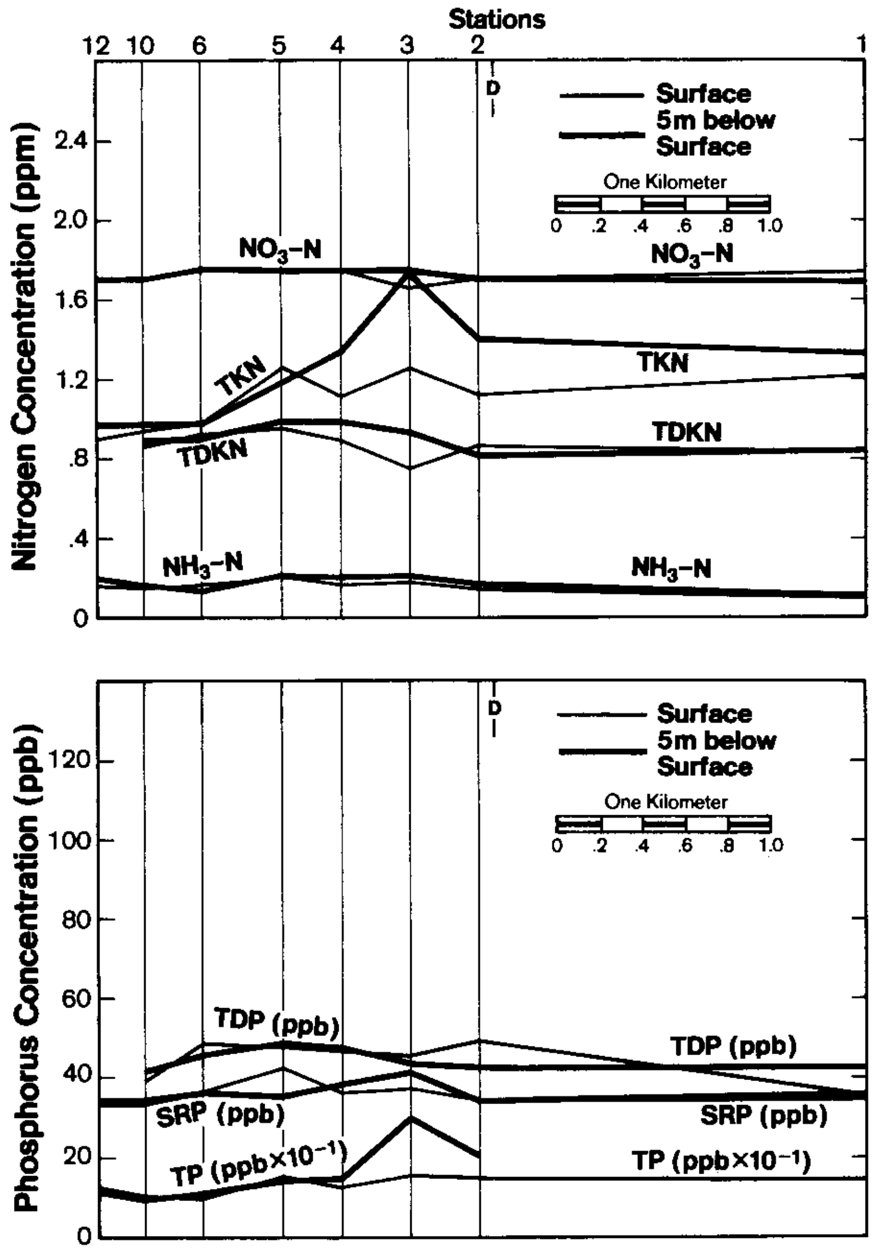

Figure 7.--*Nitrogen and phosphorus component concentrations along the first drogue track.*

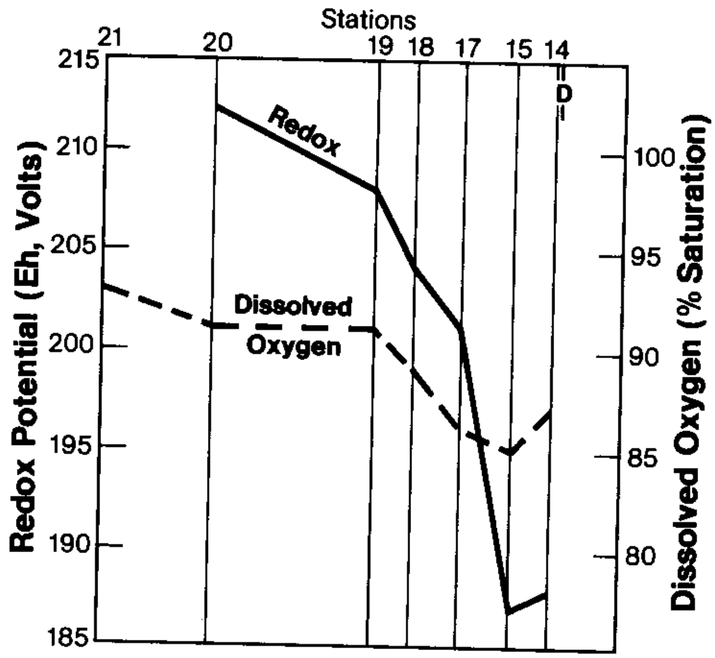

Figure 8.--*Oxygen concentrations and redox potential along the third drogue track (5-m depth).*

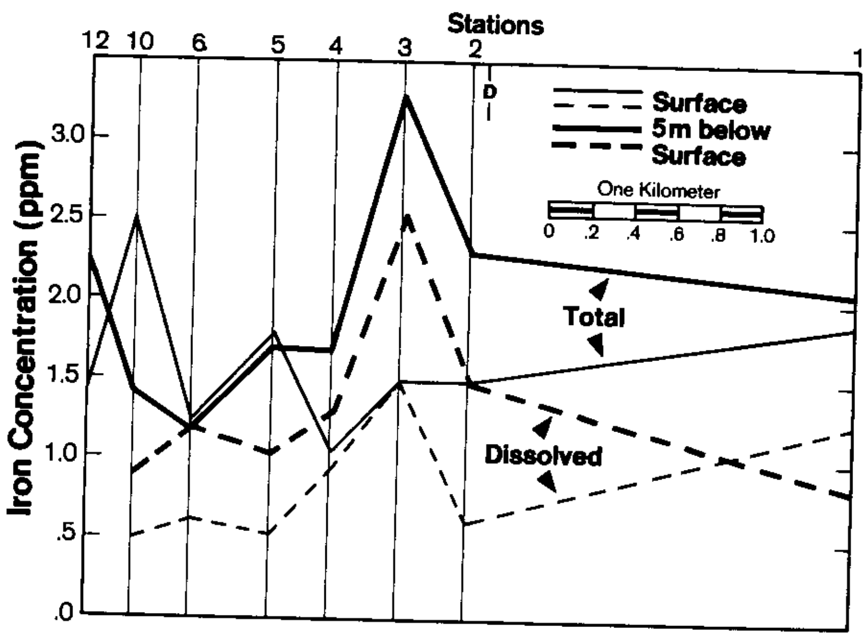

Figure 9.--*Total and dissolved iron concentrations along the first drogue track.*

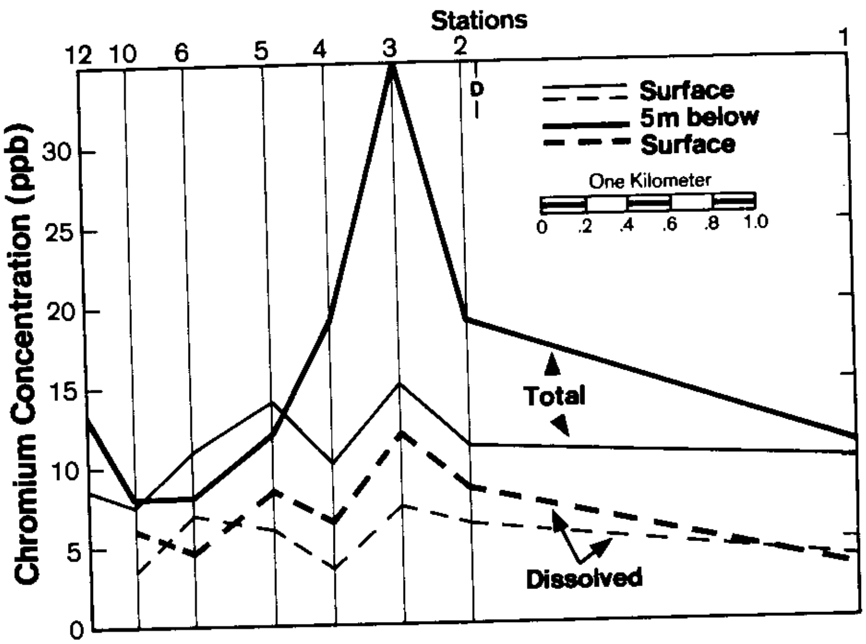

Figure 10.--*Total and dissolved chromium along the first drogue track.*

4. SUMMARY AND CONCLUSION

In the process of dredging the channel of the Grand River (or any channel), bottom material not collected by the dredge is disturbed, suspended, and possibly transported for long distances. In this manner, polluting and enriching substances "trapped" in the sediments are reintroduced into the water column and relocated.

In this study it is estimated that this dredging "leakage" contributes approximately an increased 1 percent of the annual load of total particulates to Lake Michigan and not more than that amount of nutrients and trace metals. This small amount is insignificant when compared to the year-to-year variability in river flow and consequent load.

Although small on an annual basis, the increase can represent approximately a 30-percent increase in load during the period of dredging. These short-term loading events, similar to the spring pulse in river flow, contribute to the variability and relative instability of the nearshore region. The effects of these events on the biological community are not known at present.

5. ACKNOWLEDGEMENTS

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