NOAA Technical Memorandum ERL GLERL-22

CHARACTERISTICS OF THE OSWEGO RIVER PLUME AND ITS INFLUENCE ON THE NEARSHORE ENVIRONMENT

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Ann Arbor, Michigan
October 1978

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CHARACTERISTICS OF THE OSWEGO RIVER PLUME AND ITS INFLUENCE ON THE NEARSHORE ENVIRONMENT*

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Ion and suspended material concentrations were relatively high in the Oswego River as compared to Lake Ontario background levels and generally decreased rapidly through Oswego Harbor. Most of the variables mix conservatively, with gradients similar to those of specific conductance. There were indications of loading of nutrients, chloride, chemical oxygen demand, and volatiles other than from the river. However, oxygen depletion was not a problem in any area.

Specific conductance shows that 90 percent of the dilution occurs within 3 km to the northeast and 2 km to the west of the harbor entrance. Transmissometer profiles were used to supplement the chemical and temperature data. They conveniently detail the plume structure. The prevailing nearshore current direction is northeastward; however, periods of northward and westward flows were observed. Plume configurations varied in response to stream flow, prevailing longshore currents, and current variations related to changes in wind direction and velocity. During late spring and summer the relatively warmer plume tends to spread over the cooler lake water with accompanying lake water intrusion over the harbor bottom, which complicates sedimentation patterns. In late summer and fall the relatively cooler river water tends to plunge beneath the lake surface at or near the harbor entrance.

Suspended materials varied with the river flow. During low flow periods these materials are deposited in the harbor on either side of the channel and in the plume area adjacent to the harbor. Materials with high concentrations of oil and grease and other organics exert a deleterious effect on the local environment, primarily through oxidation. Dredging operations resuspend some materials, which are then redistributed. Dredged spoil deposited offshore produces an additional impact on the deeper portion of the lake.

Sediments overlying bedrock outside the harbor were often less than 2.5 cm in thickness. The combined effects of longshore and wave generated currents tend to keep the materials moving. Particulate deposited below the wave base prior to stratification are essentially separated from the epilimnion by the development of a thermocline. Movement of fine particulates over a thermocline surface provides a mechanism by which these materials are kept in suspension and widely distributed.

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*GLERL Contribution No. 163.

1. INTRODUCTION

The Oswego River is one of four major tributaries discharging into Lake Ontario. As part of the IFYGL Program an extensive investigation of the chemical and physical characteristics of the lower river, harbor, and plume area was conducted in 1972. The objective of this study was to establish the spatial and temporal extent of the effects of the river's outflow on the harbor and nearshore zone of the lake and to relate these effects to causative forces.

A companion study of harbor and lake currents was conducted by Miller (1976) during three periods: 14-22 June, 15-24 August, and 17-25 October 1972. All references to current velocities are based on this study.

Likewise, references to the municipal and industrial effluent flow and treatment relate to conditions during 1972 and do not reflect changes in the system since that time.

The data on which this report is based are being published as a separate NOAA Technical Memorandum. Selected aspects of the study were presented at the 17th International Association for Great Lakes Research (IAGLR) Conference (Bell, 1974).

2. METHODS

2.1 Sampling Program

The program was designed to systematically sample in the river, harbor, and area of mixing in the adjacent portion of the lake. Water characteristics, bottom sediment, wave, and meteorological data were collected aboard the R/V *Shenehon* at 46 established stations (Fig. 1, Table 1) during 33 one-day cruises in five periods (Table 2) between 1 May and 10 November 1972.

Stations in the lake were spaced 0.8 km apart in a 2.4 by 5.6 km grid approximately parallel to the shore. Stations around the harbor entrance were spaced on a 0.4 and 0.8 km radius from Station 7 at the entrance, except where additional stations were required to monitor the shifting plume. The sampling pattern and analysis were varied on a daily basis in order to best define the plume. Owing to time limitations, the number of stations sampled during a cruise averaged between 20 and 25. Sampling during storm periods was restricted to the harbor and river area.

Water samples were collected in Fjarlie bottles with attached, protected reversing thermometers; samples were taken at the surface, mid-depth, and near bottom. Water samples were taken from the ship's intake at a depth of 1.5 m during bottom sediment sampling cruises. water samples to be analyzed in the Detroit laboratory were preserved with

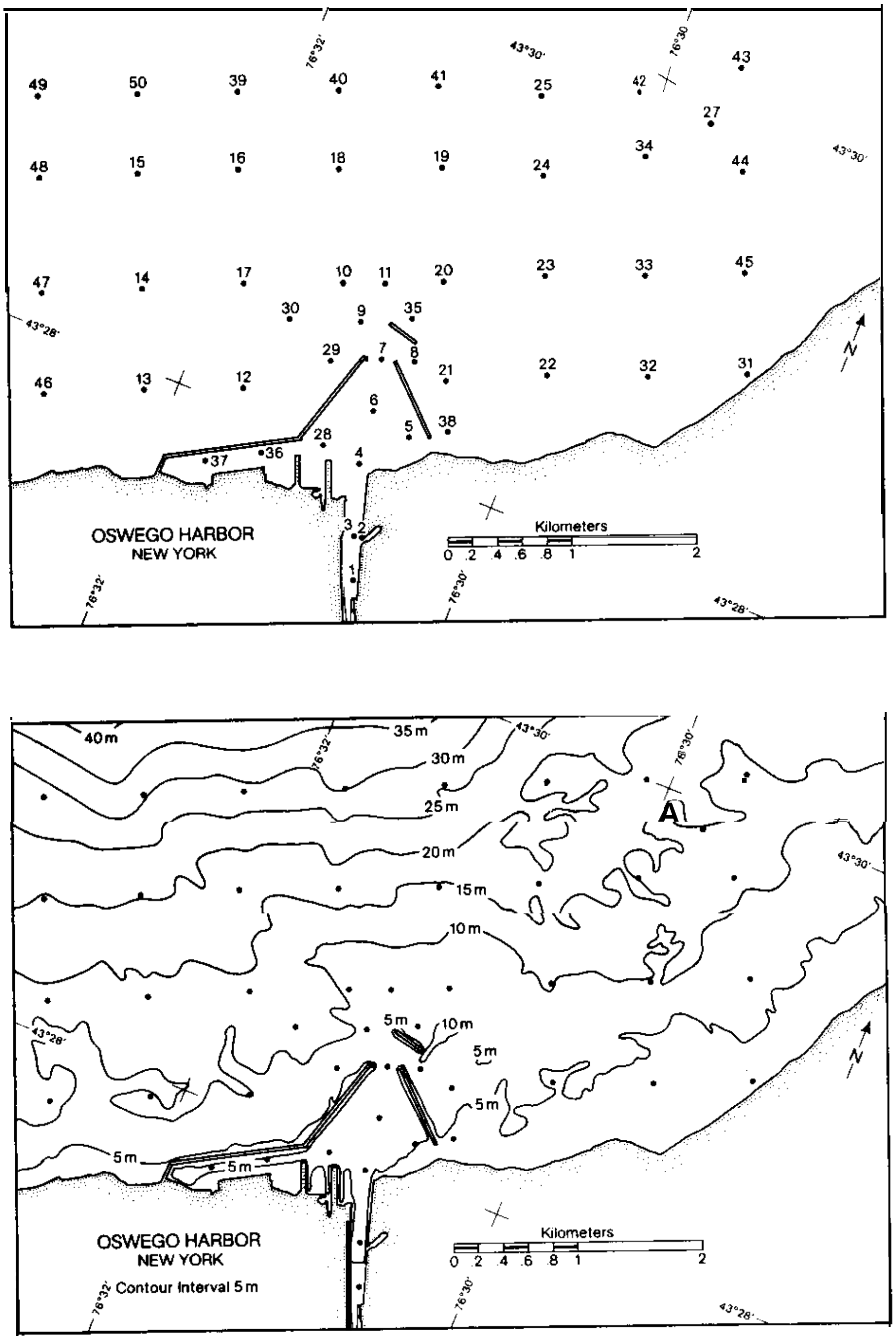

Figure 1. Station locations and bottom topography.

Table 1. Station Locations

Station	Latitude	Longitude	Station	Latitude	Longitude
1	43.458"	76.510"	26	43.508°	76.474"
2	43.461"	76.511'	27	43.498°	76.494"
3	43.461"	76.512"	28	43.466'	76.518"
4	43.466"	76.5140	29	43.472"	76.520"
5	43.469"	76.510"	30	43.474"	76.526"
6	43.470"	76.514"	31	43.482°	76.481"
7	43.474°	76.516"	32	43.480°	76.491"
8	43.4740	76.512"	33	43.486"	76.494"
9	43.476'	76.519°	34	43.493"	76.498"
10	43.478°	76.522"	35	43.477"	76.514"
11	43.4790	76.518"	36	43.464'	76.523"
12	43.468"	76.527"	37	43.462"	76.528"
13	43.4650	76.536'	38	43.471"	76.507"
14	43.472"	76.540'	39	43.4880	76.539'
15	43.479°	76.544"	40	43.491"	76.530"
16	43.482°	76.535'	41	43.4940	76.521"
17	43.475"	76.531"	42	43.5000	76.502"
18	43.4840	76.526'	43	43.503"	76.493°
19	43.487°	76.517'	44	43.496'	76.4890
20	43.481°	76.513"	45	43.489°	76.485°
21	43.4740	76.509'	46	43.462'	76.545'
22	43.477"	76.500"	47	43.469"	76.549"
23	43.4840	76.504'	48	43.476'	76.553"
24	43.490"	76.508"	49	43.4830	76.557'
25	43.497"	76.511'	50	43.4850	76.548"

Table 2. Cruise Schedule for 1972

Cruise NO.	Date	Cruise NO.	Date	Cruise NO.	Date
1	1 May	12	20 June	23	19 October
2	2 May	13	21 June	24	20 October
3	3 May	14	22 June	25	21 October
4	4 May	15	23 June	26	24 October
5	5 May	16	19 August	27	25 October
6	13 June	17	21 August	28	26 October
7	14 June	18	22 August	29	27 October
a	15 June	19	23 August	30	7 November
9	16 June	20	24 August	31	8 November
10	17 June	21	25 August	32	9 November
11	19 June	22	17 October	33	10 November

chloroform and stored in a dark area below deck. Bottom sediment samples were collected during four periods with a Shipek Sampler. Transparency of the water was measured using a Secchi disc and a G.M. Mfg. Deep Water Turbidity Meter, Model 17-M-11. Transparency as determined by the turbidity meter relates light transmission along a l-m water path to transmission along the same length path through air, and the results are expressed in percent. Temperature profiles were determined using Guideline, Marine Advisors, and Yellow Springs Electronic Bathythermographs. Sonic water depths were determined with a Raytheon Fathometer. Water sample depths were determined by meter wheel. Navigation and establishment of stations were accomplished by using Decca, radar, gyro compass, and visual fixes. Meteorological observations were recorded automatically at 0.1-h intervals at 3- and 10-m levels by a digital system employing solid-state gathering modules. Wave period was based on a timed average of 10 successive waves, and the height was estimated.

Specific conductance of the water was used for rapidly defining plume boundaries and was measured with an Industrial Instruments Conductivity Bridge, Model RC-16B2J.

2.2 Chemical Analyses

The methods used in the water analysis are those described in *Standard Methods* (American Public Health Association, 1965), Rainwater and Thatcher (1960), Fishman and Skougstad (1965), and the Pa-kin-Elmer Corporation (1971).

Water samples were analyzed immediately in the R/V *Shenehon* laboratory for dissolved oxygen, specific conductance, phenolphthalein, and total alkalinity, pH, Eh (oxidation-reduction potential), and total coliforms. Bottom sediment samples were described and the interstitial water analyzed for pH and Eh, then treated with concentrated sulfuric acid, and stored in sealed containers for later analyses of percent solid and volatile material, oil and grease, and chemical oxygen demand (COD).

Dissolved oxygen determinations were made with a Beckman Model 777 Dissolved Oxygen Analyzer that was calibrated daily in air. Two separate tests were made on each sample. The highest partial pressure and the lowest sample temperature readings were used for calculating the dissolved oxygen. The in *situ* temperature was that recorded by the reversing thermometer at the sampling depth. Two separate tests for specific conductance were made on each sample and the average expressed in micromhos at 25°C. Phenolphthalein and total alkalinity determinations were made by titrating 100-ml water samples with standard acid (H_2SO_4) to the end-points of pH 8.2 and 4.5, respectively. The end points were determined with the pH meter and the results expressed in mg/l of calcium carbonate. Measurements of pH and Eh were made using a Beckman Zeromatic pH meter, a glass pH electrode, a calomel fiber junction reference electrode, and a platinum Eh electrode. The pH meter was standardized daily using pH 7.0 and 4.0 buffers. The membrane filter process was used for total coliforms.

Water samples preserved in 500 ml plastic bottles were transferred at the end of each cruise or survey period to the Great Lakes Research Center laboratory in Detroit, where they were analyzed for phosphate, nitrate, sulfate, silica, calcium, sodium, magnesium, potassium, and chloride.

Chloride concentrations were determined by the argentometric method and by titrating a 50-ml sample of lake water. The silver nitrate was standardized and the reagent blank value determined at the beginning of each day. A Beckman DU-2 Spectrophotometer with flame attachment was used for analysis of nitrate, phosphate, sulfate, and silica and a Perkin-Elmer Atomic Absorption Spectrophotometer was used for calcium, magnesium, sodium, and potassium. Standard curves were constructed for each test and cruise. Tests for nitrate and phosphate were made on unfiltered samples upon arrival at the laboratory. Anion concentrations were determined by computer application of the absorbancy values to a standard curve, which was adjusted by paired test standards run after each set of 10 to 20 samples. These adjustments were made to compensate for any change or drift in the spectrophotometer response. Cation concentrations were read directly from a recorder strip chart.

The bottom sediment was dried overnight at 100 to 105°C and the weight expressed as a percentage of the wet weight. Volatiles were determined by burning at 600°C for 1 hr and reported as a percentage of the dry solids. The concentration of hexane extractable hydrocarbons was determined by distillation and the weight reported as a percentage of the dry solids. The COD was determined by refluxing samples of the bottom material.

The chemical data were processed by computer to obtain a mean value weighted for depth at each station, and a grand mean, standard deviation, and coefficient of variation for all cruises at a given station.

3. PRECISION LIMITS

The precision shown in Table 3 was determined for nitrate, phosphate, sulfate, and silica by a computer comparison of pairs of test standards to the standard curve that was used to reduce the samples. A pair of test standards was run after each set of 10 samples for nitrate and after each set of 20 samples for phosphate, sulfate, and silica. Tests for nitrate and phosphate were made on unfiltered samples preserved to fix the phosphorus and nitrogen, but not refrigerated.

Calcium, magnesium, sodium, and potassium analyses were run in sets of 10 samples followed by one standard and at least one standard bracketing the concentration range after each 20 samples. For both chloride and alkalinity, the estimated precision is based on the change in concentration produced by one drop (0.05 ml) of titrant and the fact that the end point was within ±1 drop. Two readings were made on each sample for specific conductance and deviations from the mean of each pair were used to compute the average deviation. Of the 117 sample pairs randomly selected, 74 percent were within 1 micromho of the mean. Two separate tests were made on each sample for dissolved oxygen and the calculations based on the highest partial pressure and the lowest sample temperature. The probe was calibrated daily in air prior to sampling. The temperature at the sampling depth was used in calculating the in *situ* percent saturation.

Table 3. Precision Achieved in Measuring Selected Variables

Variable	Unit	Estimated Precision	Average Deviation[1]
Nitrate	mg/l		±0.02
Phosphate	mg/l		±0.001
Sulfate	mg/l		±0.15
Silica	mg/l		±0.03
Calcium	mg/l	±0.5	
Magnesium	mg/l	±0.1	
Sodium	mg/l	±0.5	
Potassium	mg/l	±0.1	
Chloride	mg/l	±0.5	
Specific conductance	Micromhos at 25°C		±1.6
Total alkalinity	mg/l $CaCO_3$	±0.5	
Dissolved oxygen	mg/l	±0.1	
Dissolved oxygen	Percent sat.	±1.0	

[1] Average of the deviations of the test standards about the standard curve.

4. CHARACTERISTICS OF BASIN, RIVER, AND HARBOR

4.1 Geology and Groundwater

The Oswego drains a" area of 13,276 km^2 (U.S. Geological Survey, 1972, p. 236). Flow variations are produced by precipitation, natural storage, diversions, and diurnal fluctuations at power plants. Kantrowitz (1970) discussed aspects of the Eastern Oswego River Basin geology and chemical components of the groundwater. The area discussed covers approximately half of the total drainage basin. The bedrock is early Ordovician to late Devonian in age (Shampine, 1973) and is composed of units of sandstone, shale, limestone, and dolomite. The bedrock is overlain by glacial deposits of till, sand, and gravel. The limestone and middle shale units crop out in a broad belt across the eastern basin and are capable of producing Large quantities of water (op. cit., p. 1). Salt water production is in part from solution of rock salt within the middle shale and from deeper parts of the bedrock (op. cit., p. 91). Commercial salt production commenced in 1788-89 from springs around Lake Onondaga "ear Syracuse, N.Y., and by 1862 exceeded 9 million bushels per year (op. cit., p. 89). Salt is still produced by solution mining near Tully, N.Y. (op. cit., p. 80). Additional sources of salt are from pollution, such as water softening processes and septic tanks. Chloride content of the groundwater in the Eastern Oswego River Basin ranges from less than 1 to over 61,000 ppm, although most of the wells tested contained less than 250 ppm (op. cit., p. 90).

Major sources of sulfate are from highly soluble beds of gypsum ($CaSo_4 \cdot 2H_2O$) within the middle shale and minor sources from the dolomite and lower part of the limestone units (op. cit., p. 87). Sulfate concentrations range from 439 to 1790 ppm in the groundwater overlying the middle shale (op. cit., p. 81).

The dolomite [$CaMg(CO_3)_2$] and limestone ($CaCO_3$) units and sediments derived from these units are sources of magnesium, calcium, and carbonate hardness. Kantrowitz (op. cit., p. 81) points out that the hardness of some samples "is so great that $CaCO_3$ may precipitate out in a glass left standing overnight."

Nitrate in the groundwater ranged from 0 to 44 ppm, with the highest concentrations found in the shallow wells (op. cit., p. 90). Specific conductance of 48 water samples from wells and springs ranged from 134 to 189,000 micromhos (op. cit., pp. 72-75).

4.2 Surface Water

Sweers (1969) reported that the Oswego River contributed large loads of dissolved solids to Lake Ontario. Shampine (1973) described the characteristics of the surface water in the three regions drained by the Seneca and Oneida Rivers, which in turn flow into the Oswego River. The report, based on data from the 1958 water year and from July 1964 to

September 1966, shows that at low to moderate discharges the Oswego River is greatly influenced by the flow of highly mineralized water from Lake Onondaga. In 1958 the specific conductance ranged from 525 to 1890 and averaged 967 micromhos at Minetto, N.Y., approximately 8 km from Lake Ontario. Specific conductance varied inversely with the discharge. Sampine found that magnesium and bicarbonate concentrations remained nearly constant and sulfate fluctuated slightly with flow fluctuations. There were marked decreases in calcium, sodium, and chloride as the flow increased from 1500 to 4000 cfs and bicarbonate became the dominant ion. Concentrations at Minetto under high and low flow conditions were summarized from Figures 7A–7L (Table 4).

Table 4. Variable Concentrations at Minetto, N.Y.

Variable		Base flow	High flow
Dissolved solids	mg/l	501-1000	501-1000
Calcium	mg/l	101-250	51-100
Sodium	mg/l	>100	26-100
Bicarbonate	mg/l	126-200	51-125
Sulfate	mg/l	50-100	50-100
Chloride	mg/l	>250	26-250
Magnesium	mg/l	14 ±3	14 ±3

Flow data from the U.S. Geological Survey Station at Lock 7, 1.3 km upstream from the mouth, show an average yearly discharge over a 39-year period of 180.5 m^3/s and a maximum of 1061.9 m^3/s occurring in 1936 (U.S. Geological Survey, 1972, 1973). Flows during the 1972 calendar year ranged from a high of 914.6 m^3/s to a low of 55.8 m^3/s (Fig. 2). The five sampling periods in 1972 were during a wide range of flow conditions and included the initial runoff from Hurricane Agnes.

4.3 Harbor

Oswego Harbor, approximately 92 km east-northeast of Rochester, N.Y., is the terminus of the Oswego Canal of the New York State Barge Canal System. The breakwaters are of rubble-mound construction with a concrete superstructure (Great Lakes Pilot, 1972). The west breakwater is connected to the shore just north of the Niagara Mohawk Steam Station and extends northeasterly to the harbor entrance approximately 914 m from the mouth of the river. The east breakwater extends to within 122 m of the shore. The entrance channel, 168 m in width, is protected by a small detached breakwater 229 m east-northeast from the east breakwater.

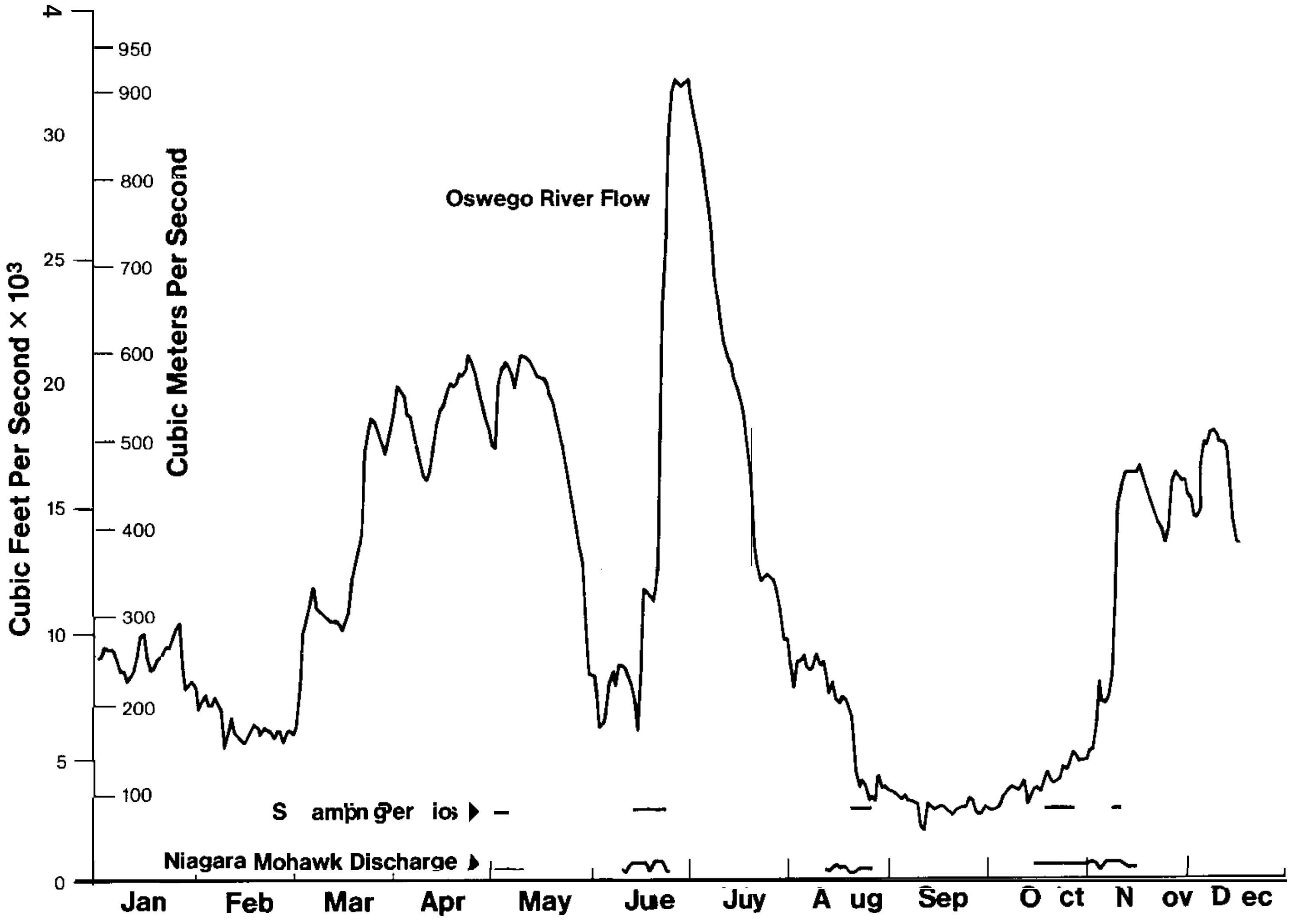

Figure 2. Oswego River and Niagara-Mohawk Steam Station flow and sampling periods during 1972

The dredged depth (below low water datum) in the outer harbor is 7.6 m in the main channel and ranges from 6.4 m along the west breakwater to 5.2 m northeast of the river mouth. A channel 6.4 m deep extends parallel to the west breakwater and terminates in a turning basin north of the Niagara Mohawk Steam Plant. The inner harbor comprises 762 m of the Oswego River from Seneca Street to the mouth and is dredged to a 7.3 m depth in the downstream 488 m portion, and to 6.4 m in the upstream portion. The State of New York maintains a channel depth of 4.3 m from Seneca Street to the Barge Canal Lock.

4.4 Municipal and Industrial Effluent

According to data provided by the City Engineer's office, there was no treatment of city sewage on either side of the river prior to 1972. A primary filtering plant was installed in January 1972 and a secondary treatment added in August to service the area east of the Oswego River. The discharge from this plant is through a pipeline commencing in the vicinity of and parallel to East Eleventh Street and extends 364 m into the lake. The unmarked outfall diffuser is at a depth of 4.9 m (Great Lakes Pilot). The flow during dry periods is approximately 0.15 m^3/s and ranges from 0.15 to 0.30 m^3/s during wet periods. Sewage from the area west of the river is untreated and discharged through 18 lines. Twelve of these lines empty along the west side of the river north of Bridge Street. Oswego College is connected into the system and discharges into the harbor just east of the Niagara Mohawk Steam Station. Six lines discharge directly to the lake. One of these, the Oswego outfall pipeline of Onondaga County (Great Lakes Pilot, 1972), discharges at a point 351 m from the shore and 2965 m from the West Pierhead light. This is within 500 m of station 46. The combined sewage flow from the west side of the city has been estimated by the City Engineer's office as 0.18 m^3/s during dry periods. Based on the percentage increase in sewage flow east of the river during wet periods, a flow of up to 0.35 m^3/s might be expected during wet periods. Since 12 of the 18 lines discharge into the river and harbor, it has been estimated that 0.67 percent, or 0.12 m^3/s, of the dry period flow is into this area.

The Niagara-Mohawk Steam Station takes cooling water from the lake and discharges it into the western turning basin. At maximum current output the total effluent volume is about 21.6 m^3/s. During the five periods of study, the flow averaged as indicated in Table 5.

Table 5. Flow through the Niagara-Mohawk Steam Station in 1972

Period	m^3/s	Period	m^3/s
1 to 5 May	12.97	17 to 27 October	15.60
13 to 23 June	16.03	7 to 10 November	18.23
19 to 25 August	8.63		

During the same periods the daily averages ranged from 5.4 to 20.9 m^3/s. To the east of the harbor, the Hammer Mill Paper Company discharges 0.03 m^3/s per day into the lake.

5. RESULTS

5.1 General Plume Characteristics

The five sampling periods are discussed separately owing to the wide variety of conditions encountered. These conditions ranged from low stream and wind velocities and calm seas, during which the plume was carried to the northeast by prevailing longshore currents, to periods of extremely high stream flow, high variable winds, waves to 3.0 m, during which the currents and plume shifted from northeast to westward. The plumes were monitored when the plume was buoyant and responded rapidly to changing wind directions and also when the plume plunged and spread over the thermocline or along the bottom. The nearshore current carried the plume eastward during 79 percent of the cruises. Landsberg *et al.* (1970) and Csanady and Scott (1974) also reported the predominant easterly flow.

Water transparency in the river and harbor was low owing to the influx of turbid river water, and Secchi disc readings were commonly less than 1 m. Throughout most of the harbor, light transmission over a l-m path was usually not detectable with the turbidity meter.

5.1.1 Period 1: 1 to 5 May

During this period the stream flow (Fig. 2) increased from 495.5 to 589 m^3/s. The winds were light northeasterly to southerly during the first 3 days (Table 6), shifting to westerly during cruises on 4 and 5 May. Seas were generally calm, with small waves developing on 4 and 5 May. The main plume was deflected around the northern end of the detached breakwater, then curved northeastward under the influence of the predominant longshore current. As the stream flow increased, the

Table 6. Summary of Wind, Wave, Current, and River Flow During Periods Studied in 1972

Date	Wind Dir.	Wave Max. Height, m	River Flow, m^3/s	Currents			
				Harbor		Lake	
				Depth, m	Vel., cm/s	Depth, m	Vel., cm/s
Period 1							
1 May	NE	calm	495.5				
2 May	NE	calm	492.7				
3 May	NE to S	calm	563.5				
4 May	W	0.2	580.5				
5 May	W	0.3	589.0				
Period 2							
13 June	NE	calm	222.3				
14 June	S	0.2	203.9				
15 June	W	calm	171.9	1.5-5	8-16	1.5-10	22-57
16 June	W	0.3	245.8				
17 June	N	0.3	331.3	1.5-5	4-16	1.5-5	8-11
19 June	S	calm	322.8				
20 June	S	0.4	320.0	1.5-5	5-27	1.5-5	20-30
21 June	SE	calm	354.0				
22 June	NE	0.8	509.7	1.5-5	24-32		
23 June	E to SE	0.3	654.1				
Period 3							
19 August	SE	0.2	198.5				
21 August	SW	calm	121.8				
22 August	S	0.2	103.9	1.5-5	7-10	1.5-5	12-23
23 August	NE	calm	112.7	1.5-5	10-14	1.5-5	13-14
24 August	NE	calm	105.1	1.5-5	2-10		
25 August	W	0.3	90.3				
Period 4							
17 October	W	0.3	97.7	1.5-5	8-16		
19 October	N to NE	1.5	119.5	1.5-5	2-7	1.5-5	8-9
20 October	W	calm	111.3	1.5-5	3-9	2.5-6.5	12-15
21 October	S	0.3	107.6	1.5-5	4-12		
24 October	NE	0.8	122.6	1.5-5	8-14	1.5-7	6-14
25 October	NW	0.6	123.5	1.5-5	11-20		
26 October	SW	0.4	130.5				
27 October	S	0.3	142.4				
Period 5							
7 November	SE	0.2	208.7				
8 November	SE	0.3	231.9				
9 November	N	1.5	320.0				
10 November	E	0.3	421.9				

plume extended farther northward (Fig. 3). The wind shifted to the west (265”) on 5 May (Fig. 4) and increased in velocity to an average of 8.0 m/s, deflecting the plume eastward even though the stream flow was increasing. A portion of the harbor effluent passed between the east and detached breakwaters during all cruises and the flow through this area increased as the wind shifted westward and increased in velocity. Chermack (1970) observed similar surface circulation patterns. Turbid water produced by wave action alongshore merged with the harbor plume near the north end of the west breakwater. The plume was sinking on 1 May and became buoyant during the remaining period. water transparency was low in the river and harbor, with Secchi disc readings ranging from 0.5 to 0.8 m in the river, from 0.5 to 1.4 m in the harbor, and from 0.7 near shore to 5.5 m in the lake. The river water was isothermal, with mean temperatures ranging from 9.7 (1 May) to 11.1°C (4 Play). The mean temperature at station 7 varied from 9.7 to 11.1°C, while temperatures at the lake stations varied from 3.1 to 11.1°C.

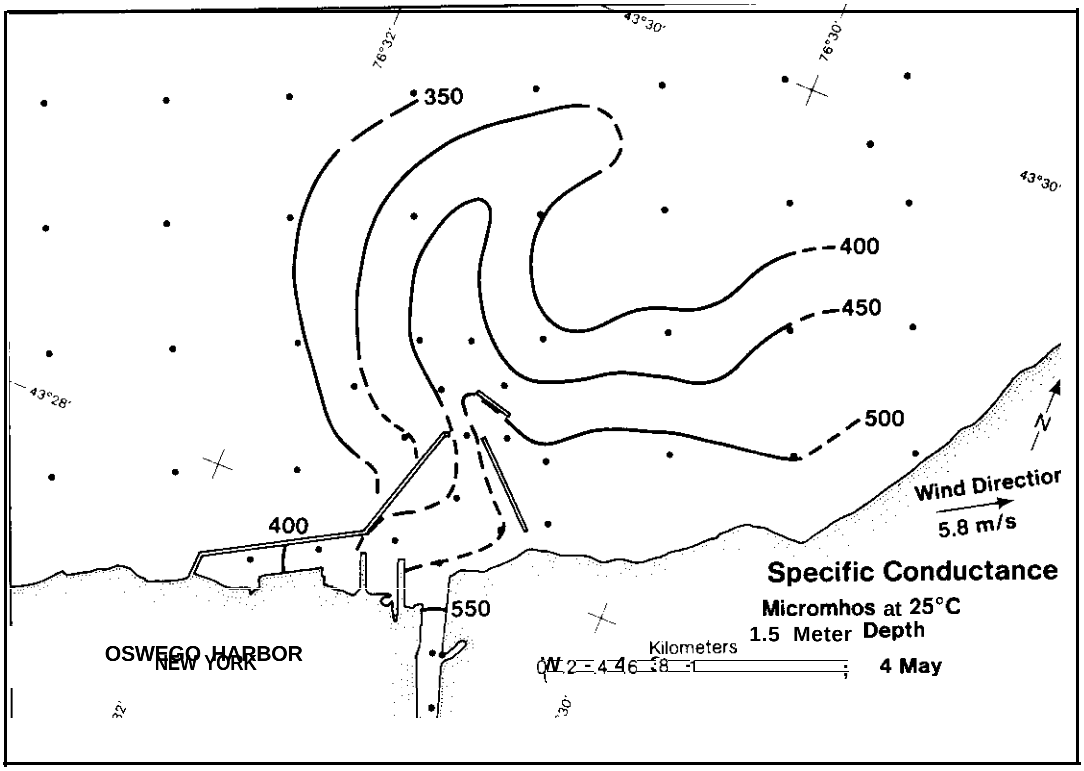

Figure 3. *Configuration of plume and specific conductance at 1.5 meters, 4 May.*

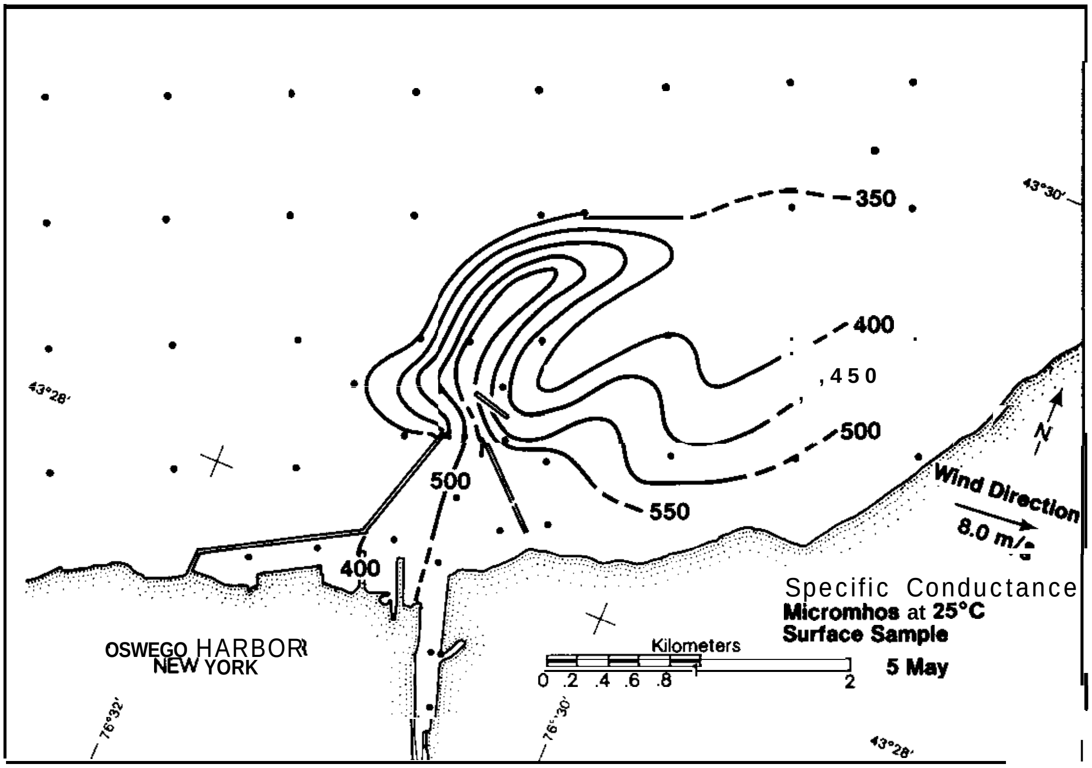

Figure 4. Configuration of plume and specific conductance at surface, 5 May.

5.1.2 Period 2: 13 to 23 June

The stream flow (Fig. 2) was increasing rapidly from 16 to 23 June due to the heavy rains associated with Hurricane Agnes. Winds were light, shifting from northeasterly through southerly to westerly during cruises on 13-15 June (Table 6) and remaining westerly to northerly through 17 June. During cruises on 19-21 June the winds were southerly, shifting to northeast to east during cruises on 21 and 22 June. Seas were calm during three cruises, with small waves during the other cruises reaching a maximum on 22 June. During cruises on 13-16 June the plume formed the same general northeastward pattern observed during period 1. Currents in the harbor on 15 June ranged from 8 to 16 cm/s to a depth of 5 m. In the lake north of the breakwater (Miller, Figs. 2 and 3) the velocities ranged from 22 to 57 cm/s to a depth of 10 m. On 17 June the plume shifted to the northwest under the influence of a north wind. Currents in the harbor ranged from 4 to 16 cm/s to a depth of 5 m. Drogues circled in eddies counterclockwise west of the channel and clockwise on the east side (Miller, Fig. 4). Two of the drogues approached the river mouth moving upstream on either side of the channel. Outside the harbor, part of the flow was eastward alongshore from the east breakwater. North of the detached breakwater, Miller observed velocities of 8 to 11 cm/s toward the northwest.

The flow toward the northwest continued through 19 June under the influence of a southeast wind (147°) averaging 4.9 m/s, then shifting back to the northeast on 20 and 21 June. On 20 June the currents moved eastward along shore to the west and north of the detached breakwater, the plume was carried toward the east-northeast by strong longshore currents. On 22 June the plume was again deflected westwardly by northeast (28°) winds averaging 7. m/s. Drogues started at the mouth of the river moved rapidly out of the harbor. The main flow was westward, but part of the flow was eastward through the opening south of the detached breakwater. Two of the drogues (Miller, Fig. 8) circled westward within the harbor. The surface expression of the plume was sharply defined by specific conductance, temperature, and transparency. Figure 5 shows the main plume curving to the northwest, then to the southwest with a rather steep gradient on the windward side. Part of the plume extended approximately 2.2 km eastward from Station 7. The surface temperature (Fig. 6)

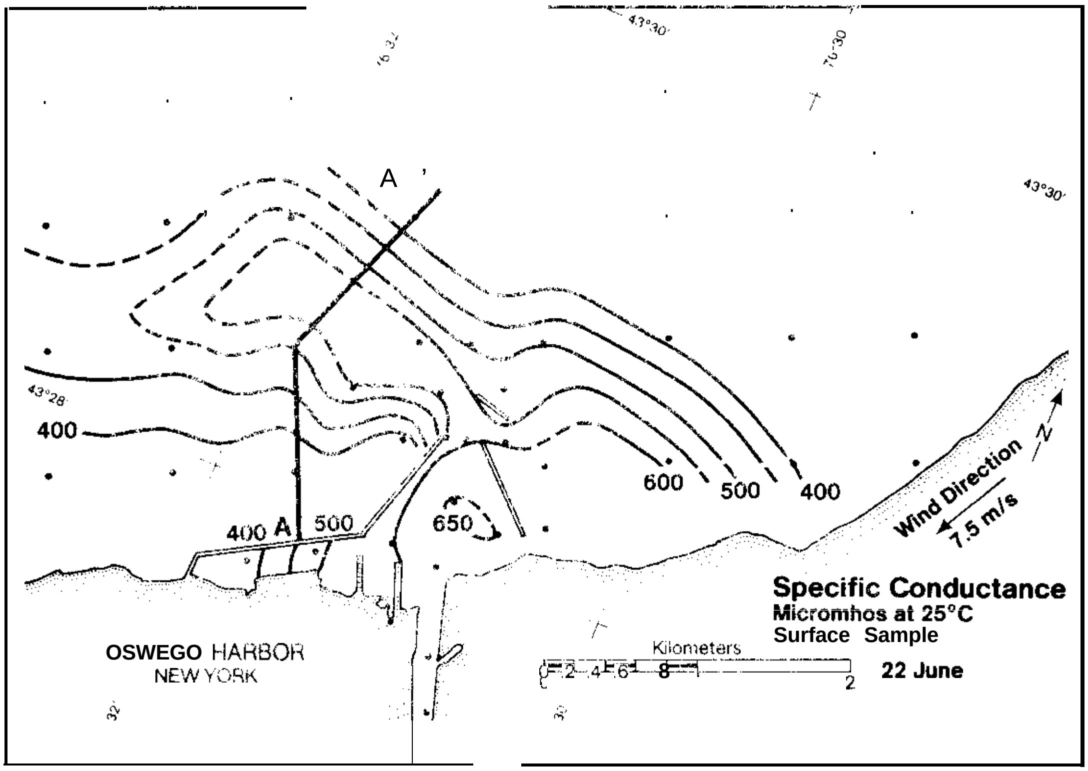

Figure 5. Configuration of plume and specific conductance at surface, 22 June.

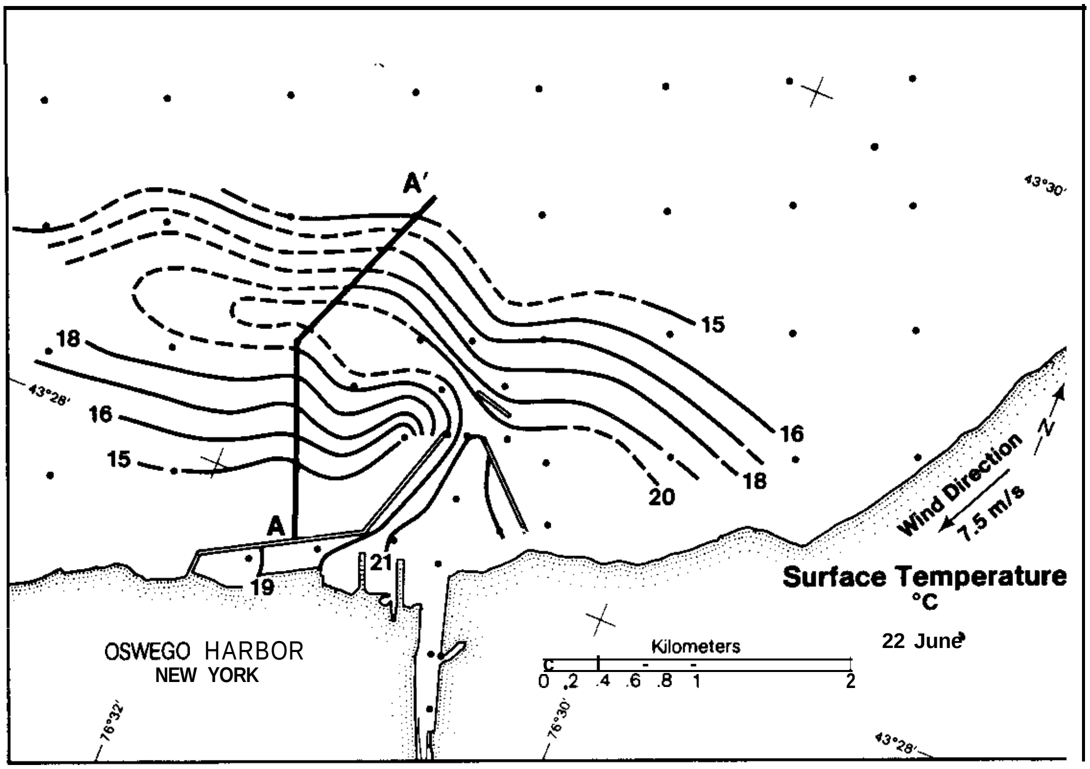

Figure 6. Surface temperature distribution, 22 June.

showed a similar pattern. Figure 7 shows the variations in the surface transparency as determined by turbidity meter and the same general plume pattern as specific conductance and temperature with the zero transparency contour following closely the 550 micromho contour (Fig. 5). Profiles across the plume along line A-A' through stations 12, 17, and 18 (Fig. 8) show the plume structure and the relationship between these three parameters. The plume is characterized by high specific conductance and low transparency. The bottom, or floor, of the plume coincides with the upper portion of the thermocline. The temperature structure indicates upwelling along the shore. Water in the harbor at station 37 near the Niagara-Mohawk Steam Station (Fig. 6) is colder than in the river. This is apparently due to upwelling around the intake, but may be due, in part, to leakage through the breakwater. The thermocline is tilted 5 m northward in 1.8 km between stations 12 and 18. This is the result of winds from the south during the previous 3 days. The sharply defined plume is due to the combined factors of continued high river flow, strong wind from the northeast, and upwelling alongshore.

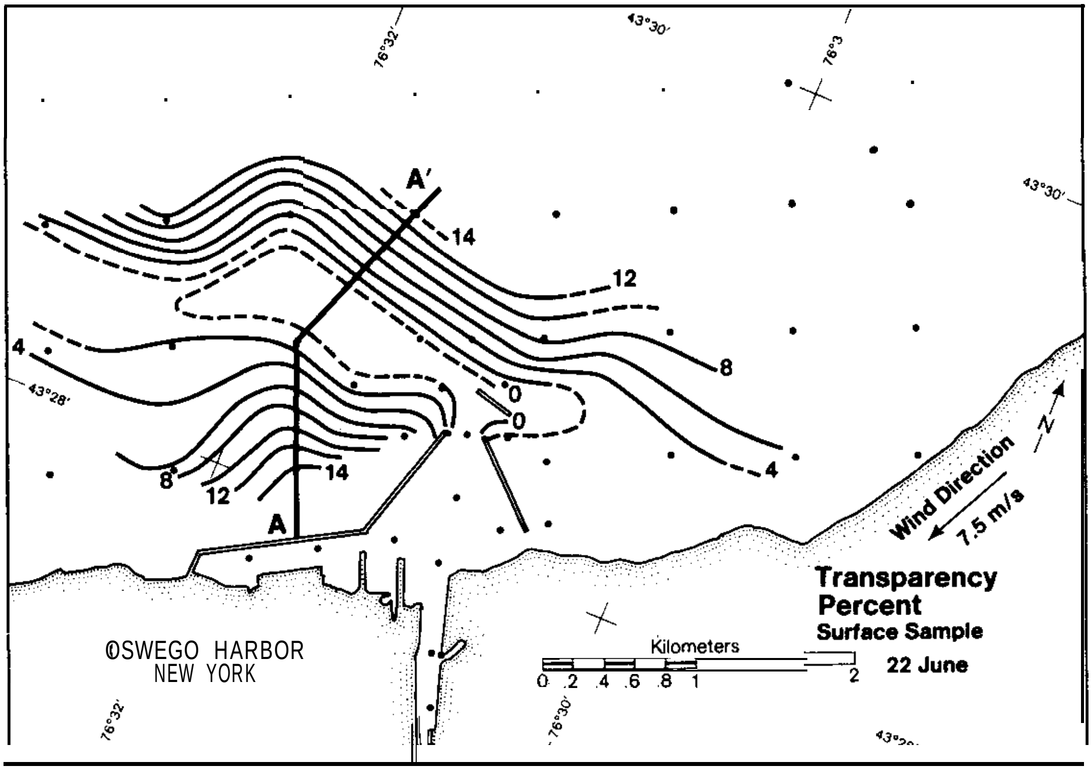

Figure 7. Variations in the transparency at the surface, 22 June.

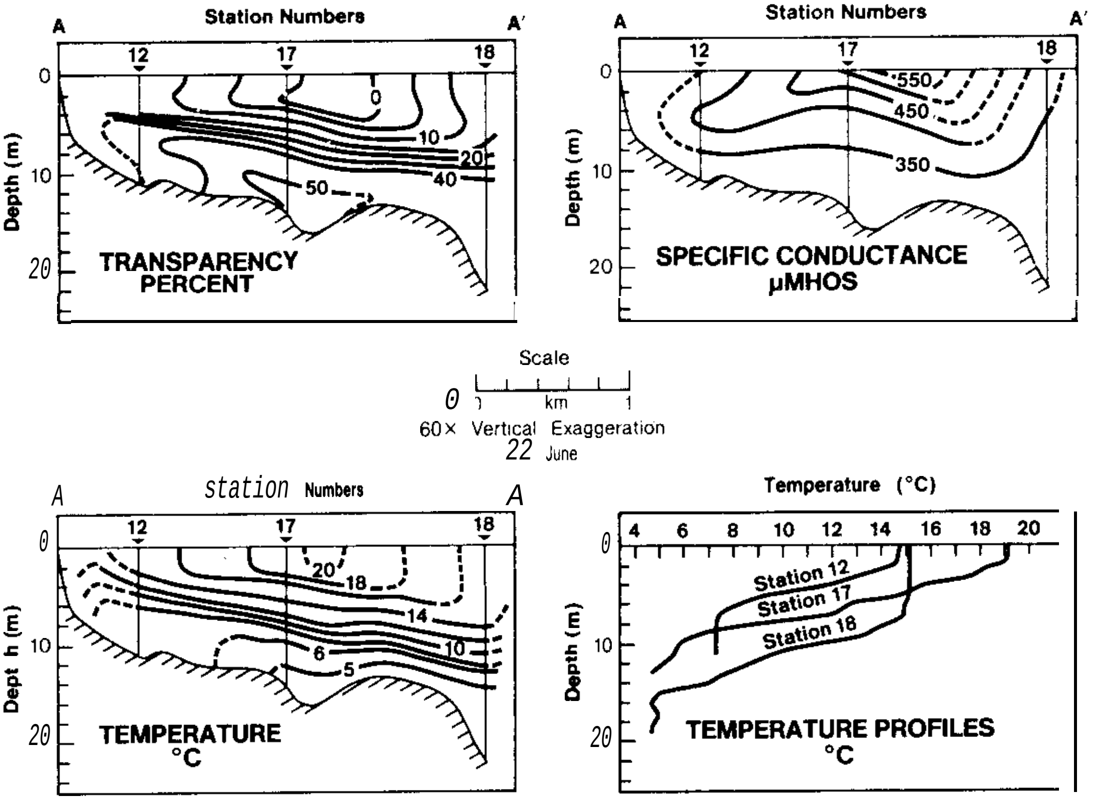

Figure 8. Profiles along A-A' through stations 12, 17, and 18 showing relationships between specific conductance, transparency, and temperature, 22 June.

Figure 9 shows the transparency profile from the harbor westward to station 47. The zone of high turbidity extends to the bottom at station 7, but becomes buoyant and spreads over the thermocline between stations 10 and 14. Figure 10 shows the areal distribution of the plume based on a comparison of the specific conductance of individual samples with the difference between the river and lake background values. The results are expressed as a mean percent of the river and harbor concentrations present at each station. The 10-percent contour outlines the area in which 90 percent of the dilution occurs.

On the following day, 23 June, the wind shifted from the northeast to the southeast, the plume became less sharply defined and began to spread more to the north and east, although the main plume continued to move in a general northwestward direction under the influence of a high river flow. All drogues circled clockwise inside the harbor. Upwelling nearshore was more pronounced, with temperatures of 5.6°C at Station 12 and 8.1°C at station 32.

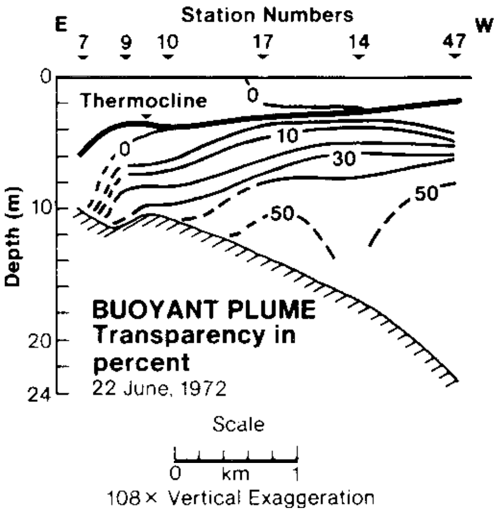

Figure 9. Profile of buoyant plume east-vest between stations 7 and 47 showing variations in transparency in relation to the thermocline, 22 June.

5.1.3 Period 3: 19 to 25 August

During this period the river flow was approaching the low for the year (Fig. 2). Winds were light and southerly during cruises on 19-22 August, shifting to easterly on 23-24 August, and from the west on 25 August. Seas were calm during most of the period (Table 6) and turbulent mixing due to wave action was at a minimum. On 18 August current velocities were 6 to 18 cm/s in the harbor and 4 to 22 cm/s to the east of the harbor. North of the detached breakwater, drogues moved northeastward at 22 to 31 cm/s. Current velocities in the harbor were low during 22-24 August (Table 6).

Plume patterns were generally similar to those observed during period 1, with part of the plume passing around the north end of the detached breakwater as well as to the east between the breakwaters. Owing to the low river flow, the plume did not extend as far into the lake before being deflected eastward by the longshore currents as observed during high flow periods. Although northeasterly winds on 23-24 August shifted the plume westward initially, prevailing eastward flowing longshore currents continued to carry the plume to the northeast. However, there was a tendency for the plume to spread more widely on 24 August. Surface water temperatures were high during this period in both the river and adjacent portion of the lake, ranging from 22.9 to 19.6°C in the river, and from 23.5°C nearshore east of the harbor to 8.3°C off shore. The thermocline was at a depth of 10 to 13 m. The initial buoyancy of the plume due to the temperature differential was limited to the area around the harbor entrance. With distance from the harbor, the plume began to sink toward the thermocline and was commonly found at

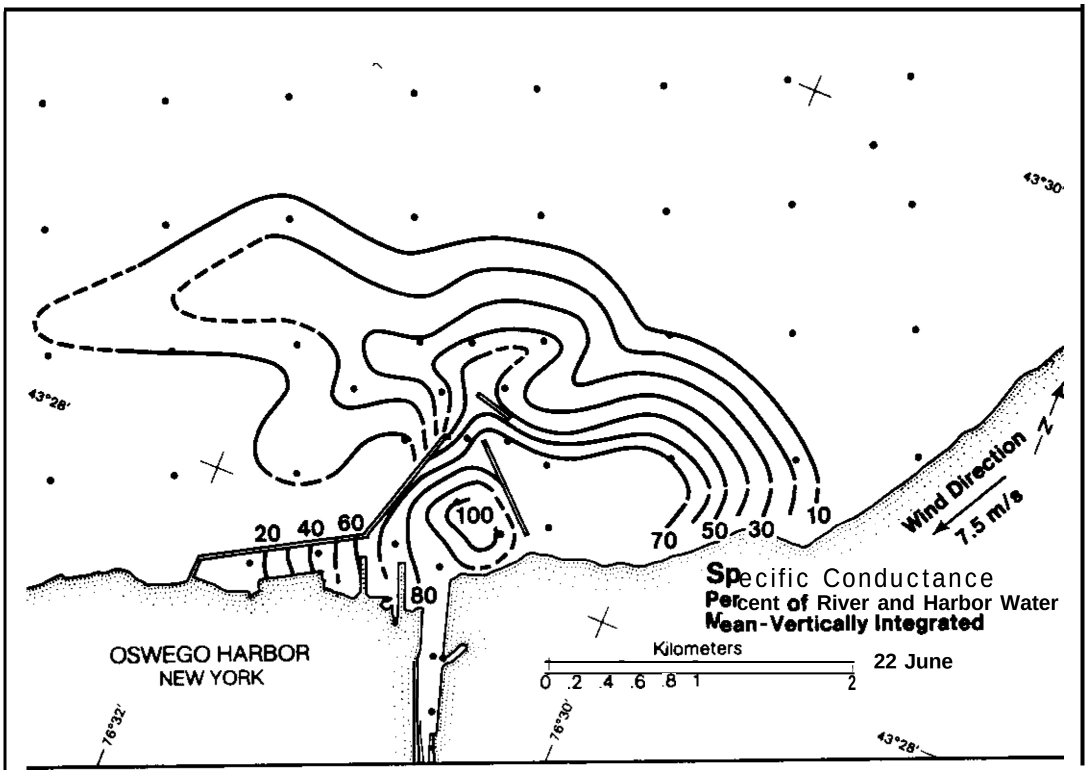

Figure 10. Mean areal distribution of plume. Results based on specific conductance and expressed as a percentage of the river and harbor concentrations present at each station, 22 June.

mid-depths or near the bottom. In the nearshore area, the bottom was shallower than the thermocline and limited the downward migration.

5.1.4 Period 4: 17 to 27 October

This period, like period 3, was characterized by low river flow, but the flow was beginning to increase (Fig. 2). Air temperatures had decreased and the surface water temperatures were approximately half of those recorded in both the river and lake during the previous period. Temperatures in the river during this period decreased from 11.2 to 8.6°C. Since the river cooled more rapidly than the lake, the plume had a tendency to plunge at or near the harbor entrance.

High west winds to 21 m/s and waves to 3 m outside the harbor were observed on 17 October (Table 6). Lake water was blown over the west breakwater and into the harbor entrance over the colder plume. Drogues in the harbor moved eastward at 12 to 16 cm/s toward the opening at the south end of the breakwater. One drogue at 6.5 m moved toward the entrance, but remained in the harbor. On 18 October the wind was from the southwest at 5 m/s (Miller, p. 15), with the main flow from the harbor continuing eastward south of the detached breakwater. The plume on 19 October, as defined by transparency, plunged and moved northwestward toward stations 10 and 29. Drogues moved from the harbor entrance toward the southwest, while drogues in the harbor circled counterclockwise under the influence of a northeast wind at 5 m/s. On 20 October the winds were westerly at 3 m/s and the Longshore current resumed the flow toward the northeast. The main harbor flow was eastward south of the detached breakwater and between the east breakwater and shore (Miller, Fig. 16). The easterly flow continued on 21 and 23 October under the influence of southerly winds. The predominant surface flow was eastward at 4 to 11 cm/s on 21 October around the southeast end of the detached breakwater. At depth the flow was out of the channel and around the north end of the detached breakwater at 11 to 12 cm/s. With few exceptions, the highest chemical and suspended material concentrations were in the lower part of the water column in both the river and the lake. On 24 October the wind shifted to the northeast at 8 to 12 m/s, with a maximum wave development of 0.8 m. The plume sank at the entrance and moved westward out of the harbor at 8 to 14 cm/s. Most of the drogues in the harbor moved to the southwest (Miller, Fig. 18). The wind on 25 october was from the northwest at 7 to 16 m/s and the plume moved eastward around the detached breakwater at 11 to 20 cm/s.

The results of the sampling on 26 October show the characteristics of a sinking plume (Fig. 11). Winds averaging 5.1 m/s were westerly, shifting to southerly in late afternoon. Wind waves in the sampling area ranged to 0.4 m, with ground swells up to 0.8 m from 270". The plume temperature at station 7 ranged from 10.4" at the surface to 9.0°C near bottom and was colder than the lake water. The plume sank near the west end of the detached breakwater and east of the harbor near the 700 micromho contour line and moved eastward near the bottom. water transparency (Fig. 12) shows the sinking and movement near the bottom along line A-A'. Specific conductance (Fig. 13) and temperature (Fig. 12) show a similar pattern. Suspended materials (Fig. 13) show the main movement along bottom with minor spreading along the surface at stations 23 and 44. The nearshore movement is shown by similar transparency and temperature patterns on Figure 12, with the main plume crossing line B-B' within 0.8 km of shore. At station 24 the transparency-temperature relationship is again seen where a decrease in transparency of 22 percent occurs with a temperature decrease of only 0.7°C. On October 27 the winds were light and southeasterly, waves ranged to 0.3 m, and the plume plunged and moved along the bottom toward the north and east, with the principal movement alongshore.

5.1.5 Period 5: 7 to 10 November

During cruises of 7 and 8 November the winds were southerly, waves within the sampling area ranged from 0.2 to 0.3 m (Table 6), and the river flow was increasing rapidly (Fig. 2). The river water, ranging from 7.9 to 7.7°C, was approximately 2°C cooler than the lake surface water adjacent to the harbor, and the main plume plunged at the entrance and spread along the bottom toward both the northeast and the northwest.

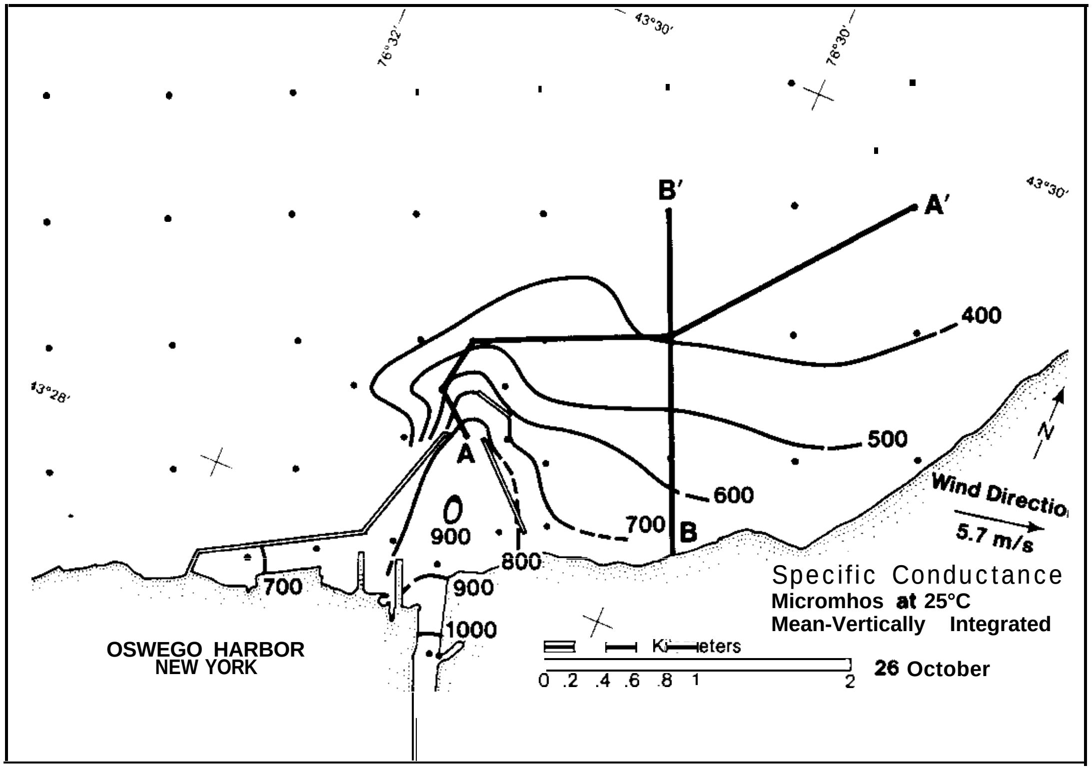

Figure 11. Sinking plume configuration, specific conductance, vertically integrated at each station, 26 October.

The highest surface specific conductance values were to the east of the harbor, indicating some surface flow between the detached and east breakwaters. There was also some movement along the surface toward the northwest. On 9 November north winds of 14 to 18 m/s during the sampling period produced waves of 1.2 to 1.5 m at the harbor entrance and deflected the plume alongshore toward the southwest in a band approximately 1.3 km in width, where it mixed with turbid water produced by wave action alongshore. Turbulent mixing overcame the tendency of the plume to sink at the harbor entrance. The winds during the final cruise on 10 November were gusty and variable from the southeast to northeast during most of the sampling period, producing waves of 0.3 m in the nearshore area. Currents produced by the previous days' storm continued

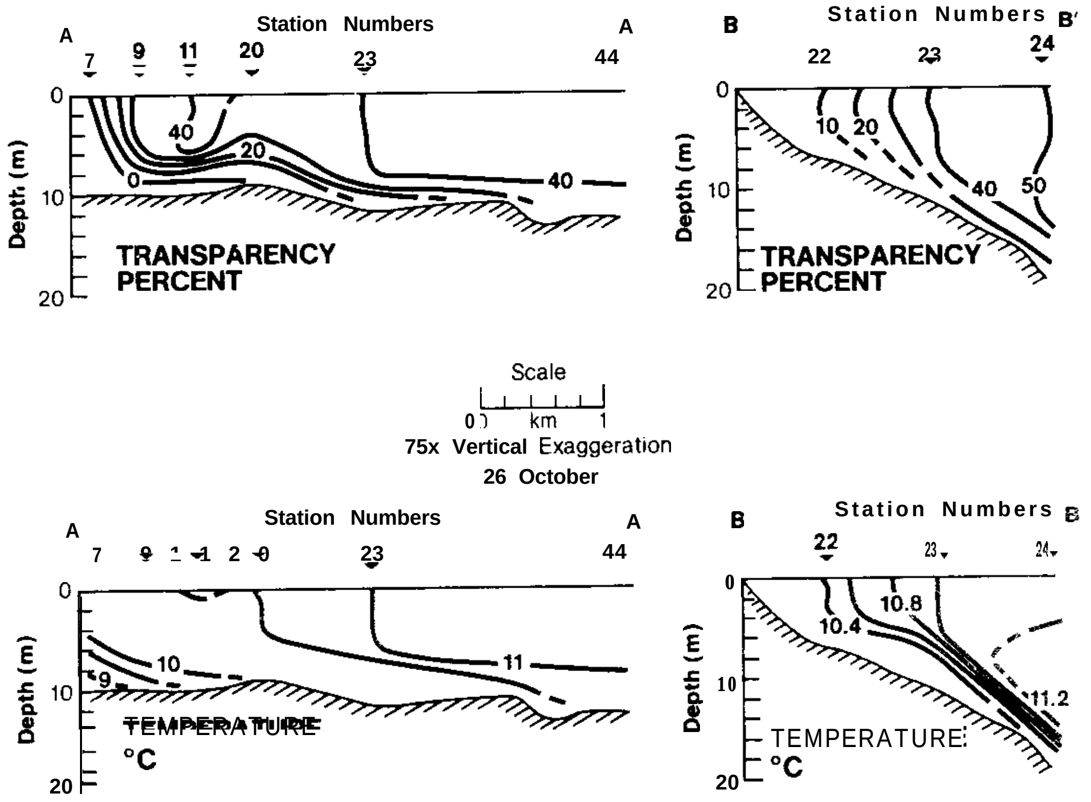

Figure 19. Profile of sinking plume showing variations in transparency and temperature along lines A-A' and B-B', 26 October.

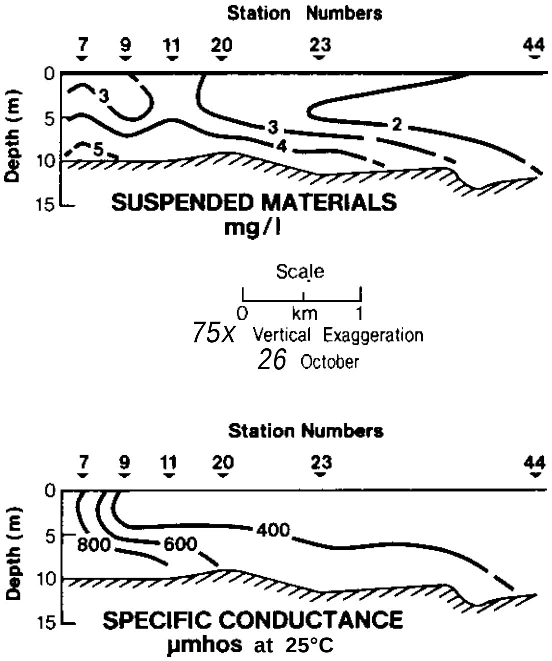

Figure 13. Profile showing variations in suspended materials and specific conductance along lines A-A', 26 October.

to deflect the main plume northwestward. However, there was some spreading eastward nearshore. Due to increasing river flow, the plume dominated the area adjacent to the harbor. Figure 14 shows the thickness and areal extent of the main plume as characterized by a transparency range of 0 to 10 percent. Transparency profiles (Fig. 15) show zero

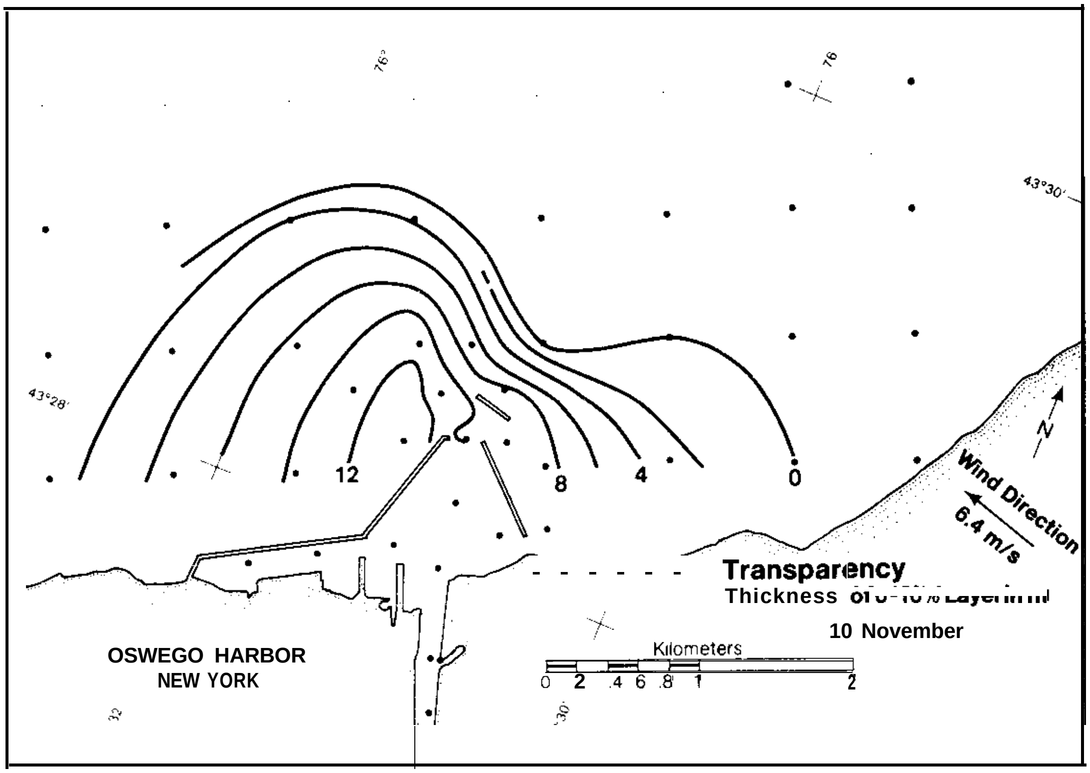

Figure 14. Thickness of 0 to 10 percent transparency layer in plume, 10 November

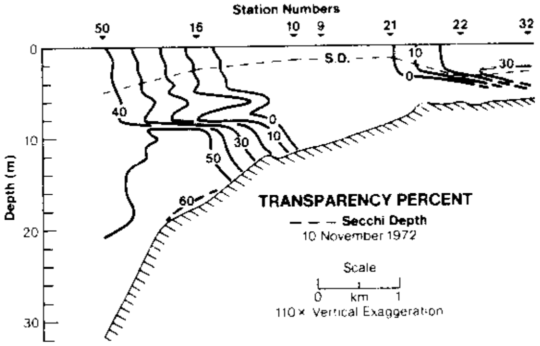

Figure 15. Profile west-east through plume showing transparency variations at 1-m depth intervals, 10 November.

values throughout the water column up to 1 km west of the harbor entrance. The river water temperature, 7.7°C at station 3, increased 1.2°C at the surface and 0.3°C at the bottom as it moved through the harbor. The plume spread at or near the surface as it moved westward offshore over colder water. A pronounced increase in transparency occurred at station 16 below a weak thermocline at 8 and 9 m, with a maximum temperature differential of 1.1°C.

5.2 Dissolved Ions and Related Parameters

5.2.1 Nitrate

Nitrate concentrations, generally higher in the river, decreased through the harbor and into the lake. Concentration levels in the river (Fig. 16), harbor, and lake were high in May during the spring runoff

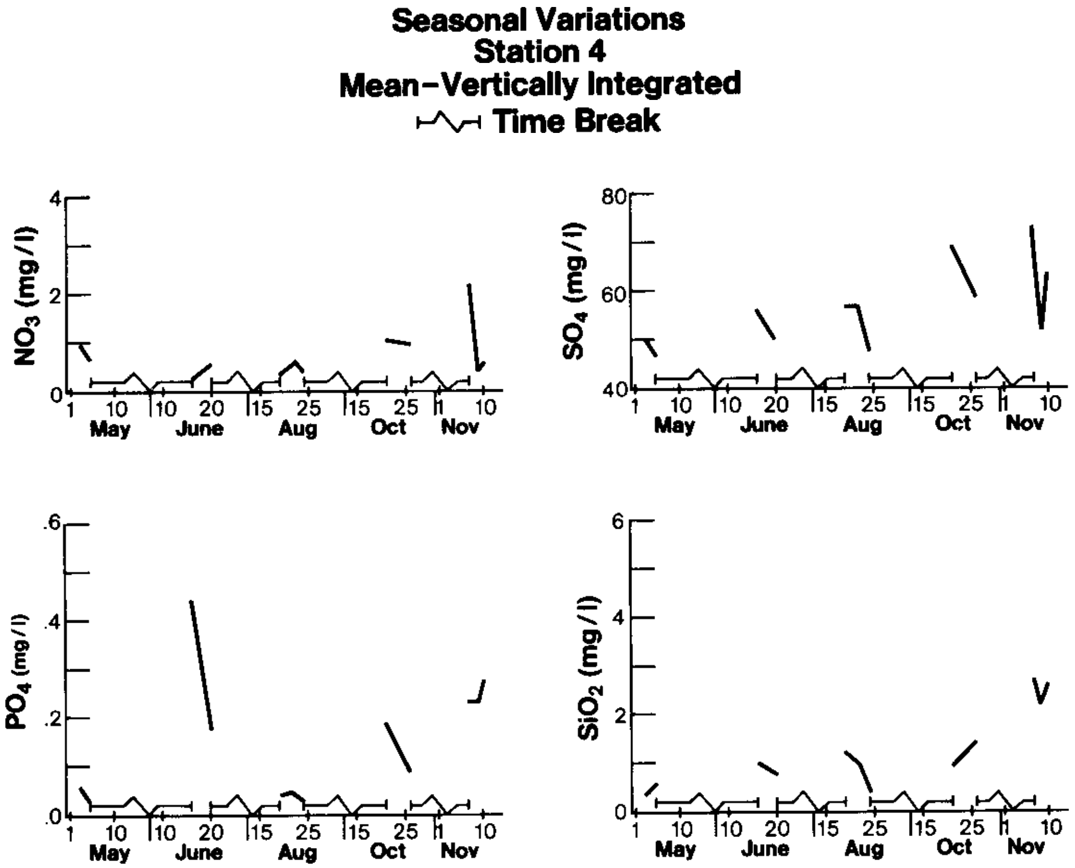

Figure 16. Seasonal variations at station 4--vertically integrated mean concentrations of nitrate, phosphate, sulfate, and silica.

and again in October and November during the fall runoff. The lowest levels were prior to and following the abnormally high runoff period associated with Hurricane Agnes. Several cruises (14 June-7 November) show the highest values in the river at stations 3 and 4. This was interpreted as being due to municipal loading. Mean concentration values in the river during the five survey periods ranged from 0.75 mg/l at station 4 to 0.61 mg/l at station 1 (Fig. 17). Within the harbor, the mean concentration ranged from 0.66 mg/l at station 28 to 0.50 mg/l at the entrance. The mean concentration was always higher in the turning basin by the Niagara-Mohawk Power Plant than at station 36 to the east. Mean lake background concentrations, based on observations at peripheral stations, ranged from 0.39 to 0.44 mg/l during period 1, from 0.32 to 0.34 during period 2, from 0.16 to 0.24 during period 3, and 0.49 during the final survey period. At the nearest offshore IFYGL station (YO), approximately 5 km offshore, the mean lake concentration was 0.42 mg/l during IFYGL cruises 14, 20, 25, and 29 between 31 July and 16 November. Anomalies of concentrations higher than in the river were observed at station 20 during 3 cruises. During cruises on 5 May and 19 August, the station was within the plume. During the cruise on 10 November, the main plume was to the west between stations 10 and 11, with part of the flow around the east end of the detached breakwater and then northward by station 20. One possible explanation is that the concentration in the river had increased during the elapsed 4-8 hr between the time of sampling in the river and at station 20. Current velocities of 6-12 cm/s would be adequate to move a different water mass approximately 1.7 km from station 4 to station 20 during the elapsed time.

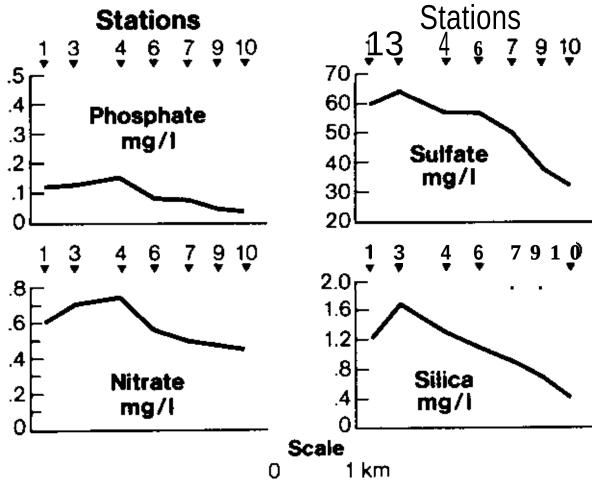

Figure 17. Concentrations of nitrate, phosphate, sulfate, and silica along the channel from the river into the lake (based on grand mean of all cruises).

Such velocities are within the ranges observed by Miller (1976). The high concentrations (Fig. 18) on the west and northwest sides of the area at stations 14, 16, 39, 40, 46, 48, and 50 do not reflect the true mean. These stations were sampled for complete analyses 1 to 2 times and only when the plume extended westward into that area. The true mean for that area should be closer to 0.4 mg/l.

5.2.2. Phosphate

As in the case of nitrate, the mean concentration levels were highest at station 4 (Fig. 17) in the river and decreased through the harbor into the lake. The highest concentrations were observed in the

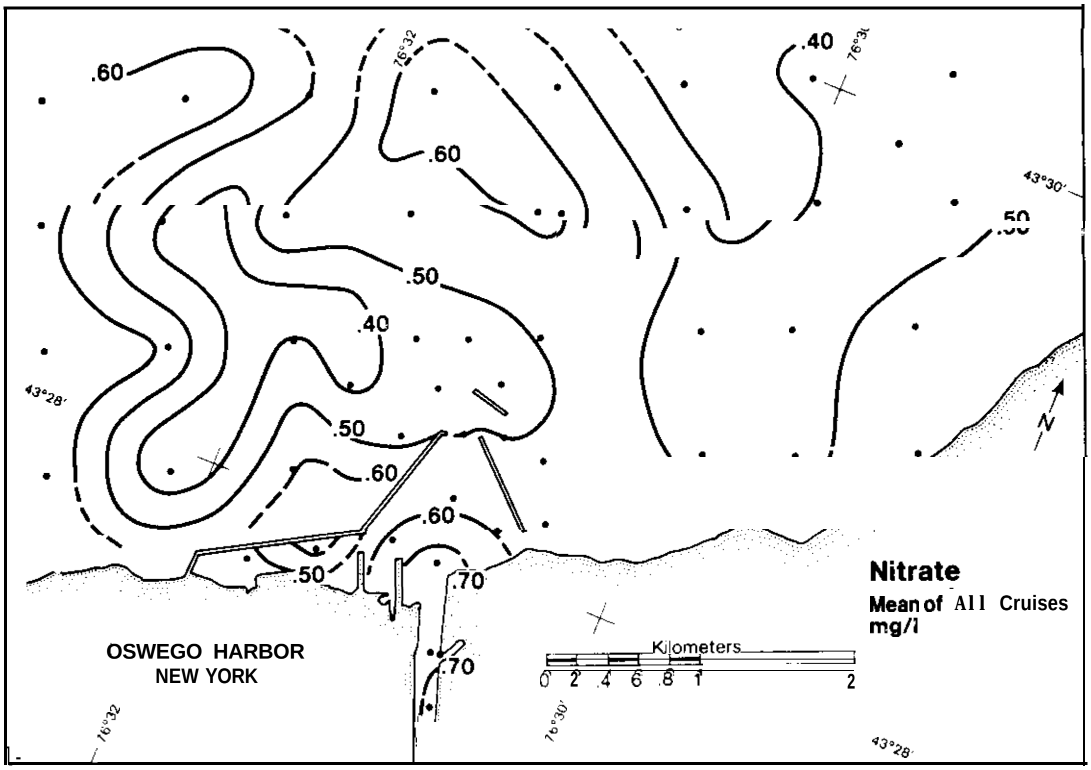

Figure 18. Distribution of nitrate (based on a grand mean of all cruises).

river and harbor during June at the beginning of the runoff from Hurricane Agnes (Figs. 16 and 19) and again during the fall runoff period in October and November. The lowest concentrations were observed during the low flow period in August. The mean in the harbor ranged from 0.068 at station 36 to 0.127 mg/l at station 5. The mean over most of the area outside the harbor ranged from 0.025 to 0.042 mg/l (Fig. 20). The range at IFYGL station 90 was from 0.002 to 0.011 mg/l. The anomalous high and low concentration areas to the west of the harbor are due to limited sampling in that area.

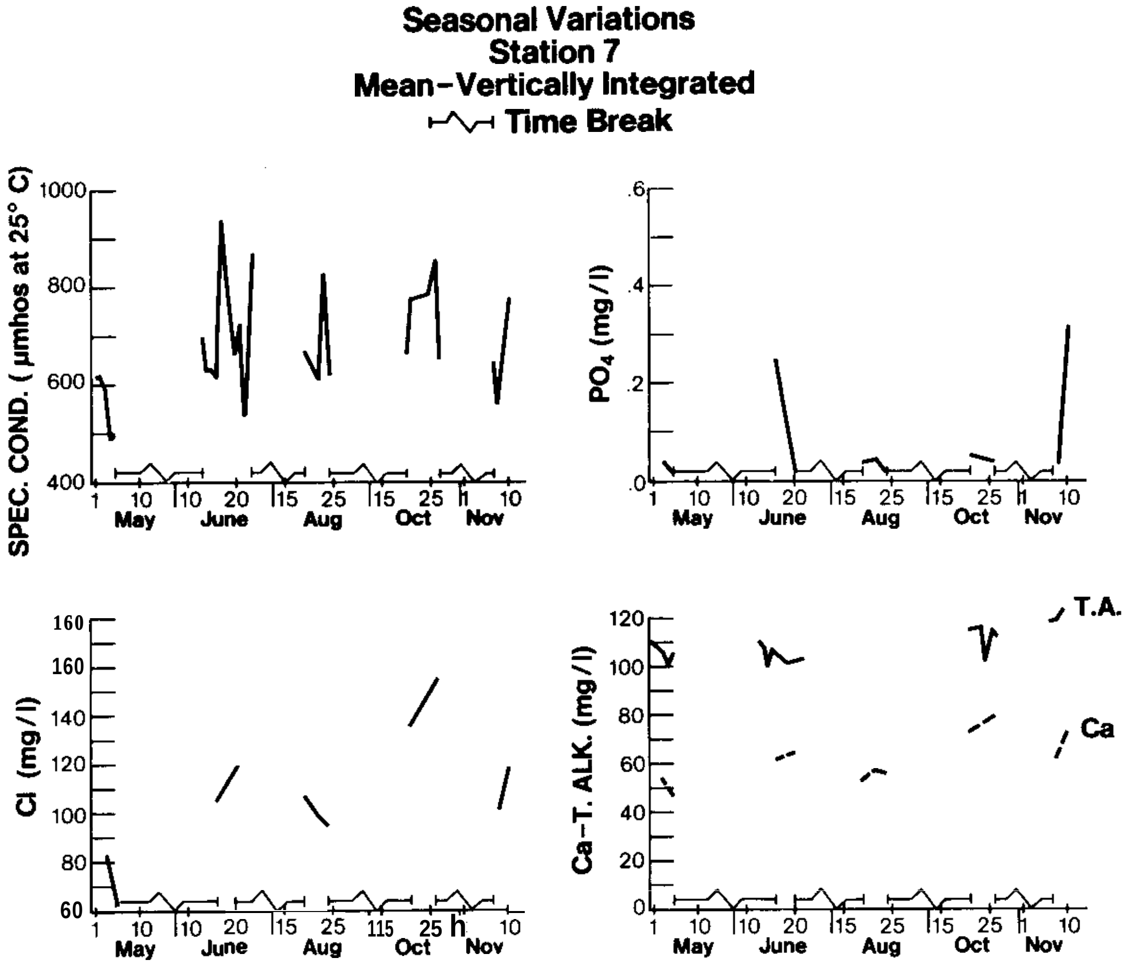

Figure 19.--Seasonal variations at station 7--vertically integrated mean concentrations of phosphate, chloride, calcium, total alkalinity, and specific conductance.

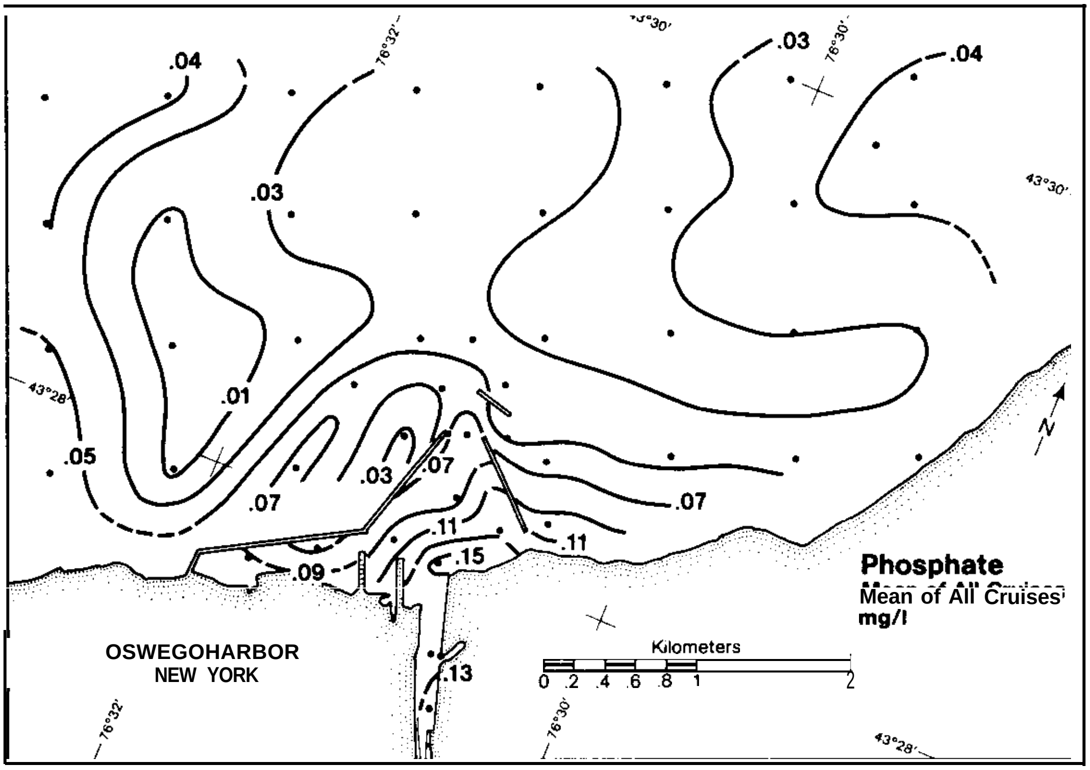

Figure 20. *Distribution of phosphate (based on a grand mean* **of all cruises).**

5.2.3 Sulfate

The mean concentration (Fig. 17) was highest at station 3 and decreased through the harbor and into the lake. Concentrations at station 4 (Fig. 16) varied seasonally, with low values during the spring runoff in May and highest values at the start of the fall runoff period. In most instances the daily changes vary inversely with flow. Sampling on 7 and 9 November showed the opposite relationship, presumably due to an initial flushing of the river system with the start of the high fall runoff. Shampine (1973, p. 76) shows an inverse relationship at Minetto during low flow and that concentrations remain within the same general range during high flow periods. Lowest values in the harbor were observed in the areas of stations 36 and 37 (Fig. 21), presumably due to dilution by the Niagara-Mohawk discharge. The dilution rate is very rapid near the harbor entrance. Values at offshore stations range from 27 to 30 mg/l and compare closely with the range of 26-30 mg/l at the nearest IFYGL stations. Eastward the dilution is less rapid and occurs largely within a zone 0.5 km from the shore.

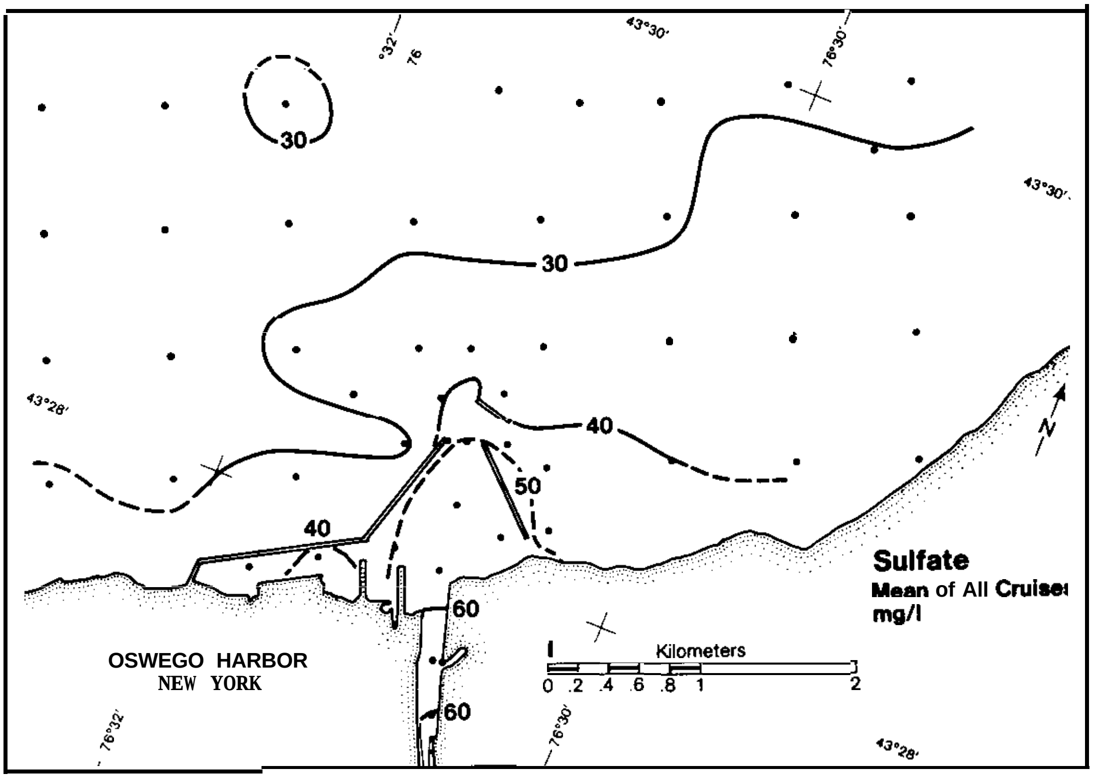

Figure 21. Distribution of sulfate (based on a grand mean of all cruises).

5.2.4. Silica

Silica (Fig. 17) shows an almost constant decrease from river station 3 to lake station 10. Beyond 1.0 km from the harbor entrance, the mean concentration (Fig. 22) is within the range of 0.1-0.4 mg/l observed at IFYGL station 90. The higher values along the west and northwest side are not representative of the mean as previously discussed under nitrate. The low value immediately west of the harbor entrance is owing to the fact that station 29 was not sampled on 10 November when the concentration was very high in that area. The concentration in the river (Fig. 16) was low during May and highest during the fall runoff in November. A comparison of the plots of silica and suspended sediment shows an inverse relationship in the river during portions of 4 out of 5 survey periods. In most cases silica has a variation pattern similar to that of sulfate and phosphate. The lowest concentrations within the harbor were in the channel leading to the Niagara Mohawk Turning Basin, indicating dilution by cooling water and possibly by some circulation through the breakwater.

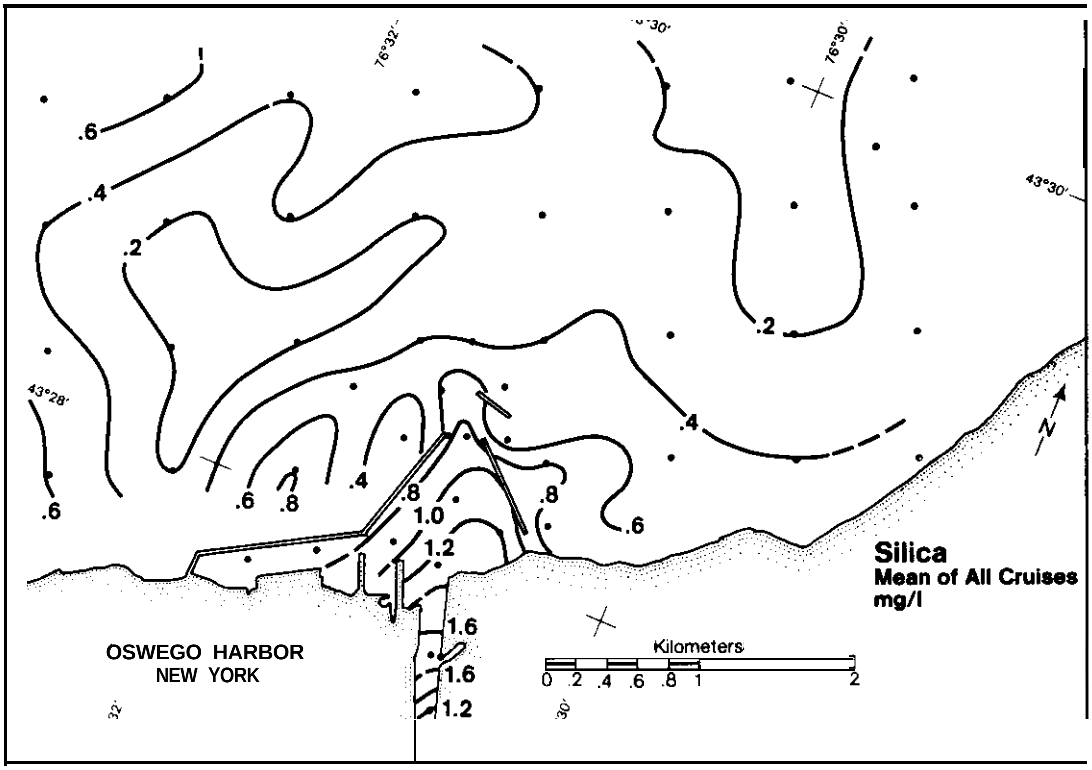

Figure 22. Distribution of silica (based on a grand mean of all cruises)

5.2.5 Calcium

Calcium shows a decrease in concentration from station 3 into the lake (Fig. 23). The mean concentration at station 3 is approximately twice that of the lake and is within the range reported by Shampine (1973) at Minetto. As in the case of most of the ions, the lowest values were observed in May. The seasonal variation at station 4 (Fig. 24) shows lower concentration values in May and the highest in November, with a pattern similar to that of magnesium and alkalinity. A similar pattern, but with lower concentrations and less pronounced short-term changes, was observed at station 7 (Fig. 19). Within the harbor the lowest values were observed in the western portion and the highest values in the vicinity of stations 5 and 6. Dilution was rapid lakeward from the harbor entrance (Fig. 25). Mean concentrations of 39 to 49 mg/l at offshore stations are from 3 to 13 mg/l higher than values observed at the nearest INGL station. As in the case of other major ions, the highest mean values in the lake were nearshore to the east of the harbor.

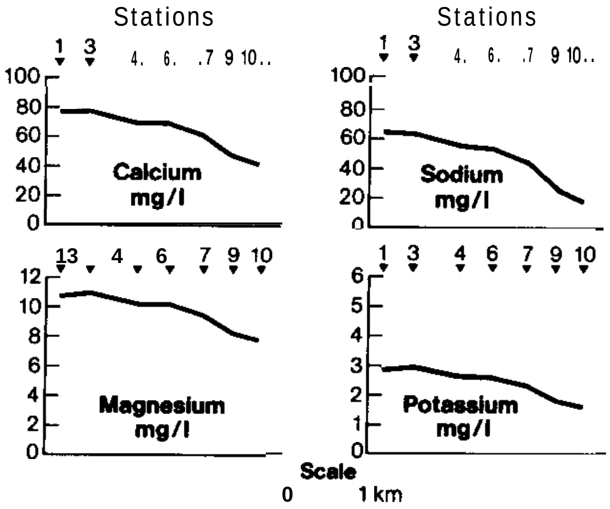

Figure 23. Concentrations of calcium, magnesium, sodium, and potassium along the channel from the river into the lake (based on a grand mean of all cruises).

5.2.6 Magnesium

The mean concentration decreased from the river through the harbor and into the lake (Figs. 23 and 26). The eastern part of the harbor in the vicinity of station 5 had a higher average concentration than the western portion. The mean concentration at station 3 was higher than at station 1 and lower than reported by Shampine (1973). The seasonal variation at station 4 (Fig. 24) is similar to that of calcium, sodium, and potassium, with the highest values being observed in November. The highest mean values in the lake are alongshore to the east and approach the offshore background concentration of 7.2-7.5 mg/l in approximately 3 km.

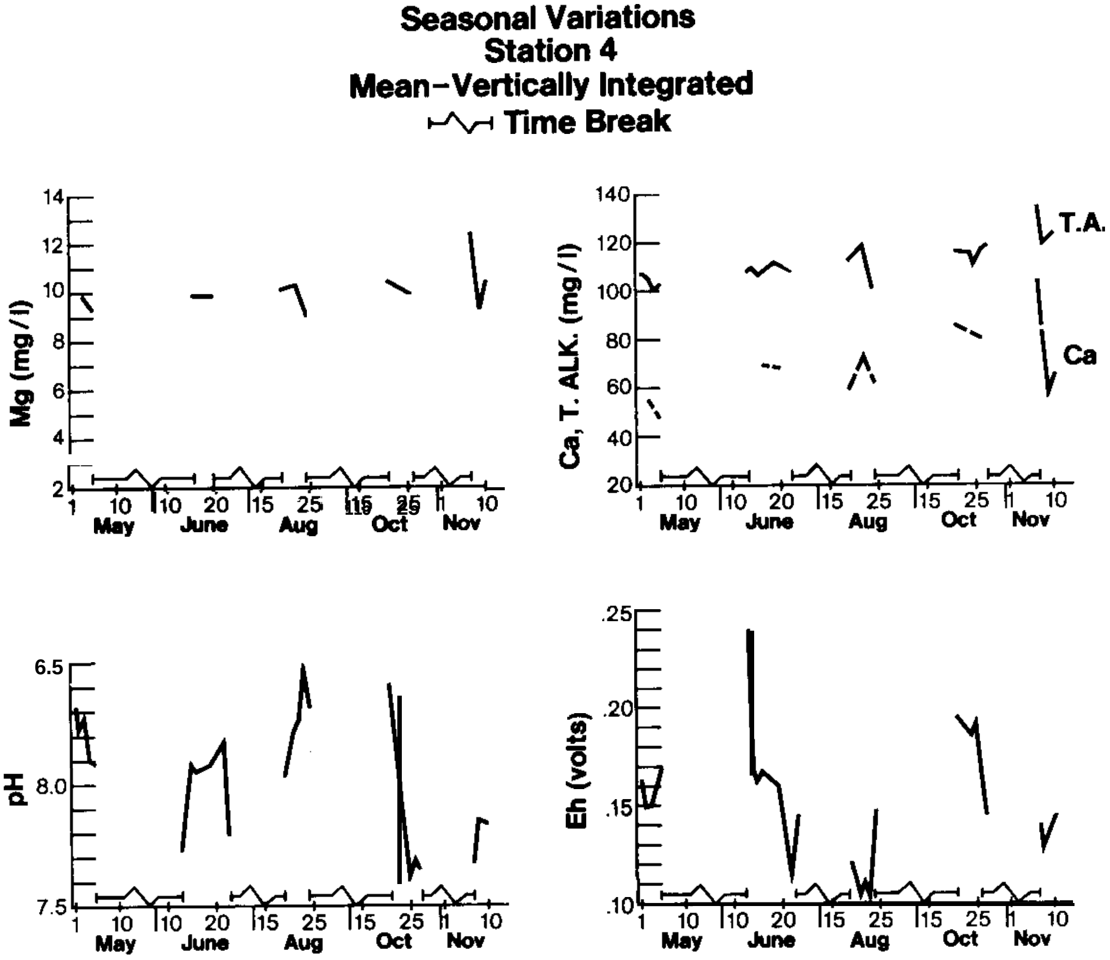

Figure 24. Seasonal variations at station 4, vertically integrated mean concentration of calcium, magnesium, total alkalinity, pH, and Eh.

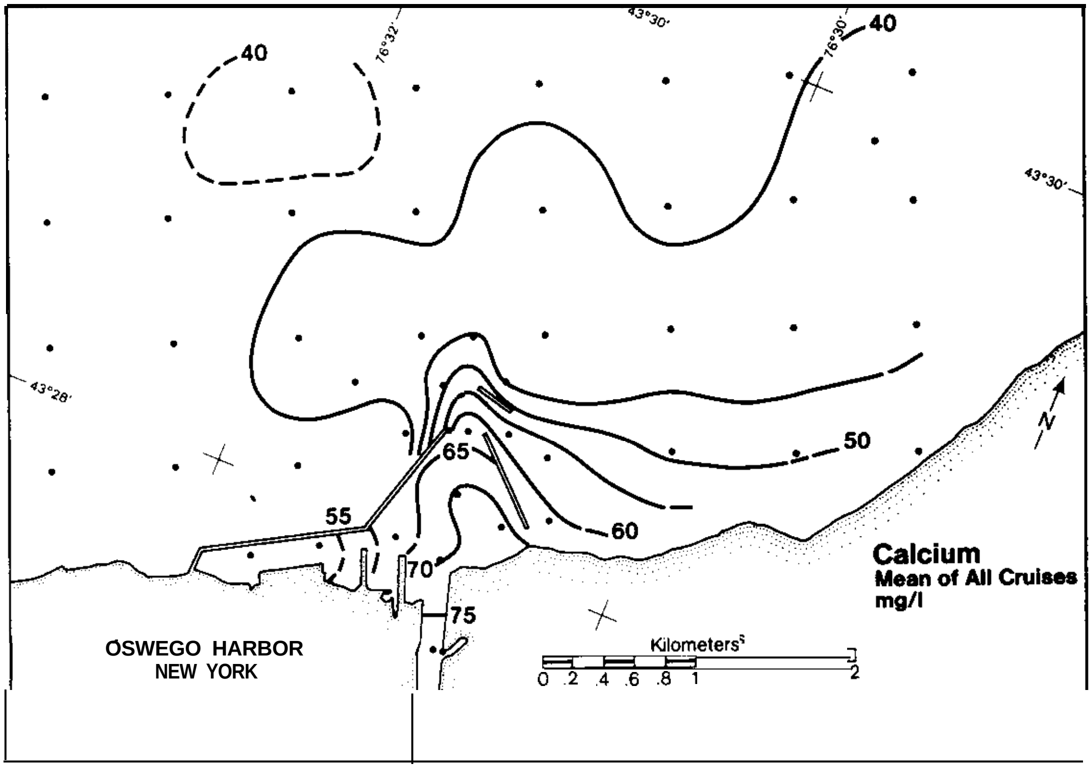

Figure 25. Distribution of calcium (based on a grand mean of all cruises).

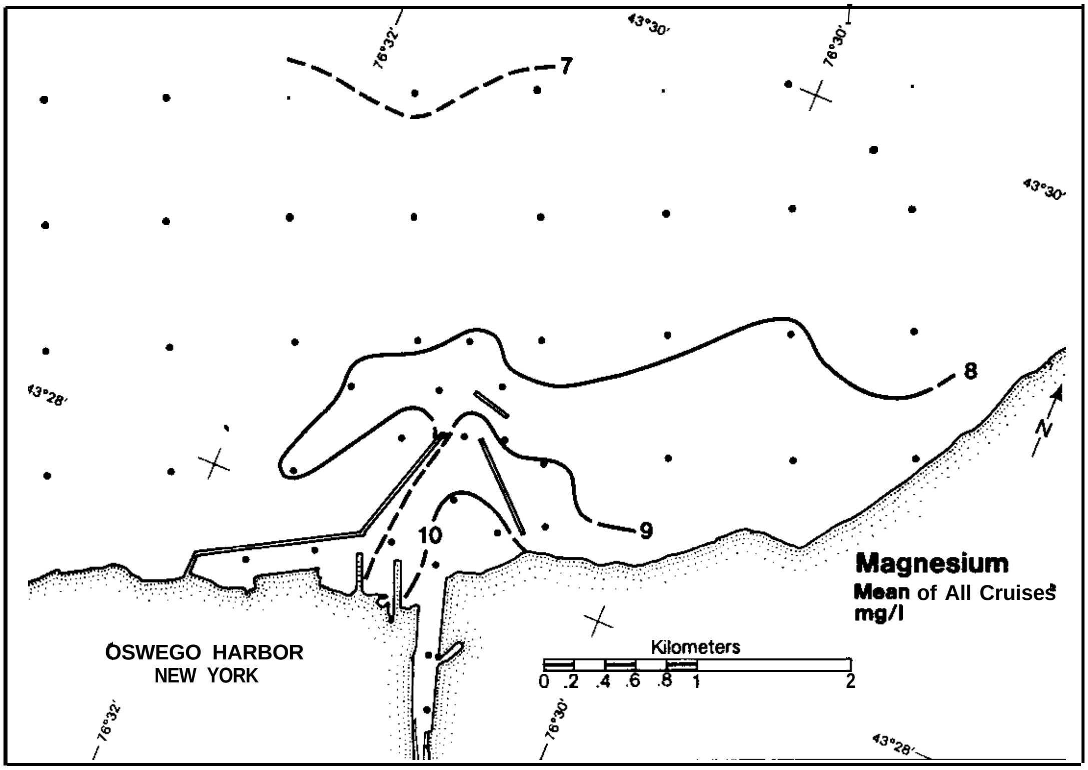

Figure 26. Distribution of magnesium (based on a grand mean of all cruises).

5.2.7 Sodium

Sodium concentrations decreased from station 1 in the river into the lake (Fig. 23). Concentrations within the harbor (Fig. 27) were lowest in the western portion. Seasonal variations (Fig. 28) in the river are similar to those of chloride. The daily mean concentrations are higher and the magnitude of the daily fluctuations are greater during the fall runoff period. Within 3 km to the north and northwest the mean concentrations were only slightly above those (12.3-13.4 mg/l) observed at the offshore IFYGL stations, but remained relatively high in the nearshore area.

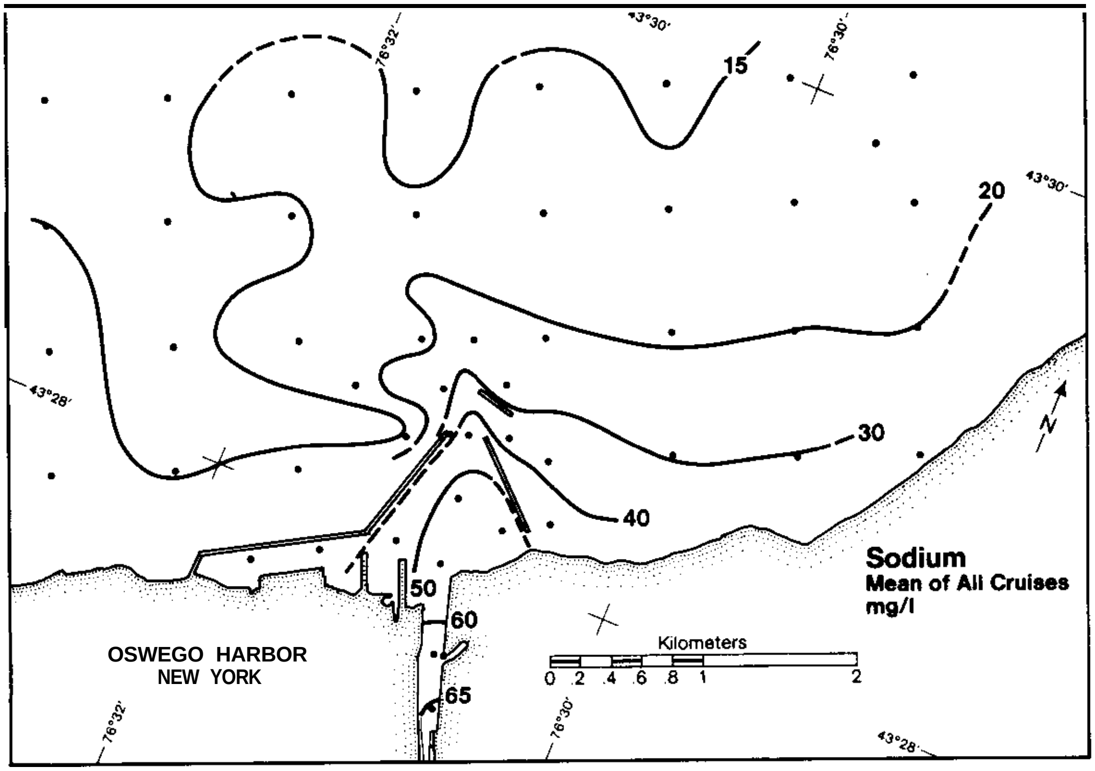

Figure 27. Distribution of sodium (based on a grand mean of all cruises).

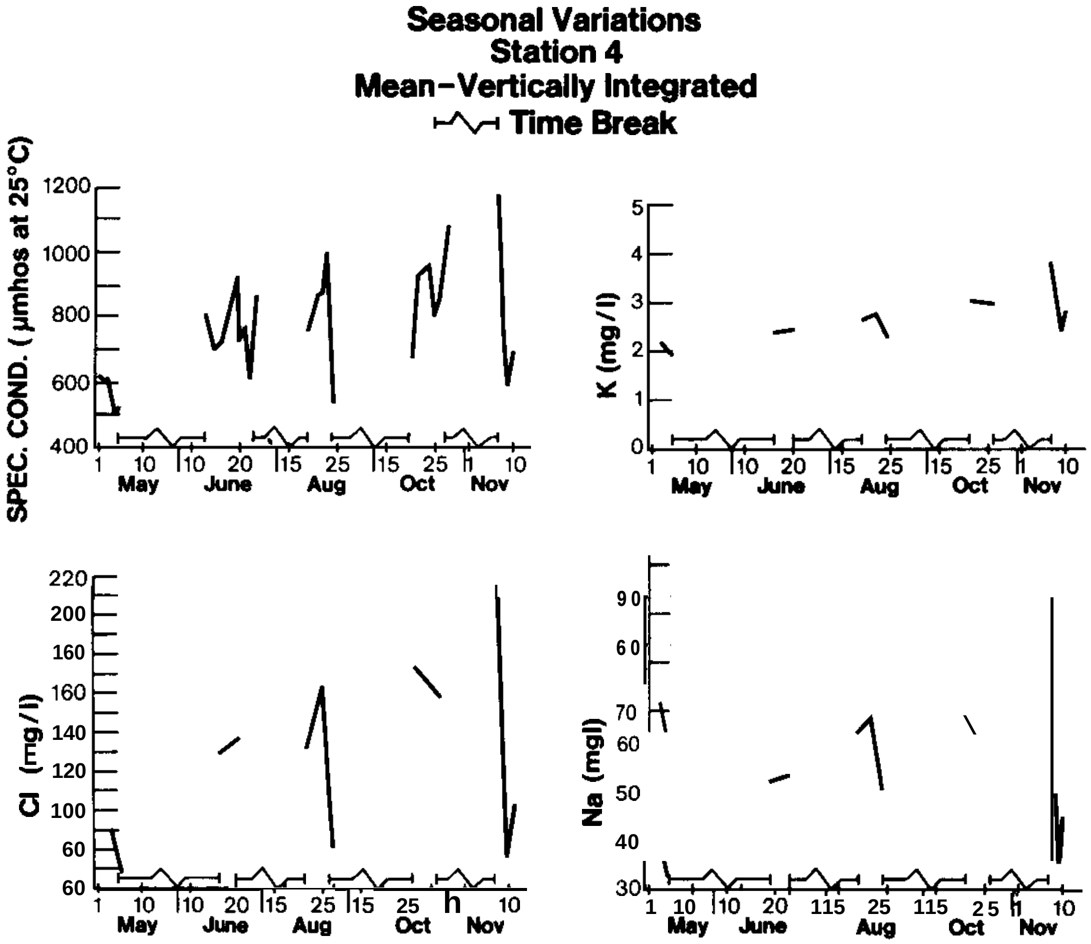

Figure 28. Seasonal variations at station 4--vertically integrated mean concentrations of chloride, sodium, potassium, and specific conductance.

5.2.8 Potassium

The mean concentration (Fig. 23) was slightly higher in the river at station 3 than at station 1 and approximately 2 times that (1.4-1.6 mg/l) observed at the nearest IFYGL lake stations. Seasonal concentration variations in the river at station 4 (Fig. 28), with low values in May and highest values in the fall, follow the same general pattern as the other major ions. Figures 23 and 29 show variations in the means within the harbor and adjacent lake that are similar to the other major ions, especially the cations.

5.2.9. Chloride

The Oswego is a major contributor of chloride to the lake (Sampine, 1973; Casey and Salbach, 1974). Very large fluctuations in concentrations were observed in the river at station 4 during August and November. Lower concentrations were observed during May than during the fall runnoff period (Fig. 28).

Relative changes in concentration at stations 4 and 7 between sampling periods (Figs. 28 and 19) followed the pattern of specific conductance and most of the major ions. The mean concentration at station

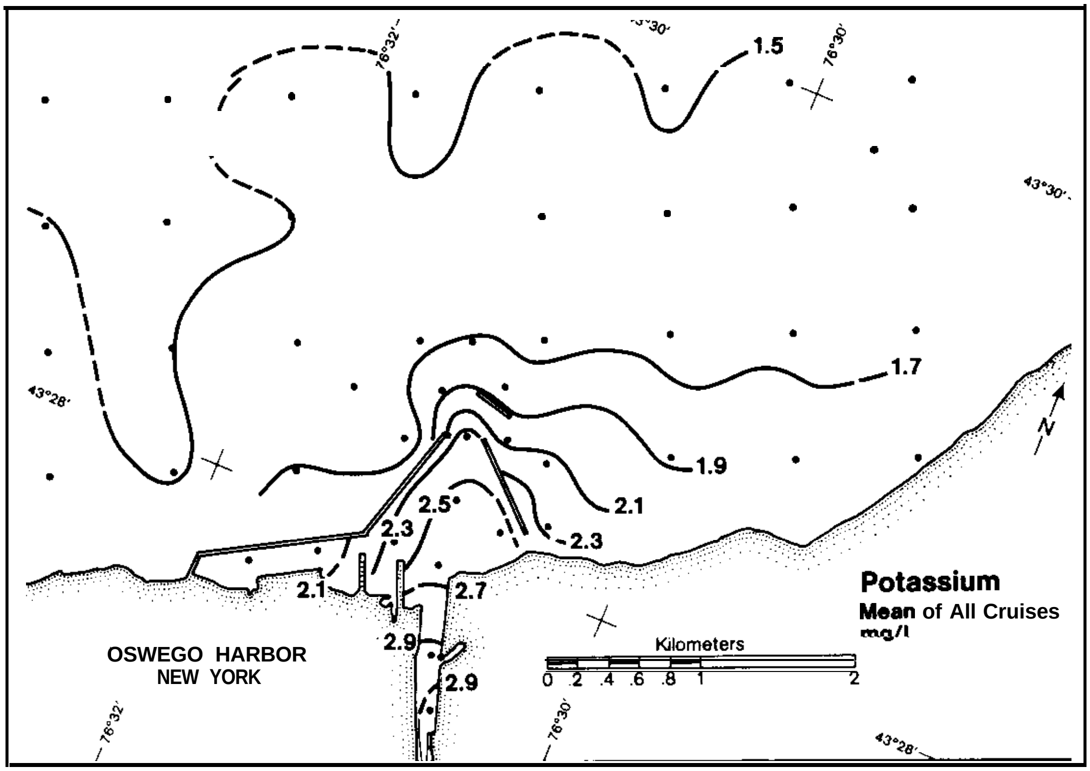

Figure 29. Distribution of potassium (based on a grand mean of all cruises).

4 (Fig. 30) is less than at station 6. A difference in the concentration was found on 4 cruises and is believed to be due to variations in the loading to this area and possibly to lake water encroachment into the vicinity of station 4. Since the concentration at stations 5 and 6 is higher than at station 4 during these periods, it is presumed that the encroachment is from the west of station 6. A comparison of values at stations 6 and 28 shows lower values at station 28, which can be explained by dilution by cooling water from the power plant in the western basin, combined with encroachment through the west breakwall and along bottom through the entrance. The dilution rate (Fig. 30) is very rapid from the harbor into the lake.

Due to the large difference between the concentration levels of the river and the lake background, the mean river effluent affected a larger nearshore area (Fig. 31) than some of the other ions. However, the mean distribution patterns are similar. Lake mean concentration at the nearest IFYGL station during 4 cruises was approximately 28 mg/l. As previously discussed, the higher values at the perimeter stations to the north and west are not representative of the mean. During 5 of 7 sampling periods, the values at station 18 were within the lake background range.

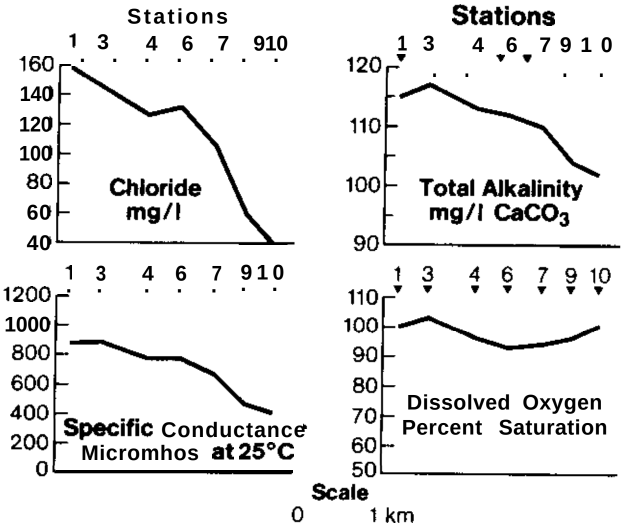

Figure 30. Concentrations of chloride, total alkalinity, dissolved oxygen, and specific conductance along the channel. from the river into the lake (based on a grand mean of all cruises).

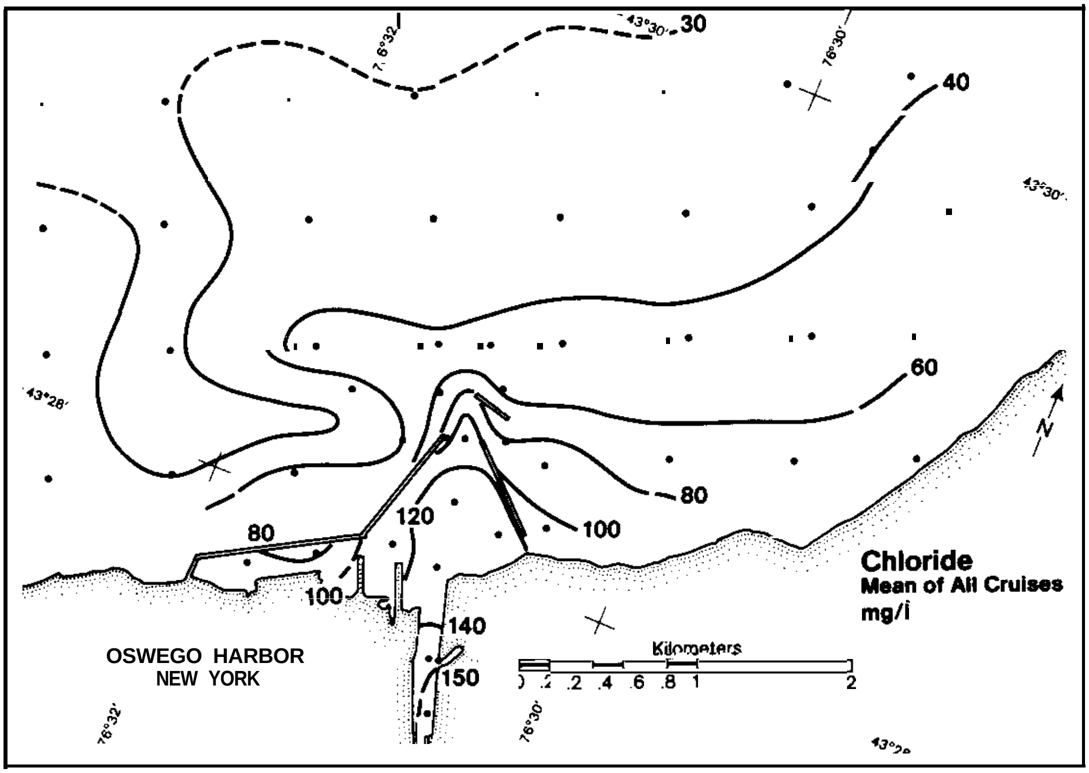

Figure 31. Distribution of chloride (based on a grand mean of all cruises).

5.2.10 Total Alkalinity

The mean concentration was highest at station 3 in the river and decreased rapidly through the harbor and into the lake area north of station 7 (Fig. 30). Within 3 km to the northeast the nearshore mean was within 3 mg/l of the offshore mean of 94 mg/l (Fig. 32). Concentrations at station 4 were lower in May and higher during the fall runoff period. A comparison of concentration values at station 4 (Fig. 24) with those at the harbor entrance (Fig. 19) show the concentration fluctuations to be smaller at station 7 and within the range of those observed at station 4.

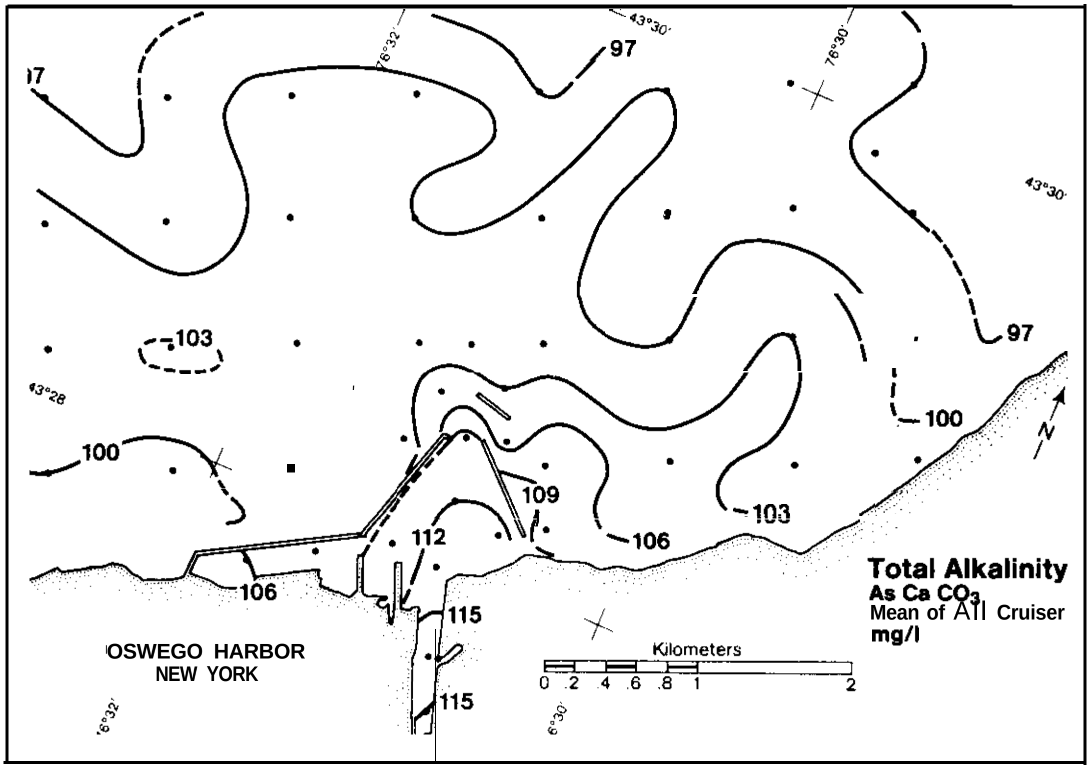

Figure 32. Distribution of total alkalinity (based on a grand mean of all cruises).

5.2.11 Specific Conductance

Specific conductance was selected as the primary parameter for defining plume patterns because of the large differential between the river and lake background values and the ease of measurement. Rapid shipboard analysis permitted the sampling program to be concentrated in and around the plume. This parameter was measured with a higher frequency than the individual ions, and the mea" distribution (Fig. 33) is more representative of the actual extent of the plume. The mea" specific conductance (Fig. 30) decreased from the river into the lake, with the highest dilution rate occurring between stations 7 and 9. The rate of decrease from station 4 to station 7 was less than the rate between stations 3 and 4 and is interpreted as being due to local input. Mean values at the peripheral stations to the north approached the mea" of 344 observed at the nearest IFYGL station and were within the range of individual offshore samples. Large daily fluctuations in the river were

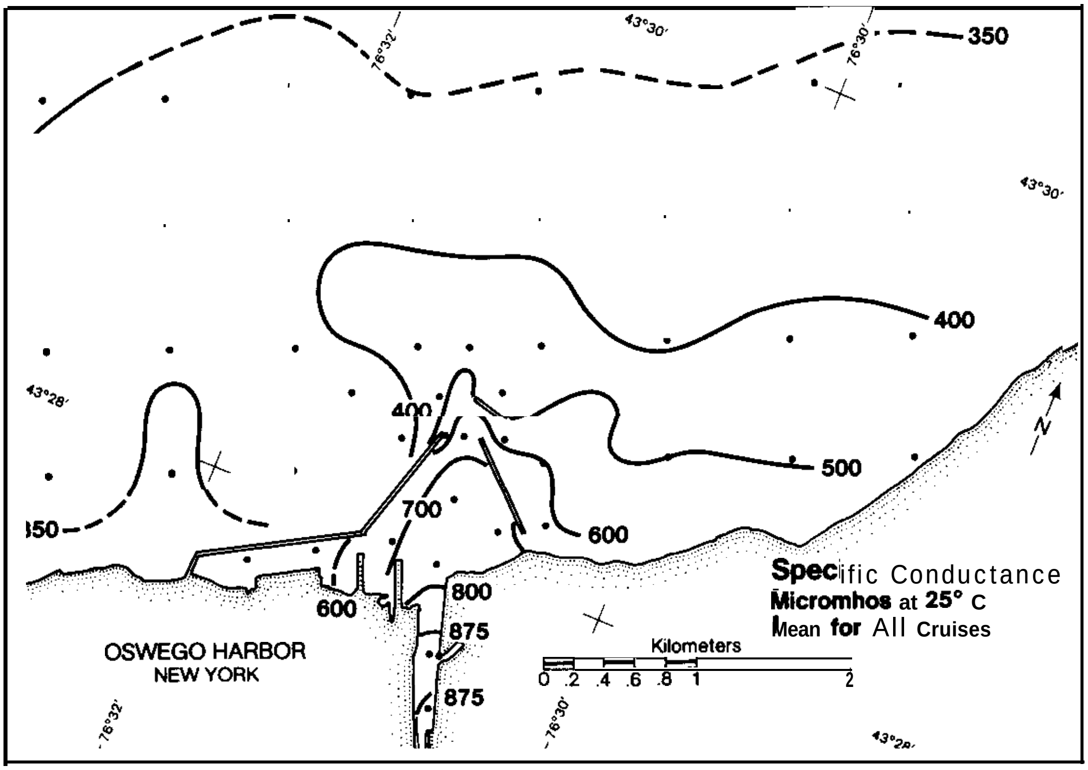

Figure 33. Distribution of specific conductance (based on a grand mean of all cruises).

common. The lowest values (Fig. 28) were recorded in May and the largest in October and November. As expected, the magnitude of the daily fluctuations were greater in the river at station 4 than at the harbor entrance (Fig. 19), except during the highest runoff periods in May and June. During these high flow periods, the river influx was great enough to dominate the harbor and allowed very little mixing with lake water along the channel within the harbor. Figure 33 shows the mean distribution, with the major influence of the plume to the east of the harbor. Periods of westward flow of the plume produced the anomaly to the northwest of the entrance. The predominant longshore flow was eastward and accounts for the higher values in the nearshore area to the east of the harbor. Figure 34 shows the areas where the variations in specific conductance were greatest. These variations are largely produced by the position of the plume at the time of sampling, and are related to the total chemical content of the river water and to the degree of mixing. The two lobes to the northeast and northwest of the harbor entrance show the area of greatest impact within the 0.2 (20-percent) coefficient of variation

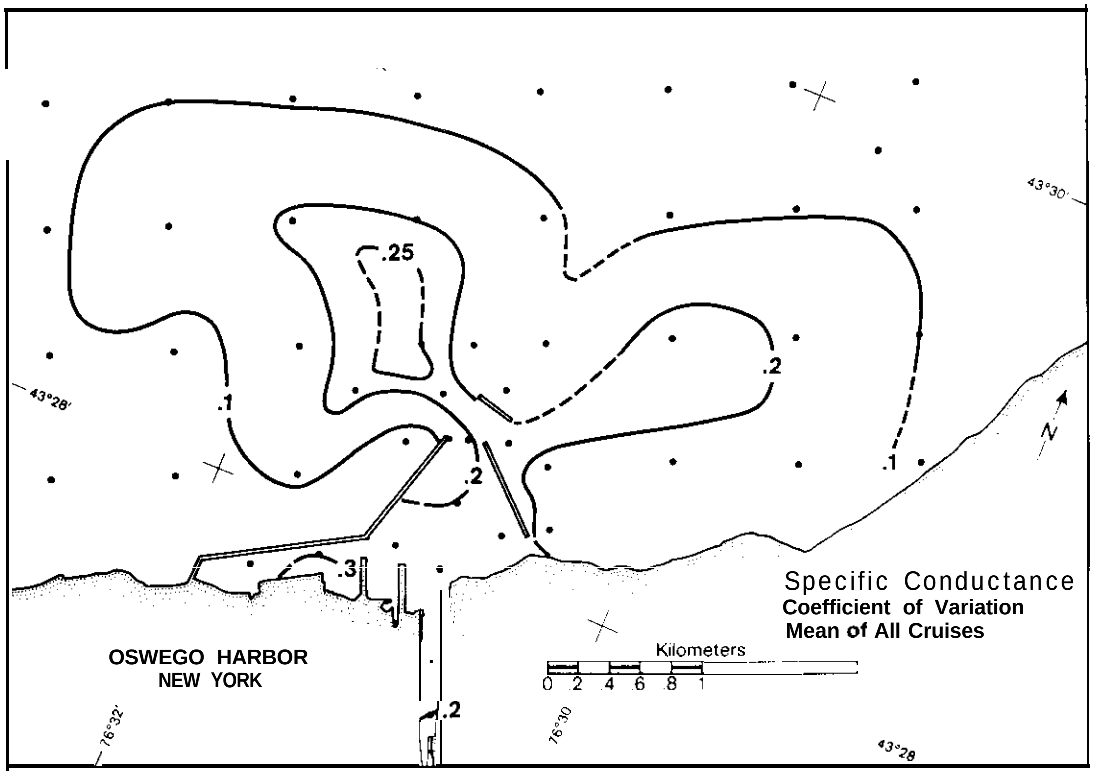

Figure 34. Variations produced by chemical changes in the water mass between sampling periods (based on the coefficient of variation of specific conductance).

contour. The nearshore area to the east of the harbor shows less variation due to the more consistent influence of the harbor effluent (Fig. 33). The coefficient of variation, as here applied, is the ratio of the standard deviation to the mean.

To determine the extent of the river influence on the adjacent lake, a program was developed to calculate the percentage of river water present in each sample. Since the concentrations do not decrease to zero, the limits were determined by using the maximum value in the river and by assuming the minimum value at peripheral stations to be lake background for this area during a given cruise. The percentage of river water present in each sample was calculated by using specific conductance for each sampling cruise as follows:

$$x = 100\left(\frac{C_s - C_L}{C_I - C_L}\right) , \qquad (1)$$

where X is the percentage of river water present in the sample, C_r is the background concentration of river water, C_L is the background concentration of lake water, and C_s is the concentration of the sample.

A mean percentage weighted for sampling depth variations was calculated for each station from formulas (2) and (3), below.

$$(D_{i+1} - D_i) \times (C_{i+1} + C_i) = P_1 \ . \qquad (2)$$

C_i is the concentration of samples of a given parameter at depths D_i, where D_1 is the depth in meters of the shallowest sample and D_n is the depth of the deepest sample. $\bar{X}_w$ is the mean weighted for sampling depth variations and can be determined as follows:

$$\bar{X}_W = \frac{(P_1 + P_2 + P_3 + \cdots + P_n)}{2(D_n - D_1)} \ , \qquad (3)$$

Example:

Depth m	Concentration mg/1	
0	50	$(5 - 0) \times (30 + 50) = 400 = P_1$
5	30	$(10 - 5) \times (10 + 30) = 200 = P_2$
10	10	$(20 - 10) \times (5 + 10) = 150 = P_3$
20	5	$\bar{X}_w = \frac{(400 + 200 + 150)}{2(20 - 0)} = 18\ 75$ mg/1

Figure 35 is based on a grand mean calculated from all of the weighted means of percentages of river water present at each station and shows the areas most effected by the river and harbor effluent. Under average conditions, the river water is diluted to 10 percent within an area extending 2 km westward and 3 km eastward.

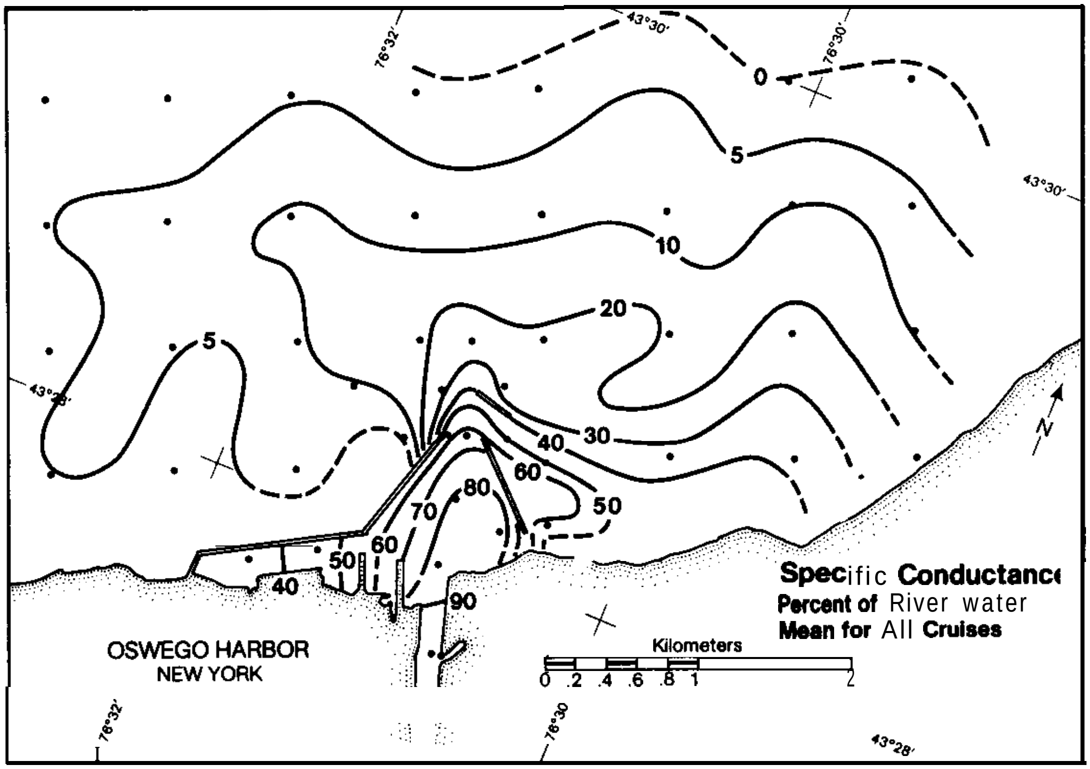

Figure 35. Mean areal variations of plume. Contours based on specific show the percentage of river and harbor water present.

5.2.12 pH

The pH of the river water was lower than that of the lake water (Fig. 36). The values observed in the river in May were higher than those in November. The magnitude of the fluctuations between cruises in the river was not as large as that of the ions (Fig. 24). During the high flow periods in June and during the fall runoff, the pH dropped to below 8.0. Shampine (1973) shows a range of from 7.0 to 7.8 at Lock 7 for the period from 1957 to 1966. When the 1972 data are compared with the older surveys, there appears to be a change to more alkaline conditions. Although this could be a trend, there are not enough long-term data for verification. Differences in analysis techniques could produce at least part of the differences. Figure 37 shows the mean distribution, with relatively low values along the northern and western sides of the area. These are due to a combination of factors produced by sampling these perimeter stations only when the plume extended into the vicinity of the station. In the area around the harbor entrance and extending approximately 3 km to the northeast, a higher sampling frequency gives a more

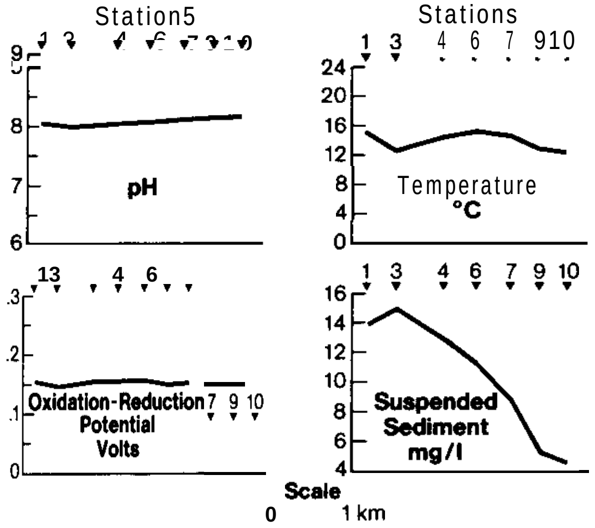

Figure 36. Variations in pH, Eh, suspended sediment, and temperature along the channel from the river into the lake (based on a grad mean of all cruises).

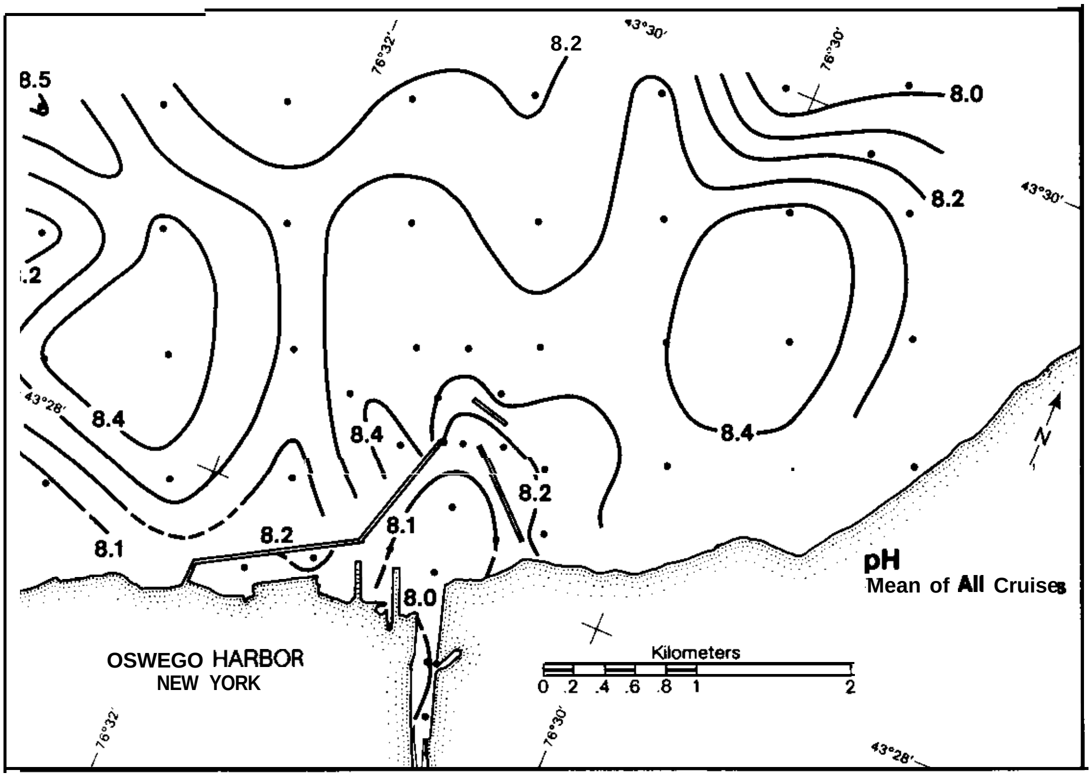

Figure 37. Distribution of pH (based on a grand mean of all cruises).

realistic mean for the nearshore area. Offshore sampling at IFYGL station 90 showed a mean of 8.31.

5.2.13 Eh

The oxidation-reduction potential of the river water fluctuated seasonally (Fig. 24). All values were positive, with individual samples ranging from a low of 0.100 to a high of 0.240 volts. Values generally decreased as the flow increased during the high runoff period in June and again in October and November at the start of the fall runoff. The highest values were recorded during the lower flow periods. The mean varied very little from station 1 (Fig. 36) to the lake. There was a slight increase lakeward along the harbor channel. Lower values were observed in the western part of the harbor (Fig. 38). Reducing conditions in the bottom sediment was also found to be greater in the western part of the harbor. The apparently anomalously low value around station 14 is due to values (0.080–0.104) recorded on 22 June when the plume was moving westward (Fig. 5). Other stations in the vicinity and within the plume on the same date did not show these lower values. There is a sewage outfall to the southwest, but it is not likely to have affected

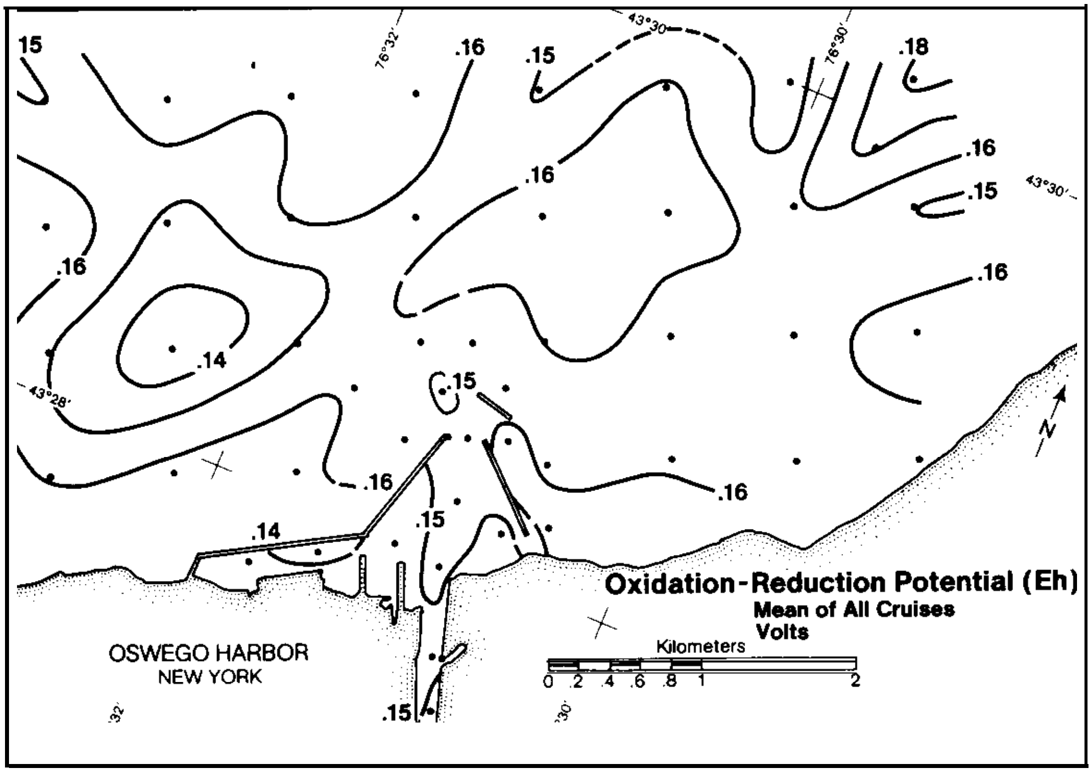

Figure 38. Distribution of oxidation-reduction potential (Eh) (based on a grand mean of all cruises).

only this station. The majority of the values in the nearshore area were within the range of from 0.114 to 0.168 observed at the nearest IFYGL station.

5.2.14 Dissolved Oxygen

The oxygen content of the river (Fig. 39) and lake water, expressed as percent saturation, was high throughout the area. At no time was there a serious depletion. The highest saturations in the river were at station 3. This is to be expected because of the upstream aeration produced by the spillway and the rapids above Bridge Street. The mean content decreased to a low of 93 percent at station 6 (Fig. 39), then increased toward the lake. The lowest mean concentration was recorded at station 36 in the western part of the harbor. The oxygen content is depleted slightly around the mouth of the harbor, but recovers rapidly. The low values at stations 41 and 43 in the northern part of the area were observed during sampling on 7 November and may be related to equipment malfunction. However, the 79 percent at station 43 does not represent a serious depletion since the mean concentration is 8.6 mg/l. The low value in the southwest corner of the area may be due to the same problem, but may also be related to depletion produced by a municipal outfall. Since the mean oxygen concentration is 9.6 mg/l at this station, the slight depletion would produce little effect on the adjacent environment.

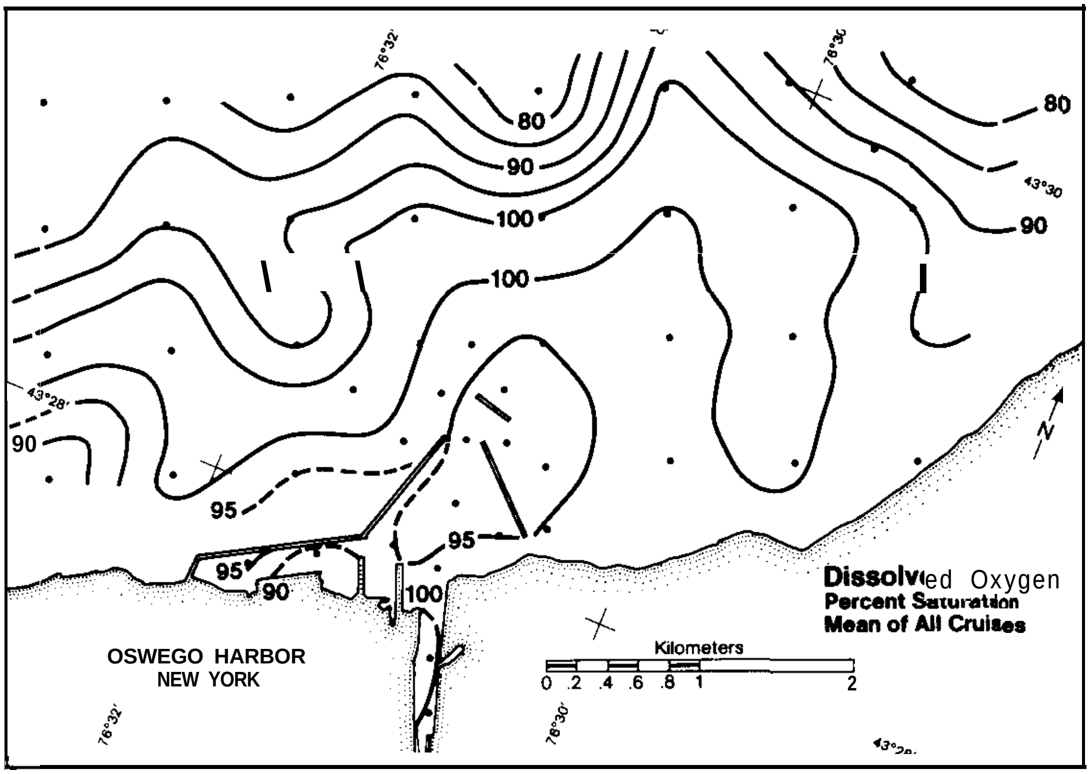

Figure 39. Distribution of dissolved oxygen (based on a grand mean of all cruises).

5.3 Suspended Sediment and Related Variables

5.3.1. Suspended Sediment

The sediment concentration was determined by filtering the 500-ml samples used for chemical analysis. There are no data for the interval within 1 m of the sediment-water interface. Figure 40 shows the suspended materials varying with the river flow, with the lowest concentrations during low flow periods in June, October, and November, and the heaviest load during the high spring flows. The mean concentration in the river reached a maximum at station 3 and decreased rapidly through the harbor into the lake (Fig. 36). The rates of decrease in concentration were similar between stations 3, 4, and 6, with a more rapid decrease between stations 6 and 9. Station 1 is in an eddy area separated by a shoal from the main river channel and the decrease appears to be due to sedimentation in that area. Sedimentation in the harbor on

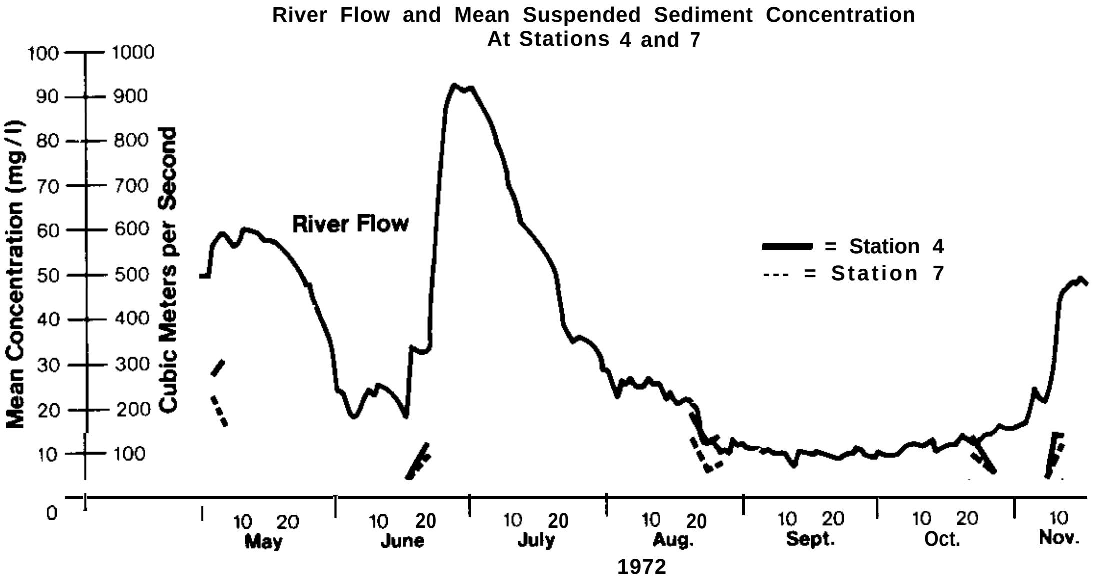

Figure 40. *Seasonal variations at stations 4 and 7 in the mean suspended sediment concentration and river flow.*

both sides of the river channel (Fig. 41) is indicated by the decrease in suspended sediment with distance from the channel. This area of sedimentation correlates with increased COD, volatiles, and oil and grease in the bottom sediment. The increased sediment concentration at station 37 is believed to be due mainly to materials resuspended by the discharge from the Niagara-Mohawk Power Plant. The concentrations were less at station 36 than at station 37; thus the river influence on the higher concentrations observed at station 37 appears minimal. Sedimentation of fine particulates occurs in the lower velocity areas around the harbor entrance and along the east breakwater. A high percentage of clay was noted in bottom sediments to the northwest of the harbor entrance and along the east side of the breakwater. The mea" suspended sediment distribution (Fig. 42) indicates that the main load is being carried eastward around both ends of the detached breakwater.

The density of the effluent is related to the combined effects of temperature and the entrained suspended and dissolved solids. I" cases where the turbulence factor is minimal, the relative densities of the effluent and the receiving water generally govern whether a plume initially has positive or negative buoyancy. The velocity of the effluent can also be an important factor, especially near the point of discharge.

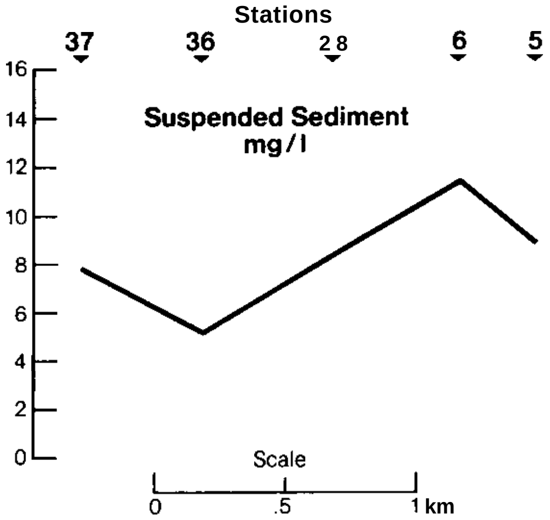

Figure 41. Variations in suspended sediment concentrations through the harbor along a southwest-northeast line between stations 37 and 5 (based on a grand mean of all cruises).

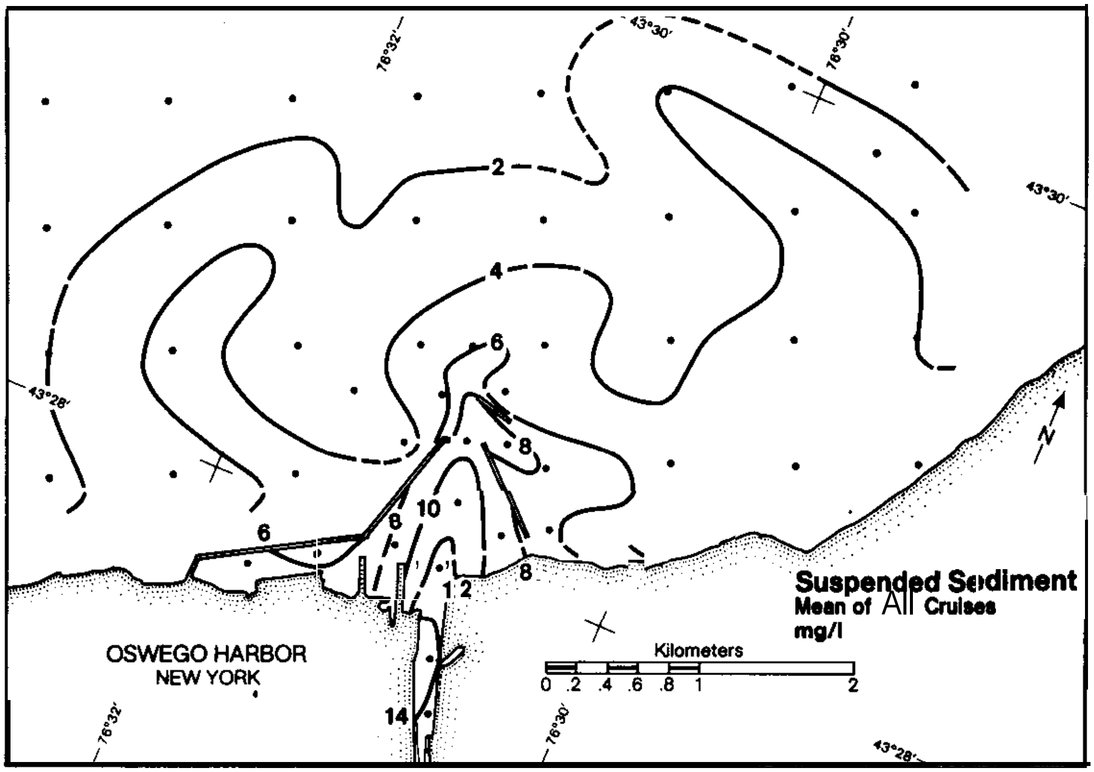

Figure 42. Distribution *of suspended sediment (based on a grand mean* **of** *all cruises).*

As a plume moves into the lake, the initial velocity decreases to that of the nearshore currents and the heavier suspended particles are deposited near the harbor mouth. The lighter particles ate carried alongshore and into the lake. If the effluent is colder than the receiving water, the plume tends to plunge (Fig. 12) at the point of merger. As a buoyant plume spreads and the temperature differential becomes negligible, the density of the turbid water produced by the suspended and dissolved solids becomes an important factor and the plume then tends to move toward the bottom. The downward movement can be interrupted by a thermocline that acts as a temporary bottom over which the plume spreads (Figs. 9, 15, and 43). The settling rate of those particles that have a density less than or near that of the hypolimnion water will be slowed, resulting in a greater concentration at or above the thermocline. Those particles will then move along the thermocline

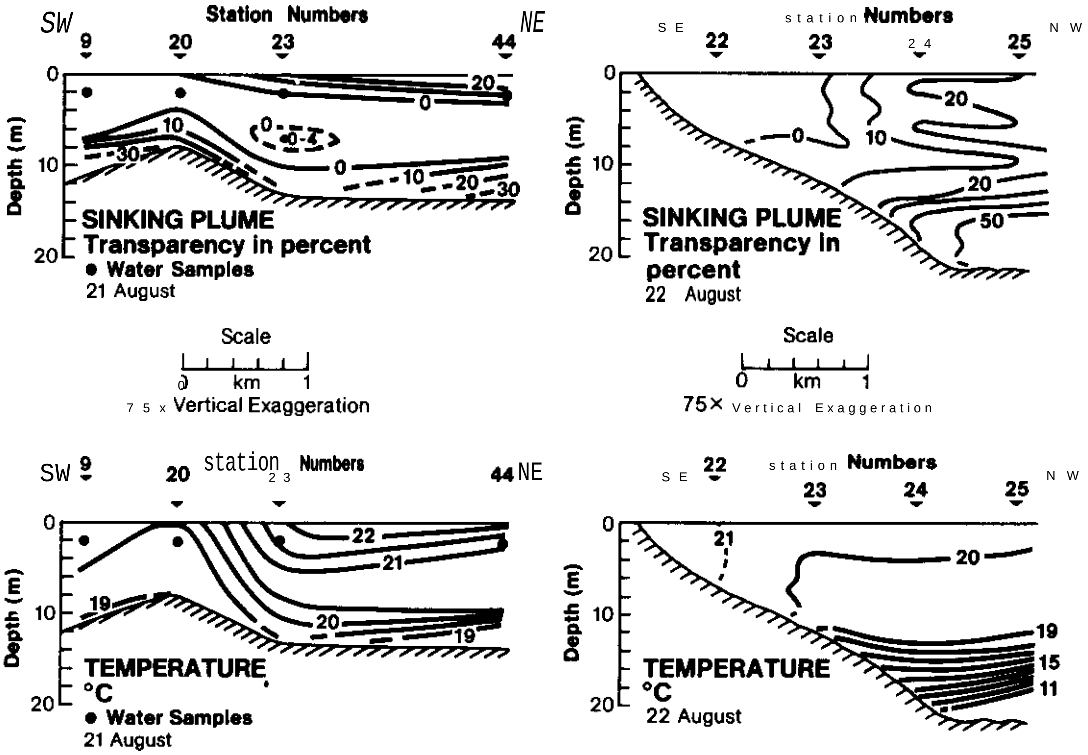

Figure 43. Movement of sinking plumes with respect to the thermocline as shown by variations in transparency and temperature, 21-22 August.

and may be widely spread before eventual sedimentation; this then results in a greater area of impact. When the thermocline dips away from the shore (Figs. 8 and 43), the density-induced movement over the inclined surface imparts a lakeward component to the plume direction, resulting in a wider distribution.

5.3.2 Transparency

The transparency of the water was determined by transmissometer and Secchi disc. The transmissometer in the configuration used is independent of incident light, dependent upon variations in suspended materials and dissolved color, and provides a means of comparing the transparency at various levels throughout the water column and between stations. It has an advantage over a Secchi disc because it can be used to construct vertical profiles and on very dark days or at night, and a disadvantage in that its use is limited under extremely turbid conditions.

Historically, the Secchi disc has been used as a measure of the light penetration into the water; it is a useful tool, especially in open-water areas. Buoyant turbid plumes can be readily detected visually and Secchi disc depths are useful in defining the lateral surface extent (Figs. 7 and 44). However, the Secchi disc gives no indication of the turbidity structure (Fig. 8) at depth. In the case of plumes with negative buoyancy, where the movement is toward and along the thermocline or bottom, the Secchi disc is of much less value (Figs. 12 and 45) and does not indicate the areal distribution.

In order to compare the transmissometer profiles with the historical Secchi disc data, it is necessary to develop a means of showing this relationship. U.S. Lake Survey Center personnel, including the author, developed a curve to show this relationship using Lake Michigan data from a 1970 survey (Pinsak, 1976, Figs. 4-56). That curve and Fig. 46 were both developed by averaging the percent transparency within the interval in which a Secchi disc was visible. Scatter on either side of the curve can be produced by the amount of available light, angle of incidence, sea state, vertical variations in concentrations of suspended materials, and/or color affecting the Secchi depth.

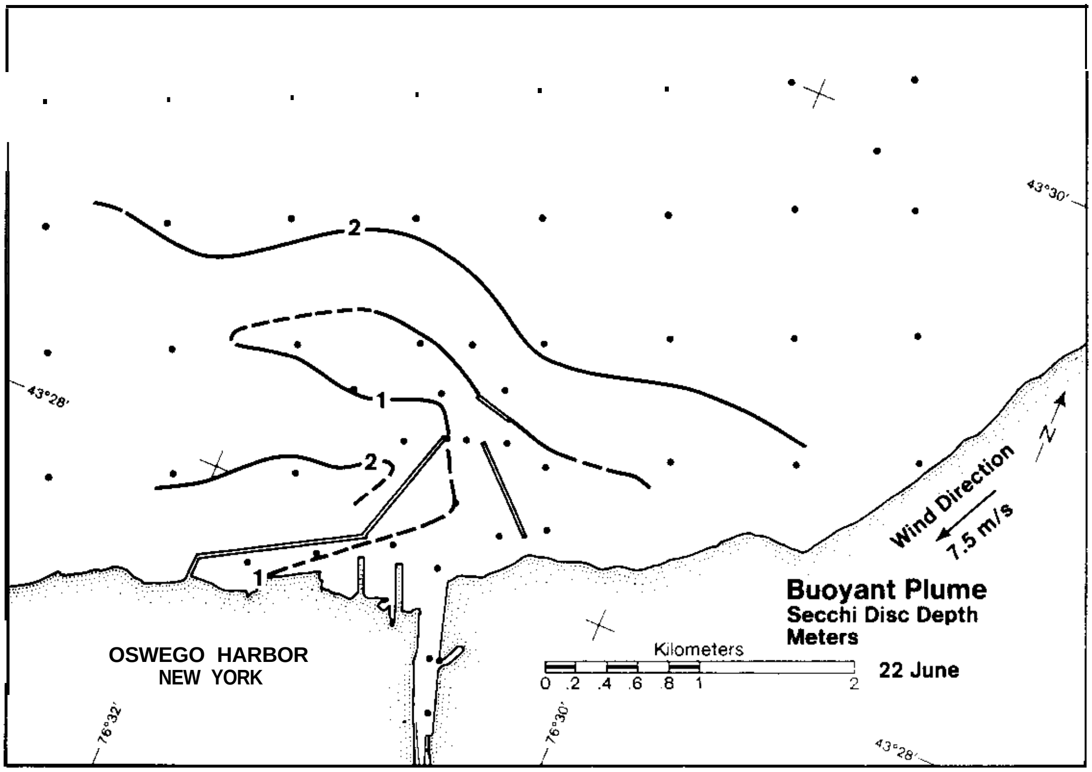

Figure 44. Secchi disc depths in buoyant plume, 22 June.

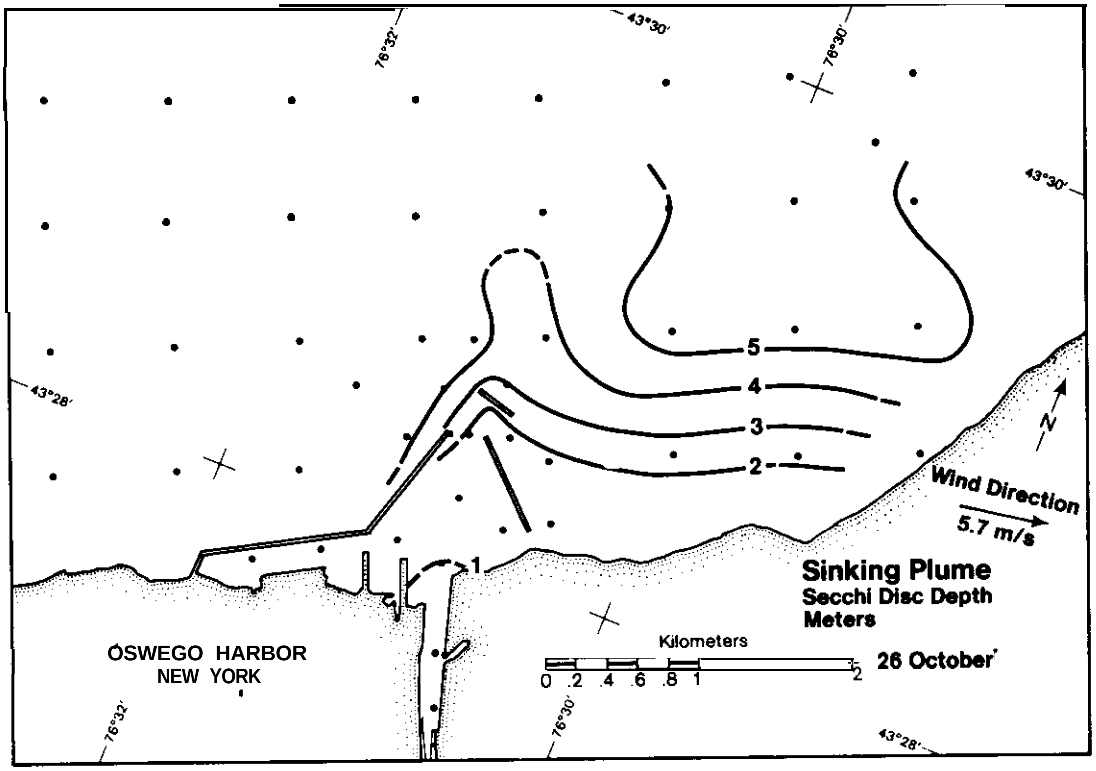

Figure 45. Secchi disc depths in sinking plume, 26 October.

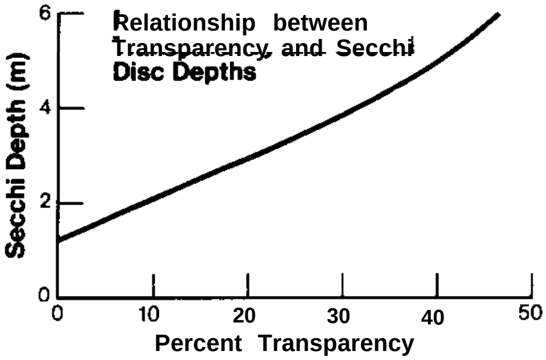

Figure 46. Relationship between Secchi disc depths and transparency as determined by transmissometer.

Water transparency in the river and harbor was low throughout the sampling season and Secchi disc depths were commonly less than 1 m owing to the influx of turbid river water. Throughout most of the harbor, light transmission along a 1-m path was usually not detectable with the transmissometer. The water in the harbor during the low flow period in October became clear enough to use the meter at stations S-7 and 36-37; however, the mean transparency did not exceed 4 percent at any station. During cruises on 19, 20, and 23 June and 19 and 20 August, wedges of lake water from 1 to 4 m in thickness, with a transparency range of from 1 to 20 percent were observed extending into the harbor along the bottom at station 7. During cruises on 19 to 24 October the river water temperature was decreasing more rapidly than in the harbor and lake, and the turbid river water was sinking in the harbor. The plume was traveling along the bottom at station 7, with less turbid water in the upper 1-5 m.

Transparency profiles were used to good advantage outside the harbor to supplement the chemical and temperature data and to detail the plume structure. Portions of the sinking plumes that were spreading over a thermocline or were positioned between or below water sampling levels (Figs. 9 and 43) were detected by variations in transparency. During the last cruise on 10 November, the plume structure was more complex. Secchi disc values (Fig. 47) indicate the westward movement,

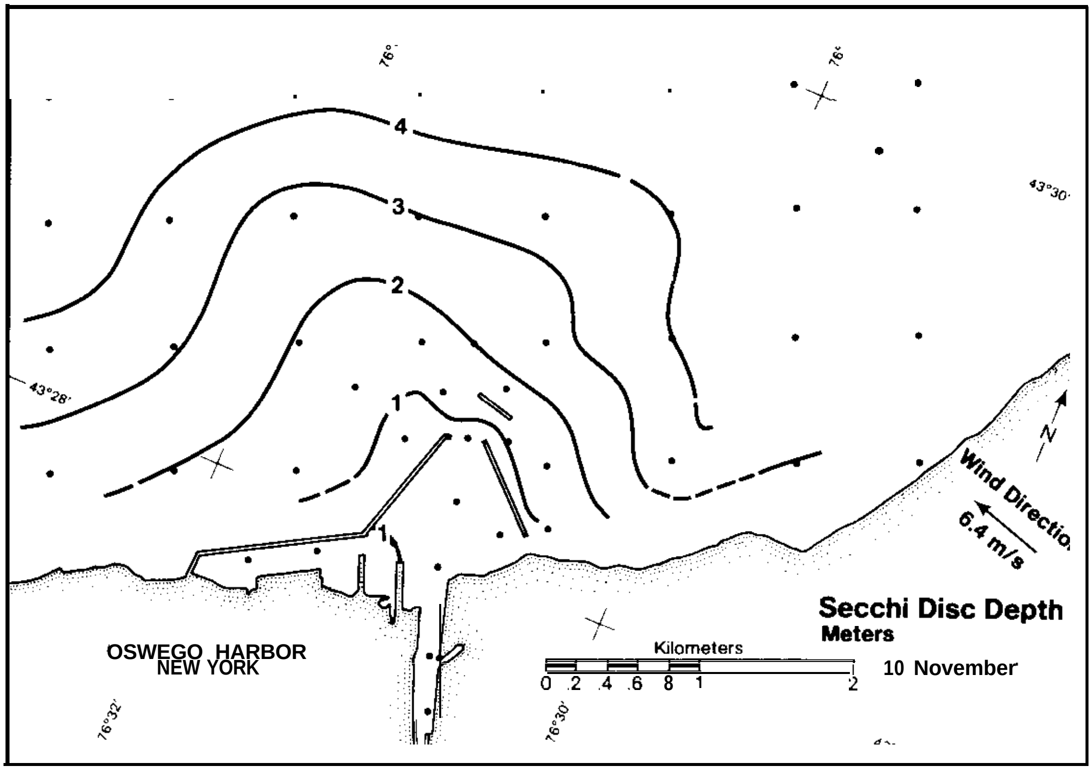

Figure 47. Secchi disc depths, 10 November.

but do not indicate which part of the water column is being most affected. Transparency profiles (Fig. 15) show that the plume occupies the entire water column near the entrance, moves along the surface toward the west and near bottom alongshore to the east. Figure 48 shows the mean transparency based on all cruises. The lowest transparency is shown in the river, harbor, and nearshore to the east with less turbid water toward the west. The feature (Fig. 48) to the northeast in which the region of lower transparencies curves north and westward was also noted for suspended sediment (Fig. 42). This current pattern was observed during cruise 15 and, to a lesser extent, cruise 11. If is not a common phenomenon as suggested by the mean transparency. Considering only the periods when both stations were sampled, the water at station 24 was 5 percent more transparent than at station 34 during 4 out of 5 cruises. Generally the main portion of the eastward moving plume passed to the south of station 24 and closer to station 34.

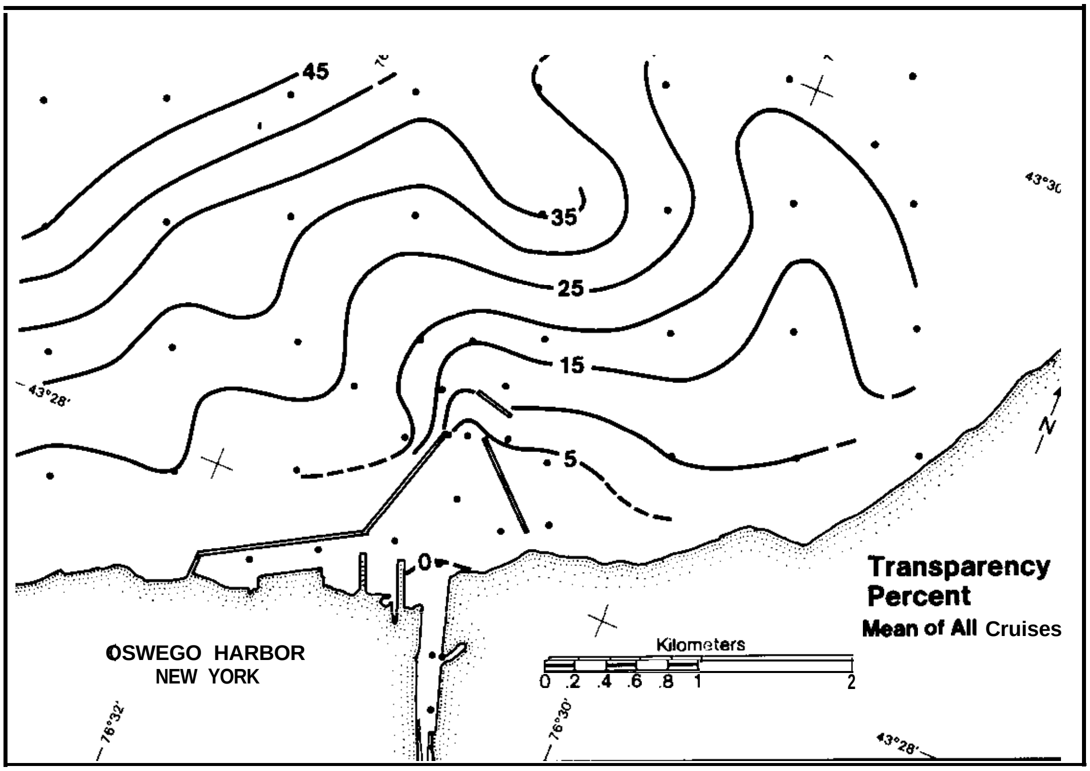

Figure 48. Distribution of transparency as determined by transmissometer (based on a grand mean of all cruises).

5.4 Bottom Sediment Characteristics

5.4.1 Harbor Sediment Sources

The river and, to a lesser extent, municipal discharge and local runoff are the principal sources of particulate material. Large annual deposits of sediment are reported by the Buffalo District Army Corps of Engineers in areas along the inside of the west breakwater and especially "ear station 28 and north of the Coast Guard basin. Their assessment (C. Zernentsch, personal communication) is that part of this material is being carried into the harbor over the west breakwater. During the 1972 sampling period, there were times when turbid water was observed going into the harbor over the west breakwater. However, no assessment was made of the volume of sediment being carried. I" 1972 a total of 97,797 m^3 of spoil was removed from the harbor by the hopper dredge *Lyman* from 25 June to 15 July and deposited in the lake. The disposal area is north of station 40 and covers an area 0.8 km square (U.S. Army Corps of Engineers, Appendix K10). Characteristically, the dredged materials and water are pumped into the hoppers and the excess water carrying finely dispersed solids is overflowed until a predetermined density of materials is reached. Most of the coarse materials settles out in the hopper, but some of the clays and silts, along with associated organics, tend to be discharged back into the harbor, where currents redistribute the fine materials or carry them into the lake.

5.4.2 General Sediment Characteristics

Bottom sediments were collected with a Shipek sampler and were usually examined with a 10X hand lens. These descriptions are summarized, but are not a part of this report.

Strong currents in the river tend to winnow the sediments, keeping the fine materials suspended and leaving the coarse materials. Sedimentation of the finely-divided materials begins on either side of the channel and in the plume area adjacent to the harbor entrance as the current velocity decreases. Fine to coarse sands and gravel with some clay were present in the high velocity area of station 3 (Fig. 49). Sands were predominant along the river channel, with decreasing grain size and increasing amounts of silts and clays in the lower velocity areas on either side of the channel and "ear stations 6 and 7. Outside the harbor, high percentages of clay were present to the northwest at stations 9, 10, 11, 17, and 30, and to the east of the breakwater at stations 8, 21, and 38. This distribution generally agrees with the suspended sediment distribution (Fig. 42). Sands with some clays are predominant throughout most of the area to the north and east of the harbor. To the west of the harbor, sediments are composed of fine to coarse sands with varying amounts of pebbles and cobbles ranging to 200 mm in diameter. Sands with gravels to 50 mm were recovered at a depth of 30 m. Sands with some coarse materials were predominate to the northeast at stations 19, 34, 42, and 43. Sediments recovered in August at stations 39 and 40 following the period of dredging and lake disposal showed alternating thin (3-25 mm) layers of clay and sand, with varying

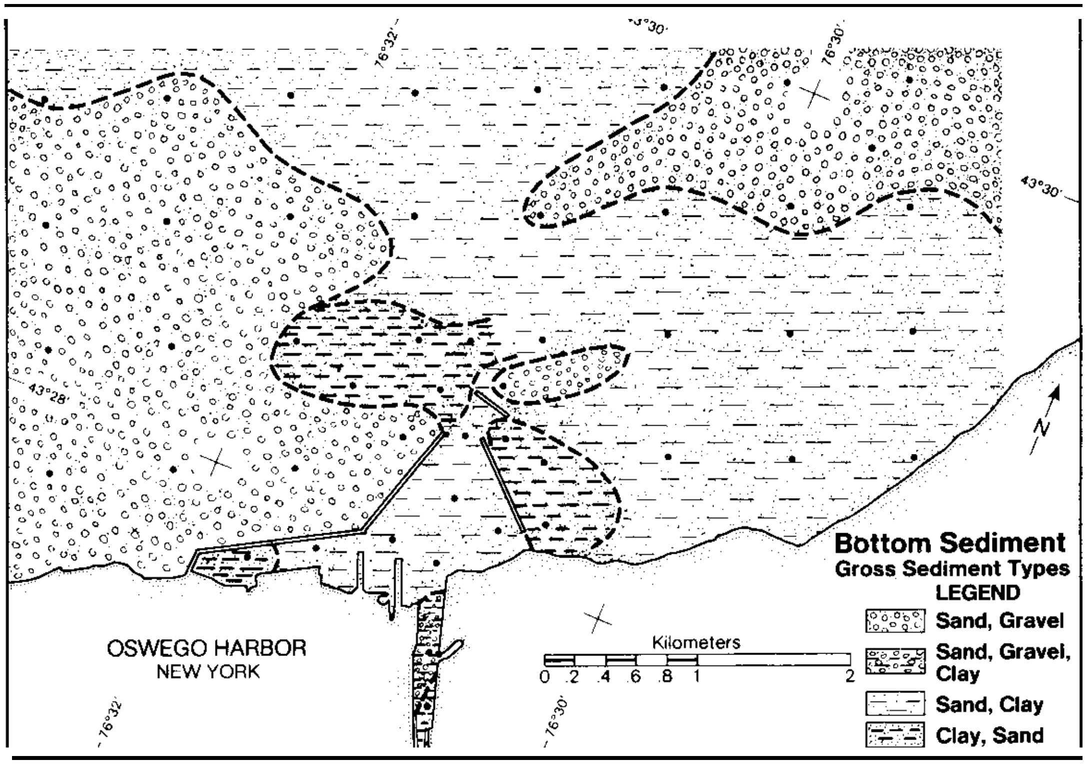

Figure 49. Distribution of gross bottom sediment types.

amounts of carbonaceous materials similar in part to sediments recovered in the harbor. The layering observed at station 39 in August was not evident in October. Layering was still present at station 40, but the percentage of clay and very fine sand had decreased.

Most of the lake bottom in the nearshore area is characterized by a very thin layer of sediment, often less than 25 mm overlying a hard bedrock (Oswego sandstone). Similar findings were reported by Sutton et al. (1970). The sediment recovered at a given station varied throughout the season from a very thin layer to none. The thickest deposits were closest to the harbor entrance or in depressions in the bedrock surface. The water depth throughout most of the sampling area is less than 20 m (Fig. 1). This is a high-energy area exposed to waves from the west, north, and east. Apparently the combined effects of the alongshore and wave generated currents, coupled with the character and volume of source sediment, tend to keep the bedrock surface relatively clean adjacent to the harbor. Sediments from the river are initially deposited in the area of the plume and later moved out of the area alongshore and ultimately into deeper water.

5.4.3 Volatiles

The volatiles, expressed as a percentage of dry solids, were highest in the river at station 1 and lowest at station 3 (Fig. 50). The percentage increased at station 4, then decreased along the channel through

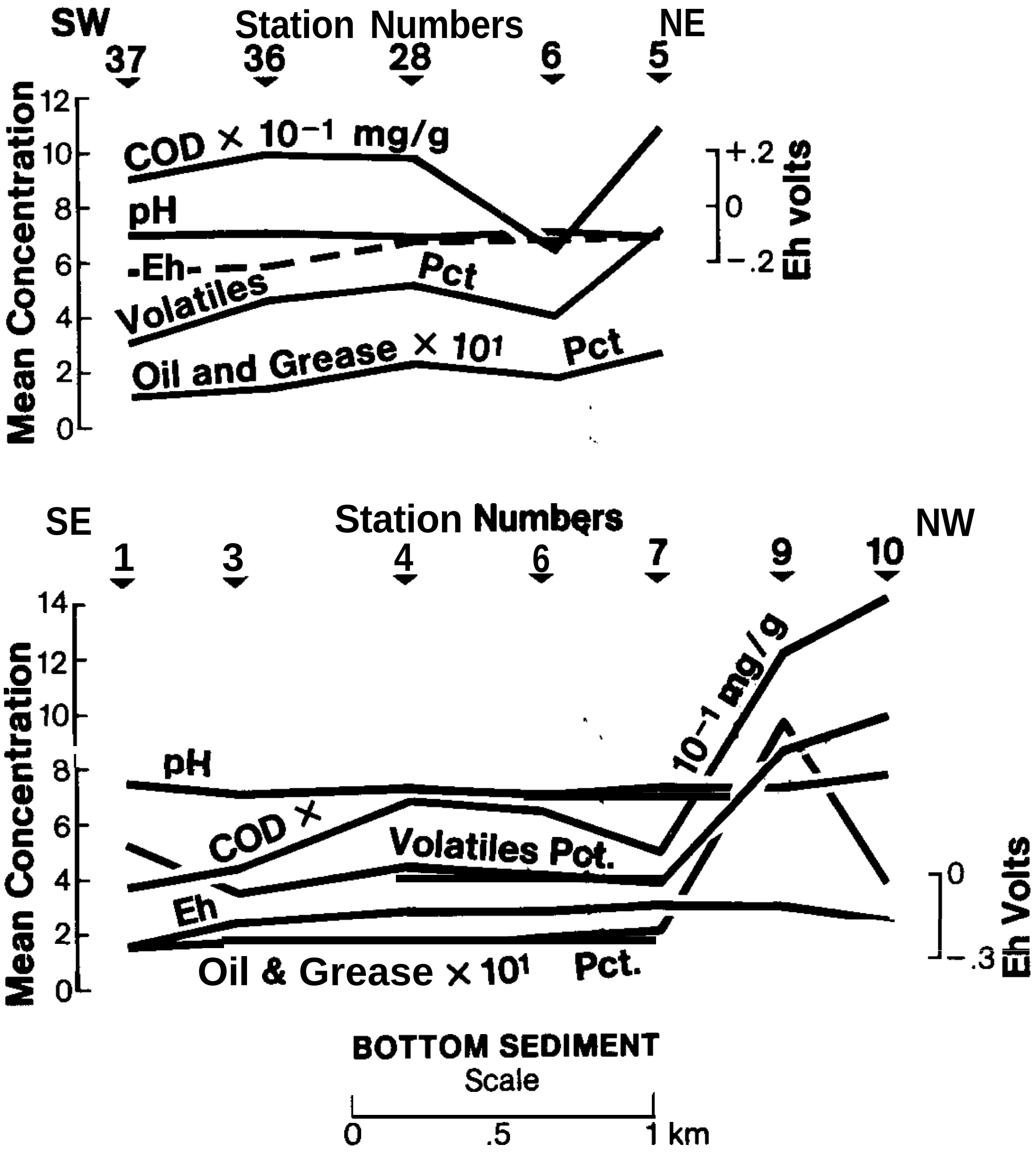

Figure 50. Chemical characteristics of the bottom sediment through the harbor and along the channel from the river into the lake.

the harbor. Outside the harbor the volatiles increased, reaching a maximum in the area north of the entrance at stations 9, 10, 11, 20, and to the east at station 45 (Fig. 51). During each of the first four sampling periods, the highest percentages were in the area immediately north of the entrance or east of the harbor in the nearshore area. The first sampling following the dredging and disposal in the lake was in August, at which time the volatile percentage was found to be 1.9 at stations 39 and 40. Mean percentages (Fig. 51) ranging from 1.3 at station 39 to 2.3 at station 25 are believed to be the result of dredged spoil disposal. The highest concentrations within the harbor were on either side of the main channel at stations 5 and 28 in areas of lower current velocity (Figs. 41 and 50).

5.4.4 Oil and Grease

Due to its course nature, the sediment at river stations 1 and 3 was not analyzed during the May and June cruises and the sediment from station 4 was not analyzed during the October cruise. Analysis in the lake area was limited by the availability of sufficient sample volume. The mean oil and grease distribution (Fig. *50)* varies along the river and harbor channel from a low of 0.13 percent of the dry solids at

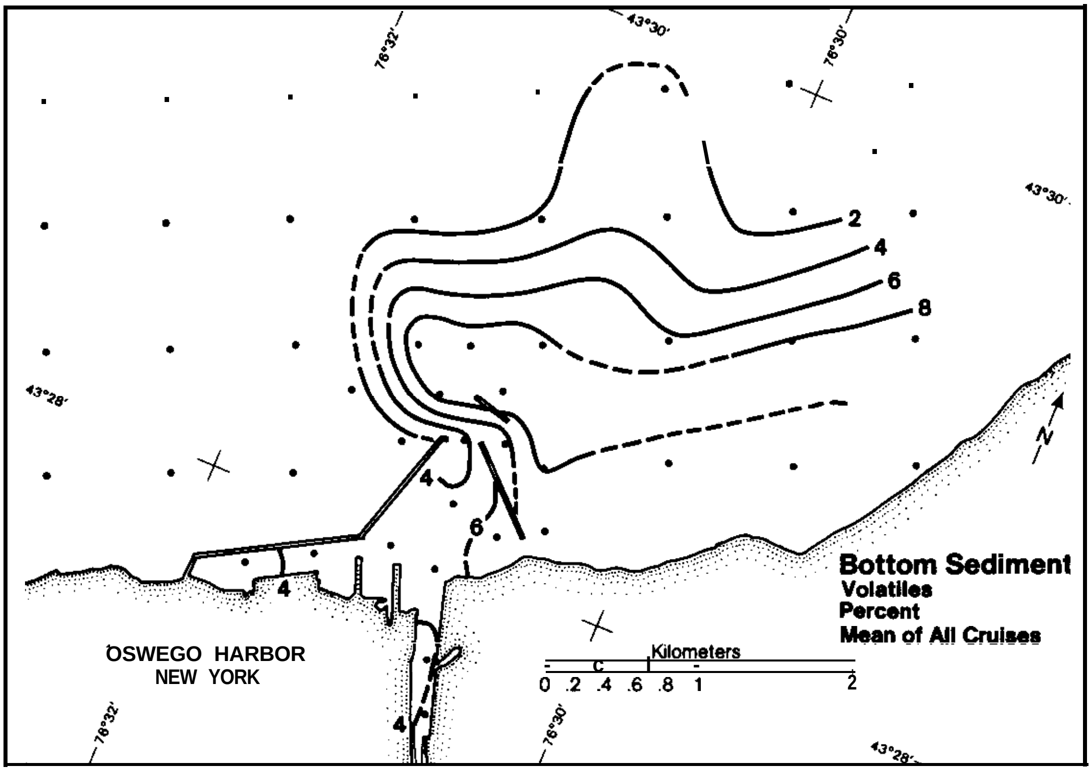

Figure 51. Distribution of volatiles in bottom sediment (based on a grand mean of all cruises).

station 4 to a high of 0.19 percent at station 7. Part of this variation is probably due to the sampling frequency. The east-west variation in the harbor is similar to that of the volatiles and COD (Fig. 41), with the highest concentration on either side of the channel. Outside the harbor the highest concentration was found north of the entrance and alongshore to the east (Fig. 52) in the same general area where clays and volatiles were found to be concentrated. Following harbor dredging, the percentages at station 40 were equal to or exceeded the percentages at stations 7 and 9. Therefore, the concentrations at stations 39-41 appear to be related to the disposal of harbor materials in this area.

5.4.5 Chemical Oxygen Demand (COD)

The COD increased from the river into the harbor (Fig. 50), reaching a maximum in the channel at station 4. The sediment at all stations on either side of the channel showed more COD (Figs. 50, and 53) than any station along the channel. The distribution pattern generally agrees with that of volatiles and, to a lesser degree, that of oil and grease. The relatively clean nature of the sediments on the west side of the harbor entrance is indicated by mean values of less than 3 mg/g at stations 29 and 30. The area of greatest impact outside the harbor is

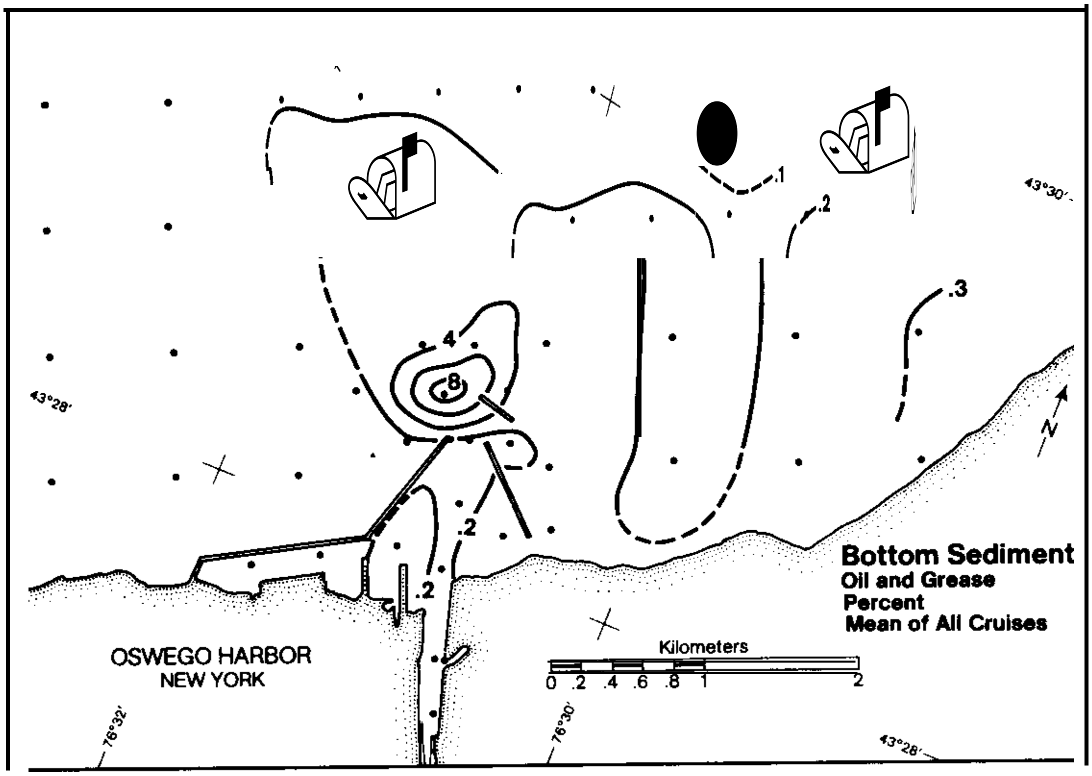

Figure 52. Distribution of oil and grease in bottom sediment (based on a grand mean of all cruises).

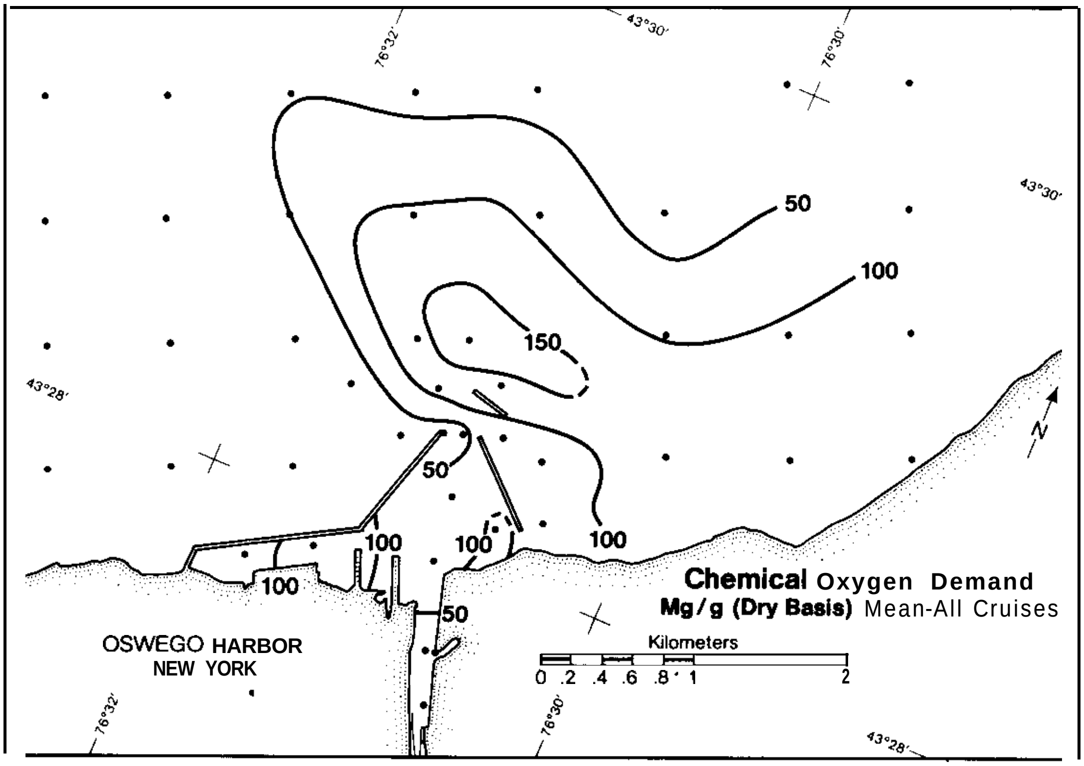

Figure 53. Distribution of chemical oxygen demand in bottom sediment. Results in mg/g (dry basis) (based on a grand mean of all cruises).

again shown to be just north of the harbor entrance and alongshore to the east of the harbor. The apparent effect of spoil disposal is again noted along the north side of the area.

5.4.6 pH

The pH or negative log of the hydrogen ion activity is a direct measurement of acidity. A glass probe was inserted into the bottom sediment and a measurement made of the interstitial water. The coarse nature of the sediments in the river and the small volume recovered at many of the offshore stations limited the number of analyses at a given station. The pH generally decreased from the river to the harbor near station 6, then increased (Figs. 50 and 54) to the lake, reaching a maximum in the area of stations 10 and 11. There was very little east-west variation through the harbor. The lowest pH values were within the harbor in the areas of sedimentation and at peripheral stations to the

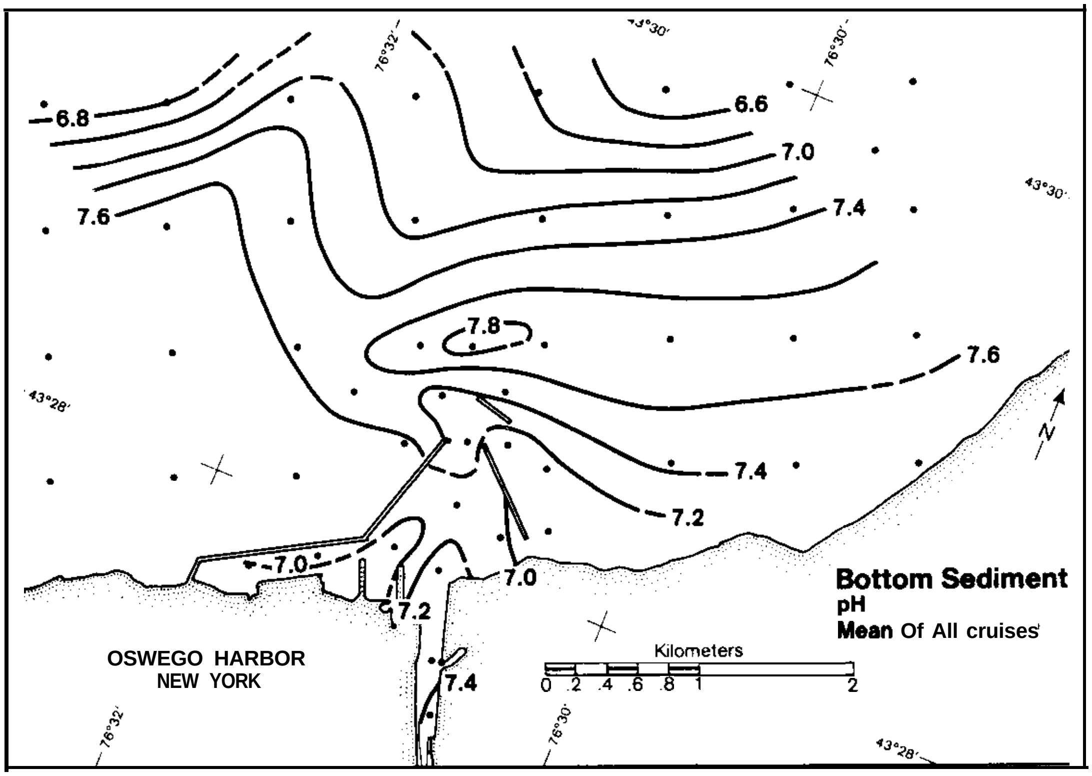

Figure 54. Distribution Of pH in the bottom sediment (based on a grand mean of all cruises).

north of the harbor. The lower values near the dumping ground were recorded following the dredging period and apparently are more related to dredged spoil from the harbor than to sedimentation from the plume.

5.4.7 Eh

The oxidation-reduction potential within the interstitial water is a measure of the reactions taking place in which electrons are gained or lost. In general, poorly-aerated fine-grained sediments high in organic content tend to be associated with reducing conditions and exhibit a. low positive or negative potential, while clean sands in a well-aerated environment are associated with oxidizing conditions and exhibit a positive potential. Reducing conditions are found (Figs. 50 and 55) throughout the river and harbor, with the maximum values noted at station 1 and at station 37 in the western portion, where the sediment contained an abundance of carbonaceous materials. The reducing conditions at station 11 are present in fine-grained sediments in which the volatiles, oil and grease, and COD were also high. Oxidizing conditions to the

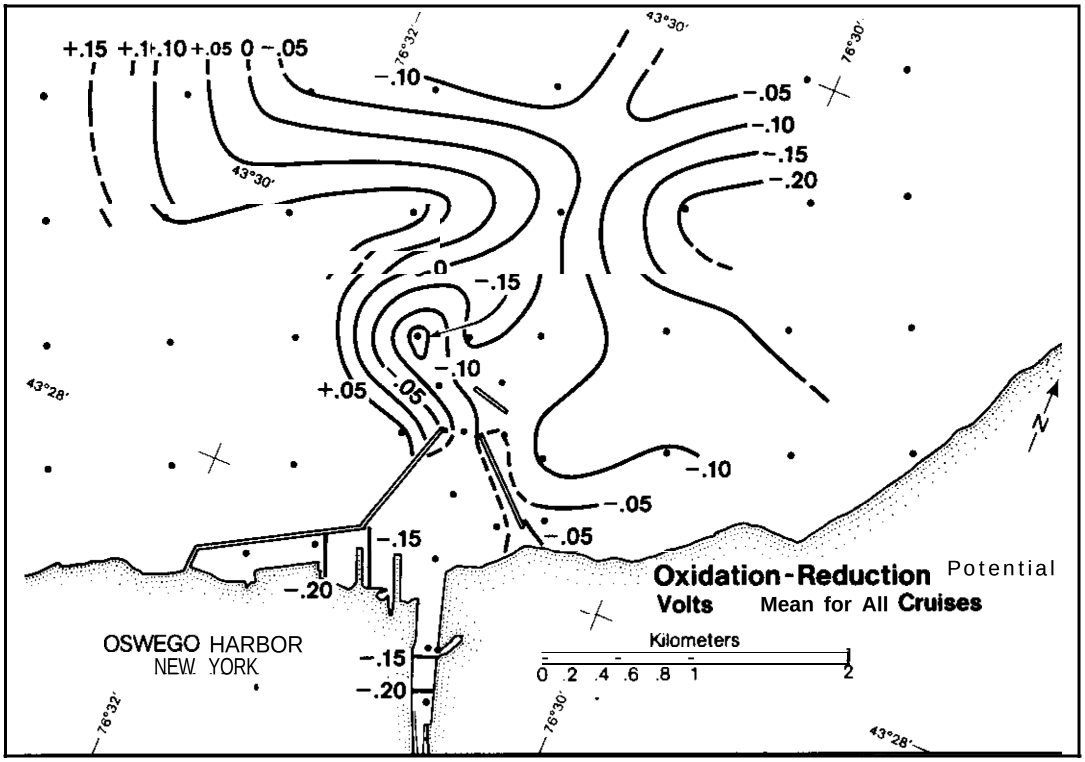

Figure 55. Distribution of oxidation-reduction potential (Eh) in volts in the bottom sediment (based on a grand mean of all cruises).

west of the zero contour were present in a predominantly sand environment (Fig. 49). To the east, reducing conditions occur in a predominantly clay-sand environment that contains varying amounts of carbonaceous materials. The values adjacent to the dumping ground were similar to those within the harbor near the main channel.

5.5 Total Coliform

The coliform group of bacteria is common and many of these bacteria are native to the intestinal tracts of warm-blooded animals and man. These commonly enter the water through fecal discharges and are associated with enteric pathogens, some of which cause dysentery, typhoid fever, and cholera. Therefore, the potentially dangerous areas in which disease-producing viruses and/or microorganisms could be present are those in which the high total counts are encountered. The survival time of the pathogens is normally shorter than that of the coliform; thus there is generally less danger in the low total count areas.

Total coliform tests were conducted less frequently than most other tests. Tests in the river, harbor, and plume area in the lake were selected for broad coverage rather than detail. The lake background outside of the plume showed counts generally less than 100 colonies per 100 ml. The counts in the harbor and river were generally in the thousands and consistently high. Seasonally, the highest counts were found in June and October and were associated with increasing stream flow. The colony counts per 100 ml at station 1 ranged from 100 on 2 May to 21,000 on 27 October and averaged 5100. Counts at station 37 in the western part of the harbor ranged from 1820 to 14,600 and averaged 5200 colonies even when the remainder of the harbor showed counts of less than 1000. Another area that "as relatively high was in the vicinity of stations 22 and 32 and especially at 32. Each of these three areas is associated with municipal outfalls.

Counts in the lake were highest in the areas where the plume was concentrated. The results of sampling on 22 August, 27 October, and 10 November were compared with the percent transparency. Regardless of whether the plume "as buoyant or sinking, the highest colony counts for a given station, with few exceptions, were in the region of low transparency. In some cases where the plume "as sinking, the high count "as in the lower part of the water column within or immediately above the plume.

5.6 Loading

The following table (7) shows the daily loadings from the river using the method adopted by the International Joint Commission to calculate the daily average tributary loading $(\bar{\mu}')$ for a year. In this case, the 1972 calendar year is used.

$$\text{Daily Loading} = \bar{\mu}' = \mu_x \cdot m_y/m_x + \frac{1 \cdot m - (m /\bar{x} \cdot m_x)}{n - 1} \qquad (4)$$

where μ_x = average daily flow for the year,

m_y = average daily loading for the days concentrations were determined,

m_x = average daily flow for the days concentrations were determined,

n = number of days concentrations were determined,

$m_y/\bar{x}$ = average ratio of loadings to flows for the days concentrations were determined.

$$m_y/x = \frac{\sum y_i/x_i}{n} \qquad (5)$$

Table 7. Loadings to the Lake by the Oswego River

Variable	$\bar{x}$ **metric** tons/day	$\bar{x}$ **metric** tons/day (Casey and Salbach, 1974)
Nitrate	21.23	17.46
Phosphate	5.16	2.86 (TP)
Chloride	3865.60	4032.83
Sulfate	1823.00	1559.01
Silica	44.59	68.73
Calcium	2143.36	2352.32
Magnesium	284.13	468.37
Sodium	1681.54	1754.25
Potassium	82.45	104.39
Total suspended materials, stations 1, 3	528.605	
Total suspended materials, station 7	378.05	

where y_i = the daily loadings and
x_i = the daily flows

for the days concentrations were determined. In all cases excepting sulfate, nitrate, and phosphate, the loadings as calculated by Casey and Salbach are higher, but in reasonable agreement with the findings of this study (Table 7). This study is based on 12 complete samplings between May and November, while Casey and Salbach reported on the results of a sampling every 2 days during the field year and should be more representative of actual river conditions. However, their sampling point was upstream opposite the lock and above the municipal discharges. Their results do not reflect the input of nitrate and phosphate into the lower river and harbor that is indicated by this study (Fig. 17).

The total suspended materials load in the river shows an input of 192,941 metric tons during the calendar year 1972. The load being discharged from the harbor at station 7 is 137,988 metric tons. This leaves a difference of 54,953 metric tons, presumably deposited within the harbor. During 1972 the Corps of Engineers dredged 97,793 m^3 (127,909 yds^3) with a reported absolute density of 2520 and an in-place density of 1670 grams/l (C. Zernmtsch, personal communication).

The percentage of dry solids in 24 samples at 7 stations in the harbor before and after dredging averaged 53.68 percent. Using the absolute density from the Corps of Engineers, I computed in-place density to be 1352.74 grams/l. This value agrees more closely with the in-place density of 1408 reported by the Corps for 1976 and is used in this report for computing the loadings to the lake by dredging. The 132,288 metric tons dredged is considerably greater than the calculated deposit of suspended materials.

Several factors may be responsible for this difference. Data are not available to estimate the river-borne bed-load materials, the volume of materials being carried into the harbor over the west breakwall, or the volume dredged from the channel outside the harbor, which was deposited by longshore currents. The sediment load being discharged at station 7 may not be as large as calculated, since it could also contain suspended materials being carried around the ends of the breakwalls by longshore currents.

Dredging varies yearly, with an average of 64,987 m^3 (85,000 yds^3), of which approximately 3823 m^3 is by private interests (B. Wallace, Personal Communication). A total of 34,624 m^3 was dredged in 1976 by the Corps.

Table 8 shows the loading due to dredging operations and disposal in the lake, but does not reflect the additional loadings due to dredging agitation and the loss of very fine particulates by dredge overflow. These polluted sediments have a large impact on the lake environment. The magnitude of overflow losses is shown in a U.S. Army Corps of Engineers report (1969, Appendix B5).

Table 8. Loading to the Lake Attributable to Dredging, 1972

Variable		Metric tons per year
Volatiles	4.6 pct. of dry solids	6,085
Oil and grease	0.187 pct. of dry solids	247
Chemical oxygen demand (COD)	84.25 mg/g, dry basis	11,145
Based on:		
Dredged total	97,793 m^3	
Percent solids	53.68	
Density, absolute	2,520 g/l	
Data from harbor stations	4, 5, 6, 7, 28, 36, and 37	

6. SUMMARY AND CONCLUSIONS

Ion concentrations, specific conductance values, and suspended materials in the river were relatively high as compared to lake background levels. In most cases the concentrations decreased rapidly through the harbor into the lake. Seasonal variations of the ions generally showed lower concentrations in the river in May and higher in the fall. Daily variations were large in some cases, especially when the river flow rate was changing. There were indications of loading of nutrients, chloride, COD, and volatiles into the lower portion of the river and harbor, presumably largely from municipal discharges. However, oxygen depletion was not a problem at any point in the harbor. The suspended materials load varied with the flow rate and was higher in May and lightest in October, when the river flow was near the year's low. During low flow periods, dilution begins in the harbor near station 4 and at times between stations 3 and 4. The degree of dilution occurring within the harbor is largely dependent upon the volume of river flow and the temperature differential between the two bodies of water.

Heat loading into the harbor, other than from the river, was from the Niagara-Mohawk Steam Station. Cooling water obtained from the lake and discharged into the western end of the harbor tends to keep the adjacent portion of the harbor warmer and less turbid and provides an additional flushing action.

Analyses of the data indicate conservative mixing for all variables, with the occasional exception of particulate matter. Under high flow conditions, the particulate matter appears conservative, but under low flow conditions, particulate matter is settling out in the plume area and on either side of the channel in the harbor. The remainder of the variables mix with gradients similar to those of conductance.

A comparison of the mean specific conductance of the river and harbor water with that of the lake background shows that 90 percent of the dilution occurs within 3 km to the northeast and 2 km to the west of the harbor entrance.

Owing to the large differential between river and lake background values, specific conductance is a rapid and easily applied test to the tracing of river water movement through the harbor and area of diffusion. Transparency profiles were used in conjunction with bathythermograph data to supplement the chemical and temperature data and to conveniently detail the plume structure. This approach was especially useful during periods of sinking plumes and in complex structures where a portion of the plume was between sampling levels or spreading over the thermocline.

The combined effects of temperature and the entrained suspended solids govern the density structure and the vertical form of the plume cross section. During late spring and summer, the relatively warmer plume tends to spread over the cooler lake water, and lake water intrudes into the harbor along the bottom. This reverse flow complicates the settling patterns of particulate matter. During late summer and fall, the relatively cooler river water tends to plunge beneath the lake surface at or near the harbor entrance.

The prevailing current direction is northeastward; however, periods of northward and westward flows were observed. The plume was moving eastward during 26 of the 33 cruises, or 79 percent of the time. The detached breakwater split the plume into northward and shoreward components during prevailing conditions. Plume configurations varied in response to modifying effects of stream flow, prevailing longshore currents, and current variations related to changes in wind direction and velocity. The buoyant plume responded more rapidly to changes in wind direction and velocity than did the sinking plume. During high stream flow, the plume was carried farther into the lake around the west end of the detached breakwater before being deflected by longshore currents.

Materials with high concentrations of oil and grease and other organics that are deposited in the harbor exert a deleterious effect on that area. Dredging operations resuspend some of these materials, which are then redistributed within the harbor or in the nearshore area. Dredged spoil deposited offshore produces an impact on the deeper portion of the lake that would not normally be present. Outside the harbor the settled particulate matter, temporarily stored in the sediment of the plume area, has a strong effect on the local environment primarily through oxidation of the river-borne labile organic matter. COD and Eh measurements of bottom sediment (homogenized upper 5 cm) show both the potential and apparent effect of the labile material on the nearshore sedimentary system.

The increase in COD and negative Eh at stations 39-41 appears to be related more to dredged spoil than to deposition from the plume. This observation is supported by the general lithologic characteristics of the sediment. The sedimentary material deposited in the neat-shore area is continually moved and its ultimate transport is presumably lakeward. Particulates deposited below wave base prior to stratification are essentially separated from the epilimnion by the development of a thermocline. After stratification the movement of fine particulates over the thermocline surface provides a mechanism by which these materials are kept in suspension and more widely distributed.

Relatively minor amounts of sediment, often less than 2.5 cm in thickness, were found overlying bedrock outside the harbor. Apparently the combined effects of the longshore and wave generated currents, coupled with the character and volume of source sediments, tend to keep the materials moving and the nearshore lake bottom surface relatively clean.

7. ACKNOWLEDGMENTS

I wish to thank A. P. Pinsak, under whom the task was developed, for guidance throughout the project; the Lake Survey Center research staff for assistance in data collection and compilation; S. D. Schiavo, U.S. Geological Survey, for river flow data; R. W. Cummings and R. C. Clancy, Niagara Mohawk Power Corporation, for discharge flow rates and temperature data from the Oswego Steam Station; the Oswego City Engineer's office for information regarding sewage disposal; B. Wallace and C. Zernentsch, U.S. Army Corps of Engineers, Buffalo District for dredging data; J. Clark, International Joint Commission, Windsor, Ont., for the tributary loading formula; and A. Robertson and B. J. Eadie for suggestions and editing support during the writing of the report.

8. REFERENCES

American Public Health Association (1965): *Standard Methods for the Examination of Water and Wastewater*, 12th ed., Washington, D.C.

Bell, G. L. (1974): Diffusion at Oswego Harbor, New York Abstract, paper presented at the 17th Conference on Great Lakes Research, International Association for Great Lakes Research, Hamilton, Ontario, August 13, 1974.

Casey, 3. J., and S. E. Salbach (1974): IFYGL stream materials balance study (IFYGL). In: *Proceedings of the 17th Conference on Great Lakes Research,* Ann Arbor, International Association for Great Lakes Research, 668-681.

Chermack, E. R. (1970): Study of thermal effluents in southeastern Lake Ontario as monitored by an airborne infrared thermometer. In: *Proceedings of the 13th Conference on Great Lakes Research,* Ann Arbor, International Association for Great Lakes Research, 904-913.

Csanady, G. T., and J. T. Scott (1974): Baroclinic coastal jets in Ontario during IFYGL. *J. Phys. Oceanogr.*, 4(4): 524-541.

Fishman, M. J., and M. W. Skougstad (1965): Rapid field and laboratory determination of phosphate in natural water, U.S. Geological Survey Professional Paper 525-B, U.S. Govt. Printing Office, Washington, D.C. 20402.

Great Lakes Pilot (1972): Published by Lake Survey Center, U.S. Dept. of Commerce, Detroit, Michigan.

Kantrowitz, I. H. (1970): Groundwater resources in the eastern Oswego River basin, New York, Basin Plan. Rept. ORB-Z, New York State Water Resources Comm.

Landsberg, D. R., J. T. Scott, and M. Fenlon (1970): Summer circulation patterns near Nine Mile Point, Lake Ontario. In: *Proceedings of the 13th Conference on Great Lakes Research,* Ann Arbor, International Association for Great Lakes Research, 444-452.

Miller, G. S. (1976): Harbor and nearshore currents, Oswego Harbor, New York, NOAA Tech. Rept. ERL 360-GLERL 7, National Technical Information Service, Springfield, Va.

The Perkin-Elmer Corporation (1971): *Analytical Methods for Atomic Absorption Spectrophometry.* Hartford, Conn.

Pinsak, A. P. (1976): Physical characteristics. In: *Great Lakes Basin Framework Study. Appendix 4: Limnology of Lakes and Embayments,* Ann Arbor, Great Lakes Basin Commission, 23-69.

Rainwater, F. H., and L. L. Thatcher (1960): Methods for collection and analysis of water samples, U.S. Geological Survey Water Supply Paper 1454, U.S. Govt. Printing Office, Washington, D.C. 20402.

Shampine, W. J. (1973): Chemical quality of surface water in the Eastern Oswego River Basin, New York, Basin Plan. Rept. ORB-6, Eastern Oswego Basin Regional Water Resources Board.

Sutton, R. G., T. L. Lewis and D. L. Woodrow (1970): Nearshore sediments in southern Lake Ontario, their dispersal patterns and economic potential. In: *Proceedings of the 13th Conference on Great Lakes Research,* Ann Arbor, International Association for Great Lakes Research, 308-318.

Sweers, H. E. (1969): Structure, dynamics, and chemistry of Lake Ontario. Canada Centre for Inland Waters, Dept. of Energy, Mines, and Resources.

U.S. Army Corps of Engineers (1969): Dredging and water quality problems in the Great Lakes, Volumes 6 and 10, Appendices B5 and K10. Department of the Army, Corps of Engineers, Buffalo District, Buffalo, N.Y.

U.S. Geological Survey (1972): Water Resources Data for New York: Part 1. Surface Water Records. U.S. Dept. of Interior.

U.S. Geological Survey (1973): Water Resources Data for New York: Part 1. Surface Water Records. U.S. Dept. of Interior.