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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Environmental Research Laboratories

Harbor and Nearshore Currents, Oswego Harbor, New York

GERALD S. MILLER

BOULDER, COLO.
JANUARY 1976

U.S. DEPARTMENT OF COMMERCE
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NOTICE

CONTENTS

FIGURES

HARBOR AND NEARSHORE CURRENTS, OSWEGO HARBOR, NEW YORK

Gerald S. Miller

Lagrangian current measurements were made in Oswego Harbor and in the nearshore area of Lake Ontario close to the harbor during the latter 2 weeks of the months of June, August, and October 1972. Currents within the harbor are primarily a function of Oswego River inflow modified by wind stress; speeds up to 50 cm/sec were observed in the harbor during anomalously high river inflow during June. Nearshore currents, responding rapidly to changes in wind stress, in turn determine the path of the harbor effluent During peak flows (spring) the turbid plume extends up to 3 km into the lake whereas during low flows (fall) the plume often does not reach the detached breakwall before being swept away by the nearshore current. Outflow from the river is buoyant during spring and summer and frequently sinks below the warmer lake water during fall months.

1. INTRODUCTION

Oswego Harbor, located on the south shore of Lake Ontario, is the terminus of the Oswego River and Oswego Canal of the New York State Barge Canal System. Two arrowhead breakwalls and a detached breakwall protect a 1.13-km^2 area which serves as a harbor of refuge and harbor terminal (fig. 1).

This report presents the results of a study to determine current patterns in the harbor and adjacent nearshore area and to relate these patterns to the main generating forces. Several coastal investigations have been conducted in the Oswego area (e.g., Scott, 1973; Scott et al., 1971; Landsberg et al., 1970; Scott and Landsberg, 1969; Scott and Lansing, 1967). The results indicate persistent eastward flowing baroclinic coastal currents. It has been observed that wind stress transports warm Lake Ontario surface water toward the south shore, thereby resulting in strong baroclinic coastal currents toward the east (Scott and Lansing, 1967). Airborne thermal mapping of the harbor area indicates that the outflow of warm river water and power-plant cooling effluent from the harbor affects the water temperature and nearshore flow patterns out to more than 4 km in the lake and that the higher temperature water is evident through all seasons (Chermack, 1970). Dynamic height analysis (Scott et al., 1971) also indicates a northward bulge at Oswego.

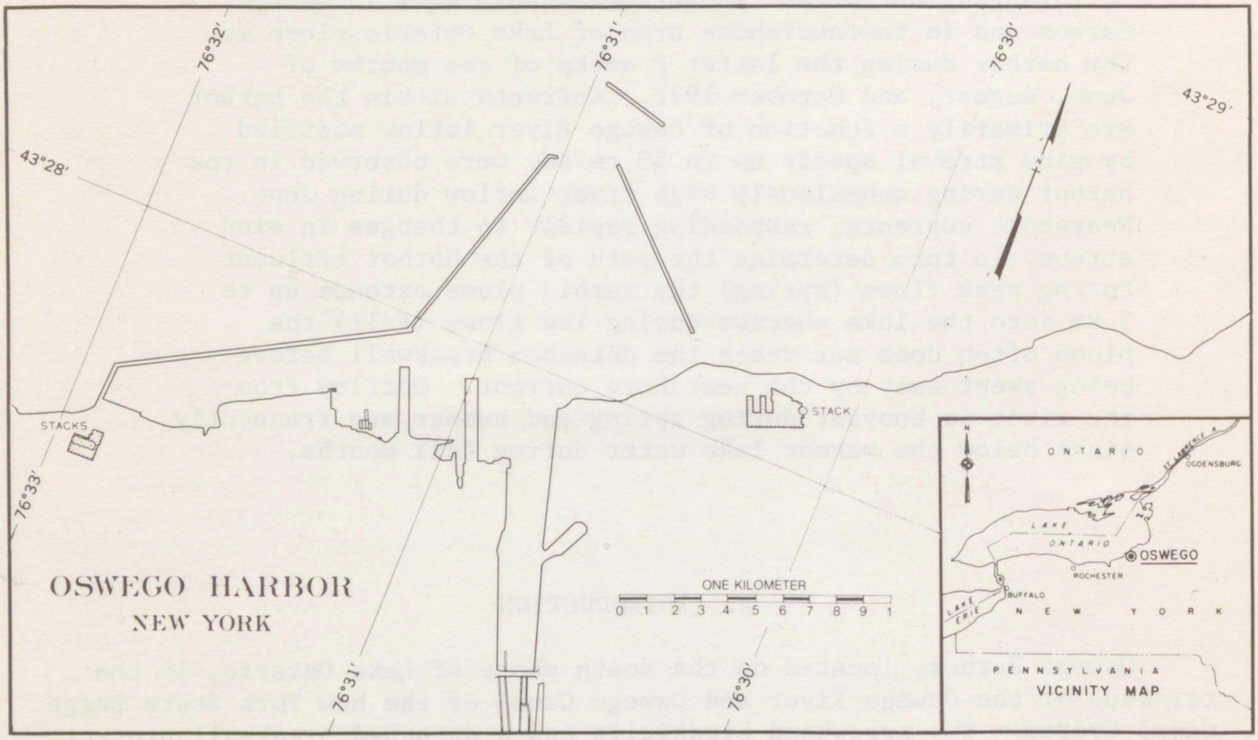

Figure 1. Location map, Oswego Harbor.

2. DATA

Current measurements were taken during three periods: 14-22 June, 15-24 August, and 17-25 October 1972. By use of transits, cruciform type

46- x 30-cm drogues were tracked to determine the current velocity. Usually, six drogues at depths of 0.3 m to 7 m were tracked simultaneously with fixes on a particular drogue every 6 or 12 minutes. Larger drogues, 1.2 m x 1.5 m, used in the mid-lake current investigation (Saylor, 1974) were deployed, when possible, in the nearshore area and tracked with Decca positioning equipment aboard the *R/V Shenehon*. Time between position fixes varied from 1/2 hour to several hours. Selected drogue data are presented in this report.

Meteorological data collected at three International Field Year on the Great Lakes (IFYGL) sites near Oswego are considered representative of conditions at the harbor. The stations are IFYGL Buoy 19 (43°71'41"N, 76°44'36"W), IFYGL Buoy 20 (43°43'00"N, 76°37'57"W), and IFYGL Land Station 29. All of the above stations operated during most of the June measurement period, but during August only the land station was operational; no wind velocity data was recorded at these IFYGL sites during the October period. Wind data for October was obtained from a site 1 km from the lake and about 8 km southwest of the harbor (Sykes, private communication). Although overwater wind velocity data are more desirable when studying water currents, land station data were used because the data are more complete and wave induced buoy motion degraded the overwater wind data.

Short-term water level fluctuations are not large or frequent on Lake Ontario. The frequency of occurrence of a 0.5-m rise at Oswego is once every 42 months (Corps of Engineers, 1952). Current velocity through an opening is a function of the rate of change and of the cross-sectional area through which it moves, not simply the magnitude of the change. The largest water level fluctuation rate during the measurement periods was 14 cm/hr, which would generate about a 2 cm/sec current through the harbor entrance. Since large short-period variations in level are infrequent at Oswego, water level variations are not considered in the current analysis.

Flow data for the Oswego River (U.S. Geological Survey, 1972; Schiavo, private communication) represent the total flow at Oswego and include the flow in Hydraulic and Oswego Barge Canals. The Oswego River drains 13,200 km^2. A large amount of natural storage and some artificial regulation is provided by the many large lakes and locks on the Erie and Oswego Barge Canal systems. The 37-year (1933-70) average flow is 176 m^3/sec. Large diurnal flow fluctuations are caused by powerplants above the gage sites; for example, the diurnal extremes between 15-25 October 1972 ranged from 48 to 125 m^3/sec. The mimimum and maximum flows typically occur at 0200-0400 and 1200-1600 EST, respectively. Diurnal fluctuations are evident only after the flow rate drops below 170 m^3/sec. The Oswego River flow was 400 and 265 percent above the previous 9-year (1963-72) average for 14-25 of June and August, respectively, and 130 percent above the average for the corresponding period in October. The large increase in flow during the latter part of June was caused by heavy precipitation associated with tropical Storm Agnes, which passed over the drainage basin on 20-25 June. Normal to above normal precipitation over the basin through July and August maintained the above normal flow.

Niagara Mohawk Corporation's Oswego Steam Station located on the west side of the harbor releases cooling water into the harbor at rates up to 22 m^3/sec. (Clancy, private communication). The mean-daily discharge ranged from 5 to 21 m^3/sec during the measurement periods, and effluent temperature averaged 18°, 25°, and 16°C for the latter 2 weeks of the months of June, August, and October 1972, respectively.

Water temperature profiles were taken by the *R/V Shenehon* at stations in and around the harbor area. Sampling stations were 400 to 800 m apart. One-meter interval temperatures were scaled from the electronic bathythermograph (EBT) trace and checked against reversing thermometer readings at selected depths, when available. Transparency profiles were also taken at some of these stations; these data are given as a percentage of the light transmission in air.

3. RESULTS

3.1 June 1972

Offshore winds dominated the 14-22 June period; eight of thirteen observations periods were during south-southeast to south-southwest winds. Fig. 2 and 3 show the trajectories of the large and small drogues during south of southwest winds on 15 June. Currents within the harbor were lakeward throughout, accelerating through the harbor entrance. The speed increased to over 40 cm/sec about 1 km lakeward from the harbor as the outflow came under the influence of coastal currents in Lake Ontario. Four large drogues released 2 km west of the harbor and 0.8 to 2 km offshore moved parallel to shore at speeds from 28 to 55 cm/sec. The northward bulge noted by Scott et al. (1971) and Chermack (1970) was evident as the drogues passed the harbor. Coastal current measurements 4.2 km southwest of Oswego Harbor (Scott, 1973) showed an alongshore current component exceeding 20 cm/sec between 3 and 7 km offshore on 14 June, increasing to 40 cm/sec 2.5 km from shore on 15 June.

Light northerly winds commenced during the early morning hours of the 17th, increasing to 4 m/sec 3 hours before the first run. The strong eastward alongshore current of the previous 3 days was replaced by a 10 cm/sec westward flow (fig. 4). Trajectories inside the harbor during the afternoon traced a figure-eight pattern, indicating several interacting eddies with some inflow through the opening between the east breakwall and shore.

Trajectories for 20 June showed the basic characteristics observed during offshore winds (fig. 5). Currents were basically lakeward through the harbor, being forced by the offshore wind and the 340 m^3/sec inflow from the Oswego River. (The previous 9-year average flow for 20 June was 100 m^3/sec.) The detached breakwall split the flow, forcing a portion of the effluent eastward. The main plume continued northward until being dominated by the nearshore current. The warmer river water, buoyed up over the cooler

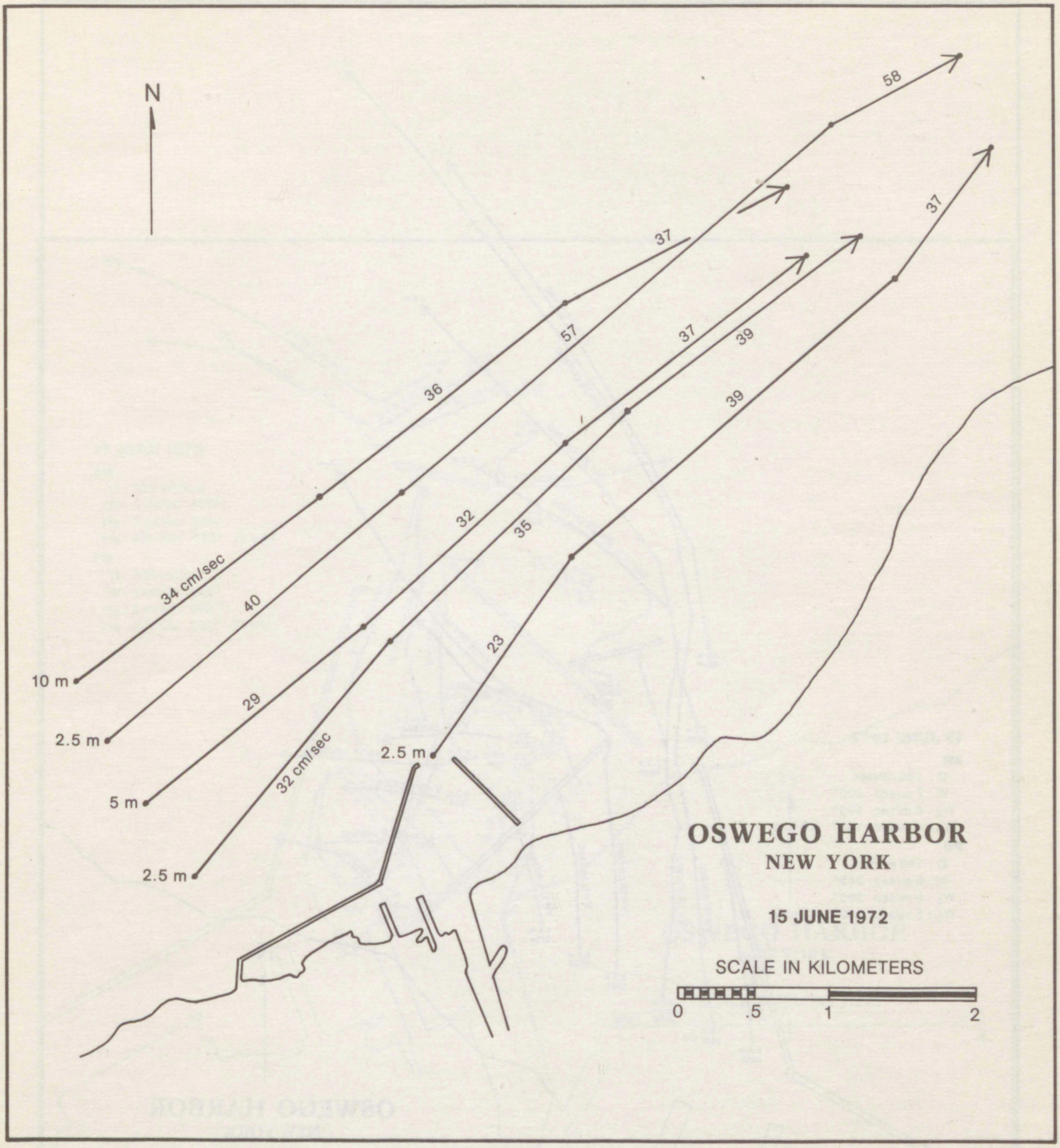

Figure 2. Large drogue trajectories, 15 June 1972. Speed between positions indicated.

NOTE: The following quantities appear on figures 3, 4, and all following trajectory figures: Q = river inflow, w = wind speed and direction during the tracking period, W_6 *= mean wind during the 6 hours prior to the measurements,* W_D *= mean wind prior to the measurements during which the wind was directionally steady.*

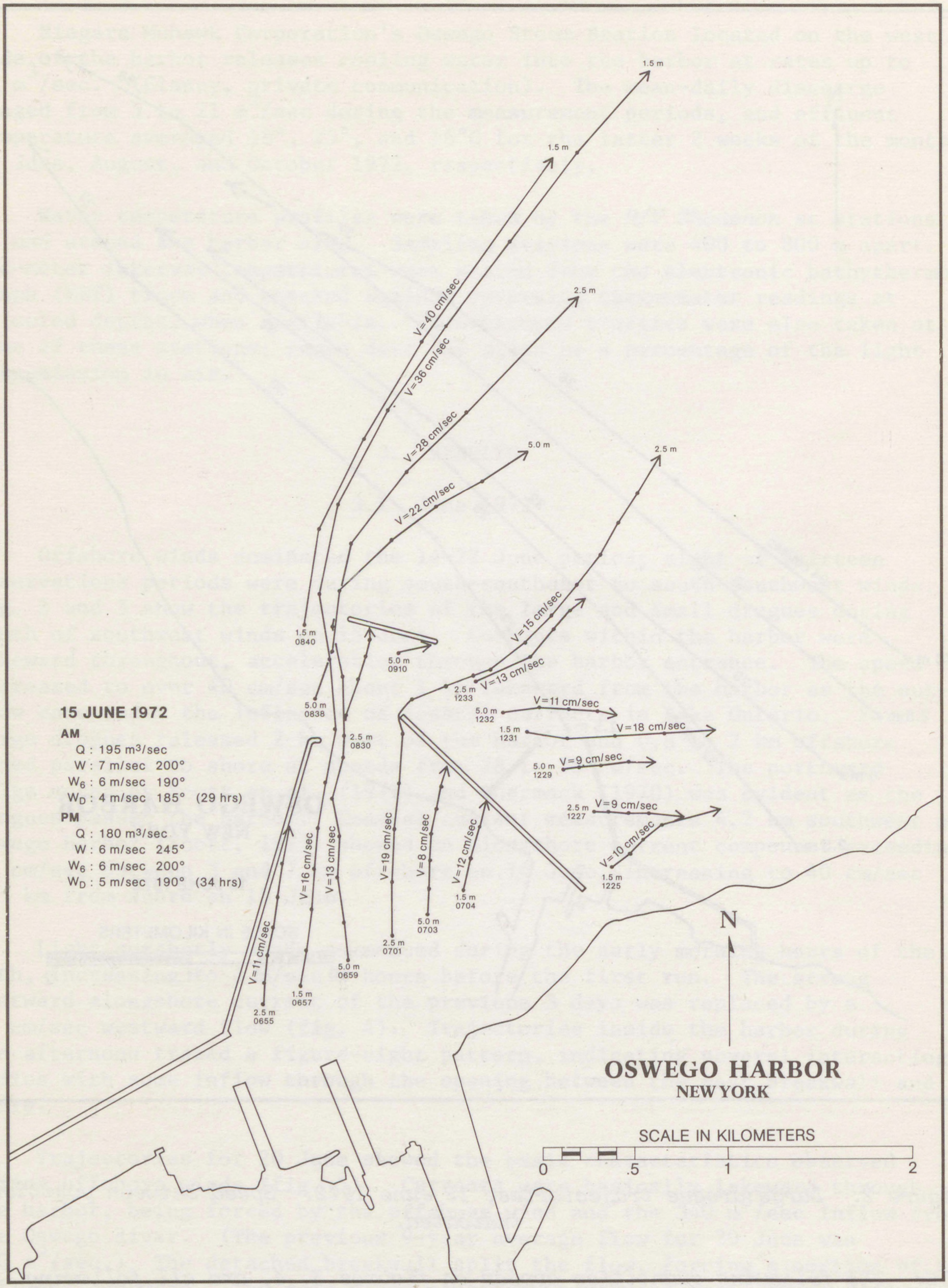

Figure 3. Drogue trajectories, 15 June 1972.

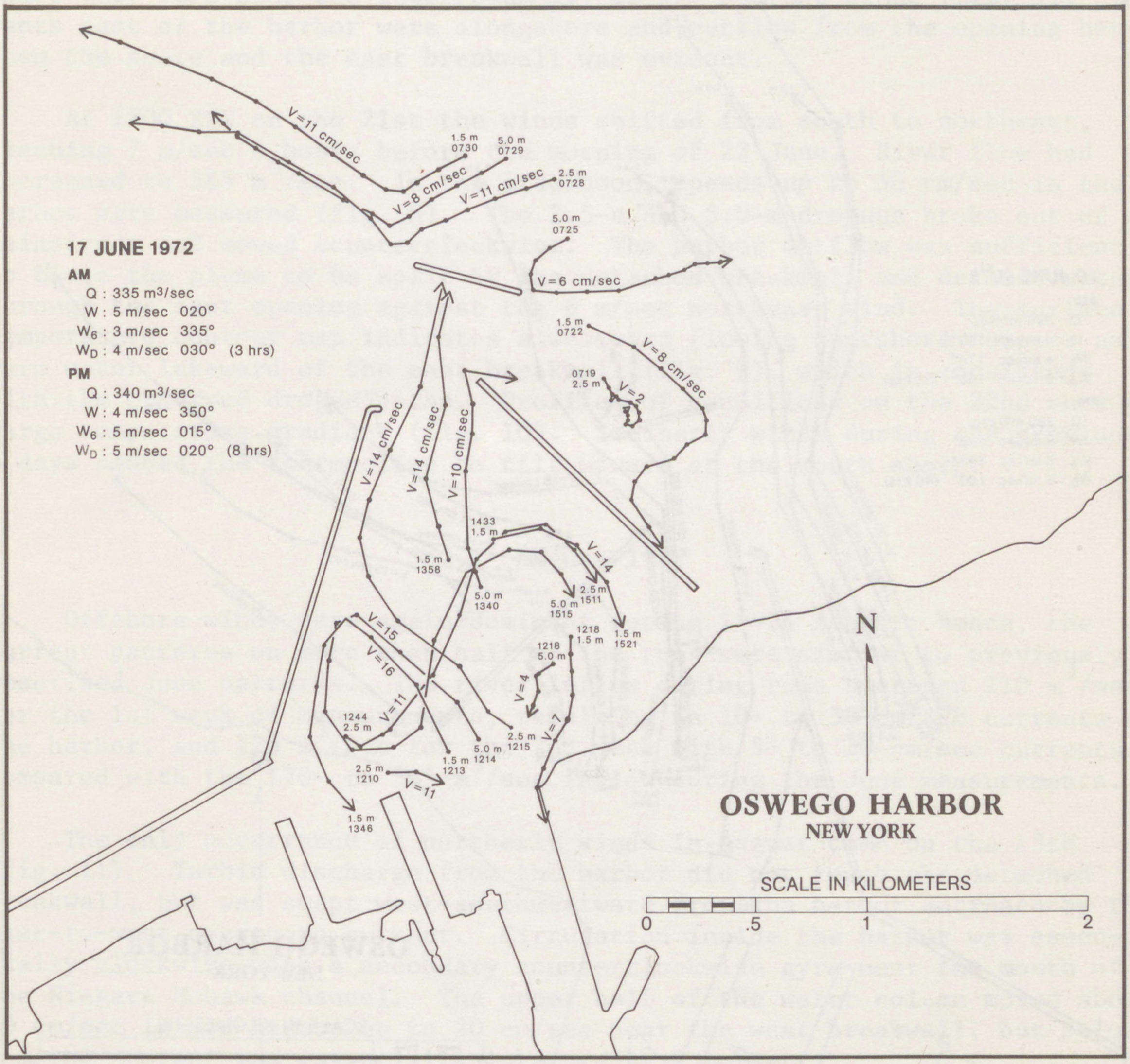

Figure 4. Drogue trajectories, 17 June 1972.

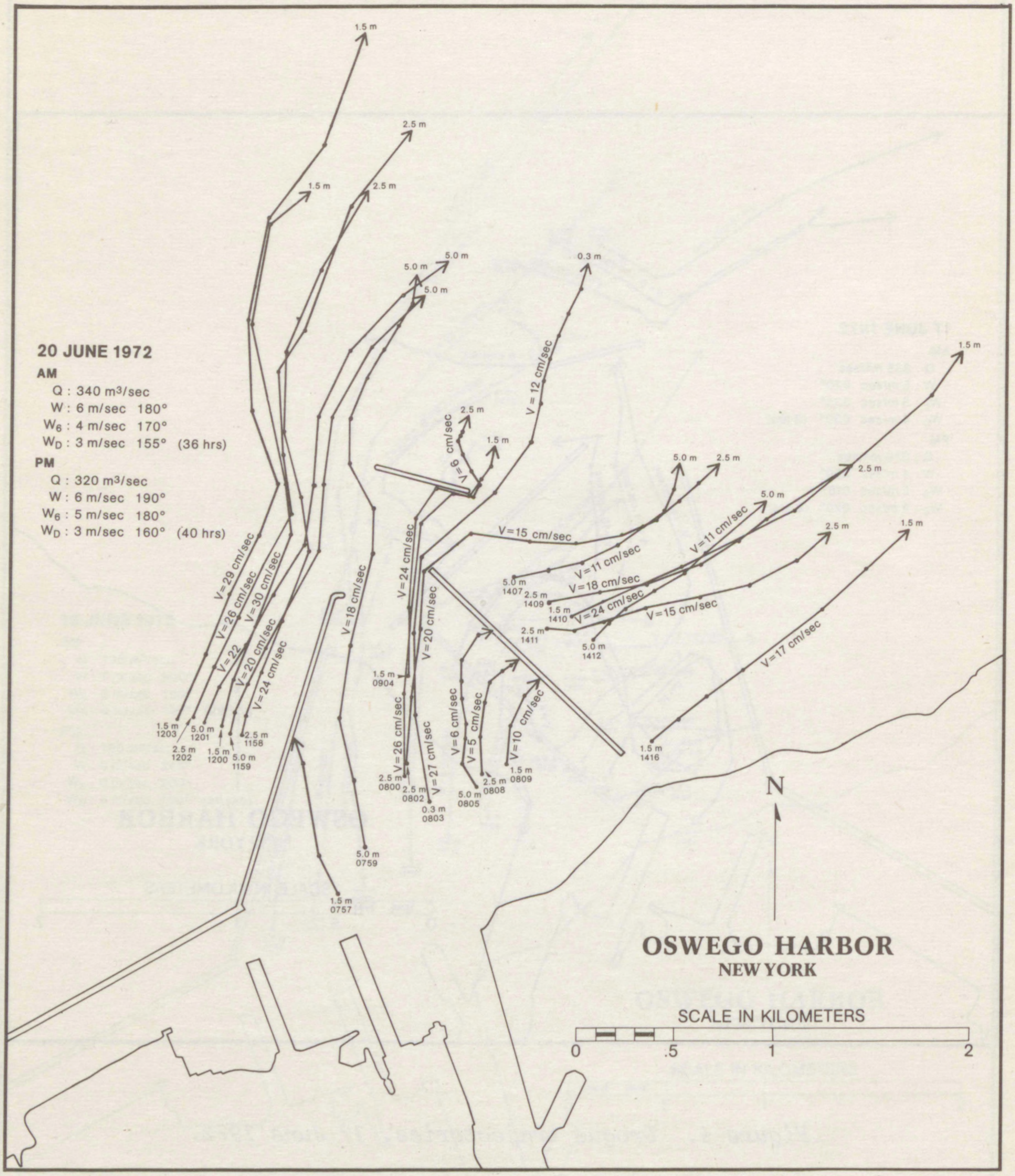

Figure 5. Drogue trajectories, 20 June 1972.

lake water which intruded into the harbor entrance, is shown in Fig. 6; the cross section approximates the plume axis. The up-current boundary of the turbid plume was very sharp, while the eastward plume had less well-defined boundaries. A cooler, less turbid area remained behind the detached wall (fig. 7). Drogues released west of the harbor paralleled the breakwall until entering the plume, whereupon they abruptly changed direction and paired up according to depth, with the deeper drogues being least affected since they were near the lower boundary of the buoyant plume (fig. 5). Currents east of the harbor were alongshore and outflow from the opening between the shore and the east breakwall was evident.

At 1800 EST on the 21st the winds shifted from south to northeast, reaching 7 m/sec 3 hours before the morning of 22 June. River flow had increased to 565 m^3/sec. In the afternoon, speeds up to 50 cm/sec in the harbor were measured (fig. 8). The 2.5-m and 5.0-m drogues broke out of the mainstream and moved counterclockwise. The harbor outflow was sufficient to cause the plume to be split by the detached breakwall and deflect water through the east opening against the 6 m/sec northeast wind. The surface temperature contour map indicates a westward flowing nearshore current and warm water lakeward of the east breakwall (fig. 9), which is consistent with the observed drogue paths. Profiles of conditions on the 22nd show a large temperature gradient (fig. 10). Southerly winds during the previous 3 days caused the thermocline to tilt upward at the south shore.

3.2 August 1972

Offshore winds were again dominant during 15-24 August; hence, the current patterns on more than half of the runs were similar to previously described June patterns. The river inflow during runs averaged 210 m^3/sec for the 1st week of measurements, resulting in 10- to 30-cm/sec currents in the harbor, and 125 m^3/sec for the 2nd week with 5- to 10-cm/sec currents as compared with the 170- to 565-m^3/sec inflow during the June measurements.

The only occurrence of northerly winds in August came on the 15th (fig. 11). Turbid discharge from the harbor did not reach the detached breakwall, but was swept west-southwestward from the harbor entrance by the east-to-west nearshore current. Circulation inside the harbor was essentially clockwise with a secondary counterclockwise gyre near the mouth of the Niagara Mohawk channel. The upper half of the water column moved about 10 cm/sec in mid-harbor up to 20 cm/sec near the west breakwall, but below 6 m the current was essentially lakeward at 2 cm/sec.

Westerly winds up to 6 m/sec commenced about 0900 EST on 18 August and by 1400 EST the surface current nearshore, which was directed due north the previous day, was eastward at 20 to 30 cm/sec (fig. 12).

The surface temperature contour maps for August yield some indication of the flow patterns, even though the temperature differences are more subtle (<2°C) and can be masked by nearshore heating. During this period the effluent from the powerplant was generally warmer than the river water, as

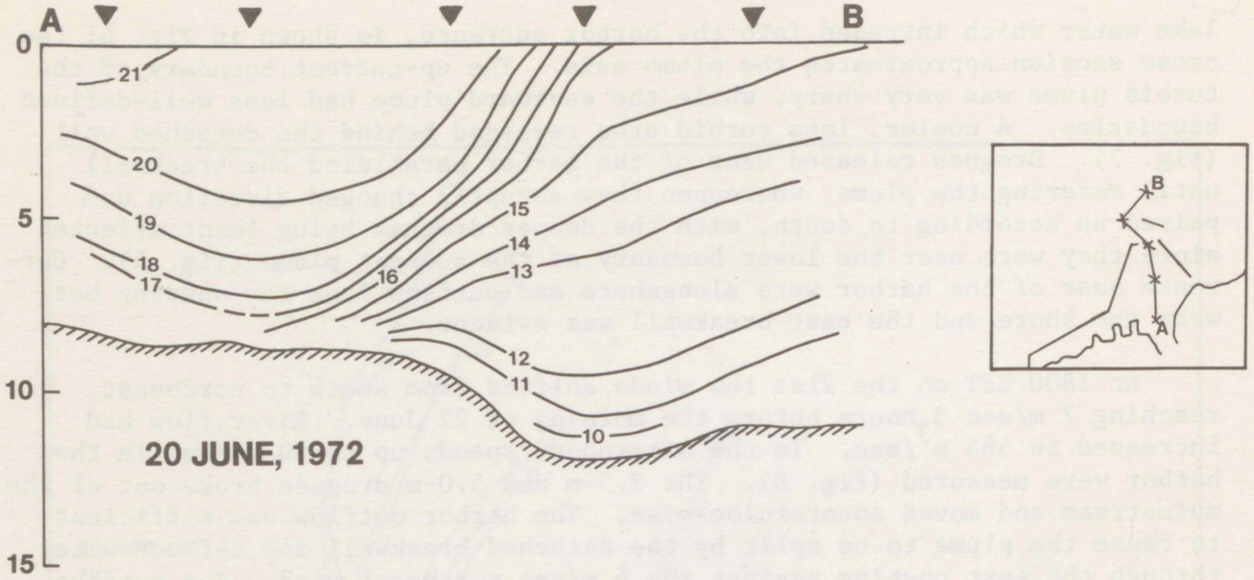

Figure 6. Temperature structure for the indicated cross section, 20 June 1972.

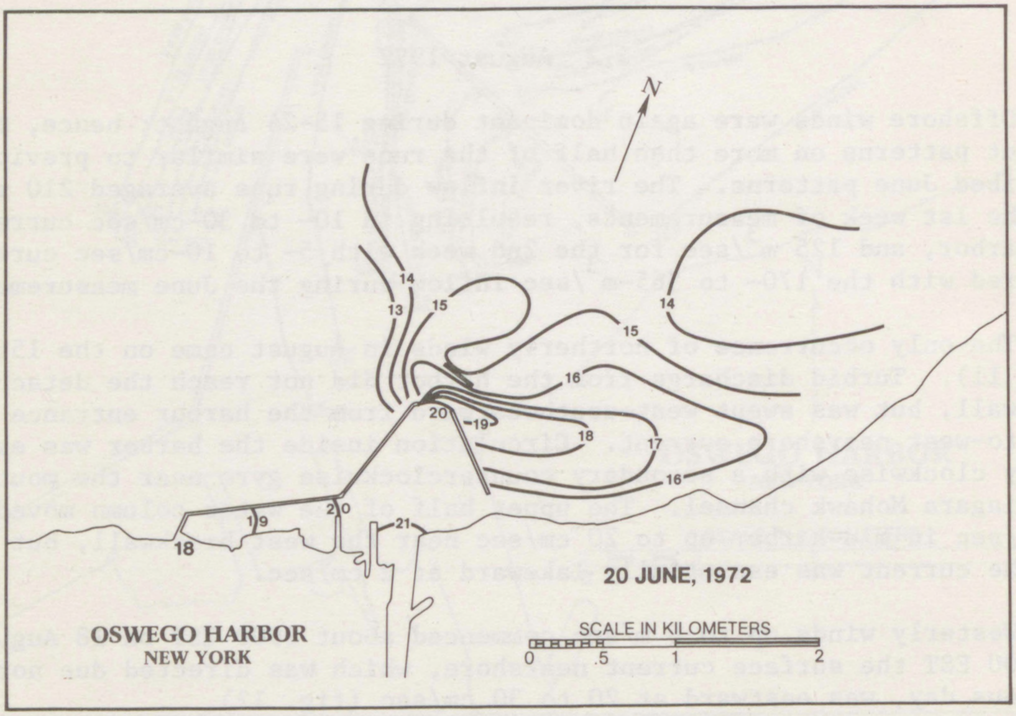

Figure 7. Surface temperature contours, 20 June 1972. The temperature of the cooling water discharged from the Oswego Steam Station is indicated at the west end of the harbor on all temperature contour figures.

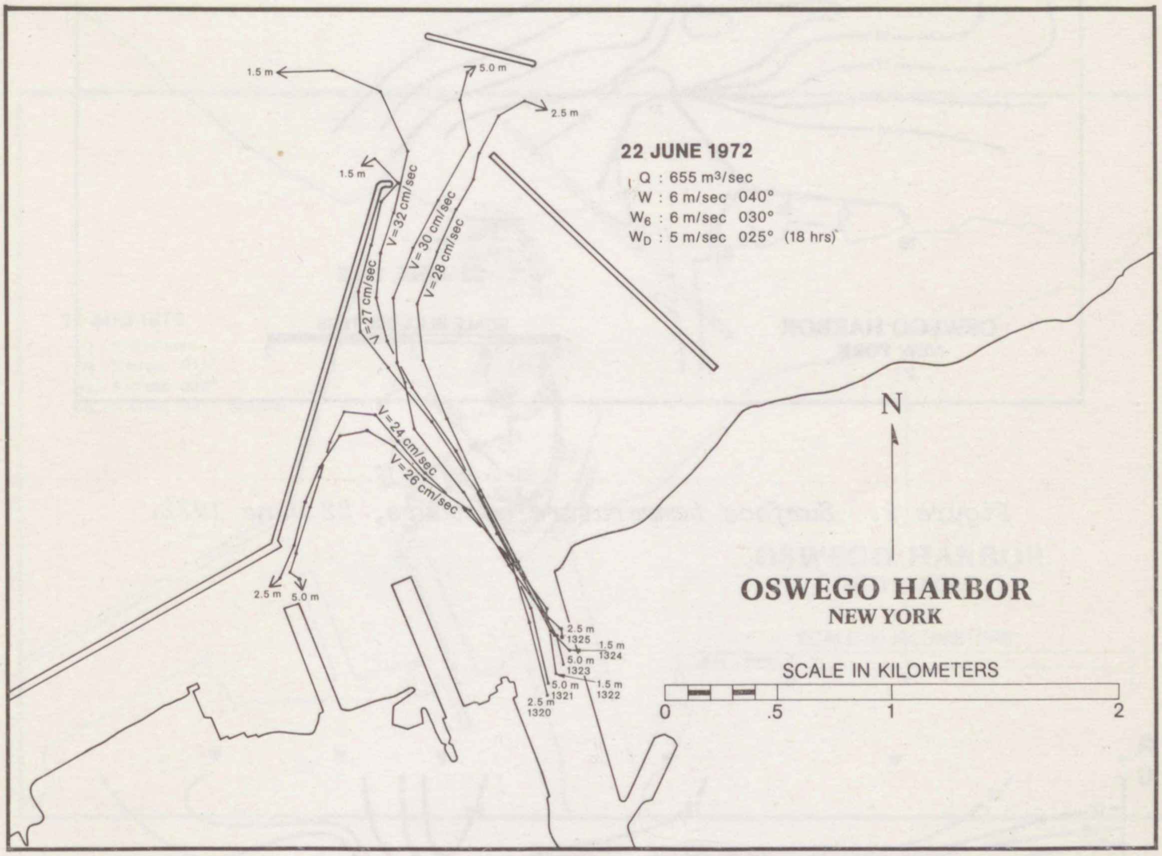

Figure 8. Drogue trajectories, 22 June 1972.

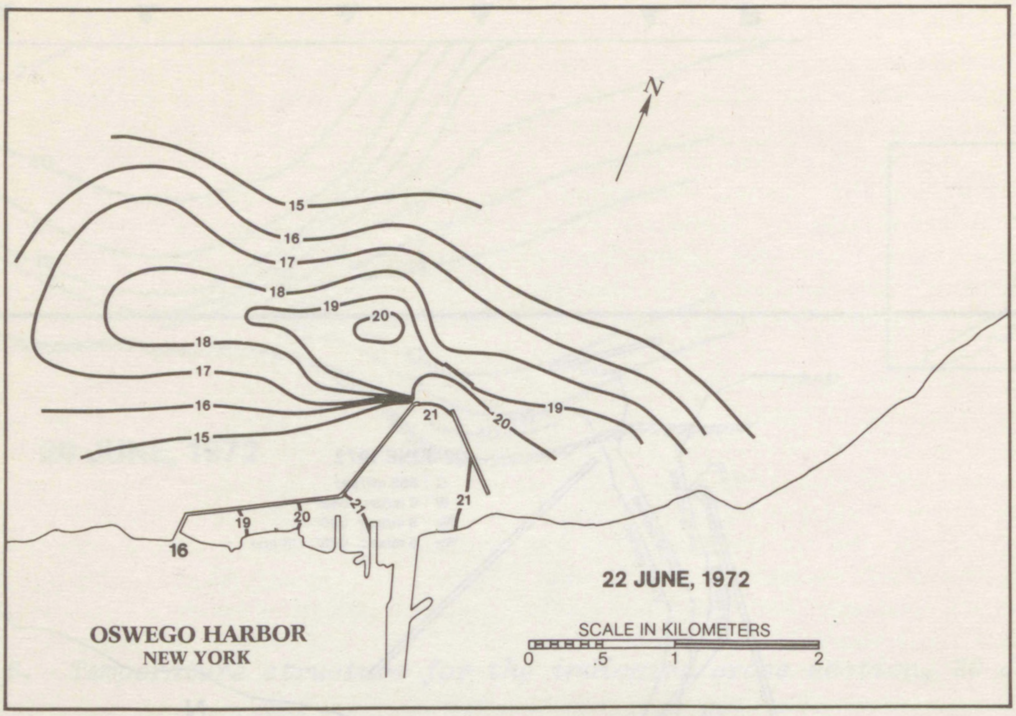

Figure 9. Surface temperature contours, 22 June 1972.

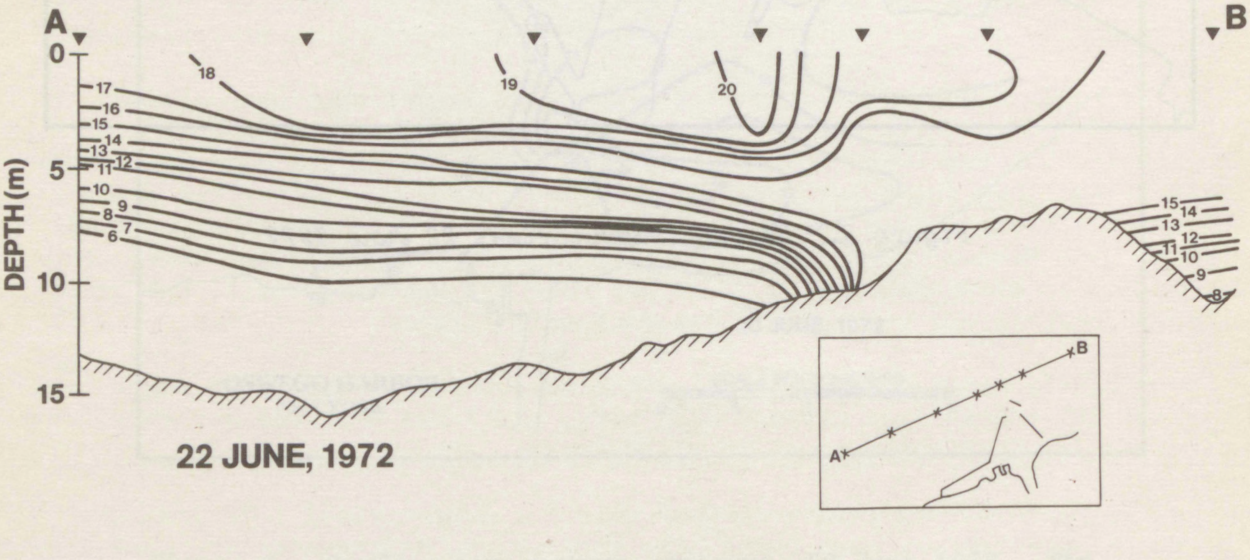

Figure 10. Temperature structure for the indicated cross section, 22 June 1972.

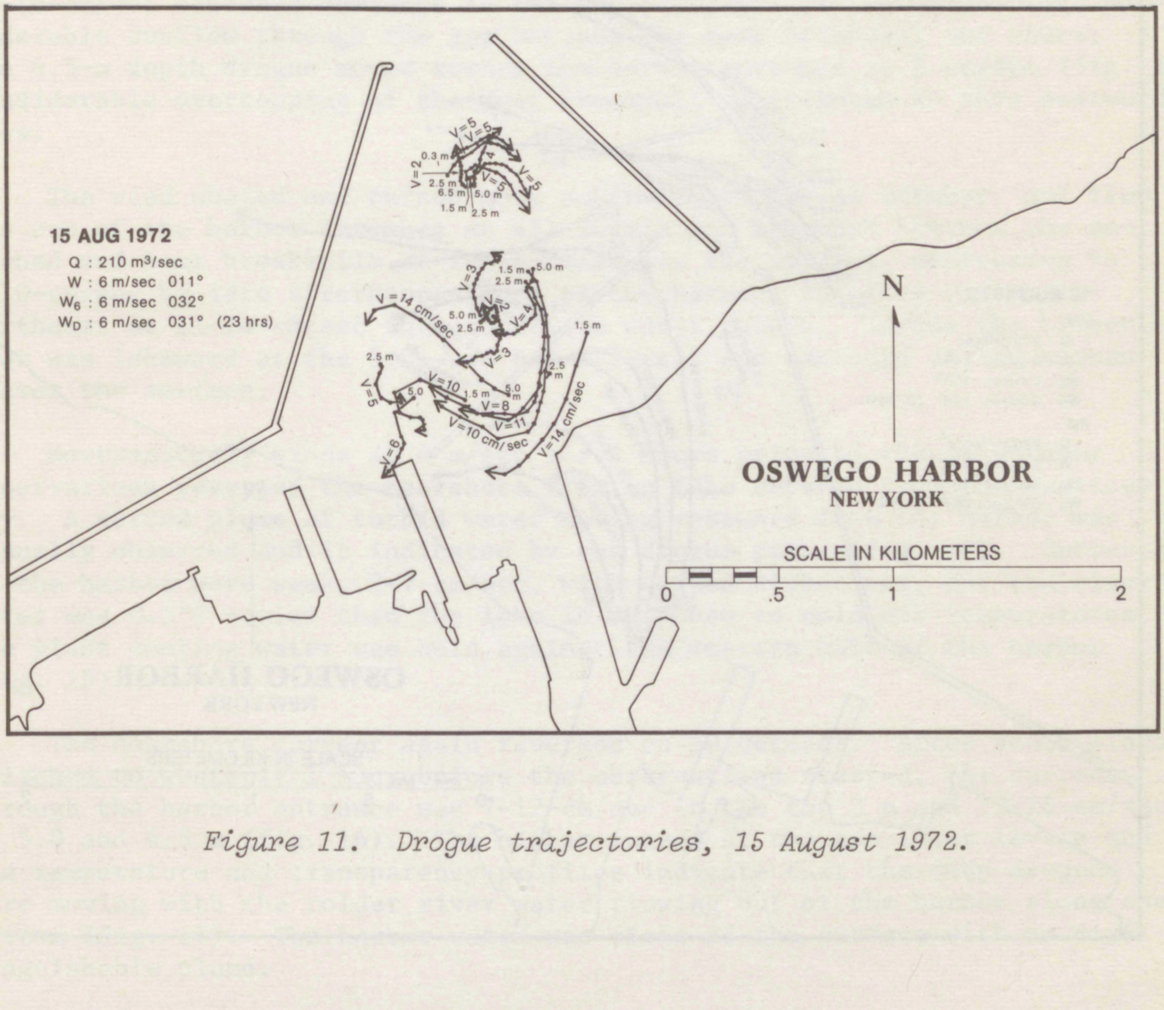

Figure 11. Drogue trajectories, 15 August 1972.

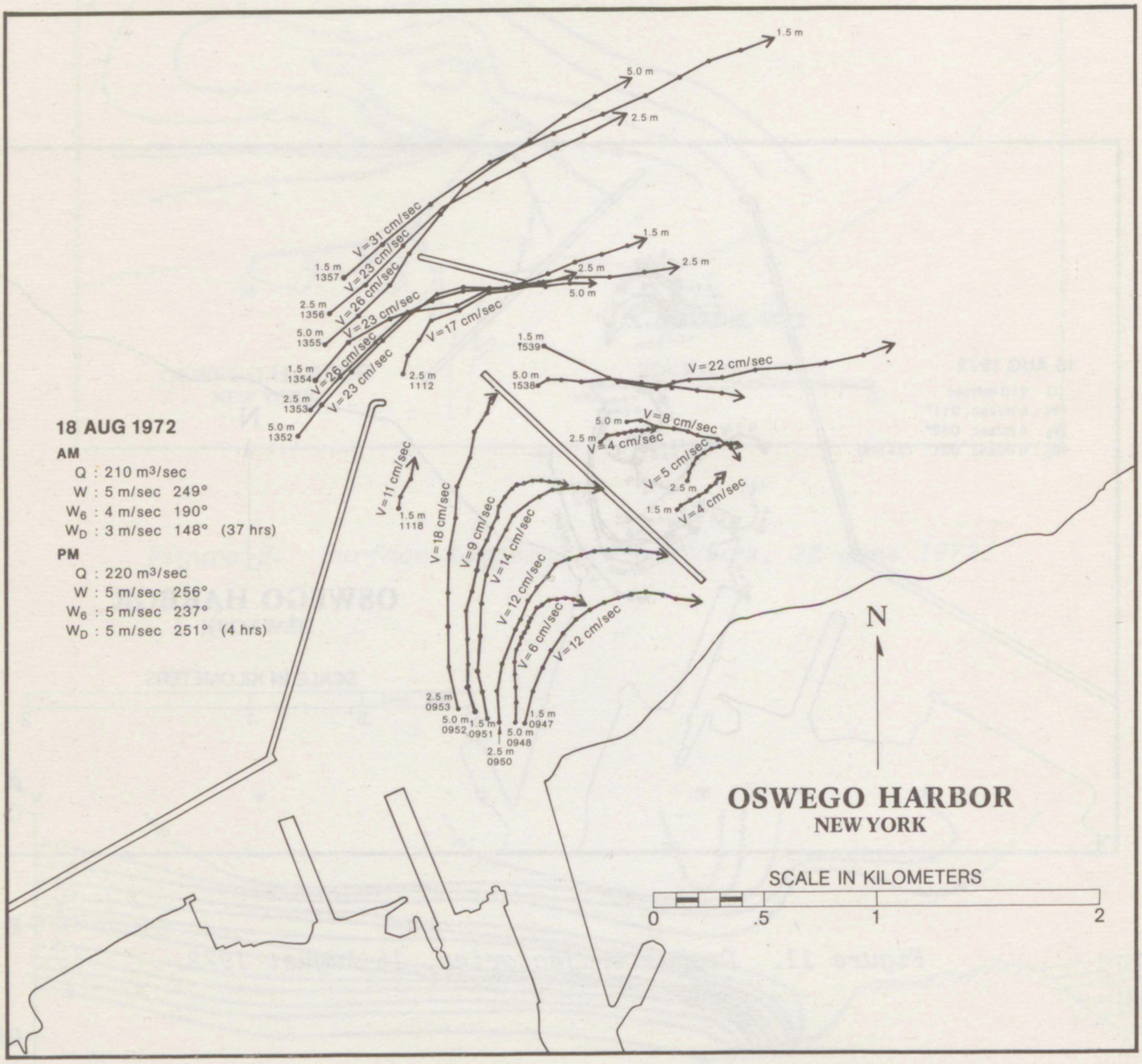

Figure 12. Drogue trajectories, 18 August 1972.

was evident from the harbor surface temperatures and cross sections. Cooler temperatures in the shadow of the detached breakwall were again seen. The depth or thickness of the plume varied, depending on the temperature difference. It was 5 m thick on 22, 23, and 24 August and extended virtually to the bottom on the 21st.

3.3 October 1972

The 17-25 October study period was characterized by variable winds and cold air temperatures. Nine-m/sec westerly winds on the 17th resulted in 12-16-cm/sec eastward currents in the top 5-m depth of the harbor with considerable outflow through the gap between the east breakwall and shore; the 6.5-m depth drogue moved toward the harbor entrance at 8 cm/sec (fig. 13). Considerable overtopping of the west breakwall contributed to this eastward flow.

The wind abated and turned more southwesterly by 18 October, and flow was out of the harbor entrance at all levels and eastward between the detached and east breakwalls at 12-16-cm/sec in the morning, decreasing to 7-10-cm/sec by late afternoon. West of the harbor, the flow was north-northeast at 11-14-cm/sec throughout the water column. Inside the harbor, flow was lakeward at the 5.0- and 6.5-m levels and eastward at low speeds nearer the surface.

Northeasterly winds at 4 m/sec for 4 hours prior to the 19 October observations reversed the nearshore flow in Lake Ontario from the previous day. A narrow plume of turbid water moving westward from the harbor was visually observed and is indicated by the drogue paths (fig. 14). Currents in the harbor were weak, 2-7 cm/sec, with varied directions, and the river water was 0.5°C cooler than the lake in response to cold air temperatures. The plant cooling water was held against the western half of the harbor (fig. 15).

The nearshore current again reversed on 20 October. After south winds switched to westerly 1 hour before the observations started, the current through the harbor entrance was 7-12-cm/sec in the top 3 m and 13-15-cm/sec at 5.0 and 6.5 m (fig. 16). The higher speeds at the two lower levels and the temperature and transparency profiles indicate that the deep drogues were moving with the colder river water flowing out of the harbor along the bottom (fig. 17). The harbor water was clear at the surface with no distinguishable plume.

Conditions during 21 and 23 October were typical of those during June and August with southerly winds. Current speed profiles in the harbor were fairly uniform (12 cm/sec) with an inflow of 115 m^3/sec and 10 m/sec south-southeasterly winds. The inflow water was about 2°C colder than the receiving water; hence, the river effluent flowed near the bottom. Cold water also intruded into the powerplant channel almost to the outfall.

North-northeasterly wind at 6 m/sec commenced 1 hour prior to the drogue runs during 24 October, and the trajectories inside the harbor showed the upper levels responding to the wind stress, while the cold river water, below the 5-m depth, flowed lakeward (fig. 18). The heated discharge from the power plant was confined to the western half of the harbor (fig. 19).

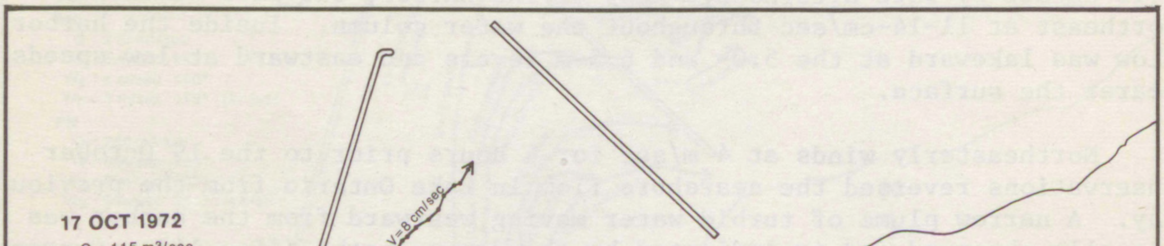

Figure 13. Drogue trajectories, 17 October 1972.

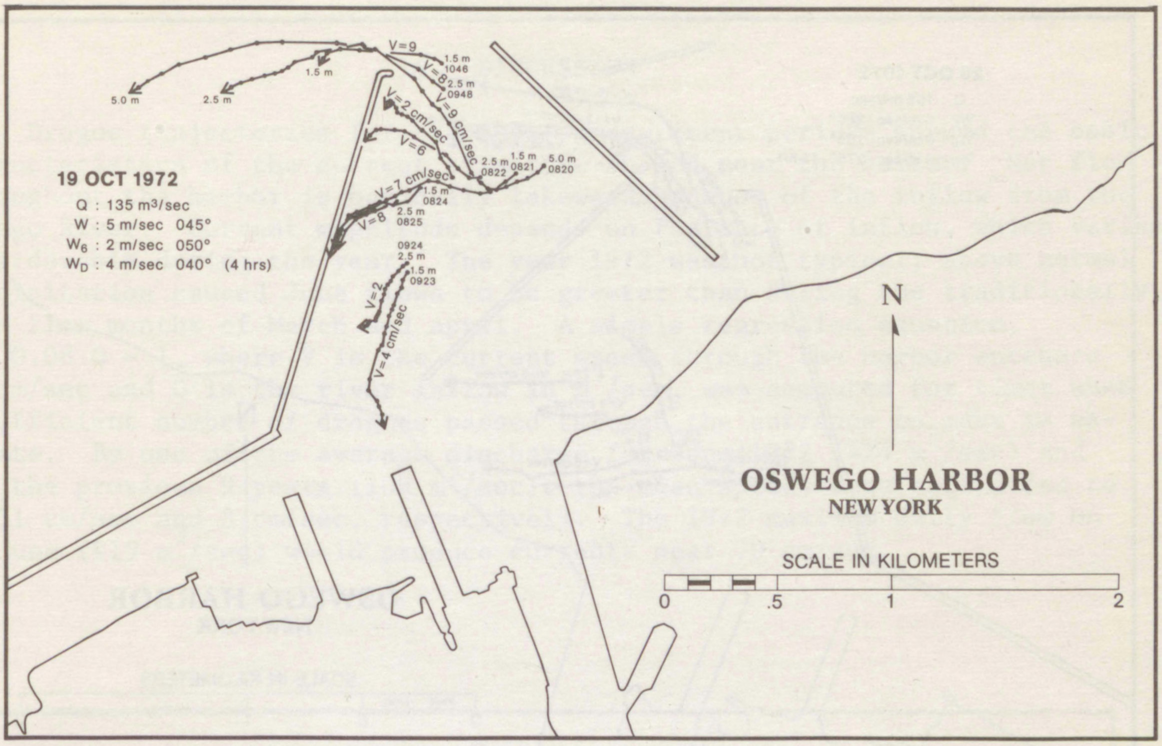

Figure 14. Drogue trajectories, 19 October 1972.

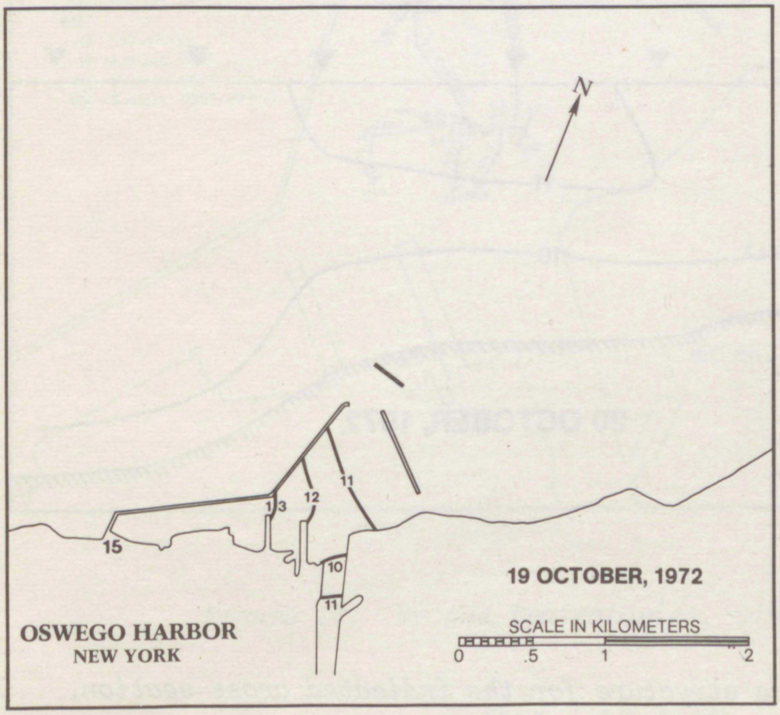

Figure 15. Surface temperature contours, 19 October 1972.

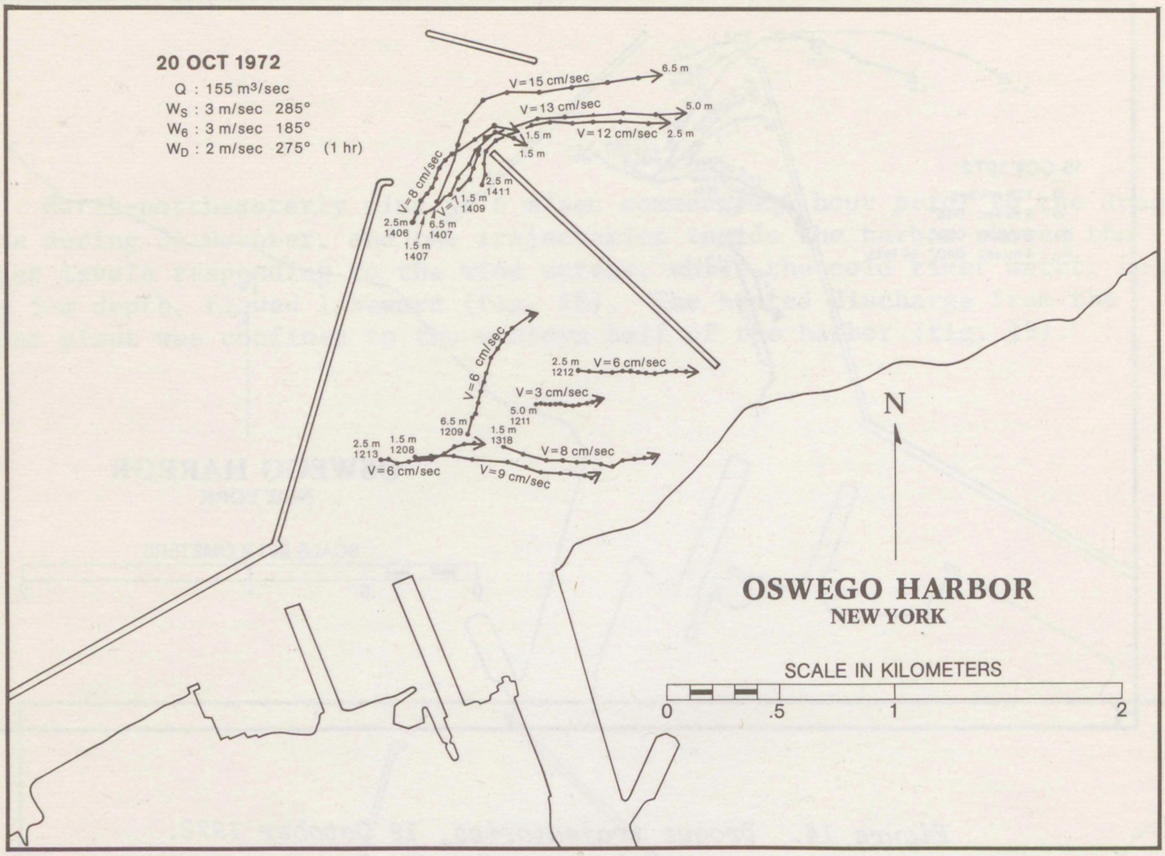

Figure 16. Drogue trajectories, 20 October 1972.

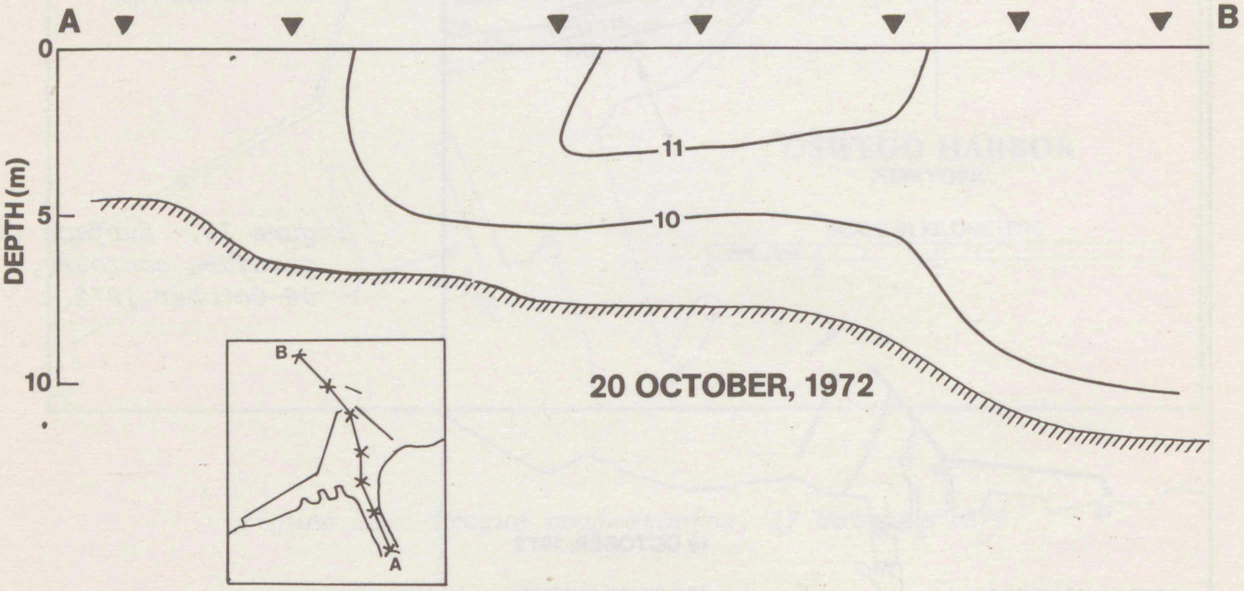

Figure 17. Temperature structure for the indicated cross section, 20 October 1972.

4. DISCUSSION

Drogue trajectories for the three measurement periods showed the basic characteristics of the current structure in and near the harbor. Net flow throughout the harbor is basically lakeward because of the inflow from the Oswego River. Current magnitude depends on the rate of inflow, which varies considerably during the year. The year 1972 was not typical; above normal precipitation caused June flows to be greater than during the traditionally high flow months of March and April. A simple regression equation, $V = 0.08\ Q - 1$, where V is the current speed through the harbor entrance in cm/sec and Q is the river inflow in m^3/sec, was computed for times when a sufficient number of drogues passed through the entrance to make an estimate. By use of the average discharge for June 1972 (414 m^3/sec) and for the previous 9 years (109 m^3/sec), the mean speeds were calculated to be 31 cm/sec and 8 cm/sec, respectively. The 1972 maximum daily flow on 27 June (915 m^3/sec) would produce currents near 70 cm/sec.

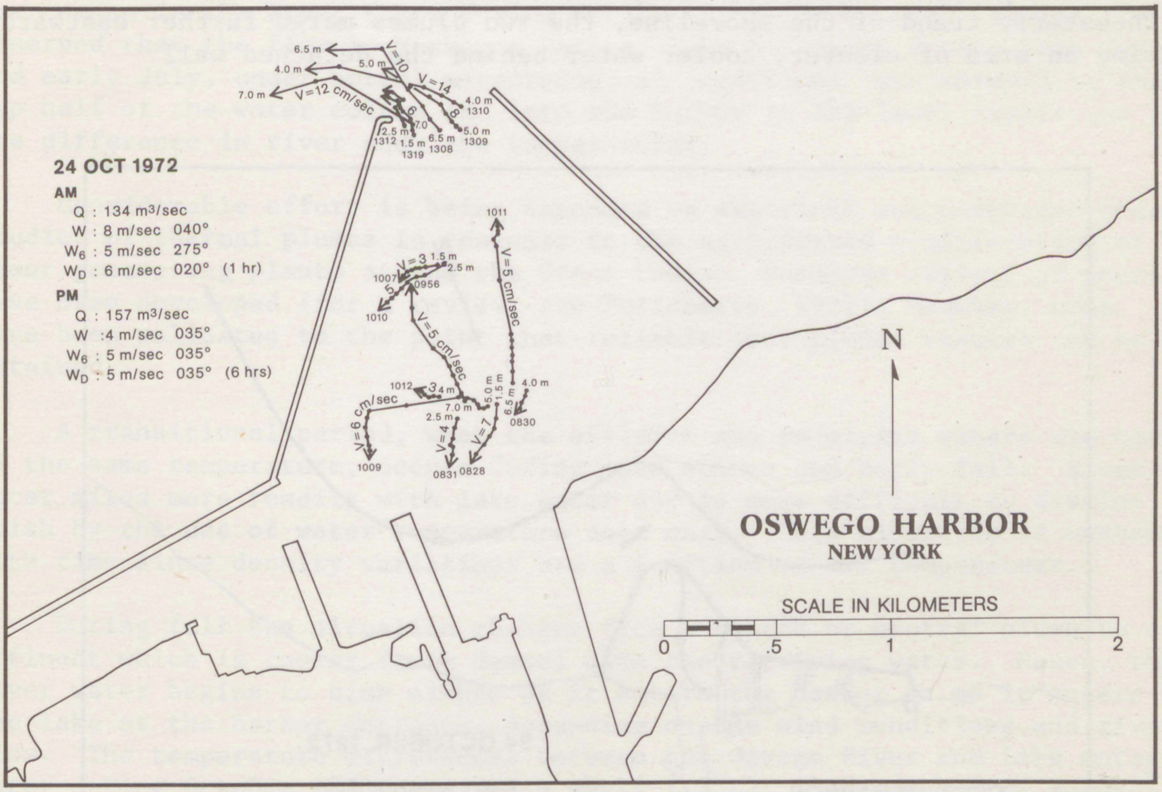

Figure 18. Drogue trajectories, 24 October 1972.

The above regression equation compares with the continuity equation using the harbor entrance cross-sectional area V = 0.05 Q. The difference in the relations is due to cold water intrusion, which reduces the "effective" cross-sectional area of the outlet. Most measurements used in computing the first equation were taken with offshore or light winds and during June when temperature differences, hence cold water intrusions, were significant. Either equation provides only a rough speed estimate since the temperature varies, and neither is suitable during fall months when the river water is colder than the lake water.

Within the harbor, wind stress affects surface layer velocities. Offshore winds result in fairly uniform lakeward movement throughout the harbor; onshore winds can cause the surface to flow opposite the deeper water, with eddies frequently set up in the corners.

The plume from the harbor is normally turbid and can be visually traced for several kilometers into the lake. Its horizontal location is subject to variation in response to wind stress, nearshore current, and river discharge. During June the plume extends 2-3 km offshore before paralleling the shore; in August and October the plume is often swept away by the nearshore current before reaching the detached breakwall. Weak fronts delineate the secondary plume that is split by the detached wall. Because of the northeasterly trend of the shoreline, the two plumes merge farther eastward, leaving an area of clearer, cooler water behind the detached wall.

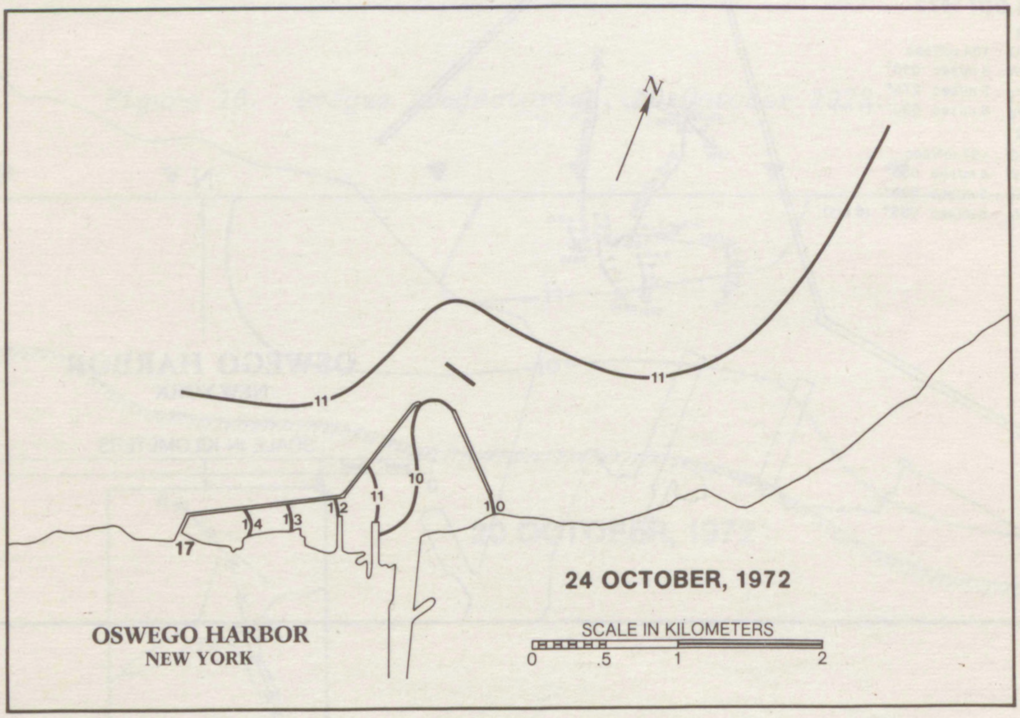

Figure 19. Surface temperature contours, 24 October 1972.

Nearshore currents are a function of wind stress. The method of data collection does not permit an accurate estimate of current response time to changes in wind direction; however, the data does indicate that current reversals in the 0.5-km to 2.0-km nearshore region occur at least within the first 2 hours after a stress change, even with moderate wind speeds. The configuration of the Oswego Harbor breakwalls influences the nearshore circulation. The west breakwall deflects eastward-moving currents lakeward and contributes to the greater lakeward intrusion of the harbor outflow. During moderate to light northwesterly winds, a clockwise gyre forms to the west of the west wall.

During spring and early summer, effluent from Oswego Harbor is considerably warmer than the receiving water. Buoyancy forces take over at or near the harbor entrance under moderate river flow conditions and inside the harbor during low flow rates or large temperature differences. Outside the harbor the warm plume is often only 2 to 4 m thick and moves at an angle to the nearshore current until its momentum is dissipated. It then follows the general nearshore current direction. The plume is normally turbid; hence, the up-current boundary is very sharp.

Buoyant outflow from harbors which have tributaries flowing into them are common in the Great Lakes during spring and early summer. Saylor (1964) observed that the flow in Muskegon Harbor, Lake Michigan, during late June and early July, under normal meteorological conditions, was outward in the top half of the water column and into the harbor in the lower layers due to the difference in river and lake temperatures.

Considerable effort is being expended on empirical and numerical model studies of thermal plumes in response to the anticipated proliferation of power generating plants around the Great Lakes. Numerous analytical models have been developed (for a review, see Policastro, 1972); however, none have been validated to the point that reliable operational results can be obtained.

A transitional period, when the effluent and receiving waters are nearly the same temperature, occurs during late summer and early fall. River water mixes more readily with lake water and is more difficult to distinguish by the use of water temperature data only. This situation is unstable with time since density variations are a function of air temperature.

During fall the situation changes from a heated or neutral plume to an effluent which is cooler (more dense) than the receiving water. Hence, the river water begins to sink either as it enters the harbor or as it enters the lake at the harbor entrance, depending on the wind conditions and river flow. The temperature differences between the Oswego River and Lake Ontario water during October 1972 were quite small (~2°C). However, after several days of cold air temperatures, the river water was sufficiently more dense to cause it to sink at the harbor entrance and move along the lake bottom.

Submerged plume occurrences are variable, depending mainly on the temperature of the incoming river water, which responds more rapidly to air temperature changes than the lake water. After the river and lake cool to their winter temperatures (<4°C), the situation would be near neutral again.

The sinking plume pheonmenon has not received the attention that buoyant plumes have, although it is important in determining pollution distribution in lakes. Serruya (1974) traced the movement of river water entering Lake Kinneret during winter and found that the depth of the river water layer was unstable with time; that is, small changes in relative densities were sufficient to cause the river water to flow along the lake bottom, on the thermocline, or at the surface. Hoglund and Spigarelli (1972) discussed the effects on biota caused by a warm sinking plume created by effluent possessing a temperature greater than 4°C entering a lake having temperatures less than 4°C. As long as the lake remains less than 4°C, the warm sinking plume may occur in late winter and early spring in the Great Lakes, but references to this type of plume emanating from "natural" sources have not been found.

A cooler jet spreads more readily than a heated plume because of bottom friction, but entrainment of lake water from above is curtailed. The jet also decays faster because of the larger velocity gradients. Bathymetry effects the distribution of a submerged plume whereas it has essentially no effect on a buoyant plume. Since this bottom layer becomes thin as it disperses, tracking the effluent requires measurements very near the bottom. Remote sensing of surface temperature and color, good indicators of effluent movement and distribution when the plume is buoyant, is not effective in tracing submerged river water. The implication of a submerged plume is that this undetected plume may reappear at another location, through upwelling for example, and biota may be affected.

The cooling water from the Oswego Steam Station is colder than the inflow from the river during June and nearly equal in temperature during August. Hence, the effluent has a cooling influence on the harbor water during spring and summer when the lake water is still relatively cold. During fall and winter, the water is considerably warmer than the inflow, and ice growth in the channel and harbor is retarded. The overall effect is not adversely detrimental to the temperature regime of the harbor or lake. Currents in the powerplant channel are light; for example, assuming maximum effluent discharge, the magnitude would be about 3 cm/sec at the 1972 water levels and normal operational discharge would produce currents of about 2 cm/sec. During times of large temperature differences, the cold water may occupy the lowest meter. In summary, the cooling water provides a slow flushing mechanism for the channel, but does not contribute to the current regime in the main harbor.

The quality of Oswego Harbor water is determined by the influent river water, not necessarily by the presence (or lack) of circulation within the harbor. According to Shampine (1973, p. 80) "...the chemical composition of its water (Oswego River) is strongly influenced by the percentage of its total flow that is derived from the highly mineralized outflow of Onondaga Lake." Thermally enriched lake water from the Oswego Steam Station and flow through the shallow opening between the east breakwall and shore provide some dilution of the harbor water.

5. SUMMARY

Current patterns and intensity inside Oswego Harbor are determined primarily by wind conditions and inflow from the Oswego River. Large water level variations are minimal and, hence, do not cause significant flows through the harbor entrance. Cooling water discharged into the harbor via the 1.2-km Oswego Steam Plant channel increases the temperature of the harbor water during summer through winter and decreases the temperature during spring and early summer.

The horizontal and vertical distribution of the plume after entering the lake from the harbor is highly variable, depending on the surface wind stress, nearshore current, density differences, and river inflow. The harbor breakwall configuration causes the dominant eastward flowing nearshore current to be forced lakeward, thereby contributing to the offshore extension of the plume. The detached breakwall splits the harbor effluent during high flow conditions, causing some water to flow eastward along shore while the greater portion moves northward before being dominated by the nearshore current and wind stress.

Effluent from the harbor is a buoyant plume during spring and early summer since the river water heats more readily than the lake. During October, November, and possibly December, the plume frequently sinks below the warmer lake water and spreads out along the lake bottom.

Pollution concentration in the harbor and nearshore area depends mainly on the input from the Oswego River; hence it is the river flow that determines the pollution concentration.

Adjustment of nearshore current to changes in wind direction and intensity normally occur within the first 2 hours, even under moderate wind speeds.

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