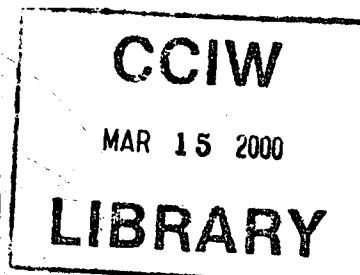
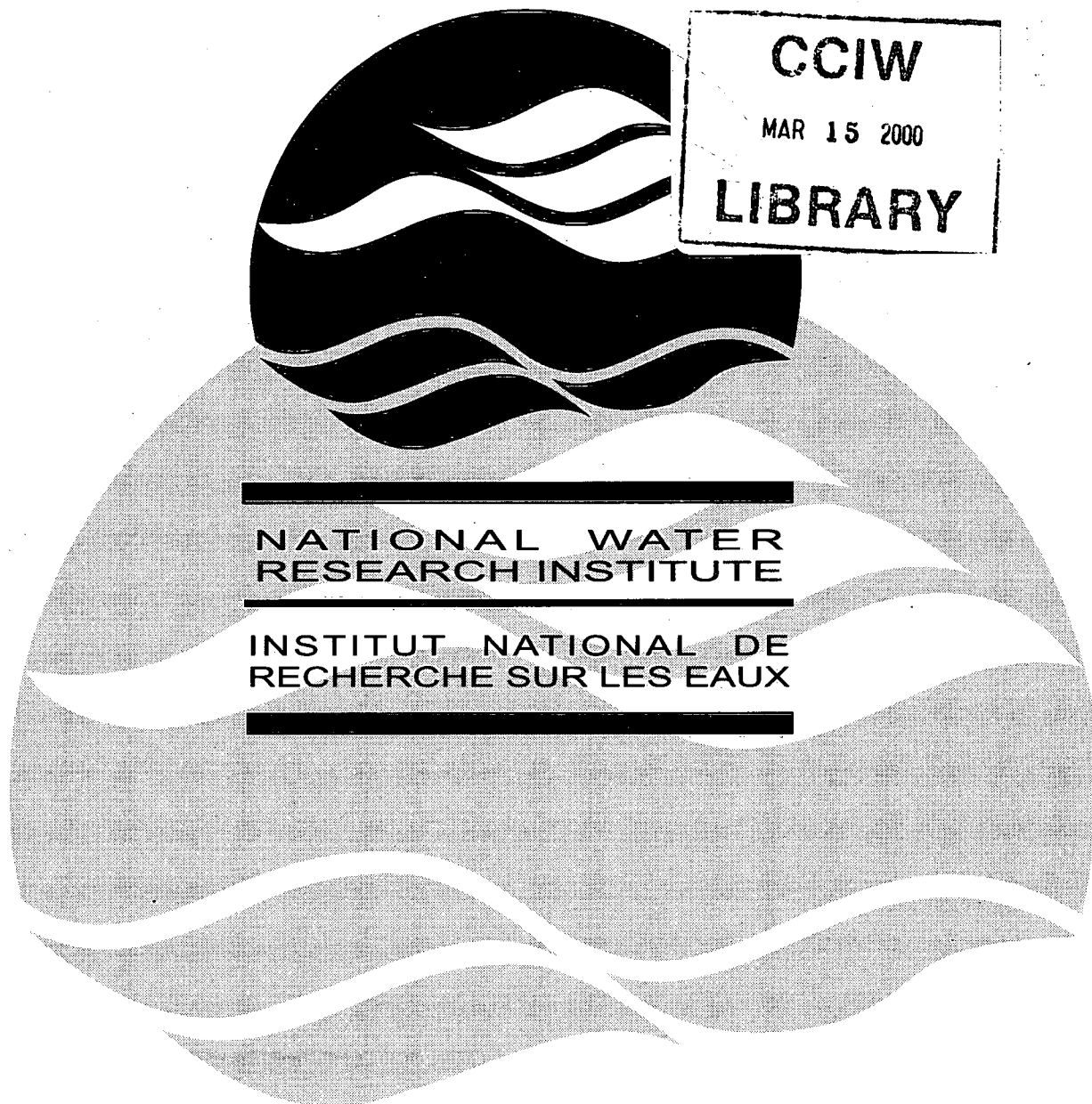


98-231



**WINTER STRATIFICATION IN
HAMILTON HARBOUR**

G.K. Rodgers

NWRI Contribution Number 98-231

Winter Stratification in Hamilton Harbour

Part I - 1993 and 1994 data

- Equation of State (Temperature, Conductivity, Total Suspended Solids) -
- Historical Record of Ice Severity -

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Management Perspective

Observations made in February and March of 1994 in Hamilton Harbour showed the existence of a layer of water on the bottom of the Harbour extending from the SE corner in Windermere Channel to the deepest part of the basin in the centre of the Harbour. This layer appears to be formed as a result of municipal wastewater and road-salt discharges. The layer at the bottom has high conductivity (high dissolved solids content), slightly higher temperature, lower oxygen levels (as low as 3.5% of saturation), high nutrient levels and high sodium and chloride content.

These observations took place at the end of a winter of extensive ice cover. The Harbour reached nearly 100% of ice cover. Based on freezing - degree - day records from the meteorological station at the Royal Botanical Gardens, this winter was the coldest in 30 years. It is possible that the ice cover reduced wind mixing and hence minimized dilution of the water as it moved through the Harbour. The intensity of this phenomenon may vary greatly depending on the severity of the winter. The use of road salt could be linked to this as well.

The consequences of this phenomenon could be harmful. The oxygen depletion was not observed to be as severe as in the summer hypolimnion. There could be effects on bottom fauna and sediment chemistry. In fact, it seems that the formation of this type of bottom layer only takes place when ice cover (and related snowfall) is extensive - maybe one year in 5 or one year in 10 at the present rate and distribution of road salt use. Road salt does increase the chloride content of the Harbour in winter and this has the potential to have deleterious effects on industrial use of bay waters due to its corrosive effects, but this is a general concern and is probably unrelated to the question of whether salt-induced stratification of the Harbour takes place.

The existence of this mechanism for exposing the aquatic environment to artificially elevated concentrations of contaminants from sewers and road run-off reinforces the need to address watershed development, treatment of melt waters and use of road salt. Also, this would support the contention that municipal wastewater treatment for suspended solids and phosphorus removal should not be relaxed in very cold winters.

This phenomenon is present in other harbours and embayments in the Great Lakes, especially where ice cover is more consistent. Additional observations would aid in developing a better idea of the scope of the phenomenon, the details of its development and its consequences. A similar phenomenon has been reported for Irondequoit Bay, New York.

N.B. The Management Perspective is being translated into French.

Table of Contents

	Page
Summary	1
Introduction	3
Observation Program	5
Results	6
- Source Indication	6
- Temperature Inversions	8
- Mass Balance Considerations	8
- Other features	21
Conclusions	23
Acknowledgements	24
References	25
Appendix 1 Standardization of conductivity readings	
Appendix 2 Oxygen Saturation Calculations	
Appendix 3 Equation of State: Density of Water as a function of temperature, dissolved solids (as measured by conductivity), and suspended solids.	
Appendix 4 Creek Surveys - April, 1994	
Appendix 5 Ice Conditions: Reconstructing the History	
Appendix 6 Data listings - Harbour Surveys	
<u>List of Figures</u>	Page
Figure 1	4
Hamilton Harbour - Surface Streams, Combined Sewer Overflows, Wastewater Treatment Plant discharges, and Industrial Intakes and Outfalls.	

Figure 2	10
Hamilton Harbour - Stations sampled on March 9th, 10th and 17th, 1994.	
Figure 3	11
Conductivity Cross-Section 9-17 March, 1994.	
Figure 4	12
Temperature ($^{\circ}\text{C}$) Cross-Section 9-17 March, 1994.	
Figure 5	13
Dissolved Oxygen (mg L^{-1}) Cross-Section 9-17 March, 1994.	
Figure 6	14
Hamilton Harbour - Stations sampled on March 28th, 1994.	
Figure 7	15
Depth of Water at stations sampled on March 28th, 1994.	
Figure 8	16
Conductivity Cross-Section 28 March, 1994.	
Figure 9	17
Dissolved Oxygen (mg L^{-1}) Cross-Section, 28 March, 1994.	
Figure 10	18
Temperature ($^{\circ}\text{C}$) Cross-Section, 28 March, 1994.	
Figure 11	19
Plot of Density as a function of Temperature and Dissolved Solids for 4 stations exhibiting apparent temperature inversions (28 March, 1994).	
Figure A3-1	A3-6
Density of Water as a function of Temperature, Conductivity and Suspended Solids in the range of $T = 0^{\circ}\text{C}$ to 10°C ($\text{TDS} = 0.52$ Conductivity 25°C).	
Figure A3-2	A3-7
Density of Water as a function of Temperature, Conductivity and Suspended Solids in the range of $T = 0^{\circ}\text{C}$ to 24°C .	
Figure A4-1	A4-4
Redhill Creek Sampling Stations - April 11, 1994.	
Figure A6-1	A6-4
Station Positions, Surveys #1A and #1B.	

Figure A6-2 **A6-10**
Station Positions, Survey #2.

Figure A6-3 **A6-16**
Station Positions, Survey #3.

Figure A6-4 **A6-20**
Station Positions, Survey #4.

Figure A6-5 **A6-34**
Station Positions, Survey #5.

Summary

Data are presented on the presence of a stratified water column in Hamilton Harbour in winter. The bottom layer has some undesirable characteristics. This layer formed in the winter months of January to March, 1994, during a winter when the Harbour was almost completely covered by ice in February. One source of the water in the lower layers is probably the combined discharges of the Woodward Avenue Sewage Treatment Plant and Redhill Creek, representing approximately 85% and 15%, respectively, of the combined inflow to the south-east corner of the Harbour through Windermere Basin. It is possible that combined sewer overflows during a high melt period could also have contributed, but no record of such overflow exists. Salty water from snow dumps could contribute to the density anomaly, but not necessarily the high nutrient condition of this lower layer.

The water mass apparently forms by virtue of its higher dissolved solids content and likely higher suspended solids content which allows it to move along the bottom of the harbour. The mixing processes that might ordinarily break up such a water mass before it entered the main body of the Harbour - namely wave action or convection - are suppressed by the ice cover. Consequently, the water mass can be traced from Windermere Basin, along the deepest parts of Windermere Channel, into the dredged 'borrow' pit (depth 20 m) on the east side of the Harbour between the Burlington Ship Canal and the Confined Disposal Facility (Pier 27). It is possible that it moved across a 13-14m depth sill between Stelco and the Canada Centre for Inland Waters, to the deepest (25m depth) basin in the central part of the Harbour (west of the NW corner of the Stelco property and south of LaSalle Park), although the trend in concentration of salts doesn't directly support this scenario. Consult Figure 1 for this pattern.

The bottom water mass carries a distinct dissolved solids signature, easily measured by its higher conductivity, with significantly higher levels of total phosphorus, ammonia, sodium and chloride. Severe depletion of dissolved oxygen also took place. At one place, at the greatest depth and at one time, dissolved oxygen was as low as 3.5% of saturation. There were extensive areas of the bottom water below 50% of saturation. This water layer, in the central parts of the Harbour, is generally warmer (3 - 3.5°C) than the overlying water masses (0.2 to 3.0°). In areas closer to the source in the eastern part of the harbour, the temperature of this bottom layer has been observed as high as 5.2°C, well above the temperature of maximum density for pure water. This is the result of dissolved solids affecting water density.

This water mass was observed in a winter in which ice cover was virtually complete (January to March, 1994). In the absence of any other winter data on water quality in this bottom layer, it is uncertain whether the observed conditions are as severe in winters when ice cover is less extensive. It is more usual for solid ice cover to form in the western half of the Harbour, and for the eastern half to be open or to

contain only partial ice cover with floating pans of ice. In the latter situation, wave action, wind-driven currents or turbulence may be sufficient to induce mixing that reduces the impact of this density current on the central deep basin.

The significance of this phenomenon is not known. Clearly, there exists a situation that resembles the more intense summer hypolimnetic oxygen depletion. It is possible that this winter chemo-hypo-limnion provides a reservoir of water with a markedly higher nutrient content and lower dissolved oxygen that might accelerate the onset of oxygen depletion in the period of formation of the summer thermocline (April to June). However, it is hard to see how it would affect the total amount of nutrient in the water column that becomes fully mixed following the break-up of the ice cover. Bottom fauna could be affected. Apparently bacterial activity is great enough to cause oxygen depletion.

Therefore the Remedial Action Plan recommendations for Hamilton Harbour, calling for major reductions in phosphorus, suspended solids and ammonia loadings have wider implications than originally considered. The loading targets in the RAP were focussed on improving summer water quality conditions. These same recommendations can now be considered as improving both winter and summer conditions. Furthermore, suggestion that phosphorus and ammonia controls might be relaxed during the winter months (in order to save operating costs) is now less acceptable, especially in very cold winters when ice cover is extensive.

Such density flows are probably quite common in winter in the Great Lakes, especially where waters of higher dissolved salt content flow into smaller, enclosed embayments or harbours. Even larger embayments may be significantly affected, where there is extensive and long-lasting ice cover. Such flows are quite predictable since they follow the drainage pattern of the bottom topography. Discharge from sewer systems and road salt are implicated. A similar phenomenon has been reported for Irondequoit Bay, New York. (Bannister and Bubeck, 1978).

Obtaining adequate observations in areas of variable, weak or shifting ice masses such as exist in Hamilton Harbour are a serious constraint to obtaining adequate information since vehicle access is awkward. Recording equipment put in place over the winter could be used to advantage.

N.B. The Management Perspective is being translated into French.

Introduction

Where there is an inflow to a lake, the incoming water, owing to its temperature, dissolved solids content or suspended solids content may have a density different from some part of the lake it is entering. This will affect the resultant circulation pattern.

Plunging density currents associated with inflows have been recognized in several lakes around the world. The Rhone River where it enters Lake Geneva and the Rhine River where it enters Lake Constance are the classical examples (Hutchinson 1957). For the Great Lakes, the winter or spring diving plumes from the Niagara River where it enters Lake Ontario (Rodgers, 1966) or from power generating stations, have been described. The Duncan River input to Kootenay Lake, B.C. is another example that has been well documented (Wiegand and Carmack, 1981). A similar phenomenon has been reported for Irondequoit Bay, New York. (Bannister and Bubeck, 1978).

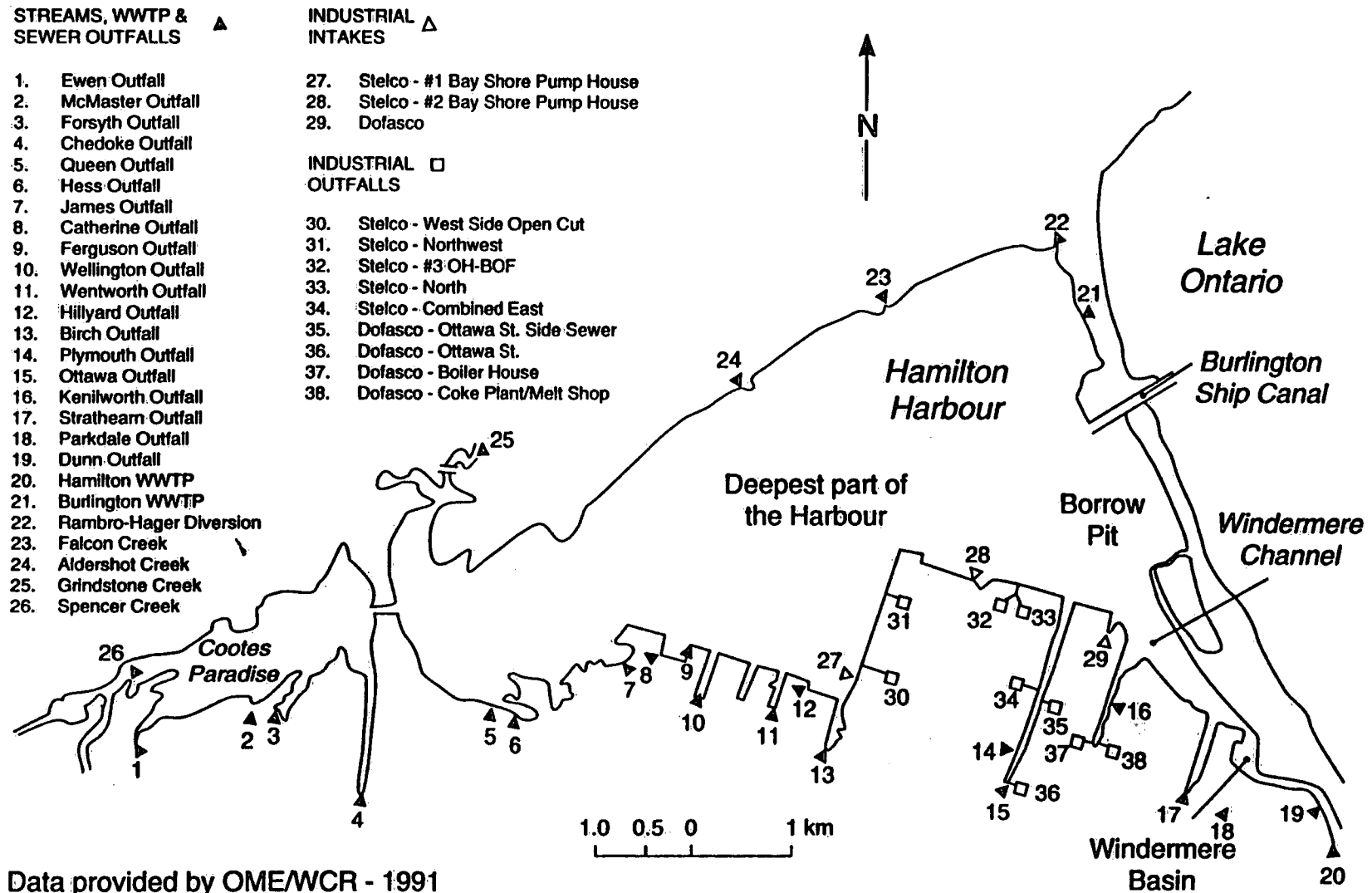
Hamilton Harbour has displayed this type of situation in the summer season. Heated effluents spread out on the surface near the point of injection in summer and gradually mix with the surface layer until they are eventually almost indistinguishable from the rest of the Harbour's surface waters. Lake Ontario water intermittently enters the Harbour on the bottom of the Burlington Ship Canal (see figure 1). It is colder than almost all waters in the Harbour in summer and tends to dive into the lower layer (hypolimnion) despite its lower dissolved solids content. Occasionally, using its low conductivity as a marker, it has been observed to form a distinct intermediate layer in the upper part of the hypolimnion (Spigel, 1989).

The discharge from Windermere Basin also has a tendency to sink to the bottom of Windermere Channel in the summer, or to form an interflow at intermediate depths (Spigel, 1989 and Charlton - personal communication). In these cases in Windermere Channel, the density flow has not been traced much further than 1 to 1.5km (i.e. to the end of the narrow channel) in summer.

The potential for density currents in winter, in retrospect, is obvious. The main body of water in the Harbour is at temperatures close to freezing, especially just under the ice at the surface. The lake-harbour exchange of water is at its seasonal minimum and therefore less likely to disrupt the circulation patterns in the Harbour. The artificial inflows, especially the sewage treatment plant effluents, discharge at full volume with higher temperatures (resulting in denser waters forming at the point where they mix or cool to 4°C), higher salt content and sometimes (especially in snow melt periods with combined sewer systems) higher suspended solids content. Streams entering the Harbour also carry extra dissolved road salt content during mid-winter thaws.

These types of inflow, combined with the reduction in vertical mixing that is associated with ice cover, provide the conditions that can allow for the development of a "river within a lake" and an associated winter pycnocline such as is reported here in Hamilton Harbour.

Figure 1 - Hamilton Harbour Surface Streams, Combined Sewer Outflows, Waste Water Treatment Plant (WWTP) Discharges, and Industrial Intakes and Outfalls.



Observation Program

The observation program developed in an opportunistic way. It grew out of a minor exploratory effort, and evolved utilizing equipment, staff and transport that happened to be available when the exploratory work indicated that a more extensive investigation was called for. This report has been prepared to assist in developing future observation plans, and to make available a general picture of what the author believes may be a widespread phenomenon of some importance in harbours and bays around the Great Lakes.

On March 5th, 1993, a survey was taken at one station in the deepest part of the Harbour (station 1) and at 3 stations in the western end. There was no indication of any significant oxygen depletion. Ice cover was fairly typical. There was fast ice in the western half of the Harbour and open conditions in the east. No problems were apparent in these data, although they were limited to temperature and dissolved oxygen measurements. The water was slightly warmer at the bottom, but that was something that could be expected in such situation even in areas far removed from urban areas or highways.

In the winter of January to March, 1994, ice formation was extensive and fast ice was present in almost all of the Harbour by mid-January. An effort was made to survey the west end and the deepest part of the Harbour before the ice went out. Two stations were completed on February 14th. An ATV breakdown caused the rest of the work to be postponed until March 2nd. Unfortunately, between these dates, the ice had started to break up in the east end due to a thaw.

Nonetheless, a Hydrolab Profiler (depth, temperature, pH, conductivity and dissolved oxygen) showed a water mass with high conductivity in the lower levels, temperature inversions (indicating density effects controlled by something other than temperature) and oxygen saturations below 50% at depths below 22m. This called for a wider survey on short notice since the ice was quickly receding.

On March 9th, technical field staff, working from shore in Windermere Channel and on the south shore docks obtained additional profiles, and then reached mid-harbour on foot over the ice from the north shore. Again the deep stations showed less than 50% saturation for oxygen associated with higher conductivity water in the bottom waters of the Harbour. The nearshore stations sampled indicated only Windermere Basin as a possible source for such high conductivity water, although other locations could have contributed. A subsequent check of Spencer Creek at Cootes Dr., and Grindstone Creek at Sunfish Pond - the other two large creeks entering the Harbour - showed low conductivities. The Skyway Wastewater Treatment Plant is another possible source in the NE corner of the Harbour, but no data on the conductivity of its effluent was available. Since the Skyway Plant serves a separated sewer system, typical conductivity values probably do not reach the levels found in the deepest part of the Harbour.

Since conductivity and temperature were not definitive indicators of the source of the water, water samples were collected for more detailed analysis on March 10th at 8m depth and 1.7m off the bottom at 2 stations in deep water beside the edge of the solid ice. By this time the east part of the Harbour was open enough to use a launch safely. These samples were submitted to the laboratory for analysis of nutrients, major ions and metals. By this time the lowest oxygen saturation levels observed were about 20%.

Finally, utilizing a launch in the open waters of the Harbour, surveys were carried out on March 17th and March 28th in an attempt to see if the water mass could be traced back to Windermere Basin or other sources. Profiles were taken at each station. In addition, water samples were taken at 2 or 3 depths (depending on the chemical structure seen on the profiler record) at several stations on March 17th. These were analyzed for nutrients and major ions. The lowest oxygen saturation level observed was found on the March 28th survey. It was 3.5% of saturation.

Some care had to be taken to establish suitable temperature standardization of conductivity readings as outlined in Appendix 1. The basis for oxygen saturation calculations is given in Appendix 2. The density of water as a function of temperature, dissolved solids content (as indicated by conductivity) and suspended solids content is described in Appendix 3. A supplementary survey of Redhill Creek temperature and conductivity was also carried out to elaborate upon its apparently unusually high conductivity compared with other major streams discharging to the Harbour - see Appendix 4.

Results - Cross Sections of the Harbour

Figures 2 to 10 illustrate temperature, conductivity and dissolved oxygen cross-sections of the Harbour from the SE corner to the central basin. It should be noted that the earlier cross-section is a composite of surveys 2 and 4 on March 9th and 17th, respectively. These data illustrate the general nature of the layer which develops on the bottom of the Harbour.

It appears that the data from the 'borrow pit' (stations 19 and 20 on March 17th; and stations 61, 62 and 72 on March 28th) at the east margin of the Harbour illustrate some altered condition either due to vertical mixing as the ice left this area, or due to the influence of currents or Lake Ontario water masses at the Canal.

Source Indication

Although it seems clear that a major source of high conductivity water is in the SE corner of the Harbour, there is an apparent inconsistency in the resultant pattern of conductivity in the bottom waters. The inconsistency lies in the fact that the conductivity in the bottom water of the borrow pit is less than in the bottom water of

the deepest part of the Harbour. It is possible that breakdown of stratification in the borrow pit area where the ice breakup occurred first could account for this. A more continuous set of surveys, or the use of recording devices over the whole winter in both the borrow pit and the deepest part of the Harbour could elucidate this situation.

Other possible Sources of the Deep Water

Other sources of water to form this bottom layer have been considered. These include melt water from salted streets, combined sewer overflows, other creeks than Redhill Creek, the Burlington WWTP, and industry.

Street melt water is present in streams. However, it does not have the high nutrient content of the WWTP effluents. Other than road salt or other salt in Redhill Creek that reinforces (rather than dilutes) the dissolved solids content of the Woodward Ave. WWTP effluent, no evidence could be found for sufficiently large flows to account easily for the layer observed. Spencer and Grindstone Creeks had notably lower conductivities than Redhill Creek - measured at $390\text{--}425\ \mu\text{Scm}^{-1}$ vs. Redhill Creek at $1100\text{ to }2000\ \mu\text{Scm}^{-1}$ (above the WWTP effluent). Indian Creek data are sparse and while it has had higher conductivity than Grindstone or Spencer Creeks, there is no data showing it to be as consistently as high as the deep water. Nor is its volume of discharge large enough.

Combined sewer overflows are intermittent and not large in volume in this area of the Harbour. However, the continual use of step feed control at the Woodward Ave. WWTP, during the last half of February and during almost all of March, suggests that there could have been hydraulic overloading of the sewer system thus contributing to combined sewer overflows. The scale of the observation program in the Harbour was inadequate to track intermittent flows, so they cannot be ruled out.

The Burlington WWTP discharges into the NE corner of the Harbour. Efforts were made to sample between the WWTP outfall and the deep basin of the Harbour, but no clear signal of this discharge could be found. This flow is about 1/5th of the combined Redhill Creek and Woodward Ave. WWTP flows. If ice conditions were better suited to sampling closer to the WWTP outfall, or a different sampling vehicle could be used to facilitate safe sampling in an area of unstable ice conditions, perhaps the fate of the Burlington WWTP effluent could be documented. It should be noted that the Burlington WWTP outfall is a 6-port diffuser that would likely reduce peak dissolved solids concentrations quite markedly. In addition, since the Burlington sewer system is not a combined sewer system, a far lower road salt component would be present in its effluent than if it were a combined sewer system. TDS or conductivity measurements were not available on this effluent water during the period of these observations on the Harbour.

A check of weekly effluent monitoring data of the steel company effluents, both during this observation period in 1994, and in the MISA monitoring data set, found no conductivity data much higher than is present in the surface waters of the Harbour and certainly not as high as the bottom water under consideration here.

Temperature Inversions

The presence of temperature inversions in the Harbour is intriguing, if somewhat academic. By temperature inversion or apparent anomaly, is meant either a decreasing temperature with increasing depth when the whole water column is below the temperature of maximum density (3.90 to 3.98°C is the temperature of maximum density for Harbour conditions), or an increasing temperature with increasing depth when temperatures are all above the temperature of maximum density, or when temperatures in one profile include temperatures both above and below the temperature of maximum density.

Profiles of the first and third kinds of these anomalies were noted. Four have been extracted from the records for survey 5, namely stations 62, 63, 72 and 906. The data are plotted on a density diagram (figure 11). Density was determined from the equation of state presented by Chen and Millero (1986) using 0.52 as a factor to convert conductivity to total dissolved solids. The factor '0.52' is based on conductivity measurements and analyses for major ions done on samples collected on March 10th (Survey 3).

It can be seen in figure 11 that the surface layer to depths of about 10m have relatively small density differences at all 4 stations. Whatever small density inversions that might appear to be present are within the margin of error for conductivity measurements. In any event, one might expect the dynamics of the upper layer to introduce some conditions in which these small variations could occur.

Once below this upper layer, stations 62, 63 and 906 show a monotonic and marked increase of density with depth regardless of temperature changes.

The profile for station 72 shows a slight instability between 16 and 18m. But again, the density differences are within the measurement error for conductivity and may not be significant.

Mass Balance Considerations

It is impractical to carry out a full mass balance because the 'loading' data are inadequate, because the sampling of the Harbour on each occasion was incomplete (or not fully representative) and because the time interval between surveys was short.

Nevertheless, it was found instructive to compare the conductivity data collected in the central basin over the full period of observations. The conductivity data for this area are shown in Table 1. Data collected on March 2nd and March 9th were taken through the ice. Data collected on March 10th and 17th were collected in open water at the edge of the solid, fast ice. Station 54 was at the edge of the ice, but station 906 was in open water about 500m from the nearest fast ice.

The net change in conductivity for each time interval between observations has been calculated and tabulated at the bottom of the table. It is interesting to note that only small net changes in conductivity were seen for stations taken close together and close in time (stations 3A and 3B). In general, the net change here was very small

$(-1/2\mu\text{Scm}^{-1})$ and there was no particular pattern throughout the column. The net change between March 9th (Station 3) and station 3A of March 10th, while small at $-1\mu\text{Scm}^{-1}$ suggests some layering - perhaps 4 layers of 0-2m, 2m - 10m, 10m - 14m and 14m to the bottom - with alternating conductivity trends. Finally, in this set, there are the stations 54 and 906 which were taken close in time, but at a distance of about 500m from each other. They were close in net difference $(-7\mu\text{Scm}^{-1})$ and there was no particular pattern of difference throughout the water column.

The remaining sets of differences (Station 3, 2 to 9th March; Station 3B to Station 24; and Station 24 to Station 54) are, respectively, $+47\mu\text{Scm}^{-1}$, $+75\mu\text{Scm}^{-1}$ and $-52\mu\text{Scm}^{-1}$. There is a net increase in conductivity through this series which is what one might expect based on a build up of the high conductivity water from discharges while there is minimal inflow or influence from Lake Ontario water (very low conductivity) coming through the Canal. However, the increases for the first 2 of these 3 periods takes place throughout the water column - not just at the bottom of the Harbour. This suggests that a completely different water mass was being sampled in each of these 2 cases.

The changes for the 11-day interval from March 17th to 28th (stations 24 and 54 - or 906) were negative but showed at least a 2-layer stratification. The top 10m increased in conductivity at rates comparable to the previous changes. However, the lower layers - especially from 10 to 18m - decreased very markedly. Since this is in the region of maximum density gradient, this may be the result of tilting of the pycnocline or internal-wave movement in the boundary between upper and lower layers associated with the situation where the eastern half of the Harbour was relatively free of ice and therefore more subject to wind stress.

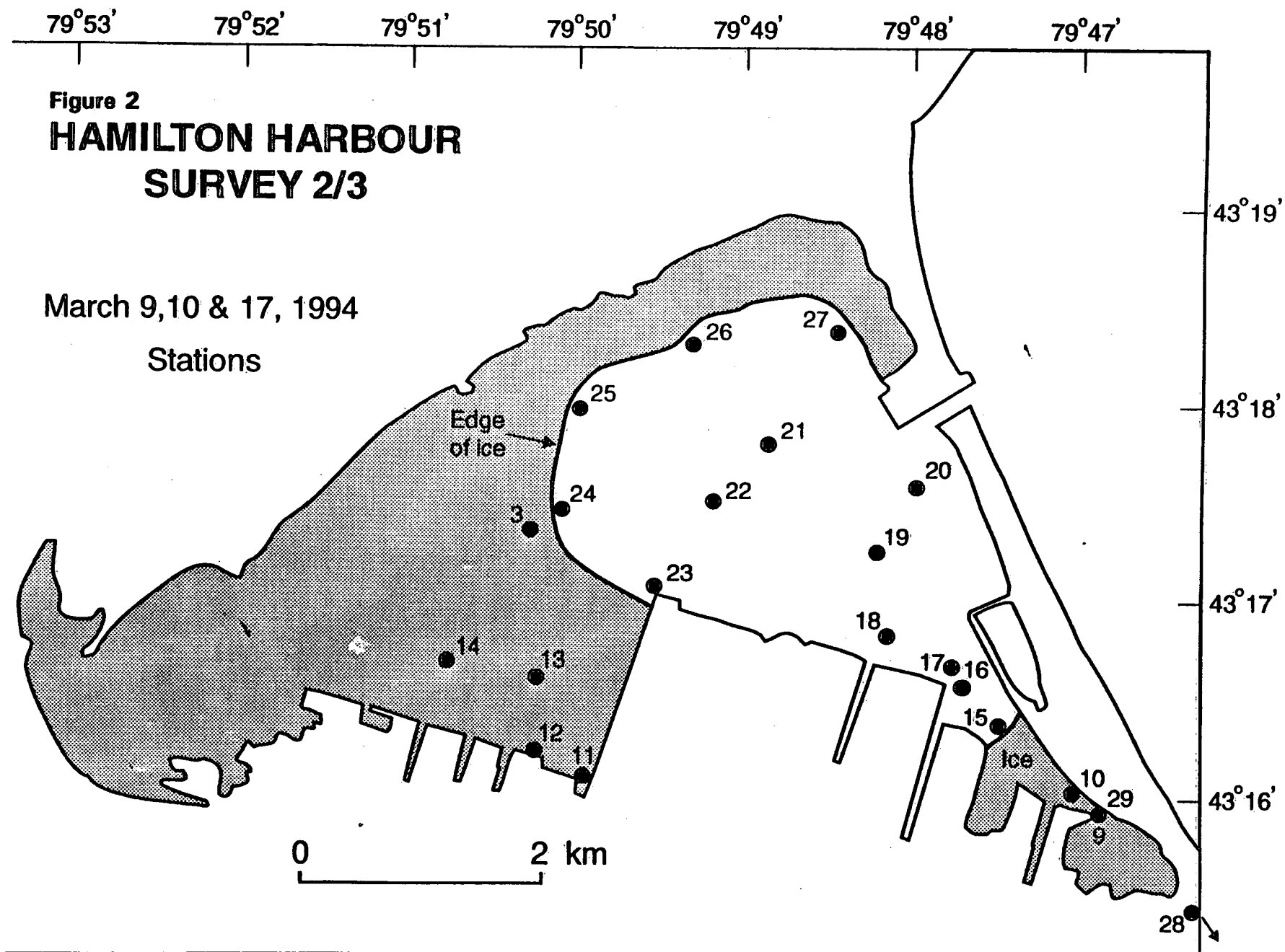


Figure 3

Survey 2/3 March 9, 10 & 17, 1994 Conductivity ($\mu\text{S} / \text{cm}^{-1}$)

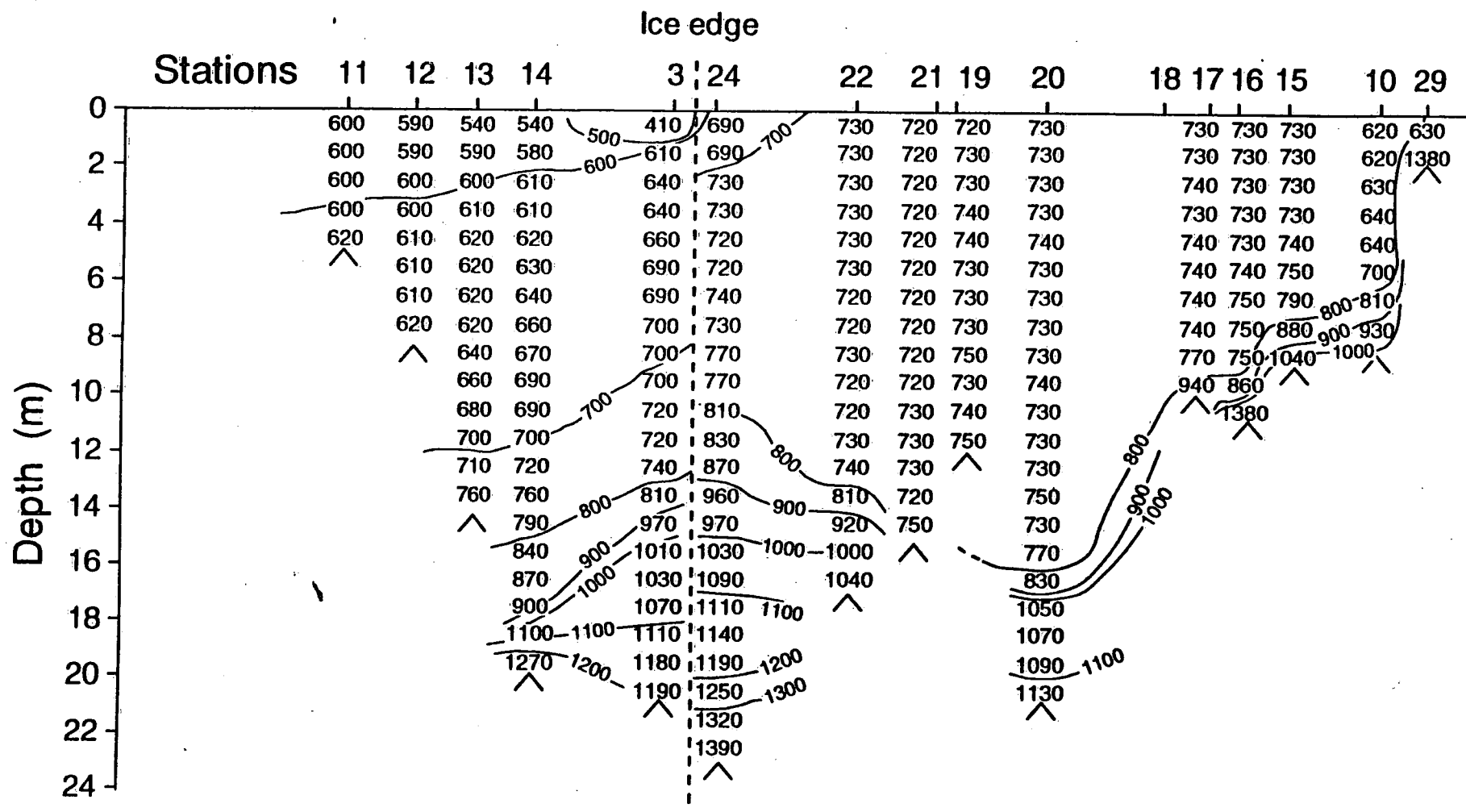


Figure 4

Survey 2/3 March 9,10 & 17, 1994 Temperature, °C

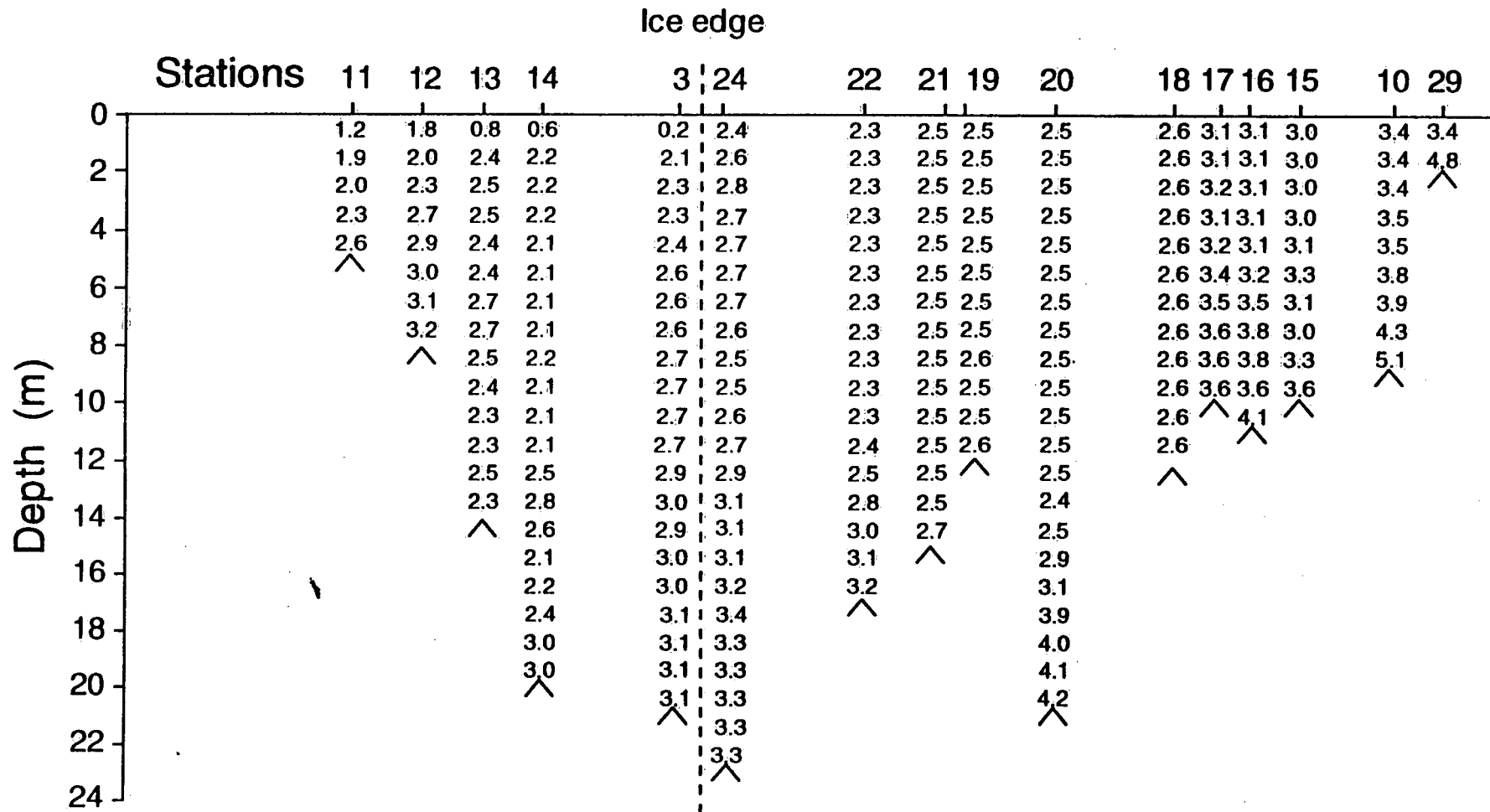


Figure 5

Survey 2/3 March 9, 10 & 17, 1994 Dissolved Oxygen (mg-L⁻¹)

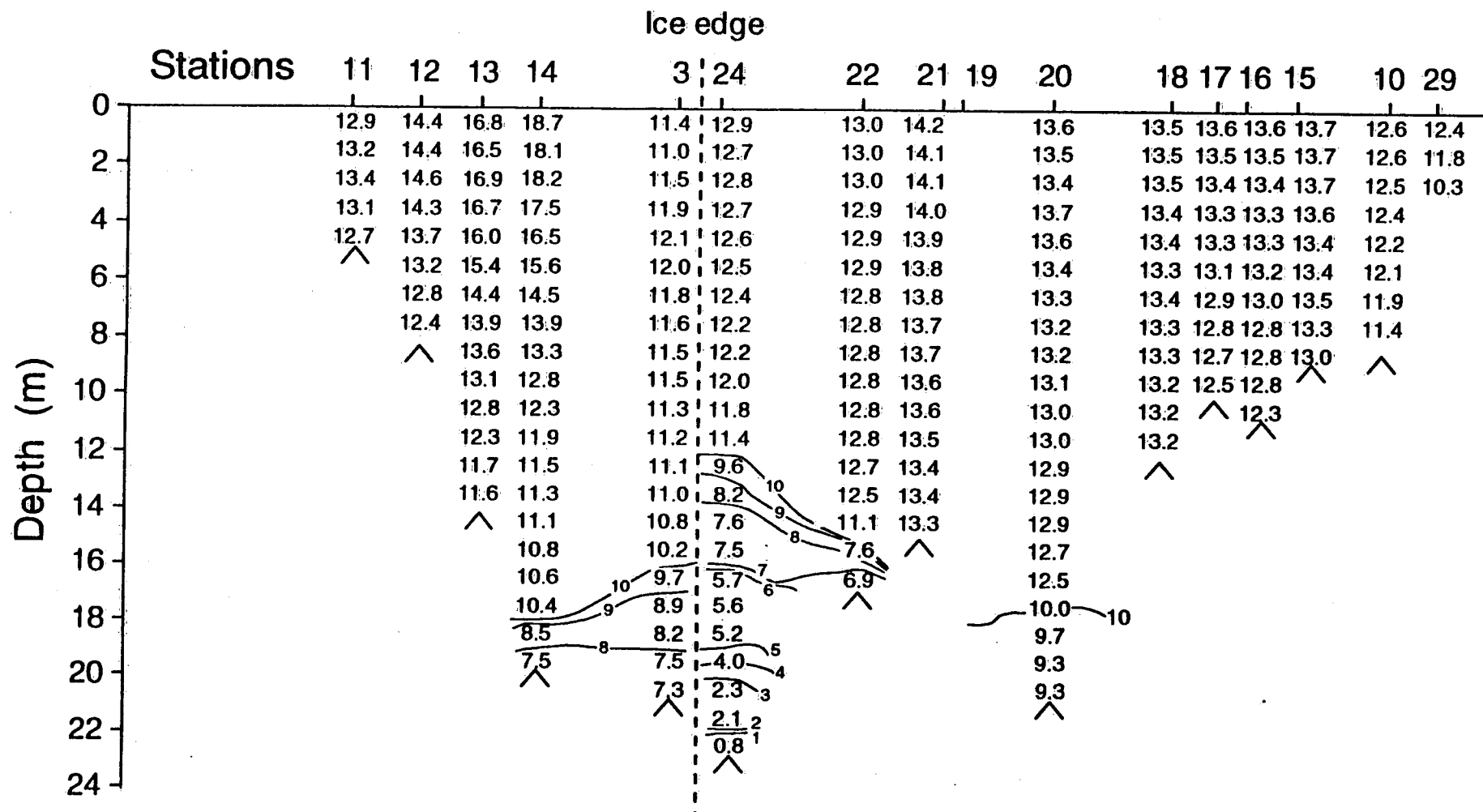
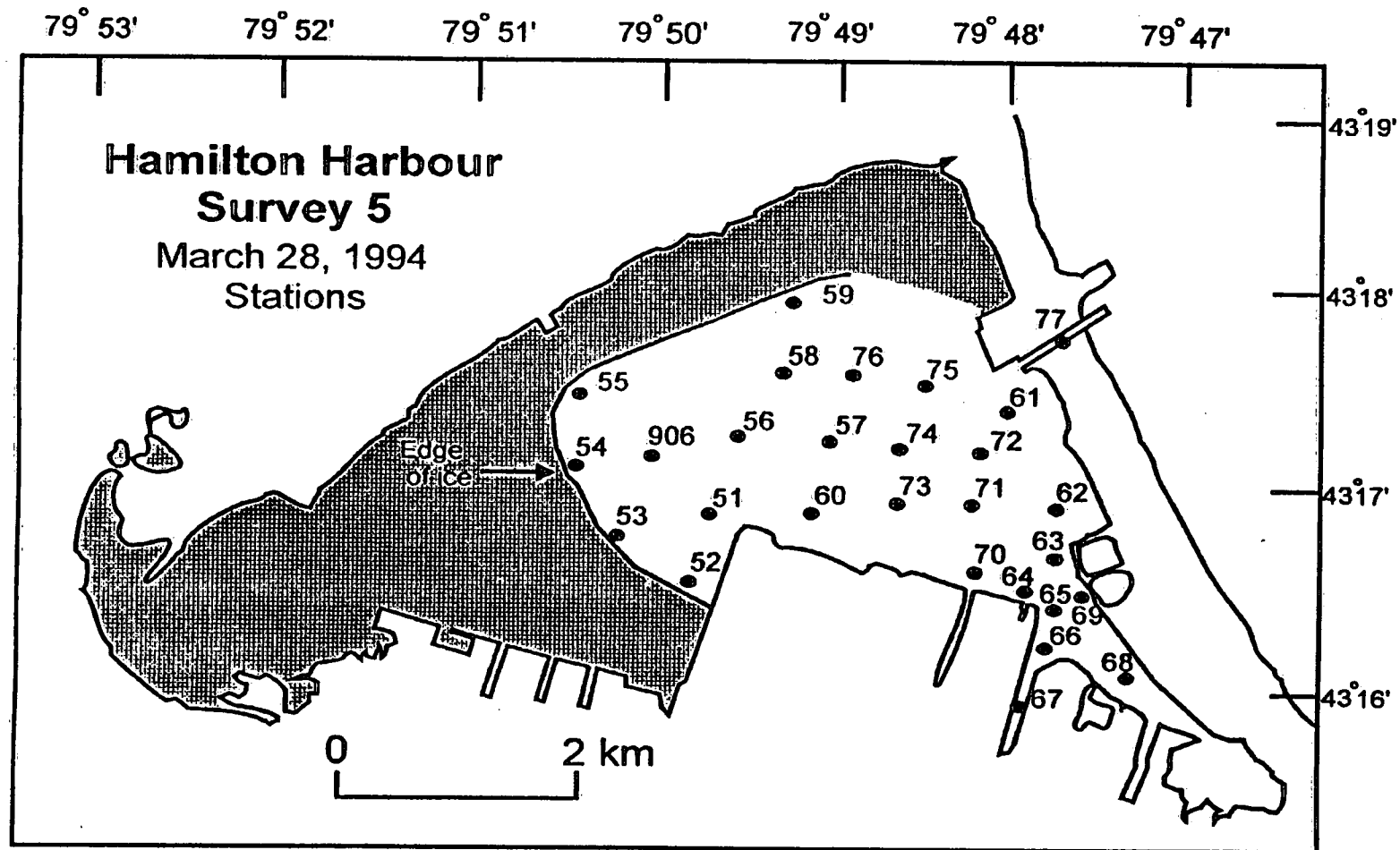


Figure 6



79°53' 79°52' 79°51' 79°50' 79°49' 79°48' 79°47'

Figure 7

HAMILTON HARBOUR SURVEY 5

March 28, 1994

Bottom Temp. (°C)

(not the layer, the
temp. reading at
the greatest depth
recorded)

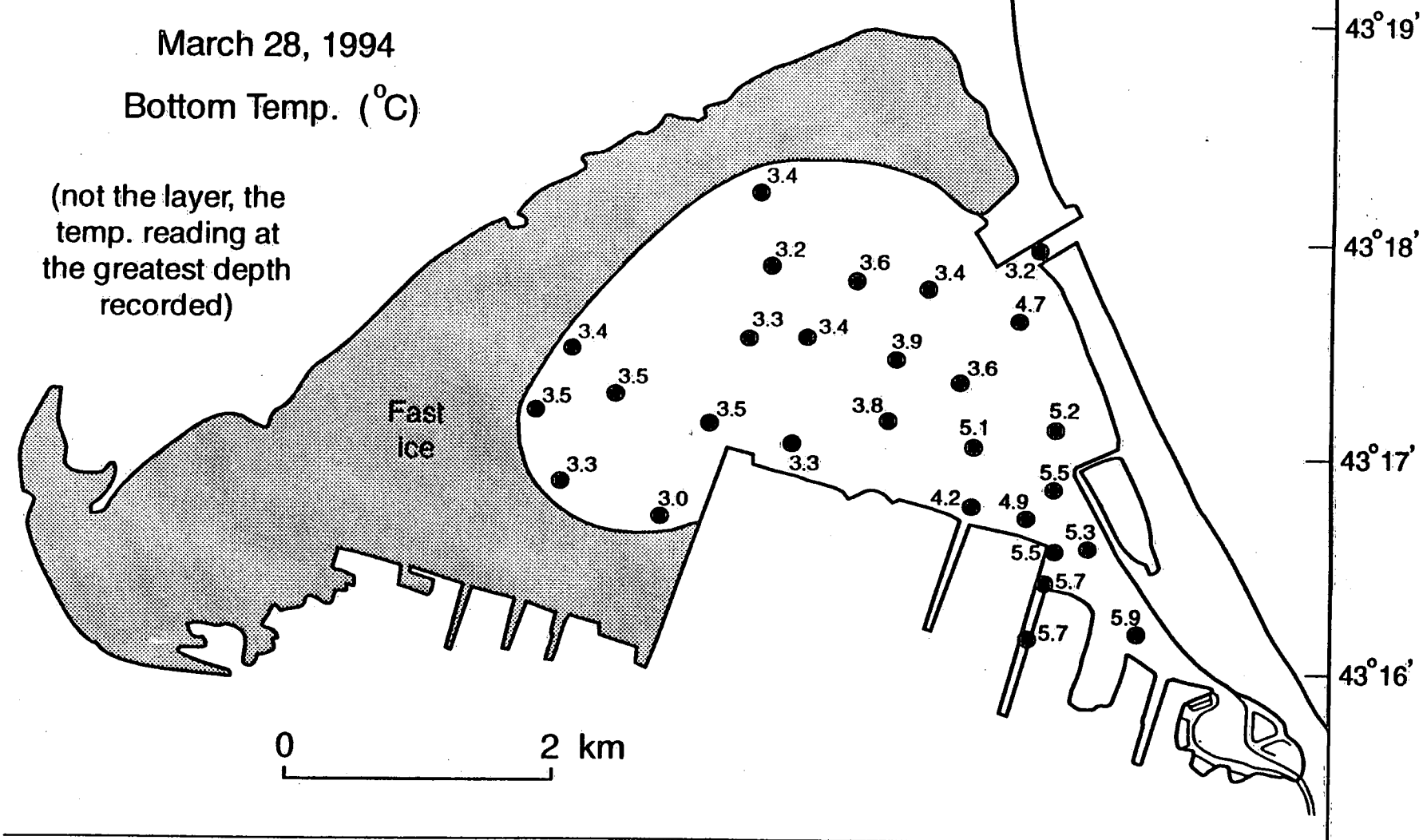


Figure 9
Hamilton Harbour Survey 5
March 28, 1994 Dissolved Oxygen (mg-L⁻¹)

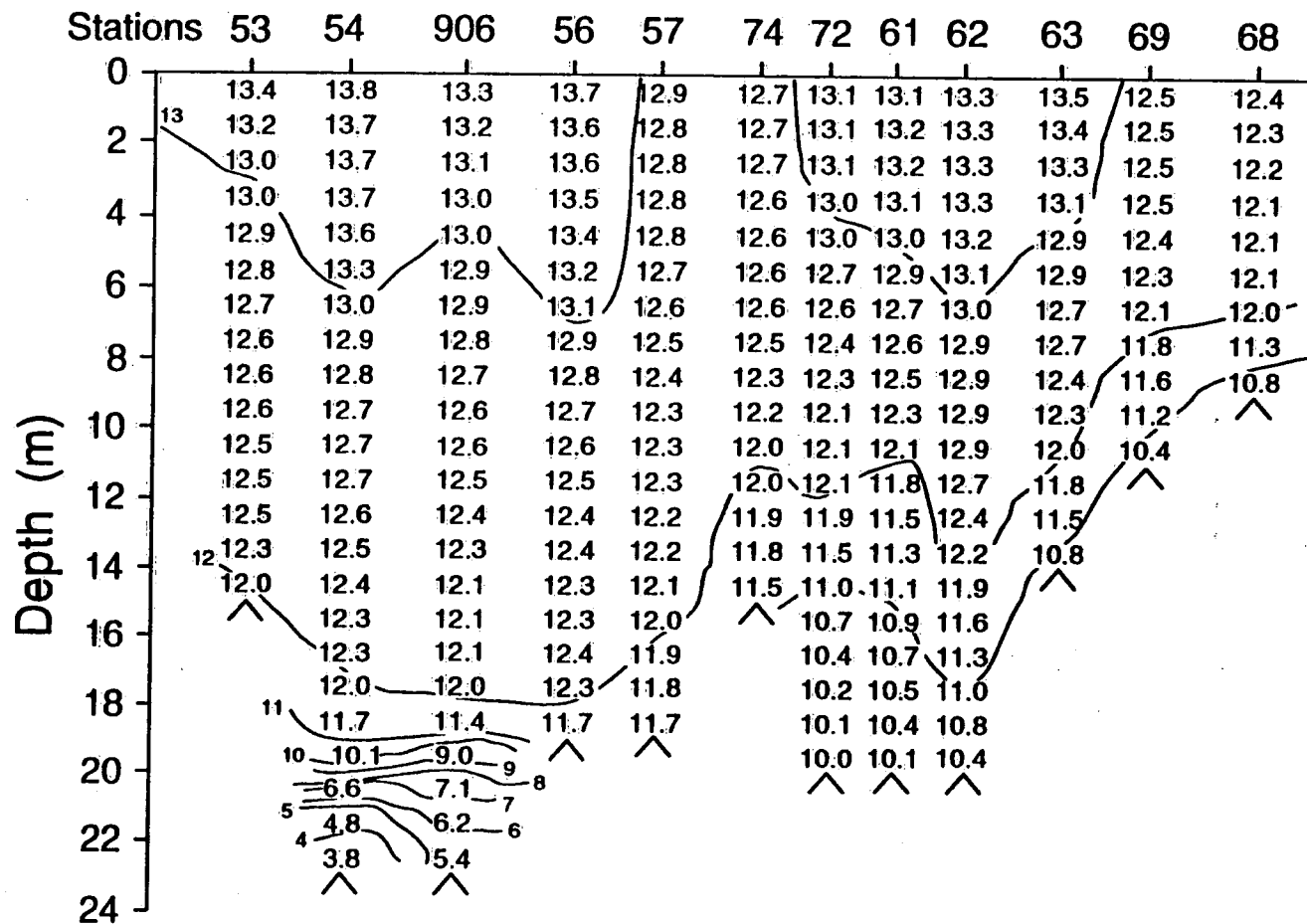


Figure 10
Hamilton Harbour Survey 5
March 28, 1994 Temperature, °C

Stations	53	54	906	56	57	74	72	61	62	63	69	68
0	3.2	3.2	3.0	3.2	3.1	3.4	3.5	3.6	3.4	3.6	3.9	4.1
2	3.1	3.1	3.0	3.1	3.1	3.4	3.4	3.5	3.4	3.6	3.9	4.1
	3.1	3.1	2.9	3.0	3.1	3.3	3.3	3.3	3.3	3.5	3.9	4.2
4	3.0	3.0	2.9	3.0	3.1	3.3	3.2	3.3	3.3	3.5	3.9	4.2
	2.9	3.0	2.9	3.0	3.1	3.3	3.1	3.3	3.2	3.5	4.0	4.3
6	2.9	3.0	2.9	3.0	3.1	3.3	3.1	3.2	3.2	3.5	4.2	4.6
	2.9	3.1	2.9	3.1	3.1	3.2	3.1	3.2	3.2	3.7	4.2	4.6
8	3.0	3.1	2.9	3.2	3.1	3.2	3.2	3.1	3.3	3.8	4.3	4.9
	3.0	3.1	3.0	3.2	3.2	3.2	3.3	3.1	3.2	4.2	4.6	5.7
10	3.0	3.1	3.1	3.1	3.3	3.3	3.3	3.1	3.3	4.4	4.9	^
	3.1	3.1	3.2	3.1	3.3	3.5	3.4	3.3	3.3	4.6	5.2	
12	3.1	3.2	3.2	3.1	3.3	3.5	3.6	3.8	3.4	4.9	^	
	3.2	3.3	3.2	3.1	3.3	3.6	3.7	3.9	3.8	5.3		
14	3.3	3.3	3.2	3.1	3.4	3.5	3.7	4.0	4.1	5.4		
	3.4	3.3	3.4	3.3	3.4	3.8	4.0	4.2	4.2	^		
16	^	3.4	3.4	3.3	3.5	^	4.1	4.4	4.2			
		3.2	3.2	3.2	3.5		4.3	4.6	4.4			
18		3.1	3.1	3.3	3.5		4.2	4.7	4.7			
		3.2	3.2	3.2	^		4.1	4.7	4.8			
20		3.3	3.3	^			3.8	^	5.2			
		3.4	3.3				^		^			
22		3.4	3.4									
		3.4	3.4									
24		^	^									

Figure 11

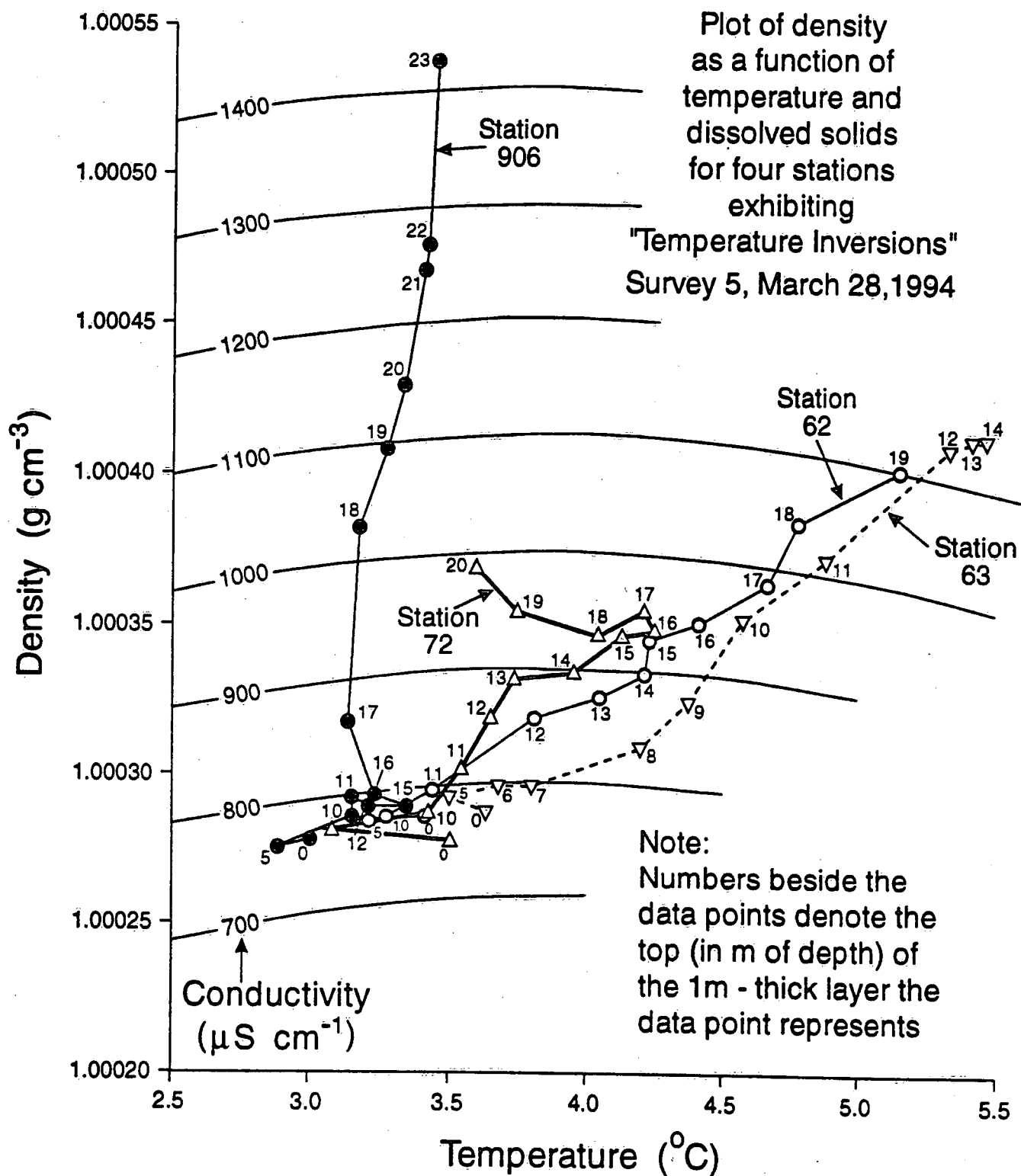


Table 1. Mid-Harbour Conductivity

Date (1994)	2 March	9 March	10 March	10 March	17 March	28 March	28 March
(Survey) > >	(1B)	(2)	(3)	(3)	(4)	(5)	(5)
STATION	3	3	3A	3B	24	54	906
Depth (m)							
0-1	482	408	620	614	685	758	768
1-2	505	614	631	630	689	764	772
2-3	568	637	631	620	734	771	766
3-4	577	639	630	630	731	764	770
4-5	581	660	637	637	722	782	769
5-6	594	693	644	643	721	776	761
6-7	606	692	660	647	739	782	778
7-8	620	695	681	685	733	782	763
8-9	646	698	690	692	768	781	769
9-10	677	701	695	702	775	776	780
10-11	704	715	719	719	806	771	779
11-12	737	722	764	750	833	775	797
12-13	762	737	792	819	872	785	790
13-14	810	806	840	857	955	783	789
14-15	916	972	934	928	969	804	796
15-16	951	1012	967	963	1034	789	785
16-17	976	1025	1015	989	1087	810	797
17-18	1006	1071	1054	1038	1109	857	863
18-19	1042	1105	1071	1090	1140	1053	1029
19-20	1071	1179	1105	1116	1188	1179	1096
20-21	1097	1186	1168	1169	1248	1204	1147
21-22	1166			1273	1318	1232	1246
22-23	1263				1392	1265	1267
Change in Water Column Conductivity: (μScm^{-1})							
(over 2 weeks)							
	(+47)	(-1)	(-1/2)	(+75)	(-52)	(-7)	

Conclusions:NOISE LEVEL $\sim \pm 10\mu\text{Scm}^{-1}$ CALIB. DIFF $\sim \pm 10\mu\text{Scm}^{-1}$

Other features

Dissolved oxygen depletion is clearly evident in the deepest waters at Station 24 on March 17th. Waters below 20m depth had an oxygen content below the Hamilton Harbour Remedial Action Plan goal of a minimum of 4 mg L^{-1} . The same condition was present on March 28th below 22m (stations 54 and 906). Winter observations done in the western end of the Harbour in 1978-79 by Morgan (1979) are consistent with the 1994 data. The sampling by Morgan went only to the depth of 12m and therefore did not show these more extreme oxygen depletions. The 1978-79 winter was also relatively severe being the 7th coldest in 36 years.

Based on the data in Table 2, which shows the chemical analyses of samples taken on March 10th at 2 depths (one above the chemocline and one below the chemocline), the lower layer is enriched in phosphorus, nitrogen (NH_3 and NO_2/NO_3), sodium and chloride. The latter two explain the increase in conductivity and density. The former pair give rise to the oxygen depletion (despite the cold temperatures).

Finally, data taken in the Canal (station 77 on March 28th given in Table 3) show an instance of warmer harbour water on the bottom of the canal and colder Lake Ontario water (low conductivity) in the surface layer. If this Lake Ontario water were to enter the Harbour, it would be lighter than all other Harbour waters and would dilute the surface layer in a stable manner as it moved into the bay.

Table 2. - Sample Analysis Report

Station#-depth > >	STN3A 8M	STN3A 19M	STN3B 8M	STN3B 20M
ALKCACO3 (MG/L)	110.5	106.2	116.5	100.7
CA (MG/L)	50.9	57.6	54.3	57.3
CL (MG/L)	109.	225.	107.	232.
SIO2 (MG/L)	2.07	3.94	2.48	3.04
SO4 (MG/L)	54.1	62.8	52.9	61.6
MG (MG/L)	12.3	13.1	13.0	13.0
K (MG/L)	4.27	5.10	4.45	5.10
NA (MG/L)	62.9	141.	63.6	146.
SPCOND (US/CM)	694.	1130.	707.	1140.
SRP-UF (MG/L)	.0091	.0304	.0153	.0304
TP-UF (MG/L)	.0443	.0963	.0467	.0534
NH3-UF (MG/L)	.793	2.98	1.31	2.58
NO3NO2-U (MG/L)	1.65	1.223	1.74	1.248
TURB (JTU)	1.30	6.25	1.15	2.20

* Samples taken on 10 March, 1994 at the stations beside the edge of the solid ice cover.

Positions:	<u>Station No.</u>	<u>Latitude N</u>	<u>Longitude W</u>	<u>Water Depth</u>
	3A	43° 17'20"	79° 50'14"	20.7m
	3B	43° 17'16"	79° 50'06"	21.7m

Table 3. - Profile data in the Burlington Ship Canal on March 28th, 1994.

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
77 (Canal)	0 - 1	2.00	371	13.8	100
	1 - 2	2.00	376	13.9	100
	2 - 3	2.00	378	13.9	100
	3 - 4	2.01	390	13.9	100
	4 - 5	2.08	404	13.8	100
	5 - 6	2.37	541	13.7	100
	6 - 7	2.96	691	13.4	99
	7 - 8	3.08	714	13.0	96
	8 - 9	3.16	738	12.6	94
	9.2 Bottom	3.19	761	12.3	92

Conclusions

Chemical stratification of the water column takes place under the winter ice cover in Hamilton Harbour. The intensity likely varies in accordance with the degree of ice cover (i.e. the weather), volumes of runoff and contamination of the runoff. The higher density water discharged from sewage treatment plants, from some streams that carry higher salt content and perhaps from combined sewer overflows, form the major characteristics of this bottom layer of thickness between 1 and 8 metres.

The biological and chemical significance of this phenomenon has not yet been investigated although it appears that it may be slight in the light of the more severe oxygen depletion that takes place every summer.

Nonetheless, it is useful to keep in mind the fact that there is the potential for this type of density flow in the winter, especially in ice-covered harbours, lakes or embayments of the temperate or arctic/antarctic latitudes.

If investigators dealing with the biological material or chemistry of this Harbour feel that this phenomenon is of sufficient significance, detailed investigations could be carried out to establish more precisely the source and the pathway of the discharges that form this density current, the year-to-year variability of the intensity of this layer formation, and the potential to alter the characteristics of the water mass to the benefit of the aquatic ecosystem.

Acknowledgements

There are special thanks due to the staff of the Technical Operations Section of NWRI at CCIW, who collected the data. Special thanks are due to John Kraft and Jackie Milne who undertook some of these observations in adverse weather conditions. F. Boyce, P.F. Hamblin and R. Allan provided useful reviews of the penultimate draft of the report.

Staff of several agencies kindly provided useful ancillary data, including Environmental Services of the Regional Municipality of Hamilton-Wentworth, staff of the Burlington Skyway WWTP, offices of the West Central Region of the Ontario Ministry of Environment and Energy, the National Laboratory for Environmental Testing of Environment Canada, Environmental Quality Branch, EC and the Canadian Climate Centre of Environment Canada.

Last, but not least, I wish to recognize the thoughtful question about the potential effects of road salt, that was posed by a citizen whose name I do not know. This question arose in a public meeting dealing with the early stages of the development of the Remedial Action Plan for Hamilton Harbour. At that time the scientific staff had no answer for the question. Now we have the beginnings of some understanding of the consequences of the higher salt content in discharges to the Harbour.

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Appendix 1

STANDARDIZATION OF CONDUCTIVITY READINGS: CALIBRATION AND TEMPERATURE STANDARDIZATION

Data collected in the Harbour were obtained using a HYDROLAB profiler (Model H₂O) with a built-in temperature compensation factor documented in their manual. Samples collected from the rivers (other than in Windermere Basin and one measurement made on Redhill Creek on March 17th) were made on-site with a Y.S.I. Conductivity Meter (Model 33, Serial No. 5059), and a temperature compensation factor applied in later computations. All data were standardized to the 25°C reference level.

Calibration of Instruments

The Y.S.I. Conductivity meter was calibrated on May 30th following the observation program (Table A1 - 1). The instrument had not been used in field work between the date of the results recorded in this report and the calibration date. Corrections were applied accordingly.

The Hydrolab profiler standard printout has been modified to suit conditions that have been observed in the Harbour. Calibration of this instrument was carried out on the following dates: Dec. 30/93 (temperature); Jan. 4/94 (conductivity); Mar. 11/94 (depth); Apr. 8/94 (temperature); Apr. 14/94 (conductivity); Apr. 13/94 (pH and dissolved oxygen). See Table A1 - 1.

Temperature Compensation

Temperature standardization or compensation to 25°C is a critical factor when measuring temperatures are below 5°C. Any error in the characterization of the temperature standardization curve is critical, and of course, the HYDROLAB profiler records data '*in situ*'. Water samples can be warmed to temperatures much closer to the standard of 25°C, although most of the Y.S.I. measurements made on stream samples for this report were made on-site at the lower temperatures. The source of the difficulty lies in the fact that the ionic composition of the dissolved material contributing to the conductivity of the water sample will affect the temperature compensation factor.

The temperature compensation factor for the Hydrolab profiler is a 5th order polynomial in temperature (see HYDROLAB profiler manual).

The temperature compensation factor used with Y.S.I. data can be based on the following equation (Johnson, 1989):

$$\text{Conductivity at } 25^{\circ}\text{C} = \frac{\text{Conductivity at } t^{\circ}\text{C}}{[1 + \alpha (t - 25)]}$$

Johnson (1989) determined that the α most suitable for a mid-Harbour summer sample was 1.88% (open Lake Ontario had an $\alpha = 2.0\%$).

The National Laboratory for Environmental Testing (NLET) has an empirical temperature compensation table that they use for Great Lakes samples. A comparison of these standardization factors (equation with $\alpha = 1.88\%$, the NLET factors and the Hydrolab polynomial) is given in Table A1 - 2. The data in D. Johnson's report tend to support the use of empirical or polynomial formulations since his data show systematic changes in the α that one computes at different temperatures.

Table A1 - 2

TEMPERATURE STANDARDIZATION FACTORS			
Temperature°C	NLET	(a) Hydrolab	(b) $\alpha = 1.88\%$
25	1.000	1.0002	1.0000
20	1.120	1.1053	1.1038
15	1.269	1.2317	1.2315
10	1.447	1.3872	1.3928
5	1.654	1.5805	1.6026
0	1.888	1.8199	1.8868

The Hydrolab profiler factors seem to be following a pattern associated with an α of 1.80% at the lower temperatures. The manufacturer states that the built-in temperature compensation is based on a 0.01 N KCl solution. Based on the data in Table A1 - 2 it was concluded that the automatic temperature compensation of this profiler had to be replaced with equation 1 using $\alpha = 1.88\%$ for this set of data. This conclusion would generally be different in other situations, depending largely on the ambient temperature of the water masses of interest.

In addition, conductivity calibration data has to be considered. The conductivity sensor for the Hydrolab instrument shows out-of-range drift in calibration from the pre-field setting of January 4th, 1994 to the April 14th post-field calibration. Computations required return to the original readings (at in-situ temperatures), and application of a drift correction based on the proportion of time between these two calibration dates, assuming a linear change with time (a shaky assumption). Some of the higher conductivity readings (around 1500 to 2000 μScm^{-1} at 25°C) may be taken as accurate to only about $\pm 4\%$.

The temperature and depth calibrations were within acceptable limits for the measurements made in this study.

Appendix 2**BASIS OF SATURATION ESTIMATES FOR OXYGEN
IN HARBOUR WATERS**

All data reported here on % oxygen saturation were based on the automatic output of the Hydrolab profiler. In the Hydrolab manual, the data used are shown as follows:

<u>T°C</u>	<u>mg dissolved oxygen/L water at 1 atmosphere</u>
0	14.57
1	14.17
2	13.79
3	13.43
4	13.08
5	12.74
6	12.42
7	12.11
8	11.81
9	11.53
10	11.26
11	10.99
12	10.74
13	10.50
14	10.57

(This is the range required for this report. For higher temperatures found in other seasons, consult the Hydrolab manual).

Appendix 3

DENSITY OF WATER AS A FUNCTION OF TEMPERATURE, TOTAL DISSOLVED SOLIDS (AS INDICATED BY CONDUCTIVITY) AND SUSPENDED SOLIDS CONTENT.

Density as a function of temperature

The equation of state published by Chen and Millero (1986) is the basis for density calculations. This equation was used directly for the computation of density as a function of temperature for pure water.

Density as a function of salinity (dissolved solids)

Since the 'salinity' (gm of dissolved salt in 1kg of lake or creek water) is not measured directly very often, the conductivity measurements were used instead. The relation between conductivity and salinity was taken as:

$$S = 0.52 \times \text{Conductivity } 25^{\circ}\text{C} \times 10^{-3} \text{ gm kg}^{-1}$$

(see Data Tables, Appendix 6), where conductivity is in μScm^{-1} .

It would be somewhat more rigorous to develop detailed relation specific to various Harbour water masses. But this 'salinity' estimation was used in Chen and Mellero's equation of state in the absence of such information.

Density as a function of suspended solids

Suspended particles displace water with materials of different (and higher) density and therefore cause the weight per unit volume to increase. Turbidity currents are a particular case of a density current induced by a high turbidity (usually consisting of inorganic particles) caused by high river flows in erodable channels or earthquakes on the continental shelves under the ocean.

The density of suspended particles found in lakes is quite variable. Organic material (decaying vegetative material, for example) has a density of 1.0 to 1.7. Inorganic particle densities range from 1.0 to 3.6 depending on their mineral composition (Ciaccio, 1981, pg. 595). In the absence of detailed study of the types and sizes of particles in the waters that were sampled a 'typical' density of 2.5 gm cm^{-3} was chosen to illustrate water density dependence on suspended solids content. This is probably a high value for quiescent lake waters, in the author's opinion, but the change in scale can be easily altered using the following equations:

$$\text{If TSS (total suspended solids)} = \text{S.S. content in mg L}^{-1}$$

The amount of water displaced by the particles is
 $\frac{\text{TSS} \times 10^{-3}}{\rho_{\text{part}}} \text{ cm}^3$ in 1L of water

A3 - 2

The weight of water displaced is
 $\frac{\text{TSS} \times 10^{-3}}{\rho_{\text{part}}} \times \rho_{t,s,o} \text{ gm}$

where $\rho_{\text{part.}}$ = particle density; and

$\rho_{t, s, ss}$ = density of water at a given temperature t , salinity s , and suspended solids content, ss .

Therefore, the density of the resultant mixture of water and suspended material is:

$$\rho_{t, s, ss} = \rho_{t, s, o} + \frac{ss \times 10^{-6}}{\rho_{\text{part.}}} (\rho_{\text{part.}} - \rho_{t, s, o})$$

$$= \rho_{t, s, o} + ss \times F$$

equation 2

$$\text{where } F = 10^{-6} \frac{(\rho_{\text{part.}} - \rho_{t, s, o})}{\rho_{\text{part.}}}$$

equation 3

Density Tabulations

For convenience, densities for temperatures from zero to 28°C and for conductivities from zero to 2000 $\mu\text{S cm}^{-1}$ are given in Table A3 - 1. This is necessary because the relationships are not linear.

The influence of suspended solids is different for the range of suspended solids encountered in the Harbour. The dependence on the value of the TSS is linear. There is a slight dependence on $\rho_{t, s, o}$, but there is a more important non-linear dependence on the density of the particles. These dependencies are shown in Table A3 - 2. The presentation of the impact of suspended solids is simplified by choosing only to illustrate the situation for low representative turbidities and one particle density (2.5 gm cm^{-3}).

**DENSITY OF WATER AS A FUNCTION OF
TEMPERATURE AND CONDUCTIVITY**

Density gm cm ⁻³				
Temp. °C	0	1	2	3
Conductivity μScm ⁻¹				
0	0.9998395	0.9998984	0.9999379	0.9999640
400	1.0000097	1.0000678	1.0001083	1.0001318
800	1.0001798	1.0002371	1.0002769	1.0002997
1200	1.0003500	1.0004065	1.0004455	1.0004675
1600	1.0005201	1.0005759	1.0006141	1.0006353
2000	1.0006904	1.0007453	1.0007827	1.0008032

TABLE A3 - 1 (cont.'d)

Temp. °C	4	5	6	7
0	0.9999720	0.9999638	0.9999402	0.9999015
400	1.0001391	1.0001302	1.0001059	1.0000665
800	1.0003063	1.0002966	1.0002717	1.0002316
1200	1.0004734	1.0004630	1.0004374	1.0003966
1600	1.0006405	1.0006294	1.0006031	1.0005617
2000	1.0008076	1.0007958	1.0007689	1.0007267

TABLE A3 - 1 (cont.'d)

A3 - 4

Temp.°C	8	10	12	16
0	0.9998483	0.9996996	0.9994976	0.9989430
400	1.0000127	0.9998630	0.9996596	0.9991030
800	1.0001771	1.0000264	0.9998217	0.9992630
1200	1.0003416	1.0001898	0.9999837	0.9994230
1600	1.0005060	1.0003532	1.0001457	0.9995830
2000	1.0006704	1.0005166	1.0003078	0.9997430

Temp. °C	20	24	28
0	0.9982041	0.9972964	0.9962334
400	0.9983624	0.9975433	0.9963892
800	0.9985206	0.9976102	0.9965451
1200	0.9986789	0.9977671	0.9967009
1600	0.9988372	0.9979240	0.9968567
2000	0.9989954	0.9980809	0.9970126

Table A3 - 2

**INFLUENCE OF SUSPENDED SOLIDS
ON THE DENSITY OF WATER**

Factor F:

<u>Temperature</u>	<u>0°C</u>	<u>24°C</u>
Particle Density gm cm ⁻³		
2.5	6.0006 x10 ⁻⁷	6.0151 x10 ⁻⁷
2.0	5.0008 x10 ⁻⁷	5.0135 x10 ⁻⁷
1.5	3.3344 x10 ⁻⁷	3.3514 x10 ⁻⁷

(gm cm⁻³ / mg L⁻¹ of TSS)

Note: TSS content of 100 mg L⁻¹ of particles with density 2.5 gm cm⁻³ adds 0.0000600 to the water density (100 x 6.0006 x10⁻⁷)

There are several modes of presenting this information. A temperature-salinity diagram with isopycnals is the traditional method in oceanography where salinity is measured indirectly with no major disruptions in the relation between the salinity and the type of measurement (chlorosity or conductivity). The uniformity of ionic composition in the open oceans is remarkable, so that this procedure is suitable.

In the case of lakes however, ionic ratios are highly variable, especially in areas of river or sewer/industrial effluent. This calls for a presentation where one can readily see the potential for changes in density due to changes in particle density (in TSS) or to changes due to differences in the salinity/conductivity relation.

Two graphical presentations are included - one for the temperature range being addressed in this report, and the second for a full range of seasonal temperature conditions. See figures A3 - 1 and A3 - 2. The utility of such figures is explained in the report as it pertains to water mass identification and to the effects of mixing of water masses or their cooling.

Simplification of density calculations

While the relation of density to temperature is non-linear, the non-linearity of density changes with respect to both TDS (or conductivity, or salinity) and TSS are linear for particular degrees of accuracy.

If accuracy to $\pm 0.00003 \text{ gm cm}^{-3}$ in density is all that is required, one can use the equation:

$$\rho_{t, s, ss} = \rho_{t, o, o} + (4.1 \times 10^{-7} \times \text{Cond}_{25^\circ}) + (6 \times 10^{-7} \times \text{TSS}) \quad \text{equation 4} \\ \text{mg/L}$$

where $\rho_{t, o, o}$ is given by the equation of state referenced above, and tabulated in the first line of Table A3 - 1.

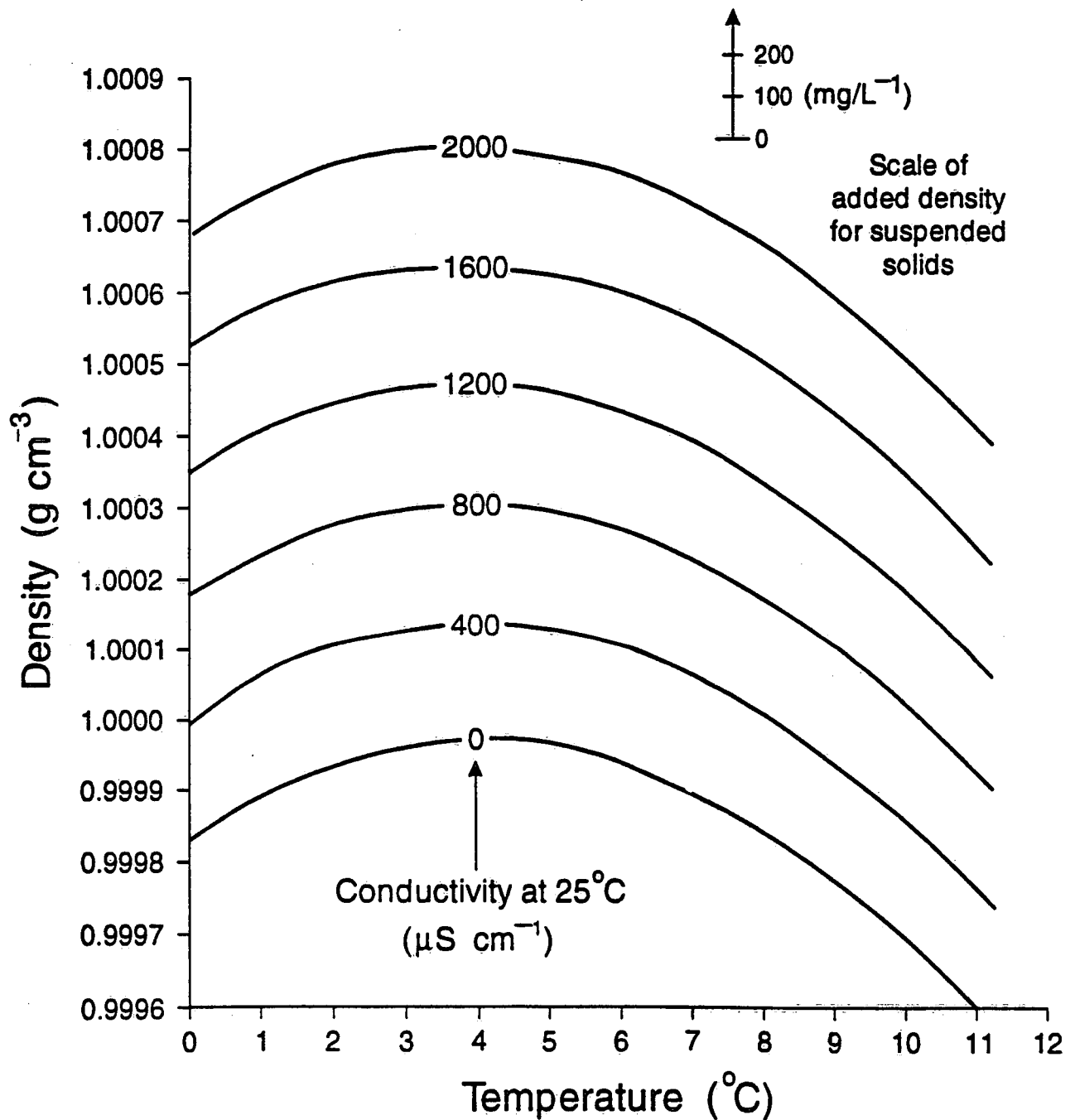
The greatest sources of potential error in this formulation are:

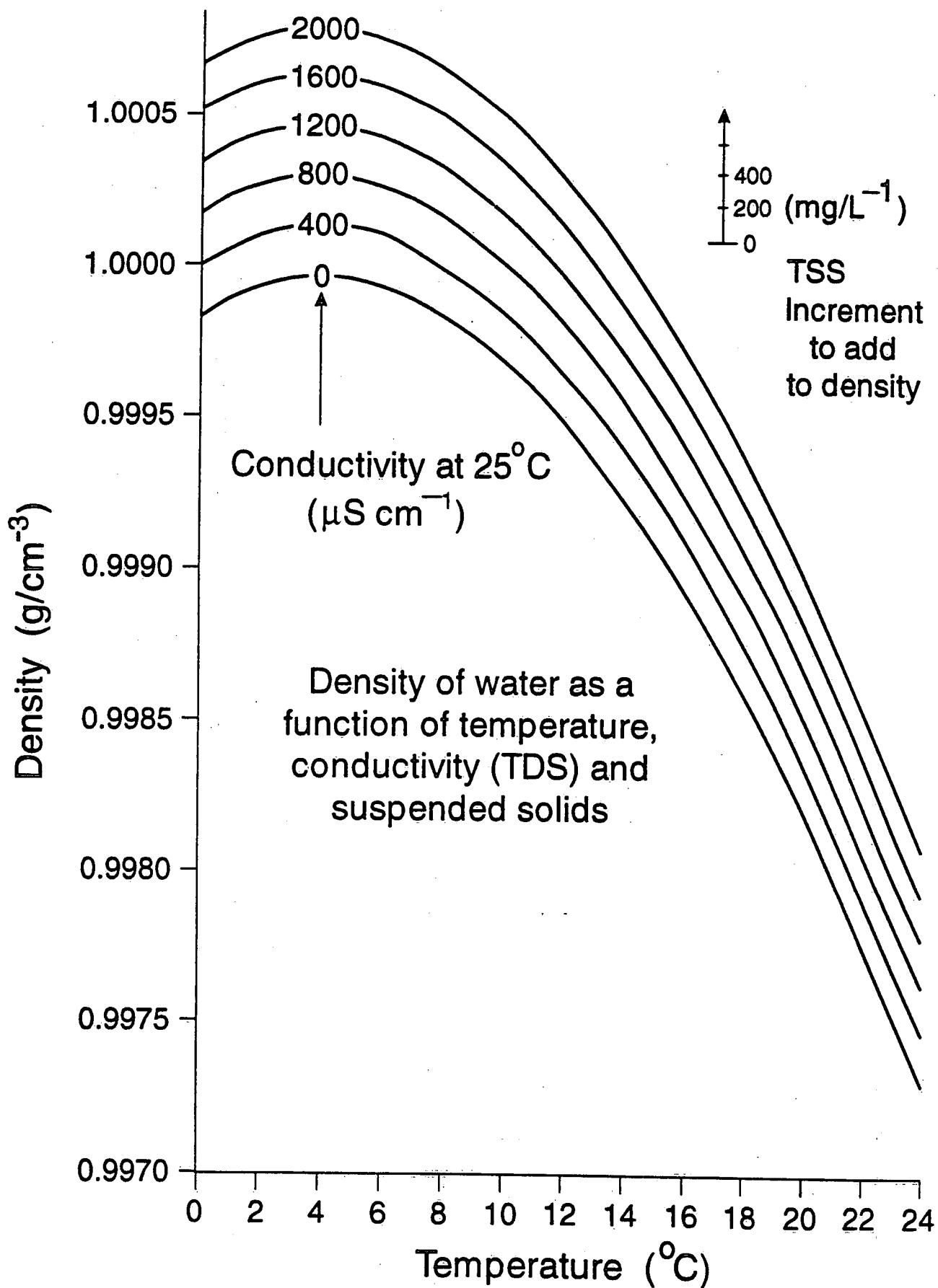
- a) the relation between conductivity and total dissolved solids, and
 - b) the density and nature of the particles that comprise the suspended solids.
- These two subjects are worthy of greater depth of study for this body of water.

Figure A3-1

Density of water as a function of
temperature, conductivity and
suspended solids

(TDS = 0.52 Cond._{25°C})





**CONDUCTIVITY - TEMPERATURE SURVEY OF
STREAMS DISCHARGING TO HAMILTON
HARBOUR AND COOTES PARADISE: APRIL, 1994**

These measurements were made on Redhill Creek on April 11th, 1994. Grindstone Creek was sampled at 2 locations, and Spencer Creek at 1 location on April 12th, 1994. The data and station location maps follow (Tables A4 - 1 and A4 - 2, Figure A4 - 1).

The conductivity of Redhill Creek water is much higher than Spencer Creek or Grindstone Creek water at this time. The origin of the Redhill Creek conductivity (upstream of the Woodward Avenue STP) is partly salt from de-icing applications on roads, but a more detailed investigation seems to be required to sort out other possible sources of higher conductivity waters.

The Spencer Creek data were not surprising. The Grindstone Creek data were somewhat surprising (surprisingly low) given that the Waterdown STP discharges into the creek upstream. Again, more detailed studies would be useful to explain why this conductivity is at the low level observed on this date.

Data collected by the OME on these 3 creeks confirm the range of conductivity values observed in this survey, and the pattern of differences noted above.

Stream Survey Stations

April 11th and 12th, 1994.

Description of sampling locations

Redhill Creek (RH) - April 11th, 1994.

RH1, 1039 hr EST - north end of Windermere Basin, sample taken from road bridge (North Side).

RH2, 1050 hr - Woodward Ave. bridge crossing of RH Creek, from north side of bridge.

RH3, 1106 hr - Creek sampled in line with Brampton St., just above rivulet entering on west side.

RH4, 1108 hr - Sample of very small rivulet coming from west along Brampton St. alignment.

RH5, 1110 hr - replicated sampling of RH#3.

RH6, - main creek on the south side of Melvin Ave., upstream of storm drains.

RH7, - storm drain water entering RH creek from the east side between RH6 and Melvin Ave. (south side of Melvin Ave.)

RH8, 1156 hr - RH Creek, just north of King St. where channel has been modified.

RH9, 1203 hr - Creek entering main RH Creek from the east side just south of King St. and on the south side of the old bridge abutment.

RH10, 1205 - Main creek, south of King St. and upstream of where the creek (RH9) enters from the east.

RH11, - Eastern-most creek of the RH system (above King), downstream of Quigley Road near the east end of the cul-de-sac of Veevers Dr.

RH12, - Second eastern-most creek of the RH system just above (south) of King St. at Greenhill Ave. (north side) just east of Mt. Albion Rd.

RH13, 1332 hr, - Sample of same creek section as RH12 but beside Albion Rd. (east side) upstream of the golf course.

RH14, - Same creek as RH12 (one branch of it) where it crosses Mud St. just east of Mt. Albion Rd. (just a ditch)

RH15, 1347 hr, - Albion Falls at Mud St.

RH16, - RH creek at eastern crossing of Stone Church Rd. (HRCA lands) just south of the road where it enters the culvert.

RH17, 1411 hr - at that branch of the creek that comes from the west at the RR crossing bridge (now gone) on the east side of the Ottawa St. Landfill.

RH18, 1450 hr - RH creek at Greenhill Ave. upstream of the holding tank discharge location.

RH19, 1452 hr - RH creek at Greenhill just downstream of the holding tank discharge location.

Grindstone Creek (GR)

GR1, 0840 hr - GR at Lambs Hollow Gate, just east of the RBG footbridge over the creek (west of Unsworth Ave.)

GR2, 1145 hr - GR at road bridge that leads to the Laking Gardens (RBG)

Spencer Creek (SP)

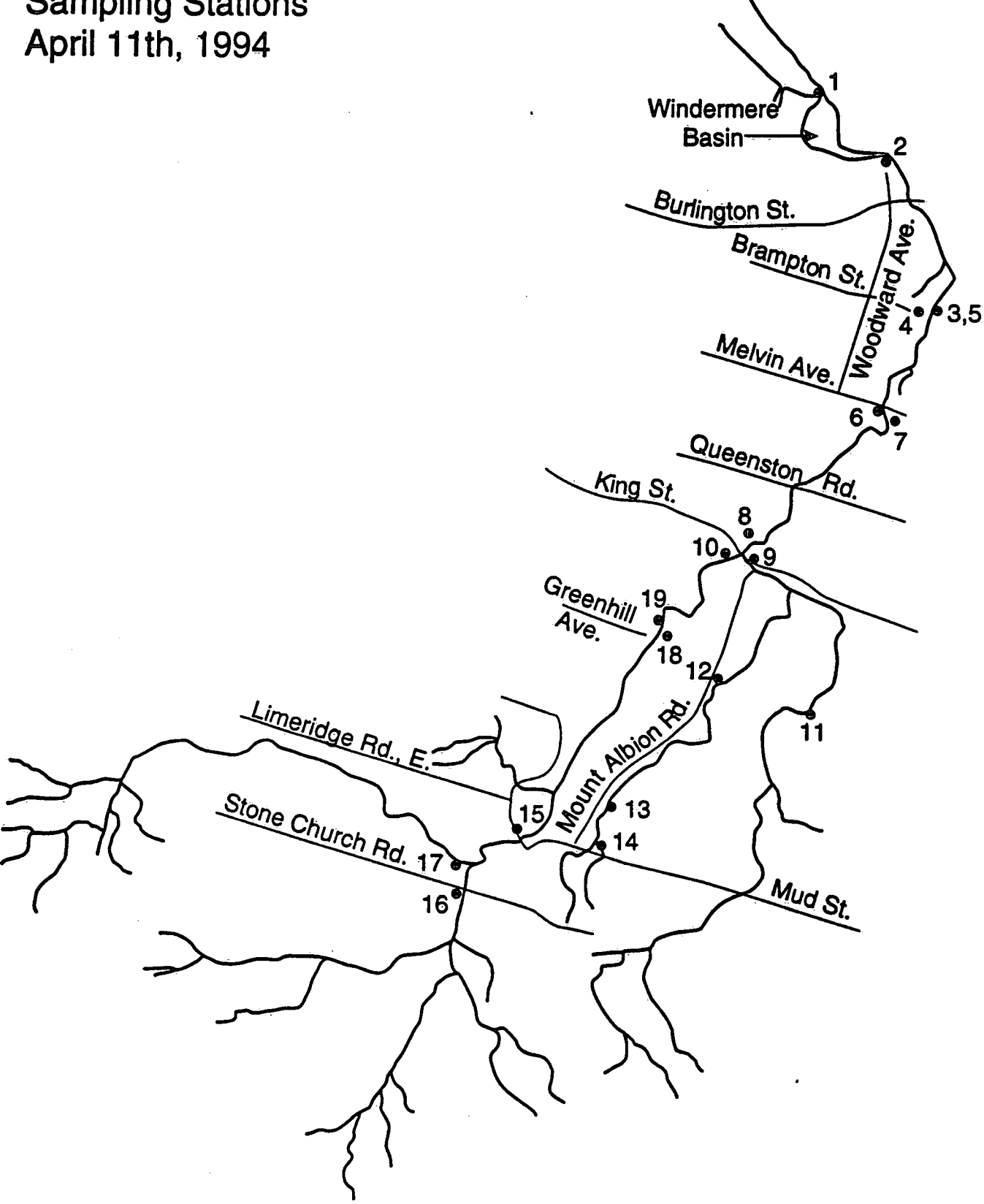
SP1, 1200 hr - Creek sample about 10m upstream of the Cootes Drive bridge.

Stream Data - April 11th and 12th, 1994.**A4 - 3**

Station		Water Temp. (°C)	Conductivity Reading ($\mu\text{S cm}^{-1}$)	Conductivity 25°C ($\alpha = 1.88\%$) (rounded off)
RH	1	20.7	1105	1200
	2	20.6	1175	1280
	3	6.2	1105	1710
	4	8.4	4130	6000
	5(RH3 repeat)	6.2	1105	1710
	6	6.8	1033	1570
	7	6.8	1680	2550
	8	7.6	1054	1570
	9	7.0	911	1380
	10	7.2	1104	1680
	11	7.8	804	1190
	12	8.5	1358	1970
	13	8.1	1358	1990
	14	11.5	870	1170
	15	10.3	1307	1810
	16	10.5	860	1180
	17	10.0	1525	2120
	18	10.6	1216	1670
	19	10.3	1216	1680
GR	1	6.7	403	620
	2	7.2	425	640
SP	1	6.5	393	600

Note: Temperature accuracy $\pm .5^\circ\text{C}$; Conductivity $\pm 4\%$.

Figure A4-1
 Redhill Creek
 Sampling Stations
 April 11th, 1994



Ice Conditions in Hamilton Harbour

There is a hint in the few observations taken in previous years, that the conditions observed in the Harbour in February and March of 1994, might be unusual. This is linked with the fact that the winter was quite severe and the ice cover of the Harbour was close to 100% by the end of February. This ice cover, in turn, is thought to inhibit vertical mixing in the south-east portion of the Harbour - an area where the higher density water enters the Harbour, and an area which is usually free of fast ice, is the last area to freeze, and is the first to open up.

There are no regular observations of ice cover available for the Harbour. There are incidental observations and occasional photographs available in files at CCIW. Presumably satellite data would also provide a useful source of information on year-to-year variations in the extent of ice cover (but not the thickness). This could be the basis of a more detailed study.

There are systematic maps of ice cover for the open Great Lakes since the mid-1960's, but they don't provide details of the ice cover within small embayments and harbours.

The only systematic study of nearshore and embayment ice conditions has been done by the National Oceanic and Atmospheric Administration of the United States. Their work dealt only with U.S. locations but they did develop a winter severity index for ice cover growth rates in nearshore areas. This could be adapted to Hamilton Harbour to gauge the relative extent of ice formation and updated to the past winter when NOAA updates their index ratings (the most recent published tabulation includes years up to and including 1983). Publications related to these studies are listed in the references for this Appendix.

This still leaves the question of how to put the past winter's ice cover into some perspective. Two lines of enquiry yield some degree of assessment.

First, the severity of a winter can be gauged from meteorological records. A tabulation of freezing - degree - days (FDD) over a 20 or 30 year period provides a general freezing climatology within which one can judge a particular winter. This data was provided by the Canadian Climate Centre, Environment Canada for the Royal Botanical Gardens meteorological station in west Burlington, and for Pearson Airport in Toronto (a pivotal reference station for most Lake Ontario climatological, heat balance and ice studies - including the NOAA studies referenced above).

On the basis of these data the winter of 1993 - 94 appears to be of a severity that could be expected on average, about once every 12 years.

Another line of enquiry utilizes the temperature of the top 100m of the water column of Lake Ontario in the deeper eastern basin on April 1st (see Rodgers, 1987). A preliminary estimate of that temperature for April 1st, 1994, is 0.5°C, based on a surveillance ship survey of Lake Ontario in early April. Based on the data presented by Rodgers (1987) this temperature is comparable to the coldest observed during the period from 1965 - 1985. This suggests an average return period of 10 to 20 years.

These lines of enquiry are very general. No one has carried out an analysis of the events that lead to formation and break-up of Hamilton Harbour ice cover. It might be anticipated that the ice conditions in the SE portion of the Harbour could depend not only on local air temperatures, but also on wind conditions and the pattern of melt periods in the midst of these cold months.

It would appear useful to investigate the development of both ice cover and the related water quality conditions in a few winters of differing ice conditions in order to gauge the degree of density current development and the frequency with which density currents affect the aquatic régime of the Harbour.

References

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- Rodgers, G. Keith, 1987. Time of Onset of Full Thermal Stratification in Lake Ontario in Relation to Lake Temperatures in Winter. Can. J. Fish. Aquat. Sci., Vol. 44, pp 2225-2229.
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Freezing Degree Days**A5 - 3****Meteorological Summary for the Royal Botanical Gardens Station**

Winter	November	December	January	February	March	Dec. + Jan. + Feb.	Rank
93-94	3.3	93.1	316.2	223.6	43.3	632.9	1
92-93	10.6	57.6	119.3	206.4	93.6	383.3	21
91-92	15.4	74.7	122.4	80.1	70.3	277.2	31
90-91	0.9	52.3	147.6	74.1	23.4	274.0	32
89-90	30.4	262.4	35.3	94.9	52.5	392.6	20
88-89	0	88.4	70.3	157.1	88.2	315.8	30
87-88	16.6	35.9	167.9	150.5	48.4	354.3	26
86-87	19.5	30.9	115.5	109.3	36.3	255.7	34
85-86	0.8	134.2	152.0	139.2	56.8	425.4	16
84-85	13.4	35.6	211.1	147.2	24.8	393.9	19
83-84	5.9	152.9	228.6	67.1	112.0	448.6	12
82-83	2.7	46.6	106.3	75.3	40.4	228.2	35
81-82	2.9	63.8	251.4	160.2	62.9	475.4	9
80-81	4.8	166.4	249.7	89.4	41.4	505.5	8
79-80	3.7	55.0	131.9	183.1	71.2	370.0	22
78-79	16.8	64.9	206.4	263.9	31.7	535.2	7
77-78	15.2	114.9	229.5	238.1	98.2	582.5	4
76-77	24.4	178.2	311.8	140.5	20.6	630.5	2
75-76	0	110.8	237.2	80.0	34.8	428.0	14
74-75	12.7	30.6	87.2	85.5	70.9	203.3	36
73-74	2.5	114.9	146.1	181.8	37.2	442.8	13
72-73	24.3	50.8	118.7	168.7	10.3	338.2	29
71-72	12.1	43.6	155.9	164.4	87.3	363.9	24
70-71	9.0	118.5	228.5	108.7	66.1	455.7	11
69-70	9.7	125.6	274.7	142.7	63.1	543.0	5
68-69	0	113.7	160.2	93.7	61.4	367.6	23
67-68	25.5	58.0	209.7	195.9	49.3	463.6	10
66-67	3.7	106.5	80.7	193.8	80.9	381.0	21
65-66	2.1	35.6	206.1	117.4	26.4	359.1	25
64-65	14.9	89.1	178.2	135.5	63.1	402.8	18
63-64	1.4	183.6	108.6	112.9	33.0	405.1	17

62-63	1.2	140.5	238.1	226.9	41.0	605.5	3
61-62	6.2	79.6	177.4	169.1	51.1	426.1	15
60-61	0.9	164.9	219.6	89.1	38.4	473.6	10
59-60	25.2	52.9	108.4	95.8	146.7	257.1	33
58-59	21.8	183.3	190.3	165.0	64.6	538.6	6
57-58	3.7	36.4	112.6	189.8	6.7	338.8	28
56-57	23.9	41.5	225.7	75.5	12.0	342.7	27
						total	36

Appendix 6

HARBOUR SURVEYS - DATA

SURVEY 1A FEB.14, 1994
SURVEY 1B MAR. 2, 1994
SURVEY 2 MAR. 9, 1994
SURVEY 3 MAR.10, 1994
SURVEY 4 MAR.17, 1994
SURVEY 5 MAR.28, 1994

HYDROLAB H₂O PROFILER ACCURACY

Conductivity $\pm 15 \mu\text{S cm}^{-1}$ *
Depth $\pm 0.2\text{m}$
Temperature $\pm 0.15 \text{C}^{\circ}$ **
Dissolved Oxygen $\pm 0.4 \text{mg L}^{-1}$ ***

These accuracies are based on calibration data and some judgement regarding the precision of temperature compensation for conductivity. Data are recorded here to 3 figures even if the accuracies do not warrant. In published work these accuracies must be reflected in the data presentations.

- * The rate of lowering the transducers varied from 4 to 20 sec m⁻¹. The conductivity sensor has a response time of about 16 sec. for 87% of a step change. This means that the conductivity readings in the layers beneath major gradients have to be viewed as approximate unless a very detailed review of the data output is undertaken.
- ** The response time for the temperature sensor is the quickest at <8 sec. for 87% of a step change.
- *** The response time for the oxygen sensor is about 70 sec. for 87% of a step change. This makes dissolved oxygen measurements below the chemocline overestimates of the actual oxygen levels. See individual notes on the records.

J.A.Kraft/NWRI/RSB/4623/srm

TO
A
Head, Technical Operations Section
Research Support Branch
National Water Research Institute

FROM
DE
J.A. Kraft
Technical Operations Section
Research Support Branch
National Water Research Institute

Security - Class. de sécurité

Our File - Notre référence

1736-4-93/94

Your File - Votre référence

Date 7 March 1994

Subject
Objet
Hamilton Harbour Hydrolab Profile Survey #1A and 1B
LRB Study 82005, February 14 and March 2

Technical Operations staff supported this study, led by Dr. G.K. Rodgers, by conducting a Hydrolab profile and ice thickness survey on Hamilton Harbour. The purpose of the survey is to investigate the possibility that anoxic conditions may develop in the harbour under the complete ice cover which has developed this winter and to try to account for the unusually high water temperatures found under the ice on a similar survey last winter. Station positions were chosen so as to attempt to determine which, if any, of several sources of warmer water is contributing to this effect seen at the deep hole in the harbour (station 3).

On February 14, the field party, consisting of two Technical Operations personnel and Constable T. McCoy of the Hamilton-Wentworth Regional Police Marine Unit, left the Marine Unit dock aboard their ARGO ATV to commence the survey. Hydrolab profiles were completed at stations 1 and 2 and the ice thickness recorded. Unfortunately, a problem developed with the ARGO and the survey was discontinued until repairs could be made.

Mild weather conditions occurring the following week produced considerable thawing so that the survey was delayed until March 2. By this time, a large area of open water had developed but good ice thickness over the remainder of the harbour allowed the Tech. Ops. field party, accompanied by Constable M. Mullaley, to complete the survey.

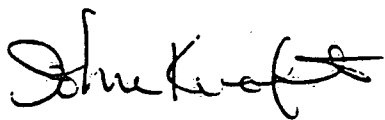
Hydrolab profiles and ice thickness measurements were completed at stations 1, 2, 3, 6 and 7. Station 5 could not be sampled since it was within the area of open water. An additional ice thickness measurement was made at station 8 to provide data from the north shore.

P.M. Healey

2

7 March 1994

STATION NUMBER	LATITUDE N.	LONGITUDE W.	ICE THICKNESS cm
1	43° 16.65'	79° 52.90'	48 (Feb. 14) 42 (Mar. 2)
2	43° 17.00'	79° 51.70'	56 (Feb. 14) 49 (Mar. 2)
3	43° 17.25'	79° 50.40'	48 Mar. 2
4	43° 17.00'	79° 49.90'	47 Mar 2
6	43° 17.00'	79° 49.15'	38 Mar 2
7	43° 16.80'	79° 49.90'	43 Mar 2
8	43° 17.36'	79° 51.40'	47 Mar 2



J.A. Kraft

c: Operations Officer, Field, TOS, RSB, NWRI
J.E. Milne, TOS, RSB, NWRI
Dr. G.K. Rodgers, Rivers Research Branch, NWRI

Enclosures: Data Sheets and Chart

79° 53'

79° 52'

79° 51'

79° 50'

79° 49'

79° 48'

79° 47'

Figure A6-1
Station Positions
Surveys 1A and 1B

HAMILTON HARBOUR

Hydrolab Survey

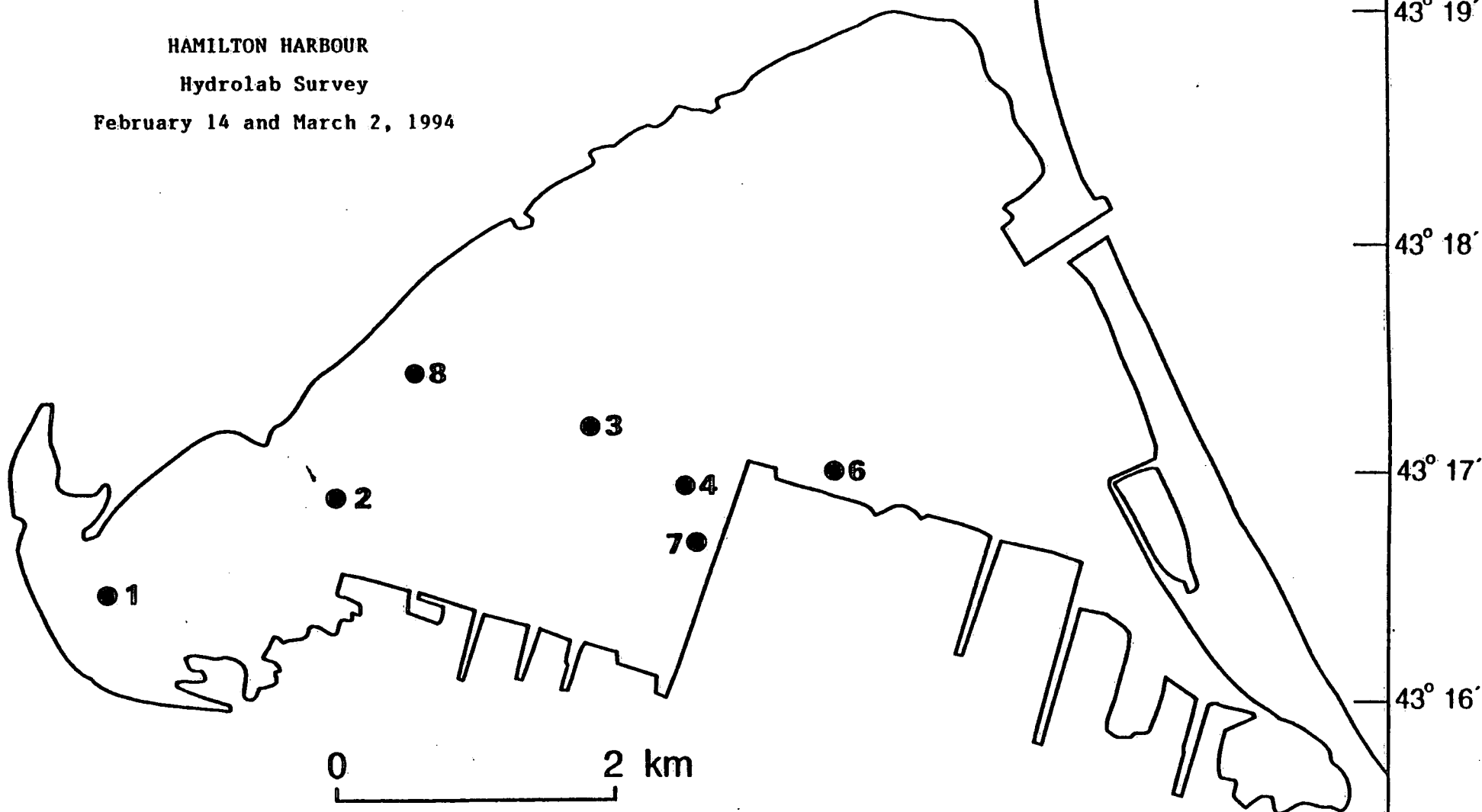
February 14 and March 2, 1994

43° 19'

43° 18'

43° 17'

43° 16'



0 2 km

Survey 1A, 14 Feb., 1994

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
1	0 - 1	0.9	569	13.9	98
	1 - 2	0.76	570	14.1	99
	2 - 3	0.87	567	13.8	97
	3 - 4	0.91	578	13.2	93
	4 - 5	1.08	587	12.1	86
	5 - 6	1.18	598	11.8	84
	6 - 7	1.44	625	11.2	80
	7 - 8	1.62	634	11.1	80
	8.1 Bottom	1.59	655	10.8	78
2	0 - 1	0.6	591	17.0	119
	1 - 2	0.42	590	16.4	114
	2 - 3	0.71	582	15.8	110
	3 - 4	1.01	579	14.6	103
	4 - 5	1.16	585	13.8	98
	5 - 6	1.3	594	13.0	93
	6 - 7	1.43	621	12.2	87
	7 - 8	1.47	626	11.5	82
	8 - 9	1.52	666	11.2	80
	9 - 10	1.68	684	11.0	78
	10 - 11	2.0	712	10.6	77
	11 - 12	2.3	731	9.9	73
	12 - 13	2.3	749	9.8	72
	13 - 14	2.30	775	9.6	71
	14 - 14.9	2.4	845	9.4	69
	14.9 Bottom	2.42	860	9.3	68

Survey 1B, 2 March, 1994

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
1	0 - 1	0.64	518	19.6	137
	1 - 2	1.35	557	19.1	136
	2 - 3	1.50	586	18.9	135
	3 - 4	1.33	622	18.3	130
	4 - 5	1.23	633	17.1	122
	5 - 6	1.45	625	15.7	112
	6 - 7	1.75	631	14.7	106
	7 - 8	2.05	649	13.8	100
	8 - 9	2.24	654	13.0	95
	9.1 Bottom	2.30	670	12.3	90
2	0 - 1	0.34	500	20.1	139
	1 - 2	0.87	555	19.7	139
	2 - 3	1.24	591	19.4	138
	3 - 4	1.49	586	18.0	129
	4 - 5	1.89	578	16.1	116
	5 - 6	1.93	602	15.0	109
	6 - 7	1.88	640	14.1	102
	7 - 8	1.79	662	13.2	95
	8 - 9	1.79	686	12.3	89
	9 - 10	1.70	703	11.8	85
	10 - 11	1.68	718	11.5	82
	11 - 12	1.86	754	11.3	82
	12 - 13	2.29	785	10.9	80
	13 - 14	2.91	840	10.5	78
	14 - 15	3.03	897	10.2	76
	15.4 Bottom	3.08	961	9.7	72

Survey 1B cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
3	0 - 1	1.81	482	17.0	122
	1 - 2	2.15	505	16.9	123
	2 - 3	2.18	568	16.4	120
	3 - 4	2.25	577	15.6	114
	4 - 5	2.25	581	14.4	105
	5 - 6	2.43	594	13.8	101
	6 - 7	2.54	606	13.0	95
	7 - 8	2.62	620	12.2	90
	8 - 9	2.89	646	11.7	87
	9 - 10	2.74	677	11.3	84
	10 - 11	2.80	704	10.9	81
	11 - 12	2.89	737	10.6	78
	12 - 13	3.01	762	10.3	77
	13 - 14	3.17	810	10.1	75
	14 - 15	3.14	916	9.9	74
	15 - 16	3.16	951	9.5	71
	16 - 17	3.36	976	8.9	67
	17 - 18	3.48	1006	8.4	63
	18 - 19	3.58	1042	8.0	61
	19 - 20	3.68	1071	7.6	57
	20 - 21	3.53	1097	7.4	56
	21 - 22	3.53	1166	6.9	52
	22 - 23	3.31	1263	6.5	49
	23.0 Bottom	3.26	1389	6.0	45

Survey 1B cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
4	0.5 Bottom	0.89	560	17.0	119
6	0 - 1	0.94	575	15.0	106
	1 - 2	1.64	604	14.3	103
	2 - 3	1.59	612	14.1	101
	3 - 4	1.76	616	13.5	97
	4 - 5	2.06	614	12.8	93
	5 - 6	2.33	611	12.3	90
	6 - 7	2.54	608	11.8	87
	7 - 8	2.61	634	11.5	85
	8 - 9	2.59	650	11.3	83
	9 - 10	2.64	681	11.1	82
	10 - 11	2.67	726	10.9	80
	11 - 12	2.66	769	10.5	77
	12.7 Bottom	2.59	784	10.0	74
7	0 - 1	1.18	577	14.9	106
	1 - 2	1.81	590	14.0	101
	2 - 3	2.05	586	13.9	101
	3 - 4	2.25	583	13.6	100
	4 - 5	2.54	587	12.9	95
	5 - 6	2.61	595	12.5	92
	6 - 7	2.64	600	12.2	90
	7 - 8	2.71	608	12.0	88
	8.6 Bottom	2.64	636	11.7	86



TO
A
Head, Technical Operations Section
Research Support Branch
National Water Research Institute

FROM
DE
J.A. Kraft
Technical Operations Section
Research Support Branch
National Water Research Institute

J.A.Kraft/RSB/NWRI/4623/srm

Security - Class. de sécurité

Our File - Notre référence

1736-4-93/94

Your File - Votre référence

Date 10 March 1994

Subject
Objet Hydrolab and Ice Thickness Survey, Study 82005, March 9

SURVEY #2

Technical Operations staff supported this project, led by Dr. G.K. Rodgers, by the collection of a series of Hydrolab profiles and ice thickness measurements in Hamilton Harbour.

Stations 9, 10, 11 and 12 were sampled from shore and stations 3, 13 and 14 were accessed on foot from LaSalle Park. Ice thickness measurements were taken where possible, otherwise the profiles were done in open water near the dock.

STATION POSITIONS

STATION NUMBER	LATITUDE N.	LONGITUDE W.	ICE THICKNESS cm
3	43° 17.25'	79° 50.40'	45
9	43° 16.10'	79° 46.90'	
10	43° 16.15'	79° 46.93'	
11	43° 16.28'	79° 50.06'	
12	43° 16.39'	79° 50.33'	
13	43° 16.82'	79° 50.30'	43
14	43° 16.90'	79° 50.82'	46

srm
J.A. Kraft

c: Operations Officer, Field, TOS, RSB, NWRI
J.E. Milne, TOS, RSB, NWRI
Dr. G.K. Rodgers

Enclosures: Chart and Data sheets

79° 53'

79° 52'

79° 51'

79° 50'

79° 49'

79° 48'

79° 47'

Figure A6-2
Station Positions
Survey #2

HAMILTON HARBOUR
Hydrolab Survey
March 9, 1994

43° 19'

43° 18'

43° 17'

43° 16'

● 3

● 14

● 13

● 12

● 11

● 10

● 9

0

2 km

Survey 2, 09 March, 1994

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
3	0 - 1	0.22	408	11.4	79
	1 - 2	2.13	614	11.0	81
	2 - 3	2.29	637	11.5	85
	3 - 4	2.32	639	11.9	88
	4 - 5	2.37	660	12.1	89
	5 - 6	2.56	693	12.0	89
	6 - 7	2.58	692	11.8	88
	7 - 8	2.63	695	11.6	86
	8 - 9	2.68	698	11.5	86
	9 - 10	2.66	701	11.5	85
	10 - 11	2.68	715	11.3	84
	11 - 12	2.71	722	11.2	84
	12 - 13	2.85	737	11.1	83
	13 - 14	3.01	806	11.0	83
	14 - 15	2.88	972	10.8	81
	15 - 16*	2.96	1012	10.2	77
	16 - 17	3.00	1025	9.7	73
	17 - 18	3.12	1071	8.9	67
	18 - 19	3.10	1105	8.2	62
	19 - 20	3.10	1179	7.5	57
	20 - 20.6	3.10	1186	7.3	55
	20.6 Bottom	3.10	1223	6.9	52

* Probe lowered through gradient at about 3 seconds/m. Therefore data below this level will be affected by the sensor time response.

Survey 2 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
9	0 - 1	3.43	632	12.4	94
	1 - 1.8	4.84	1375	11.8	94
	1.8 Bottom	6.25	1603	10.3	85
10	0 - 1	3.37	618	12.6	96
	1 - 2	3.35	624	12.6	96
	2 - 3	3.40	628	12.5	95
	3 - 4	3.48	635	12.4	94
	4 - 5	3.48	637	12.3	94
	5 - 6	3.75	703	12.1	92
	6 - 7	3.92	811	11.9	92
	7 - 8	4.34	934	11.4	89
	8.4 Bottom	5.14	1262	11.0	88
11	0 - 1	1.21	601	12.9	93
	1 - 2	1.93	603	13.2	96
	2 - 3	2.00	604	13.4	98
	3 - 4	2.32	606	13.1	97
	4 - 4.6	2.63	623	12.7	95
	4.6 Bottom	2.76	628	12.5	94

Survey 2 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
12	0 - 1	1.76	591	14.4	105
	1 - 2	2.00	592	14.4	106
	2 - 3	2.29	595	14.6	107
	3 - 4	2.74	600	14.3	107
	4 - 5	2.88	607	13.7	103
	5 - 6	3.01	612	13.2	99
	6 - 7	3.13	614	12.8	96
	7 - 8	3.15	616	12.4	93
	8.3 Bottom	2.90	654	12.2	92
13	0 - 1	0.75	542	16.8	119
	1 - 2	2.44	585	16.5	122
	2 - 3	2.48	602	16.9	125
	3 - 4	2.47	611	16.7	124
	4 - 5	2.41	619	16.0	119
	5 - 6	2.39	624	15.4	114
	6 - 7	2.68	619	14.4	107
	7 - 8	2.71	622	13.9	103
	8 - 9	2.54	643	13.6	101
	9 - 10	2.42	659	13.1	97
	10 - 11	2.30	682	12.8	95
	11 - 12	2.29	697	12.3	91
	12 - 13	2.52	713	11.7	87
	13 - 14	2.27	760	11.6	86
	14.3 Bottom	2.51	842	11.1	82

Survey 2 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
14	0 - 1	0.58	535	18.7	132
	1 - 2	2.20	583	18.1	134
	2 - 3	2.19	606	18.2	134
	3 - 4	2.20	613	17.5	129
	4 - 5	2.12	623	16.5	121
	5 - 6	2.10	627	15.6	114
	6 - 7	2.07	643	14.5	106
	7 - 8	2.12	660	13.9	102
	8 - 9	2.25	672	13.3	98
	9 - 10	2.05	692	12.8	94
	10 - 11	2.13	691	12.3	90
	11 - 12	2.13	701	11.9	88
	12 - 13	2.54	722	11.5	85
	13 - 14	2.76	758	11.3	84
	14 - 15	2.61	791	11.1	83
	15 - 16	2.07	839	10.8	80
	16 - 17	2.19	866	10.6	78
	17 - 18	2.42	897	10.4	77
	18 - 19	3.03	1100	8.5*	64
	19 - 19.9	2.96	1270	7.5*	57
	19.9 Bottom	2.85	1409	6.8*	51

* oxygen values are high due to fast lowering speeds.



S.B.Smith/RSB/NWRI/4942/srm

TO
A
Head, Technical Operations Section
Research Support Branch
National Water Research Institute

FROM
DE
Operations Officer, Field/Ships
Technical Operations Section
Research Support Branch
National Water Research Institute

Security - Class. de sécurité

Our File - Notre référence

1736-4-1993/94

Your File - Votre référence

Date 14 March 1994

Subject
Objet

Hydrolab and Water Samples, Hamilton Harbour, March 10 - SURVEY 3

On March 10, Mr. R.J. Hess and I collected a Hydrolab profile and water samples at two stations at the ice edge near the deep hole in Hamilton Harbour.

Water samples were collected from depths of 8 m and B-1.7 m at each station for nutrients, total phosphorus (unfiltered), metals and major ions.

Samples were delivered to NLET on March 11 with the appropriate paperwork. Stations were called 3A and 3B with depths of 20.7 m and 21.7 m, respectively. High conductivity and low dissolved oxygen values were found below depths of 18 m at both stations. The pH was inoperative during these casts.

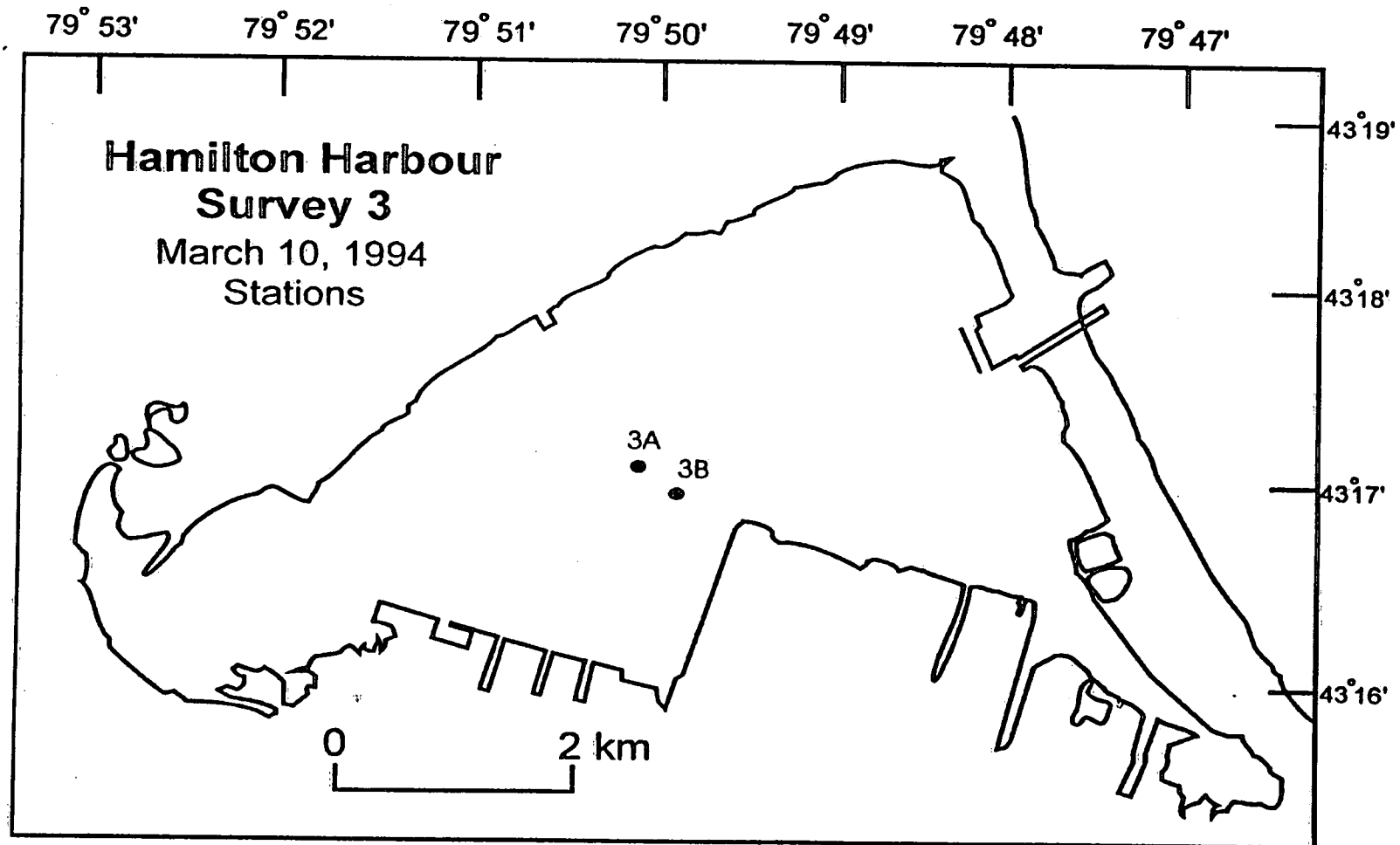
STATION NUMBER	LATITUDE N.	LONGITUDE W.
3A	43° 17' 20"	79° 50' 14"
3B	43° 17' 16"	79° 50' 06"


S.B. Smith

c: Operations Officer, Field, TOS, RSB, NWRI
Dr. G.K. Rodgers, Rivers Research Branch, NWRI
M.N. Charlton, Lakes Research Branch, NWRI

Enclosure: Hydrolab Data Printout

Figure A6-3



Survey 3, 10 March, 1994

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
3A	0 - 1	2.52	620	11.9	88
	1 - 2	2.42	631	12.0	88
	2 - 3	2.41	631	11.9	88
	3 - 4	2.41	630	11.9	88
	4 - 5	2.37	637	11.9	88
	5 - 6	2.36	644	11.9	88
	6 - 7	2.34	660	11.9	87
	7 - 8	2.30	681	11.9	87
	8 - 9	2.29	690	11.9	87
	9 - 10	2.20	695	11.7	86
	10 - 11	2.17	719	11.5	84
	11 - 12	2.54	764	11.1	82
	12 - 13	2.64	792	10.8	80
	13 - 14	2.78	840	10.3	77
	14 - 15	3.13	934	10.0	75
	15 - 16	3.10	967	7.1	53
	16 - 17	3.06	1015	7.1	53
	17 - 18	3.10	1054	6.4	48
	18 - 19	3.12	1071	5.8	44
	19 - 20	3.10	1105	5.7	43
	20 - 20.7	3.12	1168	4.5	34
	20.7 Bottom	3.12	1176	3.9	30

Survey 3, 10 March, 1994

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
3B	0 - 1	1.95	614	12.7	92
	1 - 2	2.42	630	12.2	90
	2 - 3	2.73	620	11.6	86
	3 - 4	2.63	630	11.7	87
	4 - 5	2.56	637	11.8	87
	5 - 6	2.46	643	11.7	87
	6 - 7	2.46	647	11.7	86
	7 - 8	2.22	685	11.5	85
	8 - 9	2.17	692	10.8	79
	9 - 10	2.13	702	10.6	77
	10 - 11	2.03	719	10.1	74
	11 - 12	2.05	750	10.0	73
	12 - 13	2.58	819	9.8	73
	13 - 14	2.71	857	8.5	63
	14 - 15	2.90	928	8.2	62
	15 - 16	2.96	963	7.0	52
	16 - 17	3.05	989	6.9	52
	17 - 18	3.06	1038	6.3	48
	18 - 19	3.10	1090	5.3	40
	19 - 20	3.08	1116	4.7	35
	20 - 21	3.12	1169	4.5	34
	21 - 21.7	3.03	1273	3.1	24
	21.7 Bottom	3.03	1311	2.8	21

Water samples taken at 8m and 20m.



J.E.Milne/RSB/NWRI/4941/srm

TO
A
Head, Technical Operations Section
Research Support Branch
National Water Research Institute

FROM
DE
J.E. Milne
Technical Operations Section
Research Support Branch
National Water Research Institute

Subject
Objet

Hamilton Harbour Hydrolab Profile Survey, Study 82005 - March 17 - SURVEY #4

Technical Operations staff supported this study, led by Dr. G.K. Rodgers, by conducting Hydrolab profiling at various stations in Hamilton Harbour. The purpose of this survey was to try to account for the unusually high conductivity readings and high water temperature. Station positions were chosen in an attempt to trace the areas of high conductivity from Windemere Basin to the deep hole (station 24).

Stations 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26 and 27 were sampled utilizing the CSL PARROT. Stations 28, in Redhill Creek and station 29 at the Windemere Bridge were sampled from shore. The following stations were found to have high conductivity readings: 16, 17, 20, 22, 23, 24, 25, 28 and 29.

STATION POSITIONS

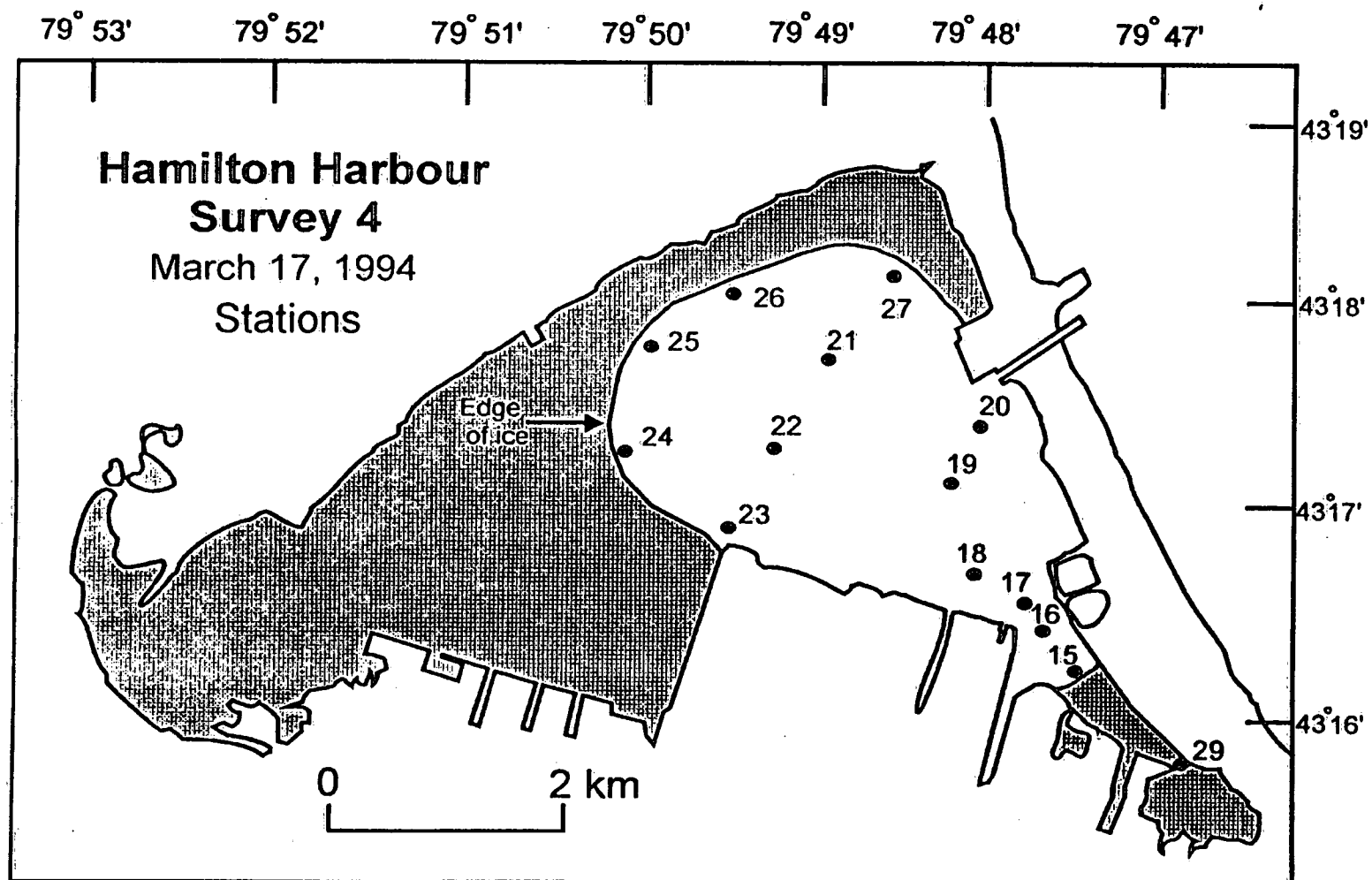
STATION NUMBER	LATITUDE N.	LONGITUDE W.
15	43° 16.60'	79° 47.47'
16	43° 16.60'	79° 47.58'
17	43° 16.73'	79° 47.69'
18	43° 16.99'	79° 48.16'
19	43° 17.28'	79° 48.14'
20	43° 17.46'	79° 47.91'
21	43° 17.74'	79° 48.84'
22	43° 17.59'	79° 49.06'
23	43° 17.22'	79° 49.51'
24	43° 17.27'	79° 49.76'
25	43° 17.77'	79° 49.60'
26	43° 18.04'	79° 49.71'
27	43° 18.18'	79° 48.48'
28	Redhill Creek above STP	
29	43° 16.15'	79° 46.90'

J.E. Milne

c: Operations Officer, Field/Ships, TOS, S RSB, NWRI
Dr. G.K. Rodgers, Rivers Research Branch, NWRI
M.N. Charlton, Lakes Research Branch, NWRI

Enclosures: Chart, Hydrolab Data Printout, Data Graphs

Figure A6-4



Survey 4, 17 March, 1994

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
15	0 - 1	3.01	730	13.7	101
	1 - 2	3.01	732	13.7	101
	2 - 3	3.01	728	13.7	101
	3 - 4	3.04	731	13.6	101
	4 - 5	3.11	743	13.4	100
	5 - 6	3.26	747	13.4	100
	6 - 7	3.08	789	13.5	100
	7 - 8	3.01	884	13.3	98
	8 - 8.6	3.26	1042	13.0	97
	8.6 Bottom	3.63	1334	12.8	96
16	0 - 1	3.08	732	13.6	100
	1 - 2	3.06	727	13.5	100
	2 - 3	3.09	729	13.4	99
	3 - 4	3.11	730	13.3	99
	4 - 5	3.13	733	13.3	99
	5 - 6	3.24	741	13.2	98
	6 - 7	3.55	753	13.0	98
	7 - 8	3.75	747	12.8	97
	8 - 9	3.81	753	12.8	97
	9 - 10	3.55	856	12.8	96
	10 - 10.4	4.08	1379	1.03	79
	10.4 Bottom	4.10	1407	9.5	72

Survey 4 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L ⁻¹	Dissolved Oxygen - % Saturation
17	0 - 1	3.11	726	13.6	101
	1 - 2	3.11	731	13.5	100
	2 - 3	3.16	737	13.4	99
	3 - 4	3.13	734	13.3	99
	4 - 5	3.21	743	13.3	98
	5 - 6	3.38	745	13.1	98
	6 - 7	3.50	736	12.9	97
	7 - 8	3.61	742	12.8	96
	8 - 9	3.61	771	12.7	95
	9 - 10	3.60	943	12.5	94
	10.0 Bottom	3.53	1081	12.0	90
18	0 - 1	2.60	720	13.5	99
	1 - 2	2.60	719	13.5	99
	2 - 3	2.60	720	13.5	98
	3 - 4	2.59	725	13.4	98
	4 - 5	2.57	723	13.4	98
	5 - 6	2.56	736	13.3	97
	6 - 7	2.62	721	13.2	97
	7 - 8	2.61	721	13.3	97
	8 - 9	2.59	733	13.3	97
	9 - 10	2.57	720	13.2	97
	10 - 11	2.62	718	13.2	96
	11 - 12	2.66	725	13.2	97
	12.6 Bottom	2.64	735	13.2	96

Survey 4 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
19	0 - 1	2.54	723	13.2	96
	1 - 2	2.54	736	13.1	96
	2 - 3	2.54	726	13.1	96
	3 - 4	2.52	741	13.1	96
	4 - 5	2.50	744	13.1	95
	5 - 6	2.50	727	13.0	95
	6 - 7	2.50	729	13.0	95
	7 - 8	2.50	730	13.0	95
	8 - 9	2.55	746	12.9	95
	9 - 10	2.51	734	12.9	94
	10 - 11	2.52	737	12.9	94
	11 - 12	2.62	748	12.9	95
	12 Bottom	2.79	763	12.8	94

Survey 4 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L ⁻¹	Dissolved Oxygen - % Saturation
20	0 - 1	2.47	726	13.6	99
	1 - 2	2.45	727	13.5	99
	2 - 3	2.47	726	13.4	98
	3 - 4	2.47	726	13.7	100
	4 - 5	2.47	738	13.6	99
	5 - 6	2.49	733	13.4	98
	6 - 7	2.47	729	13.3	97
	7 - 8	2.45	725	13.2	96
	8 - 9	2.45	727	13.2	96
	9 - 10	2.45	737	13.1	96
	10 - 11	2.45	731	13.0	95
	11 - 12	2.45	725	13.0	95
	12 - 13	2.45	728	12.9	94
	13 - 14	2.44	747	12.9	94
	14 - 15	2.49	734	12.9	94
	15 - 16	2.91	768	12.7	94
	16 - 17	3.08	828	12.5	92
	17 - 18	3.86	1047	10.0	76
	18 - 19	4.00	1072	9.7	73
	19 - 20	4.11	1090	9.3	71
	20 - 20.6	4.18	1128	9.3	71
	20.6 Bottom	4.20	1142	9.1	70

Survey 4 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
21	0 - 1	2.47	719	14.2	104
	1 - 2	2.49	711	14.1	103
	2 - 3	2.49	725	14.1	102
	3 - 4	2.45	719	14.0	102
	4 - 5	2.47	719	13.9	101
	5 - 6	2.47	728	13.8	101
	6 - 7	2.45	716	13.8	100
	7 - 8	2.45	715	13.7	100
	8 - 9	2.45	715	13.7	100
	9 - 10	2.47	722	13.6	99
	10 - 11	2.45	727	13.6	99
	11 - 12	2.49	732	13.5	98
	12 - 13	2.49	727	13.4	98
	13 - 14	2.49	719	13.4	97
	14 - 15	2.72	753	13.3	97
	15.2 Bottom	2.89	782	13.0	96

Survey 4 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
22	0 - 1	2.32	727	13.0	95
	1 - 2	2.30	726	13.0	94
	2 - 3	2.30	727	13.0	94
	3 - 4	2.30	722	12.9	94
	4 - 5	2.30	733	12.9	93
	5 - 6	2.29	726	12.9	93
	6 - 7	2.30	723	12.8	93
	7 - 8	2.30	719	12.8	93
	8 - 9	2.30	729	12.8	93
	9 - 10	2.33	715	12.8	93
	10 - 11	2.33	719	12.8	93
	11 - 12	2.40	731	12.8	93
	12 - 13	2.45	737	12.7	92
	13 - 14	2.77	809	12.5	92
	14 - 15	2.96	922	11.1	82
	15 - 16	3.09	998	7.6	56
	16 - 17	3.24	1044	6.9	51
	17.0 Bottom	3.28	1074	6.6	49

Survey 4 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
23	0 - 1	2.72	725	12.4	91
	1 - 2	2.72	722	12.4	91
	2 - 3	2.67	721	12.4	91
	3 - 4	2.66	729	12.4	91
	4 - 5	2.67	731	12.4	91
	5 - 6	2.66	732	12.4	91
	6 - 7	2.67	731	12.3	90
	7 - 8	2.66	724	12.3	90
	8 - 9	2.67	728	12.2	90
	9 - 10	2.67	728	12.2	89
	10 - 11	2.67	741	12.2	89
	11 - 12	2.66	734	12.2	89
	12 - 13	2.69	752	12.1	89
	13 - 14	2.77	847	10.3	76
	14 - 15	2.79	892	10.0	73
	15 - 16	2.96	965	8.2	60
	16 - 16.5	3.09	978	7.2	53
	16.5 Bottom	3.09	1011	7.1	53

Survey 4 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
24	0 - 1	2.42	685	12.9	94
	1 - 2	2.64	689	12.7	93
	2 - 3	2.76	734	12.8	94
	3 - 4	2.72	731	12.7	93
	4 - 5	2.69	722	12.6	92
	5 - 6	2.69	721	12.5	91
	6 - 7	2.67	739	12.4	91
	7 - 8	2.64	733	12.2	90
	8 - 9	2.51	768	12.2	89
	9 - 10	2.50	775	12.0	88
	10 - 11	2.56	806	11.8	86
	11 - 12	2.66	833	11.4	83
	12 - 13	2.88	872	9.6	70
	13 - 14	3.08	955	8.2	61
	14 - 15	3.08	969	7.6	56
	15 - 16	3.14	1034	7.5	55
	16 - 17	3.24	1087	5.7	43
	17 - 18	3.41	1109	5.6	42
	18 - 19	3.31	1140	5.2	39
	19 - 20	3.28	1188	4.0	30
	20 - 21	3.28	1248	2.3	17
	21 - 22	3.26	1318	2.1	16
	22 - 22.8	3.31	1392	0.8	6
	22.8 Bottom	3.36	1535	0.5	4

Survey 4 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
25	0 - 1	2.50	757	12.4	91
	1 - 2	2.55	753	12.4	91
	2 - 3	2.54	761	12.4	91
	3 - 4	2.66	813	12.4	91
	4 - 5	2.66	814	11.9	87
	5 - 6	2.76	838	11.2	82
	6 - 7	2.96	908	10.8	80
	7 - 8	2.99	906	8.9	65
	8 - 9	3.03	925	8.7	65
	9 - 10	3.13	963	8.4	63
	10 - 11	3.13	982	7.7	57
	11 - 12	3.14	1002	7.4	55
	12 - 13	3.15	1019	7.4	55
	13 - 14	3.11	1036	6.7	50
	14 - 15	3.23	1059	6.5	48
	15 - 16	3.28	1097	6.4	47
	16 - 17	3.31	1106	5.4	40
	17 - 18	3.31	1132	5.3	40
	18 - 18.4	3.33	1142	4.9	37
	18.4 Bottom	3.34	1131	4.8	36

Survey 4 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
26	0 - 1	2.45	725	13.3	97
	1 - 2	2.47	734	13.3	97
	2 - 3	2.47	713	13.2	96
	3 - 4	2.47	724	13.2	96
	4 - 5	2.47	728	13.2	96
	5 - 6	2.45	722	13.1	96
	6 - 7	2.45	725	13.1	95
	7 - 8	2.45	725	13.1	95
	8 - 9	2.84	790	12.9	95
	9 - 10	2.89	802	11.7	86
	10 - 11	2.99	818	11.4	84
	11 - 12	2.99	817	11.3	83
	12 - 13	2.99	826	11.2	83
	13 - 14	2.99	828	11.2	82
	14 - 15	2.99	845	11.1	82
	15.3 Bottom	3.21	967	11.0	82

Survey 4 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
27	0 - 1	2.45	729	13.2	96
	1 - 2	2.44	732	13.2	96
	2 - 3	2.44	729	13.2	96
	3 - 4	2.45	733	13.1	96
	4 - 5	2.45	729	13.1	95
	5.3 Bottom	2.45	740	13.1	95
28	Redhill Creek above the STP outfall				
	0 - 1	-----	2050	-----	-----
29	Redhill Creek at the north end of Windermere Basin (outlet to Hamilton Harbour - includes creek and STP effluent)				
	0 - 1.4	-----	1960	-----	-----

J.A.Kraft/RSB/NWRI/4623/srm

TO
A

Head, Technical Operations Section
Research Support Branch
National Water Research Institute

FROM
DE

J.A. Kraft
Technical Operations Section
Research Support Branch
National Water Research Institute

Security - Class. de sécurité

Our File - Notre référence

1736-4-94/95

Your File - Votre référence

Date 5 April 1994

Subject
Objet Hydrolab Survey, Hamilton Harbour, Study 82005 - March 28 - SURVEY #5

Technical Operations staff supported this study by the collection of a set of Hydrolab profiles from Hamilton Harbour. Two technologists from this section and Dr. G.K. Rodgers, AER collected twenty-eight profiles from the launch, PARROT in an attempt to trace the high specific conductance of water entering the harbour from the Windemere Basin, crossing the ship channel and accumulating in the harbour's deep hole. The profiles were collected in one day.

Station positions are attached.

JAK
J.A. Kraft

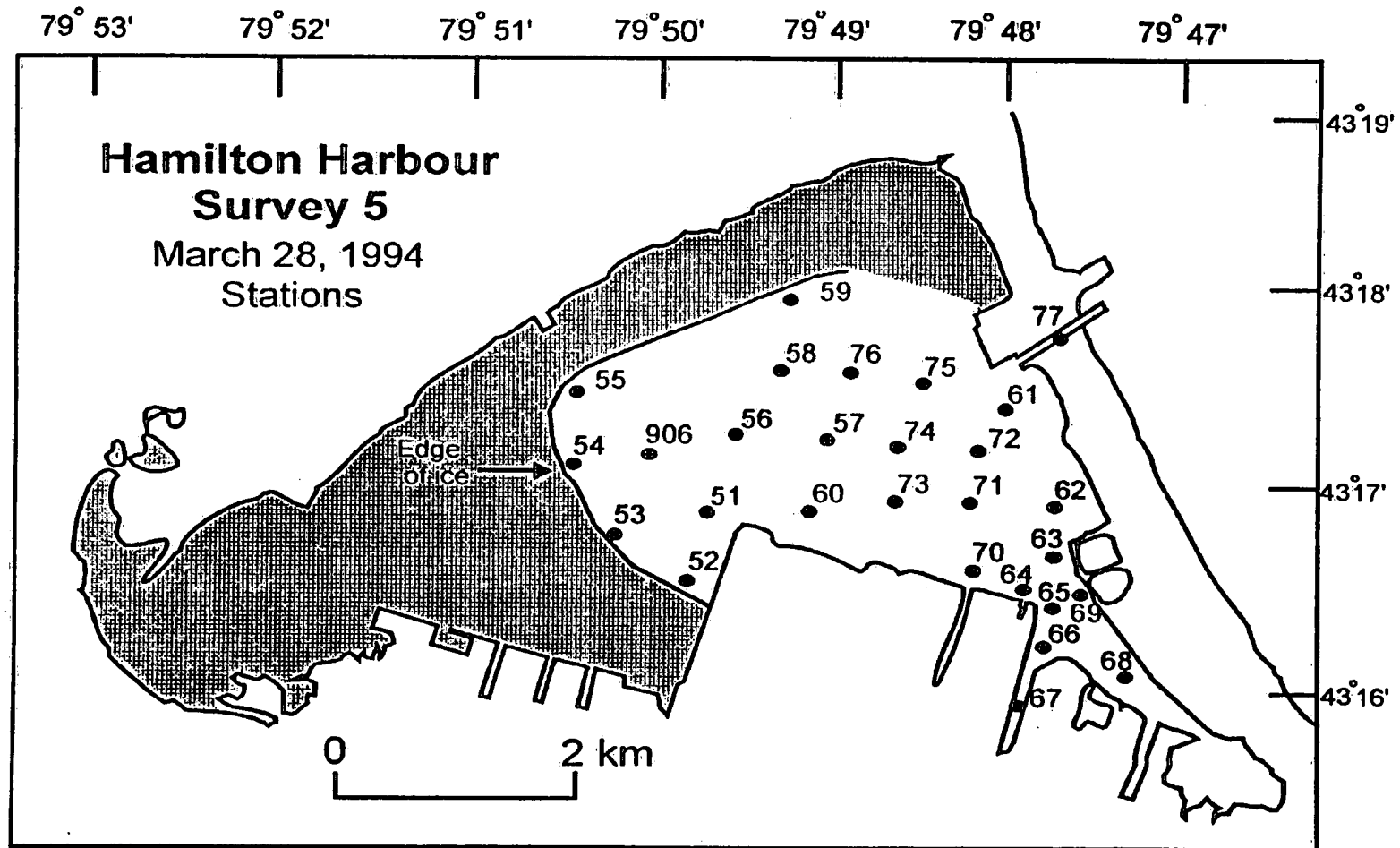
c: Operations Officer, Field, TOS, RSB, NWRI
Dr. G.K. Rodgers, Aquatic Ecosystem Restoration Branch, NWRI

Enclosure

STATION POSITIONS

STATION NUMBER	LATITUDE N.	LONGITUDE W.
51	43° 17.178'	79° 49.772'
52	43° 16.808'	79° 50.004'
53	43° 16.912'	79° 50.461'
54	43° 17.221'	79° 50.618'
55	43° 17.546'	79° 50.481'
56	43° 17.470'	79° 49.487'
57	43° 17.543'	79° 49.217'
58	43° 17.843'	79° 49.301'
59	43° 18.108'	79° 49.411'
60	43° 17.107'	79° 49.278'
61	43° 17.609'	79° 47.995'
62	43° 17.199'	79° 47.785'
63	43° 16.946'	79° 47.744'
64	43° 16.828'	79° 47.823'
65	43° 16.677'	79° 47.776'
66	43° 16.418'	79° 47.861'
67	43° 16.224'	79° 48.002'
68	43° 16.348'	79° 47.305'
69	43° 16.689'	79° 47.610'
70	43° 16.850'	79° 48.253'
71	43° 17.157'	79° 48.165'
72	43° 17.386'	79° 48.342'
73	43° 17.219'	79° 48.660'
74	43° 17.492'	79° 48.627'
75	43° 17.730'	79° 48.470'
76	43° 17.793'	79° 48.907'
77	43° 17.918'	79° 47.857'
906	43° 17.250'	79° 50.300'

Figure A6-5



Survey 5, 28 March, 1994

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
51	0 - 1	3.13	766	12.7	95
	1 - 2	3.06	766	12.7	95
	2 - 3	3.06	764	12.7	94
	3 - 4	3.04	770	12.7	94
	4 - 5	3.01	767	12.6	94
	5 - 6	3.01	759	12.6	93
	6 - 7	3.02	771	12.5	93
	7 - 8	3.03	764	12.5	93
	8 - 9	3.03	762	12.4	92
	9 - 10	3.03	762	12.4	92
	10 - 11	3.04	770	12.4	92
	11 - 12	3.03	775	12.3	91
	12 - 13	3.04	779	12.3	91
	13 - 14	3.18	788	12.2	91
	14 - 15	3.19	772	12.2	91
	15 - 16	3.19	793	12.1	90
	16 - 17	3.38	800	12.0	90
	17 - 18	3.38	957	11.8	88
	18 - 19	3.24	1063	10.0	74
	19 - 20	3.29	1108	8.2	61
	20 - 21	3.34	1231	6.6	49
	21 - 21.8	3.46	1335	4.4	33
	21.8 Bottom	3.46	1364	3.9	30

Survey 5 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L ⁻¹	Dissolved Oxygen - % Saturation
52	0 - 1	2.44	655	13.4	98
	1 - 2	2.44	654	13.2	96
	2 - 3	2.44	656	13.2	96
	3 - 4	2.62	666	13.0	95
	4 - 5	2.76	667	12.9	95
	5 - 6	2.91	692	12.8	95
	6 - 7	2.92	689	12.7	94
	7 - 8	2.94	718	12.7	94
	8 - 9	2.96	725	12.6	93
	9.4 Bottom	3.04	755	12.6	93
53	0 - 1	3.16	721	13.4	100
	1 - 2	3.11	718	13.2	98
	2 - 3	3.06	723	13.0	97
	3 - 4	3.01	723	13.0	96
	4 - 5	2.91	731	12.9	95
	5 - 6	2.86	758	12.8	94
	6 - 7	2.92	764	12.7	94
	7 - 8	2.99	769	12.6	94
	8 - 9	2.99	772	12.6	93
	9 - 10	3.01	771	12.6	93
	10 - 11	3.06	773	12.5	93
	11 - 12	3.09	770	12.5	93
	12 - 13	3.21	773	12.5	93
	13 - 14	3.31	793	12.3	92
	14 - 14.7	3.36	810	12.0	90
	14.7 Bottom	3.34	837	11.9	89

Survey 5 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
54	0 - 1	3.18	758	13.8	103
	1 - 2	3.11	764	13.7	102
	2 - 3	3.06	771	13.7	101
	3 - 4	3.01	764	13.7	102
	4 - 5	3.01	782	13.6	101
	5 - 6	3.04	776	13.3	99
	6 - 7	3.08	782	13.0	97
	7 - 8	3.09	782	12.9	96
	8 - 9	3.09	781	12.8	95
	9 - 10	3.09	776	12.7	95
	10 - 11	3.13	771	12.7	95
	11 - 12	3.16	775	12.7	95
	12 - 13	3.28	785	12.6	94
	13 - 14	3.29	783	12.5	93
	14 - 15	3.29	804	12.4	93
	15 - 16	3.41	789	12.3	92
	16 - 17	3.19	810	12.3	91
	17 - 18	3.14	857	12.0	90
	18 - 19	3.19	1053	11.7	88
	19 - 20	3.31	1179	10.1	75
	20 - 21	3.38	1204	6.6	50
	21 - 22	3.39	1232	4.8	36
	22 - 23	3.41	1265	3.8*	29
	23.2 Bottom	3.46	1334	2.7*	21

* Probe response may be too slow. Dissolved Oxygen recorded as low as 1.8 mg L^{-1} at 22.2m, 20 seconds after first observation at this level.

Survey 5 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
55	0 - 1	3.19	706	14.3	107
	1 - 2	2.86	737	14.4	106
	2 - 3	2.87	769	14.1	104
	3 - 4	2.97	768	14.0	104
	4 - 5	3.04	781	13.8	102
	5 - 6	3.06	786	13.4	100
	6 - 7	3.08	786	13.1	98
	7 - 8	3.09	779	13.0	97
	8 - 9	3.13	768	12.9	96
	9 - 10	3.13	782	12.9	96
	10 - 11	3.28	778	12.7	95
	11 - 12	3.29	792	12.7	95
	12 - 13	3.28	798	12.7	95
	13 - 14	3.28	795	12.6	94
	14 - 15	3.34	804	12.6	94
	15 - 16	3.16	818	12.5	93
	16 - 17	3.16	803	12.2	91
	17 - 18	3.11	831	12.1	90
	18 - 19	3.16	1003	11.8	88
	19 - 20	3.24	1113	11.1*	83
	20 - 20.9	3.36	1164	9.5	71
	20.9 Bottom	3.39	1199	8.3	62

* Dissolved Oxygen = 6.1 mg L^{-1} at 19.3 m 18 seconds after this reading was taken. Probe response too slow.

Survey 5

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
56	0 - 1	3.16	762	13.7	102
	1 - 2	3.08	770	13.6	101
	2 - 3	3.04	765	13.6	101
	3 - 4	3.03	775	13.5	100
	4 - 5	3.04	772	13.4	99
	5 - 6	3.04	777	13.2	98
	6 - 7	3.14	778	13.1	97
	7 - 8	3.18	781	12.9	96
	8 - 9	3.16	784	12.8	96
	9 - 10	3.14	794	12.7	95
	10 - 11	3.11	778	12.6	94
	11 - 12	3.13	790	12.5	93
	12 - 13	3.11	786	12.4	92
	13 - 14	3.13	782	12.4	92
	14 - 15	3.26	783	12.3	92
	15 - 16	3.26	790	12.3	92
	16 - 17	3.21	802	12.4	92
	17 - 18	3.31	935	12.3	92
	18 - 19	3.21	1071	11.7*	87
	19.3 Bottom	3.29	1112	9.5*	71

Survey 5 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L ⁻¹	Dissolved Oxygen - % Saturation
57	0 - 1	3.08	772	12.9	96
	1 - 2	3.06	778	12.8	95
	2 - 3	3.06	775	12.8	95
	3 - 4	3.06	766	12.8	95
	4 - 5	3.11	780	12.8	95
	5 - 6	3.13	765	12.7	94
	6 - 7	3.13	779	12.6	94
	7 - 8	3.14	780	12.5	93
	8 - 9	3.18	769	12.4	92
	9 - 10	3.26	791	12.3	92
	10 - 11	3.26	788	12.3	92
	11 - 12	3.29	778	12.3	92
	12 - 13	3.33	775	12.2	91
	13 - 14	3.41	782	12.2	91
	14 - 15	3.44	783	12.1	91
	15 - 16	3.53	802	12.0	90
	16 - 17	3.51	807	11.9	90
	17 - 17.7	3.46	838	11.8	89
	17.7 Bottom	3.39	913	11.7	88

Survey 5 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
58	0 - 1	3.16	776	13.5	100
	1 - 2	3.11	768	13.4	100
	2 - 3	3.09	776	13.4	99
	3 - 4	3.16	772	13.3	99
	4 - 5	3.09	763	13.3	99
	5 - 6	3.08	774	13.1	97
	6 - 7	3.06	775	13.0	96
	7 - 8	3.06	775	12.8	95
	8 - 9	3.08	772	12.7	95
	9 - 10	3.09	781	12.7	94
	10 - 11	3.11	774	12.6	94
	11 - 12	3.13	783	12.5	93
	12 - 13	3.09	780	12.4	92
	13 - 14	3.16	797	12.2	91
	14 - 15	3.26	797	12.1	90
	15 - 16	3.48	796	11.9	90
	16 - 17	3.39	808	11.9	89
	17.4 Bottom	3.24	907	11.2	84

Survey 5 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
59	0 - 1	3.21	776	12.8	96
	1 - 2	3.16	780	12.8	95
	2 - 3	3.18	776	12.8	95
	3 - 4	3.09	772	12.8	95
	4 - 5	3.11	776	12.8	95
	5 - 6	3.04	772	12.8	95
	6 - 7	3.04	776	12.6	94
	7 - 8	3.04	776	12.6	94
	8 - 9	3.03	774	12.6	93
	9 - 10	3.03	767	12.5	93
	10 - 11	3.04	777	12.4	92
	11 - 12	3.08	769	12.4	92
	12 - 13	3.19	778	12.2	91
	13 - 14	3.24	793	12.1	91
	14 - 15	3.26	864	12.0	90
	15 - 16	3.36	896	11.8	88
	16.5 Bottom	3.38	915	10.8	81

Survey 5 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
60	0 - 1	2.96	735	13.6	101
	1 - 2	2.96	735	13.6	100
	2 - 3	2.94	735	13.5	100
	3 - 4	2.89	740	13.5	100
	4 - 5	2.92	754	13.4	99
	5 - 6	2.94	770	13.4	99
	6 - 7	3.03	769	13.3	99
	7 - 8	3.03	778	13.2	98
	8 - 9	3.04	768	13.2	98
	9 - 10	3.04	767	13.1	97
	10 - 11	3.04	780	13.0	96
	11 - 12	3.04	761	12.9	96
	12 - 13	3.11	774	12.9	96
	13 - 14	3.24	766	12.8	95
	14.0 Bottom	3.33	781	12.7	95

Survey 5 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
61	0 - 1	3.61	744	13.1	99
	1 - 2	3.51	744	13.2	99
	2 - 3	3.34	759	13.2	99
	3 - 4	3.31	761	13.1	98
	4 - 5	3.28	760	13.0	97
	5 - 6	3.18	761	12.9	96
	6 - 7	3.16	767	12.7	95
	7 - 8	3.11	781	12.6	94
	8 - 9	3.09	782	12.5	93
	9 - 10	3.08	797	12.3	92
	10 - 11	3.26	813	12.1	91
	11 - 12	3.75	847	11.8	89
	12 - 13	3.88	858	11.5	87
	13 - 14	3.96	866	11.3	86
	14 - 15	4.20	906	11.1	85
	15 - 16	4.40	937	10.9	84
	16 - 17	4.56	956	10.7	83
	17 - 18	4.65	986	10.5	82
	18 - 19	4.66	983	10.4	80
	19.5 Bottom	4.73	1007	10.1	78

Survey 5 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissoved Oxygen - % Saturation
62	0 - 1	3.41	772	13.3	100
	1 - 2	3.41	772	13.3	100
	2 - 3	3.33	774	13.3	99
	3 - 4	3.29	771	13.3	99
	4 - 5	3.23	768	13.2	99
	5 - 6	3.21	772	13.1	98
	6 - 7	3.23	776	13.0	97
	7 - 8	3.26	774	12.9	97
	8 - 9	3.24	771	12.9	97
	9 - 10	3.26	776	12.9	96
	10 - 11	3.28	776	12.9	96
	11 - 12	3.44	797	12.7	96
	12 - 13	3.81	859	12.4	94
	13 - 14	4.05	874	12.2	93
	14 - 15	4.21	897	11.9	91
	15 - 16	4.23	927	11.6	89
	16 - 17	4.41	943	11.3	87
	17 - 18	4.66	987	11.0	85
	18 - 19	4.78	1041	10.8	84
	19 - 20	5.16	1101	10.4	82
	20.2 Bottom	5.19	1112	10.2	80

Survey 5 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
63	0 - 1	3.63	774	13.5	102
	1 - 2	3.61	788	13.4	101
	2 - 3	3.48	788	13.3	100
	3 - 4	3.48	793	13.1	99
	4 - 5	3.50	785	12.9	97
	5 - 6	3.50	790	12.9	97
	6 - 7	3.68	796	12.7	96
	7 - 8	3.80	795	12.7	96
	8 - 9	4.20	831	12.4	95
	9 - 10	4.38	875	12.3	95
	10 - 11	4.58	951	12.0	93
	11 - 12	4.88	1014	11.8	92
	12 - 13	5.34	1130	11.5*	91
	13 - 14	5.43	1143	10.8*	86
	14.5 Bottom	5.48	1147	10.2*	81

Survey 5 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
64	0 - 1	3.76	783	12.9	98
	1 - 2	3.75	786	12.9	98
	2 - 3	3.73	774	13.0	98
	3 - 4	3.71	781	13.0	98
	4 - 5	3.71	794	12.9	98
	5 - 6	3.66	780	12.9	97
	6 - 7	3.71	782	12.8	97
	7 - 8	3.76	784	12.6	96
	8 - 9	3.83	789	12.5	95
	9 - 10	3.90	798	12.4	94
	10.3 Bottom	4.90	1064	11.9	93
65	0 - 1	5.21	783	11.9	94
	1 - 2	4.68	783	12.1	94
	2 - 3	4.56	784	12.0	93
	3 - 4	4.45	799	12.0	93
	4 - 5	4.36	797	12.0	92
	5 - 6	4.36	815	11.9	92
	6 - 7	4.35	808	11.9	91
	7 - 8	4.33	806	11.8	91
	8 - 9	4.31	817	11.8	91
	9 - 10	4.48	976	11.6	89
	10 - 10.9	5.26	1199	11.3	89
	10.9 Bottom	5.51	1264	10.6	84

Survey 5 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
66	0 - 1	5.71	838	11.3	90
	1 - 2	5.67	830	11.3	90
	2 - 3	5.69	836	11.2	89
	3 - 4	5.69	836	11.2	89
	4 - 5	5.69	837	11.1	88
	5 - 6	5.71	842	11.0	88
	6 - 7	5.67	833	11.0	88
	7 - 8	5.61	833	11.0	87
	8 - 9	5.56	931	11.0	87
	9.2 Bottom	5.67	1074	10.3	82
67	0 - 1	7.70	871	10.8	90
	1 - 2	7.68	862	10.8	91
	2 - 3	7.60	865	10.8	90
	3 - 4	7.53	871	10.9	90
	4 - 5	6.89	855	11.1	91
	5 - 6	5.92	841	11.1	88
	6 - 7	5.71	853	10.8	86
	7 - 8	5.46	847	10.8	86
	8 - 8.8	5.49	883	10.6	84
	8.8 Bottom	5.67	907	10.5	84

Survey 5 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
68	0 - 1	4.11	822	12.4	94
	1 - 2	4.13	825	12.3	94
	2 - 3	4.16	823	12.2	93
	3 - 4	4.23	824	12.1	93
	4 - 5	4.25	821	12.1	93
	5 - 6	4.55	830	12.1	93
	6 - 7	4.56	911	12.0	93
	7 - 8	4.90	1043	11.3	88
	8 - 9	5.72	1313	10.8	86
	9 Bottom	5.89	1320	10.0	80
69	0 - 1	3.91	788	12.5	95
	1 - 2	3.86	794	12.5	95
	2 - 3	3.90	792	12.5	95
	3 - 4	3.91	789	12.5	95
	4 - 5	3.98	786	12.4	95
	5 - 6	4.15	801	12.3	94
	6 - 7	4.15	808	12.1	92
	7 - 8	4.33	830	11.8	91
	8 - 9	4.58	877	11.6	90
	9 - 10	4.91	1017	11.2	88
	10 - 10.8	5.24	1094	10.4	82
	10.8 Bottom	5.31	1112	9.9	78

Survey 5 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L ⁻¹	Dissolved Oxygen - % Saturation
70	0 - 1	14.30	760	9.1	88
	1 - 2	5.72	727	10.8	86
	2 - 3	3.60	735	11.1	84
	3 - 4	3.41	751	11.7	88
	4 - 5	3.43	752	12.1	91
	5 - 6	3.46	770	12.2	92
	6 - 7	3.48	766	12.2	92
	7 - 8	3.50	764	12.2	92
	8 - 9	3.48	768	12.2	92
	9 - 10	3.55	764	12.1	91
	10 - 11	3.66	769	12.1	91
	11 - 12	3.91	791	12.0	91
	12 - 12.9	4.06	794	11.9	91
	12.9 Bottom	4.16	802	11.8	90

Survey 5 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L ⁻¹	Dissolved Oxygen - % Saturation
71	0 - 1	3.29	775	12.6	94
	1 - 2	3.29	771	12.6	94
	2 - 3	3.24	776	12.6	94
	3 - 4	3.19	776	12.6	94
	4 - 5	3.19	780	12.6	94
	5 - 6	3.19	772	12.5	93
	6 - 7	3.18	780	12.4	92
	7 - 8	3.19	782	12.3	92
	8 - 9	3.28	788	12.2	91
	9 - 10	3.41	789	12.1	90
	10 - 11	3.53	788	11.9	90
	11 - 12	3.55	785	11.9	89
	12 - 13	3.76	814	11.8	89
	13 - 14	3.93	824	11.7	89
	14 - 15	3.96	846	11.6	88
	15 - 16	4.11	894	11.4	87
	16 - 17	4.60	1011	11.2	87
	17 - 18	5.01	1053	10.9	85
	18 - 18.5	5.11	1070	10.4	82
	18.5 Bottom	5.11	1094	10.3	81

Survey 5 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
72	0 - 1	3.51	751	13.1	98
	1 - 2	3.43	761	13.1	99
	2 - 3	3.33	766	13.1	98
	3 - 4	3.23	777	13.0	97
	4 - 5	3.09	789	13.0	96
	5 - 6	3.09	769	12.7	94
	6 - 7	3.13	769	12.6	93
	7 - 8	3.21	782	12.4	92
	8 - 9	3.26	770	12.3	92
	9 - 10	3.33	785	12.1	91
	10 - 11	3.43	776	12.1	90
	11 - 12	3.55	814	12.1	91
	12 - 13	3.66	858	11.9	90
	13 - 14	3.73	891	11.5	87
	14 - 15	3.96	896	11.0	83
	15 - 16	4.13	930	10.7	82
	16 - 17	4.25	938	10.4	80
	17 - 18	4.21	954	10.2*	78
	18 - 19	4.05	929	10.1*	77
	19 - 20	3.75	950	10.0*	76
	20.3 Bottom	3.60	991	9.7*	73

* Could be as low as 9.0 mg L^{-1}

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L ⁻¹	Dissolved Oxygen - % Saturation
73	0 - 1	3.39	770	12.7	95
	1 - 2	3.34	770	12.7	95
	2 - 3	3.24	768	12.8	95
	3 - 4	3.21	778	12.7	95
	4 - 5	3.19	781	12.6	94
	5 - 6	3.16	776	12.5	93
	6 - 7	3.19	773	12.4	92
	7 - 8	3.21	786	12.3	92
	8 - 9	3.23	777	12.2	91
	9 - 10	3.23	776	12.2	91
	10 - 11	3.24	783	12.2	91
	11 - 12	3.26	776	12.2	91
	12 - 13	3.31	779	12.2	91
	13 - 14	3.51	797	12.1	91
	14.1 Bottom	3.76	833	12.0	91
74	0 - 1	3.39	776	12.7	95
	1 - 2	3.36	771	12.7	95
	2 - 3	3.29	778	12.7	95
	3 - 4	3.33	778	12.6	95
	4 - 5	3.28	782	12.6	94
	5 - 6	3.26	767	12.6	94
	6 - 7	3.16	783	12.6	94
	7 - 8	3.16	781	12.5	93
	8 - 9	3.24	785	12.3	92
	9 - 10	3.34	768	12.2	91
	10 - 11	3.46	780	12.0	90
	11 - 12	3.53	790	12.0	90
	12 - 13	3.60	780	11.9	90
	13 - 14	3.53	821	11.8	89
	14 - 14.7	3.83	885	11.5	87
	14.7 Bottom	3.90	916	11.1	84

Survey 5 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
75	0 - 1	3.21	644	12.9	96
	1 - 2	3.28	713	13.0	97
	2 - 3	3.39	753	13.1	98
	3 - 4	3.33	773	13.1	98
	4 - 5	3.21	781	13.0	97
	5 - 6	3.16	773	12.8	95
	6 - 7	3.16	785	12.6	94
	7 - 8	3.18	786	12.4	93
	8 - 9	3.16	785	12.4	92
	9 - 10	3.18	785	12.3	91
	10 - 11	3.33	807	12.0	90
	11.5 Bottom	3.43	844	11.8	89
76	0 - 1	3.26	776	12.4	92
	1 - 2	3.28	783	12.3	92
	2 - 3	3.31	786	12.4	92
	3 - 4	3.29	780	12.4	92
	4 - 5	3.29	780	12.4	93
	5 - 6	3.24	786	12.4	93
	6 - 7	3.24	778	12.4	93
	7 - 8	3.23	779	12.4	93
	8 - 9	3.23	783	12.4	92
	9 - 10	3.24	782	12.3	92
	10 - 11	3.24	776	12.3	92
	11 - 12	3.26	783	12.3	92
	12 - 13	3.36	807	12.3	92
	13 - 14	3.36	822	12.1	90
	14 - 15	3.29	837	11.9	89
	15.3 Bottom	3.63	891	11.4	86

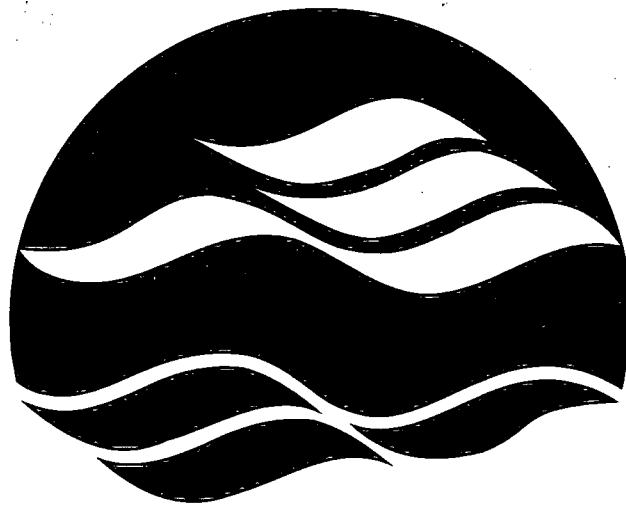
Survey 5 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
77 (Canal)	0 - 1	2.00	371	13.8	100
	1 - 2	2.00	376	13.9	100
	2 - 3	2.00	378	13.9	100
	3 - 4	2.01	390	13.9	100
	4 - 5	2.08	404	13.8	100
	5 - 6	2.37	541	13.7	100
	6 - 7	2.96	691	13.4	99
	7 - 8	3.08	7.14	13.0	96
	8 - 9	3.16	738	12.6	94
	9.2 Bottom	3.19	761	12.3	92

Survey 5 cont.'d

Station	Depth Interval (m)	Temperature (°C)	Conductivity at 25°C μScm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen - % Saturation
906	0 - 1	3.03	768	13.3	98
	1 - 2	2.97	772	13.2	98
	2 - 3	2.91	766	13.1	97
	3 - 4	2.91	770	13.0	96
	4 - 5	2.89	769	13.0	96
	5 - 6	2.89	761	12.9	96
	6 - 7	2.91	778	12.9	95
	7 - 8	2.94	763	12.8	95
	8 - 9	2.99	769	12.7	94
	9 - 10	3.08	780	12.6	94
	10 - 11	3.16	779	12.6	94
	11 - 12	3.16	797	12.5	93
	12 - 13	3.21	790	12.4	92
	13 - 14	3.23	789	12.3	92
	14 - 15	3.36	796	12.1	91
	15 - 16	3.36	785	12.1	90
	16 - 17	3.24	797	12.1	90
	17 - 18	3.14	863	12.0	89
	18 - 19	3.18	1029	11.4	85
	19 - 20	3.28	1096	9.0	67
	20 - 21	3.34	1147	7.1	53
	21 - 22	3.41	1246	6.2	46
	22 - 23	3.43	1267	5.4*	41
	23.2 Bottom	3.46	1428	3.2*	24

* On up-trace, dissolved oxygen reading 2.6 mg L^{-1} at 22.8m 10 to 15 seconds after down-trace data (recorded above)



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