COMPARISON OF BOTTOM AND SURFACE COOLING WITHDRAWALS IN A HARBOUR

Daesoo Lee[1], Paul F. Hamblin[2],
Alan A. Smith[3] and William J. Snodgrass[4]

NWRI Contribution No. 89-45

[1] Former Grad. Student, Dept. of Civil Engrg. and Engrg. Mechanics, McMaster Univ., Hamilton, Ontario, Canada L8S 4L7
[2] Research Scientist, Lakes Research Branch, National Water Research Institute, Canada Centre for Inland Waters, Burlington, Ontario, Canada L7R 4A6
[3] Prof. and Chmn., Dept. of Civil Engrg. and Engrg. Mechanics, McMaster Univ., Hamilton, Ontario, Canada L8S 4L7
[4] Assoc. Prof., Dept. of Civil Engrg. and Engrg. Mechanics, McMaster Univ., Hamilton, Ontario, Canada L8S 4L7

November 1989

MANAGEMENT PERSPECTIVE

Several industries sited on Hamilton Harbour have proposed withdrawing their substantial cooling water supplies from the deeper and hence cooler bottom waters of the harbour. The return water is presently discharged at the surface. The strong thermal layering in summer inhibits the vertical diffusion of dissolved oxygen from the surface to the frequently anoxic bottom waters. This study found that the proposed withdrawal scheme would result in a 5% increase in the volume of the epilimnion and a 2-m increase in its thickness over the summer period but that the bottom water temperatures are not greatly affected due to the influence of Lake Ontario exchange. The effect of these changes on the oxygen regime is expected to be positive. In conclusion, this proposal could enhance the warm water fishery and lead to improved overall water quality by reducing anoxic events. It is recommended that further study be undertaken to examine the effect of bottom return of industrial cooling water on the reduction of vertical stratification.

PERSPECTIVE DE GESTION

Plusieurs industries situées dans le port de Hamilton et dont les besoins en eau de refroidissement sont considérables ont proposé de s'alimenter à partir des eaux de fond du port, plus froides parce que plus profondes. Les eaux de retour sont actuellement déversées à la surface. La forte stratification thermique qui se produit en été nuit à la diffusion verticale de l'oxygène dissous provenant de la surface jusqu'aux eaux de fond fréquemment anoxiques. La présente étude a permis de constater que le plan d'extraction d'eau entraînerait une hausse de 5 % dans le volume de l'épilimnion ainsi qu'une augmentation de 2 m de son épaisseur au cours de l'été, mais que la température des eaux de fonte ne serait pas tellement affectée en raison de l'effet d'échange exercé par les eaux du lac Ontario. L'effet de ces changements sur la distribution de l'oxygène devrait être positif. En conclusion, la proposition pourrait améliorer la pêche en eau chaude et conduire à une amélioration générale de la qualité des eaux par la réduction des phénomènes anoxiques. Il est recommandé d'approfondir l'étude en examinant l'effet du retour de fond des eaux de refroidissement industrielles sur la réduction de la stratification verticale.

ABSTRACT

Hamilton Harbour has been identified as an area of persistent excedance of water quality standards for several parameters. At present, there is much interest by industries on the shorelines of the harbour in drawing in their cooling water supplies from the colder hypolimnetic region. Specifically, the study considers the sensitivity of the thermal structure to bottom withdrawal of cooling water in comparison to the current practice of surface withdrawal.

A one-dimensional simulation model indicates that bottom withdrawal would draw down the thermal structure by about two meters but that the bottom temperatures are unchanged because of large inflowing volumes of cold (12°C) Lake Ontario water. The volume of the eplimnion is increased by 5% and the density contrast is decreased between the two layers by 22% thus enhancing vertical mixing of dissolved oxygen by a corresponding amount.

RÉSUMÉ

Le port de Hamilton a été identifié comme étant une zone de dépassement persistant des normes qualitatives de l'eau pour plusieurs paramètres. À l'heure actuelle, les industries s'intéressent beaucoup aux lignes de rivage du bord afin de s'approvisionner en eau de refroidissement à partir de la zone hypolimnique plus froide. De façon plus particulière, l'étude porte sur les risques courus par la structure thermique lorsque de l'eau de refroidissement est extraite sur le fond comparativement à la pratique actuelle qui consiste à s'approvisionner en surface.

Un modèle de simulation unidimensionnel indique que l'extraction d'eau sur le fond abaisserait la structure thermique d'environ deux mètres, mais que les températures sur le fond resteraient les mêmes en raison des importantes arrivées d'eau froide (12 °C) en provenance du lac Ontario. Le volume de l'épilimnion augmenterait alors de 5 % et le contraste de densité diminuerait de 22 % entre les deux couches, améliorant ainsi d'autant le brassage vertical de l'oxygène dissous.

practice of near surface withdrawal. Since the industries have filled in some of the littoral zone the deeper zones may be reached at minimum expense as lengthy intake pipes are not required. Currently, there is industrial interest in withdrawing bottom water as not only is it more efficient for cooling but also may be less corrosive and incur lower maintenance. In this study, we are concerned only with the effect of industrial intake strategies on the thermal cycle which forms the basis of other water quality considerations.

STUDY AREA

Hamilton Harbour is an enclosed body of water connected to the western end of Lake Ontario by a ship canal of depth 9.5 m (Figure 1). This is sufficiently deep to admit large qualities of relatively colder and higher quality water to the harbour in summer. Other major inputs to the Harbour are three tributary creeks, three sewage treatment plants and two steelmills. Detailed hydraulic loadings are given by Snodgrass (1980).

Figure 1. Hamilton Harbour Bathymetry

The annual thermal cycle starts in June when a shallow (5 m) thermocline forms and deepens to 10 m in early October. At this time, fall storms mix the column uniformly. The hypolimnion is maintained by inflow from Lake Ontario at a mean temperature of 12° C. Because of the large temperature difference between epilimnion and hypolimnion and consequent high water column stability, oxygen depletion is a problem in the harbour.

Lake-Harbour exchange processes are not fully understood and therefore the exchange by total dissolved solid (TDS) mass balance method (Snodgrass, 1980) was used to estimate the summer exchange. In contrast to the densimetrically driven summer flow the winter exchange is based on water level differences between the two water bodies arising from seiches and storm surges.

The current withdrawal practice by the steelmills is to take in cooling water at a rate of approximately 20 m^3/sec from the surface. This water is heated by 7.2° C on the average before it is returned to the epilimnion (Lee, 1989).

METHODOLOGY

The period from May 1979 to April 1980 was selected by McCrimmon and Schertzer (1987) for detailed study of the harbour by a thermal simulation model, since this period had the most complete record of such model forcing as surface meteorological and hydrological data. Because the harbour generally forms winter ice cover, McCrimmon and Schertzer (1987) employed the ice covered version of the dynamic simulation model, DYRESM, (Patterson and Hamblin, 1988). This thermal structure model, while vertically one-dimensional, incorporates the principal physical processes controlling the annual temperature regime such as inflows, outflows, surface heat exchanges and vertical mixing.

In this study, we extend their application of the model by separating the industrial inputs from the municipal and tributary flows, by adding the waste heat to the industrial component and by placing the intake of the cooling water at the bottom. Next, the annual thermal regime with bottom intake is compared to the their results (current practice) as well as to the actual field observations taken during the study period.

RESULTS AND DISCUSSIONS

Figure 2 shows the effect of bottom withdrawal of the industrial cooling water on the summer thermal structure. It is evident that the thermal structure maintains its general form but is displaced downwards by 1 to 2 m. It maybe be noted in these profiles as well as additional plots presented by Lee (1989) that the bottom temperature remains the same.

Figure 2. Temperature Profiles for Two Withdrawal Methods (solid line, bottom withdrawal; dashed line, surface withdrawal; symbols, field observations)

It is considered that the reason for the invariance of the bottom temperature is that the inflow from Lake Ontario maintains the bottom temperature independently of the withdrawal strategy.

To explore this hypothesis, we have eliminated the inflow from Lake Ontario in a test simulation. It is seen in Figure 3 that the thermal structure is radically altered in this case. However, the sensitivity of the thermal structure to the withdrawal strategy is not pronounced in this case either, since there is so little temperature difference between the surface and bottom. The bottom withdrawal method results in an increase in temperature of 1 to 2° C.

Figure 3. Simulated Temperature Profiles
for No Lake-Harbour Exchange
(solid line, bottom withdrawal; dashed line, surface withdrawal)

The results for the critical summer period are compared in bulk form in Table 1. Although the hypolimnetic volume is reduced by the bottom withdrawal scheme, this reduction is small on account of the influence of the inflow of large volumes of much cooler Lake Ontario water to the hypolimnion. The average temperature difference between the two layers is reduced by 1.4° C or alternately, the density contrast is reduced by 22 % which would enhance the exchange between the two layers by promoting vertical mixing due to reduced stability.

Table 1. Average Density and Temperature over Summer Period
(June to October)

CONCLUSIONS

A one-dimensional simulation model indicates several differences between the proposed scheme and current industrial withdrawal practice. These are not as significant as might be anticipated from simple hypolimnetic residence time calculations due to the overwhelming input of colder Lake Ontario water.

The proposed scheme would increase the volume of the epilimnion, thereby resulting in a marginal increase in the warm-water fish habitat. In addition, the hypolimnetic volume will decrease, resulting in a smaller volume of less oxygenated water. The net effect of this change will be a higher dissolved oxygen concentration in the harbour. Another benefit of the proposed scheme will be to lessen the density difference between the two layers, causing enhanced vertical mixing. The increase in available oxygen in addition to greater mixing will result in improved water quality for the harbour.

Further work on this problem should focus on improved quantification of the exchange flow between Lake Ontario and the Harbour and on the effect of bottom input of heated waste water on the hypolimnetic volume and vertical stability.

ACKNOWLEDGEMENT

The authors would like to thank to B. Steele of DOFASCO for supplying cooling water data and C. McCrimmon in Canada Centre for Inland Waters for providing a copy of his computer program and input data.

APPENDIX. - REFERENCES

Lee, D., 1989. "The effect of thermal discharge on Hamilton Harbour", Masters thesis, McMaster Univ., Ontario, Canada.

McCrimmon, R.C., Schertzer, W.M., 1987. "Simulation of Hamilton Harbour thermal structure" Contract Report No. 01SE-KW405-6-0800 for Supply and Service, National Water Research Institute, Canada Centre for Inland Waters, Canada.

Patterson, J.C. and Hamblin, P.F., 1988. "Thermal simulation of a lake with winter ice cover", Limnol. and Oceanogr., Vol. 33(3), 323 - 338 p.

Snodgrass, W.J., 1980. "Material Balance for Hamilton Harbour", Report submitted for inclusion in Hamilton Harbour Report 1977. Ontario Ministry of the Environment, ed.

List of Figure Captions

	CURRENT PRACTICE		PROPOSED SCHEME	
	HYPOLIMNION	EPILIMNION	HYPOLIMNION	EPILIMNION
VOLUME (x 10^6 M^3)	1.44	1.36	1.38	1.42
TEMPERATURE (° C)	13.9	20.7	15.7	21.1
DENSITY (KG/M^3)	999.226	997.971	998.952	997.967

Table 1. Average Density and Temperature over Summer Period (June to October)

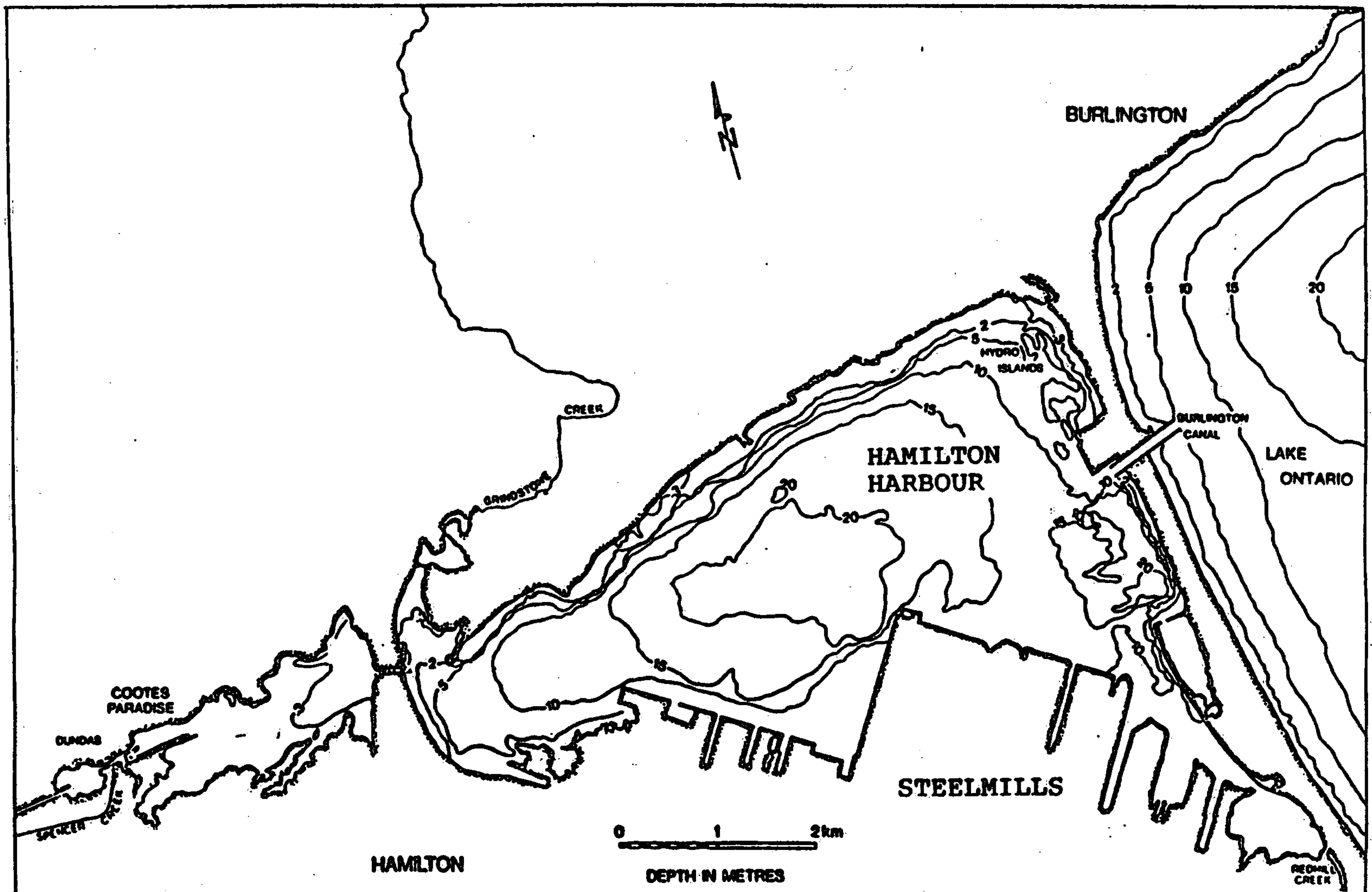
BURLINGTON
LAKE
ONTARIO
BURLINGTON
CANAL
HYDRO
ISLANDS
HAMILTON
HARBOUR
STEELMILLS
HAMILTON
COOTES
PARADISE
DUNDAS
GRINDSTONE
CREEK
SPENCER CREEK
REDHILL
CREEK
0
1
2km
DEPTH IN METRES

Figure 1

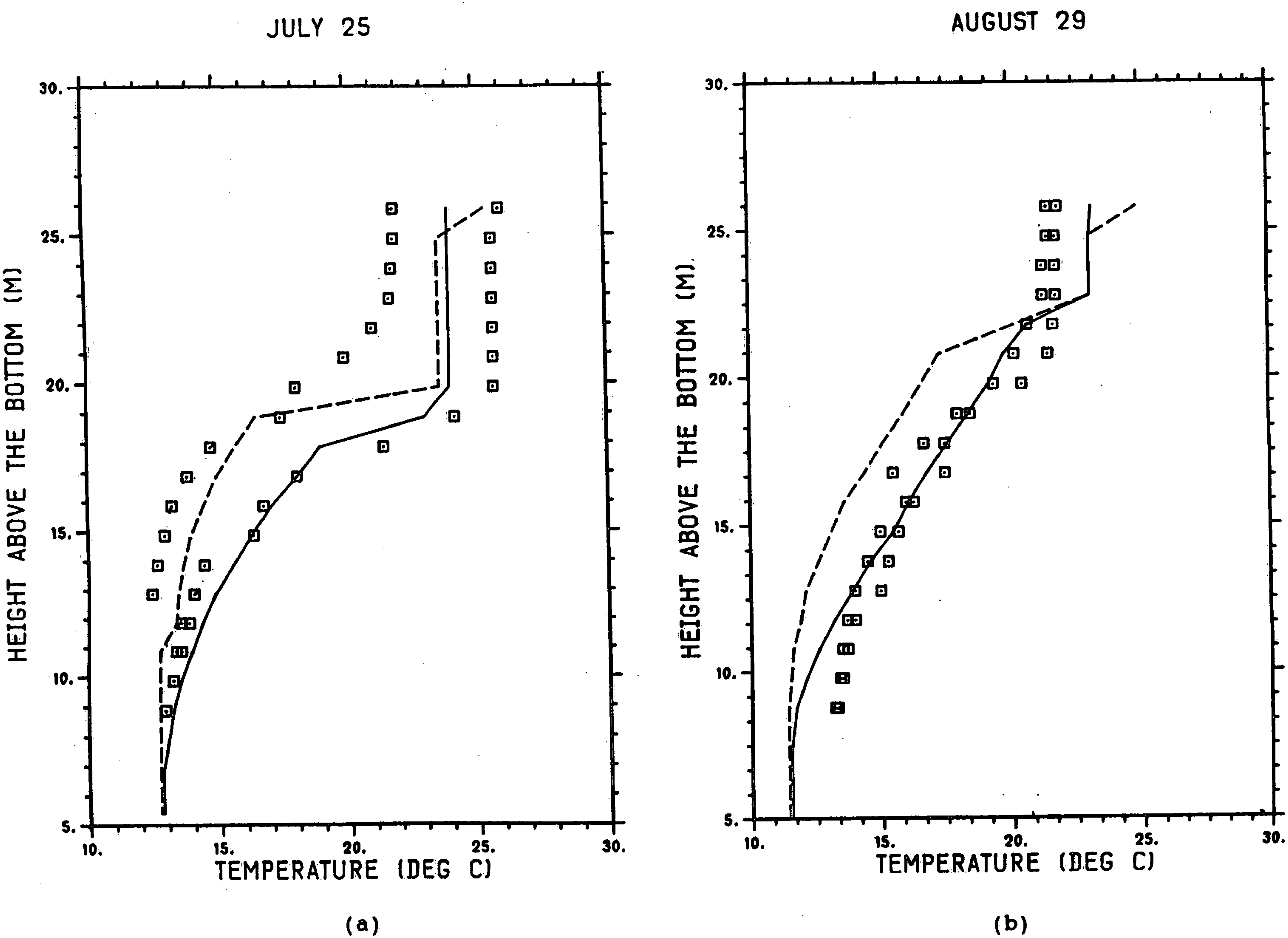
JULY 25
HEIGHT ABOVE THE BOTTOM (M)
30.
25.
20.
15.
10.
5.
10.
15.
20.
25.
30.
TEMPERATURE (DEG C)
(a)
AUGUST 29
HEIGHT ABOVE THE BOTTOM (M)
30.
25.
20.
15.
10.
5.
10.
15.
20.
25.
30.
TEMPERATURE (DEG C)
(b)

Figure 2

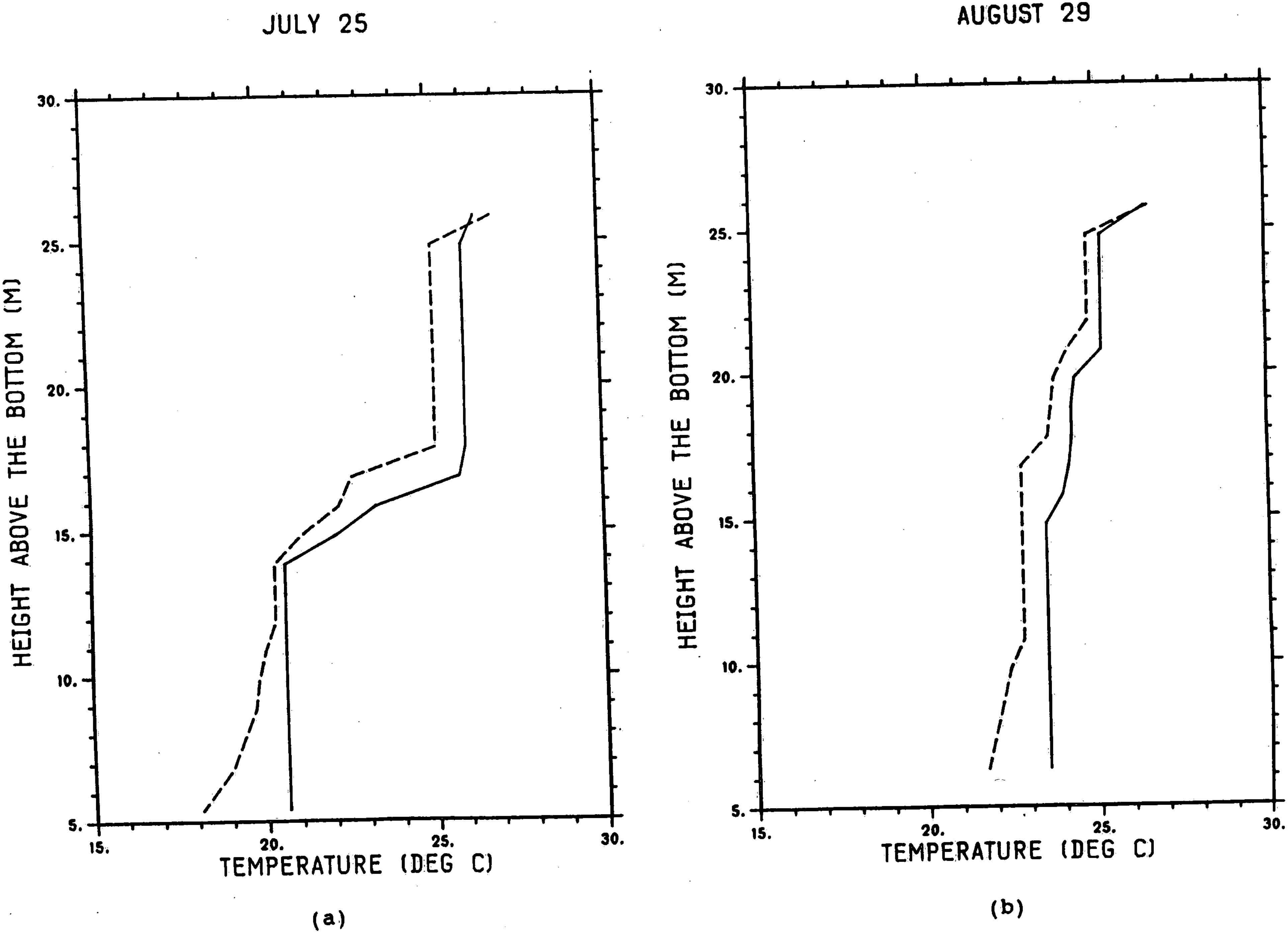
JULY 25
AUGUST 29
HEIGHT ABOVE THE BOTTOM (M)
TEMPERATURE (DEG C)
30.
25.
20.
15.
10.
5.
15.
20.
25.
30.
(a)
(b)

Figure 3

Comparison of Bottom and Surface Cooling Withdrawals in a Harbour

By Daesoo Lee[1], Paul F. Hamblin[2], Alan A. Smith[3]
and William J. Snodgrass[4]

INTRODUCTION

Hamilton Harbour has been identified by the International Joint Commission as one of 42 areas of concern in the Great Lakes where remedial action is being planned due to persistent excedances of pollutant regulatory levels. The area surrounding Hamilton Harbour is heavily industrialized with significant input of waste heat to the water body. For example, if the cooling water for the major industries were to be drawn from the hypolimnetic water of the harbour, the intake volume would be sufficient to turn over the hypolimnion in about 1.5 months which is relatively short compared to the 5 month long summer heating cycle.

The primary objective of this study is to examine whether the industrial waste heat discharge can be exploited to improve the water quality of the harbour. As a first step, we explore the sensitivity of the thermal structure to the intake of cooling water from the near bottom zone as opposed to the current

---

[1] Former Grad. Student, Dept. of Civil Engrg. and Engrg. Mechanics, McMaster Univ., Hamilton, Ont., Canada L8S 4L7.

[2] Research Scientist, Lakes Research Branch, National Water Research Institute, Burlington, Ont., Canada L7R 4A6.

[3] Prof. and Chmn., Dept. of Civil Engrg. and Engrg. Mechanics, McMaster Univ., Hamilton, Ont., Canada L8S 4L7.

[4] Assoc. Prof., Dept. of Civil Engrg. and Engrg. Mechanics, McMaster Univ., Hamilton, Ont., Canada L8S 4L7.

Address: Daesoo Lee
A-202, Sambo-ilsung Apt., 339-7, Changan-dong,
Dongdaemun-ku, Seoul, Korea 131.

Tel: 2) 243-2668