

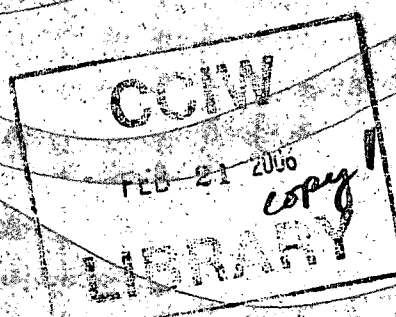
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## Thermal Structure off Hamilton water intakes in western Lake Ontario

Yerubandi R. Rao

NWRI Technical Note No. TN05-009

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National Water Research Institute  
867 Lakeshore Road  
Burlington, Ontario, L7R 4A6

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## **Preamble**

The bad taste and odour in drinking water is caused by organic compounds produced by organisms growing in the warm offshore waters. These waters are delivered to the water intakes by lake physics. Taste and odour in drinking water is a national concern, and a key focus of NWRI scientists. The City of Hamilton is seeking some guidance as to how far offshore they would have to locate their raw water intake in Lake Ontario to avoid taste and odour problems associated with surface waters in late summer. This is equivalent to asking how far from the shore the downwelling circulation (suppression of the thermocline) will be observed at the site in question under various wind conditions. This report utilizes a combination of physical limnological data and mathematical models to estimate the typical width of downwelling events that would likely to deliver surface waters to the bottom and hence to possible water intakes.

## **Préambule**

Le mauvais goût et la mauvaise odeur de l'eau potable sont causés par des composés organiques produits par des organismes qui vivent dans les eaux chaudes du large. Ce sont les caractéristiques physiques du lac qui conditionnent le déplacement de ces eaux vers les prises d'eau. Le goût et l'odeur de l'eau potable sont des préoccupations d'envergure nationale et constituent l'un des domaines d'étude prioritaires des scientifiques de l'INRE. Les autorités de la ville de Hamilton cherchent à savoir à quelle distance des rives du lac Ontario elles devraient placer la prise d'eau brute du réseau municipal pour éviter les problèmes de goût et d'odeur associés aux eaux de surface en fin d'été. Cela revient à demander à quelle distance de la rive se produit la circulation descendante (suppression de la thermocline) dans la région sous différentes conditions de vent. Le présent rapport utilise des données de limnologie physique ainsi que des modèles mathématiques pour estimer sur quelle largeur se produisent normalement les événements de plongée des eaux susceptibles d'amener les eaux de surface vers le fond, et donc vers une prise d'eau.

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National Water Research Institute

867 Lakeshore Road

Burlington, Ontario, L7R 4A6

## **Abstract**

The City of Hamilton has been studying alternate strategies such as extending their water intakes to avoid taste and odour problems associated with surface waters of Lake Ontario. This report utilizes the combination of physical limnological data and mathematical models to estimate the typical width of the coastal boundary layer in this region. Using data from nearby stations it is estimated that typical downwelling events would likely deliver surface waters to the bottom and hence to possible water intakes out to a distance of about 2.5 km from the shore in the vicinity of the present Hamilton intakes, and greater offshore distances in stronger winds.

## **Introduction**

This Technical Note has been prepared in response to a request from Mr. Greg Gowing of the City of Hamilton. The City of Hamilton is seeking some guidance as to how far offshore they would have to locate their raw water intake in Lake Ontario to avoid taste and odour problems associated with surface waters in late summer. As developed below, this is equivalent to asking how far from the shore the downwelling circulation (suppression of the thermocline) will be observed at the site in question under various wind conditions.

The thermal structure and circulation in the Great Lakes generally depends on the season because of the large annual variation of surface fluxes (Boyce et al. 1989). In summer and fall there is a distinct thermocline in the upper 20-30 m in Lake Ontario which makes it stratified. During this period of stratification, significant wind events will cause upwelling and downwelling of the thermocline along the shore. The scale of the offshore distance over which these events takes place depends on the strength and persistency of the wind stress and nearshore bathymetry, and is typically of the order of 5-10 km, known as coastal boundary layer (Rao and Murthy, 2001). The coastal boundary layer in the western Lake Ontario is generally 8-10 km wide. During the summer stratified season, the temperature variations along the northwest shore of Lake Ontario were found to be linked to the wind, with winds from westerly directions causing upwelling and cooling, and easterly winds inducing downwelling and warming.

The early work on taste and odour (T/O) research identified an abrupt increase in geosmin concentration coinciding with T/O problems of drinking water along the north-western shores of Lake Ontario. Geosmin production is observed to be indigenous, peaks annually, but only periodically at nuisance levels, and is hypothesized to originate from

offshore planktonic cyanobacteria. Historical data from water treatment plants showed that the higher geosmin levels coincided with higher water temperatures in late summer. Rao et al (2003) observed that the abrupt increase in geosmin levels coincided with increased temperatures due to downwelling forced by easterly winds. Based on this evidence, and similar observations at other water intakes along the north shore of Lake Ontario, it was hypothesized that strong downwelling and associated shoreward currents may favour the transport of geosmin produced at offshore locations to nearshore areas causing the T/O problem.

The theory of wind induced upwelling/downwelling in large lakes contains two basic elements. The first element concerns the forcing of coastal upwelling by local winds, which causes the surface layer to move to the right of the wind due to the Coriolis force. The second aspect deals with the pattern of upwelling and downwelling of isotherms, once established by the wind, that propagates around the lake. The wind induced thermocline excursions display a wave-like variation along the shore. A thermocline wave of this type is confined to a narrow strip of the coast and is known as internal Kelvin wave. They usually propagate at the speed of gravity waves near density interfaces, but due to the Coriolis force they are trapped near the shore. The alongshore propagation of warm and cold water after a major upwelling event has been observed many times in Great Lakes (Rao and Murthy, 2001).

The city of Hamilton draws raw water from the western Lake Ontario from three water intakes that extend into the lake to about 640 m to 945 m. The water is treated before supplying to the users. As observed at other locations, the high levels of geosmin at these intakes also coincided with an increase in intake temperature. The data leads researchers to believe that geosmin is being produced in the open lake and is delivered to the near shore zone, and water intakes, by downwelling events driven by easterly winds. The main objective of this study is to estimate the extent of these downwelling events near the intakes. However, there are no observations off the intakes to analyse the frequency and spatial extent of these downwelling events. The estimates must therefore be done using numerical modelling techniques aided by interpretation of data from other sites.

## **Methods**

During 1996 and 1997 an extensive field measurement program was undertaken by the National Water Research Institute (NWRI) in the western part of Lake Ontario in the nearshore area off Burlington and Hamilton (Fig.1). As a part of this field program two temperature moorings were deployed in the coastal and offshore regions and continuous temperature profiles from 24 June to 2 September 1997 were gathered. A current meter station located within 1.5 km from the Hamilton intakes also provided continuous water temperature data during this period. A meteorological buoy deployed at the offshore station provided the required wind observations. This data set was useful in estimating the downwelling region off the water intakes. A two-dimensional cross-sectional model has been used to predict the downwelling off the intakes.

## **Results**

Figure 2 shows the rose plot of observed winds at offshore station 8 during the summer stratified period (24 June to 2 September 1997). The winds are in general westerly to northwesterly, however, strong episodes of easterly winds of around 6-8 m/s occurred on a few occasions (2-3%). The positions of 10-13°C isotherms were used to define upwelling and downwelling events in Lake Ontario. By taking the position of 10°C isotherm as the depth of the thermocline, we identified upwelling (downwelling) events when the thermocline sharply moved upwards (downwards) coinciding with favorable wind directions. Table 1 shows the approximate start and end of upwelling and downwelling events, predominant wind direction and the range of wind speeds during these episodes. Figure 3 shows the daily averaged temperature obtained at stations 4 (3.5 km from shore) and 8 (8.4 km from shore) located at depths of 28.4 m and 46.7 m, respectively. Comparison of temperature and wind stress time series reveals that upwelling and downwelling events correspond to southwesterly and easterly winds. Except during strong upwelling and downwelling episodes the temperature profiles show a stable stratification. The downwelling of the thermocline was mainly caused by easterly winds. The thermocline intersected the bottom at the station 2 on two occasions (days 204-209 and days 230-235) during this period. The surface temperatures increased considerably to 20°C because of the arrival of warm waters from the north. The duration of the downwelling events were slightly longer (5-6 days) than upwelling (2-3 days) events. On some occasions it was observed that although the prevailing winds were weak, the downwelling was quite strong. This is attributed to the coastal jets with strong alongshore currents due to the alongshore propagation of internal Kelvin waves.

Comparison of sub-surface temperatures obtained at station 2 and the current meter station located in the proximity of the water intakes show high correlation. This gives us confidence in using the same two-dimensional model verified for the cross-section covering stations 2, 4, 8. It should provide reasonable estimates of the thermal structure off the Hamilton intakes. In order to obtain the relatively fine details required to model upwelling and downwelling episodes the two-dimensional model is used with the assumption that the gradients normal to the shore are much larger than in the alongshore direction. Therefore, a z-level two-dimensional model will provide reasonable estimates of the offshore extent of the downwelling region, which is typically within the coastal boundary layer. The offshore extent of the model was taken as 50 km, with a realistic bathymetry out to 14 km offshore. Beyond that a constant depth of 50 m was used. The vertical resolution of the model was 3 m. The model was forced with average winds typically observed at station 8 and constant radiative fluxes ( $300 \text{ W/m}^2$ ) in clear sky conditions. Several simulations were carried out with varying meteorological conditions. Typical downwelling of the isotherms occurred within 5-6 km from the shore. Two such examples (Figures 5a and 5b) show that under downwelling favorable winds, the thermocline will migrate to 16-18m below the surface at 2.5 km from the shoreline. This study indicates that this wind-driven downwelling circulation off Hamilton intakes is confined to 2.5 km from the shoreline under typical wind conditions. However, under much more stronger winds than simulated here it is possible that the thermocline will dip sharply to further offshore as indicated in Figure 3.

## **Summary**

Using data from a nearby site and a numerical model it is estimated that typical downwelling events would likely deliver surface waters to the bottom and hence to possible water intakes out to a distance of about 2.5 km from the shore in the vicinity of the present Hamilton intakes, and greater offshore distances in stronger winds. Due to the limited data available and simplifying assumptions used in the modelling, these results must be treated as rough estimates, not suitable for design. If more accurate estimates are required in the future, considerable more work will be necessary, including: field measurements at the site in question; careful evaluation of the wind climate; more comprehensive numerical modelling, using the field data for verification.

## **Acknowledgement**

I thank M. Charlton, Raj Murthy and M.G. Skafel for reviewing and making excellent suggestions to improve the technical note.

## **References**

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- Rao, Y.R., and C.R. Murthy, 2001b: Nearshore currents and turbulent exchange processes during upwelling and downwelling events in Lake Ontario, *J. Geophys. Res.*, 106 C(2), 2667- 2678.
- Rao, Y.R., M.G. Skafel, T. Howell and C.R. Murthy, Physical processes controlling taste and odour episodes in Lake Ontario drinking water, *Journal of Great Lakes Res.*, 29(1), 70-78.

Dates	Julian Days	Episode	Predominant Wind Direction (Towards)	Range of Mean Wind Speed (m s <sup>-1</sup> )
3 July 97- 8 July 97	184-189	Upwelling	North-East	4-6
23 July 97- 29 July 97	204-210	Downwelling	South, SouthWest	3-4
30 July 97- 3 Aug 97	211-215	Upwelling	North-West	3-5
4 Aug 97- 6 Aug 97	216-218	Downwelling	West	3-4
8Aug 97- 12Aug97	219-224	Upwelling	North-East	3-3.5
18Aug97- 23Aug97	230-235	Downwelling	West	4-5
24 Aug97- 28Aug97	236-240	Upwelling	North-East	2-3

Table 1: Upwelling and downwelling events along with predominant wind directions during these episodes.



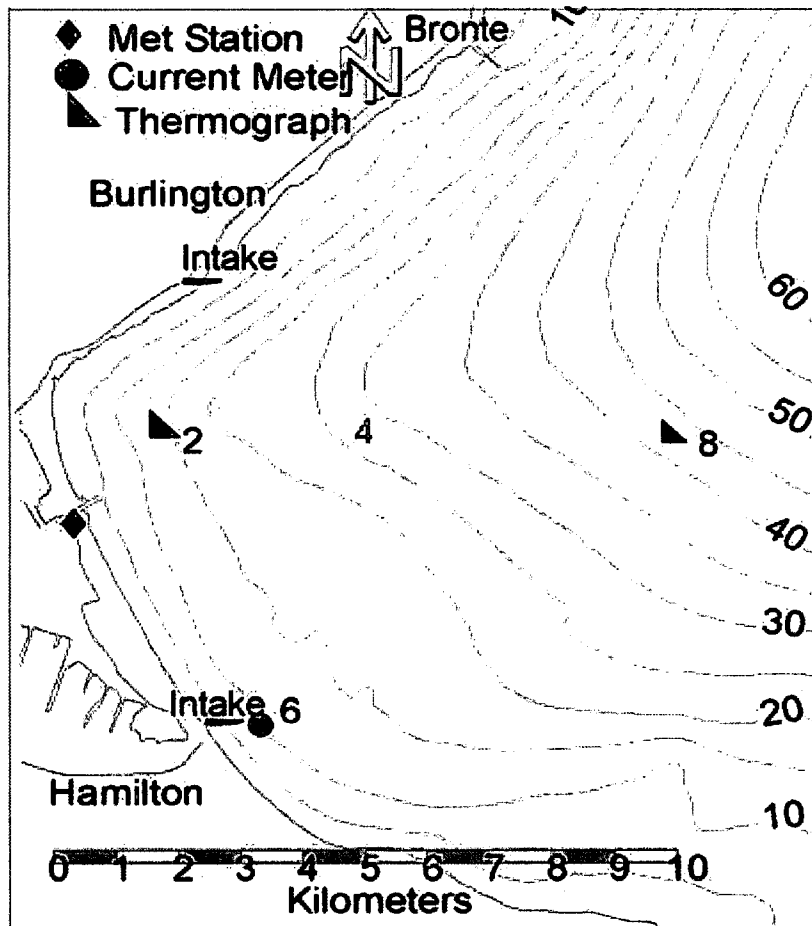


Fig. 1: Map of Western Lake Ontario with 1997 moorings

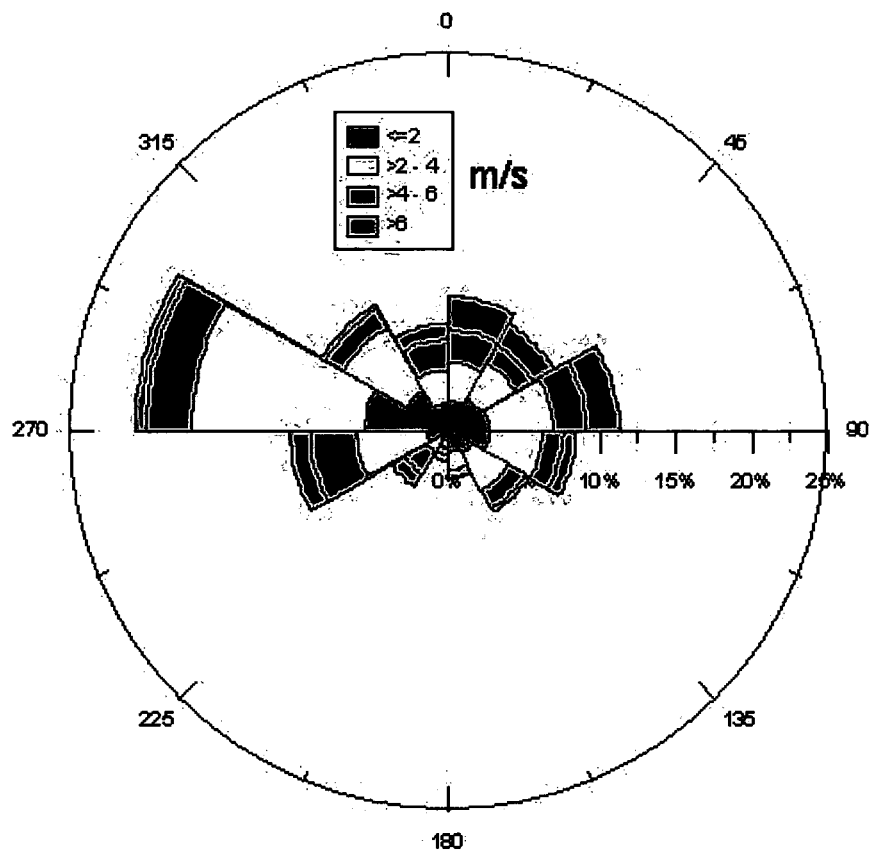


Fig 2: Rose Plot of winds at station 8

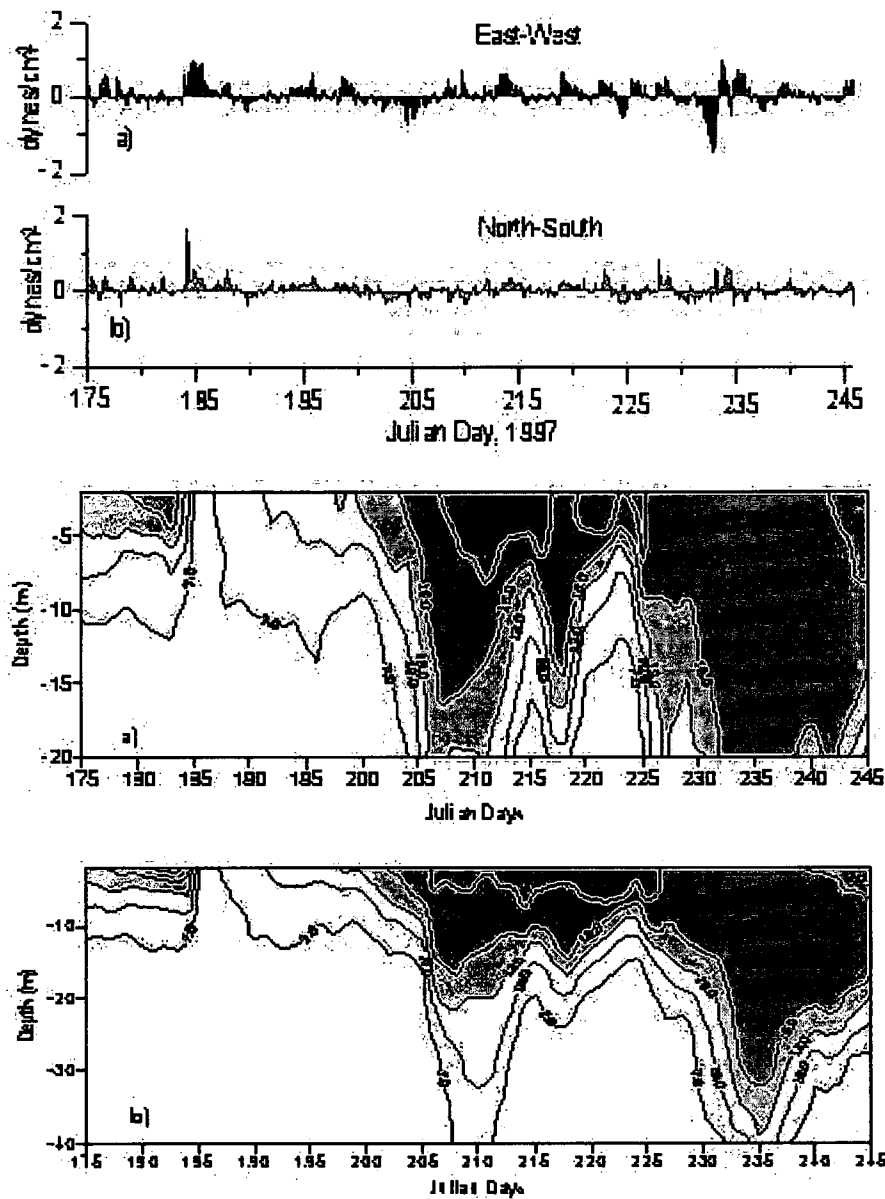


Fig 3: Daily averaged temperatures at stations a) 4 and b) 8 in western Lake Ontario basin during Julian days 175-245, 1997.

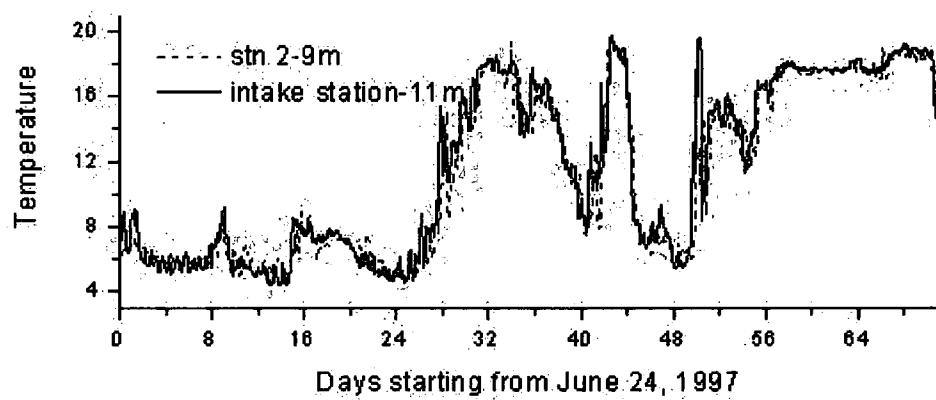


Fig 4: Comparison of sub-surface temperatures at station 2 and the station close to the intake

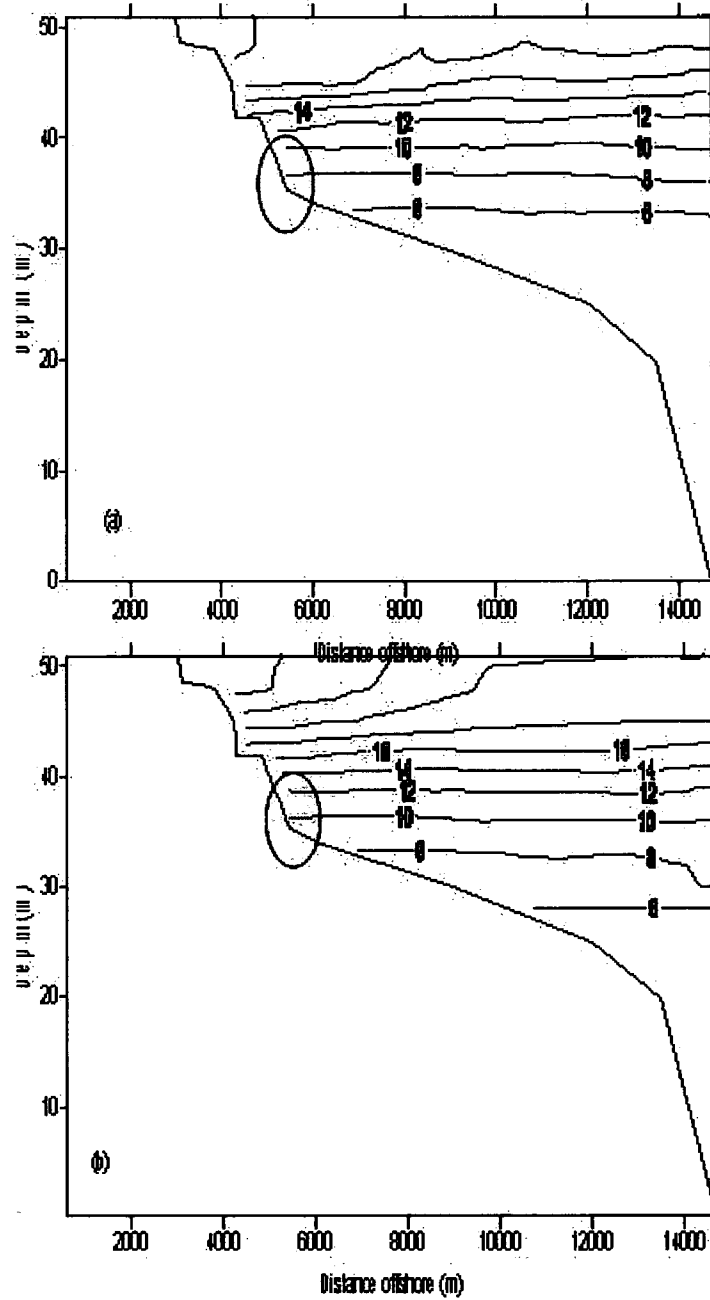


Fig 5: Typical temperature distributions during the downwelling episodes (a) with 3 days of clear skies and 4 m/s easterly wind and (b) with 5 days of clear skies and 6 m/s easterly wind.



**National Water Research Institute**  
**Environment Canada**  
**Canada Centre for Inland Waters**  
P.O. Box 5050  
867 Lakeshore Road  
Burlington, Ontario  
L7R 4A6 Canada

**National Hydrology Research Centre**  
11 Innovation Boulevard  
Saskatoon, Saskatchewan  
S7N 3H5 Canada



**NATIONAL WATER  
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**INSTITUT NATIONAL DE  
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**Institut national de recherche sur les eaux**  
**Environnement Canada**  
**Centre canadien des eaux intérieures**  
Case postale 5050  
867, chemin Lakeshore  
Burlington, Ontario  
L7R 4A6 Canada

**Centre national de recherche en hydrologie**  
11, boul. Innovation  
Saskatoon, Saskatchewan  
S7N 3H5 Canada

