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Application of a numerical model for circulation, temperature and pollutant distribution in Hamilton Harbour

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ABSTRACT

The restoration of Hamilton Harbour, from an environmental standpoint, is a current concern for the agencies involved with remediation efforts in the harbour. Estimates of circulation and mixing are needed to assess the fate and transport of water quality constituents in the harbour. A three-dimensional hydrodynamic modeling system (ELCOM) is used to study the circulation and thermal structure in the harbour. The model results were compared with profiles of temperature at several moorings and currents and water levels in the harbour. The model showed considerable skill in reproducing the thermal structure, surface currents and water levels. Mean summer circulation in the harbour showed two counter-rotating gyres occupying the harbour. The model produced harbour-lake exchange characteristics are in agreement with previous studies. Simulations using passive tracers qualitatively agreed with chemical tracer studies conducted near a sewage treatment plant outfall. The accuracy of these simulations suggests that the model is capable of describing flow and transport of material required for detailed water quality simulations.

Introduction

Hamilton Harbour is an embayment located at the western end of Lake Ontario (Fig. 1). The harbour has a roughly triangular shape with a length of 8 km along its main axis and a maximum width of 6 km along its eastern shoreline. It has a maximum depth of 23 m, an average depth of 13 m, a surface area of 21.5 km^2 and a volume of 2.8×10^8 m^3 (Barica, 1989). The three main streams that feed into the harbour are Grindstone Creek, Red Hill Creek and Spencer Creek through Cootes Paradise. The other significant inputs come from waste water treatment plants, major industries and combined sewer overflows (CSOs). As a result of these loadings the harbour suffers severe water quality problems. Hamilton Harbour has been designated as an area of concern by the International Joint Commission with regard to water quality (IJC, 1985).

The harbour is connected to western Lake Ontario by the Burlington Ship Canal (BSC), which is a man-made canal of 836 m long and about 89 m wide and 9.5 m deep (Lawrence et al., 2004). During summer, the large density difference between cold Lake Ontario and warm harbour waters results in substantial exchange between the two water bodies (Spigel, 1988). This exchange appears to be particularly significant during cold upwelling events in western Lake Ontario. Considerable work has gone into characterizing this exchange flow between the harbour and the lake (Dick and Marsalek, 1973; Hamblin, 1998; Lawrence et al., 2004). Several studies using field measurements in the harbour were conducted to quantify the currents and mixing within the harbour (OME, 1985; Boyce and Chiocchio, 1991; Wu et al., 1996). Wu et al. (1996) observed that the currents in the harbour are mainly wind-driven and detected seiches in the water levels. On the other hand, theoretical and numerical models have also been developed either to study the exchange processes between these two water bodies without specifically validating the harbour circulation (Gu and Lawrence, 2001; Hamblin and He, 2003) or simulate current movements without explicitly considering the importance of the exchange mechanisms (James and Eid, 1978; Tsanis and Wu, 1995). However, these models were not validated with extensive currents and temperature measurements in the harbour. Hydrodynamic information from these studies is used to study the water quality in the harbour (Kellershohn and Tsanis, 1999). Although the model verifications were insufficient and conducted at coarser resolution, these studies provided insights into the loadings and water quality patterns with respect to the general circulation in the harbor.

In 2006, an intensive field investigation was undertaken to gain new information about the temperature, currents and oxygen conditions in the harbour. The major focal points of this experiment were to provide information for assessment of contaminated sediments targeted for remediation, and to reassess the dissolved oxygen goal for Hamilton Harbour Remedial Action Plan (RAP). Furthermore, hydrodynamic information in the harbour is also essential for developing a predictive water quality model for the harbour. Although several studies have been conducted in the harbour, they are not sufficient to resolve the circulation and mixing for the reasons

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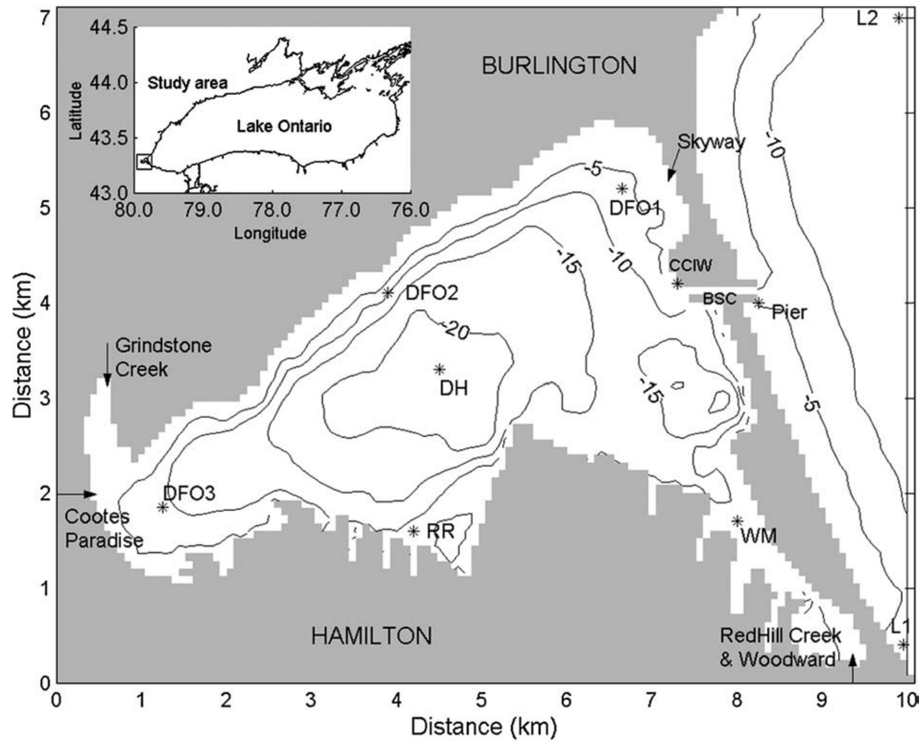

Fig. 1. Map of instrument locations and bathymetry of the Hamilton Harbour. Inflows are identified with arrows.

mentioned earlier. Recently, an Estuary Lake Coastal Ocean Model (ELCOM) has been used in several lakes and embayments (Hodges et al., 2000). This model has also been applied in the Great Lakes (Leon et al., 2005). ELCOM has an advantage because it can be easily coupled with a water quality simulator, Computational Aquatic Ecosystem Dynamics Model (CAEDYM). Because of these reasons, as a first step ELCOM has been chosen to simulate the circulation and thermal structure in Hamilton Harbour. The primary objective of this paper is to develop ELCOM model for Hamilton Harbour to provide hydrodynamic information for ongoing RAP studies. The data collected during 2006 offer the opportunity to carry out a detailed verification of the hydrodynamic model for the harbour. As a secondary objective, the model results have been used to interpret the sewage-contaminated sediments in the northeastern sector of the harbour. These estimates of circulation and mixing are critical in assessing the fate and transport of water quality constituents in the harbour for environmental restoration purposes.

Methods

Experimental data

During 2006 an extensive field measurement program was undertaken by Environment Canada (EC) in Hamilton Harbour and the western part of Lake Ontario in the nearshore area off Burlington and Hamilton (Fig. 1 & Table 1). As a part of this field program one 1200 Khz Broadband ADCP by RD Instruments was deployed at Randle Reef (RR) and continuous velocity profiles from 9 May to 26 July, 2006 have been gathered. At this location velocity profiles were obtained at 0.5 m intervals from 8 m to 0.5 m. The ADCP uses a pair of broadband encoded pulses to measure velocity throughout the water column. The data collected in each depth cell was hourly averaged for this analysis. The long-term accuracy of velocity profiles obtained from broadband ADCP are on the order of $\pm 0.2\%$. Hourly temperature profiles were obtained from three thermistor strings located in the harbour and two strings in the Lake. Water level data was obtained at L1, L2 and DH using RBR's TDR-20 sensors. Temperature data were recorded at 10 min and water level data were recorded at 1 minute intervals at these stations. The temperature data are accurate to the order of 0.1 °C. In addition, the Department of Fisheries and Oceans (DFO) deployed three moorings consisting of temperature and oxygen at 1 m above bottom (mab) along the north and western parts of the harbour.

Two meteorological stations at CCIW breakwall and on the Pier provided observations of air temperature, wind speed and direction and relative humidity. All the variables except solar radiation were measured approximately 5 m above lake level. The solar radiation was measured on the roof top of the CCIW building (~20 m above the lake level). As the winds from the Breakwall are not significantly different from Pier winds, we provide spatially uniform winds over the entire domain. The slight differences between these stations are mainly due to the presence of the CCIW building, which could not be resolved with confidence from the available data. In the computation of net longwave radiation, cloud cover observed at Hamilton Airport was used. Fig. 2 shows an example of time series of these atmospheric variables recorded at 10-min interval at CCIW. The winds were generally moderate (average speed was 3.2 m s^{-1}) and the predominant wind direction was from the west. However, close inspection

Table 1
Moored instrumentation in Hamilton Harbour and western Lake Ontario

Mooring location	Type	Instrument depths
RR	ADCP & Temp chain	ADCP (8 m to 0.5 m), 5 temperature sensors in 8 m of water depth
DH	Temp, water level	13 temperature sensors in 23 m of water depth
WM	Thermistor chain	5 temperature sensors in 8 m of water depth (2 failed)
DFO1	Temp	1 mab
DFO2	Temp	1 mab
DFO3	Temp	1 mab
L1	Temp & water level	5 temperature sensors in 8 m of water depth, water level
L2	Temp & water level	13 temperature sensors in 28 m of water depth, water level
CCIW & Pier	Meteorology	