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Impact of proposed outfall discharges in western Lake Ontario

By:

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IMPACT OF PROPOSED OUTFALL DISCHARGES IN WESTERN LAKE ONTARIO

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ABSTRACT

This paper utilizes the combination of physical limnological data and both near- and far-field mixing models to predict the waste plume characteristics for the proposed outfall in western Lake Ontario. The model results show that for treated effluents the near-field dilution ratios are satisfactory for the present discharge conditions. Far-field studies employing a two-dimensional numerical model showed no contamination near the existing Hamilton and Burlington water intakes.

IMPACT DES REJETS DE L'ÉMISSAIRE PROPOSÉ POUR L'OUEST DU LAC ONTARIO

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RÉSUMÉ
La présente communication utilise une combinaison de données physiques limnologiques avec des modèles de mélange au champ proche et au champ éloigné pour prévoir les caractéristiques du panache de déchets de l'émissaire proposé pour l'ouest du lac Ontario. Les résultats du modèle montrent que, pour les effluents traités, les taux de dilution au champ proche sont satisfaisants dans les conditions actuelles de rejet. Les études au champ éloigné, utilisant un modèle numérique bidimensionnel, ont montré qu'il n'y avait pas de contamination près des prises d'eau existantes d'Hamilton et de Burlington.

NWRI RESEARCH SUMMARY

Plain language title

Sewage discharges in western Lake Ontario

What is the problem and what do scientists already know about it?

Over the last ten years there has been a question of whether municipal treated sewage presently discharged to Hamilton Harbour could be discharged into Lake Ontario as is the practice in other municipalities. Alternate strategies of lake discharge may alleviate the need for unusually stringent treatment needed to meet water quality goals of the Hamilton Harbour Remedial Action Plan (HHRAP). The latest update of the HHRAP recommended a study of the possibility of offshore discharges.

Why did NWRI do this study?

In consideration of the water quality concerns and others raised in conjunction with a long-term interest in sustainable use of nearshore waters, NWRI decided to undertake a detailed study of the physical limnology of the area near the proposed outfall. This paper utilizes the combination of physical limnological data and mathematical models to predict the waste plume characteristics for the existing Burlington STP outfall in the Hamilton Harbour and for the proposed outfall in the lake.

What were the results?

The proposed diffuser at 1200 m offshore gave satisfactory dilutions for typical summer and winter conditions. The near-field defined as a zone, where the outfall jet induced mixing takes place, is limited to within 300 m from the diffuser. Typical summer stratification assures that the diluted effluents remain in the bottom 4-5 m.

How will these results be used?

The physical limnology observations and model results in the vicinity of the proposed location of the outfall is essential for siting the diffuser. The results clearly show that a multi-port diffuser will provide the necessary dilution during the major part of the year. This study indicates that by discharging the treated sewage from an outfall in Lake Ontario it is possible to achieve the Hamilton Harbour RAP goals.

Who were our main partners in the study?

Regional Municipalities, Hamilton Harbour RAP

Sommaire des recherches de l'INRE

Titre en langage clair

Rejets d'eaux usées dans l'ouest du lac Ontario

Quel est le problème et que savent les chercheurs à ce sujet?

Ces dix dernières années, on s'est demandé si les eaux usées urbaines traitées, actuellement rejetées dans le port d'Hamilton, pourraient l'être dans le lac Ontario, comme c'est la pratique dans d'autres municipalités. Des stratégies de rechange en faveur du rejet dans le lac permettraient d'éviter le traitement exceptionnellement rigoureux exigé pour satisfaire aux objectifs de qualité de l'eau du Plan d'assainissement (PA) du port d'Hamilton. Dans la dernière mise à jour du Plan, on recommande une étude sur la possibilité de rejeter les effluents au large.

Pourquoi l'INRE a-t-il effectué cette étude?

En raison des préoccupations, notamment au sujet de la qualité de l'eau, soulevées dans le contexte d'une utilisation durable des eaux côtières, l'INRE a décidé d'entreprendre une étude minutieuse sur la limnologie physique de la région proche du point de rejet proposé. Notre article présente une étude dans laquelle on utilise une combinaison de données de limnologie physique et de modèles mathématiques pour faire des prévisions sur les caractéristiques du panache pour l'actuel point de rejet dans le port d'Hamilton de la station de traitement des eaux usées de Burlington et pour l'émissaire proposé, avec rejet dans le lac.

Quels sont les résultats?

Le diffuseur proposé à 1200 m au large a donné des dilutions satisfaisantes pour les conditions estivales et hivernales types. Le champ proche, qui est défini comme la zone où a lieu le mélange induit par le jet de l'émissaire, se situe à moins de 300 m du diffuseur. La stratification estivale type fait en sorte que les effluents dilués demeurent à une profondeur de 4-5 m.

Comment ces résultats seront-ils utilisés?

Les observations de limnologie physique et les résultats fournis par le modèle au voisinage de l'emplacement proposé de l'émissaire sont essentiels pour le choix de l'emplacement du diffuseur. Les résultats montrent clairement qu'un diffuseur multivoies permettra d'obtenir la dilution nécessaire pendant la majeure partie de l'année. Cette étude indique qu'en rejetant dans le lac Ontario les eaux usées traitées, il est possible d'atteindre les objectifs du PA du port d'Hamilton.

Quels étaient nos principaux partenaires dans cette étude?

Municipalités régionales, PA du port d'Hamilton.

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ABSTRACT

This paper utilizes the combination of physical limnological data and both near- and far-field mixing models to predict the waste plume characteristics for the proposed outfall in western Lake Ontario. The model results show that for treated effluents the near-field dilution ratios are satisfactory for the present discharge conditions. Far-field studies employing a two-dimensional numerical model showed no contamination near the existing Hamilton and Burlington water intakes.

INTRODUCTION

The western Lake Ontario shore is rapidly becoming one continuous urban community. This area forms an almost unbroken urban landscape from Oshawa, east of Toronto, to St. Catharines near the Niagara River, and is home to over 5 million residents. These communities turn to Lake Ontario almost exclusively for both water supply and wastewater disposal. Intakes and discharges alike are typically installed in a narrow band of the lake extending, at most, a few kilometers offshore. Improvements in water purification and sewage treatment technology have offset the deleterious effects of increased development. However, current treatment technology seems to be nearing its practical design limit, while the demand for clean water and the need for suitable waste disposal facilities continue to rise at an ever-increasing rate. Excessive loadings of phosphorus, ammonia, and suspended solids from sewage treatment plants, bacterial contamination from Combined Sewer Overflows (CSO) and storm runoffs contribute to the problems of nearshore water clarity and poor water quality. In addition, loadings of toxic substances continue to be a concern today. One factor that has helped to minimize the degradation of the western Lake Ontario waters has been that the sewage treatment plants (STP) of Burlington and Hamilton discharge into Hamilton Harbour. This, of course, has been greatly detrimental to water quality in the harbour (Charlton and LeSage, 1996).

The Hamilton Harbour Remedial Action Plan (RAP) is formulated through a wide variety of government, private sector, and community participants. It provides the framework for numerous initiatives aimed at restoring and maintaining the harbour environment. The RAP guidelines call for further reductions in contaminant loading over time, while continued development in Hamilton and Halton Regions will require substantial expansion of wastewater treatment facilities to meet the additional demand. For facilities discharging into Hamilton Harbour it will likely be very difficult to meet RAP loadings targets and still keep up with future demands using foreseeable improvements in treatment technology. Charlton (1997) presented phosphorous load scenarios based on present design flows and expanded flows. He observed that even with optimum performance of the effluent plant, the total phosphorous loads into the harbour would exceed the RAP goals.

The preferred alternative of recommendations in the original short list called for expansion of the Skyway and Mid-Halton treatment plants, with the Skyway STP continuing to discharge into Hamilton Harbour (W_2O, 1995). The other two remaining alternatives were also based on these expansions; however, one scheme would add tertiary treatment at Skyway to meet RAP loading targets, and the other would relocate the plant discharge from the harbour into Lake Ontario. The improvement to discharge quality that one could reasonably expect from upgrading to tertiary treatment - a very costly option - might still fail to prevent an unacceptable increase in nutrient loading to the harbour at the projected effluent volume. After meetings with a number of agencies and the public, the alternative involving relocation of the outfall was deemed most desirable. A study conducted for the city of Burlington recommended a location for proposed outfall in Lake Ontario (Figure 1). McCorquodale (1998) further noted that except during the wet weather flows, the treated sewage from Burlington STP may be diverted to the lake. However, the recommendation for partial or overall diversion of STP effluent to the lake will only be considered after all other technically feasible and practical options have been implemented (RAP, 1992).

In this paper, we provide a description of mixing and transport characteristics near the proposed outfall location in the lake. This study uses long-term observations of temperature and current profiles, and different types of numerical models for near-field and far-field mixing scenarios for the total treated effluent loads.

DATA AND METHODS

Current meter data include time-series of current speed and direction data plus water temperature. Where possible, nearby concurrent meteorological data are also included in the analysis. Locations of moored instruments in western Lake Ontario during 1996 and 1997 are shown in Figure 1. The data were hourly averaged for the analysis. In addition to data from moored current meters and meteorological stations, results of the analysis of trajectories of satellite-tracked drifting buoy released about a kilometre east of the proposed outfall site in 1997 are also included to estimate the circulation and horizontal exchange coefficients. Current profiles near the present location of the outfall in the Hamilton Harbour were obtained from a bottom mounted ADCP deployed from May 31 to September 7, 2000 (Figure 2).

Near-Field Models

The primary goal of an outfall diffuser system is to accomplish a rapid initial mixing of the effluent with the receiving waters and thus minimize detrimental effects of the effluent discharge on the environment. Hydrodynamic mixing processes of effluent discharge depend primarily on the discharge condition, diffuser length, and the ambient current and density conditions. Initial mixing occurs within about 100 m (near-field) and within a few minutes after release from the diffuser. A wastefield is established at the end of the initial mixing region (IMR), which drifts with the currents to be diffused by lake turbulence in the far-field. Mathematical mixing models have been developed to predict the near-field characteristics of effluent discharges. Some of the important wastefield parameters of submerged effluent discharges are the height to the top of the established wastefield, Z_e, the height of the level of maximum concentration (minimum dilution), Z_m, and the thickness, h_e (Roberts, 1996). The minimum dilution at the end of initial mixing region (x_i) is S_m, which is defined as the smallest value of the dilution observed in a vertical plane through the wastefield at the end of the IMR.

The PLUMES modeling suite consists of two initial dilution models RSB and UM3 for fresh water and marine applications (Frick et al. 2000). The RSB model can be broadly classified as an updated model of USEPA's earlier ULINE model. It also accommodates the effects of varying source momentum flux and port spacing. It is based on the experimental results for merging plumes in linearly stratified cross-flows. The RSB model assumes that the density profile is linearized up to the top of the plume, and so can be used with non-linear stratification also. Because RSB is based on experiments, it will, of course, provide reliable estimates of minimum dilution, rise height and other wastefield characteristics for these experiments. Independent comparisons of RSB predictions have been reported in several studies (Roberts and Wilson, 1990).

For negatively buoyant plumes, we use the UM3 model, another resident initial dilution model in PLUMES. The UM3 model is a three-dimensional Lagrangian entrainment model. The equations for conservation of mass, momentum and energy are solved at each time step, giving dilution along the plume trajectory. To determine the growth of each element, UM3 uses the shear entrainment hypothesis and the projected-area-entrainment hypothesis (Frick, 1984). The model output consists of plume characteristics along its trajectory such as dilution, height of the centreline concentration.

Far-field model

In view of the limitations of Gaussian Plume model developed for the northshore of Lake Ontario (Kuehnel et al. 1981), and the inadequacy of the information regarding the flow field, a simple transport and diffusion model was developed for western Lake Ontario. For the present case, a two-dimensional (x, y) model is found to be adequate, if we assume that the effluents are contained and vertically mixed in the top few meters during summer stratification, and well-mixed during the winter season.
The two-dimensional transport equation for a moving patch of pollutant is given as

$$\frac{\partial c}{\partial t}+u\frac{\partial c}{\partial x}+v\frac{\partial c}{\partial y}=K_x\left(\frac{\partial^2 c}{\partial x^2}\right)+K_y\left(\frac{\partial^2 c}{\partial y^2}\right)-kc+S_c, \qquad (1)$$

where c is the concentration, u and v are velocity components, K_x and K_y are eddy diffusivities, S_c is the pollutant source and k is the decay constant. The boundary conditions completing the model impose a no-flux condition at a solid boundary, and at open boundaries, the diffusive flux is assumed zero. At the pollutant source, the input concentrations are taken from the output of the near-field model. A central difference scheme is applied for the diffusion terms, and advection terms are solved by an upstream finite difference scheme. Thus, the distribution of an effluent can be obtained by solving equation (1) for a sufficiently long period until the steady state is reached. A simple objective analysis method was found to be adequate to define the flow field (Lam et al. 1984). It consists of interpolation of currents by radii of influence around the observed points. The currents at all current meters were first daily averaged, and then interpolated to the grid points to generate u and v components.

HAMILTON HARBOUR DISCHARGES

Hamilton Harbour is located at the western tip of Lake Ontario. A sandbar separates the Harbour from Lake Ontario and Lake-Harbour exchange is accommodated through the Burlington Ship Canal (Fig. 2). The Harbour is roughly triangular in shape and has an east-west axis of 8km and a north-south axis of 5km. It has a surface area of 2,150 ha with a maximum depth of 23m and a mean depth of 13 m (Barica, 1989). Hamilton Harbour is one of the Areas of Concern that has been identified by International Joint Commission (IJC, 1978) (one of the 42 Great Lakes sites) whose aquatic environment is so degraded that remedial action must be undertaken. Among the municipal sources, four sewage treatment plants discharges more than 400,000 m^3/d of treated effluent directly or indirectly to Hamilton Harbour (Coakley et al., 2002).

Burlington Skyway STP discharges treated effluent through a diffuser pipe into the north-eastern corner of Hamilton Harbour. The diffuser pipe is located in approximately 7 m of water and 1.5 m above bottom. The diffuser is assumed to be 200 m in length and in straight-line configuration with 21 ports, and port width is around 90 cm. During 1996 the discharges were over 93000 m^3/d, and by 2011 the expanded design flows will be in the order of 140,000 m^3/d. Burlington Skyway STP is allowed to discharge effluent concentration of 1.0 mg/L total phosphorous. However, under experimental trails, the plant achieved effluent concentrations of 0.30 mgP/L (Charlton, 1997). In order to generate the best achievable estimate of near-field mixing, we assumed that 0.30 mgP/L effluent concentrations could be achieved in all our simulations.

The annual cycle of effluent density (based on temperature and conductivity) shows that only during September to December the effluent is positively buoyant. During the rest of the year the effluent seems to be denser than the receiving waters (Coakley et al. 2002). The RSB model is not suitable for negatively buoyant plumes, hence the UM3 model is used for near-field simulations for this period. Coakley et al. (2002) also discussed the current structure near the outfall site. They found considerable vertical structure associated with stable thermal stratification during summer deployments. They observed that the surface flows were generally towards the east, and at the bottom to the west, and northerly at the intermediate depths. Currents in the near-bottom depths were generally weak (< 5cm/s) and were directed towards the west and north-westward directions (Fig. 3).

For summer conditions we have taken the mean temperature profile obtained from several water quality surveys during 1987-1992 (Charlton et al., 1998), and for winter simulations we assumed ice-free and homogeneous condition with 4°C as the mean temperature. For ambient flow velocities we considered two different cases with currents perpendicular to the diffuser. The simulated outfall was as described above. For weak currents (3 cm/s) the dilution rates predicted by the model for design flow conditions of 140,000 m^3/d (1.74 m^3/s) are in the range of 12.8:1. With higher current speeds (5 cm/s) the initial mixing region and dilutions increased considerably. In the winter the buoyant jet rises and forms a stable layer at the surface due to homogeneous conditions. The actual frequency of surfacing of plume is probably less than predicted here, because the harbour is covered by ice during part of the winter season.

As discussed above during the summer the effluent density is slightly higher than ambient density, hence, the near-field simulations were carried out using UM model. For weak currents (3 cm/s) the effluent is trapped below 5.5 m with a discharge rate of 1.74 m^3/s. The horizontal distance from the pipe where the effluent hit the bottom varied very little and remained at 18-20 m from the diffuser. With increased current speeds (5 cm/s) the initial dilutions and horizontal distances increased marginally. Charlton (1997) observed that the phosphorous loads from Burlington STP into the harbour accounts only 25 % of the total treated sewage loads, and the rest comes from Hamilton STP. These results indicate that the near-field mixing zone of Burlington STP is confined to an area of 0.048 sq km in the north-eastern corner during the summer season. However, Coakley et al. (2002) observed that sediment contamination of low concentrations of Coprastanol extending beyond the initial mixing region. This indicates that after the initial mixing due to the diffuser and currents, contaminants are transported and dispersed by prevailing currents.

Charlton (1997) noted that treated sewage damages small-enclosed areas such as Hamilton Harbour because the sedimentation and dilution processes are not sufficient to prevent high ambient phosphorous and algae levels. Hamblin and He (2002) estimated that the residence time of Hamilton Harbour is 217 days during the unstratified season, but could be as low as 64 days during intense upwelling period that stimulate harbour-lake exchange. The exchange process between Hamilton Harbour and Lake Ontario through the Burlington Ship Canal is complex and episodic (Dick and Marsalek, 1973; Poulton et al, 1986; Wu et al, 1996). Based on annual average phosphorous concentrations in the harbour of 40 μg/L, lake concentrations of 15 μg/L, and exchange flows, Hamblin and He (2002) estimated that phosphorous loading from harbour to lake is on average 153 kg/d during the summer and 39 kg/d during the winter. The algae infested water discharges from the harbour canal in a low-velocity plume parallel to local beaches.

LAKE DISCHARGE

The rationale for supporting discharge into the lake, over and above the desire to reduce pollutant loadings to the harbour, has a basis in the intuitive notion that the comparatively huge volume of the lake and its anticipated higher energy dynamics would much more effectively disperse the effluent. In fact, mixing zone studies were conducted prior to the expansion of the Oakville Southwest-Mid Halton STP for its combined outfall. The outcome of this study showed that chemical and bacteriological parameters were lower than Provincial Water Quality Objectives at a distance of about 900 meters from the source for an average flow rate of 195,460 m^3/day. Not only is this flow rate substantially greater than the projected discharge for Skyway (by almost 40%), but the updated Skyway plant would maintain year-round non-toxic effluent quality through nitrification, and non-toxic disinfection, which would likely reduce the size of the effective mixing zone even more.

The complete details of the experimental work and historical results are presented in a comprehensive report (Miners et al. 2002) and are not the subject of this paper. From these observations, the distribution of current speed and direction during summer and winter conditions were computed (Figure 4). Over nearly 80 percent of the period the mean currents were weak (<3 cm/s) to moderate (3-7 cm/s). The currents show significant vertical structure, however the predominant direction seems to be oriented alongshore. In summer, stratification typically developed at 5-8 m depth then decayed in the fall until temperature profiles became isothermal and remained so over the winter. From the results of drifter experiments conducted between May and October 1997, the ensemble averaged zonal and meridional components of drifter velocities were five and 10 cm/s, respectively. The root-mean-square values were 7 cm/s along the zonal and 6 cm/s along the meridional direction.

The proposed site for a new outfall for Skyway STP is 1200 m offshore in Lake Ontario to the east of the treatment plant. The mean local depth at this location is approximately 14 m with a bed slope of 1% eastward. Burlington's water intake is approximately 3.4 km north-east of the outfall site and Hamilton's is approximately 5.8 km to the south. For modelling purposes, a 200 m staged diffuser was used, the nozzle spacing was defined as 10 m with port diameter of 180 mm. All of the nozzles were given a vertical angle of 30° above the horizontal and an alternating angle of 10° with respect to the line of the diffuser. Figure 6a shows the mean monthly distribution of ambient (Lake) and effluent temperatures throughout the year based on Skyway plant data. Generally, the effluent temperatures were greater than the lake temperatures; however, we observe large fluctuations in the lake temperature due to upwelling and downwelling events during summer stratification that could have significant impact on ambient density.

Near-field simulations

The RSB model was used to obtain near-field dilution characteristics for different flow conditions. For summer conditions we have taken the mean temperature profile obtained from thermistor chain data for August (station 2), and for winter simulations we assumed homogeneous condition with 4°C as the mean temperature. For ambient flow velocities, we considered three different cases with currents perpendicular to the diffuser. The simulated outfall was as described above. In the simulations the expected phosphorous concentration for the plant design flow of $2m^3/s$ would be 300 μgP/L (McCorquodale, 1998). In these calculations, we assume that the phosphorous is a conservative tracer and simulated for typical summer flows. Table 1 shows the predicted results of waste field characteristics and dilution rates near the outfall for summer conditions with different current speeds based on the frequency distribution of currents. The dilution rates predicted by the model for a flow of 2 m^3/s are in the range of 12.3 :1 to 27.3:1 during the summer season. Since the ambient stratification during the summer is strong the wastefield is trapped below 4-5 m depth. In the winter the buoyant jet rises to the surface due to homogeneous conditions. The difference in dilution between summer and winter is very large mainly because of the effect of density stratification.

If the outfall capacity were increased to 600,000 m^3/day by combining the Hamilton and Burlington discharges into this location the initial dilution rates would be expected to decrease considerably. By taking the same ambient current speeds and vertical density profiles in the previous section, we carried out the RSB near-field model simulations for a waste discharge rate of 6.94 m^3/s, with concentrations of 300 μgP/L. Table 2 shows the summary of the predicted results. It was predicted that near-field dilution rates during the summer season would be significantly reduced to the values calculated for the present discharge conditions. Under strong ambient currents (10 cm/s), the dilution rates would be decreased to 13.9:1 during summer.

Far-field simulations

In these numerical experiments the modelled area extends over a region of 10.5 km in the x-direction (east-west) and 11.4 km in y-direction (north-south) with a grid resolution of 300x300 m. For this grid interval a time step of 30 sec is found to be consistent with computational stability. The decay rate is taken as zero in the simulations. The choice of horizontal diffusion coefficients is very important to the prediction of model concentrations. The horizontal diffusion coefficients varied significantly during episodic events compared to summer or winter conditions (Rao and Murthy, 2001). Horizontal eddy diffusivity values also varied in space and time. However, in this study we use the average values of diffusion coefficients as K_x (0.48 m^2/s) and K_y (1.02 m^2/s) obtained from both Lagrangian and Eulerian experiments. As described earlier a simple objective analysis method was used to define the flow field for the model.

In an experiment for a discharge rate of 2 m^3/s the near-field mixing model yielded initial dilution of 17.6:1 for current speed of 5 cm/s which is equivalent to a concentration of 17.05 µgP/L. By introducing this input as a continuous source the model was run for a typical shore parallel episode occurring from August 1 to 5, 1997. Figures 4(a) and 4(b) show the concentration distributions on 1st and 5th August, respectively, with current vectors at the model grid points superimposed. The area affected by the effluent was confined to the region near the outfall. Several other numerical experiments are conducted with the current and future discharge rates (Tables 1 and 2). The far-field calculations show that for proposed outfall location and flow conditions concentrations would attain lake background levels (10 µgP/L) within 510-m from the diffuser for weak to moderate currents. These results also suggest that, with a flow of 2 m^3/s, the pollutants may not extend beyond 4-5 sq km from the outfall. However, when the outfall capacity was increased to 6.94 m3/s, it is expected that the concentrations be higher than 10 µgP/L near the beaches. In another numerical experiment the outfall was relocated to 2 km (20-m depth) from the shore. The results show that dilutions at 100-m and beyond improved considerably by relocating the discharge location to offshore.

SUMMARY AND CONCLUSIONS

Population and development estimates for Halton Region predict that by the year 2011 a 50% increase in capacity will be required at the Skyway STP. From a Hamilton Harbour RAP perspective the near-field impact from the outfall at the present location will not increase significantly for typical discharges of 1.74 m^3/s to 2 m^3/s. However, Charlton (1997) noted that in order to maintain such high levels of treatment, Skyway plant might have to add tertiary filters at an additional cost of $27 million to meet the RAP goals. In addition, he also observed that it would leave no capacity for growth past 2011. One proposal to stay within the permissible effluent limits would involve shifting the Skyway outfall from Hamilton Harbour to western end of Lake Ontario. Therefore, we have examined the near and far-field impacts from a proposed new outfall that discharges the treated sewage in the lake. Based on the thermal and flow characteristics in the western Lake Ontario a suitable site would be at 14-m water depth, which is 1200 m off Burlington.

Near field dilutions obtained from a mixing zone model show that, for treated effluents with a discharge conditions of 2 m^3/s at the proposed outfall site at Burlington, the dilution ratios are in the range of 13:1 to 27:1 for weak to moderate currents during summer stratification. With proposed Burlington outfall location and discharge conditions no far-field contamination is observed near the beaches or water intakes for typical summer and winter conditions. With the increased treatment capacity to 6.94 m^3/s (representing the combined flow of Burlington and Hamilton outfalls) the near-field dilution ratios decreased considerably. This study has not considered the impact of certain episodic events such as upwelling/downwelling, thermal bar on the outfall dilution characteristics, and long-term impacts due to toxic contaminants.

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Table 1: Wastefield characteristics during summer with discharge of $2m^3/s$ (concentration 300 μg/l)

current speed cm/s	IMR (m)	Ze (m)	he(m)	Zm	Initial Dilution Sm	Dilution at 100m	Distance of 10 μg/l (m)
3	10.5	5.7	5.1	3.8	12.3	14.9	510 m
5	17.5	5.7	5.1	3.8	17.6	20.3	470 m
10	35.2	4.5	4.0	3.0	27.3	31.4	<100 m

Table 2: Wastefield characteristics during summer with 6.94 m^3/s concentration 300 μg/l)

current speed cm/s	IMR (m)	Ze (m)	he(m)	Zm	Initial Dilution Sm	Dilution at 100m	Distance of 10 μg/l (m)
5	18.1	8.6	7.6	5.8	8.7	10	1150 m
10	37.2	7.9	7.0	5.3	13.9	15.2	1300 m
15	52.6	6.9	6.2	4.6	18.3	21.0	<1300 m

Lake Ontario (May 1996 - October 1997)

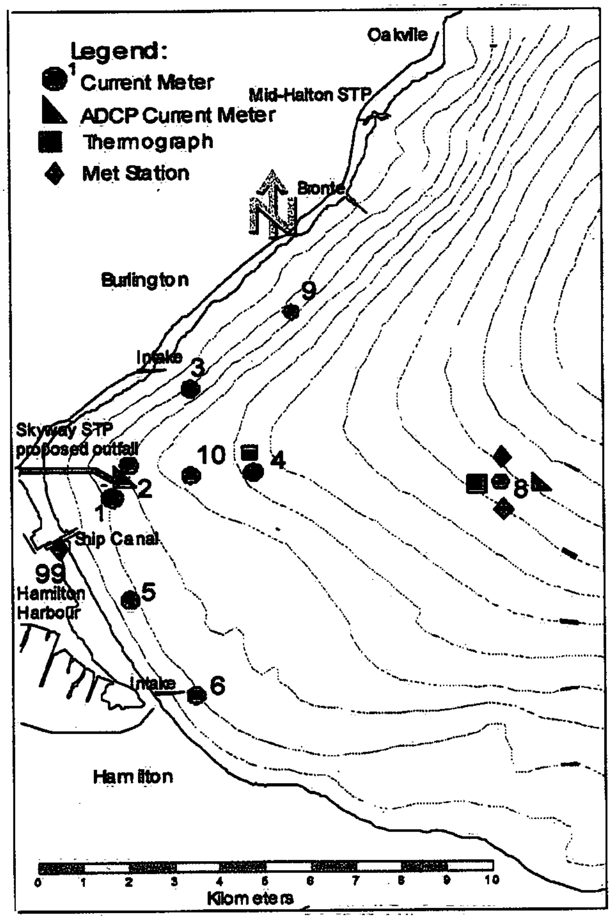

Fig 1: Map of 1996-97 study area, station locations and proposed outfall location.

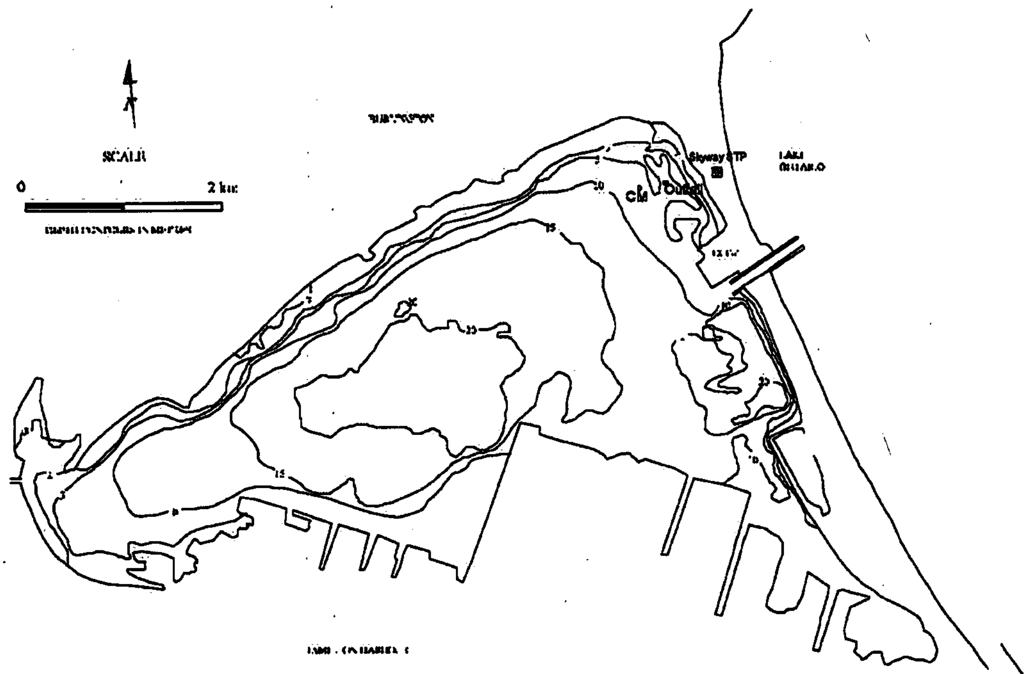

Fig. 2: Map of Hamilton Harbour with current meter location and existing Skyway outfall position.

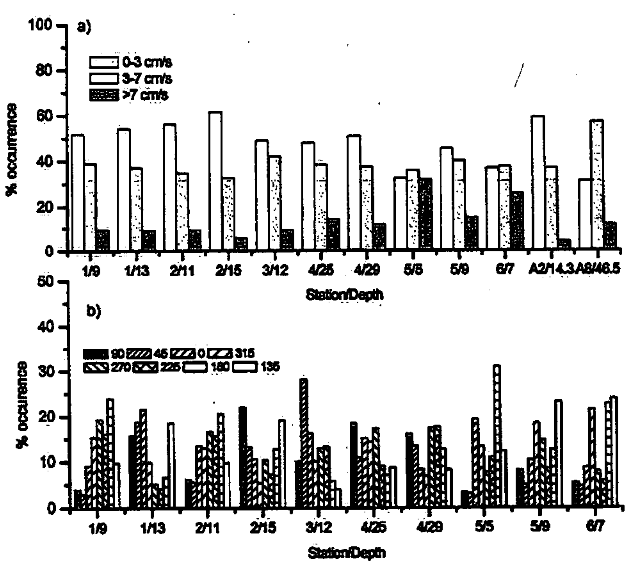

Fig. 3: Distribution of current speed and direction in western Lake Ontario.

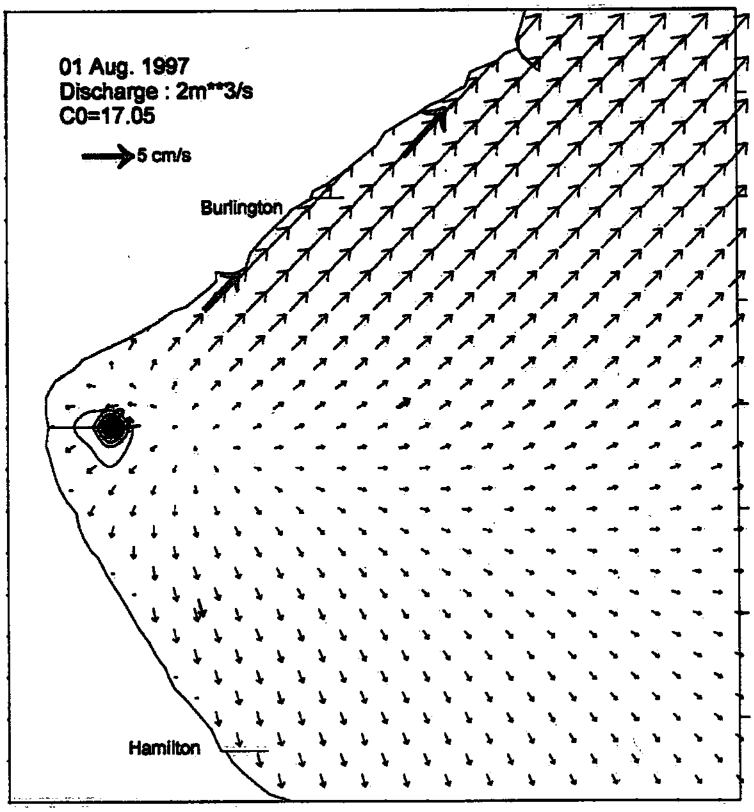

Fig 4a: Simulated concentration field on 1 Aug 1997 superimposed on circulation. (Thick red arrows from observations; thin arrows from model results).

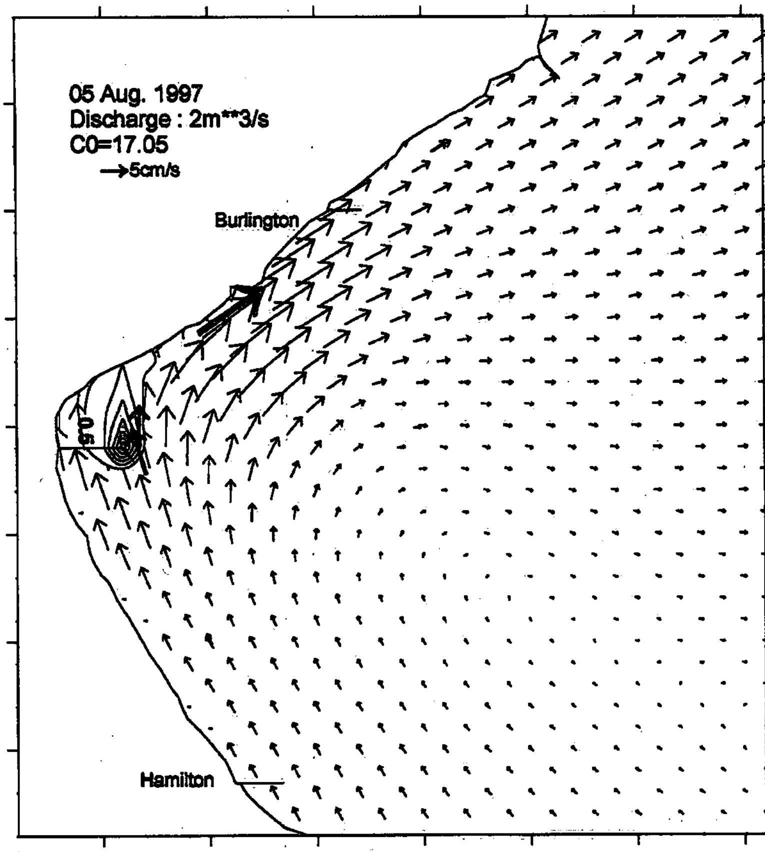

Fig 4b: Same as 4a, except for 5 Aug 1997.

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