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MICROBIOLOGICAL POLLUTION IN THE CANADIAN UPPER GREAT LAKES CONNECTING CHANNELS[1]

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MANAGEMENT PERSPECTIVE

The closing of swimming beaches, caused by fecal bacteria contamination, is one of the most common water use impairments caused by urban pollution. Such incidents are particularly frequent in urban areas with combined sewer overflows or malfunctioning sewer systems. The report that follows addresses this problem in three Areas of Concern in the Upper Great Lakes Connecting Channels - the St. Marys River in Sault Ste. Marie, the St. Clair River in Sarnia and the Detroit River in Windsor. The report presents the methodology proposed for the assessment of microbiological contamination of the receiving waters and the screening of remedial measures. This methodology comprises field observations of indicator microorganisms in the receiving waters and source discharges, simulations of bacterial loads by a loading model, and simulation of bacterial transport and levels in the receiving waters.

The study findings will assist the Remedial Action Plan teams in the three areas studied and should be also of interest to others dealing with fecal bacteria contamination of receiving waters by urban sources.

SOMMAIRE À L'INTENTION DE LA DIRECTION

La fermeture de plages à la baignade, à cause de la contamination des eaux par des bactéries fécales, est l'une des entraves les plus courantes à l'utilisation de l'eau dont la pollution urbaine est responsable. De tels incidents sont particulièrement fréquents dans les secteurs urbains pourvus d'égouts évacuateurs unitaires ou dont le réseau d'égouts est défectueux. Le rapport qui suit traite de ce problème dans trois secteurs préoccupants des voies interlacustres du secteur supérieur des Grands Lacs - la rivière St. Marys à Sault Ste. Marie, la rivière St. Clair à Sarnia et la rivière Detroit à Windsor. Le rapport présente la méthodologie proposée pour l'évaluation de la contamination microbiologique des eaux réceptrices et le choix des mesures correctrices. La méthodologie comprend la mesure de microorganismes indicateurs dans les eaux réceptrices et les points d'évacuation de sources de pollution, la simulation de charges bactériennes à partir d'un modèle et la simulation du transport des bactéries et de leur nombre dans les eaux réceptrices.

Les résultats de l'étude aideront les équipes du plan d'assainissement dans les trois secteurs étudiés et devraient également intéresser ceux qui s'occupent de la contamination des eaux réceptrices par des bactéries fécales d'origine urbaine.

ABSTRACT

The fecal microbiological pollution was investigated in the Canadian Upper Great Lakes Connecting Channels by focusing on the near-shore zones of the St. Marys River in Sault Ste. Marie, the St. Clair River in Sarnia and the Detroit River in Windsor. Towards this end, water samples were collected at various sources of fecal pollution and at sampling stations in these rivers, and analyzed for several microbiological parameters. In this report, the discussion is limited to the indicator organism recommended by Health and Welfare Canada - *Escherichia coli*. The observed bacterial counts were characterized by geometric means and probabilistic distributions, and assessed in terms of compliance with the Ontario recreational water quality guideline of 100 *E. coli*/100 mL. In the three urban areas studied, the degree and extent of microbiological pollution were closely correlated with the number of sewer outfalls (particularly those for combined sewer overflows, CSOs) and dry weather source contributions (malfunctioning sewer systems). Thus, an excellent water quality was found in Sault Ste. Marie (no CSOs), but poor quality was found in the St. Clair River along a relatively short Sarnia waterfront (4 CSOs) and in a long stretch of the Detroit River in Windsor (25 CSOs). The screening of remedial measures needed in Sarnia and Windsor was accomplished by the demonstrated methodology - statistical interpretation of observed microbiological data, simulation of bacterial fluxes with a loading model, and examination of bacterial transport and levels in the receiving waters. Among the remedial measures, the highest priority should be assigned to dry-weather source controls. Local improvements in microbiological water quality can be achieved by manipulating bacteria transport in rivers - preventing influx of contaminated waters to the areas used for water-based recreation.

RÉSUMÉ

On a étudié la pollution des voies interlacustres du secteur supérieur des Grands Lacs par des bactéries fécales en examinant surtout des zones situées près du rivage de la rivière St. Marys à Sault Ste. Marie, de la rivière St. Clair à Sarnia et de la rivière Detroit à Windsor. À cette fin, on a prélevé des échantillons d'eau à diverses endroits pollués par des bactéries fécales et à des stations d'échantillonnage sur ces rivières et on a analysé plusieurs paramètres microbiologiques. Dans le rapport, la discussion a été limitée à l'organisme indicateur recommandé par Santé Canada, soit *Escherichia coli.* Le nombre de bactéries observé a été caractérisé par l'obtention de la moyenne géométrique et par des calculs de distribution probabiliste, et on a déterminé si ce nombre respectait la norme de l'Ontario en matière de qualité des eaux utilisées à des fins récréatives, soit 100 *E. coli*/100 mL. Dans les trois secteurs urbains étudiés, le degré et l'étendue de la pollution microbiologique étaient étroitement corrélés au nombre d'émissaires d'évacuation (notamment ceux des égouts évacuateurs unitaires, ÉÉU) et aux sources de pollution par temps sec (réseaux d'égouts défectueux). Ainsi, la qualité de l'eau était excellente à Sault Ste. Marie (pas d'ÉÉU), mais elle était mauvaise dans la rivière St. Clair le long d'un secteur riverain de Sarnia relativement peu étendu (4 ÉÉU) et sur une longue section de la rivière Detroit (25 ÉÉU). Le choix des mesures correctrices nécessaires à Sarnia et à Windsor a été effectué à partir de l'interprétation statistique (par une méthode éprouvée) des données microbiologiques observées, de la simulation des flux de bactéries à l'aide d'un modèle de charge et de l'examen du transport des bactéries et de leur nombre dans les eaux réceptrices. En ce qui concerne les mesures correctrices, la priorité la plus élevée doit être accordée à l'élimination des sources de pollution par temps secs. On peut améliorer localement la qualité microbiologique de l'eau en utilisant les données sur le transport des bactéries dans les rivières et en empêchant l'apport d'eaux contaminées dans les secteurs où l'eau est utilisée à des fins récréatives.

INTRODUCTION

The Upper Great Lakes Connecting Channels Study (UGLCCS, 1988) identified fecal pollution as one of the causes of the impairment of water uses in the St. Marys, Detroit and St. Clair Rivers in the cities of Sault Ste. Marie, Sarnia and Windsor, respectively (see Fig.1). These concerns are particularly serious in view of the ongoing use of these rivers for such purposes as drinking water supply, swimming, boating/sailing, and commercial and sport fishing (UGLCCS, 1988).

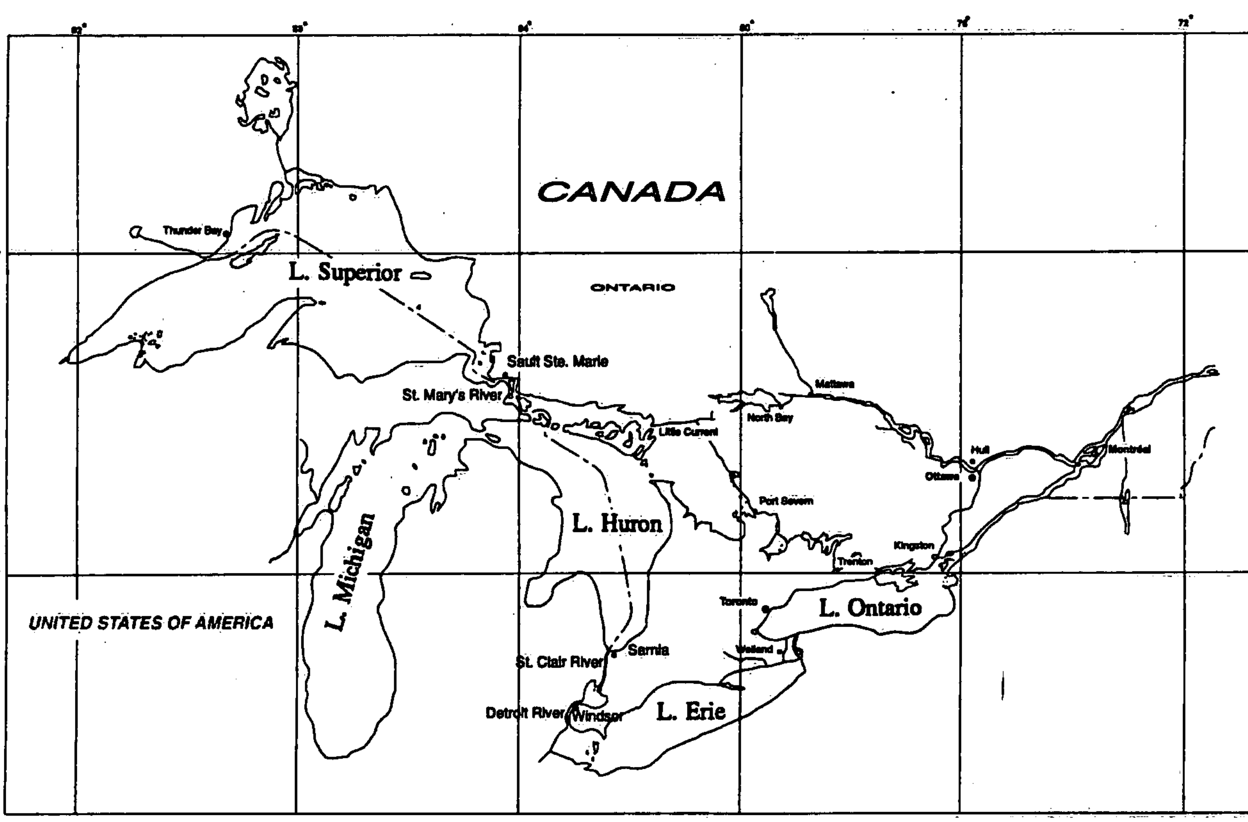

Fig.1. Upper Great Lakes Connecting Channels - Location Map

The UGLCC Study also identified the sources of contamination, including combined sewer overflows (CSOs) and urban stormwater, and recommended a management strategy to correct the impairment of water uses in the UGLCC area. Such a strategy includes detailed assessments of contributions of contaminant sources and the development and implementation of effective control measures. As a first step in the implementation of such measures, the Cleanup Fund Program (Environment Canada) and the National Water Research Institute, assisted by the Ontario Ministry of Environment and Energy, University of Windsor and McMaster University, initiated three studies of fecal bacterial pollution in the UGLCC, with the following main objectives:

- Assess the levels of dry and wet weather faecal bacterial contamination of the near-shore zone of the affected three rivers
- Characterize the selected sources of faecal bacteria including wastewater treatment plant (WTP) effluents, stormwater and CSOs
- Where required, assess the feasibility of developing remedial measures for controlling fecal bacterial contamination, and
- Assess the feasibility of modelling indicator bacteria levels in support of the development of remedial measures.

While the detailed findings of these studies have been reported elsewhere (Dutka and Marsalek, 1993; Marsalek et al., 1994; McCorquodale et al., 1991 and 1992), the main purpose of this paper is to develop more general conclusions by comparison of study approaches and findings.

STUDY AREAS

The study areas encompassed selected reaches of the three studied rivers and the adjacent urban areas contributing faecal pollution through stormwater, CSO and WTP effluent discharges. A summary of the basic characteristics of the study areas is given in Table 1.

The above characteristics indicate that the three study areas should differ significantly in terms of faecal bacterial loadings, with the Windsor area having by far the largest number of CSO, the

Sarnia area having relatively few, and Sault Ste. Marie none, except for sanitary sewer overflows, which come into operation very rarely. The WTPs employ effluent disinfection and the larger primary treatment plants discharge at the downstream end of study reaches, which limits the impact of their discharges within the terms of reference of this study. The receiving waters, the three rivers, are characterized by relatively high discharges and fast flows, thus providing quick flushing of discharged pollutants. However, in each river, there are some small embayments characterized by low velocities and slow flushing.

TABLE 1 Basic Characteristics of the Study Areas

Characteristics	Area of Concern		
1. River	St. Marys	St. Clair	Detroit
Average discharge (m^3/s)	2,200	5,200	5,300
Typical width (km)[1]	0.3-6.0	0.2-0.8	0.7-3.0
Velocity (m/s)[1]	0.6-1.5	1.1-2.1	0.3-0.6
2. Urban Area	Sault Ste. Marie	Sarnia	Windsor
Sewerage system	Separate	Combined	Combined
Number of stormwater outfalls[1]	30	13	34
Number of CSO outfalls[1]	---	5	25
Wastewater treatment	Secondary/primary[2]	Primary	Second./primary[2]
Population served	80,000	70,000	183,000
WTP Capacity (1000 m^3/day)	18 + 55	65	36 +164

[1] Within the reach studied
[2] There are two WTPs; the upstream one (secondary treatment, smaller capacity) and the downstream one (primary treatment, higher capacity)

METHODS FOR ASSESSMENT OF FAECAL BACTERIA POLLUTION

Sampling sites. The main purpose of the field surveys was to assess indicator bacteria densities in the receiving waters and source discharges. Towards this end, samples were collected at a number of sampling stations and analyzed for several microbiological parameters. Total numbers of sampling stations for Sault Ste. Marie, Sarnia and Windsor were 16, 14 and 21, respectively.

The selection of these stations was driven by the need to evaluate faecal bacterial densities in the receiving water body and in discharges from sources. In each area, the most upstream station served as a reference (control) station located upstream from all significant urban sources of faecal bacteria.

Sample Collection. Water samples (200 mL) were collected from shore using a 1.5 metre reversing grab sampler. In shallower areas, samples were collected by wading out to approximately 0.8 to 1.0 metre depth and collecting sub-surface samples by hand. Effluent samples from the two WTP plants were collected from the plant outfall, as close as possible to the end of the discharge pipe. For these samples, sample bottles contained 0.2 mL of 10% solution $Na_2S_2O_3$ for inactivating chlorine. Samples were collected in both dry and wet weather. Routine dry weather samples were collected after there had been at least 3 days without rain. During rain events samples were collected, whenever possible, at the start of a rain event, and then at 12 to 24 hours intervals, up to 84 hours after the event started. The collected samples were placed in ice coolers and delivered to the Microbiological Laboratories of the Ministry of Environment and Energy (London, Ontario) or the National Water Research Institute (Burlington, Ontario) where the sample processing started immediately and all analyses were initiated within less than 24 hours of the sample collection.

Microbiological Parameters and Analyses. All water samples were tested for *Escherichia coli* (*E. coli*), faecal coliforms, *Pseudomonas aeruginosa*, and some were also tested for faecal streptococci and coliphage. A complete description of laboratory methods can be found in Dutka and Marsalek (1993) and Marsalek et al. (1992). For brevity, the discussion in this paper focuses on *E. coli* which was recommended by Health and Welfare Canada (1992) as the indicator organism for assessing the health risk in recreational waters. Consequently, a brief description of laboratory methods is given only for this indicator. *E. coli* populations were estimated by adding 4-methylumbelliferyl-B-D-glucuronide (MUG) to the A-1 broth (0.05 g/L) used for estimating fecal coliform densities. This enumeration procedure is based on the ability of *E. coli* to break down MUG and release 4- methylumbelliferone a compound which when exposed to long wave ultraviolet light produces a blush-white fluorescence (Dutka and Marsalek, 1993).

RESULTS AND DISCUSSION

The geometric means of the observed *E. coli* densities are presented in Table 2. The corresponding probabilistic distributions of observed data were also prepared and found to follow the log-normal distributions. Such distributions were then used to estimate compliance with the Ontario recreational water quality guidelines (RWQGs), which recommend that the geometric mean of not less than ten samples, taken over a 30-day period, should be less than 100 *E. coli* units per 100 mL (MOE 1984; Health and Welfare Canada, 1992). The probabilities of *E. coli* densities being smaller than 100 EC/100 mL are presented in Table 2. In these estimates, it was assumed that the faecal coliform density distributions, presented earlier, were valid during the swimming season, taken from June 1 to August 31.

TABLE 2 Summary of Ranges of Bacteriological Data

Assessment Parameter	*E. coli* densities (EC/100 mL) Sault Ste. Marie	Sarnia	Windsor
Geometric mean			
Dry weather	4-12	17-2046	49-395
Wet weather	4-162	62-5130	392-1929
Compliance with RWQG[1]			
dry weather	95.2-99.9	2-95	1.8-69.0
wet weather (%)	42.0-99.9	0.1-65.0	0.4-1.3

The data in Table 2 indicate large differences in microbiological pollution at the three study sites. The most upstream area, the St.Marys River, is characterized by an exceptionally high microbiological water quality resulting in high compliance with the RWQGs in both wet and dry weather. Recognizing that the average number of wet days during the swimming season varies from 20 to 30 in these areas and the wet weather after-effects last less than 24 hours, the dry weather conditions represent from 1/3 to 1/2 of the swimming season.

The data from Sarnia indicate a greater microbiological pollution and much lower probabilities of compliance. As the range of values indicates, there are significant variations in the microbiological water quality in this area. The best values are found in the upstream section of the river, and that is where the recreational beaches are located (Marsalek et al. , 1994). As one proceeds in the downstream direction through the urban area, the microbiological quality becomes worse not only in wet weather, but also in dry weather. The latter case indicates that sewer outfalls (storm or CSO) must be discharging even in dry weather, thus indicating some operational problems in the sewer network.

Finally, the results from Windsor indicate the same trends as those from Sarnia, but with greater severity. This can be explained by the large size of this urban area and the high number of CSO outfalls in the city. In both Sarnia and Windsor, the observed impacts of faecal pollution on the near-shore zones of the receiving waters is rather severe, in spite of the large sizes of these rivers. This indicates that in larger urban areas with combined sewers the remediation of microbiological water quality is one of the most difficult tasks requiring reductions of bacterial levels from typical levels of 10^6-10^7 units/100 mL, at the source, in CSOs (somewhat less in stormwater) to 10^2 units/100 mL in the receiving waters. Consequently, the concerns about microbiological water quality will be driving the pollution control planning in many municipalities with excessive wet weather pollution.

The integrated impacts of urban areas on microbiological water quality were examined by comparing the data from the most downstream station to those from the most upstream station. In both Sarnia and Windsor, the indicator bacteria levels downstream from the study area exceeded those at the most upstream station by an order of magnitude, in both wet and dry weather. In all areas, the microbiological water quality first worsened along the urban waterfront, but recovered downstream from the most populated section of the city through effluent mixing and dispersion. In Sault Ste. Marie, such increases in faecal pollution along the river did not appear statistically significant and the indicator bacteria counts at the downstream end were almost the same as at the upstream end.

The impacts of wet weather were observed in all the three areas and could be characterized by bacterial count increases ranging from 1.5 times to more than 40 times, in the immediate vicinity of sewer outfalls. After cessation of rain, runoff, and flushing (advection) of pollutants from the river reaches studied, the bacteria counts should return to the dry weather levels in less than 24 hours. Extended durations of elevated bacterial levels pointed towards difficulties with sewer operation at some locations in both Sarnia and Windsor (Marsalek et al., 1992; McCorquodale et al., 1992).

REMEDIAL MEASURES

The microbiological water quality in the St. Marys River in Sault Ste. Marie was found to be very good and, apart from some minor local measures, no immediate remedial action was required. The situation was quite different in the other two areas, Sarnia and Windsor, where the microbiological pollution requires attention under the local Remedial Action Plans and is addressed in the ongoing pollution control planning for these cities. For the development of remedial options, it is advantageous to screen various options by the proposed modelling procedure, which comprises three steps - (a) developing source/loading models, (b) setting up receiving water models, and (c) modelling remedial measure effects on bacterial levels. Detailed modelling results were presented elsewhere (Tsanis et al., 1995; McCorquodale et al., 1992) and only their summary is included here.

Bacterial source/loading model. Two types of sources can be recognized - point sources (mostly discharges from WTPs) and diffuse sources (storm sewer and CSO outfalls). The former sources can be readily modelled using plant records of discharges and bacterial counts. For modelling diffuse sources, an existing flow generator (the STORM model) was used in conjunction with a water quality rating curve, expressed in the form $F = a\,Q^b$, where F is a bacterial flux, Q is the source discharge, and parameters a and b were fitted to the local observed data (Schroeter, 1991).

Using local precipitation records, bacterial loading files were produced for all the outfalls in both study areas and used to simulate bacterial loadings to the receiving waters.

Receiving Water Models. Two different models were used - the FDM in Sarnia (Tsanis et al., 1995) and the KETOX model in Windsor (McCorquodale et al., 1992). The two-dimensional depth-averaged irregular finite-difference FDM model comprised two dynamic equations, a continuity equation and a transport equation describing two distinct mechanisms - advection and turbulent diffusion. The transport equation also included bacterial decay. The KETOX model used in Windsor simulated a steady or quasi steady river system approximated by a link-node system. In each link, the hydrodynamics of two-dimensional non-recirculating flow is based on one of two options - friction and gravity forces equilibrium, or a momentum redistribution option that operates on a given upstream momentum distribution. The local eddy viscosity and lateral dispersion were approximated by the k-ε model and a mixing component was also included. The model contained options for several kinetics processes (e.g. exponential decay of bacteria) as well as interaction with suspended and bed sediments. Both models were calibrated as much as the available data allowed. For the hydrodynamic parts, the results of drogue and dye tracing studies were used (Tsanis et al., 1995; McCorquodale et al., 1992). For bacteria, limited calibration/verification was achieved using the field survey data (Marsalek et al., 1994) and some earlier measurements in the Detroit River (McCorquodale et al., 1992).

Modelling Results. In Sarnia, the main modelling results included the simulated persistence of elevated bacterial levels after the cessation of rainfall (flushing times) for various locations in the receiving waters, and the screening assessment of several remedial measures including the disconnection of outfalls, flushing of Sarnia Bay by unpolluted riverine water, and construction of a deflector barrier to prevent circulation transporting sewer discharges into the Bay. These results indicated that water pumping would be ineffective, and to achieve the RWQG value of 100 EC/100 mL, a combined remedial measure, comprising source controls and construction of a barrier, would be needed (Marsalek et al., 1994).

In Windsor, the KETOX model was used to produce time series of bacterial counts along the river section studied. During wet weather, the simulated data agreed fairly well with those observed. In dry weather, the model underestimated the observed bacterial levels, obviously because of the input from unexpected sources (i.e. malfunctioning sewer systems discharging in dry weather). To account for these sources, dry weather loadings equal to about 8% of the wet weather loadings had to be assumed. The model also indicated that polluted waters may be detained in small embayments along the shoreline and contribute to elevated bacterial counts (after-effects) in dry weather. Among the remedial options, the elimination of five major CSO outfalls was considered. If all these five sources were eliminated, the probability of compliance with the recreational water quality guidelines (100 EC/100 mL) would increase from the current 40% to about 70%.

CONCLUSIONS

Urban drainage effluents, including CSOs, stormwater and WTP effluent discharges, strongly contribute to the microbiological pollution of receiving waters and the resulting violations of recreational water quality guidelines. Among the three areas studied, the degree and extent of microbiological pollution were closely correlated with the number of sewer outfalls (both storm sewers and CSOs) and dry weather sources (malfunctioning sewer systems). Thus, an excellent water quality was found in the St. Marys River in Sault Ste. Marie (no CSOs), but poor quality was found in the St.Clair River along the relatively short Sarnia waterfront (5 CSOs) and in a long stretch of the Detroit River in Windsor (25 CSOs). The development of remedial measures needed in Sarnia and Windsor can be accomplished by the demonstrated methodology - statistical interpretation of observed microbiological data, simulation of bacterial fluxes with a loading model accounting for both wet and dry weather sources (the latter ones may have to be determined from model calibrations), and examination of bacterial transport and levels in the receiving waters. Among the remedial measures, the highest priority should be assigned to source controls, particularly in the case of dry weather sources. Local improvements in water quality can be obtained by manipulating bacteria transport in rivers -preventing influx of contaminated waters to the areas used extensively for water-based recreation.

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