Science of the Total Environment 508 (2015) 228–239

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Local environmental conditions determine the footprint of municipal effluent in coastal waters: A case study in the Strait of Georgia, British Columbia

Sophia C. Johannessen [a,*], Robie W. Macdonald [a], Brenda Burd [b], Albert van Roodselaar [c,1], Stan Bertold [c,2]

[a] Institute of Ocean Sciences, Fisheries and Oceans Canada, 9860 W. Saanich Rd., P.O. Box 6000, Sidney, BC V8L 4B2, Canada
[b] Ecostat Research Ltd., 1040 Clayton Rd., N. Saanich, BC V8L 5P6, Canada
[c] Metro Vancouver, 4330 Kingsway, Burnaby, BC V5H 4G8, Canada

HIGHLIGHTS

- Municipal wastewater fluxes are compared to regional geochemical budgets.
- Wastewater contributes <1.5% of organic C, N, and oxygen demand in the Strait.
- Wastewater contributes <10% of metals and PCBs captured in the sediment.
- Wastewater contributes about 60% of PBDEs captured in the sediment.
- Effects on benthos are limited to 1–10 km and result from organic carbon flux.

ARTICLE INFO

Article history:
Received 30 September 2014
Received in revised form 25 November 2014
Accepted 28 November 2014
Available online xxxx

Editor: D. Barcelo

Keywords:
Municipal effluent
Geochemical budgets
Organic carbon
Nitrogen
Oxygen
Contaminants

ABSTRACT

To predict the likely effects of management action on any point source discharge into the coastal ocean, it is essential to understand both the composition of the effluent and the environmental conditions in the receiving waters. We illustrate a broadly-applicable approach to evaluating the comprehensive environmental footprint of a discharge, using regional geochemical budgets and nearfield monitoring. We take as a case study municipal effluent discharged into the Strait of Georgia (west coast of Canada), where there has been public controversy over the discharge of screened or primary-treated effluent directly into the ocean. Wastewater contributes ≤1% of the nitrogen, organic carbon and oxygen demand in the Strait and is unlikely to cause eutrophication, harmful algal blooms or hypoxia in this region. Metals (Hg, Pb, Cd) are controlled by natural cycles augmented by past mining and urbanization, with 0.3–5% of the flux contributed by wastewater. Wastewater contributes ~5% of PCBs but ≤60% of PBDEs and is likely also important for pharmaceuticals and personal care products. Effects of high organic flux on benthos are measurable in the immediate receiving environment. The availability of particle-active contaminants to enter the food chain depends on how long those contaminants remain in the sediment surface mixed layer before burial. Secondary treatment, slated for completion in Vancouver in 2030, will reduce fluxes of some contaminants, but will have negligible effect on regional budgets for organic carbon, nitrogen, oxygen, metals and PCBs. Removal of PBDEs from wastewater will affect regional budgets, depending on how the sludge is sequestered.

1. Introduction

The coastal ocean links land with the open sea. Geochemical cycles driven by global-scale circulation are augmented in coastal waters by discharges from human activities on land that can have profound effects on local ecosystems. With limited resources managers have to decide how to prioritize possible actions to limit the effects of those activities.

Municipal wastewater is one highly visible discharge that carries a complex mixture of contaminants. In some parts of the world wastewater discharge has led to eutrophication, harmful algal blooms, hypoxia, extinctions of bottom fauna and fish mortality (Islam and Tanaka, 2004). However, the effects of wastewater discharge are not the same everywhere. For example, phosphates in household wastewater can have dramatic effects on lakes, causing eutrophication and harmful algal blooms, while anthropogenic phosphate has little effect on marine

* Corresponding author.
E-mail addresses: sophia.johannessen@dfo-mpo.gc.ca (S.C. Johannessen), robie.macdonald@dfo-mpo.gc.ca (R.W. Macdonald), bburd@telus.net (B. Burd), avanrood@telus.net (A. van Roodselaar), bertold@shaw.ca (S. Bertold).
[1] Present address: 2787 Cultus Crt, Coquitlam, BC V3C5A8, Canada.
[2] Present address: 903-2288 Pine Street, Vancouver, BC V6J 5G4, Canada.

http://dx.doi.org/10.1016/j.scitotenv.2014.11.096
0048-9697/

ecosystems, where productivity is more often limited by nitrate (Correll, 1998). Similarly, wastewater can affect one coastal sea differently from another, depending on processes occurring in the receiving environment. Consequently, management actions that are developed for one area, such as introducing a particular level of wastewater treatment, might not have the anticipated effect when applied to another.

The purpose of this paper is to present a blueprint for a comprehensive and specific analysis of the effects of a point-source discharge that can be applied to any coastal setting, taking into account both the potentially harmful characteristics of the effluent and the local characteristics of the receiving environment that may amplify or reduce harm. We use regional geochemical mass balance budgets, together with a local monitoring programme, to determine the total effect on the environment, or environmental footprint, of municipal wastewater in a particular coastal sea, with the ultimate aim of informing local management action. We illustrate this type of analysis, taking as a case study the discharge of municipal wastewater into the Strait of Georgia, a semi-enclosed sea on the west coast of Canada bordered by two metropolitan areas.

Metro Vancouver (population 2.3 million; 2011 census) and Victoria's Capital Regional District (population 0.36 million) together treat and discharge approximately 5×10^{11} L of municipal wastewater each year into the Strait of Georgia, through 5 treatment plant outfalls near Vancouver and 3 outfalls near Victoria (Fig. 1). Wastewater is also discharged into the Strait from the smaller cities of Nanaimo, Comox and Campbell River, as well as from the Gulf Islands. The wastewater contains nutrients (N, P), organic carbon, persistent organic pollutants, metals, pharmaceuticals and pathogens. Because the effluent at some sites is treated only to primary level (including a settling step), and at two sites is only screened (Table 1), local environmental organizations have raised concerns about the potential for municipal wastewater to pollute and cause eutrophication in the Strait of Georgia.

As a relatively deep coastal sea (max depth 420 m) with restricted circulation, the Strait of Georgia might seem particularly vulnerable to contamination and to the development of hypoxia or even anoxia in the deep basins, driven by the discharge of nutrients, organic carbon and other contaminants near the surface. However, the effects of municipal wastewater are modified by local circulation, sedimentation and biogeochemical cycles. In addition, wastewater discharge is only one of many pathways of material to the Strait of Georgia: others are rivers, atmospheric deposition, exchange with the Pacific Ocean, and other anthropogenic discharges (pulp mills, aquaculture, ocean dumping).

We use geochemical mass balance budgets for components of municipal wastewater to assess the regional contribution of the discharge, comparing components that have large, natural cycles with those that

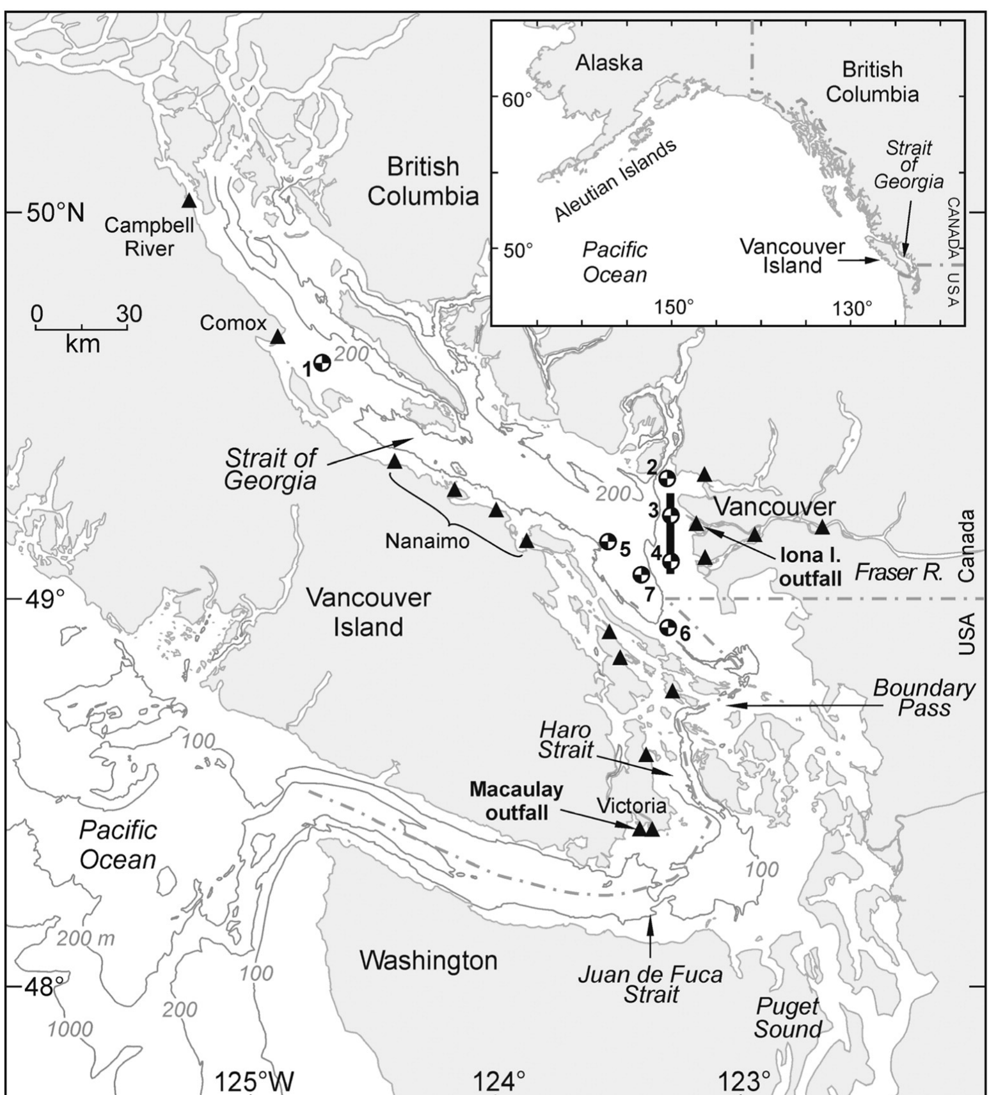

Fig. 1. Study area, showing municipal wastewater outfalls (black triangles) and sediment core locations (quartered circles numbered 1–7).