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Dispersal and dilution of wastewater from an ocean outfall at Davis Station, Antarctica, and resulting environmental contamination

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HIGHLIGHTS

- Effluent is likely to be constrained in a narrow plume very close to the coast.
- Sewage bacteria were in high concs. around the outfall and found up to 1.5 km away.
- Metals, PBDEs, hydrocarbons and faecal sterols were detected up to 2 km away.
- Dispersal and degradation were insufficient to prevent accumulation of contaminants.
- Microbial contamination poses an environmental risk to local wildlife.

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ABSTRACT

The Antarctic Treaty permits the discharge of wastewater into Antarctic marine waters providing that conditions exist for initial dilution and rapid dispersal. We investigated the dilution and dispersal of macerated wastewater around Australia's Davis Station in East Antarctica and examined sediments for evidence of contaminants. Methods used to examine hydrodynamic conditions included current meters, dye release experiments and measurement of sewage-associated microbial markers and surfactants in the water column. We measured marine sediments for metals, nutrients, PBDEs, hydrocarbons and faecal sterols. We propose that if there is adequate dilution and dispersal there would be no significant difference in contaminant concentrations in sediments around the outfall compared to distant control sites. Currents were strongly correlated with prevailing wind conditions. Modelling indicated that diffusivity of wastewater had the greatest effect on dilution factors and that neither discharge rates nor local currents had as much effect. During summer conditions of open water, wastewater is likely to be constrained in a narrow plume close to the coast. Concentrations of sewage bacteria were high around the outfall and detected up to 1.5 km away, along with dye. There were significant differences in sediment concentrations of metals, PBDEs, hydrocarbons, nutrients and faecal sterols between sites within 2 km of the outfall and control sites. We conclude that dilution and dispersal conditions at the Davis outfall are insufficient to prevent the accumulation of contaminants in local sediments and that microbial hazards posed by wastewater are an environmental risk to local wildlife.

1. Introduction

The handling, treatment and disposal of sewage and wastewater (hereafter referred to collectively as wastewater) is a challenge faced by all 31 countries (COMNAP, 2015) currently operating

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research stations in Antarctica. The majority of these stations are situated on the coast (Gröndahl et al., 2009; Tin et al., 2009) and most discharge wastewater into the sea, after treatment ranging from none to high level tertiary (Gröndahl et al., 2009). Management of sewage and wastewater in Antarctica is guided by the Protocol on Environmental Protection to the Antarctic Treaty 1991 (known as the Madrid Protocol, hereafter referred to as the Protocol), which entered into effect in 1998. The Protocol requires that sewage and domestic liquid wastes are removed from the Antarctic region to the maximum extent possible (Annex III, Article 2). Where this is not practically achievable, the Protocol allows that "*Sewage and domestic liquid wastes may be discharged directly into the sea, taking into account the assimilative capacity of the receiving marine environment and provided that (a) such discharge is located, wherever practicable, where conditions exist for initial dilution and rapid dispersal*" (Annex, III, Article 5). For stations where the summer population is 30 or more, maceration is required before discharge to the sea (Annex, III, Article 5). The Protocol does not, however, define the terms initial dilution and rapid dispersal, nor how these might be assessed, nor what is meant by the assimilative capacity of the marine environment.

No studies have attempted to assess the discharge of sewage and wastewater in Antarctica against the principles of the Protocol, in particular whether the receiving environment provides initial dilution and rapid dispersal. Research to date has focused on measuring the extent of wastewater dispersal around Antarctic Stations including McMurdo (McFeters et al., 1993; Edwards et al., 1998; Lisle et al., 2004), Dumont d'Urville (Delille and Delille, 2000), Rothera (Hughes, 2003; Hughes and Thompson, 2004), Terra Nova Bay (Bruni et al., 1997) Comandante Ferraz in Admiralty Bay (Martins et al., 2002, 2012) and Davis (Green and Nichols, 1995). A variety of methods have been used to trace wastewater (Table 1), including: indicator micro-organisms in seawater such as faecal coliform bacteria, (McFeters et al., 1993; Delille and Delille, 2000), or specific enteric bacteria such as *Clostridium perfringens* (Edwards et al., 1998; Hughes and Thompson, 2004), *Escherichia coli* (Lisle et al., 2004) and streptococci (Bruni et al., 1997); analysis of faecal sterols in marine sediments (Venkatesan and Mirsadeghi, 1992; Martins et al., 2012; Leeming et al., 2015); hydrocarbons in sediments including linear alkylbenzenes (Martins et al., 2002) found in surfactants and detergents, and aliphatic and polycyclic aromatic hydrocarbons associated with fossil fuels (Martins et al., 2004). Wastewater has been detected at distances from 50 m to 2 km (Table 1) from the point of discharge. There has been relatively little work investigating the environmental impacts of outfalls in Antarctica but several studies have detected negative impacts on marine benthic communities including at McMurdo (Conlan et al., 2004; Kim et al., 2010) and Casey (Stark et al., 2003a; Stark, 2008).

From the 1980s until 2005 wastewater at Davis Station was managed using a secondary treatment system comprising a rotary biological contactor and was discharged at a shoreline outfall adjacent to the wharf. The system was often bypassed in summer as it was unable to handle the higher summer population and it broke down permanently in 2005. Since then, maceration has been the only treatment applied to wastewater discharged to the sea at Davis.

This study was part of a scientific research program by the Australian Antarctic Division (AAD) to determine the environmental impact of wastewater discharged from Davis station into adjacent coastal waters. It was instigated to guide the AAD in the choice of the most suitable replacement wastewater treatment facility at Davis and to support decisions that would enable Australia to meet the standards set for the discharge of wastewaters in Antarctica in national legislation and international commitments. In this paper we assess the extent to which the receiving environment at Davis provides initial dilution and rapid dispersal of sewage and wastewater discharged into the sea. We determine the likely dilution of wastewater under varying conditions and assess the assimilative nature of the local marine environment by examining accumulation of wastewater associated contaminants in sediments. We propose that if the receiving marine environment meets these requirements by providing an appropriate level of initial dilution and dispersal, there would be no significant difference in the concentration of sewage biomarkers or contaminants in marine sediments around the outfall in comparison to control sites. Evidence of the accumulation of contaminants in marine sediments would thus indicate insufficient dilution and dispersal conditions around an outfall.

2. Methods

Davis Station is in the Vestfold Hills in East Antarctica at 68.5764° S, 77.9689° E (Fig. 1). The marine environment in the region of Davis station consists of shallow waters (2–40 m), and is described in O'Brien et al. (2015). Sea ice cover is variable in duration over the

Table 1
Summary of studies using tracers used to measure sewage and wastewater distribution in the marine environment around Antarctic Stations.

Location	Tracer	Matrix	Distance detected above background	Reference
McMurdo	Total coliforms	Seawater	1 km alongshore, 0.2–0.3 km seaward	Howington et al. (1992); McFeters et al. (1993)
Dumont d'Urville	Total coliforms	Seawater	2 km	Delille and Delille (2000)
McMurdo	*Clostridium perfrigens*	Sediment, invertebrates, fish	0.8 km	Edwards et al. (1998)
McMurdo	Total coliforms, faecal coliforms, *E. coli*, Enterococci, *C. perfrigens*	Seawater, sediments	0.9 km	Lisle et al. (2004)
Terra Nova Bay	Total conforms, faecal coliforms, streptococci	Seawater	0.1 km	Bruni et al. (1997)
Ferraz, Admiralty Bay	Faecal sterols, linear alkylbenzenes	Sediments	0.7 km	Martins et al. (2002); Montone et al. (2010); Martins et al. (2012)
Ferraz, Admiralty Bay	Aliphatic and polycyclic aromatic hydrocarbons	Sediment	0.05 km	Martins et al. (2004)
Rothera	*C. perfringens*, faecal sterols	Seawater, sediments	0.3 km	Hughes and Thompson (2004)
Rothera	Presumptive feacal coliforms	Seawater	0.5 km	Hughes (2003), (2004)
Davis	Faecal sterols	Sediments	1 km alongshore, 0.2 km seaward	(Green and Nichols, 1995)
Davis	Faecal sterols	Sediment	2 km	(Leeming et al., 2015)