Cold Regions Science and Technology 113 (2015) 52–62

Contents lists available at ScienceDirect

Cold Regions Science and Technology

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

Physical, chemical, biological and ecotoxicological properties of wastewater discharged from Davis Station, Antarctica

Jonathan S. Stark [a,*], James Smith [b,1], Catherine K. King [a], Margaret Lindsay [a], Scott Stark [a], Anne S. Palmer [a], Ian Snape [a], Phil Bridgen [c], Martin Riddle [a]

[a] Terrestrial and Nearshore Ecosystems Program, Australian Antarctic Division, 203 Channel Hwy, Kingston 7050, Tasmania, Australia
[b] School of Earth, Environmental Biological Sciences, Faculty of Science and Engineering, Queensland University of Technology, Brisbane, QLD, Australia
[c] AsureQuality, 1C Quadrant Drive, Waiwhetu, Lower Hutt 50106, New Zealand

ARTICLE INFO

Article history:
Received 23 January 2014
Received in revised form 4 February 2015
Accepted 5 February 2015
Available online 12 February 2015

Keywords:
PBDEs
Metals
Wastewater treatment
Sewage
Antarctic stations
Environmental risk

ABSTRACT

The properties and toxicity of untreated wastewater at Davis Station, East Antarctica, were investigated to inform decisions regarding the appropriate level of treatment for local discharge purposes and more generally, to better understand the risk associated with dispersal and impact of wastewaters in Antarctica. Suspended solids, nutrients (nitrogen, phosphorus), biological oxygen demand (BOD), metals, organic contaminants, surfactants and microbiological load were measured at various locations throughout the wastewater discharge system. Wastewater quality and properties varied greatly between buildings on station, each of which has separate holding tanks. Nutrients, BOD and settleable solid levels were higher than standard municipal wastewaters. Microbiological loads were typical of untreated wastewater. Contaminants detected in the wastewater included metals and persistent organic compounds, mainly polybrominated diphenyl ethers (PBDEs). The toxicity of wastewater was also investigated in laboratory bioassays using two local Antarctic marine invertebrates, the amphipod *Paramoera walkeri* and the microgastropod *Skenella paludionoides*. Animals were exposed to a range of wastewater concentrations from 3% to 68% (test 1) or 63% (test 2) over 21 days with survival monitored daily. Significant mortality occurred in all concentrations of wastewater after 14 to 21 days, and at higher concentrations (50–68% wastewater) mortality occurred after only one day. Results indicate that the local receiving marine environment at Davis Station is at risk from existing wastewater discharges, and that advanced treatment is required both to remove contaminants shown to cause toxicity to biota, as well as to reduce the environmental risks associated with non-native micro-organisms in wastewater.

1. Introduction

Wastewater treatment and disposal has long been recognised as a practical and human health concern for countries managing Antarctic research stations and more recently is also seen as an environmental issue (Connor, 2008; Gröndahl et al., 2009). Currently 30 countries operate a combined total of 82 research stations which includes both permanently occupied stations and summer only stations, which are occupied for up to 6 months over the spring/summer period (COMNAP, 2013). All stations discharge some products of wastewater treatment into the environment. The quantity, quality and environmental risks associated with these discharges depend on the characteristics of the station population, the treatment methods and the location. Treatment varies between maceration (effectively no treatment) to advanced treatment (to drinking water quality). The majority of stations are located in coastal areas and release treated and untreated wastewater into the marine environment (Hughes, 2004). Those without direct access to open sea can use deep ice pits or subsurface ice-wells.

Of the 44 permanently manned stations, 37% lack any kind of wastewater treatment (Gröndahl et al., 2009; Hughes, 2004). Of those stations that do treat wastewater, many of the treatment systems suffer from operational problems or inefficiencies during periods of peak station occupancy (Bruni et al., 1997; Gröndahl et al., 2009). Effective treatment of wastewater in Antarctica requires an understanding of the properties of the wastewater, local conditions and the receiving environment, and of the constraints imposed by Antarctic environmental conditions on the efficacy of treatment technologies. Various mechanisms and pathways through which wastewater discharges may cause detrimental environmental impacts in Antarctica have recently been identified (Conlan et al., 2010; Hughes and Thompson, 2004; Smith and Riddle, 2009) and attention has turned to the development of new approaches

* Corresponding author. Tel.: +61 3 6232 3589.
E-mail addresses: jonny.stark@aad.gov.au (J.S. Stark), smithjj16@tpg.com.au (J. Smith), cath.king@aad.gov.au (C.K. King), margaretcmlindsay@gmail.com (M. Lindsay), scott.stark@aad.gov.au (S. Stark), anne.palmer@aad.gov.au (A.S. Palmer), ian.snape@aad.gov.au (I. Snape), Phil.Bridgen@asurequality.com (P. Bridgen), martin.riddle@aad.gov.au (M. Riddle).
[1] Present address: JJSC 84 E. Fieldview Circle, Bozeman, MT 59715, USA.

http://dx.doi.org/10.1016/j.coldregions.2015.02.006
0165-232X/

to wastewater treatment specifically designed to prevent or mitigate these impacts (Barker et al., 2013; Connor, 2008; Gröndahl et al., 2009; Hughes, 2004).

The principal guideline for waste management in Antarctica is the Protocol on Environmental Protection to the Antarctic Treaty (the Protocol), primarily Annex III, Waste Disposal and Waste Management. The Annex creates a general obligation that all wastes produced or disposed of in the Antarctic Treaty area shall be reduced as far as practicable so as to minimise impacts on the environment. The Protocol further requires that all liquid wastes, including sewage and domestic liquid wastes, shall, to the maximum extent practicable, be removed from the Antarctic Treaty area (Annex III, Article 2). Liquid wastes not removed must not be disposed of onto ice-free land or into freshwater systems and as far as is practicable should not be disposed of onto sea ice, ice shelves or grounded ice sheet (Annex III, Article 4). The Protocol does allow sewage and domestic liquid wastes to be discharged directly into the sea (Annex III, Article 5), provided that where practicable, conditions in the receiving environment will lead to initial dilution and rapid dispersion. For stations where the summer population is 30 or more, sewage must be treated at least by maceration before discharge to the sea.

The Protocol does not explicitly mention the risk of introducing non-native micro-organisms to Antarctica through the practice of discharging sewage wastewater to the environment. However, the risk posed by introduced micro-organisms from other sources is clearly recognised. Biological wastes including carcasses of imported animals, laboratory cultures of micro-organisms and plant pathogens and introduced avian products must all be removed from the Treaty area unless they have been made sterile (Annex III, Article 2). In addition, Annex II (Conservation of Antarctic Fauna and Flora) clearly recognises the threat of non-native microorganisms to native Antarctic biodiversity and requires that precautions should be taken to prevent the introduction of micro-organisms not naturally present in the native fauna and flora. These precautions are required without the need to demonstrate that they are pathogenic or likely to cause further detrimental impacts to the ecosystem beyond their presence.

All Antarctic Treaty Parties are required to ensure compliance within their jurisdiction to the Protocol, typically by establishing domestic legislation which reflects the obligations of the Protocol. In Australia, Annex III of the Protocol is implemented by the Antarctic Treaty (Environment Protection) (Waste Management) Regulations 1994. Although the actions of all Parties are guided by the Protocol, the actual management of wastewater by the many countries operating in Antarctica varies considerably, from no treatment to advanced treatment methods. The domestic standards of many countries require higher levels of wastewater treatment than their Antarctic research stations. There is a growing movement, however, towards regarding the obligations under the Protocol as the minimum, with several nations applying the same requirements as they would to equivalent communities within their respective countries. For example, a replacement wastewater treatment plant installed at New Zealand's Scott Base in 2001/02 was designed to meet domestic standards then in place in New Zealand (Connor, 2008).

Antarctica poses a number of challenges to the practicalities of wastewater treatment (Smith and Riddle, 2009). It is remote, very cold and very dry and wastewater treatment infrastructure has to be designed to operate under these conditions. In addition, the energy required to operate treatment facilities including heating, pumps and motors, is much more expensive than in temperate regions and is usually provided by burning fossil fuel to drive electrical power generators. Wastewater systems must also be capable of coping with high diurnal load fluctuations and marked seasonal variation in the volume of wastewater (Connor, 2008) generated by transient Antarctic station populations that range from 10 to 20 in winter to 50 to 100 over summer. The largest station, McMurdo, supports a population of 200 in winter rising to 1200 in summer. The input also differs from standard municipal wastewaters. Faecal material may represent a larger proportion of the total because there is very little possibility for stormwater runoff to get in to the system and, at times, restrictions on water use limit the amount of greywater in the wastewater stream. Site-specific system characteristics may also be determined by the layout of the station, such as distributed wastewater storage tanks where stations consist of several disconnected buildings. Contemporary wastewater treatment in Antarctica must address all these issues; it must deal effectively with the highly variable nature and volume of the wastewater stream, and should aim to protect the local environment. As a minimum, it should meet the *intention* of the Madrid Protocol — to prevent contamination and the introduction of the non-native species.

In this paper we provide a comprehensive evaluation of the physical, chemical, biological and ecotoxicological properties of wastewater in Antarctica, using Davis Station as an example. This information is critical for the design of a treatment system that meets the environmental imperatives and balances the need for energy efficiency and reliability. Davis is representative of the majority of coastal research stations in station population and the types of wastewater inputs. The practical problem at Davis Station is similar to that faced by many other research stations. There is an aging infrastructure and a legacy of environmental practices that were widely accepted in the 1980s, but are well below the world's best practice today. Davis operated a rotary biological contactor from the 1980s until 2005 when it was removed. That system was often on bypass in summer because it could not cope with the higher summer population and it finally broke down permanently, forcing a full time switch to by-pass and maceration. In 2009 an environmental impact assessment was conducted by the Australian Antarctic Division (AAD) to guide the choice of the most suitable replacement treatment facility, taking into account the nature of the wastewater stream, the dispersing characteristics of the receiving environment, and the potential for environmental impacts. The first stage of this assessment was to determine the characteristics of the wastewater generated at Davis Station, including the physical and chemical properties, contaminant levels, microbiological hazards and toxicity to Antarctic biota. This forms baseline data on the quality of discharged wastewater against which future improvements to wastewater quality can be evaluated and is essential for designing an appropriate treatment technology for the future.

2. Methods

2.1. Davis Station wastewater system

Davis Station consists of a number of separate buildings connected to services (electricity, water and wastewater) by heated conduits. Eight of the main buildings contain wastewater holding tanks of various sizes (Table 1) which are connected to the main wastewater line. Once each tank reaches a set volume it is pumped into this wastewater line. Due to the small volumes generated in some buildings, wastewater may reside in holding tanks or in the wastewater line for some time before moving through a maceration pump and discharging at the outfall. The wastewater outfall is located on the southern side of the Davis

Table 1
Volume of separate holding tanks in each building, with main wastewater sources listed.

Building	Volume of holding tank (L)
Summer Accommodation Module (SAM): Toilets, showers.	1000
Temporary Accommodation Dormitory (TAD): Toilets, showers.	400
Operations (OPS): Offices, toilets.	400
Sleeping/Medical Quarters (SMQ): Accommodation, toilets, showers.	2000
Living Quarters (LQ): Kitchen, toilets.	1000
Science (SCI): Offices, toilets, laboratories.	450
Workshop (WKSHP): Toilets, workshop sinks and water/oil separators.	250
Atmospheric and Space Physics (ASP): Offices, toilets.	450