Marine Pollution Bulletin 60 (2010) 1993–2006

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

Environmental contamination associated with a marine landfill ('seafill') beside a coral reef

Ross Jones *

Australian Institute of Marine Science, The UWA Oceans Institute (M096), 35 Stirling Highway, Crawley, WA 6009, Australia
Bermuda Institute of Ocean Sciences (BIOS), 17 Biological Lane, St. George's, Bermuda

ARTICLE INFO

Keywords:
Coral
Reef
POPs
Metals
Pollution
Sediment quality guidelines

ABSTRACT

In Bermuda, bulk waste such as scrap metal, cars, etc., and blocks of cement-stabilized incinerator ash (produced from burning garbage) are disposed of in a foreshore reclamation site, i.e., a seafill. Chemical analyses show that seawater leaching out of the dump regularly exceeds water quality guidelines for Zn and Cu, and that the surrounding sediments are enriched in multiple contaminant classes (metals, polycyclic aromatic hydrocarbons, petroleum hydrocarbons, dioxins and furans, polychlorinated biphenyls and an organochlorine pesticide), i.e., there is a halo of contamination. When compared against biological effects-based sediment quality guidelines (SQGs), numerous sediment samples exceeded the low-range values (where biological effects become possible), and for Hg and Zn exceeded the mid-range value (where they become probable). A few metres away from the edge of the 25 acre dump lies a small coral patch reef, proposed here as most contaminated coral reef in the world.

1. Introduction

In Bermuda, as with many other densely populated small island nations, waste disposal is a major problem. In the absence of suitable landfill space, bulk waste (metallic and building waste such as cars and fridges) and municipal solid waste incinerator ash has been dumped in the sea in a 'foreshore reclamation site' – effectively a marine landfill or 'seafill'. No attempt is made to control the leaching of xenobiotics to the surrounding seawater, for example by a retaining wall lined with clay or by impermeable membranes. Aerial images show the seafill has grown to encompass an area of 25 acres over the last 35 years (Fig. 1). The extent of the environmental contamination associated with this disposal option has never been fully evaluated.

The ecology of the harbour that contains the landfill (Castle Harbour) and the history of past anthropogenic disturbances have been described in detail by Flood et al. (2005). Briefly, the most significant biological features are mangroves, seagrasses, patch and fringing coral reefs, some of which are in very close proximity (i.e., metres) to the dump. The reefs in Castle Harbour are degraded, having been damaged from dredging and land reclamation operations in the 1940s (Dodge and Vaisnys, 1977; Flood et al., 2005). The dump is located in the north west quadrant of the basin (Fig. 1), in an area of restricted water flow close to comparatively deep (10–15 m) dredged areas. The nearest reef is only a few metres away from the current edge of the landfill (Fig. 1) but will almost certainly be buried in the near future.

The marine landfill started operation sometime in the early 1970s, although exact dates are uncertain. Bulk waste, such as scrap metal, cars, buses, mopeds, domestic appliances, construction waste (soils, rubble, and plasterboard), electrical goods, PVC plastics, and used tyres, is bull dozed into the sea at the site. The co-disposal of municipal solid waste incinerator ash, generated from combustion of household garbage, started at the same area since the mid-1990s. The ash is composed of bottom ash (consisting of primarily coarse, non-combustible materials collected at the outlet of the combustion chamber) and fly ash (consisting of fine particulate matter collected by the electrostatic precipitators in the flue gases, Sabbas et al., 2003). The two ash types are combined and mixed with cement, and then poured into moulds, producing approximately $30 \times 1\ m^3$ cubed blocks (each weighing 2 tonnes) each day. After curing, the blocks are dumped into the sea and used to construct containment walls or 'cells'. The cells form the outer walls of the dump and are in-filled with bulk waste. In 2002, some 60–70,000 tonnes of garbage was processed by incineration and 12,180 tonnes of ash was produced. The purpose of the solidification/cement-stabilization is to reduce the leachability of contaminants out of the waste mix (Knap et al., 1991a,b; Hjelmar, 1996; Sabbas et al., 2003). Further information on waste management is available in the Bermuda 2005 State of the Environment report (Anon, 2005).

There have been a few published and unpublished reports of environmental contamination caused by the dump, see for example Jickells and Knap (1984), Burns et al. (1990), Knap et al.

* Tel.: +61 8 6369 4015; fax: +61 8 6488 4585.
E-mail address: r.jones@aims.gov.au

0025-326X/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.marpolbul.2010.07.028

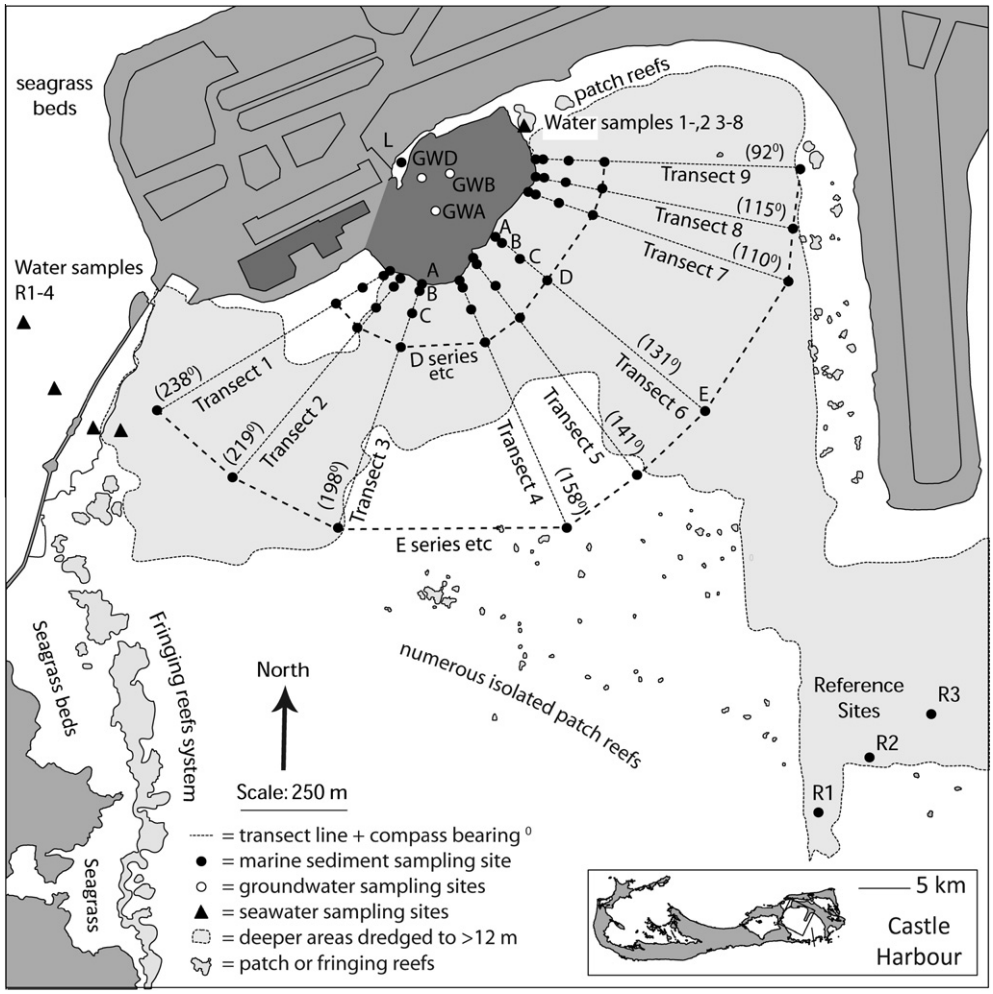

Fig. 1. Location map showing the marine landfill (dump) in Castle Harbour, a semi-enclosed basin on the eastern portion of Bermuda (see inset map). Sediments samples were collected 2 m, 20 m, 80 m, 160 m and 680 m from the edge of the dump (encompassing areas of 5398 m^2, 15,570 m^2, 55,007 m^2, 129,298 m^2, and 913,250 m^2, respectively) on nine transect lines (T1–T9), and at three 'reference' sites (R1–R3) 1.6 km from the dump and in the lagoon (L) behind the dump. The dashed lines represent the 'D' series and 'E' series of samples. Water samples were collected on the NE side of the dump beside a small patch reef and either side of a road-bridge (Causeway) separating Castle Harbour from Grotto Bay. GWA, GWB, GWD represent groundwater sampling sites in the study of Chapman (2008).

(1991a,b), Smith and Hellin (1998). These studies describe trace metal, polychlorinated biphenyl (PCB), and polycyclic aromatic hydrocarbon (PAH) enrichment in water and in sediments adjacent to the dump; however, the studies were limited in spatial extent (i.e., generally one or at most a few samples collected immediately beside the dump), and although the studies have shown contamination (i.e., concentrations above natural background levels), they have not provided any information on pollution (i.e., contamination that causes adverse biological effects in the natural environment, Chapman, 2007).

Sediment quality guidelines (SQGs) have been developed and introduced around the world in regulatory and non-regulatory contexts to aid in the interpretation of the relationships between chemical contamination and measures of adverse biological effects (see for example Burton, 2002; Long et al., 2006). Two commonly used sets of numerical sediment quality guidelines (SQGs) are the National Oceanic and Atmospheric Administration (NOAA) guidelines (i.e., effects range low [ERL] and effects range median [ERM] – Long et al., 1995) and the similarly derived Florida Department of Environmental Protection (FDEP) guidelines (threshold effects level [TEL] and probable effects level [PEL] – MacDonald et al., 1996). These SQGs are based upon statistical analysis of large databases of synoptic toxicity data and sediment chemistry that identify chemical concentrations that are likely to be associated with biological effects. Both techniques derive three ranges of chemical concentrations, including a low range within which adverse biological effects are unlikely to occur (i.e., <TEL or <ERL), a middle range in which biological effects are possible (i.e., ⩽ERL and >ERM or ⩽TEL and >PEL), and a high range within which biological effects are likely to occur (i.e., >ERM or >PEL). SQGs have been used to rank and/or prioritize contaminated areas or chemicals of concern for further investigation (Long et al., 1998), or to evaluate spatial patterns of sediment contamination (Crane and MacDonald, 2003). Their use in recent years has been encouraged by research showing reasonable predictive abilities (Long et al., 1998), but their use also reflects a practical need for protective management tool where anthropogenic chemicals present a risk to benthic biota (Fairey et al., 2001).

For marine and freshwaters a number of guidelines are available, but the Florida (US) standards for class 3 waters (i.e., water designated for recreation, propagation and maintenance of a healthy, well-balanced population of fish and wildlife) and Australian guidelines (ANZECC/ARMCANZ, 2000) are most applicable for Bermuda. Both Florida and Australia have extensive coral reef systems, and their use in the context of this investigation seems applicable. The ANZECC/ARMCANZ guidelines are mostly derived from single-species toxicity tests on a range of test species. A statistical distribution approach is used to protect a pre-determined percentage of