MOBILIZATION OF AQUEOUS CONTAMINANTS LEACHED FROM ORDOT LANDFILL IN SURFACE AND SUBSURFACE FLOWS

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OF THE WESTERN PACIFIC
UNIVERSITY OF GUAM

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Ordot Landfill looms over the Lonfit River valley where it occupies ~60 acres of land space and towers upwards to a height in excess of 90m at its mid-point (2003 photo: courtesy Leroy Heitz, WERI)

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ABSTRACT

In 2001, two single leachate samples taken from the perimeter of Ordot Landfill, in central Guam, were screened for fecal indicator bacteria and 175 chemical contaminants including most of those listed as priority pollutants under Section 307(a) of the Clean Water Act. Identified contaminants of concern included the fecal indicator bacteria, *Enterococci* and *E. coli,* inorganic N and P, and several heavy metals. Al, Bo and Fe were the most abundant elements identified, while Cd, Hg and Ag (high concentrations previously reported by other investigators) were undetected. Al was almost exclusively present in the particulate form. Low concentrations of eight common industrial solvents were identified including tetrahydrofuran, a highly polar ether used in paints, building materials and furnishings, and 1,2-dichlorethane, used extensively in the manufacture of PVC. Both of these compounds are not readily degradable in the environment. No PCBs or PAHs were detected and the only pesticide identified out of 20 tested for, was p-dichlorobenzene, a moderately degradable compound used extensively in home and industry to control moths, mould and mildew. Despite the presence of several dioxins and furans in one of the leachate samples, the highly toxic members of both classes of contaminants were not detected.

Surface and subsurface waters downgradient of the landfill were monitored periodically over one year (Oct '02-'03) for total coliforms, *Enterococci* and *E. coli*, inorganic N and P, and heavy metals. Fecal indicator bacteria MPN counts in receiving surface waters dropped sharply within a few hundred meters downstream of the leachate stream impaction point. However, values often exceeded the US EPA recreational water quality standards all the way to the coast. *Enterococci* and *E coli* were significantly correlated with one another only at counts of ~200 or more. Inorganic N was dominated by NH_3-N in the leachate stream and NOx-N in the river. Occasional exceedences of the US EPA surface water quality standard for nitrate (as NOx) were observed at all downstream sites. Inorganic P was mostly undetectable in all receiving surface waters despite relatively high levels in the leachate stream. Likewise, the majority of heavy metal contaminants that were enriched in the leachate stream were close to or below the limits of analytical detection in the river. The formation of Fe and Mn oxyhydroxides at redox boundaries within the leachate stream were suspected of scavenging inorganic P and heavy metals from the water column and dumping them in bed sediments. Soil pore waters collected at various depths (0.61-1.83 m) ~100-250 m downgradient of the landfill were comparatively free of fecal indicator bacteria. Inorganic N levels, though enriched, were appreciably lower than those in the leachate stream. Net losses were thought to reflect microbial assimilation, denitrification, and sorption onto positively charged clay particles. Average P levels were also low suggesting removal by oxidic iron in surface layers coupled with soil sorption processes. Neither inorganic N nor P concentrations varied significantly with depth. In contrast, mean pore water concentrations of Al, Cd, Fe and Zn were generally more concentrated at the shallowest level.

Inorganic N enrichment, and its effect on plant and algae growth in the lower reaches of the Lonfit River, was considered to be the most significant ecological impact of the landfill on the watershed. The transmission of human pathogens from the landfill into the river, in leachate streams and surface runoff, and the incorporation of potentially toxic metals into food chains ultimately leading to man, are likely the most important issues from a human health perspective.

INTRODUCTION

Landfills are a major source of surface and groundwater contamination worldwide (Epstein *et al.* 1982). In Guam, all civilian solid waste is disposed of at a single landfill located in the center of the island just outside the village of Ordot. This particular landfill has been in continuous use for over 50 years and receives about 2,500 cubic feet of solid waste per day (GEPA 1995). Until quite recently it was used as an open dump with little control over what was put in it. Vermin, flies, periodic fires and the stench or rotting garbage have plagued the site and tormented nearby residents for decades. The landfill was slated for closure almost 30 years ago and has been operating at over capacity for at least ten years (Mendoza 1997). Today it occupies a staggering area of almost 60 acres and towers to ~90m at its mid-point (Smit 2001). The western border of the landfill encroaches onto wetlands that drain into the Lonfit River. This rather picturesque stream converges with the Sigua River further down current to form the Pago River. Local residents fish all three rivers for food and the adjacent lands support a variety of agricultural activities including subsistence farming.

Ordot Landfill is thought to have started out as a dumping ground for the Japanese and US Naval military forces in the 1940s. It was transferred from the US Navy to the Government of Guam in the 1950's and has served as the island's only municipal waste disposal site ever since. There are no records to indicate what types of materials were disposed of at the dump during those early pre- and post-war years although military hardware, munitions, organic solvents, waste oil, PCBs and pesticides seem likely contenders (Wood 1989). Thus, Ordot Dump (as it is locally known) probably contains the same array of inorganic and organic chemicals as discovered at other military installations and dumpsites around the island. Superimposed upon this are various hazardous wastes derived from residential and commercial sections of the civilian community over the years. Contributions from these sources would have continued unabated until control measures were introduced in 1981 (Wood 1989).

Unlike modern sanitary landfills, the Ordot Landfill is not lined with an impervious material and does not have a leachate retention system in place. As a consequence, seasonally dependent streams of brown, foul smelling liquid emerge at a number of points along the western edge and southern toe of the dump. These flow downgradient into the Lonfit River permeating into the surrounding soil *en route*. In 1990, US EPA Region 9 issued an Administrative Order (AO), which found Guam Department of Public Works (DPW) in violation of the Clean Water Act for discharging pollutants (untreated leachate) into the Lonfit River. The AO ordered Guam DPW to carry out specific actions to eliminate the discharge of untreated leachate to the Lonfit River. DPW has taken no substantive actions to comply with the AO and discharge of untreated leachate to the Lonfit River continues to this day (Bettencourt 1998).

The first chemical analyses of leachate emanating from the landfill were undertaken in the early 1980s (Black and Veitch 1983, Camp Dresser and McKee 1987). Further work continued on a piecemeal basis over the next few years and by 1998 leachate samples from around the landfill had been screened for 53 priority pollutants and 26 non-priority pollutants (US EPA 2002). These included 21 trace elements, 21 pesticides, 15 organic solvents, 7 commercial PCB mixtures, 2 phthalate esters, cyanide, total petroleum hydrocarbons, N and P (Table 1). Nutrients and heavy metals were among most frequently encountered contaminants and were often found at levels that exceeded the US EPA surface water quality standards. Of the 46 organic compounds tested for, only the non-priority pollutant 2-butanone was ever detected.

Contaminant data collected from the Lonfit River from sites upstream and downstream of the leachate streams, over the same time frame (US EPA 2002), are summarized in Tables 2 and 3 respectively. Once again, nutrients and heavy metals were the dominant contaminants present although reported concentrations were typically an order of magnitude or more below those found in leachate samples. While inorganic N levels generally seem to be more concentrated downstream of the dump, there is no compelling evidence to suggest the same is true for heavy metals. Nevertheless, given the dump's close proximity to surface water resources and arable lands, and the paucity of data thus far collected, there is understandable concern among local residents over the environmental and human health effects of sustained and uncontrolled leachate discharges into the area.

Clearly, we know comparatively little about the chemical and biological composition of leachate discharged from Ordot Landfill and even less about its long-term impact on the resident flora and fauna of the Lonfit River and Pago River systems. While nutrients and various heavy metals undoubtedly qualify as contaminants of primary concern, there may be others in the mix that have eluded detection over the years because of inadequate analytical capabilities, or because they simply weren't looked for. Certainly, the surface water priority pollutant list is considerably longer today than it was 20 years ago. We have also seen a tremendous improvement in the sophistication and sensitivity of analytical instrumentation over the same time frame. These two facts alone provide strong incentives to revisit the Ordot Landfill and update the contaminant database for the aqueous waste streams discharged into the Lonfit River valley.

In the study described herein, leachate samples from two sites along the western and southern edge of the landfill were screened for a range of biological and chemical contaminants, including the 126 priority toxic pollutants listed under Section 307(a) of the Clean Water Act. Surface waters and soil pore waters downgradient of the landfill were subsequently monitored for all primary contaminants (fecal indicator bacteria, nutrients and heavy metals) over one year to gain insight into their mobilization rates and distribution pathways into the watershed. The study was part of a larger program to determine the potential impact of the leachate on water quality of the Lonfit-Pago River system and the biological resources of Pago Bay.

Table 1
Summary of Historical Water Quality Data for Ordot Landfill Leachate Streams (1980-1998)[a]

ANALYTE

INORGANICS		Units	Range
Metals			
Aluminum	✓	µg/l	<100 - 4580
Antimony		µg/l	<20.2
Arsenic	✓	µg/l	0.154 - 9.1
Barium	✓	µg/l	0.063 - 307
Beryllium		µg/l	<0.2
Boron	✓	µg/l	458 - 4,980
Cadmium	✓	µg/l	<0.2 - 4.76
Calcium	✓	mg/l	7.1 - 120
Chromium	✓	µg/l	0.09 - 27.8
Cobalt	✓	µg/l	<2.1 -13
Copper	✓	µg/l	2.5 - 101
Iron	✓	µg/l	149 - 14,000
Lead	✓	µg/l	0.029 - 66.7
Magnesium	✓	mg/l	19 - 64
Manganese	✓	µg/l	48 - 1,280
Mercury	✓	µg/l	<0.2 - 32.8
Nickel	✓	µg/l	3 - 30
Potassium	✓	mg/l	14.7 - 92
Selenium	✓	µg/l	0.022 - 6.06
Silver	✓	µg/l	0.004 - 9.52
Sodium	✓	mg/l	92.9 - 340
Thallium		µg/l	<10
Tin		µg/l	<17
Vanadium	✓	µg/l	nd - 9
Zinc	✓	µg/l	2.3 - 140
Nutrients			
Total N	✓	mg/l	3 - 83
TON	✓	mg/l	1.7 - 9.3
Nitrate-N	✓	mg/l	0.5 - 36
Nitrite-N	✓	mg/l	0.343
NOx-N	✓	mg/l	0.65 - 36
Ammonia-N	✓	mg/l	27.1 - 42.5
Total P	✓	mg/l	0.09 - 0.21
Others			
Cyanide	✓	µg/l	<10 - 19

ORGANICS	Units	Range
Pesticides		
Aldrin	µg/l	<0.2
BHC-alpha	µg/l	<0.16
BHC-beta	µg/l	<0.4
BHC-delta	µg/l	<0.2
BHC-gamma	µg/l	<0.2
Chlordane-alpha	µg/l	<0.1
Chlordane-gamma	µg/l	<0.1
4,4'-DDD	µg/l	<0.4
4,4'-DDE	µg/l	<0.2
4,4'-DDT	µg/l	<0.4
Diazinon	µg/l	<0.4
Dieldrin	µg/l	<0.1
Endosulfan sulfate	µg/l	<0.1
Endrin	µg/l	<0.2
Enthion	µg/l	<0.4
Heptachlor	µg/l	<0.24
Malathion	µg/l	<0.4
Methoxychlor	µg/l	<0.2
Naled	µg/l	<2
Parathion, ethyl	µg/l	<2
Parathion, methyl	µg/l	<2
Petroleum Hydrocarbons		
TRPH	mg/l	<1
Phthalate Esters:		
Diethyl phthalate	µg/l	<20
Di(2-ethylhexyl) phthalate	µg/l	<10
Polychlorinated Biphenyls (PCBs):		
PCB 1016 Aroclor	µg/l	<1
PCB 1221 Aroclor	µg/l	<2
PCB 1232 Aroclor	µg/l	<1
PCB 1242 Aroclor	µg/l	<0.1 - <1
PCB 1248 Aroclor	µg/l	<1
PCB 1254 Aroclor	µg/l	<1
PCB 1260 Aroclor	µg/l	<1

ORGANICS		Units	Range
Solvents:			
Acetone		µg/l	<5 - <10
2-butanone	✓	µg/l	<5 - 12
Carbon disulfide		µg/l	<5
Chlorobenzene		µg/l	<5
Chloroethane		µg/l	<5
1,1-dichloroethane		µg/l	<5
Ethyl benzene		µg/l	<5
2-hexanone		µg/l	<5
4-methyl-2-pentanone		µg/l	<5
Methylene chloride		µg/l	<5
Phenol		µg/l	<10
Styrene		µg/l	<5
Toluene		µg/l	<5
Vinyl acetate		µg/l	<5
Xylenes		µg/l	<5

a = USEPA 2002; priority toxic pollutants listed in Guam Water Quality Standards (GEPA 2001) in bold type; ✓ = analyte detected in one or more leachate samples; nd = not detected

Table 2
Summary of Historical Lonfit River Water Quality Data Upstream of Ordot Landfill (1980-1998)[a]

ANALYTE

INORGANICS		**Units**	**Range**	**ORGANICS**	**Units**	**Range**	**ORGANICS**	**Units**	**Range**
Metals				***Pesticides***			***Solvents:***		
Aluminum	✓	µg/l	<100 - 591	**Aldrin**	µg/l	-	Acetone	µg/l	<5
Antimony		µg/l	<20.2	**BHC-alpha**	µg/l	-	2-butanone	µg/l	<5
Arsenic	✓	µg/l	0.106-13.7	**BHC-beta**	µg/l	-	Carbon disulfide	µg/l	<5
Barium	✓	µg/l	0.625 - 207	**BHC-delta**	µg/l	-	**Chlorobenzene**	µg/l	<5
Beryllium		µg/l	<0.2 - <5	**BHC-gamma**	µg/l	-	**Chloroethane**	µg/l	<5
Boron		µg/l	<100	**Chlordane-alpha**	µg/l	-	**1,1-dichloroethane**	µg/l	<5
Cadmium	✓	µg/l	<0.1 - 8.89	**Chlordane-gamma**	µg/l	-	**Ethyl benzene**	µg/l	<5
Calcium	✓	mg/l	78.8 - 120	**4,4'-DDD**	µg/l	-	2-hexanone	µg/l	<5
Chromium	✓	µg/l	0.06 - 9.52	**4,4'-DDE**	µg/l	-	4-methyl-2-pentanone	µg/l	<5
Cobalt		µg/l	<2.1 - <6.8	**4,4'-DDT**	µg/l	<0.1	**Methylene chloride**	µg/l	<5
Copper	✓	µg/l	<0.3 - 84	Diazinon	µg/l	-	**Phenol**	µg/l	<10
Iron	✓	µg/l	11.3 - 1,858	**Dieldrin**	µg/l	<0.1	Styrene	µg/l	<5
Lead	✓	µg/l	0.033 - 83.3	**Endosulfan sulfate**	µg/l	<0.1	**Toluene**	µg/l	<5
Magnesium	✓	mg/l	7.00 - 9.30	**Endrin**	µg/l	-	Vinyl acetate	µg/l	<5
Manganese	✓	µg/l	9 - 44.2	Enthion	µg/l	-	**Xylenes**	µg/l	<5
Mercury	✓	µg/l	<0.2 - 1.107	**Heptachlor**	µg/l	-			
Nickel		µg/l	<0.6 - <4	Malathion	µg/l	-			
Potassium	✓	mg/l	0.95 - 1.70	Methoxychlor	µg/l	-			
Selenium	✓	µg/l	0.02 - 6.77	Naled	µg/l	-			
Silver	✓	µg/l	0.01 - 9.52	Parathion, ethyl	µg/l	-			
Sodium	✓	mg/l	14.2 - 22.0	Parathion, methyl	µg/l	-			
Thallium		µg/l	<10 - <160						
Tin		µg/l	nd - <17	***Petroleum Hydrocarbons***					
Vanadium	✓	µg/l	nd - 6.5	TRPH	mg/l	<1			
Zinc	✓	µg/l	<0.1 - 22						
				Phthalate Esters:					
Nutrients				**Diethyl phthalate**	µg/l	<20			
Total N		mg/l	<0.15 - <0.75	**Di(2-ethylhexyl) phthalate**	µg/l	<10			
TON		mg/l	<0.15						
Nitrate-N	✓	mg/l	<0.05 - 0.32	***Polychlorinated Biphenyls (PCBs):***					
Nitrite-N		mg/l	-	**PCB 1016 Aroclor**	µg/l	<1			
NOx-N		mg/l	<0.03 - <0.05	**PCB 1221 Aroclor**	µg/l	<2			
Ammonia-N		mg/l	<0.06	**PCB 1232 Aroclor**	µg/l	<1			
Total P	✓	mg/l	<0.1 - 0.54	**PCB 1242 Aroclor**	µg/l	<0.1 - <1			
				PCB 1248 Aroclor	µg/l	<1			
Others				**PCB 1254 Aroclor**	µg/l	<1			
Cyanide	✓	µg/l	<10	**PCB 1260 Aroclor**	µg/l	<1			

a = USEPA 2002; priority toxic pollutants listed in Guam Water Quality Standards (GEPA 2001) in bold type; ✓ = analyte detected in one or more leachate samples; nd = not detected; dashes = no data

Table 3
Summary of Historical Lonfit River Water Quality Downstream of Ordot Landfill (1980-1998)[a]

ANALYTE

INORGANICS		Units	Range	ORGANICS	Units	Range	ORGANICS	Units	Range
Metals				***Pesticides***			***Solvents:***		
Aluminum	✓	µg/l	<100 - 530	**Aldrin**	µg/l	-	Acetone	µg/l	<5
Antimony		µg/l	<20.2	**BHC-alpha**	µg/l	-	2-butanone	µg/l	<5
Arsenic	✓	µg/l	0.009 - <10	**BHC-beta**	µg/l	-	Carbon disulfide	µg/l	<5
Barium	✓	µg/l	0.063 - 25	**BHC-delta**	µg/l	-	**Chlorobenzene**	µg/l	<5
Beryllium		µg/l	<0.2 - <5	**BHC-gamma**	µg/l	-	**Chloroethane**	µg/l	<5
Boron		µg/l	<100	**Chlordane-alpha**	µg/l	-	**1,1-dichloroethane**	µg/l	<5
Cadmium	✓	µg/l	0.01 - <4.3	**Chlordane-gamma**	µg/l	-	**Ethyl benzene**	µg/l	<5
Calcium	✓	mg/l	38.0 - 55.0	**4,4'-DDD**	µg/l	-	2-hexanone	µg/l	<5
Chromium	✓	µg/l	0.008 - 0.9	**4,4'-DDE**	µg/l	-	4-methyl-2-pentanone	µg/l	<5
Cobalt		µg/l	<6.8	**4,4'-DDT**	µg/l	<0.1	**Methylene chloride**	µg/l	<5
Copper	✓	µg/l	<0.3 - 1.5	Diazinon	µg/l	-	**Phenol**	µg/l	<10
Iron	✓	µg/l	21.3 - 1,100	**Dieldrin**	µg/l	<0.1	Styrene	µg/l	<5
Lead	✓	µg/l	0.08 - 0.3	**Endosulfan sulfate**	µg/l	<0.1	**Toluene**	µg/l	<5
Magnesium	✓	mg/l	8.20 - 11.0	**Endrin**	µg/l	-	Vinyl acetate	µg/l	<5
Manganese	✓	µg/l	23 - 880	Enthion	µg/l	-	**Xylenes**	µg/l	<5
Mercury	✓	µg/l	0.002 - 6.2	**Heptachlor**	µg/l	-			
Nickel		µg/l	<0.6 - 51	Malathion	µg/l	-			
Potassium	✓	mg/l	0.95 - 3.30	Methoxychlor	µg/l	-			
Selenium	✓	µg/l	0.02 - <5	Naled	µg/l	-			
Silver	✓	µg/l	0.002 - <5.1	Parathion, ethyl	µg/l	-			
Sodium	✓	mg/l	19.2 - 31.0	Parathion, methyl	µg/l	-			
Thallium		µg/l	<10						
Tin		µg/l	<17	***Petroleum Hydrocarbons***					
Vanadium	✓	µg/l	3.6	TRPH	mg/l	<1			
Zinc	✓	µg/l	<0.6 - 18						
				Phthalate Esters:					
Nutrients				**Diethyl phthalate**	µg/l	<20			
Total N		mg/l	<0.75 - 0.8	**Di(2-ethylhexyl) phthalate**	µg/l	<10			
TON		mg/l	-						
Nitrate-N	✓	mg/l	0.23 - 0.68	***Polychlorinated Biphenyls (PCBs):***					
Nitrite-N		mg/l	0.05	**PCB 1016 Aroclor**	µg/l	<1			
NOx-N		mg/l	0.52 - 0.9	**PCB 1221 Aroclor**	µg/l	<2			
Ammonia-N		mg/l	-	**PCB 1232 Aroclor**	µg/l	<1			
Total P	✓	mg/l	<0.1 - 0.77	**PCB 1242 Aroclor**	µg/l	<0.1 - <1			
				PCB 1248 Aroclor	µg/l	<1			
Others				**PCB 1254 Aroclor**	µg/l	<1			
Cyanide	✓	µg/l	<10	**PCB 1260 Aroclor**	µg/l	<1			

a = USEPA 2002; priority toxic pollutants listed in Guam Water Quality Standards (GEPA 2001) in bold type; ✓ = analyte detected in one or more leachate samples; nd = not detected; dashes = no data

MATERIALS & METHODS

Sample Collection

Leachate: In December 2002, a single set of leachate samples were collected for bacteriological and chemical analysis, from two separate streams along the western and southern edge of the landfill (Fig. 1). The bacteria of interest were total coliforms and the fecal indicators, *E. coli* and *Enterococci*, while the chemicals included many of those listed as surface water priority pollutants in the *Guam Water Quality Standards* (GEPA 2001). Both samples were screened for 175 different chemicals including 19 metals, 76 volatile organic compounds (VOCs) and 75 synthetic organic compounds (SOCs) (Tables 4 and 5).

Samples for bacteriological analysis were collected in sterile polycarbonate 100-ml bottles while those for organic and inorganic chemical analysis were captured in amber glass and high-density polypropylene bottles respectively. The unfiltered samples for 'total' metal analysis were preserved with concentrated nitric acid (1 ml/L). An additional 25-ml leachate sample from the southern site was taken for 'soluble' metal analysis using a pre-cleaned 50-ml polypropylene syringe. The sample was passed through an in-line filter (0.45 µm) into an acid washed 80-ml polyethylene screw cap vial containing 25 µl of concentrated nitric acid. Samples for nutrient analysis were taken by the same technique but were not acidified prior to analysis. All samples were chilled immediately on 'blue ice' and transported to the laboratory in insulated containers.

Surface Waters: Surface waters for bacteria, nutrient and metal analyses were periodically collected over one year (October 2002 to October 2003) from five river sites between the landfill and ocean (Fig. 1). The first site, R1, was located in a leachate contaminated, unnamed stream that coursed along the western edge of the landfill and drained into the Lonfit River. Samples from this site were taken ~300 m upstream of the confluence point and ~150 m downgradient of the landfill. Sites R2 and R3 were located in the Pago River ~950 and 1250 m downstream of the point where the tributary entered the Lonfit. Sites R4 and R5 were located near a residential area ~4.8 km and ~5 km further downstream in the Pago River estuary.

Samples for bacteria analyses were taken just below the water surface in hand-held polycarbonate containers. Those required for nutrient and metal analyses were withdrawn directly into a 50-ml polypropylene syringes and filtered (0.45 µm) into 80-ml polyethylene vials as described above. All samples were chilled immediately.

Soil Pore Waters: Soil pore waters were taken over the same time frame from five sites (L1-L5) across the southwestern toe of the landfill (Fig. 1) and analyzed for the same suit of contaminants as those for surface waters. The sites were all downgradient of the landfill at distances ranging from ~100-250 m from the leading edge. Ceramic suction cup, vacuum lysimeters (pore size: 1.3 µm) were used to collect the pore water samples. These were buried to depths of 0.61m (2ft), 1.22m (4ft) and 1.82m (6ft) below ground level at each site and were evacuated 5-7 days prior to sample collection. The unfiltered samples were removed from the lysimeters under vacuum into a clean glass vacuum flask and poured directly into their appropriate containers for subsequent analysis. All samples were immediately chilled and those for metal analyses were later acidified in the laboratory.

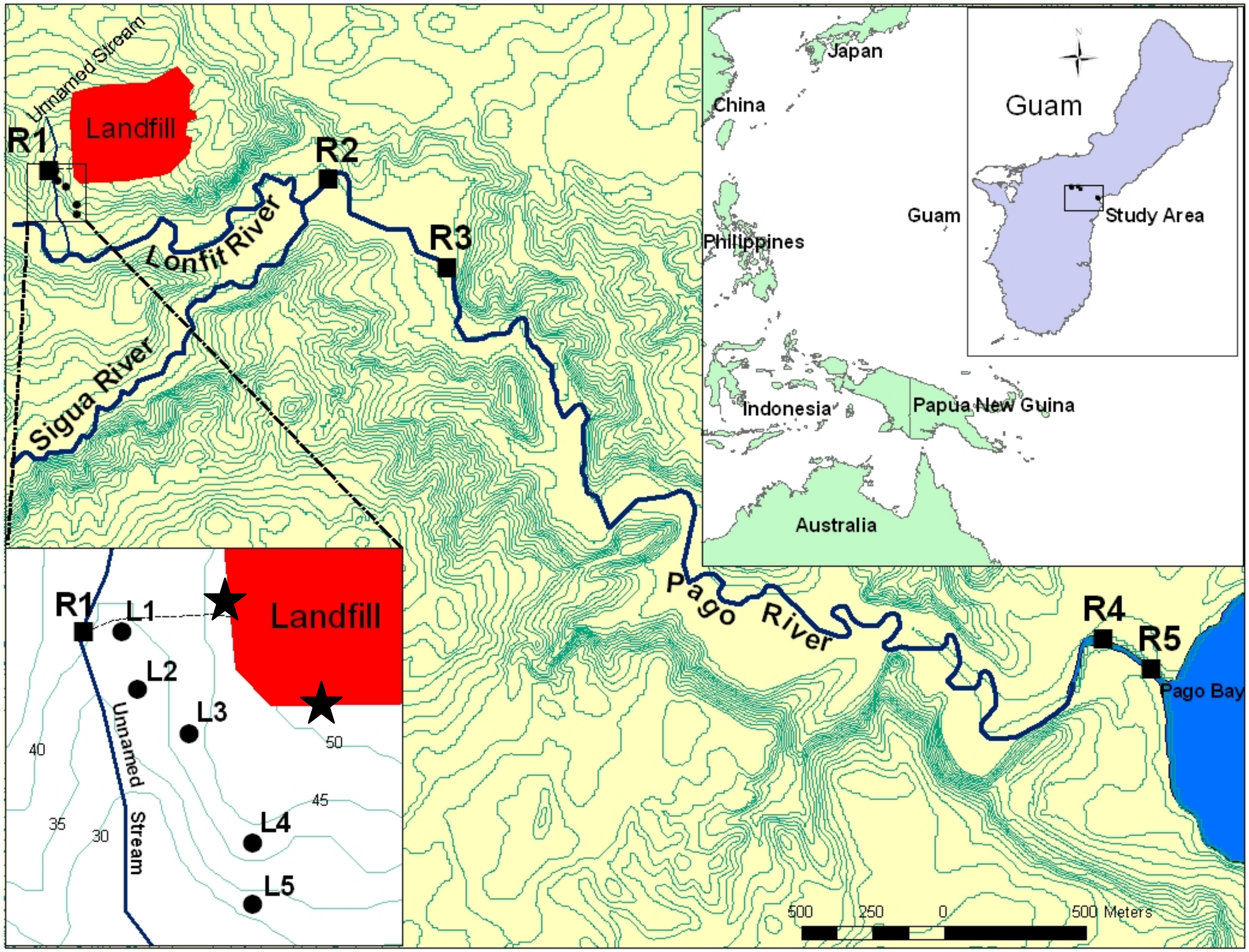

Figure 1: Map of Study Area Showing Location of Leachate (*) Surface Water (R1-R5) and Pore Water (L1-L5) Collection Sites Downgradient of Ordot Landfill, Guam

Table 4
Inorganic Chemicals Analyzed in Leachate Samples from Ordot Landfill

CONTAMINANT	RL	CONTAMINANT	RL
Metals (total)	**(µg/l)**	*Nutrients*	**(µg/l)**
Aluminum [a]	**125**	Nitrate-N	**1**
Antimony	**5.0**	Ammonia-N	**2**
Arsenic	**20**	Phosphate-P	**1**
Barium	**10**		
Beryllium	**1.0**	*Others*	**(µg/l)**
Boron [a]	**50**	**Asbestos**	**74 MFL**
Cadmium	**5.0**	*Cyanide*	**5**
Chromium	**10**		
Copper[a]	**10**		
Iron [a]	**100**		
Lead	**2.5**		
Manganese [a]	**10**		
Mercury	**0.2**		
Nickel	**20**		
Selenium	**50**		
Silver[a]	**10**		
Thallium	**5.0**		
Vanadium	**15**		
Zinc[a]	**20**		

Chemicals in bold type are listed as priority pollutants under Section 307(A) of the Clean Water Act
Chemicals in italics are additional surface water priority pollutants listed in Guam Water Quality Standards (2001)
Chemicals underscored are primary drinking water contaminants under the Safe Drinking Water Act
a = Chemicals are secondary drinking water contaminants under the Safe Drinking Water Act
RL = Reporting Limit; MFL = milion fibers per liter

Table 5
Organic Chemicals Analyzed in Leachate Samples from Ordot Landfill

CONTAMINANT	RL	CONTAMINANT	RL
Organochlorine Pesticides:	(µg/l)	*Polychlorinated Dibenzodioxins (TCDDs):*	(pg/l)
Aldrin	**50**	**2,3,7,8-TCDD**	**1.0**
BHC-alpha	**50**	1,2,3,7,8-PeCDD	2.2
BHC-beta	**50**	1,2,3,4,7,8-HxCDD	1
BHC-delta	**50**	1,2,3,6,7,8-HxCDD	1.1
BHC-gamma (Lindane)	**50**	1,2,3,7,8,9-HxCDD	1.1
Chlordane (tech)	**250**	1,2,3,4,6,7,8-HpCDD	23
4,4'-DDD	**50**	1,2,3,4,5,6,7,8-OCDD	25
4,4'-DDE	**50**	Total TCDD	2.9
4,4'-DDT	**50**	Total PeCDD	3.7
Dieldrin	**50**	Total HxCDD	8.4
Endosulfan I (alpha)	**50**	Total HpCDD	23
Endosulfan II (beta)	**50**		
Endosulfan sulfate	**50**	*Polychlorinated Dibenzofurans (TCDFs):*	(pg/l)
Endrin	**50**	2,3,7,8-TCDF	3.3
Endrin aldehyde	**50**	1,2,3,7,8-PeCDF	1.1
Heptachlor	**50**	2,3,4,7,8-PeCDF	1.1
Heptachlor epoxide	**50**	1,2,3,4,7,8-HxCDF	0.83
Hexachlorobenzene	**50**	1,2,3,6,7,8-HxCDF	0.58
Methoxychlor	50	2,3,4,6,7,8-HxCDF	0.79
Toxaphene	**750**	1,2,3,7,8,9-HxCDF	0.44
		1,2,3,4,6,7,8-HpCDF	3.6
Polycyclic Aromatic Hydrocarbons (PAHs):	(µg/l)	1,2,3,4,7,8,9-HpCDF	1.1
Acenaphthene	**50**	1,2,3,4,5,6,7,8-OCDF	3.7
Acenaphthylene	**50**	Total TCDF	3.3
Anthracene	**50**	Total PeCDF	1.6
Benzo(a)anthracene	**50**	Total HxCDF	0.83
Benzo(b)fluoranthene	**50**	Total HpCDF	3.6
Benzo(k)fluoranthene	**50**		
Benzo(g,h,i)perylene	**50**	*Phthalate Esters:*	(µg/l)
Benzo(a)pyrene	**50**	**Bis(2-ethylhexyl) phthalate**	**50**
2-Chloronaphthalene	**50**	**Butylbenzyl phthalate**	**50**
Chrysene	**50**	**Diethyl phthalate**	**50**
Dibenzo(a,h)anthracene	**50**	**Dimethyl phthalate**	**50**
Fluoranthene	**50**	**Di-n-butyl phthalate**	**50**
Fluorene	**50**	**Di-n-octyl phthalate**	**50**
Indeno(1,2,3-c,d)pyrene	**50**		
Naphthalene	**50**	*Halomethanes:*	(µg/l)
Phenanthrene	**50**	**Bromoform (Tribromomethane)**	**0.5**
Pyrene	**50**	**Carbon tetrachloride**	**0.5**
		Chloroform (Trichloromethane)	**0.5**
Polychlorinated Biphenyls (PCBs):	(µg/l)	Dichlorodifluoromethane	0.5
PCB 1016 Aroclor	**500**	**Dibromochloromethane**	**0.5**
PCB 1221 Aroclor	**500**	Dichlorobromomethane*	0.5
PCB 1232 Aroclor	**500**	**Methylene chloride (Dichloromethane)**	**3.0**
PCB 1242 Aroclor	**500**	**Methyl bromide**	**0.5**
PCB 1248 Aroclor	**500**	**Methyl chloride**	**0.5**
PCB 1254 Aroclor	**500**	Trichlorofluoromethane	0.5
PCB 1260 Aroclor	**500**		
Total PCBs	500		

Chemicals in bold type are listed as priority pollutants under Section 307(A) of the Clean Water Act; * = recently removed from Priority Pollutant List; chemicals underscored are primary drinking water contaminants under the Safe Drinking Water Act; RL = Reporting Limit

Table 5(cont.)
Organic Chemicals Analyzed in Leachate Samples from Ordot Landfill

CONTAMINANT	MRL (µg/l)	CONTAMINANT	MRL (µg/l)
Volatile Organic Compounds:		***Volatile Organic Compounds:***	
Acetone	10	**1,2-Diphenylhydrazine**	**50**
Acrolein	**50**	**Ethyl benzene**	**0.5**
Acrylonitrile	**50**	**Hexachlorobutadiene**	**50**
Benzene	**0.5**	**Hexachlorocyclopentadiene**	**100**
Benzidine	**50**	**Hexachloroethane**	**50**
2-Butanone (MEK)	10	2-Hexanone	10
Carbon disulfide	0.5	**Isophorone**	**50**
Chlorobenzene	**0.5**	4-Methyl-2-pentanone (MIBK)	10
Chloroethane	**0.5**	**Nitrobenzene**	**50**
bis(2-Chloroethoxy) methane	**50**	**2-Nitrophenol**	**100**
bis(2-Chloroethyl) ether	**50**	**4-Nitrophenol**	**100**
bis(2-Chloroisopropyl) ether	**50**	**N-Nitrosodimethylamine**	**50**
p-Chloro-m-cresol	**50**	**N-Nitrosodi-N-propylamine**	**50**
4-Chloro-3-methylphenol	**50**	**N-Nitrosodiphenylamine**	**50**
2-Chlorophenol	**50**	**Pentachlorophenol**	**50**
4-Chlorophenyl phenyl ether	**50**	**Phenol**	**50**
m-Dichlorobenzene (1,3-DCB)	**0.5**	Phenolic Compounds	10
o-Dichlorobenzene (1,2-DCB)	**0.5**	Styrene	0.5
p-Dichlorobenzene (1,4-DCB)	**0.5**	**1,1,2,2-Tetrachloroethane**	**0.5**
3,3'-Dichlorobenzidine	**50**	**Tetrachloroethylene (PCE)**	**0.5**
1,1-Dichloroethane	**0.5**	Tetrahydrofuran	10
1,2-Dichloroethane	**0.5**	**Toluene**	**0.5**
cis-1,2-Dichloroethene	0.5	**1,2,4-Trichlorobenzene**	**50**
trans-1,2-Dichloroethene	**0.5**	**1,1,1-Trichloroethane**	**0.5**
2,4-Dichlorophenol	**50**	**1,1,2-Trichloroethane (1,1,2-T)**	**1**
1,1-Dichloroethylene (1,1DCE)	**0.5**	**Trichloroethylene (TCE)**	**0.5**
1,2-Dichloropropane	**0.5**	**2,4,6-Trichlorophenol**	**100**
cis-1,3-Dichloropropene*	0.5	Vinyl acetate	10
trans-1,3-Dichloropropene*	0.5	**Vinyl Chloride (VC)**	**0.5**
2,4-Dimethylphenol	**50**	m,p-Xylenes	0.5
4,6-Dinitro-o-cresol	**100**	o-Xylene	0.5
2,4-Dinitrophenol	**200**	Total xylenes	0.5
2,4-Dinitrotoluene	**50**		
2,6-Dinitrotoluene	**50**		

Chemicals in bold type are listed as priority pollutants under Section 307(A) of the Clean Water Act; * = recently removed from Priority Pollutant List; chemicals underscored are primary drinking water contaminants under the Safe Drinking Water Act; RL = Reporting Limit

Sample Analysis
Bacteriological samples were processed within six hours of collection. Appropriate dilutions were made up to 100 ml with sterile water prior to the addition of IDEXX growth media (18-h 'Colilert' for total coliforms and *E. coli,* and 24-h 'Enterolert' for *Enterococci*). After mixing, the samples were poured into Quanti-Tray 2000 ™ trays, sealed and incubated at 35°C and 41°C for Colilert and Enterolert cultures respectively. Bacteria counts were subsequently determined using mean probable number (MPN) tables.

Nutrient determinations (NOx-N, NH_3-N and reactive-P) were made using a multi-channel *Quickchem 800,* flow injection analyzer (Lachat Instruments, Australia). The analytical methods recommended by the manufacturer were essentially the same as those described in *Standard Methods,* Part 4500 (APHA-AWWA-WPCF 1992), with modifications for flow injection analysis. All nutrient analyses were performed within 24-h of sample collection.

The metal analyses for surface waters and soil pore waters were carried out by conventional flame and flameless atomic absorption spectroscopy (AAS) with appropriate background correction capabilities. Split samples were analyzed by inductively coupled plasma spectroscopy (ICP) at an independent laboratory. Certified off-island laboratories determined metals and organic compounds in the two unfiltered leachate samples.

Field blanks and reagent blanks were incorporated into all the biological and chemical analyses performed during this study. Matrix spikes were also part of the QA/QC protocols for all chemical analyses.

Statistical Analysis:
Non-parametric tests were used to determine significant depth-dependant differences ($P<0.05$) in pore water concentrations of nutrients and heavy metals (Kruskal-Wallis ANOVA and multiple comparison test), and pair wise correlations (Spearman Rank test) between *E. coli* and *Enterococci* in surface waters, and all detectable metals in surface water and pore water data sets. All computations were performed using the 'Number Cruncher Statistical Systems 2000' software package (Hintze, 2001).

Plate 1: Retrieving samples from leachate stream on western edge of Ordot Landfill

Plate 2: Retrieving samples from leachate stream on southern edge of Ordot Landfill

Plate 3: Close up of hot, malodorous leachate stream on southern edge of Ordot Landfill

Plate 4: Capturing leachate sample from Ordot Landfill for heavy metal analysis

Plate 5: Taking surface water sample from R1 site for heavy metal and nutrient analysis

Plate 6: Coring lysimeter insertion holes with soil auger downgradient of Ordot Landfill

Plate 7: Seating the lysimeter in position with soil slurry and packing with fine sand

Plate 8: Removing soil pore water sample from lysimeter with vacuum pump.

RESULTS & DISCUSSION

All individual data sets are included in the appendices at the end of this report. Only tabulated data summaries are presented here.

Leachate

The biological and chemical contaminants detected in leachate samples are listed in Table 6 together with their respective surface water quality standard where available. Especially noticeable are the extremely high counts of fecal indicator bacteria, which exceeded the Guam recreational water quality standards for both marine and freshwater environments by at least three orders of magnitude. Presumably, these elevated numbers reflect unsanitary human wastes (e.g., disposable diapers) and animal carcasses placed in the landfill as well as fecal contributions from the large populations of rodents, stray dogs and wild pigs in the area.

Of the chemicals detected in the leachate samples, 11 were found at levels that equaled or exceeded the appropriate water quality standards. Nutrient levels were particularly high, especially NH_3-N. In fact, the pungent smell of ammonia was very noticeable at one of the collection sites. Total Cu and Pb levels were also high in one of the samples compared with their respective surface water quality standards. Both metals are relatively toxic to aquatic organisms (Mance 1987). Levels of all detectable metals were reasonably similar to those determined by earlier investigators (Table 1) and several orders of magnitude above those normally encountered locally in uncontaminated river waters (Denton *et al.* 1998). For those elements analyzed in both filtered and unfiltered samples, levels were consistently higher in the latter. The difference between the two fractions was particularly pronounced for Al indicating it to be predominantly in the particulate form.

It is noteworthy that relatively few organic solvents were found in the leachate and no pesticides other than p-dichlorobenzene were detected. Likewise, no PCBs or PAHs were detected in either sample despite numerous fires at the landfill in recent years and earlier reports of PCB contaminated electrical transformer oil being buried there (Black and Veitch 1983). Despite the presence of several dioxins and furans in one of the leachate samples, the highly toxic members of both classes of compounds were not detected. Nevertheless, a total 2,3,7,8-TCDD toxicity equivalent concentration (TEQ) of 214.26 pg/l was calculated for all detectable congeners, with the hepta- and octa-chlorinated dioxins contributing to most of the sample TEQ. It is noteworthy that the drinking water standard for 2,3,7,8-TCDD is just 0.03 pg/l.

The only organic compound previously detected in leachate from the Ordot Landfill was the common industrial solvent, 2-butanone (methyl ethyl ketone), at 12 µg/l (Camp Dresser and McKee 1987). This chemical is degraded relatively quickly in the environment (ASTDR 1992) and was not detected during the present study at a method reporting limit (MRL) of 10 µg/l.

Surface Waters

The bacteriological data for surface waters downgradient of the Ordot Landfill are summarized in Table 7. Also included are the 30-day geometric mean and instantaneous water quality standards currently adopted for *E. coli* and *Enterococci*. Although both of these organisms can be used to monitor the recreational quality of Guam's rivers and streams, *E. coli* is currently the

Table 6
Biological and Chemical Contaminants in Leachate from Ordot Landfill

Pollutant	Units	Results	Guam Water Quality Standards For Category S-2 Surface Waters
Bacteria;			
Total Coliforms	MPN Index/100 ml	96,000 - 2,419,200	-
E. coli	MPN Index/100 ml	1,515 - 137,400	126 (235) [a]
Enterococci	MPN Index/100 ml	59,600 - 298,100	33 (61) [a]
Nutrients:			
NOx	µg/l	213 -604	200 [b]
Ammonia-N	mg/l	144 - 503	3.08 [c]
Reactive-P	µg/l	166 - 759	50
Metals (total):			
Aluminum	mg/l	1.6 - 4.5 (0.043) [f]	1 [d]
Antimony	µg/l	<5 - 9.7	-
Arsenic	µg/l	7 - 46	150 [d]
Barium	µg/l	85 - 240 (69.2) [f]	-
Boron	mg/l	1.6 - 5	-
Chromium	µg/l	17 - 210 (19.6) [f]	210 (Cr^{3+}), 11 (Cr^{6+}) [d, e]
Copper	µg/l	23 - 92 (76.7) [f]	12 [d, e]
Iron	mg/l	0.68 - 3.0 (0.16) [f]	3 [d]
Lead	µg/l	4.7 - 45 (<0.5) [f]	3.2 [d]
Manganese	µg/l	290 - 340 (121) [f]	-
Nickel	µg/l	50 - 110 (73.3) [f]	52 [d, e]
Vanadium	µg/l	26 - 62	-
Zinc	mg/l	0.083 - 21 (0.061) [f]	0.11 [d, e]
Pesticides:			
p-dichlorobenzene	µg/l	3.4	-
Dioxins:			
Total TCDD	pg/l	<2.9 - 30	-
Total PeCDD	pg/l	<3.7 - 170	-
1,2,3,4,7,8-HxCDD	pg/l	<1.0 - 190	-
1,2,3,6,7,8-HxCDD	pg/l	<1.1 - 170	-
1,2,3,7,8,9-HxCDD	pg/l	<1.1 - 75	-
Total HxCDD	pg/l	<8.4 - 3700	-
1,2,3,4,6,7,8-HpCDD	pg/l	<23 - 9,400	-
Total HpCDD	pg/l	<23 - 20,000	-
OCDD	pg/l	130 - 65000	-
Furans:			
Total TCDF	pg/l	<3.3 - 46	-
Total PeCDF	pg/l	<1.6 - 31	-
1,2,3,6,7,8-HxCDF	pg/l	<0.58 - 28	-
Total HxCDF	pg/l	<0.83 - 380	-
1,2,3,4,6,7,8-HpCDF	pg/l	<3.6 - 800	-
Total HpCDF	pg/l	<3.6 - 1700	-
OCDF	pg/l	<3.7 - 960	-
Organic Solvents:			
Acetone	µg/l	17	-
Benzene	µg/l	3.1	-
Ethylbenzene	µg/l	7.3	-
Tetrahydrofuran	µg/l	10	-
Toluene	µg/l	18	-
cis-1,2-Dichloroethane	µg/l	1.1	-
m,p-Xylenes	µg/l	8	-
o-Xylene	µg/l	3.6	-
Others:			
Cyanide	µg/l	7-16	5.2
Phenolic Compounds	µg/l	74-155	-

a = standard is geometric mean of five sequential samples taken over a thirty day period. The number in parenthesis is the maximum allowable instantanous reading; b = as nitrate nitrogen; c = Criteria Chronic Concentration (CCC) at pH 7.0; d = Guam Numerical Criteria for Freshwater Oranisms Chronic; e = CCC estimated at total hardness of 100 mg/l; f = data from a single filtered sample in parenthesis; Dashes indicate no standards currently available; MPN = Mean Probable Number

Table 7
Bacteriological Data Summary of Surface Waters Collected Monthly Downgradient of Ordot Landfill

Site #	Description	Downstream Distance from Landfill (m)	MPN Index/100 ml		
			Total Coliforms	***E. coli***	***Enterococci***
			geometric mean (range)	**geometric mean (range)**	**geometric mean (range)**
R1	Unnamed stream	150	63,690 (17,329 - 1,046,224)	1,270 (262 - 5,012)	3,014 (211 - 17,239)
R2	Pago River	1,400	12,682 (4,352 - 24,192)	52 (5 - 359)	100 (20 - 703)
R3	Pago River	1,700	14,276 (4,160 - 64,880)	67 (10 - 369)	140 (30 - 816)
R4	Pago River estuary	5,250	24,684 (8,050 - 72,700)	291 (51 - 1,609)	152 (5 - 2,942)
R5	Pago River estuary	5,450	22,504 (5,850 - 141,360)	405 (20 - 5,794)	144 (10 - 2,584)
Guam Water Quality Standards					
			30-d geometric mean of 5 sequential samples:	126	33
			maximum allowable instantaneous reading:	235	61

indicator of choice. All data comparisons were made with reference to the 30-day water quality standards unless otherwise indicated.

As expected, all bacterial counts were highest at site R1 as a result of leachate contamination from the nearby landfill. MPN counts for both fecal indicator bacteria at this site exceeded the Guam recreational water quality standards on all occasions. Further downstream, at sites R2 and R3 on the Pago River, MPN counts for *E. coli* were consistently within acceptable limits during the dryer months (Dec-June). However, exceedences were observed in water samples from at least one of these sites, and usually both, during the wet season. At sites R4 and R5, in the Pago River estuary, recreational water quality exceedences for *E. coli* were evident during the dry season and much of the wet season. A similar picture was demonstrated by *Enterococci,* at the latter sites, with dry season exceedences occurring on all but one occasion at R4 and on all but three occasions at R5.

The Guam Environmental Protection Agency (GEPA) regularly monitored fecal coliforms in the Lonfit and Pago Rivers, between 1974 and 1998. Samples were collected from the primary leachate stream flowing into the Lonfit River and from sites approximately 100 m upstream and downstream from the point of confluence. A review of GEPA's quarterly data clearly demonstrates elevated levels of fecal bacteria in the leachate stream and the downstream site. Elevated bacterial counts were also commonplace further downstream in the Pago River and were assumed to reflect contributions from the landfill. Our study clearly demonstrates that this is not the case. Thus, the higher incidence of exceedences noted in this region compared with further upstream may reflect seepage from residential septic tanks or highway runoff. Other potential sources in this area include domestic animals, watercraft and a small sewage treatment plant (aerated sludge system) that services about 15 houses.

A scatter plot of all fecal indicator bacteria data sets for surface waters is presented in Fig 2. Correlation analysis revealed a highly significant positive relationship between MPN values for both organisms ($R=0.6714$; $P<0.001$). However, the strength of this relationship was found to be dependent upon the population density of each organism. For example, no correlation was evident between data sets for counts of 200 or less, for either indicator. At such densities, it is possible that independent, free-living populations of *E. coli* and *Enterococci* in bottom sediments mask fecal contributions of both organisms in the water column. Such non-fecal sources of indicator bacteria have certainly been demonstrated in other tropical regions of the world (Hazen 1988, Hardina and Fujioka 1991, Davies *et al.* 1995, Solo-Gabriele *et al*. 2000, Desmarais *et al.* 2002).

Nutrient analysis revealed inorganic N enrichment in surface waters from all sites (Table 8). However, levels generally diminished with increasing distance downstream of the landfill. NH_3-N dominated total inorganic N levels at R1, although levels were close to an order lower than those found in the leachate streams, while NOx-N concentrations were about ten times higher. Such changes undoubtedly reflect a gradual improvement in dissolved oxygen as the stream waters flow downgradient into the Lonfit River. Levels of NOx measured at all sites in the Pago River were generally higher than those found upstream of the landfill (US EPA 2002).

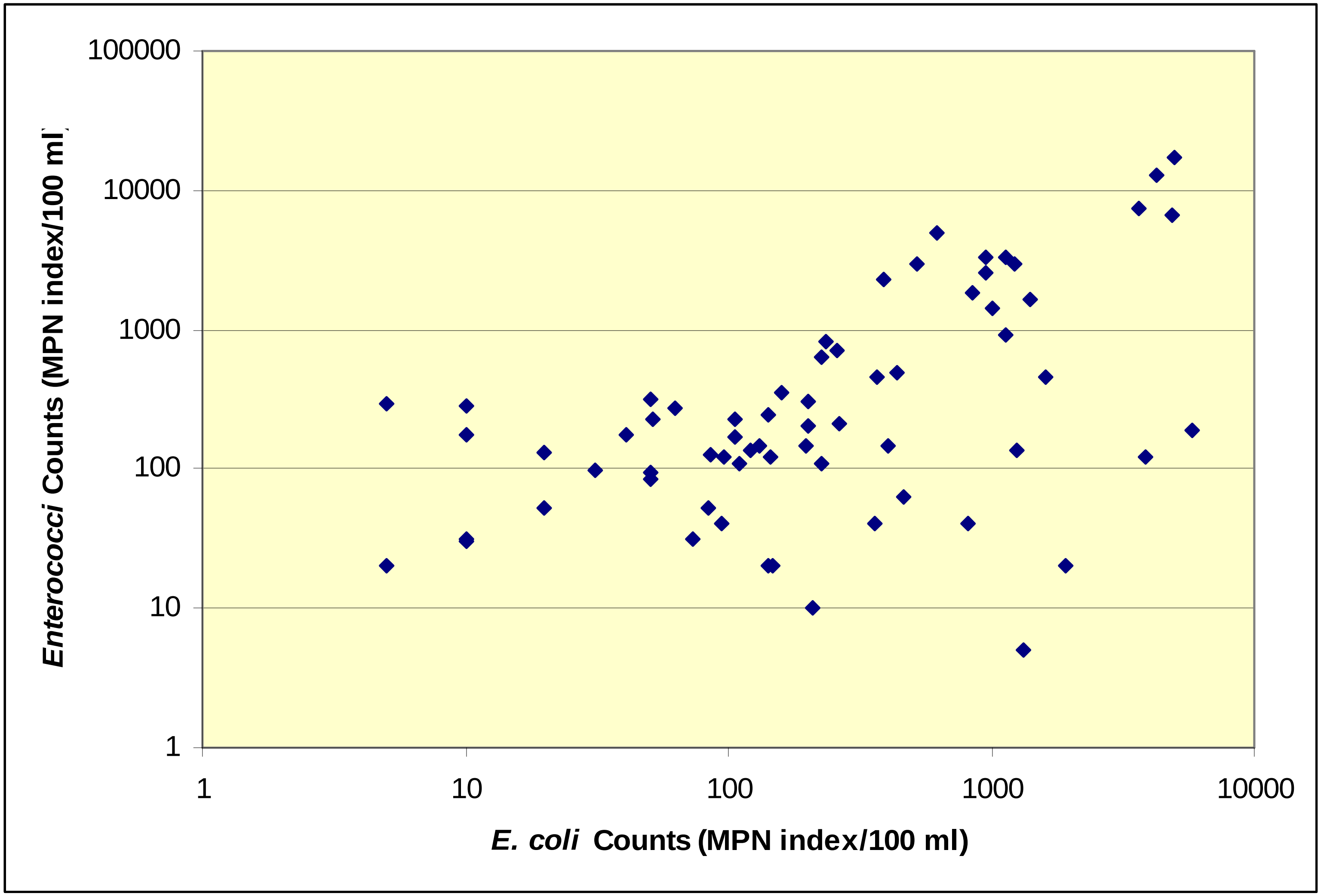

Figure 2: Relationship Between *E. coli* and *Enterococci* MPN Counts in Surface Waters Downgradient of Ordot Landfill, Guam

Table 8
Nutrient Data Summary of Surface Waters Downgradient of Ordot Landfill

Site #	Description	Downstream Distance from Landfill (m)	Nutrients (mg/l) NOx-N	Ammonia-N	Orthophosphate-P
			geometric mean (range)	geometric mean (range)	geometric mean (range)
R1	Unnamed stream	150	3.85 (1.35 - 9.44) n = 7	29.9 (10.5 - 44.3) n = 5	0.002 (<0.001 - 0.005) n = 7
R2	Pago River	1,400	0.361 (0.229 - 0.499) n = 6	0.016 (0.003 - 0.447) n = 4	0.001 (<0.001 - 0.003) n = 6
R3	Pago River	1,700	0.316 (0.111 - 0.546) n = 6	0.022 (0.003 - 0.346) n = 4	0.001 (<0.001 - 0.002) n = 6
R4	Pago River estuary	5,250	0.196 (0.050 - 0.567) n = 6	0.037 (<0.003 - 0.096) n = 5	0.002 (<0.001 - 0.005) n = 6
R5	Pago River estuary	5,450	0.142 (0.047 - 0.302) n = 6	0.029 (0.009 - 0.084) n = 4	0.001 (<0.001 - 0.004) n = 6
	Guam Water Quality Standards for S-2 waters:		0.2 [a]	3.08 [b]	0.05

a = as nitrate-N; b = the Criteria Chronic Concentration (CCC), i.e., the 30-d average concentration of total ammonia-N not to be exceeded more than once every 3 years at neutral pH

NOx-N concentrations determined at sites R2-R5 were compared directly with the surface water quality standard for NO_3-N, since the latter accounts for almost all of NOx-N in well oxidized waters (Schlesinger 1997). As expected, exceedences of the water quality standard were found to be more prevalent at sites R2 and R3 in the upper part of the watershed.

The absence of detectable P concentrations in most samples from R1 was unexpected considering the elevated concentrations in leachate draining into it (Table 6). Presumably, this nutrient is rapidly scavenged from solution by Fe and Mn oxyhydroxides formed at redox boundaries as oxygen levels in the stream improve.

Evidence of metal enrichment (Ba, Cr, Cu, Fe, Mn and Ni) in surface waters was only seen at R1 (Table 9). Samples from this site demonstrated a highly significant positive correlation between Ba and Mn (Fig. 3). The almost perfect linear relationship between these elements suggested they share a common source in the landfill. Typically, Ca and Mg were the most abundant elements detected followed by Ba, Fe, Mn and Al. Although Cu and Ni were detected in the majority of surface water samples from the upper reaches of Pago River, both elements were undetectable in the estuary. Quantifiable levels of Cr, Pb and Zn were seldom encountered at any site in the Pago River and Cd concentrations were consistently below the limits of analytical detection. Correlation analysis revealed a significant positive relationship between Fe and Mn in the upper Pago River. Both metals were also positively correlated with hardness in this section of the watershed.

Much of the early surface water data for metals upstream and downstream of the landfill (Table 2; US EPA 2002) are erroneously high and suggestive of sample contamination, inadequate instrumentation or inappropriate analytical techniques. A study conducted by Denton and Wood during the early 1990s produced some of the more reliable data that is currently available for this region. This previously unpublished information is summarized below in Tables 10 and 11 for filtered and unfiltered samples respectively. It clearly demonstrates that levels of all detectable metals were essentially the same at sampling sites 100 m upstream and downstream of leachate streams. Moreover, levels were significantly indistinguishable ($P>0.05$) from data gathered from the Sigua River, a nonpolluted river that flows into the Lonfit River a short distance below the downstream site. The study also highlights the significance of the particulate bound metal fraction and its potential for impacting bottom sediments and resident biota.

Soil Pore Waters:

Pore water samples were only available after significant rain events. Thus, much of the data presented below were from samples collected during the wet season.

Bacterial counts in soil pore waters downgradient of Ordot Landfill were surprisingly low considering the extremely high numbers present in leachate (Table 12). Even total coliform counts rarely exceeded 1000 per 100 ml sample and were mostly less than 100 per 100 ml sample. Both fecal indicator bacteria were rarely encountered at counts over 10 per 100 ml sample. Whether this is because bacteria in leachate from the landfill are physically trapped in the overlying surface soil layers, or consumed by other soil microbes, or both, remains to be established. In any event, the data imply little to no subsurface movement of bacterial pathogens from the landfill into the watershed.

Table 9
Elemental Composition of Surface Waters Downgradient of Ordot Landfill

Element	Units	Site									
		R1 (n = 5)		R2 (n =5)		R3 (n = 5)		R4 (n = 5)		R5 (n = 5)	
		mean	range	mean	range	mean	range	mean	range	mean	range
Al	µg/l	5.9	3.1 -10	3.0	<1.1 - 5.5	3.0	<0.5 - 7.1	14	6.9 - 40	11	7.8 - 21
Ba	µg/l	176	162 -194	8.8	4.2 - 48	10	4.1 - 121	18	8.4 - 51	18	9.0 - 51
Ca	mg/l	90	84 - 100	47	35 - 50	47	34 - 54	110	70 - 137	118	84 - 145
Cd	µg/l	<0.16	<0.16 - 1.9	-	all <0.16		all <0.16	-	all <0.16	-	all <0.16
Cr	µg/l	1.1	0.87 - 1.4	<0.16	<0.14 - 0.26	<0.16	<0.14 - 0.20	-	all <0.14	-	all <0.14
Cu	µg/l	2.5	0.9 - 9.1	0.41	<0.33 - 1.0	0.42	<0.33 - 1.7	-	all <0.33	-	all <0.33
Fe	µg/l	76	65 - 99	27	10 - 49	32	16 - 50	16	6.2 - 38	9.2	4.7 - 24
Mg	mg/l	25	24 - 27	9.0	6.6 - 10	9	6.5 - 11	205	129 - 299	236	162 - 299
Mn	µg/l	348	260 - 471	30	13 - 49	30	10 - 51	74	48 - 118	70	45 - 117
Ni	µg/l	14	12 - 18	0.81	<0.72 - 1.2	0.65	<0.72 - 1.2	-	all <0.72	-	all <0.72
Pb	µg/l	<1	<1 - 2	<1	<1 - 2	<1	<1 - 3	-	all <1	-	all <1
Zn	µg/l	1.4	<0.36 - 11	-	all <0.36	<0.7	<0.36 - 7.5	<1.2	<0.36 - 9.6	<1.3	<0.36 - 9.6

Means are geometric means; reporting limits and half-reporting limits used to calculate means of data sets with <100% quantifiable data, i.e., half reporting limits used to calculate means o data sets data sets with 50% or more quantifiable data and are given as positive values, and reporting limits used to calculate means for data sets with <50% quantifiable data and are giver 'less than' values.

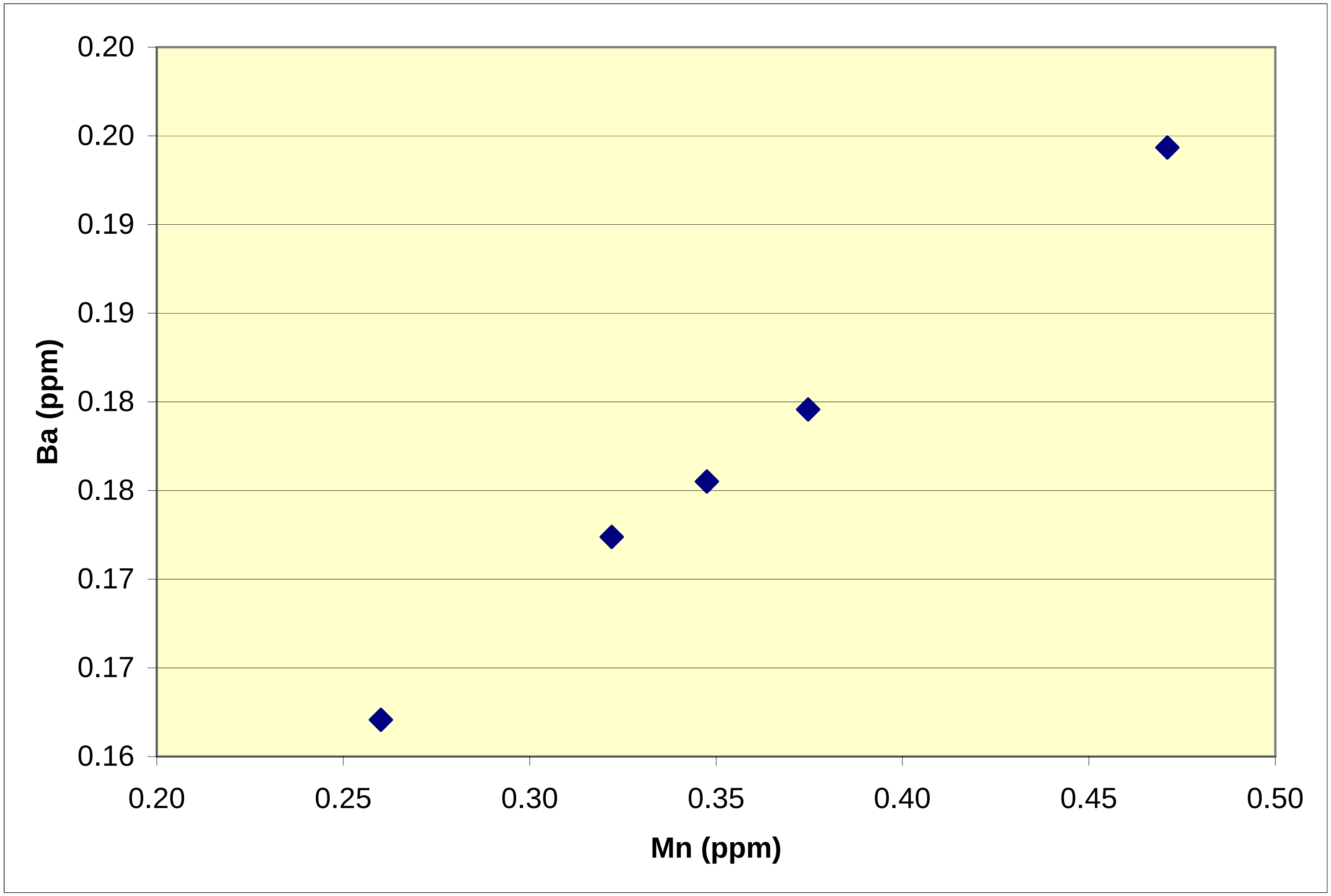

Figure 3: Scattergram of Barium and Manganese Concentrations Determined in Surface Water Samples from Site R1 Downgradient of Ordot Landfill

Table 10
Heavy Metal Levels (µg/l) in Filtered Surface Waters of the Lonfit and Sigua Rivers (1990-1993)[a]

Metal	Statistic	Leachate Stream R1 (n = 17)	Lonfit River 100 m Upstream (n = 17)	Lonfit River 100 m Downstream (n = 8)	Sigua River 100 m from Confluence with Lonfit (n = 7)
Cd	range	all <0.2	all <0.2	all <0.2	all <0.2
	median	<0.2	<0.2	<0.2	<0.2
	mean	nc	nc	nc	nc
Cr	range	1.1 - 5.0	<0.3 - 0.9	all <0.3	all <0.3
	median	1.9	<0.3	<0.3	<0.3
	mean	2.0	nc	nc	nc
Cu	range	1.7 - 31	0.3 - 4.1	0.3 - 1.0	0.3 -1.0
	median	4.9	0.4	0.4	0.3
	mean	5.6	0.6	0.5	0.4
Fe	range	12.0 - 646	1.0 - 38.0	4.7 - 33.3	4.3 - 45.9
	median	83.1	9.8	17.3	10.4
	mean	87.0	7.7	16.5	11.1
Hg	range	all <0.3	all <0.3	all <0.3	all <0.3
	median	<0.3	<0.3	<0.3	<0.3
	mean	nc	nc	nc	nc
Mn	range	83.3 - 966	3.8 -122	8.3 - 52.3	18.6 - 58.6
	median	306	14.5	17.4	40.2
	mean	272	18.8	21.4	35.5
Ni	range	2.70 - 33.0	all <0.6	all <0.6	all <0.6
	median	16.7	<0.6	<0.6	<0.6
	mean	12.9	nc	nc	nc
Pb	range	<0.3 - 4.00	<0.3 - 1.0	all <0.6	all <0.6
	median	<0.3	<0.6	<0.6	<0.6
	mean	nc	nc	nc	nc
Zn	range	1.20 - 6.00	<0.1 - 2.7	<0.1 - 0.5	<0.1 - 0.3
	median	2.9	0.8	0.1	0.1
	mean	2.8	0.4	0.1	0.1

a = from Denton and Wood (unpublished data); means are geometric means

Table 11
Heavy Metal Levels (μg/l) in Unfiltered Surface Waters of the Lonfit and Sigua Rivers (1990-1993)[a]

Metal	Statistic	Leachate Stream R1 (n = 8)	Lonfit River 100 m Upstream (n = 6)	Lonfit River 100 m Downstream (n = 4)	Sigua River 100 m from Confluence with Lonfit (n = 4)
Cd	range	all <0.2	all <0.2	all <0.2	all <0.2
	median	<0.2	<0.2	<0.2	<0.2
	mean	nc	nc	nc	nc
Cr	range	1.2 - 3.8	<0.3 - 3.3	<0.3 - 0.9	<0.3 - 0.8
	median	2.1	0.4	<0.3	<0.3
	mean	1.9	0.5	nc	nc
Cu	range	2.6 - 36.0	<0.3 - 4.6	<0.3 - 1.5	0.6 - 1.6
	median	10.1	1.0	1	1.1
	mean	8.3	1.0	0.7	1.0
Fe	range	149 - 4713	11.3 - 1858	21.3 - 556	23.1 - 222
	median	1080	327	135	74.1
	mean	892	204	120	72.4
Hg	range	all <0.3	all <0.3	all <0.3	all <0.3
	median	<0.3	<0.3	<0.3	<0.3
	mean	nc	nc	nc	nc
Mn	range	100 - 1113	9.6 - 130	33.2 - 67.4	29.7 - 88.5
	median	292	36.3	47.1	62.4
	mean	313	36.3	46.2	54.7
Ni	range	3.0 - 30.0	<0.6 - 0.8	all <0.6	all <0.6
	median	15.6	<0.7	<0.6	<0.6
	mean	11.1	nc	nc	nc
Pb	range	<0.6 - 3.4	<0.6 - 4.8	all <0.3	all <0.3
	median	1.2	0.5	<0.3	<0.3
	mean	0.9	0.6	nc	nc
Zn	range	2.3 - 22.0	<0.1 - 3.7	<0.1 - 1.4	0.1 - 0.60
	median	8.0	0.5	0.15	0.2
	mean	7.1	0.4	0.19	0.2

a = from Denton and Wood (unpublished data); means are geometric means

Table 12
Bacteriological Data Summary of Soil Pore Waters Downgradient of Ordot Landfill

Soil Depth (m)	N	MPN Index/100 ml		
		Total Coliforms	***E. coli***	***Enterococci***
		mean (range)	**mean (range)**	**mean (range)**
0.61	47	15 (<2 - 4740)	<2 (<2 - 83)	2 (<2 - 400)
1.22	45	10 (<2 - 7016)	<2 (<2 - 177)	<2 (<2 - 55)
1.83	49	11 (<2 - 4838)	<2 (<2 - 4)	<2 (<2 - 237)

means are geometric means

Pore water counts for each bacterial group were found to be independent of one another and were unrelated to soil depth. In contrast, their frequency of detection decreased with depth (Fig. 4). This was especially noticeable for *Enterococci*, detectable in 31% of samples collected at 0.6 m compared with only12% at 1.8 m.

Nutrient concentrations determined in soil pore waters over the study period are summarized in Table 13. The data was highly variable, especially for NOx-N. Statistical analysis of all data sets failed to find any depth-dependant relationships ($P>0.05$). NOx-N enrichment was evident at all three depths, often excessively so. However, total inorganic N levels (NOx-N + NH_3-N) paled in comparison to those determined in leachate samples. Some losses of inorganic N were expected as a result of microbial assimilation and denitrification processes. It now seems that soil adsorption mechanisms in relation to electrical charge are also important in this context. Most soils are negatively charged and do not hinder the mobility of the nitrate anion through the soil profile. Interestingly, soils from our lysimeter sites turned out to be positively charged (Golabi *et al*. 2006). This unusual characteristic restricts movement of nitrate through the soil and lowers soluble levels in pore waters. Inorganic P is similarly affected, which accounts for the generally low pore water concentrations found during the present investigation. This notwithstanding, the lush stands of vegetation in the river valley, downgradient of the landfill, suggest residual concentrations of both nutrients in subsurface flows are more than sufficient to sustain normal plant growth.

The elemental composition of pore waters collected over the study period is summarized in Table 14. Levels of all elements varied appreciably over time at each depth. Most heavy metals were substantially enriched compared with levels in the river waters analyzed. In fact, maximum levels of Al, Ba, Cr, Cu, Fe, Pb, Ni and Zn were within concentration ranges found in leachate (Table 6). This infers subsurface movement of these elements from the landfill into the underlying soil. With the possible exception of Ba, however, all appear to be rapidly attenuated in the deeper layers, presumably as a result of soil adsorption and precipitation processes. Significant depth-dependent relationships ($P<0.05$) were identified for Al, Cd, Fe and Zn, with the highest concentrations of each generally occurring at the shallowest level. The absence of high soluble Fe levels at depth infers that drainage is sufficient to maintain the surrounding soil in a reasonably aerobic state. Prevailing redox conditions, therefore, favor the oxidation and subsequent precipitation of soluble Fe in the upper soil horizons. Heavy metals and inorganic P are sequestered by this transformation process, and co-precipitate out of solution with the hydrated Fe oxide. An aerobic soil also explains the relatively low levels of NH_3-N recovered from pore water samples. Whether a similar situation exists in soil around the entire perimeter of the landfill is unknown. It is possible that anaerobic conditions prevail in some areas, in view of the various soil types that have been used as cover on this facility over the years. Under such conditions, the downward migration of heavy metals into the deeper soil layers will be considerably enhanced.

Correlation analysis revealed a significant positive relationship between Ba, Cu, Mn and Ni at all three depths ($P<0.05$). Water hardness also seemed to influence levels of Ba, Cu and Al in a positive fashion at each level. This presumably reflects variations in water percolation rates in relation to metal dissolution and partitioning processes from the surrounding soil. Mn and Ni were also positively correlated with hardness in the pooled data sets.

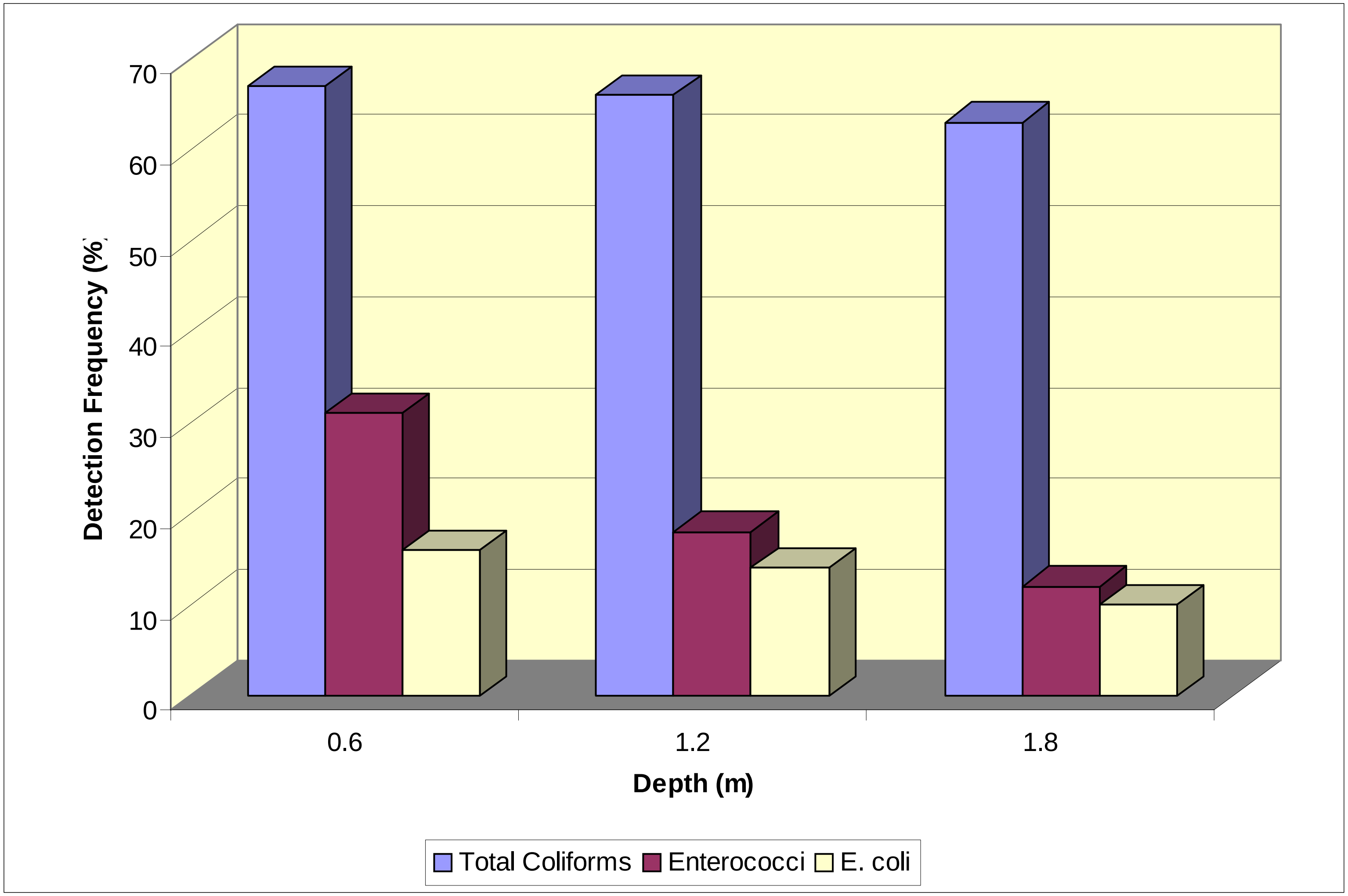

Figure 4: Frequency Histogram of Bacteria Detections in Pore Waters Downgradient of Ordot Landfill

Table 13
Nutrient Data Summary of Soil Pore Waters Downgradient of Ordot Landfill

Depth (m)	Nutrients (mg/l)		
	NOx-N	Ammonia-N	Ortho-P
	mean (range)	mean (range)	mean (range)
0.61	0.190 (0.003 - 12.3) n = 20	0.003 (<0.002 - 0.023) n = 15	0.003 (<0.001 - 0.051) n = 20
1.22	0.351 (<0.001 - 17.8) n = 22	0.004 (<0.002 - 0.141) n = 16	0.004 (<0.001 - 0.049) n = 23
1.83	0.309 (0.001 - 35.4) n = 25	0.004 (<0.002 - 0.035) n = 18	0.003 (<0.001 - 0.059) n = 25

means are geometric means

Table 14
Elemental Composition of Soil Pore Waters Downgradient of Ordot Landfill

Element	Units	Soil Depth (m)					
		0.61 (n = 5)		1.22 (n = 5)		1.83 (n = 5)	
		mean	range	mean	range	mean	range
Al	µg/l	21	7.9 - 1231	10.9	<1.1 - 55	12	4.7 - 141
Ba	µg/l	58	1.1 - 369	52	<0.13 - 240	55	2.2 - 347
Ca	mg/l	54	12-186	46	6.6 - 173	43	1.4 - 336
Cd	µg/l	0.12	<0.16 - 0.55	<0.16	<0.16 - 0.20	<0.16	<0.16 - 0.18
Cr	µg/l	0.23	<0.14 - 226	0.14	<0.14 - 0.90	<0.16	<0.14 - 1.2
Cu	µg/l	2.9	0.62 - 13	2.2	<0.33 - 11	1.7	<0.33 - 64
Fe	µg/l	6.8	0.6 - 2682	3.4	<0.78 - 121	1.8	<0.78 - 17
Mg	mg/l	19	5 - 48	16.1	4.3 - 44	17	1.3 - 83
Mn	µg/l	7.7	<0.27 - 3510	8.1	<0.27 - 2743	8.9	<0.27 - 1010
Ni	µg/l	3.1	<0.72 - 115	3.3	<0.72 - 48	4.3	1.3 - 39
Pb	µg/l	<1.3	<1.0 - 26	<1.1	<1.0 - 2.0	<1.1	<1.0 - 2.0
Zn	µg/l	4.9	<0.36 - 135	3.7	<0.36 - 27	1.5	<0.36 - 20

Means are geometric means; reporting limits and half-reporting limits used to calculate means of data sets with <100% quantifiable data, i.e., half reporting limits used to calculate means of data sets data sets with 50% or more quantifiable data and are given as positive values, and reporting limits used to calculate means for data sets with <50% quantifiable data and are given as 'less than' values.

CONCLUSIONS AND RECOMMENDATIONS

The current study has expanded the leachate contaminant database by almost 100 chemicals and reaffirmed that heavy metals and nutrients are among the more important contaminants present. We have also identified the presence of a number of other organic constituents, albeit at low levels, including several relatively toxic dioxin and furan congeners. The study also highlights the landfill as a potential source of waterborne diseases in view of the high densities of fecal indicator bacteria encountered.

The most significant ecological impact of the landfill on the Lonfit-Pago River system appears to be one of nitrate enrichment. Inorganic N readily moves from the landfill down the watershed in surface and subsurface flows and average levels in soil pore water are about the same as those encountered in the river below and about an order of magnitude higher than those normally present further upstream. As a consequence, the river valley downstream of the landfill is luxuriantly vegetated with palm trees, rambling shrubs and tropical grasses. The river itself supports several species of fish, gastropods and shrimp and the waters are usually clear between storm events. Although blooms of filamentous green algae and waterweeds tend to occur in some of the larger swimming holes downstream of the landfill during the dry season, they appear to have little negative impact on resident fish and invertebrate populations.

Of greater concern are the human health risks associated with the leachate stream mobilization of human pathogens from the landfill into the river. This could pose a very real threat to recreational bathers and local fishermen in the area, especially during the wetter months when significant seepage and surface runoff occurs around the base of the landfill. For this reason, it is imperative that the hygienic quality of the Lonfit and Pago Rivers be routinely monitored. Unfortunately, the recreational water quality-monitoring program for Guam rivers was abandoned by the Guam Environmental Protection Agency about ten years ago because of funding and man power constraints. Clearly, it needs to be reactivated in the interest of public safety.

The soil underlying the dump is composed of very fine-grained volcanic sediment with high clay content (USEPA 2002). It is relatively impervious, and the current work indicates that it provides a reasonably effective barrier against the subsurface movement of bacteria and heavy metals. This would explain why previous groundwater studies in the area have failed to find any evidence of metal enrichment (Black and Veitch 1983, Camp Dresser and McKee 1985).

Low heavy metal levels in the Pago River imply that much of the soluble heavy metal load in the leachate stream rapidly partitions out onto suspended particulates upon entering the watershed and ultimately ends up in bottom sediments. Since the watershed is prone to seasonal flash flooding, sediment sequestered contaminants are periodically flushed downstream and out into the bay. Sediment cores taken at strategic locations along the Pago-Lonfit River systems and out into Pago Bay would provide a more realistic measure of heavy metal distribution and abundance in this area. Such a sampling program would also provide a better understanding of the potential impact of these contaminants on the biota, particularly the suspension and deposit feeders and those organisms living in intimate contact with bottom deposits

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APPENDICES

Raw Data Sets

APPENDIX A

Bacteriological Data for Surface Waters

BACTERIOLOGICAL DATA FOR SURFACE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Downstream Distance from Landfill (m)	MPN Index/100 ml		
			Total Coliforms	*E. coli*	Enterococci
3-Oct-02	R1	150	57940	520	2920
	R2	1,400	17850	121	135
	R3	1,700	24192	200	310
	R4	5,250	19863	51	85
	R5	5,450	24192	20	130
17-Oct-02	R1	150	24192	1137	907
	R2	1,400	24192	145	122
	R3	1,700	19863	199	148
	R4	5,250	24192	52	231
	R5	5,450	24192	110	110
7-Nov-02	R1	150	24192	620	4884
	R2	1,400	24192	259	703
	R3	1,700	24192	233	816
	R4	5,250	24192	228	631
	R5	5,450	24192	160	359
5-Dec-02	R1	150	24192	391	2310
	R2	1,400	11199	63	278
	R3	1,700	15531	107	231
	R4	5,250	24192	51	318
	R5	5,450	24192	107	171

BACTERIOLOGICAL DATA FOR SURFACE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Downstream Distance from Landfill (m)	MPN Index/100 ml		
			Total Coliforms	*E. coli*	Enterococci
10-Jan-03	R1	150	92080	4880	6570
	R2	1,400	14360	31	98
	R3	1,700	8164	96	122
	R4	5,250	9834	1609	450
	R5	5,450	19890	467	63
14-Feb-03	R1	150	68670	960	3270
	R2	1,400	6488	41	175
	R3	1,700	4160	10	175
	R4	5,250	14136	143	246
	R5	5,450	12110	840	1850
13-Mar-03	R1	150	24192	5012	17329
	R2	1,400	10462	51	93
	R3	1,700	9208	10	30
	R4	5,250	24192	820	41
	R5	5,450	24192	5794	187
24-Apr-03	R1	150	92080	3640	7280
	R2	1,400	4352	5	292
	R3	1,700	5172	10	281
	R4	5,250	8050	1334	5
	R5	5,450	5850	3873	121

BACTERIOLOGICAL DATA FOR SURFACE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Downstream Distance from Landfill (m)	MPN Index/100 ml		
			Total Coliforms	*E. coli*	Enterococci
30-May-03	R1	150	17329	4280	12810
	R2	1,400	6870	5	20
	R3	1,700	15531	86	126
	R4	5,250	24810	1254	134
	R5	5,450	26130	1904	20
30-Jun-03	R1	150	241920	1145	3325
	R2	1,400	14140	73	31
	R3	1,700	8360	10	31
	R4	5,250	41060	228	108
	R5	5,450	14140	211	10
30-Jul-03	R1	150	1046224	1405	1659
	R2	1,400	13960	84	52
	R3	1,700	22470	131	148
	R4	5,250	61310	408	148
	R5	5,450	38730	437	496
28-Aug-03	R1	150	72700	1014	1401
	R2	1,400	17230	20	52
	R3	1,700	18500	148	20
	R4	5,250	36540	95	41
	R5	5,450	16070	143	20
1-Oct-03	R1	150	77010	262	211
	R2	1,400	18920	359	41
	R3	1,700	64880	369	457
	R4	5,250	72700	1231	2942
	R5	5,450	141360	959	2584

APPENDIX B

Nutrient Data for Surface Waters

NUTRIENT DATA FOR SURFACE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Downstream Distance from Landfill (m)	Nutrients (mg/l)		
			NOx-N	Ammonia-N	Orthophosphate-P
13-Mar-03	R1	150	2.976	43.2	<0.001
	R2	1,400	-	-	-
	R3	1,700	-	-	-
	R4	5,250	-	-	-
	R5	5,450	-	-	-
24-Apr-03	R1	150	1.350	41.1	<0.001
	R2	1,400	0.229	0.003	<0.001
	R3	1,700	0.111	0.003	<0.001
	R4	5,250	0.567	<0.003	<0.001
	R5	5,450	0.100	0.018	<0.001
30-May-03	R1	150	3.380	-	<0.001
	R2	1,400	0.487	-	<0.001
	R3	1,700	0.305	-	<0.001
	R4	5,250	0.151	-	<0.001
	R5	5,450	0.130	-	<0.001
18-Jun-03	R1	150	2.309	44.3	0.002
	R2	1,400	0.340	0.004	0.001
	R3	1,700	0.502	0.074	<0.001
	R4	5,250	0.050	0.008	0.002
	R5	5,450	0.047	0.009	<0.001

Dashes indicate no data

NUTRIENT DATA FOR SURFACE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Downstream Distance from Landfill (m)	Nutrients (mg/l)		
			NOx-N	Ammonia-N	Orthophosphate-P
30-Jul-03	R1	150	6.680	-	0.003
	R2	1,400	0.264	-	0.001
	R3	1,700	0.258	-	0.001
	R4	5,250	0.160	-	0.003
	R5	5,450	0.165	-	0.004
23-Aug-03	R1	150	9.440	29.15	0.005
	R2	1,400	0.441	0.011	0.003
	R3	1,700	0.415	0.003	0.002
	R4	5,250	0.265	0.096	0.005
	R5	5,450	0.264	0.084	0.004
1-Oct-03	R1	150	6.310	10.5	0.005
	R2	1,400	0.499	0.447	0.003
	R3	1,700	0.546	0.346	0.002
	R4	5,250	0.313	0.067	0.003
	R5	5,450	0.302	0.053	0.003

Dashes indicate no data

APPENDIX C

Elemental Data for Surface Waters

ELEMENTAL COMPOSITION[a] OF SURFACE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Metal (mg/l)											
		Al	Ba	Ca	Cd	Cr	Cu	Fe	Mg	Mn	Ni	Pb	Zn
7-Nov-2002	R1	0.00864	0.17551	85.6	<0.00016	0.00087	0.00113	0.06923	25.0	0.34750	0.01201	<0.001	0.00315
7-Nov-2002	R2[b]	<0.00108	<0.00013	0.05	<0.00016	<0.00014	<0.00033	<0.00078	0.01	<0.00027	<0.00072	0.002	<0.00036
7-Nov-2002	R3	0.00533	0.00647	45.6	<0.00016	<0.00014	<0.00033	0.01605	9.00	0.03725	0.00075	<0.001	<0.00036
7-Nov-2002	R4	0.02849	0.01951	133	<0.00016	<0.00014	<0.00033	0.00617	299	0.11837	<0.00072	<0.001	<0.00036
7-Nov-2002	R5	0.02106	0.01963	133	<0.00016	<0.00014	<0.00033	0.00591	299	0.11668	<0.00072	<0.001	<0.00036
5-Dec-2002	R1	0.00335	0.16207	90.6	0.00019	0.00113	0.00837	0.06928	24.4	0.26008	0.01380	0.002	<0.00036
5-Dec-2002	R2	0.00547	0.04785	47.3	<0.00016	<0.00014	0.00037	0.03109	9.24	0.03004	0.00124	<0.001	<0.00036
5-Dec-2002	R3	0.00505	0.12075	49.7	<0.00016	0.00020	0.00045	0.03864	9.48	0.03949	0.00115	<0.001	0.00749
5-Dec-2002	R4	0.00689	0.05049	121	<0.00016	<0.00014	<0.00033	0.00837	241	0.09975	<0.00072	<0.001	0.00805
5-Dec-2002	R5	0.00779	0.05122	134	<0.00016	<0.00014	<0.00033	0.00471	281	0.09878	<0.00072	<0.001	0.00815
10-Jan-2003	R1	0.00765	0.17958	83.9	<0.00016	0.00089	0.001142	0.06463	24.4	0.37472	0.01310	0.001	0.00517
10-Jan-2003	R2	0.00547	0.00620	48.3	<0.00016	<0.00014	<0.00033	0.04881	10.0	0.04880	0.00120	<0.001	<0.00036
10-Jan-2003	R3	0.00520	0.00620	52.2	<0.00016	<0.00014	<0.00033	0.04980	10.4	0.05122	<0.00072	<0.001	<0.00036
10-Jan-2003	R4	0.00982	0.01127	105	<0.00016	<0.00014	<0.00033	0.02917	151	0.04807	<0.00072	<0.001	<0.00036
10-Jan-2003	R5	0.00827	0.01154	107	<0.00016	<0.00014	<0.00033	0.02441	162	0.04478	<0.00072	<0.001	<0.00036
14-Feb-2003	R1	0.00311	0.19434	90.0	<0.00016	0.00129	0.00090	0.09903	26.9	0.47104	0.01490	<0.001	<0.00036
14-Feb-2003	R2	<0.00108	0.00486	50.1	<0.00016	<0.00014	0.00047	0.03173	10.1	0.04646	<0.00072	0.002	<0.00036
14-Feb-2003	R3	<0.00108	0.00551	54.1	<0.00016	<0.00014	0.00066	0.04535	10.5	0.03063	0.00104	0.003	<0.00036
14-Feb-2003	R4	0.00769	0.01977	137	<0.00016	<0.00014	<0.00033	0.02003	256	0.06907	<0.00072	<0.001	<0.00036
14-Feb-2003	R5	0.00839	0.01896	145	<0.00016	<0.00014	<0.00033	0.00955	283	0.06006	<0.00072	<0.001	<0.00036
31-Jul-2003	R1	0.01044	0.17238	100	0.00016	0.00143	0.00913	0.07986	25.1	0.32205	0.01773	<0.001	0.01131
31-Jul-2003	R2	0.00508	0.00420	34.7	<0.00016	0.00026	0.00099	0.01028	6.59	0.01254	0.00079	<0.001	<0.00036
31-Jul-2003	R3	0.00706	0.00405	34.3	<0.00016	0.000178	0.00165	0.02226	6.48	0.00977	<0.00072	<0.001	<0.00036
31-Jul-2003	R4	0.03963	0.00844	70.0	<0.00016	<0.00014	<0.00033	0.03837	129	0.05472	<0.00072	<0.001	0.00652
31-Jul-2003	R5	0.01183	0.00895	84.0	0.00025	<0.00014	<0.00033	0.01016	192	0.05514	<0.00072	<0.001	0.00960
Reporting Limit		0.00108	0.00013		0.00016	0.00014	0.00033	0.00078		0.00027	0.00072	0.001	0.00036

[a] All samples analyzed by ICP at FENA Laboratory (US Navy), Guam; [b] Data set considered erroneous and omitted from all statistical computations

APPENDIX D

Bacteriological Data for Soil Pore Waters

BACTERIOLOGICAL DATA FOR SOIL PORE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Depth (m)	MPN Index/100 ml		
			Total Coliforms	*E. coli*	Enterococci
3-Oct-02	1	0.61	<10	<10	<10
	1	1.22	<10	<10	<10
	1	1.83	**20**	<10	<10
	2	0.61	<10	<10	<10
	2	1.22	<10	<10	<10
	2	1.83	<10	<10	<10
	3	0.61	<10	<10	<10
	3	1.22	<10	<10	<10
	3	1.83	<10	<10	**10**
	4	0.61	**199**	**20**	<10
	4	1.22	<10	<10	<10
	4	1.83	<10	<10	<10
	5	0.61	**4740**	<10	**400**
	5	1.22	10	<10	<10
	5	1.83	10	<10	<10
Summary	**all sites**	**0.61**	**<10-4740 (2/5)**	**<10-20 (1/5)**	**<10-400 (1/5)**
		1.22	**<10 (0/5)**	**<10 (0/5)**	**<10 (0/5)**
		1.83	**<10-20 (1/5)**	**<10 (0/5)**	**<10-10 (1/5)**

Total number of positive sites at each depth shown in parenthesis

BACTERIOLOGICAL DATA FOR SOIL PORE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Depth (m)	MPN Index/100 ml					
			Total Coliforms		*E. coli*		Enterococci	
17-Oct-02	1	0.61	<2		<2		<2	
	1	1.22	**60**		**8**		**10**	
	1	1.83	<2		<2		<2	
	2	0.61	<2		<2		<2	
	2	1.22	**2**		<2		<2	
	2	1.83	**4**		<2		<2	
	3	0.61	<2		<2		<2	
	3	1.22	<2		<2		<2	
	3	1.83	**6**		<2		<2	
	4	0.61	**6**		**2**		<2	
	4	1.22	**4**		**2**		<2	
	4	1.83	<2		<2		**2**	
	5	0.61	**821**		**2**		<2	
	5	1.22	<2		<2		<2	
	5	1.83	**2**		<2		<2	
Summary	**all sites**	**0.61**	**<2-821**	**(2/5)**	**<2-2**	**(2/5)**	**<2**	**(0/5)**
		1.22	**<2-60**	**(3/5)**	**<2-8**	**(2/5)**	**<2-10**	**(1/5)**
		1.83	**<2-6**	**(3/5)**	**<2**	**(0/5)**	**<2-2**	**(1/5)**

Total number of positive sites at each depth shown in parenthesis

BACTERIOLOGICAL DATA FOR SOIL PORE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Depth (m)	MPN Index/100 ml					
			Total Coliforms		*E. coli*		Enterococci	
7-Nov-02	1	0.61	**115**		<2		**2**	
	1	1.22	**6**		<2		<2	
	1	1.83	**8**		<2		<2	
	2	0.61	<2		<2		<2	
	2	1.22	**45**		<2		**2**	
	2	1.83	**8**		<2		<2	
	3	0.61	**140**		<2		<2	
	3	1.22	**147**		<2		<2	
	3	1.83	**160**		<2		<2	
	4	0.61	**31**		<2		**2**	
	4	1.22	**8**		<2		<2	
	4	1.83	<2		<2		<2	
	5	0.61	**1226**		<2		<2	
	5	1.22	<2		<2		<2	
	5	1.83	<2		<2		<2	
Summary	**all sites**	**0.61**	**<2-1226**	**(4/5)**	**<2**	**(0/5)**	**<2-2**	**(2/5)**
		1.22	**<2-147**	**(4/5)**	**<2**	**(0/5)**	**<2-2**	**(1/5)**
		1.83	**<2-160**	**(3/5)**	**<2**	**(0/5)**	**<2**	**(0/5)**

Total number of positive sites at each depth shown in parenthesis

BACTERIOLOGICAL DATA FOR SOIL PORE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Depth (m)	MPN Index/100 ml					
			Total Coliforms		*E. coli*		Enterococci	
5-Dec-02	1	0.61	**2**		<2		**2**	
	1	1.22	**2**		<2		<2	
	1	1.83	**>4838**		<2		<2	
	2	0.61	**2**		<2		<2	
	2	1.22	**13**		<2		<2	
	2	1.83	**24**		<2		<2	
	3	0.61	**707**		<4		**93**	
	3	1.22	**41**		<10		**31**	
	3	1.83	**160**		<2		<2	
	4	0.61	**2**		<2		<2	
	4	1.22	<2		<2		<2	
	4	1.83	<2		<2		<2	
	5	0.61	**10**		<2		<2	
	5	1.22	**2**		<2		<2	
	5	1.83	**2**		<2		<2	
Summary	**all sites**	**0.61**	**2-707**	**(5/5)**	**<2**	**(0/5)**	**<2-93**	**(2/5)**
		1.22	**<2-41**	**(4/5)**	**<2**	**(0/5)**	**<2-31**	**(1/5)**
		1.83	**<2->4838**	**(4/5)**	**<2**	**(0/5)**	**<2**	**(0/5)**

Total number of positive sites at each depth shown in parenthesis

BACTERIOLOGICAL DATA FOR SOIL PORE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Depth (m)	MPN Index/100 ml					
			Total Coliforms		*E. coli*		Enterococci	
10-Jan-03	1	0.61	**2**		<2		<2	
	1	1.22	**18**		<2		<2	
	1	1.83	**4838**		<2		**2**	
	2	0.61	**18**		<3		**3**	
	2	1.22	**20**		<10		<5	
	2	1.83	**10**		<2		<2	
	3	0.61	**39**		<3		**5**	
	3	1.22	**>7016**		**3**		**3**	
	3	1.83	**8**		<2		<2	
	4	0.61	<2		<2		**2**	
	4	1.22	**16**		**11**		**5**	
	4	1.83	<2		<2		**2**	
	5	0.61	<4		<4		**54**	
	5	1.22	<3		<3		<3	
	5	1.83	<2		<2		<2	
Summary	**all sites**	**0.61**	**<2-39**	**(3/5)**	**<2**	**(0/5)**	**<2-54**	**(4/5)**
		1.22	**<3- >7016**	**(4/5)**	**<2-11**	**(2/5)**	**<2-5**	**(2/5)**
		1.83	**<2-4838**	**(3/5)**	**<2**	**(0/5)**	**<2-2**	**(2/5)**

Total number of positive sites at each depth shown in parenthesis

BACTERIOLOGICAL DATA FOR SOIL PORE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Depth (m)	MPN Index/100 ml					
			Total Coliforms		*E. coli*		Enterococci	
14-Feb-03	1	0.61	<4		<4		<4	
	1	1.22	**-**		**-**		**-**	
	1	1.83	**857**		<4		<4	
	2	0.61	<2		<2		<2	
	2	1.22	<2		<2		<2	
	2	1.83	<2		<2		<2	
	3	0.61	**21**		<4		<4	
	3	1.22	**-**		**-**		**-**	
	3	1.83	**-**		**-**		**-**	
	4	0.61	**2**		<2		<2	
	4	1.22	**-**		**-**		**-**	
	4	1.83	**4**		<2		<2	
	5	0.61	**-**		**-**		**-**	
	5	1.22	**-**		**-**		**-**	
	5	1.83	**192**		<4		<4	
Summary	**all sites**	**0.61**	**<2-21**	**(2/4)**	**<2**	**(0/4)**	**<2**	**(0/4)**
		1.22	**<2**	**(0/1)**	**<2**	**(0/1)**	**<2**	**(0/1)**
		1.83	**<2-4838**	**(3/4)**	**<2**	**(0/4)**	**<2**	**(0/4)**

Total number of positive sites at each depth shown in parenthesis; dashes indicate no sample available from lysimeter

BACTERIOLOGICAL DATA FOR SOIL PORE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Depth (m)	MPN Index/100 ml					
			Total Coliforms		*E. coli*		Enterococci	
13-Mar-03	1	0.61	-		-		-	
	1	1.22	-		-		-	
	1	1.83	**188**		<4		<4	
	2	0.61	<2		<2		<2	
	2	1.22	<2		<2		<2	
	2	1.83	<2		<2		<2	
	3	0.61	-		-		-	
	3	1.22	-		-		-	
	3	1.83	-		-		-	
	4	0.61	<4		<4		<4	
	4	1.22	<5		<5		<5	
	4	1.83	<2		<2		<2	
	5	0.61	-		-		-	
	5	1.22	-		-		-	
	5	1.83	<3		<3		<3	
Summary	**all sites**	**0.61**	**<2**	**(0/2)**	**<2**	**(0/2)**	**<2**	**(0/2)**
		1.22	**<2**	**(0/2)**	**<2**	**(0/2)**	**<2**	**(0/2)**
		1.83	**<2-188**	**(1/4)**	**<2**	**(0/4)**	**<2**	**(0/4)**

Total number of positive sites at each depth shown in parenthesis; dashes indicate no sample available from lysimeter

BACTERIOLOGICAL DATA FOR SOIL PORE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	**Site**	**Depth (m)**	**MPN Index/100 ml**					
			Total Coliforms		***E. coli***		**Enterococci**	
24-Apr-03	1	0.61	-		-		-	
	1	1.22	-		-		-	
	1	1.83	-		-		-	
	2	0.61	<2		<2		<2	
	2	1.22	<2		<2		<2	
	2	1.83	<2		<2		<2	
	3	0.61	-		-		-	
	3	1.22	-		-		-	
	3	1.83	-		-		-	
	4	0.61	-		-		-	
	4	1.22	<2		<2		<2	
	4	1.83	<2		<2		<2	
	5	0.61	-		-		-	
	5	1.22	-		-		-	
	5	1.83	-		-		-	
Summary	**all sites**	**0.61**	**<2**	**(0/1)**	**<2**	**(0/1)**	**<2**	**(0/1)**
		1.22	**<2**	**(0/2)**	**<2**	**(0/2)**	**<2**	**(0/2)**
		1.83	**<2**	**(0/2)**	**<2**	**(0/2)**	**<2**	**(0/2)**

Total number of positive sites at each depth shown in parenthesis; dashes indicate no sample available from lysimeter

BACTERIOLOGICAL DATA FOR SOIL PORE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Depth (m)	MPN Index/100 ml					
			Total Coliforms		*E. coli*		Enterococci	
30-May-03	1	0.61	-		-		-	
	1	1.22	-		-		-	
	1	1.83	-		-		-	
	2	0.61	-		-		-	
	2	1.22	-		-		-	
	2	1.83	<2		<2		<2	
	3	0.61	-		-		-	
	3	1.22	-		-		-	
	3	1.83	-		-		-	
	4	0.61	-		-		-	
	4	1.22	-		-		-	
	4	1.83	-		-		-	
	5	0.61	-		-		-	
	5	1.22	-		-		-	
	5	1.83	-		-		-	
Summary	**all sites**	**0.61**	**-**		**-**		**-**	
		1.22	**-**		**-**		**-**	
		1.83	**<2**	**(0/1)**	**<2**	**(0/1)**	**<2**	**(0/1)**

Total number of positive sites at each depth shown in parenthesis; dashes indicate no sample available from lysimeter

BACTERIOLOGICAL DATA FOR SOIL PORE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Depth (m)	MPN Index/100 ml					
			Total Coliforms		*E. coli*		Enterococci	
30-Jun-03	1	0.61	-		-		-	
	1	1.22	-		-		-	
	1	1.83	-		-		-	
	2	0.61	-		-		-	
	2	1.22	-		-		-	
	2	1.83	-		-		-	
	3	0.61	-		-		-	
	3	1.22	-		-		-	
	3	1.83	-		-		-	
	4	0.61	20.2		2		<2	
	4	1.22	-		-		-	
	4	1.83	-		-		-	
	5	0.61	-		-		-	
	5	1.22	-		-		-	
	5	1.83	-		-		-	
Summary	**all sites**	**0.61**	**20.2**	**(1/1)**	**2**	**(1/1)**	**<2**	**(0/1)**
		1.22	**-**		**-**		**-**	
		1.83	**-**		**-**		**-**	

Total number of positive sites at each depth shown in parenthesis; dashes indicate no sample available from lysimeter

BACTERIOLOGICAL DATA FOR SOIL PORE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Depth (m)	MPN Index/100 ml					
			Total Coliforms		*E. coli*		Enterococci	
30-Jul-03	1	0.61	4		<2		2	
	1	1.22	19.6		<2		<2	
	1	1.83	24		<2		<2	
	2	0.61	10.4		<2		<2	
	2	1.22	16.8		<2		<2	
	2	1.83	21.8		<2		<2	
	3	0.61	29		<2		<2	
	3	1.22	19.2		<2		<2	
	3	1.83	12.6		4		<2	
	4	0.61	85.2		12.6		<2	
	4	1.22	444.8		<2		2	
	4	1.83	26.4		<2		<2	
	5	0.61	156.8		<2		10.4	
	5	1.22	29.2		<2		<2	
	5	1.83	34.6		<2		<2	
Summary	**all sites**	**0.61**	**4-156.8**	**(5/5)**	**<2-12.6**	**(1/5)**	**<2-10.4**	**(2/5)**
		1.22	**12.6-444.8**	**(5/5)**	**<2**	**(0/5)**	**<2-2**	**(1/5)**
		1.83	**12.6-34**	**(5/5)**	**<2-4**	**(1/5)**	**<2**	**(0/5)**

Total number of positive sites at each depth shown in parenthesis

BACTERIOLOGICAL DATA FOR SOIL PORE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Depth (m)	MPN Index/100 ml		
			Total Coliforms	*E. coli*	Enterococci
28-Aug-03	1	0.61	581.8	82.6	40.2
	1	1.22	551	176.8	55
	1	1.83	976.8	2	4
	2	0.61	428.6	<2	4
	2	1.22	61	4	<2
	2	1.83	24.2	<2	<2
	3	0.61	-	-	-
	3	1.22	-	-	-
	3	1.83	-	-	-
	4	0.61	471.8	2	12.6
	4	1.22	32	<2	<2
	4	1.83	>4838.4	<2	237.4
	5	0.61	1095	21.8	70
	5	1.22	409.2	<2	2
	5	1.83	-	-	-
Summary	**all sites**	**0.61**	**428.6-1095 (4/4)**	**<2-82.6 (3/4)**	**4-70 (4/4)**
		1.22	**32-551 (4/4)**	**<2-176.8 (2/4)**	**<2-55 (2/4)**
		1.83	**24.2->4838 (3/3)**	**<2-2 (1/3)**	**<2-237.4 (2/3)**

Total number of positive sites at each depth shown in parenthesis; dashes indicate no sample available from lysimeter

BACTERIOLOGICAL DATA FOR SOIL PORE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Depth (m)	MPN Index/100 ml					
			Total Coliforms		*E. coli*		Enterococci	
1-Oct-03	1	0.61	27		<2		<2	
	1	1.22	29.2		<2		<2	
	1	1.83	6.2		<2		<2	
	2	0.61	64.6		<2		<2	
	2	1.22	26.8		<2		<2	
	2	1.83	35		2		<2	
	3	0.61	43.6		<2		<2	
	3	1.22	14.8		<2		<2	
	3	1.83	37.4		2		<2	
	4	0.61	80.8		<2		<2	
	4	1.22	238.2		<2		<2	
	4	1.83	155.2		<2		<2	
	5	0.61	17.2		<2		<2	
	5	1.22	35		<2		<2	
	5	1.83	2		<2		<2	
Summary	**all sites**	**0.61**	**17.2-80.8**	**(5/5)**	**<2**	**(0/5)**	**<2**	**(0/5)**
		1.22	**14.8-238.2**	**(5/5)**	**<2**	**(0/5)**	**<2**	**(0/5)**
		1.83	**2-155.2**	**(5/5)**	**2**	**(2/5)**	**<2**	**(0/5)**

Total number of positive sites at each depth shown in parenthesis

APPENDIX E

Nutrient Data for Soil Pore Waters

NUTRIENT DATA FOR SOIL PORE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Depth (m)	Nutrients (µg/l)		
			NOx-N	Ammonia-N	Orthophosphate-P
13-Mar-03	1	0.61	-	-	-
	1	1.22	-	-	-
	1	1.83	4954	7.9	4.6
	2	0.61	339	2.9	2.9
	2	1.22	10.4	141	3.2
	2	1.83	5.23	35	1.4
	3	0.61	-	-	-
	3	1.22	-	-	-
	3	1.83	-	-	-
	4	0.61	8124	5.8	16
	4	1.22	8991	2.9	19
	4	1.83	35,455	11	12
	5	0.61	-	-	-
	5	1.22	-	-	-
	5	1.83	408	4.3	7.9

Dashes indicate no data

NUTRIENT DATA FOR SOIL PORE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Depth (m)	Nutrients (µg/l)		
			NOx-N	Ammonia-N	Orthophosphate-P
24-Apr-03	1	0.61	-	-	-
	1	1.22	-	-	-
	1	1.83	-	-	-
	2	0.61	1270	6.0	<1
	2	1.22	1400	49	<1
	2	1.83	580	27	<1
	3	0.61	-	-	-
	3	1.22	-	-	-
	3	1.83	-	-	-
	4	0.61	-	-	-
	4	1.22	5990	14	18
	4	1.83	19,300	12	9
	5	0.61	-	-	-
	5	1.22	-	-	-
	5	1.83	-	-	-

Dashes indicate no data

NUTRIENT DATA FOR SOIL PORE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Depth (m)	Nutrients (µg/l)		
			NOx-N	Ammonia-N	Orthophosphate-P
30-May-03	1	0.61	-	-	-
	1	1.22	-	-	-
	1	1.83	-	-	-
	2	0.61	-	-	-
	2	1.22	-	-	-
	2	1.83	900	-	20
	3	0.61	-	-	-
	3	1.22	-	-	-
	3	1.83	-	-	-
	4	0.61	-	-	-
	4	1.22	9,510	-	49
	4	1.83	62	-	59
	5	0.61	-	-	-
	5	1.22	-	-	-
	5	1.83	-	-	-

Dashes indicate no data

NUTRIENT DATA FOR SOIL PORE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Depth (m)	Nutrients (µg/l)		
			NOx-N	Ammonia-N	Orthophosphate-P
18-Jun-03	1	0.61	10	<2	20
	1	1.22	-	-	-
	1	1.83	15	8	21
	2	0.61	-	-	-
	2	1.22	-	-	-
	2	1.83	-	-	-
	3	0.61	-	-	-
	3	1.22	-	-	-
	3	1.83	-	-	-
	4	0.61	2245	5	23
	4	1.22	7729	<2	33
	4	1.83	99	<2	23
	5	0.61	3	7	51
	5	1.22	-	19	20
	5	1.83	-	-	-

Dashes indicate no data

NUTRIENT DATA FOR SOIL PORE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Depth (m)	Nutrients (µg/l)		
			NOx-N	Ammonia-N	Orthophosphate-P
30-Jul-03	1	0.61	24	-	<1
	1	1.22	64	-	<1
	1	1.83	508	-	3
	2	0.61	91	-	0.5
	2	1.22	55	-	0.5
	2	1.83	45	-	0.5
	3	0.61	3	-	2
	3	1.22	5	-	2
	3	1.83	3	-	0.5
	4	0.61	4540	-	1
	4	1.22	6910	-	9
	4	1.83	4110	-	1
	5	0.61	78	-	2
	5	1.22	13	-	<1
	5	1.83	29	-	<1

Dashes indicate no data

NUTRIENT DATA FOR SOIL PORE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Depth (m)	Nutrients (µg/l)		
			NOx-N	Ammonia-N	Orthophosphate-P
28-Aug-03	1	0.61	-	-	-
	1	1.22	17840	2	2
	1	1.83	31610	7	2
	2	0.61	1120	<2	<1
	2	1.22	104	4	2
	2	1.83	214	2	0.5
	3	0.61	15	13	5
	3	1.22	7	2	3
	3	1.83	13	8	3
	4	0.61	1020	23	4
	4	1.22	1050	5	13
	4	1.83	356	8	4
	5	0.61	6	16	4
	5	1.22	77	6	3
	5	1.83	54	2	2

Dashes indicate no data

NUTRIENT DATA FOR SOIL PORE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Depth (m)	Nutrients (µg/l)		
			NOx-N	Ammonia-N	Orthophosphate-P
2-Oct-03	1	0.61	12322	<2	<1
	1	1.22	15093	<2	<1
	1	1.83	15478	<2	<1
	2	0.61	702	<2	<1
	2	1.22	1	<2	<1
	2	1.83	11527	<2	<1
	3	0.61	896	<2	<1
	3	1.22	612	<2	<1
	3	1.83	15	<2	<1
	4	0.61	898	<2	<1
	4	1.22	297	<2	12
	4	1.83	1770	<2	<1
	5	0.61	10	<2	<1
	5	1.22	41	<2	<1
	5	1.83	8	<2	<1

APPENDIX F

Elemental Data for Soil Pore Waters

ELEMENTAL COMPOSITION[a] OF SOIL PORE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Depth (m)	Metal (mg/l)											
			Al	Ba	Ca	Cd	Cr	Cu	Fe	Mg	Mn	Ni	Pb	Zn
7-Nov-2002	1	0.61	0.02385	0.20884	109	<0.00016	0.00057	0.00716	0.02345	26.9	0.26670	0.02085	<0.001	0.05477
	1	1.22	0.01680	0.14464	101	<0.00016	0.00024	0.01121	0.00189	25.5	0.04552	0.01668	<0.001	0.00419
	1	1.83	0.01579	0.12185	102	<0.00016	<0.00014	0.00888	0.00159	25.8	1.01020	0.03902	<0.001	0.00192
	2	0.61	0.01368	0.12021	100	<0.00016	<0.00014	0.00150	0.00232	11.9	0.16449	0.00415	<0.001	0.00460
	2	1.22	0.05506	0.14064	95.2	<0.00016	0.00015	0.00279	0.12109	12.4	2.32780	0.00833	<0.001	0.02659
	2	1.83	0.01423	0.17392	69.4	<0.00016	<0.00014	0.00600	0.00441	17.5	0.06712	0.00732	<0.001	0.00169
	3	0.61	0.01228	0.08793	11.7	<0.00016	0.000169	0.00062	0.00521	7.39	0.00553	0.00140	<0.001	0.00997
	3	1.22	0.00452	0.08305	11.7	<0.00016	<0.00014	0.00048	0.00247	6.22	0.00782	0.00106	<0.001	0.02042
	3	1.83	0.01039	0.04008	2.44	<0.00016	<0.00014	<0.00033	0.00126	2.04	0.03915	0.00275	<0.001	0.01043
	4	0.61	0.01780	0.09007	72.0	<0.00016	<0.00014	0.00161	0.00278	29.2	0.00531	<0.00072	<0.001	0.00638
	4	1.22	0.01314	0.11894	85.9	<0.00016	<0.00014	0.00058	0.00129	34.4	0.00535	0.00179	<0.001	0.00261
	4	1.83	0.01511	0.09661	100	<0.00016	<0.00014	0.00220	0.00147	36.2	0.00405	0.00183	<0.001	0.00444
	5	0.61	0.32215	0.00394	29.7	<0.00016	0.00059	0.01108	0.29712	18.8	0.00447	0.00235	0.0013	0.02510
	5	1.22	0.00523	0.00571	24.5	<0.00016	<0.00014	0.00071	0.00165	16.0	0.00028	0.00128	<0.001	0.00786
	5	1.83	0.00759	0.00782	42.5	<0.00016	<0.00014	<0.00033	0.00144	25.2	0.00202	0.00189	<0.001	0.00414
	Reporting Limit		0.00108	0.00013		0.00016	0.00014	0.00033	0.00078		0.00027	0.00072	0.001	0.00036

[a] All samples analyzed by ICP. All analyses performed by US Navy FENA Lab, Guam

ELEMENTAL COMPOSITION[a] OF SOIL PORE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Depth (m)	Metal (mg/l)											
			Al	Ba	Ca	Cd	Cr	Cu	Fe	Mg	Mn	Ni	Pb	Zn
5-Dec-2002	1	0.61	0.00892	0.18242	97.4	0.00022	0.00048	0.00659	0.00488	23.7	0.077214	0.01644	0.001	0.02058
	1	1.22	0.01510	0.14493	105	0.00016	0.00054	0.00771	0.00188	25.9	0.005950	0.01467	<0.001	<0.00036
	1	1.83	0.01009	0.12402	105	<0.00016	<0.00014	0.00800	<0.00078	26.4	0.166980	0.02961	0.001	<0.00036
	2	0.61	0.01608	0.12869	99.7	0.00018	<0.00014	0.00219	0.01029	11.70	0.120920	0.00484	<0.001	<0.00036
	2	1.22	0.04101	0.13441	91.4	0.00020	0.00037	0.00401	0.09174	11.69	2.217600	0.00918	0.002	0.006376
	2	1.83	0.01600	0.32610	108	0.00018	0.00015	0.00918	0.00993	27.2	0.366090	0.01614	<0.001	<0.00036
	3	0.61	1.23133	0.22846	71.1	0.00055	0.22620	0.01332	2.68230	37.5	0.258150	0.11492	0.026	0.13547
	3	1.22	0.00694	0.07079	9.93	<0.00016	0.00019	0.00211	0.01076	5.28	0.008245	0.00291	0.002	0.002697
	3	1.83	0.00469	0.02707	1.43	<0.00016	<0.00014	0.00063	0.00303	1.33	0.023791	0.00261	0.001	<0.00036
	4	0.61	0.01939	0.08169	68.1	<0.00016	<0.00014	0.00244	0.00479	27.4	0.004065	0.00078	0.002	<0.00036
	4	1.22	0.01042	0.10106	77.7	<0.00016	<0.00014	0.00173	<0.00078	30.6	0.004301	0.00178	<0.001	<0.00036
	4	1.83	0.01072	0.07922	84.1	<0.00016	<0.00014	0.00285	0.00145	30.7	0.004834	0.00254	<0.001	<0.00036
	5	0.61	0.02219	0.00263	29.6	<0.00016	0.00023	0.00203	0.02673	18.5	0.000558	0.00163	0.002	<0.00036
	5	1.22	0.00186	0.00448	24.8	<0.00016	0.00014	0.00116	0.00231	16.0	0.000289	0.00179	0.001	<0.00036
	5	1.83	0.00498	0.00581	41.2	<0.00016	<0.00014	0.00029	0.00117	23.7	0.000447	0.00352	0.002	<0.00036
	Reporting Limit		0.00108	0.00013		0.00016	0.00014	0.00033	0.00078		0.00027	0.00072	0.001	0.00036

[a] All samples analyzed by ICP. All analyses performed by US Navy FENA Lab, Guam

ELEMENTAL COMPOSITION[a] OF SOIL PORE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Depth (m)	Metal (mg/l)											
			Al	Ba	Ca	Cd	Cr	Cu	Fe	Mg	Mn	Ni	Pb	Zn
10-Jan-2003	1	0.61	0.02508	0.33703	177	<0.00016	0.00091	0.01252	0.01228	45.7	3.50980	0.06276	<0.001	0.06943
	1	1.22	0.02276	0.24018	173	<0.00016	0.00058	0.01069	0.03026	44.2	2.05560	0.04778	<0.001	0.00931
	2	0.61	0.01674	0.15576	116	<0.00016	<0.00014	0.00110	0.00386	14.1	0.14960	0.00459	<0.001	0.00542
	2[a]	1.22	<0.00108	<0.00013	0.26	<0.00016	<0.00014	<0.00033	<0.00078	0.01	0.01124	<0.00072	<0.001	<0.00036
	2	1.83	0.02227	0.30683	103	<0.00016	<0.00014	0.00713	0.01683	26.3	0.76309	0.01562	<0.001	0.01230
	3	0.61	0.01580	0.15472	21.0	<0.00016	<0.00014	0.00134	0.00994	12.7	0.00263	0.00092	<0.001	0.00987
	3	1.22	0.00490	0.12599	14.5	<0.00016	<0.00014	0.00128	0.00203	8.91	0.00413	0.00183	0.001	0.01260
	3	1.83	0.00819	0.06102	3.98	<0.00016	<0.00014	<0.00033	0.00101	3.23	0.04231	0.00395	<0.001	0.01326
	4	0.61	0.02767	0.09287	77.2	<0.00016	<0.00014	0.00139	0.00411	31.9	0.00305	0.00073	<0.001	0.00512
	4	1.22	0.02209	0.11639	89.0	<0.00016	<0.00014	0.00586	0.00248	34.8	0.00730	0.00142	<0.001	0.00909
	4	1.83	0.01710	0.09256	97.6	<0.00016	<0.00014	0.00180	0.00135	35.7	0.00167	0.00142	<0.001	0.00358
	5	0.61	0.01167	0.00233	31.4	<0.00016	<0.00014	0.00098	0.00579	19.9	0.00045	0.00083	<0.001	0.01075
	5	1.22	0.00586	0.00380	25.3	<0.00016	<0.00014	0.00051	0.00146	16.4	0.00049	0.00117	<0.001	0.00752
	5	1.83	0.00669	0.00549	43.5	<0.00016	<0.00014	<0.00033	0.00148	24.9	<0.00027	0.00129	<0.001	0.00470
	Reporting Limit		0.00108	0.00013		0.00016	0.00014	0.00033	0.00078		0.00027	0.00072	0.001	0.00036

[a] All samples analyzed by ICP. All analyses performed by US Navy FENA Lab, Guam; [b] Data set considered erroneous and omitted from all statistical computations

ELEMENTAL COMPOSITION[a] OF SOIL PORE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Depth (m)	Metal (mg/l)											
			Al	Ba	Ca	Cd	Cr	Cu	Fe	Mg	Mn	Ni	Pb	Zn
14-Feb-2003	1	0.61	0.02317	0.36864	186	<0.00016	0.00056	0.00991	0.01162	47.6	0.05427	0.01869	<0.001	0.12566
	1	1.22	0.02149	0.20093	134	<0.00016	0.00090	0.00756	0.00563	39.7	0.01490	0.01689	0.001	0.02387
	1	1.83	0.01198	0.15523	118	<0.00016	<0.00014	0.00128	0.00166	14.1	0.09786	0.00413	<0.001	<0.00036
	2	0.61	0.01466	0.18053	146	0.000181	0.00044	0.00838	<0.00078	37.9	0.01648	0.02171	<0.001	<0.00036
	2	1.22	0.01388	0.13549	93.3	<0.00016	0.00014	0.00218	0.03367	11.8	2.74320	0.00880	0.001	<0.00036
	2	1.83	0.00692	0.23057	81.6	<0.00016	<0.00014	0.00505	0.00216	19.8	0.37536	0.00935	<0.001	<0.00036
	3	0.61	0.00980	0.10320	13.2	<0.00016	<0.00014	0.00179	0.00376	8.32	0.00155	0.00089	0.002	<0.00036
	4	0.61	0.01563	0.09280	78.4	<0.00016	<0.00014	0.00180	<0.00078	32.0	0.00156	0.00126	<0.001	<0.00036
	4	1.22	0.01580	0.11528	90.2	<0.00016	<0.00014	0.00112	0.00180	35.0	0.00840	0.00161	0.002	<0.00036
	4	1.83	0.01328	0.10057	109	<0.00016	<0.00014	0.00220	<0.00078	39.5	<0.00027	0.00179	<0.001	<0.00036
	5	0.61	0.01674	0.00159	23.8	<0.00016	0.00018	0.00149	0.01978	14.8	0.00061	0.00118	0.002	0.00202
	5	1.22	0.00345	0.00257	23.3	<0.00016	0.00017	0.00079	0.00150	14.9	<0.00027	0.00157	0.002	0.01263
	5	1.83	0.00706	0.00486	46.0	<0.00016	<0.00014	0.00075	0.00148	25.5	<0.00027	0.00232	0.002	<0.00036
	Reporting Limit		0.00108	0.00013		0.00016	0.00014	0.00033	0.00078		0.00027	0.00072	0.001	0.00036

[a] All samples analyzed by ICP. All analyses performed by US Navy FENA Lab, Guam

ELEMENTAL COMPOSITION[a] OF SOIL PORE WATERS DOWNGRADIENT OF ORDOT LANDFILL

Date	Site	Depth (m)	Metal (mg/l)											
			Al	Ba	Ca	Cd	Cr	Cu	Fe	Mg	Mn	Ni	Pb	Zn
31-Jul-2003	1	0.61	0.01834	0.15153	78.7	<0.00016	0.00048	0.00459	0.00385	19.4	0.00349	0.00556	<0.001	0.02136
	1	1.22	0.01872	0.10674	84.6	<0.00016	0.00037	0.00548	0.00189	18.9	0.00161	0.00464	<0.001	0.01279
	1	1.83	0.14076	0.34694	336	<0.00016	0.00118	0.06385	0.00496	83.4	0.00326	0.02591	<0.001	0.02011
	2	0.61	0.01516	0.05523	45.2	0.000173	<0.00014	0.00141	0.00246	5.03	0.00086	0.00201	<0.001	0.01298
	2	1.22	0.00894	0.06891	50.3	<0.00016	<0.00014	0.00283	0.00130	5.68	0.02368	0.00156	<0.001	0.01014
	2	1.83	0.01132	0.17419	68.3	<0.00016	0.00021	0.00391	0.00144	16.4	0.02653	0.00351	<0.001	0.00625
	3	0.61	0.00788	0.13458	18.4	<0.00016	0.00019	0.00300	<0.00078	10.3	<0.00027	0.00082	<0.001	0.00437
	3	1.22	0.00443	0.06211	6.64	<0.00016	<0.00014	0.00105	<0.00078	4.34	0.00236	0.00274	<0.001	0.00956
	3	1.83	0.01875	0.03101	2.10	<0.00016	0.00018	0.00087	0.00105	1.83	0.01241	0.00287	<0.001	0.00924
	4	0.61	0.01864	0.06170	54.4	<0.00016	<0.00014	0.00466	0.00206	21.6	0.00130	0.00124	<0.001	0.00802
	4	1.22	0.01708	0.07616	64.3	<0.00016	<0.00014	0.00388	0.00236	25.0	<0.00027	0.00149	<0.001	0.00660
	4	1.83	0.02029	0.04448	59.3	<0.00016	0.00018	0.00454	0.00281	21.4	<0.00027	0.00149	<0.001	0.00512
	5	0.61	0.00987	<0.00013	17.0	<0.00016	0.00034	0.00279	0.00302	10.7	<0.00027	0.00242	<0.001	0.01090
	5	1.22	0.01046	0.00115	15.9	<0.00016	0.00031	0.00169	0.00186	10.1	<0.00027	0.00154	<0.001	0.00505
	5	1.83	0.00737	0.00218	28.4	<0.00016	0.00021	0.00055	0.00144	15.7	<0.00027	0.00173	<0.001	0.00630
	Reporting Limit		0.00108	0.00013		0.00016	0.00014	0.00033	0.00078		0.00027	0.00072	0.001	0.00036

[a] All samples analyzed by ICP. All analyses performed by US Navy FENA Lab, Guam