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Impact of Ordot Dump on water quality of the Lonfit River basin in central Guam. 2. Aqueous chemical and biological contaminants

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Abstract—Leachate samples taken from the perimeter of the Ordot Landfill, in central Guam, were screened for priority pollutants listed under Section 307(a) of the Clean Water Act. Identified contaminants of concern were the fecal indicator bacteria, *Enterococci* and *E. coli,* inorganic nitrogen (N) and phosphorus (P), and several heavy metals. These contaminants were monitored in surface and subsurface waters down gradient of the landfill at monthly intervals for one year. Fecal indicator bacteria MPN counts in receiving surface waters dropped sharply within a few hundred meters downstream of leachate stream impaction points. However, values often exceeded the U.S. EPA recreational water quality standards all the way to the coast. Inorganic N was dominated by ammonium in the leachate stream and nitrate in the river. Occasional exceedences of the U.S. EPA surface water quality standard for nitrate (as NOx) were observed at all downstream sites. Inorganic (reactive) P was mostly undetectable in surface waters despite relatively high levels in the leachate stream. Likewise, heavy metal contaminants that were enriched in the leachate stream were mostly close to the limits of analytical detection in the river. Soil pore waters collected at various depths (0.61-1.83 m) ~100 m down gradient of the landfill were comparatively free of fecal indicator bacteria. Inorganic nitrogen levels, though enriched, were appreciably lower than those in the leachate stream, suggesting either denitrification, high assimilation by soil microbes, and/or high sorption by clays. Average P levels were also low suggesting removal by oxidic iron in surface layers. Neither inorganic N nor P concentrations varied significantly with soil depth. In contrast, mean pore water concentrations of aluminum, cadmium, iron and zinc were generally more concentrated at the shallowest soil 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.

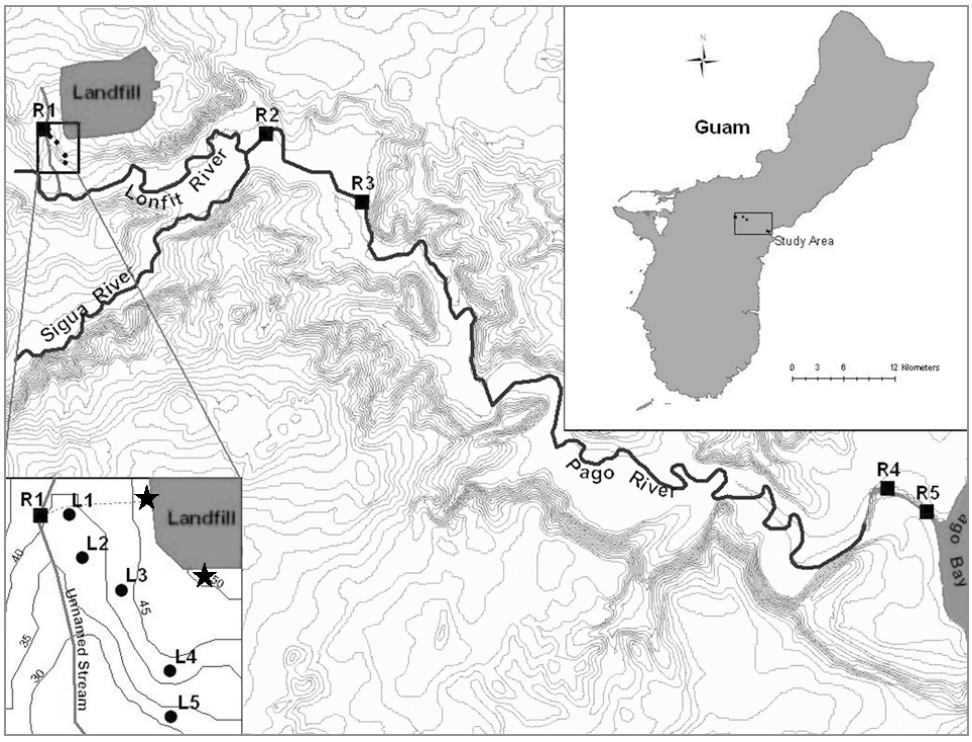

Figure 1. Map of study area showing location of leachate (*), surface water (R1-R5) and pore water (L1-L5) collection sites down gradient of Ordot Landfill, Guam.

Introduction

The only civilian landfill in Guam is located just outside the village of Ordot in the central part of the island. This facility 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 primary 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 landfill 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).

Ordot landfill was slated for closure over 30 years ago and has been operating at over capacity for at least 20 years (Mendoza, 1997). It currently

occupies an area of ~24 hectares 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, which in turn drains into Pago Bay on the eastern side of the island. In terms of water quality, these rivers are categorized as S-2 (medium quality) waters that may be used for recreational purposes, including swimming, potable water supply after treatment, the propagation and preservation of aquatic wildlife, and aesthetic enjoyment (GEPA 2001).

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, the seasonally dependent streams of brown, foul smelling liquid that emerge along the western edge and southern toe of the landfill, saturate the surrounding soil and ultimately move down gradient into the Lonfit River. To date, the chemical composition of this leachate has received relatively little attention despite the unrestricted dumping of hazardous wastes at the landfill in earlier times.

The first chemical analyses of leachate from Ordot 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 (U.S. EPA 2002). These included 21 trace elements, 21 pesticides, 15 organic solvents, seven commercial PCB mixtures, two phthalate esters, cyanide, total petroleum hydrocarbons, N and P. Nutrients and heavy metals were among most frequently encountered contaminants and were often found at levels that exceeded Guam surface water quality standards. Of the 46 organic compounds tested for, only the non-priority pollutant 2-butanone was ever detected.

Given the close proximity of Ordot landfill 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. For this reason, a pilot study was undertaken to determine the levels of biological and chemical contaminants in leachate streams arising from the landfill and monitor their surface and subsurface movement down gradient into the adjacent waters of the Lonfit and Pago Rivers (Fig. 1). The findings of the study are presented here. The physical and chemical characteristics of soils in the area were reported earlier (Golabi *et al*. 2006)

Materials and Methods

Sample Collection

Leachate: In December 2002, leachate samples were collected for bacteriological and chemical analysis, from two separate streams along the

southern face 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 and 75 semi volatile organic compounds.

Samples for bacteriological analysis were collected in sterile polycarbonate 100-ml bottles while those for organic chemical and metal analysis were captured in amber glass and high-density polypropylene bottles respectively. None of these samples were filtered. Those for metal analysis were preserved with concentrated nitric acid (1 ml/L) for 'total' metal determinations. A single 25-ml leachate sample taken from the southern site was filtered for 'soluble' metal analysis. This was accomplished by withdrawing the sample into a pre-cleaned 50-ml polypropylene syringe and passing it 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 collected from both leachate streams for nutrient analysis were similarly filtered 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 collected at approximately monthly intervals (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 here were taken ~300 m upstream of the confluence point and ~150 m down-gradient 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 River. 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 surface in hand-held polycarbonate containers. Those required for nutrient and metal analyses were withdrawn directly into pre-cleaned, 50-ml polypropylene syringes and filtered (0.45 μm) into acid washed 80-ml polyethylene vials as described above. Particulate bound metals and nutrients retained by the filter were not analyzed. All samples were chilled immediately.

Subsurface Soil Pore Waters: Pore water samples were only available after significant rain events and were mostly confined to the wet season. They were collected from five sites (L1-L5) across the southwestern toe of the landfill (Fig. 1) and analyzed for the same suit of contaminants as the surface water samples. The sites were all downgradient of the landfill at distances ranging from ~100-250 m from the leading edge. Ceramic suction cup, vacuum lysimeters (mean 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 chilled immediately and those for metal analyses were later acidified in the laboratory.

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 (nitrate-N and nitrite-N collectively analyzed as NOx-N, ammonium-N and reactive-P) were performed within 24-h of sample collection using a multi-channel *Quickchem 800,* flow injection analyzer (Lachat Instruments). 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 metal and organic chemical determinations of aqueous samples, including the two unfiltered leachate samples, were outsourced to certified analytical laboratories.

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 difference ($P<0.05$) in pore water concentrations of nutrients and heavy metals (Kruskal-Wallis ANOVA and multiple comparison test). All computations were performed using the 'Number Cruncher Statistical Systems 2000' software package (Hintze 2001).

Results and Discussion

The biological and chemical contaminants detected in leachate samples are listed in Table 1. Eleven contaminants (bacteria, inorganic N and P, several metals and cyanide) were found at levels that equaled or exceeded existing surface water quality standards. 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

Table 1. Biological and chemical contaminants in unfiltered leachate from Ordot Landfill.

Pollutant	Units	Results	Standards*
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	-

Table 1, cont.

Pollutant	Units	Results	Standards*
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	-

* Guam Water Quality Standards for Category S-2 Surface Waters.
Notes: (a) Standard is geometric mean of five sequential samples taken over a thirty day period. The number in parenthesis is the maximum allowable instantaneous 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.

degraded in the environment. 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). The only pesticide detected, out 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 compounds were not detected. Nevertheless, a total 2,3,7,8-TCDD toxicity equivalent concentration (TEQ) of 214 pg/l was calculated for all detectable congeners, with the hepta- and octa-chlorinated dioxins contributing to most of

the sample TEQ. While there is currently no surface water quality standard for 2,3,7,8-TCDD, the Guam safe drinking water standard is just 0.03 pg/l.

Fecal indicator bacteria, inorganic N and P, and heavy metals were the most abundant contaminant groups present in the leachate samples. The migration of these contaminant groups from the landfill down gradient into the Pago River watershed in surface and subsurface flows is discussed below.

FECAL INDICATOR BACTERIA

Enteric bacteria like *Enterococcus* and *E. coli* generally have limited survival times in the environment. Their presence in natural waters is therefore presumed to reflect recent fecal contamination. While this assumption generally holds true for cooler latitudes, it is seriously compromised in tropical regions where free-living forms of *Enterococcus* and *E. coli* can survive indefinitely in warm, moist soil and sediments (Hazen 1988, Hardina and Fujioka 1991, Davies *et al*. 1995, Desmarias *et al*. 2002). The bacteriological tests adopted during this study do not differentiate between fecal and non fecal sources of *Enterococcus* and *E. coli*, nether do they discriminate between human and animal wastes. That said, they continue to be used to monitor the hygienic quality of recreational waters in the absence of suitable alternatives.

Enterococcus and *E. coli* counts in leachate exceeded the Guam recreational water quality standards for both marine and freshwater environments by at least three orders of magnitude. Such high numbers greatly exceed background densities of these organisms normally encountered in Guam's streams and rivers and presumably 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.

Densities of both indicators rapidly diminished downstream (Table 2) and were consistently within acceptable limits at sites R2 and R3 during the dryer months (Dec-June). However, exceedences were usually observed at both sites during the wet season, and may in part reflect microbiological contributions from river bank erosion. Surprisingly, exceedences for both fecal indicators were observed throughout much of the year at sites R4 and R5 in the Pago River estuary. The higher incidence of exceedences noted in this region compared with further upstream, clearly cannot be attributed to runoff from the landfill and may reflect seepage from residential septic tanks or highway runoff. Other potential sources in this area include domestic animals, watercraft, a nearby sewage lift station, and a small sewage treatment plant (aerated sludge system) that services about 15 houses.

The Guam Environmental Protection Agency (GEPA) regularly monitored fecal coliforms in the Lonfit and Pago Rivers, between 1974 and 1998. The elevated bacterial counts that were frequently recorded in the Pago River estuary

Table 2: Bacteriological data summary of unfiltered surface waters collected down-gradient of Ordot Landfill

Site #	Description	Downstream Distance from Landfill (m)	N	MPN Index/100 ml, geometric mean (range)		
				Total Coliforms	*E. coli*	*Enterococci*
R1	Unnamed stream	150	13	63,690 (17,329–1,046,224)	1,270 (262–5,012)	3,014 (211–17,239)
R2	Pago River	1,400	13	12,682 (4,352–24,192)	52 (5–359)	100 (20–703)
R3	Pago River	1,700	13	14,276 (4,160–64,880)	67 (10–369)	140 (30–816)
R4	Pago River estuary	5,250	13	24,684 (8,050–72,700)	291 (51–1,609)	152 (5–2,942)
R5	Pago River estuary	5,450	13	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

Table 3: Bacteriological data summary of ceramic cup filtered soil pore waters collected down-gradient of Ordot Landfill.

Soil Depth (m)	N	MPN Index/100 ml, mean* (range)		
		Total Coliforms	*E. coli*	*Enterococci*
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

Table 4. Nutrient Data Summary of Filtered Surface Waters Collected Down Gradient of Ordot Landfill

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

Table 5: Nutrient Data Summary of Ceramic Cup Filtered Soil Pore Waters Collected Down Gradient of Ordot Landfill

Depth (m)	Nutrients (mg/l), mean (range)		
	NOx-N	Ammonia-N	Ortho-P
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

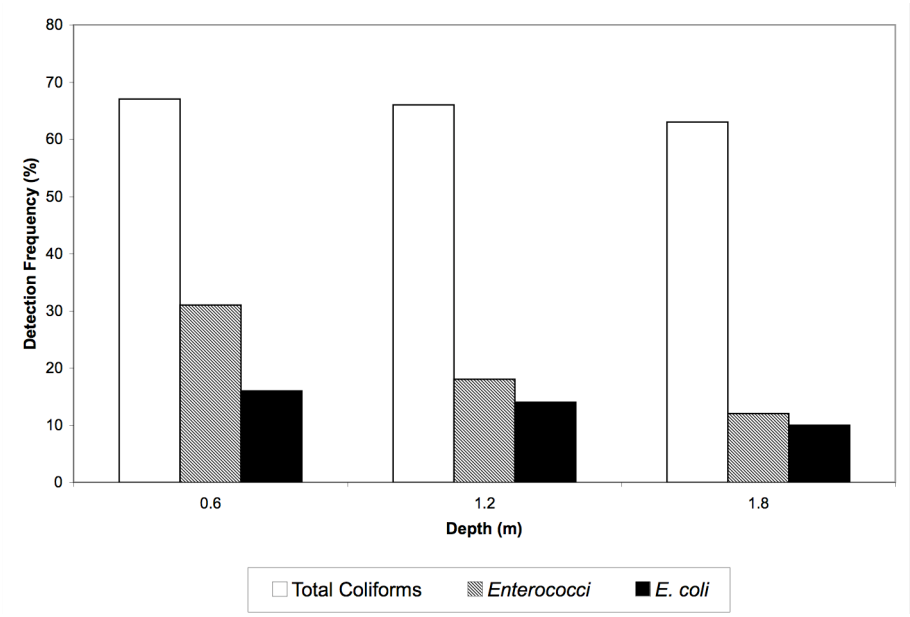

Figure 2: Frequency distribution histogram of bacteria detections in pore waters down-gradient of Ordot Landfill, Guam

were assumed to reflect contributions from the landfill. Our study clearly demonstrates that this is not the case.

Bacterial densities in soil pore waters down gradient of the Ordot landfill were surprisingly low considering the extremely high numbers present in leachate (Table 3). MPN counts for total coliforms rarely exceeded 1000 (per 100 ml sample) and were mostly below 100. Densities of both fecal indicator bacteria rarely exceeded 10. Whether this is because bacteria in the leachate 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.

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. 2). This was especially noticeable for *Enterococci,* detectable in 31% of samples collected at 0.6 m compared with only12% at 1.8 m.

INORGANIC NITROGEN AND PHOSPHORUS

Concentrations of inorganic N in the oxygen depleted leachate samples were particularly high with ammonium predominating (Table 1). Further downstream NOx (mostly nitrate) was the most abundant inorganic form (Table 4). All

downstream surface water sites revealed substantial inorganic N enrichment despite levels generally decreasing with increasing distance downstream of the landfill. Levels reported here were generally higher than those found upstream of the landfill by earlier investigators (U.S. EPA 2002).

Inorganic (reactive) P was seldom detected in surface water samples downstream of the landfill (Table 4). Presumably, this nutrient is rapidly scavenged from solution by iron and manganese oxyhydroxides formed at redox boundaries as oxygen levels improve in emergent leachate streams.

Nurtient levels found in soil pore waters over the study period are summarized in Table 5. The data was highly variable, especially for NOx. Statistical analysis of all data sets failed to find any depth-dependant relationships ($P>0.05$). NOx enrichment was evident at all three depths, often excessively so. These findings highlight the mobility of the nitrate anion down through the soil profiles and could account, at least in part, for the relatively lush vegetation growing further down the watershed. Ammonium-N and reactive P levels were generally low at all depths possibly as a result of soil adsorption processes.

METALS

Thirteen elements were detected in leachate samples at levels several orders of magnitude above those normally encountered in river waters (Wilson 1980, Denton et al. 1998). Seven of them (aluminum, arsenic, chromium, copper, lead, nickel and zinc) equaled or exceeded existing surface water standards in at least one of the samples. Aluminum, boron and iron were the most abundant metals identified. Cadmium, mercury and silver were not detected in either sample. For those elements analyzed in both filtered and unfiltered samples, levels were consistently higher in the latter. This was especially true for aluminum, which was present almost exclusively in the particulate form (Table 1).

Evidence of metal enrichment in surface waters was only seen at site R1 and only for barium, chromium, copper, iron, manganese and nickel (Table 6). Although copper and nickel were found in the majority of surface water samples from the upper reaches of Pago River, both elements were undetectable in the estuary. Quantifiable levels of chromium, lead and zinc were seldom encountered at any site in the Pago River and cadmium concentrations were consistently below the limits of analytical detection.

A summary of the elemental composition of pore waters collected over the study period is presented in Table 7. Levels of all elements varied appreciably over time at each depth. However, significant depth-dependant relationships were identified for aluminum, cadmium, iron and zinc with the highest levels of each occurring in the shallowest pore waters.

Table 6. Elemental Composition of Filtered Surface Waters Collected Down Gradient 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 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.

Table 7: Elemental composition of ceramic cup filtered soil pore waters collected down gradient 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.

Although most elements were substantially enriched in soil pore waters compared with levels found in Pago River, maximum levels of aluminum, barium, chromium, copper, iron, lead, nickel and zinc were within the concentration ranges found in leachate samples. This infers that there is some subsurface movement of these elements from the landfill into the underlying soil. However, with the possible exception of barium, all appear to be rapidly attenuated in the deeper layers, presumably as a result of soil adsorption processes.

Concluding Remarks and Recommendations

In the current study, we have 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 a number of other organic constituents in the mix, albeit at low levels, including several relatively toxic dioxin and furan congeners. The study further 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 nitrogen 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 adjacent to 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 twelve 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 (U.S. EPA 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 implies 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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