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METAL CONCENTRATIONS IN GUAM URBAN RUNOFF

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of the
Western Pacific

Technical Report No. 25

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for

HEAVY METAL CONCENTRATIONS IN GUAM URBAN RUNOFF

OWRT Project No. A-011-Guam, Grant Agreement No. 14-34-0001-9012

Principal Investigator: Stephen J. Winter

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ABSTRACT

Five sets of water samples were collected over a three-month period and analyzed for dissolved metals, and in some sets, suspended metals. The 13 metals investigated were arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, silver and zinc.

Concentrations (in µg/ℓ range) of these metals were generally lower than observed in other U. S. communities. Runoff samples collected from commercially developed areas were generally much higher in metals than runoff from residential areas. Likewise, the metal concentrations were usually much higher as suspended metal as opposed to dissolved metal.

Concentrations of arsenic, barium, selenium and silver were very low and most likely are not affecting groundwater or coastal receiving-water quality. Concentrations of mercury, cadmium, and lead in urban runoff at times or at specific sampling locations approached or exceeded drinking and surface water quality standards. Measurements of pH, total solids, hardness, and other parameters indicate that urban runoff quality has not changed appreciably in the past four years in comparison to previous testing.

Guam's urban runoff is of relatively high quality with respect to metals and, with the possible exception of mercury, lead, and cadmium, environmental degradation by metals is probably minimal. Further analyses of receiving waters, sediments and biota and additional limestone precolation studies are needed to determine the distribution of metals in Guam's environment.

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INTRODUCTION

From November 1975 through May 1977 a comprehensive study of urban runoff water quality was conducted that included sampling from 15 different runoff collection sites in northern Guam (Zolan et al., 1978). Heavy metal analyses were not performed as part of that study. This present study was conducted to gather heavy metal data from five of the previously studied sampling sites with the objective of characterizing Guam's urban runoff with regard to metal pollution.

The number of runoff sampling sites was limited to the five which best characterized runoff from commercially and residentially developed areas on Guam. There are no industrial areas in northern Guam. One of the commercial study sites selected allows urban runoff to flow into nearshore marine waters. The other four sites empty into ponding basins or sink areas and allow waters to percolate into the limestone substrata.

Practically all of northern Guam serves as a recharge watershed for the underground aquifer that supplies most of Guam's drinking water. Future economic development will mean increasing dependence upon this aquifer for potable water. The possible contamination of the aquifer by human activities associated with urban development and agriculture is a major concern.

The Guam Environmental Protection Agency has enacted water quality standards and pollution control regulations (GEPA, 1975, 1977) concerning construction and the discharging of wastewaters in aquifer recharge areas. These standards are taken directly from the 1972 NAS-NAE 1972 Report of the Committee on Water Quality Criteria (NAS-NAE, 1974). Marine waters, as receiving waters, are also protected by these regulations. Metal pollution is covered by separate maximum allowable concentrations for drinking waters and surface waters. Runoff waters are exempted from surface water limits. However, once they percolate below the surface they become waters (class 1b) that recharge groundwaters which are used as a drinking water resources, are potential drinking waters, or are marginal groundwaters (classes 1b-I, 1b-II, 1b-III respectively). The percolating groundwaters of class 1b-I are kept free of pollution, the other two classes specify treatment of any discharges to protect groundwater quality for their categorized use (GEPA, 1975).

The 13 metals selected for investigation include all metals covered by the drinking water standards and all but six metals covered by surface-water quality standards. The six metals not investigated either did not have maximum numerical limits listed in the standards or are usually associated with specific industrial wastewaters.

Although a large volume of metal pollution research has been conducted, much of it deals with specific problems or areas, making direct comparisons to Guam conditions dubious. Factors which influence metal concentrations in runoff, such as land use, particle size, rainfall activity and metal solubility are well-covered by Burrell (1974) and by the EPA (1973). The last document constructs a metal loading projection for a hypothetical city

based on data accumulated from urban areas across the United States. Review literature by Goyer and Mehlman (1977), Abernathy (1978), EPA (1975), Burrell (1974), Ming et al. (1973) and Chapman (1978) discuss the toxicological ramifications of metal pollution along with other topics concerning metals in urban runoff.

There is very little data on metal concentrations in Guam urban runoff. A single sampling of the Continental Hotel storm drain runoff was analyzed for five metals (Clayshulte and Zolan, unpublished) of which chromium was found to be the only major contaminant (in excess of the drinking water standard). Receiving waters were not measurably degraded by this discharge. Two samples of urban runoff from GHURA 502 and Baza Gardens housing developments were analyzed for metals covered by drinking water standard in 1979. The analyses was performed by the U.S. Navy Laboratory at the Fena Reservoir for Pacific Basin Consultants. Results showed concentrations of all metals to be less than the maximum allowable limits.

The GEPA has conducted two series of metal analyzes of the 67 wells used for drinking water supplies. The initial testing in 1976 revealed metal contamination of some well waters by cadmium. However, a follow-up survey (in December, 1978) failed to confirm the earlier results. The 1978 series of analyses are used for comparison to urban runoff concentrations in this report. The GEPA also conducts annual tests of the distribution system waters. The published data (EPA, 1979) show levels of arsenic and manganese within 10% of the standard limit. The concentrations of the other metals covered by the drinking water standards are well below the limits allowed.

The United States Geological Survey (USGS) monitors metal concentrations quarterly in the Pago River below the confluence of the Lonfit and Sigua Rivers. Their results are published annually. Their latest results (USGS, 1980) are used for comparison to the urban runoff metal concentrations.

METHODS

Sampling Locations

The five sampling sites that were chosen for study had been included in the previous urban runoff study by Zolan et al. (1978). Two of the five sites are runoff collection points for the commercial area along Route 1, Tamuning. The remaining three sites, located at ponding basins, receive runoff from residential subdivisions in northern Guam.

One of the sites located in the commercial district was at the storm water culvert between the Johnston Theater and Marks L. P. Gas store on Sereno Ave. (Figure 1). The culvert discharges into an open ditch which leads to the sea some 350-400 m away. The ditch was dredged out in 1978 at the time the cement culvert was put into place. This new culvert was constructed to increase the carrying capacity of the storm water collection system as well as to put it entirely underground. During the previous runoff study (Zolan et al., 1978) storm and runoff waters flowed along Route 1 in an open ditch to the Route 1 Camp Watkins Road intersection and then to the Sereno Avenue outlet by a series

of open ditches and drainage pipes. At the time of the heavy metal sampling, the drainage ditch had returned to the pre-1978 condition of having its banks lined with tall grass and weeds and the ditch itself was choked with a variety of grasses and aquatic plants (Hydrilla verticillata being the major aquatic plant). Runoff at this site is derived from Route 1 and paved and unpaved areas along Route 1 to the north and east of the culvert. Samples of running water leaving the culvert were collected.

The other site selected in the Tamuning commercial area was the drainage basin adjacent to the Mendiola Hotel and Hertz Rental Car off Chalan Pasajeros (Airport Road) (Figure 2). Just prior to the start of the heavy metal sampling program, the cement lined drainage basin was cleared of coral rubble and sediment deposits that had accumulated over the previous four years as a result of natural deposition and construction activity related to the new airport terminal presently under construction. Runoff collected at this site is derived from the airport runway and apron areas to the south of the present terminal and from streets and parking areas in front of the terminal. Samples of ponded runoff were collected at the confluence of the two runoff ditches adjacent Hertz Rental Car.

One of the residential area ponding basins selected for study was ponding basin L-2 at Latte Heights Estates at the corner of Daisy Lane and Macheche Road. This subdivision consists of single unit dwellings. Samples were collected from the pool at the base of the cement chute in the south-west corner of the basin (Figure 3). The runoff at this stie is derived from yards and streets (feeding into Daisy Lane) in that sector of the subdivision.

A second site representative of residential development was selected at the Perez Acres subdivision ponding basin on the north side of Chalan Lujuna (Figure 4). This subdivision consists of townhouse style multiple unit dwellings that were built in 1974. A permanent pond has formed since that time. The ponding basin collects runoff from all areas of the development. Since the previous urban runoff study, the areas inside the fence surrounding the pond have completely overgrown. Because of this, samples of ponded runoff were collected approximately 20m north of the southernmost drain pipe opening.

The third sampling site representative of residential development was at the ponding basin below Barrigada Heights. The basin system is located along the right-hand side of Route 16 at the sharp turn heading north prior to reaching the main turn-off to the subdivision. The sampling site was at the opening of the cement storm water drains that open at the north-east end of the ponding basin system (Figure 5). This site was designated B2 in the previous urban runoff study (Zolan et al., 1978). Runoff is derived from paved and unpaved areas in and surrounding the subdivision. No changes or additions were noted in the drainage configuration from four years ago except that the entire ponding basin system was overgrown by vegetation and a machete was required to reach and clear the sampling site. A more detailed description of all five sites is given in the Zolan et al. (1978) report.

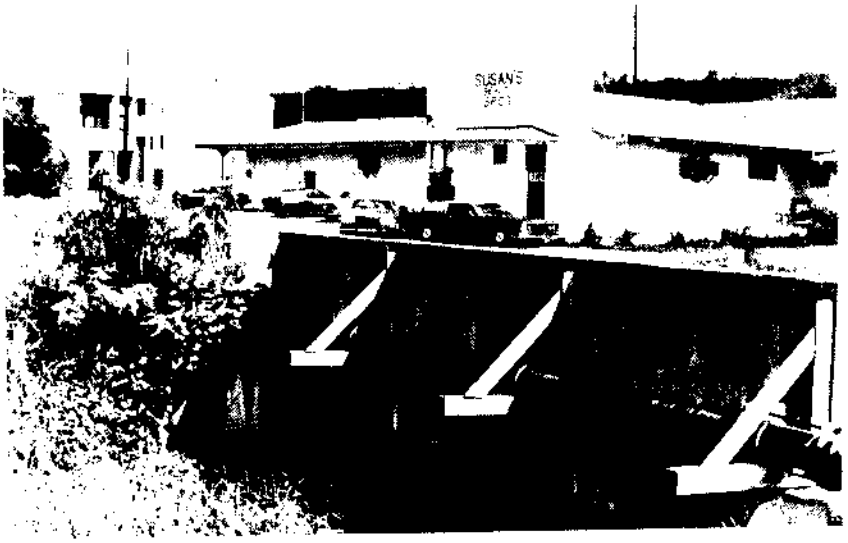

Fig. 1. Sampling location at the storm water culvert on Sereno Avenue, Tamuning.

Fig. 2. Sampling location on Chalan Pasajeros (Airport Road).

Fig. 3. Sampling location at the bottom of chute in ponding basin L-2 of Latte Heights Estates.

Fig. 4. Perez Acres ponding basin. The water surface is covered by Hydrilla verticillata.

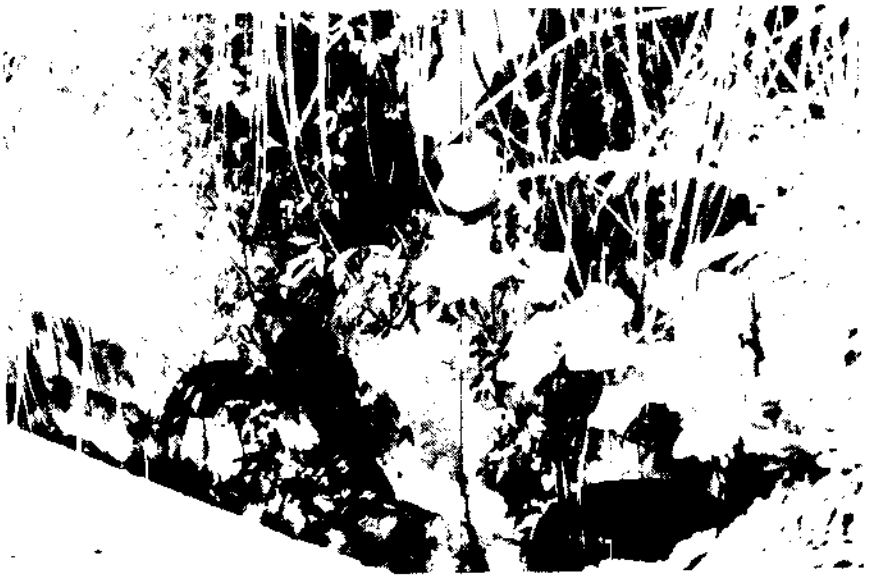

Fig. 5. Sampling site at the Barrigada Heights ponding basin system. The double pipe opening lies at the northern end of the system.

Sampling Techniques

Five sets of samples were collected during the course of the study. The samples were analyzed for 13 metals: arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, and zinc. In addition, field pH, specific conductance, chlorides, total non-filterable residue, volatile total non-filterable residue, total hardness, and calcium hardness were determined for most samples to determine if runoff characteristics at the sites had changed over the past four years. These parameters also influence the retention or removal of dissolved metals in natural and runoff waters. Samples were collected July 31, August 11, August 20, August 27 and October 27, 1980.

All samples were collected in 500 mℓ white linear polyethylene bottles that had been precleaned by letting them sit in Nochromix acid solution overnight and then rinsed with distilled-deionized water to remove all traces of the acid. Sampling was done by hand by holding the bottles below the surface. At pooled runoff sites, the bottle was drawn through the water to decrease the chance of contamination by the technician. When the water was flowing the bottle was held from behind and allowed to fill by the flowing stream. Samples that were collected for unfiltered total metals were acidified at the site with 5 mℓ ultrex nitric acid. Samples that were collected for dissolved and suspended metals were returned to the lab, filtered through acid-washed 0.45 μm membrane filters and then acidified with ultrex nitric acid (1 mℓ/100 mℓ filtrate). The membrane filters in the last three samplings were saved and analyzed for suspended metal concentrations. All sample preparation and digestion procedures were according to Methods for Chemical Analysis of Water and Wastes (EPA, 1979). Special digestion procedures were used on sample aliquots to release organically bound mercury and arsenic. These procedures were according to EPA methods (EPA, 1979). Resulting concentrations of these metals are total dissolved and total suspended arsenic and mercury. Flameless methods were used throughout since initial flame analyses showed very low metal concentrations. The flameless methods were according to the EPA (1979) methods book or to the analytical manuals provided with the HGA2200 and mercury/hydride MHS-10 system (Perkin Elmer, 1978, 1979). Appendix A gives the burning programs of all elements used in these procedures. A recorder (Hitachi Model 56) was set to monitor the absorbance signal at 10 mv. For most elements, the spectrophotometer was operated with automatic background correction. Otherwise, separate tests of each sample were run to see if background radiation was elevating the absorbance signal and the necessary corrections were made.

Standard curves were run daily or more frequently for each element being tested to check instrument and matrix performance. Standards were prepared from commercial (Alpha Analytical Laboratories) stock solutions. The method of standard additions was used to check matrix affects on metal absorption.

pH was measured with an Orion field model 407 pH meter. Chlorides were determined by mercuric nitrate titration (APHA, 1975). Specific conductance was determined at the sampling site with a Lab-Line Lectro Mho Meter. Residues and hardness tests were performed according to "Standard Methods" (APHA, 1975) using 105° drying temperature for total residue.

RESULTS AND DISCUSSION

Dissolved metal concentrations in urban runoff varied considerably from sample to sample (Tables 1-5). The coefficient of variation (the standard deviation as % of the mean) ranged from 45 to 251 percent (Table 6). Variation in concentrations over time would be expected since many variables are involved in determining the initial metal concentrations and their retention or removal in runoff waters. Also, the concentrations are more susceptable to changes in environmental conditions from sampling period to sampling period. As a result, the average concentrations presented here may not accurately reflect the true average concentrations of metal runoff if more numerous samples were drawn over a longer period of time. More valid are the overall concentration ranges observed, the tendency for certain metals to be much more highly concentrated as suspended metals versus dissolved metals, and the trends of metals noted to be more concentrated in commercial runoff versus residential runoff (Table 6).

Metal concentrations in urban runoff from commercially developed areas were significantly (t distribution, = 0.05) higher than metal concentrations from residential areas (Table 6). Only cadmium, mercury and zinc were not significantly higher in commercial runoff. Arsenic was significantly higher in commercial runoff when using a t = 0.10 level of significance.

The initial comparison of unfiltered acidified samples to filtered then acidified samples showed such inconsistency (See Appendix B) that prefiltering and separate determinations for suspended and dissolved metals is recommended in future metal analyses of urban runoff when both fractions are required. At times, the amount of metal in suspended material may exceed dissolved metal by a factor of 10 or more.

Urban runoff waters are classified as class 2c waters under current waters quality standards (EPA, 1975). As such, they are exempt from numerical concentration limits. However, the concentrations still must not reach levels which degrade receiving water quality whether these are surface or groundwater. The standards for both surface waters, drinking waters and well water metal concentrations are presented in Table 7. The metal concentrations of a similar urban runoff study in northern Virginia (Randall et al., 1978) are presented for comparison to Guam urban runoff (Table 8).

The 13 metals studied can be divided into three groups based on their concentrations in runoff as related to Guam water quality standards for drinking and surface waters. Those metals which were not observed to approach drinking or surface water quality standards can be put into the first group. These metals are arsenic, barium, selenium and silver (Table 7). The second group are those metals which did not exceed drinking water standards but did occassionally or frequently approach or exceed surface water quality standards. These metals include chromium, copper, iron, manganese, nickel and zinc. These metals represent low level pollutants but an adequate assessment of the problem requires further work to determine additional runoff, receiving water, sediment, and biota concentrations of these metals. The third group are those metals which were found to approach or exceed drinking water standards and, if not removed from the dissolved state by precipitation, adsorption to substrata or other means, represent possible pollutants to Guam's drinking water supplies. A comparison

Table 1. Dissolved and suspended (in parenthesis) metal concentrations at the Sereno Avenue drainage ditch in Tamuning. Metal concentrations are in µg/ℓ.

	7/31/80	8/11/80	8/20/80	8/27/80	10/27/80	$\bar{X}$ (Zolan et al., 1978)	S (Zolan et al., 1978)	N (Zolan et al., 1978)
Arsenic	0.6	2.1	1.9 (2.3)	2.2	--			
Barium	15	2.5	25 (16)	37	--			
Cadmium	0.3	1.4	0.3 (4.8)	5.6	0.4 (28)			
Chromium	27	12	15 (5)	22	--			
Copper	60	11	38 (59)	74	18 (274)			
Iron	220	150	250 (1380)	72	88 (1812)			
Lead	7	52	32 (160)	18	15 (330)			
Manganese	44	41	52 (122)	47	--			
Mercury*	0.4	0.6	1.9	2.3 (1)	3.8 (14)			
Nickel	32	24	5.2 (11)	20	--			
Selenium	<0.2	<0.2	<0.2 (<0.2)	0.4	--			
Silver	0.1	0.4	0.5 (0.5)	<0.1	--			
Zinc	7.8	20	26 (6.2)	14	22 (122)			
pH	7.86	7.79	7.97	7.26	7.50	7.05	0.17	3
Temperature (°C)	31	28.5	28.8	29	27.7	29.8	0.9	3
E.C. (µmhos/cm)	853	228	253	1310	293	737	334	3
Chloride (mg/ℓ)	119	27	22	258	27	62	61	3
Total Hardness (mg/ℓ$CaCo_3$)	94	72	68	144	93	231	108	3
Calcium Hardness (mg/ℓ$CaCo_3$)	77	72	62	128	83	190	120	2
TNFR (mg/ℓ)	--	--	19	6.6	16	10.6	8.6	3
VTNFR (mg/ℓ)	--	--	5	3.6	4.8	5.9	4	3
Total Residue (mg/ℓ)	--	--	--	696	162	1180	--	1
Volatile Total Residue(mg/ℓ)	--	--	--	74	42	--	--	--

*Total dissolved metal, including organically bound metal.

Table 2. Dissolved and suspended (in parenthesis) metal concentrations of runoff collected at the storm drainage ditch on Chalan Pasajeros. Metal concentrations are in µg/ℓ.

	7/31/80	8/11/80	8/20/80	8/27/80	10/27/80	$\bar{X}$ (Zolan et al., 1978)	S	N
Arsenic*	5.2	<0.2	0.3 (3.5)	0.2	--			
Barium	12	8	7 (8)	18	--			
Cadmium	1.9	2.2	0.6 (9.1)	0.2	0.2 (80)			
Chromium	4	4	7 (27)	8	--			
Copper	95	18	8.4 (3.2)	36	10 (22)			
Iron	220	26	26 (168)	32	8 (245)			
Lead	7	13	2 (20)	5	<1 (32)			
Manganese	23	6.5	2.6 (12)	7.1	--			
Mercury*	0.5	0.8	0.8	1.8 (2.1)	2.2 (6)			
Nickel	11	69	10 (9.9)	12	--			
Selenium	<0.2	<0.2	<0.2 (<0.02)	<0.2	--			
Silver	0.3	0.1	0.1 (0.2)	0.4	--			
Zinc	15	4.2	2.6 (0.4)	19	2.8 (2.3)			
pH	8.44	9.07	9.64	7.88	10.33	7.90	0.72	18
Temperature (°C)	34	30	34.9	30.5	28.9	31.6	3.1	18
E.C. (µmhos/cm)	795	130	124	179	166	175	50	17
Chloride (mg/ℓ)	91	5.8	3.1	18	27	14	6.1	17
Total Hardness (mg/ℓ$CaCO_3$)	180	48	54	88	53	71	22	3
Calcium Hardness (mg/ℓ$CaCo_3$)	108	--	46	80	53	62	27	3
TNFR (mg/ℓ)	12	--	11	2.6	4.6	10	7.5	18
VTNFR (mg/ℓ)	--	--	3.4	1.4	1.2	9.8	7.4	17
Total Residue (mg/ℓ)	--	--	--	216	81	245	160	17
Volatile Total Residue (mg/ℓ)	--		--	78	36	97	74	10

*Total dissolved metal, including organically bound metal.

Table 3. Dissolved and suspended (in parentheses) metal concentrations at ponding basin L-2 in Latte Heights Estates. Metal concentration are in µg/ℓ.

	7/31/80	8/11/80	8/20/80	8/27/80	10/27/80	$\bar{X}$ (Zolan et al., 1978)	S (Zolan et al., 1978)	N (Zolan et al., 1978)
Arsenic*	--	1.2	0.8 (1)	0.5	--			
Barium	--	9	8 (8)	8	--			
Cadmium	--	8.4	0.2 (7.1)	0.5	0.1 (12.5)			
Chromium	--	2	4 (14)	3	--			
Copper	--	4.4	4.7 (8.1)	8.9	4.8 (60)			
Iron	--	22	50 (120)	25	10 (775)			
Lead	--	3	3 (30)	5	1 (40)			
Manganese	--	3.6	3.8 (<0.1)	4.6	--			
Mercury*	--	0.6	1.7	1.3 (3.6)	0.6 (3.3)			
Nickel	--	4.3	11 (55)	30	--			
Selenium	--	<0.2	<0.2 (<0.2)	<0.2	--			
Silver	--	<0.1	0.6 (2.5)	<0.1	--			
Zinc	--	4.9	53 (9.5)	5.7	13 (2.7)			
pH	--	8.86	7.62	7.37	9.10	9.22	0.82	23
Temperature (°C)	--	28.7	30.8	28.5	29	32.7	3.3	20
E. C. (µmhos/cm)	--	279	739	165	78	104	37	23
Chloride (mg/ℓ)	--	28	94	15	5.6	8.1	8.2	13
Total Hardness (mg/ℓ$CaCo_3$)	--	84	155	61	29	37	--	1
Calcium Hardness (mg/ℓ$CaCo_3$)	--	--	110	32	28	34	--	1
TNFR (mg/ℓ)	--	--	19.4	4.6	5.3	14	13	14
VTNFR (mg/ℓ)	--	--	14.4	4.6	1.3	8.0	8.7	11
Total Residue (mg/ℓ)	--	--	--	118	40	102	50	12
Volatile Total Residue(mg/ℓ)	--	--	--	52	15	37	42	6

*Total dissolved metal; including organically bound metal.

Table 4. Dissolved and suspended (in parentheses) metal concentrations in the Perez Acres ponding basin. Metal concentrations are in µg/ℓ.

	7/30/80	8/11/80	8/20/80	8/27/80	10/27/80	$\bar{X}$ (Zolan et al., 1978)	S	N
Arsenic*	<0.2	0.3	.0.3 (2.7)	0.4	--			
Barium	<0.5	1.1	<0.5 (1.9)	<0.5	--			
Cadmium	0.2	<0.1	0.4 (0.3)	0.8	0.2 (1.4)			
Chromium	2	1	1 (8)	2	--			
Copper	3.2	3.4	4.5 (3)	3.8	2.4 (8)			
Iron	12	108	9.4 (584)	9	10 (200)			
Lead	<1	2	<1 (13)	1	<1 (11)			
Manganese	7.8	26	3.8 (36)	21	--			
Mercury*	<0.1	<0.1	0.2	0.2 (1.3)	4.7 (0.7)			
Nickel	8.8	2.3	1.4 (<0.3)	3.7	--			
Selenium	0.3	0.3	<0.2 (<0.2)	<0.2	--			
Silver	0.1	<0.1	<0.1 (0.6)	<0.1	--			
Zinc	1	0.4	11 (2.3)	2.7	6.4 (<1)			
pH	10.06	7.53	9.52	8.54	9.87	9.20	0.65	24
Temperature (°C)	33	28	31	29.5	29.9	29.6	2.4	25
E. C. (µmhos/cm)	101	122	114	78	108	93	26	24
Chloride (mg/ℓ)	4.2	3.8	3.5	2.5	5.3	7.8	3.6	21
Total Hardness (mg/ℓ$CaCo_3$)	--	52	40	32	38	31	2.6	3
Calcium Hardness (mg/ℓ$CaCo_3$)	--	50	~40	~32	37	28	0.7	2
TNFR (mg/ℓ)	2.9	--	3.6	4.4	25	25	19	21
VTNFR (mg/ℓ)	--	--	2.8	4	14	12	4.9	17
Total Residue (mg/ℓ)	--	--	--	30	62	210	188	21
Volatile Total Residue(mg/ℓ)	--	--	--	16	35	61	19	10

*Total dissolved metal; including organically bound metal.

Table 5. Dissolved and suspended (in parentheses) metal concentrations at the Barrigada Heights ponding basin. Metal concentrations are in µg/ℓ.

	7/31/80	8/11/80	8/20/80	8/27/80	10/27/80	$\bar{X}$ (Zolan et al., 1978)	S	N
Arsenic*	--	<0.2	0.8 (2.6)	0.2	--			
Barium	--	1.4	1.9 (3.4)	5.2	--			
Cadmium	--	0.1	0.4 (2.7)	0.2	0.5 (38)			
Chromium	--	2	1 (10)	2	--			
Copper	--	2.4	2.2 (7)	7.2	3.9 (14)			
Iron	--	26	12 (912)	41	16 (775)			
Lead	--	4	2 (40)	9	1 (40)			
Manganese	--	5.8	2.9 (24)	27	--			
Mercury*	--	0.3	1.7	0.9 (1.5)	<0.2 (<0.5)			
Nickel	--	4.5	4.3 (3.6)	1.4	--			
Selenium	--	<0.2	<0.2 (<0.2)	0.2	--			
Silver	--	<0.1	<0.1 (0.2)	0.1	--			
Zinc	--	1.6	2.6 (<0.4)	1.6	6 (19)			
pH	--	7.80	8.46	7.36	8.25	7.74	0.54	30
Temperature (°C)	--	26.7	28.6	28	27.3	27.3	1.6	30
E. C. (µmhos/cm)	--	92	69	165	81	125	53	28
Chloride (mg/ℓ)	--	3.1	1.3	13	3.8	12	8.5	20
Total Hardness (mg/ℓ$CaCO_3$)	--	38	19	72	31	60	24	3
Calcium Hardness (mg/ℓ$CaCO_3$)	--	--	~19	56	~31	54	31	3
TNFR (mg/ℓ)	--	--	2	4.8	6.0	9.9	8	19
VTNFR (mg/ℓ)	--	--	1.4	3.8	2.3	5.5	4.9	16
Total Residue (mg/ℓ)	--	--	--	74	45	129	86	20
Volatile Total Residue (mg/ℓ)	--	--	--	28	15	51	25	11

*Total dissolved metal; including organically bound metal

Table 6. Dissolved urban runoff metal concentrations (ug/ℓ) according to urban development type and as dissolved and suspended metal concentrations combining the results from commercial and residential runoff. Concentrations reported as "less than, <" were assigned 0.0 in calculating the mean concentrations.

	Commercial				Residential				Dissolved				Suspended			
	R*	$\bar{X}$	C.V.**	N	R	$\bar{X}$	C.V.	N	R	$\bar{X}$	C.V.	N	R	$\bar{X}$	C.V.	N
Arsenic***	<0.2-5.2	1.6	106	8	<0.2-2.7	0.4	100	10	<0.2-5.2	0.9	135	18	1.0-3.5	2.4	38	5
Barium	7.0-37	18	56	8	<0.5-12	3.5	106	10	0.5-37	10	103	18	1.9-16	7.5	74	5
Cadmium	0.2-5.6	1.3	29	10	<0.1-8.4	0.9	251	13	<0.1-8.4	1.1	55	23	0.3-125	22	170	10
Chromium	4 - 27	14	53	8	1 - 4	2.0	45	10	1 - 27	6.6	115	18	5 - 27	13	67	5
Copper	8.4-95	37	81	10	2.2-8.9	8.5	129	13	2.2-95	18	138	23	3.2-274	46	181	10
Iron	8 - 250	90	97	10	9 - 108	27	104	13	8 - 250	54	124	23	168-1812	702	79	10
Lead	<1 - 52	16	100	10	<1 - 9	2.4	104	13	<1 - 52	8.3	148	23	11-330	72	140	10
Manganese	2.6-52	28	72	8	2.9-27	11	91	10	2.6-52	18	95	18	<0.1-122	39	125	5
Mercury***	0.4-3.8	1.5	73	10	<0.1-4.7	0.9	144	13	<0.1-4.7	1.2	102	23	<0.5-14	4.2	106	10
Nickel	5.2-69	23	119	8	1.4-30	7.2	119	10	1.4-69	14	118	18	<0.3-55	16	140	5
Selenium	<0.2-0.4	<0.2	——	8	<0.2-0.3	<0.2	——	10	<0.2-0.4	<0.2	——	18	<0.2	<0.2	——	5
Silver	<0.1-0.5	0.2	——	8	<0.1-0.6	0.1	——	10	0.1-0.6	0.2	——	18	0.2-2.5	0.8	121	5
Zinc	2.6-26	9.5	102	8	0.4-53	8.4	190	10	0.4-53	11	112	23	<0.4-122	16	228	10

* R stands for range

** C.V. stands for the coefficient of variation of analyzed samples to the mean concentration, where

$$C.V. = \frac{100\,\sigma}{\bar{X}}$$

*** Total dissolved metal; including organically bound metal.

Table 7. Urban runoff metal concentrations (µg/ℓ) compared to the Guam water quality standards for metals and to the mean metal concentrations of 62 drinking water wells (GEPA data, 1978). The last column indicates how the metals compare to the water quality standards: group 1 metals do not exceed the standards; group 2 metals exceed surface water standards; group 3 metals exceed surface and drinking water standards.

	Drinking Water Standard	Surface Water Standard	Wells	Urban Runoff as Total[1],	as Dissolved	Grouping
Arsenic	50	10	12	3.2	0.9	1
Barium	1000	300	75	16	10	1
Cadmium	10	0.2	4.5	12	1.1	3
Chromium	50	10	17	18	6.6	2
Copper	(1000)[1]	10	-	56	18	2
Iron	(300)[1]	50	-	775	54	2
Lead	50	10	9.3	77	8.3	3
Manganese	50	20	-	52	18	2[3]
Mercury	2	0.05	0.2	4.8	1.2	3
Nickel	-	2	-	22	14	2
Selemium	10	5	2.0	<0.2	<0.2	1
Silver	50	1.0	5.3	1.0	0.2	1
Zinc	2000	20	-	31	11	2

1. Mean of those samples where both dissolved and suspended metals were analyzed.
2. Standard recommended in Quality Criteria for Water (EPA, 1976).
3. Manganese showed high concentrations only at the Sereno Ave. sampling station.

Table 8. Guam urban runoff metal concentrations (µg/ℓ) compared to the urban runoff in a similar study in northern Virginia (Randall et al., 1978) and to natural waters of the Pago River.

	Guam Urban Runoff (dissolved metal)		Urban Runoff Occoquan Watershed Virginia (dissolved metal)		Pago River 1978-1979 below the Lonfit-Sigua Confluence	
	Commercial	Residential	Commercial	Residential	Dissolved	Suspended
Arsenic	1.6	0.4	**	**	0.8	--
Barium	18	3.5	--	--	< 1	< 1
Cadmium	1.3	0.9	--	--	2	0
Chromium	14	2.0	20	46	13	7
Copper	37	8.5	44	42	2	0.3
Iron	90	27	168	1122	7	100
Lead	16	2.4	84	15	10	13
Manganese	28	11	395	302	23	17
Mercury	1.5	0.9	**	**	0.0	0.0
Nickel	14	6.8	34	25	-	-
Selenium	< 0.2	< 0.2	**	**	< 1	< 1
Silver	0.2	0.1	14	0	0.0	0.3
Zinc	9.5	8.4	824	70	0.3	0.3

of urban runoff volume to natural watershed volume has to be made in assessing the problem posed by these metals since undeveloped-watershed runoff percolate will substantially dilute those waters from urbanized areas. This third group of metals consists of mercury, cadmium, and lead. Dissolved manganese concentrations were very low except at the Sereno Avenue sampling station where they exceeded drinking water standards. Because these waters only affect surface waters, manganese more properly belongs in the second grouping of metal pollutants. While the concentrations of the second and third group metals may approach or exceed water quality standards, the concentrations observed are low to very low in comparison to the average metal concentrations seen in other U.S. communities (EPA, 1973; Randall et al., 1978) and other natural waters in Guam (Table 8). Further work in the metals of the second and third groups should be undertaken to assess the fate of these metals in standing and percolating urban runoff.

A presentation of results for each metal analyzed follows. Unless otherwise stated concentrations are for dissolved metal.

Arsenic

Concentrations of arsenic ranged from <0.2 µg/ℓ to 5.2 µg/ℓ as total dissolved arsenic. At these levels arsenic concentrations were usually well below 10% of the drinking water limit of 50 µg/ℓ and below 50% of the 10 µg/ℓ limit for surface waters. Samples collected from the Tamuning area average approximately 1.6 µg/ℓ compared to approximately 0.5 µg/ℓ recorded from the residential developments (Table 6). Analyses of Pago River water by the USGS found arsenic averaging approximately 0.8 µg/ℓ (USGS, 1980).

Because arsenic is accumulated in living tissues (Goyer and Mehlman, 1977; Ming et al., 1973), arsenic in runoff entering the marine waters may be contaminating marine life including edible shellfish and fish. A comparative study of arsenic levels in marine organisms collected around discharge areas with organisms living away from discharge points would show if arsenic is concentrating in abnormal levels in the food chain.

Barium

Barium concentrations showed the familiar pattern of having greater concentrations in the commercial area runoff than in the residential runoff (Tables 1-5). Barium ranged from 0.5 µg/ℓ to 12 µg/ℓ in residential runoff. In the commercial runoff, barium concentrations ranged 7.0 to 37 µg/ℓ. The mean concentration for commercial runoff was 18 µg/ℓ. This is over 25 times less than the standard allowed for surface waters and 50 times less than allowed drinking water supplies. Barium does not appear to pose a threat to the environmental health or public safety aspects of Guam's water resources at this time. The USGS reported barium concentrations in the Pago River less than detectable limits (USGS, 1980). If this result is characteristic of natural runoff from watershed areas, barium contamination is present in street runoff but at relatively low concentrations.

Selenium

Selenium concentrations were usually lower than any other metal with the occassional exception of silver. Of the 31 selenium analyses (including all unfiltered, suspended and dissolved analyses) 23 were below the detection limit of 0.2 µg/ℓ. The highest concentration of dissolved selenium was 0.4 µg/ℓ at the Sereno Avenue sampling location. Selenium pollution in Guam urban runoff appears to inconsequential. The USGS reported less than detectable limits of selenium at their Pago River sampling station.

Silver

Silver concentrations were very low with an approximate mean concentration of 0.2 and 0.1 µg/ℓ for commercial zone and residential zone runoff respectively. These concentrations are less than 1/250th of the drinking water standard for silver and less than 20% the silver standard for surface waters.

The USGS reported dissolved silver in samples collected from their Pago River sampling site to be less than the detectable limit. Along with barium and selenium, silver is not a pollutant of concern in Guam's urban runoff.

Chromium

Dissolved chromium (Cr^{+3}+ Cr^{+6}) concentrations ranged from 4 to 27 µg/ℓ in commercial area runoff and from 1 to 4 µg/ℓ in residential area runoff. The mean chromium concentration for the commercial area runoff was 14 ± 7.4 (standard deviation) µg/ℓ. This mean concentration exceeds the 10 µg/ℓ limit for surface waters. For residential area runoff the mean concentration was 2.0 ± 0.9 µg/ℓ. Water quality standards for surface waters specify a 10 µg/ℓ limit for chromium. The drinking water limit is 50 µg/ℓ. Chromium concentrations in urban runoff appear to be significantly below the drinking water limit though runoff tends to exceed the surface water chromium standard in commercial areas.

The GEPA metal analyses for December 1978 show total chromium concentrations at 16.9 ± 4.5 µg/ℓ for 62 wells sampled. The USGS analyses of Pago River water averaged 13 µg/ℓ dissolved chromium for the 1978-1979 annual sampling period. Suspended chromium average 6.7 µg/ℓ in the river samples. The Pago River chromium concentrations are similar to concentrations found in commercial area urban runoff. Residential area urban runoff had much lower concentrations than observed in Pago River.

The Pago River sampling site lies downstream from an open solid-waste landfill. Possible leaching of metals from the solid waste cannot be ruled out. However, the USGS data do not indicate significant metal contamination.

A comparative study of sediments and substrate action on urban runoff should indicate (as in the case of cadmium) the binding and retention capacity of these materials with respect to chromium. Chromium appears to be a low level pollutant in Guam urban runoff. Interestingly, the mean total chromium concentration for drinking well water (16.9 µg/ℓ, GEPA data) exceeds the 10 µg/ℓ limit for surface waters.

Copper

Dissolved copper concentrations ranged from 8.4 to 95 µg/ℓ in runoff from the commercial district and from 2.2 to 8.9 µg/ℓ in runoff from residential developments. Mean dissolved copper concentrations in commercial and residential runoff were 37 ± 30 µg/ℓ and 8.5 ± 11 µg/ℓ respectively. Water quality standards limit surface waters to 10 µg/ℓ. There is no Guam drinking water limit for copper. Copper is a required nutrient in humans who require as adults about 2 mg/day (Sollman, 1957). The surface water limit is set mainly to protect fish some species of which are copper sensitive at concentrations in excess of 20 µg/ℓ (Burrell, 1974). However, copper toxicity is greatly reduced by increasing alkalinity and hardness (EPA, 1976), conditions that are met by ocean waters. Because most receiving waters affected by Guam urban runoff are marine, the observed concentrations of copper in urban runoff are probably not toxic. However, receiving waters should be investigated to determine ambient concentrations and the extent marine receiving waters are affected by higher than ambient copper concentrations.

The USGS reported Pago River total recoverable copper concentrations to range from 1 to 7 µg/ℓ.

Iron

Iron was the most abundant metal, as dissolved and as suspended metal, in urban runoff. Dissolved iron ranged from 9 to 108 µg/ℓ in runoff from residential developments and from 8 to 250 µg/ℓ in runoff from the commercial district. The mean dissolved iron content was 90 ± 87 µg/ℓ and 27 ± 28 µg/ℓ for commercial and residential runoff respectively. There is no Guam drinking water limit for iron. Surface waters may not exceed 50 µg/ℓ. This limit is set to protect aquatic insects which have shown sensitivity to iron in concentrations as low as 320 µg/ℓ (Warnick and Bell, 1968). Iron precipitates (mainly iron hydroxide) may also affect fish by coating gills or eggs (Olsen et al., 1941). Iron precipitates in high alkalinity water so the extent of dissolved iron in high alkalinity runoff and marine receiving waters is slight. When dissolved iron is present it is chelated. The precipitation of iron may have accounted for some of the high concentrations of suspended iron observed in the runoff. Suspended iron ranged from 168 µg/ℓ to 1812 µg/ℓ. The USGS recorded suspended iron concentrations of 70-120 µg/ℓ in the Pago River. If this is characteristic of background iron concentrations in natural runoff, urban runoff is considerably enriched by suspended iron containing particles or by particles containing adsorbed iron.

Manganese

While there does appear to be a difference in the concentrations of manganese with type of land use in the runoff area, the difference appears less marked than for chromium. Dissolved manganese concentrations ranged from 2.6 to 122 µg/ℓ in commercial area runoff compared to a range of 2.9 to 27 µg/ℓ in residential area runoff. Commercial area runoff averaged 28 ± 20 µg/ℓ dissolved manganese while residential area runoff averaged 11 ± 10 µg/ℓ. These concentrations exceed or approach water quality standards for surface waters. Manganese is accumulated and concentrated in mollusk tissue (NAS, 1974).

Because it is accumulated in living tissues, the concentration of manganese in surface waters is limited to 20 µg/ℓ. Only one set of samples for Sereno Avenue exceeded (both suspended and dissolved fractions) the drinking water limit of 50 µg/ℓ. Manganese is not a dangerous human toxin and the drinking water quality limit is established to prohibit water from staining clothes and to prohibit the taste of water from being degraded.

Manganese was more abundant as suspended rather than dissolved metal. The five samples that were analyzed for manganese both as suspended and dissolved manganese had 2 to 30 times more suspended than dissolved manganese. The USGS data on the Pago River averaged 23 µg/ℓ for dissolved manganese; suspended manganese averaged 16.7 µg/ℓ.

Nickel

Dissolved nickel ranged from 1.4 µg/ℓ to 30 µg/ℓ in runoff sampled from residential ponding basins. In commercial area runoff, dissolved nickel ranged from 5.2 to 69 µg/ℓ. Dissolved nickel averaged 23 ± 21 µg/ℓ in commercial area runoff and 7.2 ± 8.6 µg/ℓ in residential runoff (Table 6). While there is no nickel water quality standard for drinking waters, surface waters may not exceed 2 µg/ℓ. The concentrations found in urban runoff usually exceeded that concentration.

Nickel is generally considered non-toxic to man and mammals when ingested as metallic nickel or as nickel salts. However, marine life may be affected at levels greater than 50 µg/ℓ (Burrell, 1974). Neither the GEPA nor the USGS conduct nickel analyses of ground or surface waters. Considering the relatively high concentrations of nickel observed in urban runoff in comparison to the current surface water quality standards, nickel should be routinely monitored and further research undertaken to see how pervasive nickel is in urban runoff and natural waters.

Zinc

Zinc ranged from 0.4 to 53 µg/ℓ (dissolved metal) in runoff from residential area as compared to a range of 2.6 to 26 µg/ℓ in commercial runoff. Mean concentrations were essentially the same with 9.5 ± 9.7 µg/ℓ in commercial runoff and 8.4 ± 16 µg/ℓ in residential runoff. This concentration is very low and zinc does not appear to be a major contaminant in urban runoff regardless of source. However, it may occasionally exceed the surface water quality standard of 20 µg/ℓ.

The samples that were analyzed for suspended as well as dissolved metal content showed dissolved zinc to predominate (Table 6). The USGS reported dissolved zinc at about 7 µg/ℓ in the Pago River and suspended zinc at less than 7 µg/ℓ. Zinc concentrations in the study of urban runoff in Virginia (Randall et al., 1978) found zinc concentrations in the µg/ℓ range (Table 7).

Cadmium

Cadmium concentrations ranged from 0.1 to 8.4 µg/ℓ as dissolved metal and 0.3 to 125 µg/ℓ as suspended metal (Table 6). Concentrations of cadmium in suspended matter greatly exceeded the dissolved fraction. Adsorption of cadmium onto suspended particles or precipitation may serve to remove almost all cadmium from solution. Concentrations of cadmium in the sediments of ponding basins and ocean discharge sites should be investigated as cadmium is an accumulative poison which concentrates in food chains. The presence of high concentrations of cadmium in sediments may be contaminating benthic organisms and their predators (Burrell, 1974).

Concentrations of cadmium in commercial and residential runoff appeared similar. Commercial zone runoff averaged 1.3 µg/ℓ dissolved cadmium while residential zone runoff averaged 0.9 µg/ℓ. Drinking water standards limit cadmium to 10 µg/ℓ. For surface waters the limit is 0.2 µg/ℓ which is exceeded by typical concentrations observed in urban runoff.

Dissolved cadmium in runoff waters averaged less than observed total recoverable (unfiltered samples digested with mineral acid) cadmium in the 62 wells monitored by the Guam Environmental Protection Agency in December 1978. The wells averaged 4.5 µg ± 3.0 µg/ℓ total recoverable cadmium. The USGS reported dissolved cadmium at 1.7 µg/ℓ and zero (0) µg/ℓ suspended cadmium at their Pago River sampling station.

Suspended cadmium, found to be occassionally high in urban runoff, is unlikely to be a factor in affecting dissolved concentrations in groundwater due to filtering of suspended solids by the limestone substrate. However, the binding and retention capacity of local limestones for both dissolved and suspended cadmium should be investigated.

Lead

Dissolved lead concentrations ranged from less than 1 to 52 µg/ℓ in commercial area runoff. Runoff from residential developments ranged from less than 1 to 9 µg/ℓ. Mean lead concentrations were approximately 16 ± 16 µg/ℓ for commercial runoff and 2.4 ± 2.5 µg/ℓ for residential runoff. Lead contamination in runoff from the commercial areas appears to be much greater than in residential runoff. This pattern was also observed in runoff from residential and commercial areas in Virginia (Randall et al., 1978).

Suspended lead was found in quantities far exceeding the dissolved concentrations. For ten samples, suspended lead ranged from 11 to 330 µg/ℓ with a mean of 72 ± 100 µg/ℓ. The USGS reported Pago River water to contain from 0 to 39 µg/ℓ suspended lead and 0 to 25 µg/ℓ dissolved lead. The Guam Environmental Protection Agency reported that 62 wells ranged from 0.0 to 45 µg/ℓ total recoverable lead with a mean of 10 ± 9.7 µg/ℓ. This value is higher than dissolved lead contained in residential area runoff waters but less than most suspended lead concentrations. The runoff data collected from the ponding basins and drainage ditches indicates that suspended lead is high while dissolved lead is low. A study of suspended lead retention in the soil and limestone would help assess whether suspended lead in runoff poses a significant threat to groundwater quality. Also, lead concentrations in benthic organisms of receiving waters should be investigated for evidence of excessive bioaccumulation.

Mercury

Mercury concentrations ranged from <0.1 to 4.7 µg/ℓ as total dissolved mercury in runoff collected from residential area ponding basins and from 0.4 to 3.8 µg/ℓ in commercial area runoff (Table 6). The average mercury concentration for residential runoff was 0.9 ± 1.3 µg/ℓ compared to 1.5 ± 1.1 µg/ℓ for commercial runoff. Because of high blanks obtained in the digestion procedure for mercury, analyses values under 0.5 µg/ℓ are considered uncertain. Water quality standards limit mercury to less than 0.05 µg/ℓ in surface waters and 2.0 µg/ℓ in drinking waters. Urban runoff contained concentrations over the surface water limit but below the drinking water standard. A more detailed study of runoff entering the marine habitat should be conducted to determine how extensive mercury pollution is by analyses of receiving waters, sediments, and organisms in the vicinity of runoff discharges.

The samples tested for both suspended and dissolved mercury revealed three of the sites to have higher suspended mercury concentrations (one Sereno Avenue sample had 14 µg/ℓ) than dissolved mercury. The USGS reported mercury concentrations of (.0) µg/ℓ, both dissolved and suspended mercury. GEPA reported concentrations of 0.0 to 0.6 µg/ℓ in the 62 groundwater wells that supply 80% of the island's drinking water.

Other Physical and Chemical Parameters

Generally, the range of values for other physical and chemical parameters of the five metal sampling sites fall within the mean ± one standard deviation of the values observed four years ago (Table 1-5). There was insufficient data on the Sereno Ave. collection station to make a valid comparison. Also, the sample collection site was located closer to Marine Drive.

The high pH of sample waters ($\bar{x}$ of 8.44 ± 0.95) and the presence of suspended material ($\bar{x}$ of 8.8 ± 7.0 µg/ℓ) would favor the precipitation, chelation, and adsorption of dissolved metal species. The major fraction of runoff metals were suspended metals. Sediments composed of naturally occurring metals could also contribute to the suspended metal fraction.

SUMMARY

Analyses of non-point urban runoff from northern Guam for arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, mercury nickel, selenium, silver, and zinc revealed low levels (in the µg/ℓ range) of these metals. While there are no numerical water quality limits for metal concentrations in urban runoff, runoff waters must not degrade receiving waters, whether ground or surface water. A more detailed study of runoff and receiving waters emphasizing certain metals is needed to determine if receiving waters are being degraded, and if so, to what extent.

Mercury, lead, and cadmium approached or exceeded drinking water standards as dissolved metal in urban runoff. These metals are also highly toxic and should be key metals in future research in groundwater or surface waters with respect to metal contamination from human activities.

Concentrations of chromium, copper, iron, manganese, nickel and zinc were below drinking water standards but approached or exceeded standards for surface waters. The initial judgement, based on the pH, hardness, and the dilution factor of marine receiving waters is that the effects of the observed concentrations of the above metals would be negligible due to dilution, precipitation and/or adsorption to suspended particulates. However, a follow-up metals study of receiving waters is needed to confirm this judgment.

The concentrations of arsenic, barium, selenium, and silver in urban runoff were very low and these metals should be given a lower priority in future related work.

Concentrations of metals were much higher in commercial runoff than in runoff from residential areas. The average concentrations of dissolved barium, chromium, copper, iron and lead in commercial runoff exceeded the concentrations of the same metals in residential area runoff by at least 300%. At present, commercially developed areas extend only along the coast. Commercial area runoff waters either are discharged into the nearshore marine waters or are ponded at the periphery of the island. Therefore, they do not pose a threat to groundwaters used as drinking waters. Any future commercial development of northern Guam will result in increased metal concentrations in runoff waters. The concentrations would probably be similar to those observed in this study for commercial runoff, depending upon the density and type of commercial development.

Metals were usually more abundant as suspended metal than as dissolved metal. This was especially the case with lead, cadmium, copper, iron, and silver. Zinc, mercury, and barium had approximately equal concentrations of dissolved and suspended metal in the samples collected.

In comparison to runoff quality in communities off-island, Guam urban runoff is low in metal contamination. This is probably due to the fact that both residential and commercial areas of Guam are less developed and have a smaller developed area than in the case of Honolulu or other stateside communities.

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APPENDIX A: Dry, char, and atomization temperatures for analyzed elements using the HGA2200 graphite furnace. Times for dry, char, and atomization stages were 30, 30, and 10 seconds, respectively, except nickel (drying time of 40 seconds). Ramp times for the dry, char, and atomization stages were 25, 25, and 8 seconds, respectively, except nickel (35, 25, and 8 seconds). Arsenic, Mercury and Selenium were analyzed with the MHS-10 system as describe in Perkin Elmer (1978) following digestion procedures given in the EPA methods manual (EPA, 1979). The detection limits (μg/ℓ) are given in the last column for each metal analyzed.

Element	Gas flow (cc/min)	Dry (°C)	Char	Atomize	Detection Limit
Arsenic	Metallic	hydride	generation		0.2
Barium	55	90	1600	2800	0.5
Cadmium	40	125	250	1900	0.1
Chromium	40	90	1100	2700	1
Copper	55	90	900	2700	1
Iron	40	125	1000	2700	0.1
Lead	40	100	500	2300	1
Manganese	40	95	1100	2700	0.1
Mercury		Cold	Vapor		0.1
Nickel	40	80	900	2700	1
Selenium	Metallic	hydride	generation		0.2
Silver	55	90	400	2700	0.1
Zinc	40	90	400	2500	0.1

APPENDIX B: Analyses results of replicate samples; one replicate acidified to 1% nitric acid upon collection the other, filtered through prewashed 0.45 µm membrane filters then acidified to 1% nitric acid. Results are of Sereno Avenue and Perez Acres respectively.

	7/31/80		8/11/80	
	Unfiltered	Filtered	Unfiltered	Filtered
Arsenic	1.6, 1.7	0.6, 0.3	1.7, 0.4	2.1, <0.2
Barium	25, 1.0	25, 1.1	16, 1	15, <0.5
Cadmium	0.6, 0.1	0.3, 0.2	12, 0.2	1.4, <0.1
Chromium	36, 1	27, 2	10, 1	12, 1
Copper	73, 4.2	60, 3.2	8.6, 6.9	11, 3.4
Iron	230, 34	220, 12	240, 25	150, 108
Lead	19, <1	7, <1	55, 2	52, 2
Manganese	44, 20	44, 7.8	31, 34	41, 26
Mercury	0.8, <0.1	0.4 <0.1	0.4, <0.1	0.6 <0.1
Nickel	86, 16	32, 8.8	22, 24	2.0, 2.3
Selenium	0.2, 0.3	<0.2, 0.3	<0.2, 0.3	<0.2, 0.3
Silver	0.8, <0.1	0.1, 0.1	0.4 <0.1	0.4 <0.1
Zinc	3.1, 2.1	7.8, 1.0	14, 20	1.0, 0.4