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TOXIC SUBSTANCES IN THE COASTAL ENVIRONMENT OF THE US VIRGIN ISLANDS, 1986

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ABSTRACT

A two phase investigation was made of the concentration levels of toxic substances in the marine sediments and coastal waters around the U S Virgin Islands. The Pilot Phase, March 1986, served to screen six composites of three bottom samples each, representing the main pollution impact areas and a control, for all 129 EPA priority toxic substances. Based on the virtual absence of any toxic organics in any of these composites, the Main Phase, July/August 1986, concentrated on sampling and analyzing for the 13 priority toxic trace elements in pairs of samples of seawater and marine sediment at 24 locations around the three islands.

Locally elevated concentrations were found of several trace elements, especially Ni, Pb, Hg, Zn and Cu. Highest contamination occurred in the fine muds off HOVIC, St Croix and Mangrove Lagoon, St Thomas. By contrast, concentrations at the Sewage Treatment Plant (STP) outfall off St Croix were significantly below average. The order of degree of pollution by island was St Croix > St Thomas > St John.

Very low correlation was found for trace element levels in marine sediments and in adjacent terrestrial rocks and soil analyzed by USGS, suggesting that erosion contributes little to the trace element distribution pattern, with the possible exception of Ni. Distribution of Hg and Pb can be partly explained from transport by the predominant trade winds. Other 'hot spots', e.g. Cu and Zn in harbors, clearly result from point sources of anthropogenic inputs.

In conclusion, the USVI marine environment is relatively pure and impacts of inorganic trace elements are largely localized.

INTRODUCTION

An investigation was made of the toxic substances in the sediments, seawater and biota of the coastal environment of the US Virgin Islands (USVI). The project was carried out by a combined team from the College of the Virgin Islands (CVI)[1] and Millersville University (MU), under contract to the Department of Conservation and Cultural Affairs (DCCA)[2] of the USVI. It comprised sampling and chemical analysis, review of available relevant data, and recommendations on required legislation, monitoring and research.

The U S Virgin Islands are located in the Caribbean at a latitude of 18 to 19 degrees North about 70 km east of Puerto Rico (Fig. 1). The three main islands are St Thomas, with a population of 51,020 (1985) and area of 83 km^2, St Croix: 57,020 and 218 km^2 and St John: 2,760 and 52 km^2. Because of the tropical setting, clear waters, attractive beaches and protected bays, tourism is the main source of income, reflected in 1,220,586 visits during 1985. By contrast, industry and manufacturing have declined in the last decade - which witnessed the discontinuation of Martin Marietta's Aluminum smeltery as well as Hess Oil refineries-, while agriculture and fisheries are negligible.

[1] now University of the Virgin Islands
[2] now Department of Planning and Natural Resources

Two major sets of environmental problems associated with the increase in population and tourism are water supply and waste disposal. The principal **point sources** of pollution, requiring discharge permits from the DCCA under the NPDES (National Pollutant Discharge Elimination System) are WAPA (Water and Power Authority, desalination plants on St Croix and St Thomas), POTW's (Publicly Owned Treatment Works), sanitary landfills, and a few industries, chiefly HOVIC (Hess Oil of the Virgin Islands)(Fig. 1). **Non-point sources** include atmospheric input, natural drainage, urban runoff, vessel waste and floating oil and tar (USVI Department of Health, 1972; DCCA, 1979; Wernicke, 1986; Wernicke & Towle, 1983).

Previous investigations of toxic substances in USVI coastal waters are reported by USEPA (1973) and Alonso (1983), and compiled in EPA's STORET data bank. Site-specific studies which include some data on toxics were made by Nichols and Towle (1977) and USACE (1982) on Mangrove Lagoon/Benner Bay, St Thomas, Beck (1974) on WAPA, and USEPA (in STORET), chiefly on HOVIC Harbor. Soils, river sediments and rocks on St John and St Thomas were analyzed by the USGS (Hopkins et al., 1984)

Our results indicate that all USEPA defined priority organic toxic substances were below detection limits. As to inorganic toxics, however, local elevated concentrations were found of several trace elements, including Ni, Pb, Hg, Zn and Cu. The highest degree of contamination occurred in the fine muds off HOVIC, St Croix and Mangrove Lagoon, St Thomas. By contrast, concentrations were significantly below average at both POTW outfalls.

PROCEDURES

The study consisted of two parts: the Pilot Phase, conducted in March, 1986, and the Main Phase, July/August 1986. Because of the high cost of a complete analysis for all 129 EPA priority toxic substances - in excess of $1,000 for a single sample - only few samples could be completely analyzed. We, therefore, opted to combine sample sets into composites. In the first phase, five composites of three sediment samples each from four main impact areas and the St John control site were analyzed for all 129 EPA priority toxic substances. Based on the initial results, the second phase emphasized the 13 EPA priority toxic trace elements in both sediment and seawater at 24 sample sites (Fig. 1).

Sampling around St Thomas and St John was done from the CVI's R.V. 'Burkholder', while the DCCA's monitor vessel was used around St Croix. SCUBA divers wearing disposable plastic sterile gloves used appropriate pre-

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cleaned containers to take water samples at mid-depth, as well as a teflon-coated scoop to collect a surface sediment layer of about 5-10 cm into a large plastic jar. Although occasionally biota were collected and analyzed, results are not reported here. All samples were kept refrigerated and hand-carried to the EPA - certified Radiation Management Corporation (RMC) Laboratory in Pottsville, PA for analysis in accordance with EPA's (1982) specified procedures for storage, holding time and method of analysis.

Associated field measurements included position by handbearing compass, depth by Lowrance CG 336-2003 portable fathometer, dissolved oxygen by YSI Model 54A oxygen analyzer, salinity and temperature by YSI Model 33 _in situ_ conductivity-salinometer, and water transparency by standard Secchi disc. Grainsize analyses were performed at CVI and MU by sieving at 1/2 phi intervals or, in the case of muds, by pipette (Folk, 1952)

RESULTS

Station locations for the four composites collected in March and for all 24 stations sampled in July/August 1986 are plotted in Figure 1. Table 1 shows specific details of the 24 stations, including latitude and longitude, water depths and type of pollution activity.

The water column was characterized by temperatures ranging from 25.5 to 31.5^0 C, salinities from 31.8 to 37.9 ‰, and generally excellent visibility. Most of the sediments consisted of medium - to fine-grained sands (Table 1), very poorly to moderately well-sorted, and principally biogenous in composition (fragmented shell, algae, foraminifera, corals, echinoids and sponge-spicules). Odiferous anaerobic muds were found in HOVIC Harbor, St Croix, and Mangrove Lagoon, St Thomas, and slightly smelly, greasy silts in Coral Harbor and Cruz Bay, St John.

Because of financial restrictions only the four composite bottom sample shown in the inset of Figure 1, as well as one water sample from HOVIC Harbor were tested completely for all 129 EPA priority toxic substances. All organic toxic substances occurred in concentrations below detection limits, but the 13 toxic inorganic trace elements did not and therefore required more detailed studies, which are summarized in Table 2. Based on replicate sampling and interlaboratory comparison (Oostdam, 1986), all elemental analyses except those for Antimony (Sb) were accepted as reliable. The latter are included, however, because of their internal consistency.

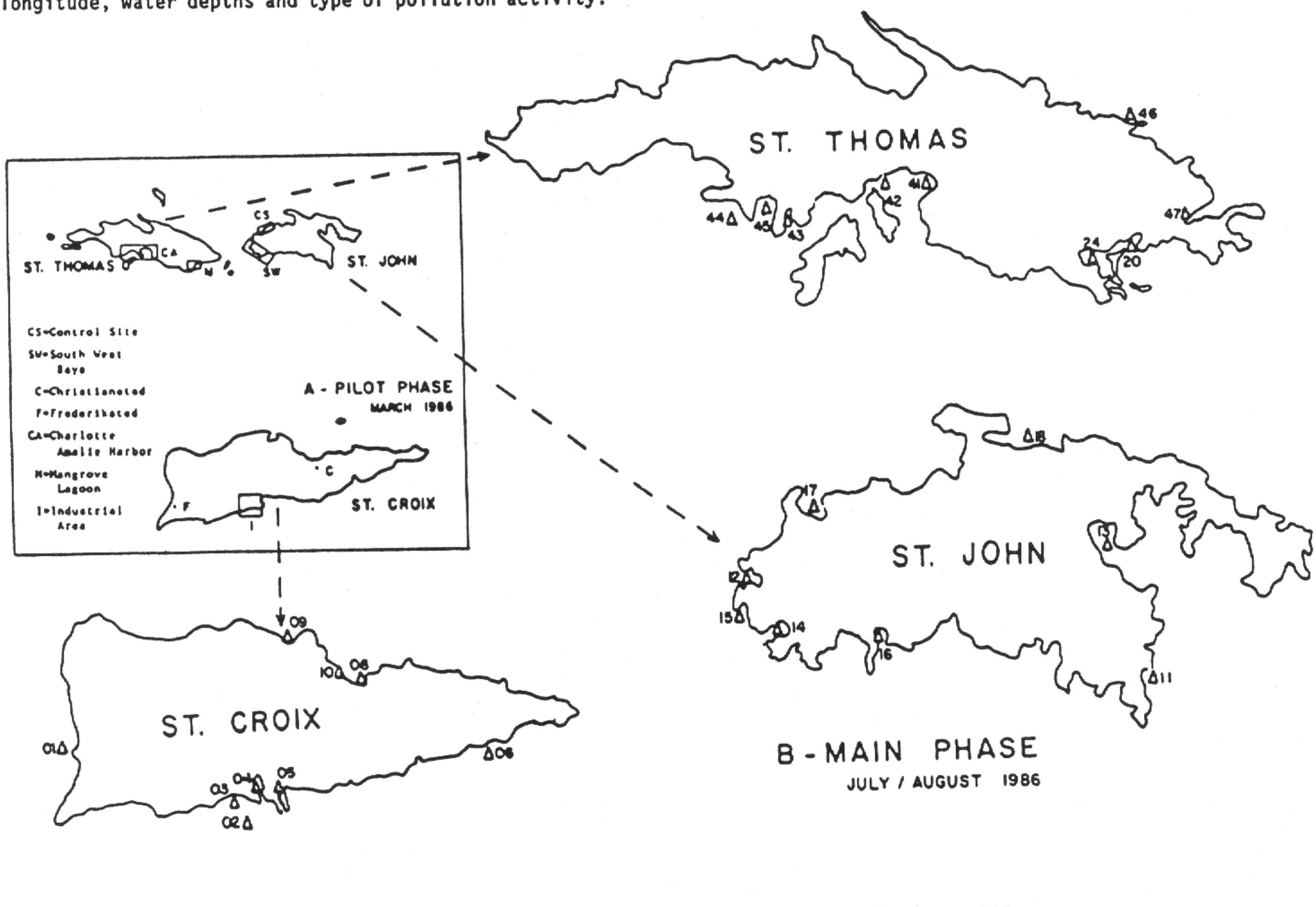

Figure 1. Station Locations, U.S.V.I. Toxic Substances Project,1986
Quadrangles of inset represent pollution impact areas and the overall control site of the Pilot Phase.
Triangles on main part of map are individual sampling sites of the Main Phase. Note: main map is not to scale.

DISCUSSION

Disregarding values below the lower detection limits, there is a considerable variation in the concentrations of several of the trace elements. Pb, Ni and Cu vary through three orders of magnitude, As, Cr and Hg through two; in fact, the ratio of the highest Pb measured to lowest amounts to 7,470, almost four orders. These high variabilities strongly suggest anthropogenic effects, even though natural variability of trace elements is also high.

Comparison with earlier data sets, e.g. EPA's 1972, 1979 and 1982 results, suffer from differences caused by improved analytical techniques (Amore, 1976) which render them inadequate for assessing temporal variations (Oostdam, 1986).

By contrast, areal variations can be more reliably evaluated. In general, trace element concentrations in sediments were highest in St Croix and lowest in St John, as expected on the basis of degree of pollution activity and impact. The worst polluted sites were the industrial complex off southern St Croix, specifically HOVIC Harbor and vicinity (Figure 2). On St Thomas, Benner Bay, Mangrove Lagoon and Careening Cove showed elevated concentrations. Each of these sites also displayed high percentages fines &/or low percentages solids (Tables 1 and 2), which contributes to the adsorption capacity of the sediments.

TABLE 1: STATION LOCATIONS AND RELATED DETAILS, US VIRGIN ISLANDS TOXIC SUBSTANCES PROJECT (July 15-August 7, 1986)

STA	LATITUDE (N)	LONGITUDE (W)	WATER DEPTH (M)	LOCATION	DATE	SEDIMENTS(1): % FINES/	MEAN PHI	REMARKS
				ST. CROIX:				
01	17 42.9	64 53.2	9.2	Frederiksted	July 15	0.40	1.65	harbor
02	17 40.8	64 47.0	7.9	STP Outfall	July 16	0.02	1.18	sewage
03	17 41.7	64 47.2	1.5	off Anguilla	July 16	0.16	1.96	dumpsite
04	17 42.0	64 46.0	0.9	Krause Lagoon	July 16	3.0	-0.35	former Al.Smeltery
05	17 42.1	64 45.1	7.6	HOVIC Harbor	July 16	49.0	3.49	oil refinery
06	17 43.7	64 37.6	2.4	Robin Bay	July 16	0.27	1.36	Control site
08	17 45.4	64 42.9	7.0	Gallows Bay	July 15	12.1	2.01	marina
09	17 46.5	64 45.4	2.7	Salt River	July 15	7.33	1.32	yacht basin
10	17 45.2	64 42.8	1.5	Christiansted	July 15	4.86	1.41	desal. plant
				ST. JOHN:				
12	18 19.4	64 47.4	5.8	Great Cruz Bay	August 6	12.8	2.25	harbor
13	18 20.7	64 42.7	4.9	Coral Harbor	August 5	31.5	3.45	harbor
14	18 20.1	64 47.8	4.6	Cruz Bay	August 5	16.5	3.32	harbor
15	18 19.7	64 47.9	4.9	Turner Bay	August 5	0.62	1.30	sewage discharge
16	18 19.3	64 45.8	1.5	Fish Bay	August 6	4.65	2.16	dumpsite
17	18 21.0	64 46.8	4.9	Hawksnest Bay	August 5	0.62	1.87	CONTROL SITE
				ST. THOMAS:				
20	18 19.2	64 52.1	1.5	Benner Bay	August 6	11.4	1.83	marina
24	18 19.1	64 52.9	1.2	Mangrove Lagoon	August 6	2.61	0.33	dumpsite
41	18 20.2	64 52.2	9.2	Long Bay	July 30	14.1	0.64	harbor, marina
42	18 20.3	64 56.4	6.1	Careening Cove	July 30	10.1	2.13	marina
43	18 20.0	64 57.7	5.5	Krum Bay	July 30	11.5	1.93	desal. plant
44	18 20.0	64 58.5	20.7	off Red Point	July 31	17.2	1.99	sewage outfall
45	18 20.0	64 57.9	4.3	Lindbergh Bay	July 31	1.29	1.38	WAPA discharge
46	18 21.1	64 52.0	5.5	Coki Bay	August 7	0.14	1.17	control site
47	18 19.5	64 51.2	1.2	Vessup Bay	August 7	1.27	0.85	marina

(1) % FINES = fraction finer than 4 phi (very fine sand):
PHI = $-LOG_2$ (diameter in mm): e.g. 4 phi = 0.125mm

TABLE 2: USEPA PRIORITY TOXIC TRACE ELEMENT CONCENTRATIONS IN USVI MARINE SEDIMENTS, July/August, 1986
(mg. kg^{-1}, or ppm, dry weight)

SAMPLE (NOTE 1)	% SOLIDS (NOTE 2)	SB (NOTE 3)	AS	BE	CD	CR	CU	PB	HG	NI	SE	AG	TL	ZN
01-30	80.9	148	0.37	0.04	<0.012	5.32	5.32	1.48	<0.025	0.74	0.74	<0.012	<0.062	4.25
02-26	84.6	160	0.07	<0.012	<0.012	0.59	0.17	0.01	<0.015	3.07	1.00	<0.012	<0.059	2.91
03-05A	67.5	76.1	8.9	0.089	0.415	14.8	24.4	17.0	0.015	5.19	2.15	0.030	<0.044	91.1
04-03	7.1	625	28.2	<0.141	<0.141	50.7	69.0	2.39	0.141	8.45	6.90	<0.141	<0.704	49.2
05-25	29.8	179	10.1	0.340	0.30	90.6	117	40.3	0.77	60.4	3.36	0.067	<0.168	386
06-08 cs	76.9	148	1.43	<0.013	<0.013	7.54	0.78	0.156	<0.143	0.78	2.08	<0.013	<0.065	3.95
08-23	73.6	123	5.43	0.14	0.04	14.9	312	40.8	0.48	5.71	2.58	0.08	<0.068	79.8
09-09	49.0	20.4	14.3	0.82	0.06	23.5	198	13.5	0.08	15.3	1.00	0.04	<0.102	10.6
10-05	78.9	44.0	6.34	0.51	0.03	35.5	45.6	10.1	<0.005	20.3	3.04	0.013	<0.063	47.4
12-19B	70.7	68.4	4.26	0.07	0.03	14.2	17.0	0.47	<0.006	2.70	2.98	<0.014	<0.071	32.3
13-16B	71.2	59.7	5.62	0.08	<0.013	7.02	14.0	0.58	0.125	84.3	4.78	<0.014	<0.070	21.2
14-15B	71.0	78.6	1.13	0.04	0.03	9.86	11.3	0.66	0.023	1.27	5.63	<0.014	<0.070	26.2
15-16B	75.1	87.6	5.33	0.03	<0.013	5.19	4.53	0.21	<0.005	21.3	4.93	<0.013	<0.067	6.13
16-05B	72.2	82.0	2.77	0.04	<0.013	9.70	11.1	0.15	<0.006	1.25	6.09	<0.014	<0.069	19.7
17-16B CS	76.9	103	1.30	0.01	<0.013	5.20	0.91	0.08	<0.005	0.39	5.85	<0.013	<0.065	3.51
20-05	49.8	51.0	9.04	0.42	0.08	14.1	98.4	26.1	0.18	8.03	4.82	0.100	<0.100	8.23
24-04	43.2	72.7	13.9	0.19	0.09	18.5	55.5	5.09	0.063	764	4.17	0.116	<0.116	81.0
41-30	79.6	43.6	7.54	0.10	0.05	12.6	151	50.3	0.33	6.03	1.88	0.163	<0.063	95.7
42-20B	50.9	48.5	13.8	0.20	0.18	31.4	157	74.7	0.59	15.7	2.36	0.33	<0.099	356
43-18B	57.6	60.2	8.51	0.10	0.07	19.1	71.2	26.0	0.28	13.9	3.65	0.07	<0.087	104
44-68B	73.4	76.0	3.00	0.04	0.03	8.2	6.6	5.4	0.03	1.36	5.86	0.14	<0.068	28.1
45-14B	72.5	78.5	0.69	0.03	<0.014	6.5	6.8	0.69	<0.005	1.38	6.34	<0.014	<0.069	14.8
46-18B cs	79.6	85.6	0.25	<0.013	<0.013	13.8	0.75	0.10	<0.005	0.25	6.16	<0.013	<0.063	3.6
47-04B	70.7	57.0	3.54	0.03	0.057	5.52	45.3	4.38	0.10	0.99	4.10	0.057	0.071	55.2

Note 1: 45-14B represents sample Number 45, waterdepth 14 feet, replicate B
cs = control station for island, CS = control station for three islands

Note 2: data are calculated on dry weight basis, accounting for water in muddy sediments
this column details the % solids of the entire sample - the rest is water

Note 3: based on replicate - and interlaboratory comparison, values for Sb are considered spuriously high, because they are internally consistent, however, they are included for the purpose of comparing areal variations.

Based on an intercomparison of concentrations of **sewage-related trace elements** in the STP outfalls off St Croix (Figure 2) and St Thomas with sewage disposal sites off the continental USA and in Solway Firth, U.K. (Table 3), the USVI sites, especially St Croix, showed surprisingly little impact from the marine discharge operations. This fact is attributed to the lower discharges and better dispersal, and is clearly relevant to future licensing and exemption considerations.

Comparing the **specific toxic trace elements** from USVI averages and control (sample 17-16B) with STORET means for ambient USA ocean sediments and with worldwide means (Table 4), USVI sediments appear enriched - though not dangerously so - in Se and Ni (and possibly Sb), but much below STORET values in the elements Be, Cd, Hg and Ag.

TABLE 3: COMPARISON OF SEWAGE - RELATED TRACE ELEMEMENTS

IN SEDIMENTS NEAR USVI STP OUTFALLS WITH THOSE OF

SIMILAR SITES WORLDWIDE

(mean concentrations, in mg. kg^{-1}, (ppm) dry weight)

Trace Element:	Cr	Cu	Ni	Pb	Zn	
Average Daily Ingestion: ($ug.d^{-1}$)	144	2,100	460	138	16,900	(1)
US VIRGIN ISLANDS:						
- Control, STA 17:	5.2	0.91	0.39	0.08	3.51	
- St. Croix STP, STA 02:	0.59	0.17	3.07	0.01	2.91	
- ST. Thomas STP, STA 44:	8.2	6.8	1.36	5.4	28.1	
FORMER PHILADELPHIA DUMPSITES:						(2)
- Off Delaware Bay (n=25):	1.11	-	1.56	2.84	4.02	
- Off Ocean City MD (n=6):	1.22	-	2.20	2.80	6.0	
NEW YORK BIGHT:						(3)
- Unaffected	6	3	3	12	18	
- Center of Former Dump: (n=21)	105	141	24	157	259	
S. CALIFORNIA BIGHT:						
- Los Angeles Harbor (n=5):	123	99	31	174	202	(4)
- Whites Point (1 km from Los Angeles City Outfall):						(5)
-Sediments	730	590	84	430	1,800	
-Wastewater Particulates	1,700	1,120	220	570	4,100	
SOLWAY FIRTH, UK: (n=53):	39	10	-	40	66	(6)

(1) Anon., 1974 (2) Oostdam et al., 1975 (3) Carmody et al., 1973

(4) Emerson et al ., 1976 (5) Bruland et al., 1974 (6) Halcrow et al., 1973

A search for possible sources indicated very low correlations between trace element concentrations in marine sediments and in adjacent terrestrial rocks and soil (Hopkins et al. 1984; also see Ramos-Perez and Gines-Sanchez, 1988), with the possible exception of high values for Ni on St John and St Thomas. The distribution pattern of Pb and Hg suggests the influence of transport by the prevailing trade winds. Other distribution patterns are best explained by local anthropogenic inputs, e.g. Cu and Zn in harbors and marinas.

CONCLUSION

The USVI marine environment in general is relatively pure, especially with respect to organic toxic substances. Impacts of inorganic toxic trace elements on bottom sediments is largely localized, e.g. HOVIC Harbor.

Anthropogenic inputs of some trace elements, e.g. Cu, Pb and Hg, exceed natural inputs from erosion and cause fluctuations in concentrations through three or more orders of magnitude. Although sediments with elevated toxic trace element concentrations need not be inherently dangerous to man, consumption of shellfish caught in such sediments should be avoided.

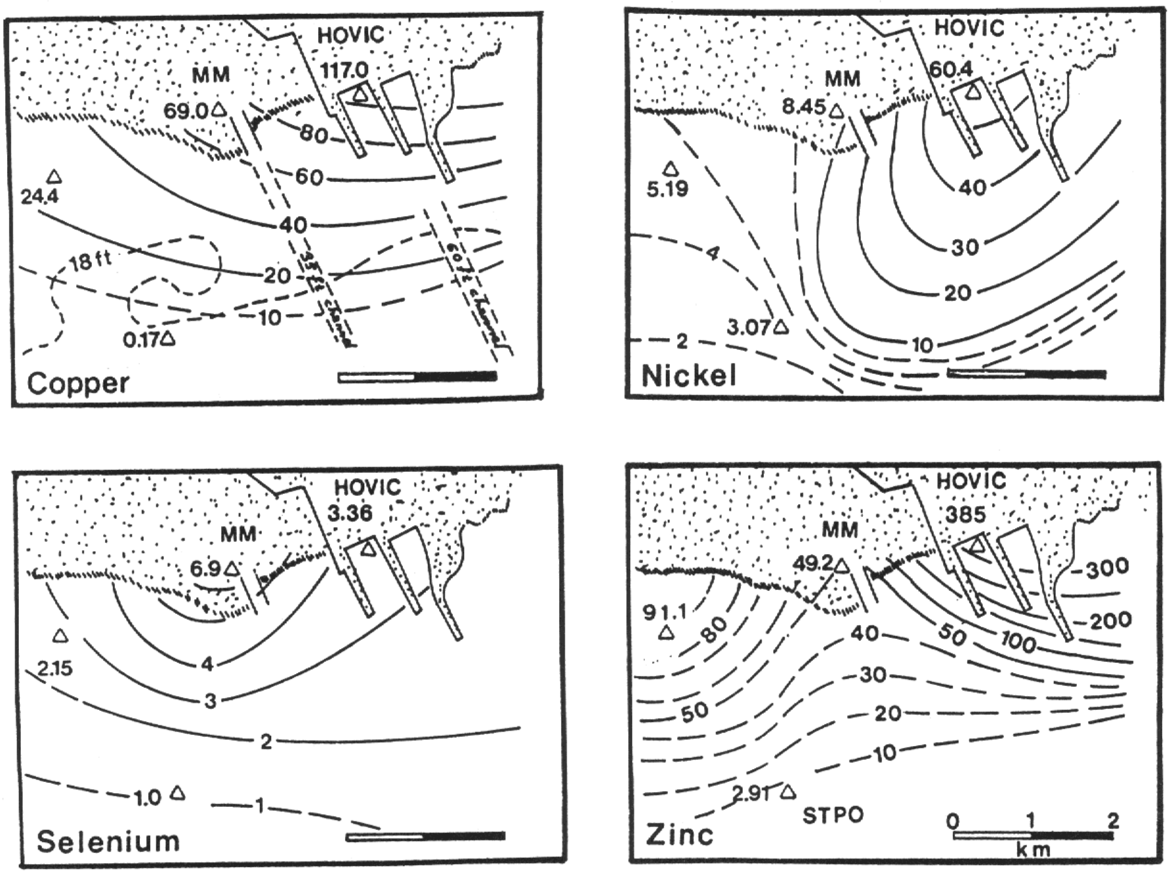

Figure 2. Concentration Contours for Selected Toxic Trace Elements in Nearshore Sediments off Southern St. Croix, U.S.V.I., 1986. Concentrations are in mg per kg dry weight (ppm). The area shown corresponds to rectangle 1 on inset of Figure 1. Triangles represent sampling sites.
MM = Martin Marietta Aluminum Smelter (now VIALCO)
HOVIC = Hess Oil of the Virgin Islands Corp., oil refinery
SL = site directly off Sanitary Landfill
STPO = Sewage Treatment Plant Outfall

TABLE 4: COMPARISON OF TOXIC CONCENTRATION MEANS OF USVI SEDIMENTS WITH STORET AND WORLDWIDE MEANS.

Toxic trace element or compound	CONCENTRATION			(milligram per kilogram (ppm) dry)			
	USVI mean (n=24)	USVI control <STA 17> (n=1)	Storet ambient ocean seds 1)	WORLDWIDE MEANS continental rock 2)	soil 2)	rivers susp. sed. 2)	deep sea clay 2)
Sb*	<101.	103	4.66	0.90	1.00	2.50	0.80
As	6.49	1.30	8.22	7.90	6.00	5.00	13.0
Be	<0.146	0.01	1.57	-	-	-	-
Cd	<0.072	<0.013	6.37	0.20	0.35	1.00	0.23
Cr	17.7	5.20	489.2	71	70	100	100
Cu	59.2	0.91	12.1	32	30	100	200
Pb	13.4	0.08	13.9	16	35	100	200
Hg	<0.143	<0.005	1.44	-	-	-	-
Ni	43.4	0.39	18.2	49	50	90	200
Se	3.85	5.85	0.91	-	-	-	-
Ag	<0.062	<0.013	3.09	0.070	0.050	0.070	0.100
Tl	<0.103	<0.065	0.18	-	-	-	-
Zn	63.8	3.51	118	127	90	250	120

*USVI - values for Sb are considered spuriously high

1) From USEPA STORET sample data for ambient ocean samples collected between 1967 and 1986, using all values (including >, <, and est.). The number of samples ranges from minimum of 8 for Tl to a maximum of 3,984 for Zn, Courtesy Mr. John Higgins, USEPA, Edison, NJ..

2) After Martin and Whitfield, Tables 5 and 6, in Wong, C.S. et al., 1983.

Additional Studies should include investigation of:

(1) The interrelation between toxic substances in sediments and their superjacent waters.

(2) The causes of variation in concentrations of toxic trace elements in water, sediment and biota.

(3) The optimization of sampling and monitoring operations.

(4) Mechanisms of effective regulation and enforcement, including setting of realistic criteria, standards and guidelines.

(5) Improvements in emergency preparedness for spills of toxic substances, including oil and raw sewage, caused by such disasters as the recent Hurricane

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REFERENCES

Alonso, John C., 1983, Toxic Pollutants in Sediment, St. Croix, USVI., Unpubl. Report, USEPA/DCCA, 8 pp.

Amore, F., 1976, Losses, Interferences and Contamination in Trace Analysis- Some Examples. Nat. Bur. of Standards Spec. Publ. 442: Accuracy in Trace Analysis: Sampling, Sample Handling and Analysis, Vol.1, p.661-669.

Anon., 1974, Chemistry, Vol.47, no.6, p.4-5.

Beck, R.W. and Associates, 1974, NPDES Environmental Analysis for the Virgin Islands Water & Power Authority.

____,1986, Review and Evaluation of the Wastewater Discharge Monitoring at the St. Thomas and St. Croix Power Plants, VI Water and Power Authority.

Bruland, Kenneth W., 1983, Trace Elements in Sea-Water, in Chemical Oceanography, Vol.8, p.157-220, Academic Press, London.

Carmody, D.J., Pearce, J.B. and Yasso, W.E., 1973, Trace Metals in Sediments of the New York Bight. Mar. Pollut. Bull., Vol.4, no.9, p.132-135.

Department of Conservation and Cultural Affairs, USVI, 1979, Virgin Islands' Lead Implementation Plan.

____, 1984, Handbook for Homebuilders and Developers. VI Coastal Zone Management Program, 153 pp.

Department of Health, USVI, 1972, Contingency Plan for the Control of Oil and Other Hazardous Materials in the US Virgin Islands, 20 pp.

Federal Register, Nov. 28, 1980, Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Life and Its Uses. Vol.45, p.79341 (revised in 50 FR 308784, July 29, 1985).

Folk, Robert L., 1974. Petrology of Sedimentary Rocks. Hemphill Publ. Co., Austin, Texas, 182 pp.

GESAMP (IMCO/FAO/UNESCO/WMO/WHO/IAEA/UN) Joint Group of Experts on the Scientific Aspects of Marine Pollution, 1976, Review of Harmful Substances. Reports and Studies no. 2, 80 pp.

Halcrow, W., MacKay, D.W., and Thornton, I., 1973, The Distribution of Trace Metals and Fauna in the Firth of Clyde in Relation to the Disposal of Sewage Sludge. Jour. Mar. Biol. Assoc. U.K., Vol.53, p.721-739.

Hopkins, R.T., Tucker, R.E., Roemer, T.A., Sharkay, J.D., and Aubin, L.L., 1984, Analytical Results from a Geochemical Survey of St. Thomas and St. John, USVI, Using Soil, Rock and Panned Concentrate Samples. Open File Report 84-784, US Dept. Interior, Geol. Survey, 64 pp.

Ketchum, Bostwick H., 1977, The Water Environment, in The Integrity of Water, USEPA Symp., p.25-32.

Martin, J.M., and Whitfield, M., 1983, The Significance of the River Input of Chemical Elements to the Ocean, in Trace Metals in Sea Water (Wong et al., editors), Plenum Press, New York, p.265-296.

Nichols, Maynard and Towle, Edward, 1977, Water, Sediments and Ecology of the Mangrove Lagoon and Benner Bay, St. Thomas, Rept. By Island Resources Foundation to Dept. of Conservation and Cultural Affairs, USVI, 159 pp.

Oostdam, B.L., 1983, Sewage Sludge Dumping in the Mid-Atlantic Bight in the 1970's: Short-, Intermediate- and Long-term Effects, in Wastes in the Ocean, vol. 1, (Duedall, I, editor) Proc. Second Internat. Symp. on Ocean Dumping, Woods Hole, Mass, 1980, p.196-209.

Ramos-Perez, Carlos and Cindy Gines-Sanchez, 1988, Geochemistry of St. John and Influence on Marine Systems, Virgin Islands Resource Management Cooperative, Biosphere Reserve Research Rept. no. 28, 34 pp.

US Army Corps of Engineers, 1982, Section 107, Reconnaissance Report, Benner Bay, St. Thomas, USVI., U.S. Engnrs. District, Jacksonville, FL.

US Environmental Protection Agency, 1980, Ambient Water Quality Criteria For....[individual publications for each of the thirteen toxic trace elements].

____, 1982, Water Quality Standards Handbook. Off. of Water Regulations and Standards, Washington, DC.

Wernicke, W., 1986, Urban Pollution Survey, Christiansted and Charlotte Amalie, USVI. Rept. by Donald L. Hamlin Consulting Engnrs. for Dept. of Conservation and Cultural Affairs, USVI.

Wernicke, W. and Towle, E.L., 1983, Vessel Waste Control Plan for the USVI. Rept. by Island Resources Foundation for Dept. of Conservation and Cultural Affairs, USVI.

Wong, C.S., Boyle, Edward, Bruland, Kenneth W., Burton, J.D. and Goldberg, Edward D. (editors), 1982, Trace Metals in Sea Water. NATO Confer. Series, no. 12, Elsevier Scient. Publ. Co., New York.

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