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WATER QUALITY OF CISTERN WATER
IN ST. THOMAS, U.S.V.I.

A. Preliminary Survey

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B. Microbial Analysis and Major Ion Composition

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DISCLAIMER

ABSTRACT

A study in two phases was conducted in the Virgin Islands to determine the major ions and microbial species in the cistern water of the U.S. Virgin Islands. The first phase was a survey of a sample set of cisterns to determine the scope and limits of the problem. The second phase was an indepth study of bacterial species and eight ion species.

A significant proportion of water supply in the U.S. Virgin Islands comes from the rainfall which is stored in cisterns. All dwelling units are required by law to have cisterns. Since cistern water is not part of the public distribution system, it is not covered by the Safe Drinking Water Act (Public Law 93-523). The objective of this study was to determine whether cistern water supplies pose a potential health hazard to their users.

Cistern water supplies were studied to assess the types of heterotrophic bacteria and ion species that may be present. The bacterial study was directed towards identifying those organisms capable of causing disease in water supplies. Total coliform, fecal coliform, fecal streptococcus, and Salmonella/shigella spp. were enumerated. The presence of coliform bacteria, fecal streptococcus, and Salmonella/shigella spp. in most of the cistern water supplies suggest potential health problem. There was no clear pattern of contamination found; however, the general prevalence of contamination suggests potentially dangerous chronic infection from several possible sources and the levels of contamination were higher in public housing projects, located near main roads, and where trees overhung collection surfaces.

Generally the levels of metals contamination found were well within the Public Health standards. Very few of the private cisterns however met microbial standards. Only three of the public housing tests met the legal health standards, and two of those had high Salmonella/shigella test results which meets "legal" standards but may be more significant health-wise.

A recommendation is made to carry out a detailed study of contamination types, levels, and sources for water supplies in the Virgin Islands. Also suggested is creation of a local law regulating the quality of all water for sale and all cisterns. Such water sources are not now controlled.

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TABLE OF CONTENTS

LIST OF TABLES

Page

PHASE I

PHASE II

LIST OF FIGURES

Page

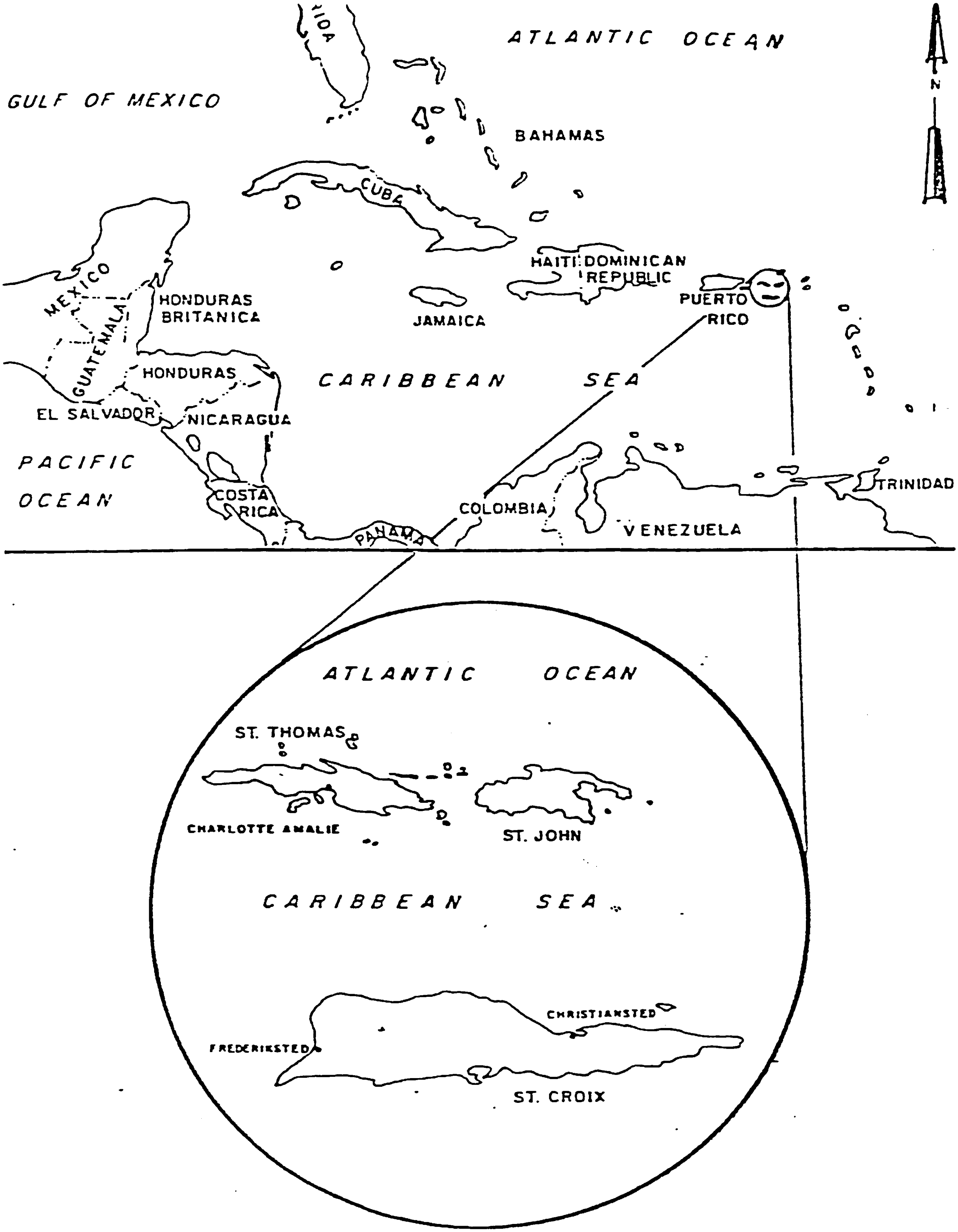
PHASE I

PHASE II

SETTING

St. Thomas, a Caribbean island in the U.S. Virgin Islands, relies on a variety of sources for its domestic water supply. In the early 1970's, these sources included wells on the eastern part of the island, three desalinization plants, water barged from Puerto Rico, and a large number of individual household cistern systems. At one time, large municipal cisterns were operating, however, these systems have not been maintained and were functioning only at the College of the Virgin Islands during this study. Duplicate water samples were collected from over 130 household cisterns as well as from other sources of domestic water on the island. This paper presents the results of the chemical and microbial analyses done on these samples and discusses the type and water quality of household cistern water supplies for domestic use.

St. Thomas is 4.8 km (3 miles) wide and 19 km (12 miles) long. It has a backbone ridge of mountain which rise to approximately 457 m (1500 ft.) above sea level. The climate of St. Thomas is essentially marked by constant easterly trade winds and maximum average temperatures about 27°C (80°F) in the winter and 30 to 32°C (87-89°F) during the summer. Average relative humidity is above 80%. Rainfall



THE U.S. VIRGIN ISLANDS
LOCATION MAP

Fig. 1

frequently occurs in the form of brief showers, with the higher elevations on the island tending to receive greater amounts of rainfall, on the order of 102-186 cm (40-80 in.) per year. Average monthly rainfall for the month of December through June is 5 to 7.5 cm (2-3 in.), while for July through November it is on the order of 10 to 12.5 cm (4-5 in.) of which 80% is during July and November.

The population of the Virgin Islands is approximately 110,000 persons, having doubled in 15 years and being expected to double again in the next 10 years. The water problem is expected to parallel or exceed this growth rate.

INTRODUCTION

Fresh water has always been in critical supply in St. Thomas. Rain collected on roofs and stored in cisterns is still the source of water for most rural and urban domestic supplies. Before 1960, hillside rain catchments and a few dug wells were the major source of water for public supplies. Since that time desalted water barged from Puerto Rico, was a close second until 1981. Barging has been discontinued for 2 years at this time.

Charlotte Amalie has a dual public water system. Fresh water is used for drinking and general household needs, and salt water is used for sanitary and fire-control purposes. The fresh-water supply is obtained from salt-water distillation plants, hillside rain catchments, and wells. In the late 1950s, with the exception of 1957, a drought year, catchments were the major source of water. Barged water became the major source of supply in the early 1960s, but by the late 1960s, desalted water became the principal source of supply.

At the time of sampling, these desalinization plants were producing only 2.5 mgd. Since the desalinized water, well water, and water barged in from Puerto Rico were likely to be of markedly different chemical composition, the composition of the domestic waters of Charlotte Amalie could be somewhat variable.

Rooftop catchments and cisterns are still the major source of water for rural St. Thomas. During prolonged dry periods, rain water is supplemented by water hauled from public-supply points in Charlotte Amalie. Small ponds have been constructed, tapping storm runoff for irrigation water for truck gardening and drinking water for stock. Since 1962 about 40 wells have been drilled, but these are not systematically pumped, and many are contaminated from inadequate septic tank leaching fields or storm runoff.

This study represents a follow-up of critical directions indicated by Isquith and Winters (1981), and Lee and Jones (1982). These studies indicated that wells were heavily contaminated, and at least some cisterns were no better. A preliminary study done by Rinehart, et al, as a guide to areas of concern has been described under Phase I of this report. The Rinehart report showed problems existed but called into question the two other reports in terms of degree and extent.

Phase II explores the degree, nature, and possible pattern of contamination. The conclusions and recommendations are aimed at local interests and management as well as water resource scientists.

CHARACTERISTICS OF HOUSEHOLD CISTERN SYSTEMS

Many of the homes in St. Thomas are constructed in such a way that all, or at least a substantial part, of the roof collects rain water and transports it to storage tanks located within or below the house. Debris that collects on a roof accumulates in the storage tank along with the rain water. The water from this tank is used to meet most household needs. Some residents find that for a variety of reasons the cistern water supply is inadequate to meet the needs of the household. Supplemental water can be purchased from a private water supplier who delivers water via truck to the cistern systems. The trucked water was, at the time of this study, derived primarily from wells that had been found to have elevated coliform counts, even though the water from these wells was chlorinated. Private trucks also deliver desalinated water from government stand pipes.

There are no restrictions on the composition of the cistern roof collection systems or their paint. The cistern tanks were composed of various materials, including painted and unpainted concrete, galvanized metal, sheet-rubber lined concrete and fiberglass. The existing roof collection systems also varied widely in their construction and composition. Some were galvanized iron, usually painted with red lead paint within a few years after construction. Others were terracotta tile, concrete, or plywood covered with tar paper and coated with hypolon. The roofs of many of the newer homes were constructed of fiberglass-desco which was periodically painted.

There are several types of paint used frequently for roofs on this island. One is an "asbestos fiber/liquid aluminum" paint containing 4% asbestos and about 18% titanium dioxide. Other paint used frequently contain zinc oxide or tributyl tin oxide for controlling mildew, while many roofs are surfaced with neoprene rubber and "Hypalon". There has been some concern in the past about the use of paints containing mercury on roofs that are part of a roof-cistern system.

A few cisterns were screened to exclude frogs, lizards, rats, but most either were not or else the screens were rusted or displaced.

Survey studies by Isquith and Winters (1981) and Lee and Jones (1982) indicated potential problems with microbes, algae, and protozoa.

PHASE I

PRELIMINARY SURVEY

by

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PHASE I

Drinking water in the U.S. Virgin Islands is available in limited supply and is often of questionable quality. Water in private homes, schools and public housing is usually stored in cisterns and comes from one of three primary sources: desalinized water delivered through a leaky distribution system or by trucks, ground water piped to the surface and delivered by trucks, and rainwater collected on the roof of each building and delivered to its cistern through gutters. Each source of water has known, or potential, public health dangers associated with it. The distribution system for desalinized water, for instance, is known to be leaky and to share routes with a sewage collection network also known to be leaky. Ground water sources are also prone to contamination, not only from sewage seepage, but from salt water intrusion. Trucking water for home delivery involves transfer procedures which are also potential public health hazards.

Collected rainwater might also be contaminated from a variety of sources. It contains atmospheric dust and aerosols, accumulated dust and debris from roofs, breakdown products from roofing materials, organic debris from overhanging trees, micro-organisms, fecal material from rodents, birds, and lizards, and salt deposited from sea spray. During storage, it interacts with cistern walls. Frogs may visit or reside in the cistern. Under special circumstances, the cistern itself can be subjected to ground water seepage.

This paper describes a preliminary study done on the quality of collected rainwater stored in the cisterns of private homes. Cisterns selected for study were known to have received only rainwater for at least the previous two years. While study sites were selected from areas all over the island, no special attempt was made to document water quality such as sites near the Bovoni Dump or close to heavily-traveled roads. The intent of the study was to characterize the quality of water collected and stored under the best circumstances.

Samples were tested for chemical composition and bacterial contamination by a variety of standard methods. Water was tested for total solids, conductivity, chloride, nitrate, calcium, magnesium, iron, copper, and, in some cases, lead. The total concentration of bacteria of all types was determined. The concentration of coliform bacteria, an indicator of the possible presence of pathogenic bacteria, was also measured. Other possible chemical and biological tests were not performed due to limitations in time or experimental facilities.

METHODS OF ANALYSIS

1. Sampling

Samples were obtained from private homes around St. Thomas. The geographical distribution is indicated in Table 1.

TABLE 1

Geographical Distribution of Study Sites

Study Site Number	Location
1	Estate Hope, Fortuna
2	CVI, Contant, Solberg
3	Dorothea, Hull Caret, Pearl
4	Charlotte Amalie
5	Frenchman's Bay, Bolongo
6	Bovoni, Nazareth
7	Wintberg, Rosendahl
8	Tutu, Anna's Retreat

Each donor was asked to fill out a questionnaire describing the cistern from which water was drawn and the roof which collected the water. Each donor collected water samples from a well-used household tap according to written instructions. For bacteriological tests, donors were supplied with a sterile collecting bottle. If the cistern water had been previously chlorinated, 0.2 ml of 10% sodium thiosulfate was added to the collecting jar before sterilization to deactivate the chlorine. Samples to be used for chemical analysis were collected in treated glass or polypropylene bottles. The treatment consisted of a detergent wash, chromic acid rinse, distilled water rinse, nitric acid rinse, and repeated distilled water rinses.

2. Bacteriological Testing

Water samples were tested for total bacterial concentration and also for coliform bacterial concentration by standard water testing methods.

a. Total Plate Count: A total bacterial count was done on each sample. Several dilutions of the samples were made in buffered water. Then, 0.100 ml of each dilution was mixed with 10.0 ml of standard method agar in petri dishes. After incubation in an inverted position for 48 hours, the number of colonies was determined. Colonies were counted on those plates which had between 30-300 colonies per plate.

b. Most Probable Number (MPN) Determination: Lactose lauryl sulfate tryptose broth (LLSTB) was used in a presumptive coliform test. For this test, tubes contained 20.5 ml of the fermentation broth and inverted Durham tubes. 10.0 ml of the sample was added to each of tubes, the tubes were incubated at 35°C for 24 hours and checked for gas formation. All negative tubes were incubated for another 24 hours and checked for gas formation. A tube with even a small amount of gas is considered to be a positive indication of gas forming bacteria. From each positive tube, a loopful of material was transferred to a tube containing 10.5 ml of brilliant green lactose bile broth (BGLBB) and an inverted Durham tube for a confirmation test. All tubes were incubated at 35°C for 24 hours, checked for gas formation, and reincubated for an additional 24 hours if no gas had formed. The MPN index was determined from the number of tubes containing gas-forming bacteria.

TABLE 2

Most Probable Number Index

Postitive Tubes	Index
0	< 2.2
1	2.2
2	5.1
3	9.2
4	16.0
5	>16.0

Any index equal or greater than 5.1 is considered a positive indication of the presence of coliform bacteria and is presumptive of the presence of human fecal material.

Confirmation tests were done on any sample for which three or more tubes gave positive indications of gas formation. A loopful of the BGLBB culture was streaked on a plate of Levin EMB agar and incubated at 37°C, transferred to LLSTB medium and checked for gas formation after incubation at 35°C for 48 hours. Slants were prepared, incubated 18-24 hours at 35°C and stained with gram stain to check for the presence of gram negative rods, single or in pairs.

c. Membrane Filter Technique: This is a second standard test for the presence of coliform bacteria. 25.0 ml of each sample was filtered through sterilized 0.45 micron gridded filters and rinsed twice with buffered water. Each filter was placed in a petri dish on a sterile pad saturated with about 2 ml of M-endo broth. Inverted dishes were incubated at 35°C and 95% humidity for 24 hours. Total colonies were then counted as were those colonies which appeared dark red with a green-gold metallic sheen under fluorescent light. These colonies are indicative of coliform bacteria. Filters chosen for counting had between 20-80 colonies of all types. If the number of coliform colonies per 100 ml of sample is greater than 4, it is considered excessive.

Coliform bacteria were confirmed by sampling typical colonies and incubating them in LLSTB broth. Tubes which were positive for gas formation were used to innoculate BGLBB cultures which were in turn checked for gas formation. Depending on the number of colonies from the membrane filter verified as coliforms, adjustments in the number of coliform colonies per 100 ml were made.

3. Chemical Analysis

Total solids were determined by placing 100 ml of fresh, unfiltered samples in pre-weighed evaporating dishes and evaporated over steam. Residues were dried overnight at 105°C before re-weighing. Some samples were also filtered through pre-washed 0.45 micron Millipore filters to remove suspended solids prior to evaporation. No significant difference between the measurement of total solids and dissolved solids was reliably detected.

Conductivity studies were done on fresh samples using a Beckman conductivity bridge with a calibrated dip cell.

Chloride analysis was done with the Mohr argenometric technique. Nitrate was determined with the standard brucine sulfate colorimetric assay.

Cation analysis was done using atomic absorption spectrophotometry. A Varian Techtron single beam spectrophotometer was used. Samples were stored for extended periods prior to analysis in pre-treated bottles in the presence of distilled nitric acid to prevent adsorption. Minimum detection limits for the determined cations are in Table 3.

TABLE 3

Cation Detection Limits/ppm

Ca^{2+}	Mg^{2+}	Pb^{2+}	(Fe^{2+} & Fe^{3+})	Cd^{2+}	Ag^{+}	Cu^{2+}
0.02	0.001	0.05	0.05	0.01	0.007	0.03

RESULTS

Fresh samples usually were slightly turbid (no direct measurements of turbidity were done) and were often slightly colored, usually golden-brown though occasionally green. Some qualitative statements about suspended solids may be made from the appearance of 0.45 micron Millipore filters after a portion of each water sample had been filtered. The material retained on the filters was, like the solutions, golden brown or occasionally green. Some were not heavily colored, others were and these often clogged. Measurements (not reported) of the weight of retained solids after drying were not consistent. This was in large part due to inadequate experimental measures but also strongly suggested that the dry weight of retained substances was not large. It is likely that bacteria and algae, which would dessicate on drying, are responsible for the bulk of the colored retained material.

Results of the chemical analysis on 24 cistern water samples are presented in Table 4. Inorganic substances in cistern water are present in small quantities. Measurements of total solids (after drying) and conductivity both show the concentrations of dissolved salts to be small. For purposes of comparison, Table 4 also contains a summary of the results of an earlier study (Robinson et al.) on well water. Both means and ranges of measurements on nine wells chosen randomly from their study are presented. The primary constituent of the solids in cistern water is calcium ion, about 20% by mass. Since cistern water is well-equilibrated with the concrete walls of the cistern, this observation is not startling. (Concrete is composed of carbonate, sulfate, and aluminosilicate salts of calcium). Sodium ion is present in large enough quantities to intensely color the flame in the atomic absorbtion spectrophotometer. Sodium was not directly measured due to the lack of a suitable method. Chloride is another major constituent (10% of total solids). One obvious source of chloride would be atmospheric aerosols containing NaCl from the surrounding sea. Although not directly measured, carbonates and sulfates are probable important constituents. It is interesting to note that, if one assumes that the chloride is present as NaCl and calcium carbonate, the two would comprise, on average, about 31 mg/l of sample, or about 60% of the total solids.

Measurements of heavy metal content of cistern water were done for only a few metals, lead, cadmium, silver, iron, and copper. Only copper and iron were found in any of the samples and only in very low concentrations. Iron could leach from cistern walls or from plumbing. Copper is also likely to leach from plumbing. It should be remembered that all samples were collected at the tap.

Nitrate concentrations were small. It may be significant that the cistern with the largest nitrate concentration (8.1 mg/l) was also found to harbor a large concentration of bacteria.

Bacterial assays are reported in Table 5. Two different types of assays were done. The first estimates the total number of bacteria present in the sample. There is no accepted limit for total bacterial count in drinking water.

Second, an estimate of the concentration of coliform bacteria was made by two methods. The most probable number assay relies upon the gas-forming characteristic of coliform bacteria. Five tubes of diluted sample were examined for the presence of gas bubbles. If two or more contained gas, coliforms were subjected to confirmatory tests. A separate estimate of the number of coliform bacteria was obtained by trapping bacteria on a membrane filter and culturing them in conditions favoring growth of coliforms. Any suspect coliform colonies were subjected to confirmatory tests. Four or more coliform bacteria per 100 ml of water is unacceptable. Of the 30 cisterns tested, only four were contaminated by either of these standards.

There is no clear correlation between total bacterial count and the presence of coliforms in these samples. Although three of the four cisterns with large coliform counts also had very large total bacterial concentrations (29,000, 58,000 and 92,000 bacteria per ml), one (sample 3.6) had a relatively low concentration (2,100 bacteria/ml). In addition, several cisterns with relatively large numbers of bacteria had no detectable coliform bacteria, e.g. 2.5, 4.2.

No attempt was made to identify bacteria other than coliforms at this stage of the study. Many samples contained non-coliform fermenting bacteria, most likely Aerobacter, a soil bacterium. No measurements of algae or unicellular organisms were attempted.

TABLE 4

Chemical Analysis

Concentrations in mg/l (ppm)

Sample	Solids	Cl^-	NO_3^-	Ca^{2+}	Mg^{2+}	Fe ions	Cu^{2+}	Conductivity[a]
1.1	47	5.6	1.37	5.3	0.14	0.15	0.03	70
1.2	37	4.6	1.06	6.6	0.17	0.04		56
2.4	60	7.7	1.76	5.9	0.13	0.16		94
2.5	75	ND[b]	0.24	10.4	0.56	ND	ND	75
3.1	75	5.0	1.51	9.5	0.40	ND	0.01	139
3.2	38	4.6	1.00	7.2	0.15	0.07		68
3.3	33	4.6	1.06	6.5	0.24	ND	0.01	75
3.4	24	4.5	0.85	4.6	0.39	ND	0.04	49
3.5	53	4.9	0.91	7.0	0.25	ND		69
3.7[c]	53	8.4	0.94	10.8	0.17	0.06	0.06	99
3.8	31	5.5	0.91	6.5	0.57	ND		62
3.9	39	ND	0.27	11.1	0.40	ND	ND	79
3.10	59	ND	0.32	20.2	1.68	ND	ND	136
4.1	56	5.1		10.7	0.19		0.08	
4.2	62	3.9	1.14	11.6	0.25	0.12	0.03	81
5.1	49	4.8	1.33	7.3	0.10	0.09	0.04	88
5.2	27	4.2	0.55	5.8	0.29	ND	0.03	56
6.1	65	5.6		8.2	0.20	0.03	0.03	
6.2	54	6.4	1.19	7.5	0.15			73
6.3	39	ND	0.26	9.6	0.73	ND	ND	81
7.1		ND	0.22	9.9	ND	ND	ND	
7.2	28	ND	0.22	9.9	ND	ND	ND	62
8.1	63	4.7	3.68	10.1	0.29	0.10	0.06	89
wells[d]	1079 (641-1300)	227 (35-300)	19 (4.5-68)	49 (30-88)	41 (24-68)			1705 (858-2200)

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a. conductivity in units of micromhos
b. Not Detected
c. this sample has been previously chlorinated
d. well water samples, nine samples chosen randomly from Robinson *et al*. (ranges in parenthesis)

TABLE 5

Bacterial Assays

Sample	Total Bacterial Assay[a]	Coliform Assays MPN[b]	MF[c]	Roof Construction	Environment
1.1	100	0	0	paint, good condition	overhang trees
1.2	610	0	0		
2.1	1,430	0	0	permacoat	
2.2	92,000	5	38	hypalon	overhang trees
2.3	25,000	0	0	hypalon	overhang trees
2.4	950	1	1	desco	clear
2.5	220	0	0	plywood, plastic roof cement	clear
2.6	1,800	0	0	permacoat	clear
2.7	1,000	0	0	permacoat	clear
3.1	10,000	0	0	unpainted concrete	salt spray
3.2	1,030	0	0	hypalon	roof annually scribbed
3.3	1,800	0	0	paint on insulfoam	poor paint
3.4	600	0	0	good paint	clear
3.5	1,400	0	0	galvanized	overhang trees
3.6	2,100	3	8	desco	overhang trees
3.7	29,000	5	TNTC[d]	hypalon	overhang trees
3.8	2,900	0	0	galvanized, painted	poor paint, overhang trees
3.9	1,100	0	0	good paint	clear
3.10	2,700	0	0	concrete	overhang trees dust
4.1	1,150	1	0	concrete	town, 100 feet from busy street
4.2	16,300	1	1	galvanized, 2 months old paint	overhang tree
5.1	3,200	0	0	permacoat	overhang tree smoke from dump
5.2	3.000	0	0	painted metal	clear
6.1	6,600	0	0	concrete	beach, smoke, dust
6.2	20,000	0	0	hypalon, recent	birds
6.3	430	0	0	galvanized, hypalon coated	near lagoon, highway
6.4	2,200	1	1		
7.1	1,460	1	0	desco over plywood	overhang trees
7.2	180	0	0	unpainted galvanized	overhang trees
8.1	58,000	5	16	rooftex over plywood	overhang trees highway

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a. Bacteria per milliliter of water
b. MPN Index (See Table II)
c. Millipore filter Assay, coliforms per 100 ml.
d. TNTC means "too numberous to count"

TABLE 6A: TOTAL BACTERIAL COUNT

Bacteria/100ml

Site	Dec. 1979	Feb. 1980	July 1980	Oct. 1980
St. Thomas				
Bovoni	8.7×10^3	2.0×10^4	5.8×10^6	$>1.0 \times 10^3$
Smith Bay	7.2×10^5	1.5×10^5	2.4×10^7	$>1.0 \times 10^4$
College of the Virgin Islands	7.0×10^3	7.8×10^4	7.3×10^6	$>1.0 \times 10^3$
Hoff	5.6×10^2	4.0×10^4	4.0×10^6	6.0×10^3

TABLE 6B: TOTAL COLIFORM COUNT

Coliform/100ml

Site	Dec. 1979	Feb. 1980	July 1980	Oct. 1980
St. Thomas				
Bovoni	9.1×10^1	2.1×10^2	0	$>2.0 \times 10^3$
Smith Bay	7.5×10^2	2.1×10^2	0	1.0×10^3
College of the Virgin Islands	2.3×10^2	N.D.	0	$>2.0 \times 10^3$
Hoff	1.6×10^2	0	1.1×10^5	8.75×10^3

(continued...)

TABLE 6C: TOTAL STREPTOCOCCI COUNT

Fecal Strep/100ml

Site	Feb. 1980	July 1980	Oct. 1980
St. Thomas			
Bovoni	3.6×10^1	$<1 \times 10^3$	4.0×10^2
Smith Bay	0	$<1 \times 10^5$	5.0×10^5
College of the Virgin Islands	N.D.	$<1 \times 10^3$	5.0×10^5
Hoff	0	$<1 \times 10^3$	7.5×10^2

TABLE 6D: TOTAL SALMONELLA SP. COUNT

Salmonella sp./100ml

Site	Feb. 1980	July 1980	Oct. 1980
St. Thomas			
Bovoni	+	N.D.	4.0×10^5
Smith Bay	–	N.D.	8.0×10^5
College of the Virgin Islands	+	6.0×10^1	9.3×10^4
Hoff	–	4.2×10^4	3.3×10^4

N.D. – Not Done
TNTC – Too Numerous to Count

All counts were done using the standard plate count described in the 14th Edition of Standard Methods for Examination of Water and Wastewater.

FROM: Isquith and Winters, 1981

CONCLUSION

This study has resulted in a partial characterization of rainwater caught in cisterns. Cistern water, although it often appears turbid, is relatively devoid of inanimate material. The principal components are calcium, sodium, chloride, carbonate (inferred), sulfate (inferred), and silicate (inferred). Few cisterns are contaminated with coliforms, although other non-pathogenic bacteria abound. Many of these are likely to be soil bacteria and will also be found in other water supply sources in the Virgin Islands.

One may compare these findings in a general way with what is known about other local sources of water. Groundwater has a large mineral content (see Table 4). Nitrate levels in well water are often unacceptably large and such water is prone to coliform contamination from septic fields. Wells are also notoriously prone to salt water contamination. Desalinated sea water, delivered through pipes, is subject to similar kinds of contamination. The community is often warned by public health officials to boil this water prior to consumption.

Provided that cisterns are occasionally checked for coliform bacteria, nothing in this study suggests the violation of health standards for consumers of cistern water (unless one's intake of minerals from other sources is insufficient). One cistern which did not show coliform bacteria in this survey (sample 3.3) later became contaminated. The source of contamination was found to be drainage from a septic field uphill from the cistern and subsequent seepage into the cistern underground.

There are many questions not addressed in this preliminary study. A conscious choice was made to sample water from the tap. It is quite likely that the composition of cistern water varies with depth, particularly close to the bottom where sediments accumulate. Analysis of sediments for the presence of pesticides was done several years ago (report on file, CRI) but a more general study of the composition of sediments might prove interesting. Certain materials might be found in particular cisterns such as asbestos particles from degrading roofs or high concentrations of zinc from galvanized roofs. Some cisterns may contain potentially harmful non-coliform bacteria such as Salmonella or pathogenic unicellular organisms. Some cisterns near heavily traveled roads might have detectable levels of lead from auto emissions, although this potential problem is apt to disappear with the advent of unleaded fuel. Hydrocarbons might be present in some cisterns from a similar source or in locations downwind from the airport. Although this study does not answer these questions, it does provide a baseline for examination of the contents of rainwater stored in cisterns.

PHASE II

MICROBIAL ANALYSIS AND MAJOR ION COMPOSITION

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St. Thomas, U.S.V.I.   00802

SAMPLING AND ANALYTICAL PROGRAM

Over 100 private home cistern supplies from all parts of the island were selected for study. The sampling procedure involved lowering a sterile BOD bottle into the cistern or, where that was not feasible, allowing the kitchen sink faucet to run for about one minute, then collecting the water from this faucet in a sterile BOD bottle. Samples were processed at the Environmental Laboratory at the Caribbean Research Institute (CRI). Metal ions were determined by atomic absorption spectroscopy. All values reported in this study are for the total element content without regard to form.

In addition to individual home cistern water supplies, several public and private wells were sampled, as well as the municipal water supply for Charlotte Amalie, the principal city on St. Thomas. The city has had water from two sources; one is the desalinization plants, the other was barged water from Puerto Rico (not currently done). The barged water was from Roosevelt Road Navy Base (U.S.), which originally came from the Rio Blanco River on the east coast of Puerto Rico in San Juan. The Rio Blaco water is purified by coagulation with alum, fluorination, and chlorination. The barged water was supposed to be mixed with the desalinized water in a ratio of one part barged water to nine parts desalinized water. A League of Women Voters of St. Thomas (1970) brochure indicates that the demand for fresh water on St. Thomas averaged 1.44 mgd, 68% of which was provided from the three desalinization plants that exist on the island.

An elevated number of coliforms present would be expected, because many individual household waste disposal systems are septic tanks, many of which failed, resulting in untreated waste water entering cisterns via subsurface cracks or coming to the surface. Birds, frogs, lizards, and other animals such as rats and mongooses, could readily transport bacteria from the domestic sewage on the surface of the ground or from their feces to the roof-cistern collection system.

Visual inspection of the cisterns in some households revealed that there were a few centimeters to as much as 44 centimeters of sludge in the bottom of the cisterns. This sludge consisted largely of plant debris, dust, animal feces, and decomposing animal remains, which had been washed in from the roof collection system.

It is evident that the individual household cistern water supplies on St. Thomas are subject to potentially significant contamination from a variety of materials, including fecal materials transported from improperly constructed and managed septic tanks by birds or other animals. Leaf and other litter, debris, and dustfall, as well as materials used in roof construction and maintenance, may also be present. Because of the inadequacy of the cistern system to reliably provide for the total water needs of some families, contamination of the household water supply could readily occur through purchased water.

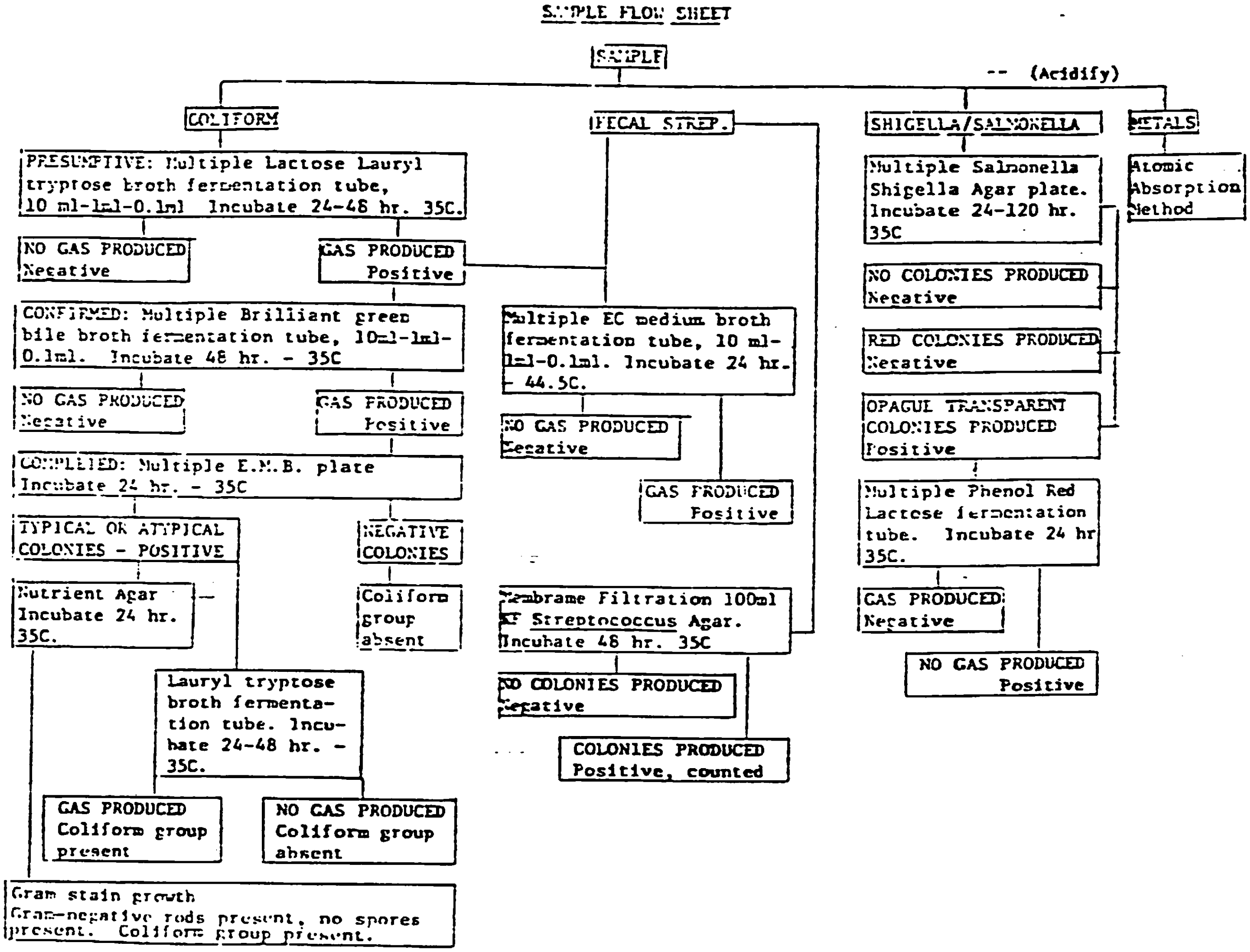

FIGURE 1: Sample Flow Sheet for Water Analysis

TABLE 1

MEDIA

CONSTITUANTS OF THE MEDIA USE IN MICROBIAL TESTS

LAURYL TRYPTOSE BROTH (DIFCO)

Bacto-Tryptose	20	g.
Bacto-Lactose	5	g.
Dipotassium Phosphate	2.75	g.
Monopotassium Phosphate	2.75	g.
Sodium Chloride	5	g.
Sodium Lauryl Sulfate	0.1	g.

PHENOL RED LACTOSE BROTH (BBL)

Trypticase Peptone	10	g.
Sodium Chloride	5	g.
Lactose	5	g.
Phenol Red	0.018	g.

BRILLIANT GREEN BILE BROTH (BBL)

Bacto-Peptone	10	g.
Bacto-Lactose	10	g.
Bacto-Oxgall	20	g.
Bacto-Brilliant Green	0.0133	g.

EC MEDIUM (BBL)

Bacto-Tryptose	20	g.
Bacto-Lactose	5	g.
Bacto-Bile Salts No. 3	1.5	g.
Dipotassium Phosphate	4	g.
Monopotassium Phosphate	1.5	g.
Sodium Chloride	5	g.

(continued...)

LEVIN E.M.B. AGAR (BBL)

Bacto-Peptone	10	g.
Bacto-Lactose	10	g.
Dipotassium Phosphate	2	g.
Bacto-Agar	15	g.
Bacto-Eosin Y	0.4	g.
Bacto-Methylene Blue	0.065	g.

SALMONELLA, SHIGELLA AGAR (BBL)

Beef Extractives	5	g.
Polypeptone™ Peptone	5	g.
Lactose	10	g.
Bile Salts Mixture	8.5	g.
Sodium Citrate	8.5	g.
Sodium Thiosulfate	8.5	g.
Ferric Citrate	1	g.
Neutral Red	0.025	g.
Agar	13.5	g.
Brilliant Green	0.33	mg.

KF STREPTOCOCCUS AGAR (DIFCO)

Proteose Peptone No. 3, Difco	10	g.
Bacto-Yeast Extract	10	g.
Sodium Chloride	5	g.
Sodium Glycerophosphate	10	g.
Maltose	20	g.
Lactose	1	g.
Sodium Azide	0.4	g.
Bacto-Brom Cresol Purple	0.015	g.
Bacto-Agar	20	g.

NUTRIENT AGAR (BBL)

Pancreatic Digest of Gelatine Peptone	5	g.
Beef Extractives	3	g.
Agar	15	g.

RESULTS

The bacterial profile by site (Table 2) provided a means for determining the density of aerobic and facultative anaerobic heterotrophic bacteria in the cistern waters. This was an empirical measurement, since no single growth medium could satisfy the physiological requirements of all bacteria in the waters sample. Therefore, the actual number of bacteria was probably higher than the actual number of viable bacteria counted.

Many different genera of bacteria were isolated. These genera included _Pseudomonas_, _Aerobacter_, _Proteus_, _Achromobacter_, and _Serratia_. Many of these organisms are considered secondary pathogens, can grow in low nutrient waters, or are chlorine resistant. The high density of bacteria in some of the cistern waters (Table 2) suggested an undesirable deterioration of the water quality. This monitoring of bacterial density seemed important in light of the fact that chlorine was not often used.

This bacteriological measurement can be used as an indicator of nutrient input into the system. While there was no maximum level for the general bacterial population covered by the Safe Drinking Water Act, it has been generally recommended that drinking water should contain fewer that 5×10^4 bacteria per 100 ml. Some special standard should be devised to cover the allowable levels of secondary pathogens also.

TABLE 2: BACTERIAL PROFILES FOR 100 CISTERNS

Bacteria/100 ml

Dates	Location	P.C.*	P.H.C.*	Rainfall	Total Coliform	Salmonella sp.	Shigella	Fecal Strep.
3/09	Pearl	*		Dry	33	-	90	N.D.
3/11	Hidden Valley	*		Dry	22	-	-	N.D.
3/14	Pearl	*		Dry	240	-	-	N.D.
3/14	Caret Bay	*		Dry	49	-	-	N.D.
3/15	Contant	*		Dry	0	-	-	N.D.
3/15	Tutu	*		Dry	2.2	-	-	N.D.
3/17	Lerkenlund	*		Dry	2.2	-	-	N.D.
3/17	Smith Bay	*		Dry	2.2	-	-	N.D.
3/21	Lyttons Fancy	*		Dry	130	-	-	N.D.
3/21	C.V.I.	*		Dry	918	3	3	N.D.
3/21	Tutu	*		Dry	33	-	-	N.D.
3/22	C. Amalie	*		Dry	130	-	-	N.D.
3/24	Nadir	*		Dry	542	-	-	N.D.
4/04	Frenchman Bay	*		Dry	0	-	-	-
4/07	Marindahl	*		Dry	130	TNTC	TNTC	6
4/09	Bovoni		*	Dry	0	-	-	-
4/09	Harmony	*		Dry	240	-	15	2
4/11	Frenchman Bay	*		Dry	2400	0	25	-
4/12	St. Peter Mt.	*		Dry	918	-	17	2
4/13	Crown/Hawk	*		Dry	2400	-	TNTC	2
4/13	Crown/Hawk	*		Dry	2400	-	102	2
4/13	Crown/Hawk	Gov.	Runoff C	Dry	345	-	134	-
4/15	C.V.I.	*		Dry	0	-	-	-
4/16	Donoe		*	Dry	1600	-	7	-
4/16	Donoe		*	Dry	0	-	-	-
4/16	Donoe		*	Dry	348	-	-	2
4/19				18"				
4/22	Nadir	*		Ave.	240	TNTC	TNTC	-
4/23	Bovoni		*	Ave.	130	-	7	2

(continued...)

Date	Location	P.C.*	P.H.C.*	Rainfall	Total Coliform	Salmonella sp.	Shigella	Fecal Strep.
4/23	Bovoni		*	Ave.	130	-	7	2
4/23	Bovoni		*	Ave.	0	-	1	-
4/23	Bovoni		*	Ave.	0	-	32	-
4/23	Bovoni		*	Ave.	542	-	10	-
4/26	Hospital Grd.	*		Ave.	130	-	-	-
4/28	Papaya Hill	*		Ave.	0	-	1	2
4/28	Papaya Hill	*		Ave.	348	-	3	2
4/28	Pearl	*		Ave	0	-	-	-
5/03	Esperance	*		Ave.	79	-	-	2
5/03	C.V.I.	*		Ave.	2.2	-	2	-
5/03	C.V.I.	*		Ave.	2.2	-	6	-
5/03	C.V.I.	*		Ave.	4	-	2	-
5/03	Hospital Grd.	*		Ave.	0	-	-	-
5/05	Lindberg Bay	*		Ave.	0	-	-	-
5/05	Annas Retreat	*		Ave.	0	-	-	-
5/07	Bordeaux	*		Ave.	0	-	-	-
5/07	Bordeaux	*		Ave.	0	-	-	-
5/07	Bordeaux	*		Ave.	6	2	17	2
5/07	Bordeaux	*		Ave.	0	-	3	69
5/07	Bordeaux	*		Ave.	0	-	1	11
5/07	Bordeaux	*		Ave.	0	-	1	-
5/07	Bordeaux	*		Ave.	0	-	-	-
5/07	Bordeaux	*		Ave.	0	-	-	-
5/07	Bordeaux	*		Ave.	79	-	10	-
5/07	Bordeaux	*		Ave.	79	-	2	10
5/07	Bordeaux	*		Ave.	2400	-	6	240
5/07	Bordeaux	*		Ave.	0	-	-	-
5/07	Estate Hope	*		Ave.	0	-	-	-
5/09	Nazareth	*		Ave.	79	-	-	2
5/14	Tutu	*	*	Ave.	2400	-	1	-

(continued...)

Date	Location	P.C.*	P.H.C.*	Rainfall	Total Coliform	Salmonella sp.	Shigella	Fecal Strep.
5/14	Tutu		*	Ave.	2400	-	-	2
5/14	Tutu		*	Ave.	2400	-	-	-
5/14	Tutu		*	Ave.	542	2	10	-
5/14	Tutu		*	Ave.	918	2	13	79
5/14	Tutu		*	Ave.	2400	-	1	79
5/14	Tutu		*	Ave.	2400	3	1	-
5/14	Tutu		*	Ave.	2400	4	3	-
5/14	Tutu		*	Ave.	2400	1	8	79
5/14	Tutu		*	Ave.	2400	12	13	69
5/14	Tutu		*	Ave.	2400	-	-	49
5/14	Tutu		*	Ave.	109	-	-	2
5/14	Tutu		*	Ave.	2400	-	1	49
5/14	Tutu		*	Ave.	2400	-	-	79
5/17	Pearl	*		Ave.	0	-	-	-
5/17	Pearl	*		Ave.	109	4	10	-
5/21	Smith Bay	*		Ave.	0	-	-	-
5/21	Smith Bay	*		Ave.	0	-	-	-
5/21	Smith Bay	*		Ave.	0	-	-	-
5/21	Sapphire	*		Ave.	130	-	13	-
5/21	Vessup Bay	*		Ave.	0	-	-	-
5/21	Tutu		*	Ave.	2400	-	-	2
5/21	Mandahl	*		Ave.	17	-	-	-
5/21	Mandahl	*		Ave.	2400	-	-	-
5/21	St. Joseph	*		Ave.	0	-	-	-
5/21	Rosendahl	*		Ave.	0	-	-	-
5/21	Dorothea	*		Ave.	130	-	-	2
5/21	Dorothea	*		Ave.	240	-	2	240
5/21	Lerkenlund	*		Ave.	918	-	-	2
5/26	Scott Beach	*		Ave.	2400	-	1	240
5/26	Vessup Bay	*		Ave.	0	-	-	-

(continued...)

Date	Location	P.C.*	P.H.C.*	Rainfall	Total Coliform	Salmonella sp.	Shigella	Fecal Strep.
5/26	Vessup Bay	*		Ave.	240	-	-	-
5/26	Bolongo Bay	*		Ave.	109	-	-	-
5/26	Compass Point	*		Ave.	0	-	-	-
5/28	St. Peter Mt.	*		Ave.	0	-	-	-
5/28	Caret Bay	*		Ave.	7	-	-	2
5/28	Caanan	*		Ave.	918	-	-	2
5/28	Caanan	*		Ave.	918	-	1	9
5/28	Caanan	*		Ave.	1600	-	6	13
5/28	Luisenhoj			Ave.	0	-	-	-
5/28	Luisenhoj	*		Ave.	0	-	-	-
5/28	Caret Bay	*		Ave.	0	-	-	-
5/28	(Tortola)	*		Ave.	0	-	-	-
6/07	Esperance	*		Ave.	1600	-	1	TNTC
6/07	Esperance	*		Ave.	1600	-	-	TNTC
6/07	St. John	*		Ave.	27	-	-	7
6/08	Bovoni	*		Ave.	7	-	-	3
6/13	Hidden Valley	*		Ave.	5	-	-	-

P.C. = Private Cistern
P.H.C. = Public Housing Cistern

Table 3 presents the results of the chemical analyses of the cistern water supplies on St. Thomas. To assess the relative potable and palatable quality of these waters, a compilation of existing U.S. EPA water quality criteria and regulations was developed (Table 4). The sources for the concentration limits presented in Table 4 are the National Academy of Science and National Academy of Engineering (1973) "Blue Book" of water quality criteria, the U.S. EPA (1976a) "Red Book" of water quality criteria, and the U.S. EPA (1980) Water Quality Criteria (toxic chemicals).

In general, the most recently revised criterion for each parameter is presented in Table 4. A critical comparison of Tables 2-4 for each of the parameters is presented below, with particular emphasis given to the characteristics of the household cistern water supplies.

I. pH. The recommended pH range for domestic water supplies, based on welfare characteristics such as minimizing corrosion and scale formation, is 5 to 9. All of the water samples collected had acceptable pH values.

II. Calcium, Magnesium, Sodium, Potassium. The Ca and Mg concentrations (hardness) of the water supply systems were within the acceptable range for domestic water supplies. The cistern water supplies that were not receiving significant amounts of the private water supply well water, as well as the Charlotte Amalie waters, would all be considered soft water

TABLE 3: pH AND METAL IONS

Date	Location	P.C.*	P.H.C.*	Rainfall	pH	Ca	Mg	K	Na	Cu	Fe	Mn	Zn.
4/07	Mariendahl	*		Dry	8.2	11.0	2.5	0.6	22.9	0.03	0.04	-	0.07
4/09	Bovoni		*	Dry	7.8	30.1	54.0	2.3	450.0	0.02	0.08	0.01	0.05
4/09	Harmony	*		Dry	7.4	11.8	0.9	2.6	9.0	0.02	0.09	0.01	0.05
4/11	Frenchman Bay	*		Dry	8.5	7.6	0.6	2.5	8.0	0.01	0.03	0.01	0.01
4/12	St. Peter Mt.	*		Dry	7.2	12.9	2.3	8.0	13.0	0.07	0.13	0.04	0.31
4/13	Crown/Hawk	*		Dry	7.4	16.8	2.5	5.2	21.3	0.01	0.24	0.02	0.23
4/13	Crown/Hawk	*		Dry	7.2	22.4	5.1	9.9	35.7	0.01	0.07	0.01	0.06
4/13	Crown/Hawk	Gov.	Runoff C.	Dry	7.4	37.4	8.4	4.4	39.8	0.02	0.21	0.01	0.10
4/15	C.V.I.	*		Dry	8.6	9.7	4.6	1.5	34.4	0.10	0.13	0.02	0.01
4/16	Donoe		*	Dry	8.0	23.2	25.5	1.3	441.0	0.02	0.20	0.02	0.01
4/16	Donoe		*	Dry	8.0	8.8	11.5	1.1	279.0	0.02	0.12	0.01	0.01
4/16	Donoe		*	Dry	8.2	23.2	27.1	1.5	350.0	0.02	0.04	0.01	0.01
4/19				18"									
4/21	C.V.I.	*		Ave.	7.8	25.1	16.0	1.0	337.0	0.01	0.09	0.01	0.01
4/21	C.V.I.	*		Ave.	7.5	4.5	3.0	0.3	19.3	0.02	0.08	0.01	-
4/21	C.V.I.	*		Ave.	7.5	6.7	4.3	0.7	27.7	0.05	0.11	0.01	0.01
4/22	Nadir	*		Ave.	7.1	4.7	4.3	0.4	26.6	0.03	0.18	-	0.01
4/23	Bovoni		*	Ave.	8.3	10.0	22.0	1.7	430.0	0.02	0.04	-	0.03
4/23	Bovoni		*	Ave.	8.3	7.7	15.6	1.3	420.0	0.01	0.08	0.05	0.01
4/23	Bovoni		*	Ave.	8.0	25.6	33.9	2.0	550.0	0.01	0.07	0.01	0.01
4/23	Bovoni		*	Ave.	8.2	22.1	29.5	1.8	360.0	0.03	0.02	0.01	0.01
4/23	Bovoni	*		Ave.	7.8	5.2	2.6	1.0	20.0	0.03	0.42	0.01	0.01
4/24	Hospital Grd.	*		Ave.	6.3	3.8	1.3	0.2	0.8	0.02	0.01	-	0.74
4/28	Papaya Hill	*		Ave.	7.7	6.2	2.0	0.5	3.1	0.01	-	-	0.40
4/28	Papaya Hill	*		Ave.	8.2	5.7	2.9	0.7	9.8	0.01	-	-	0.05
4/28	Pearl	*		Ave.	8.2	8.4	1.8	0.6	2.2	0.01	-	-	0.46

(continued...)

Date	Location	P.C.*	P.H.C.*	Rainfall	pH2	Ca	Mg	K	Na	Cu	Fe	Mn	Zn.
5/03	Bonne Esp.	*		Ave.	7.4	8.9	2.0	0.7	3.4	0.05	-	-	0.15
5/03	C.V.I.	*		Ave.	7.8	5.0	1.1	0.3	2.2.	0.02	0.05	-	0.04
5/03	C.V.I.	*		Ave.	8.2	7.4	1.2	0.6	4.0	0.02	-	-	-
5/03	C.V.I.	*		Ave.	9.0	8.2	2.7	0.3	2.1	0.02	-	-	0.01
5/02	Hospital Grd.	*		Ave.	8.4	8.1	2.4	0.2	2.5	0.01	0.46	-	0.22
5/04	Lindberg Bay	*		Ave.	8.5	5.9	0.8	0.4	5.0	0.04	-	-	-
5/04	Annas Retreat	*		Ave.	8.2	6.1	0.8	0.4	2.5	0.02	0.03	-	-
5/07	Bordeaux	*		Ave.	8.2	7.3	0.9	0.2	3.6	0.01	-	-	0.06
5/07	Bordeaux	*		Ave.	8.2	9.8	1.4	0.6	6.4	0.02	0.05	-	0.01
5/07	Bordeaux	*		Ave.	8.2	11.0	1.7	0.8	5.0	-	-	-	-
5/07	Bordeaux	*		Ave.	8.0	10.6	1.6	0.3	2.5	0.01	-	-	-
5/07	Bordeaux	*		Ave.	8.2	16.3	2.7	0.5	7.4	-	-	-	0.05
5/07	Bordeaux	*		Ave.	8.2	8.6	1.6	0.1	1.9	0.01	0.21	-	0.03
5/07	Bordeaux	*		Ave.	8.4	9.4	1.5	0.6	3.8	0.01	0.03	-	0.14
5/07	Bordeaux	*		Ave.	8.4	12.1	2.1	0.7	4.8	0.01	0.02	-	-
5/07	Bordeaux	*		Ave.	8.2	12.6	1.9	1.4	10.0	-	-	-	0.01
5/07	Bordeaux	*		Ave.	8.2	9.4	1.1	0.7	3.6	-	-	-	-
5/07	Bordeaux	*		Ave.	8.0	8.5	0.6	1.4	6.3	0.01	-	-	-
5/07	Bordeaux	*		Ave.	8.0	7.3	1.2	0.5	4.5	0.01	0.06	-	-
5/07	Est. Hope	*		Ave.	7.7	8.5	0.8	0.4	4.8	0.04	0.01	-	0.09
5/08	Nazareth	*		Ave.	8.3	8.3	1.0	1.0	6.0	0.01	-	0.01	-

P.C. = Private Cistern
P.H.C. = Public Housing Cistern

TABLE 4: DRINKING WATER GUIDELINES AND REGULATIONS

Parameter	Max. Legal Conc.	(*)
pH (range)	5-9	1
Specific conductance (μmhos/cm) (dissolved solids mg/ℓ)	350 (500)	1
Alkalinity (mg/ℓ as $CaCO_3$)	>400	1
Hardness (Ca and Mg) (mg/ℓ as $CaCO_3$)	>150 ?	-
Na	none	-
K	none	-
Chloride (mg/ℓ)	250	1
$SO_4^=$ (mg $SO_4^=$/ℓ)	250	1
Total PO_4	none	-
NO_2^- + NO_3^- (mg N/ℓ)	10	3
Ammonia (mg N/ℓ)	0.5	4
Organic N	none	-
F^- (mg/ℓ)	1.4	3
Zn (mg/ℓ)	5	2
Cu (mg/ℓ)	1	2
Cd (μg/ℓ)	10	2
Pb (μg/ℓ)	50	2
Cr (μg/ℓ)	50	2
Ni (μg/ℓ)	13.4	2
Fe (mg/ℓ)	0.3	1
Mn (μg/ℓ)	50	1
Hg (μg/ℓ)	2	2

---

*1 = U.S. EPA (1976a); 2 = U.S. EPA (1980); 3 = U.S. EPA (1976b); 4= NAS. NAE (1973)

(*)From: Lee and Jones, 1982

and would tend to be somewhat corrosive (c.f. Table 5 Isquith and Winters, 1981; Table 6, Jordan and Cosner, 1973). The well waters, on the other hand, (Table 6), especially the private wells, would be considered hard water. The Na and K concentrations in most waters investigated were satisfactory for domestic water use.

III. Other Ions. The transition group metals; copper, zinc, iron, and manganese were analyzed for, since they are more soluble than heavy metals and are biologically active. In low concentrations they are active in vitamins and co-enzymes. In higher concentrations they act similar to heavy metals, poisoning proteins and membrance structures. In this study these metals ions were found to be in the acceptable range.

DISCUSSION

For routine examination of most potable water supplies, which are usually disinfected with chlorine, the presence or absence of coliform bacteria is used as the legal measure of water quality. These bacteria are always present in the normal intestinal tract of man and other warm-blooded animals and eliminated in large numbers in fecal wastes. Therefore, the absence of total coliform bacteria is used as an indicator of the bacteriologically safe water.

In practice, particularly in cisterns with a heavy sediment or organic loam, this may not be the case.

The coliform group has included all aerobic and facultative anaerobic Gram-negative, non-sporeforming, rod-shaped bacteria that ferment lactose with gas formation within 48 hours at 35°C. Water of "good" quality for drinking will be less than 20 per 100 ml, "very good to excellent" quality 1 per 100 ml. Most of the cistern water samples could be classified as unacceptable based upon their total coliform count (Table 2). Analyses of the total coliform group through the use of the IMViC test (Indole, Methyl Red, Voges-Proskauer and Citrate) showed that most of the coliform group isolated were of the Klebsiella-Aerobacter type bacteria. This suggested that most cisterns had been contaminated for a considerable length of time and had not been chlorinated. It also points to probable heavy loading with rotting vegetation.

TABLE 5: CHEMICAL AND OTHER CHARACTERISTICS OF CISTERN AND OTHER WATER SUPPLIES FOR ST. THOMAS, VIRGIN ISLANDS

TYPE OF SUPPLY	pH	SPEC. CONDUC. (µmhos /cm @ 20°C	ALK. AS $CaCO^3$	Ca	Mg	Na	K	Cl	SO_4	T-PO_4 AS P	NO_2 + NO_3	NH_4+	ORG N	F	HEAVY METALS Zn	Cu	Cd	Pb	Cr	Ni	Fe	Mn	Hg
			(mg/ℓ)								(mg N/ℓ)				(µg/ℓ)								
Public Water Supply Charlotte Amalie																							
West Part of City	7.6	610	11.4	8.1	2.9	24	0.8	57.2	9.8	0.075	<0.05	<0.05	<0.05	<0.05	104	3.6	0.2	<1	<4	1.4	16	<5	2.7
Savan Street Faucet	8.5	200	11.8	9.2	3.3	28	0.5	54	8.5	0.28	<0.05	<0.05	0.25	0.1	1	6.7	<0.2	<1	<4	0.9	110	<5	3.0
Storage Tank Savan	7.1	290	45.6	22.7	3.4	34	3.5	53	8.5	0.34	0.27	<0.05	0.14	<0.05	116	5.8	0.6	<1	<4	1.2	4	<5	0.4
Private Well Used for Private Water Supply East End of Island	7.4	1600	400	73	43	240	1.5	183	37	0.04	2.5	<0.05	0.14	0.82	4	3.5	0.5	<1	<4	<0.5	< 1	<5	~12
Government of Virgin Islands [illegible] Station Well & Cistern	8.1	840	298	19	7	176	0.7	103	31	0.09	0.92	<0.05	<0.05	0.26	133	0.7	0.9	1	<4	<0.5	< 1	<5	1.6
North Side of Island—Well Only	8.0	1150	369	15	9.5	208	0.4	58	36	0.08	<0.05	<0.05	<0.05	0.37	19	4.3	0.2	<1	<4	<0.5	< 1	<5	0.8
Private Home Cistern Supply																							
No. 1	8.2	200	213	28	17	202	1.8	80	14.2	0.2	1.1	<0.05	<0.05	0.25	>150	35	3.2	7	<4	10.6	84	21	0.8
2	7.1	110	42	11	0.9	5.7	0.2	8.2	5.0	0.07	0.13	<0.05	0.06	<0.05	22	4.0	<0.2	<1	<4	<0.5	<1	<5	0.3
3	7.0	79	26.6	10.1	0.5	4.9	<0.1	10.5	3.1	0.04	0.1	<0.05	<0.05	<0.05	54	4.5	0.7	<1	<4	<0.5	<1	<5	3.2
4	6.8	60	22	8.5	0.4	3.6	<0.1	9.7	2.6	0.026	<0.05	<0.05	<0.05	<0.05	3	2.2	0.6	<1	<4	0.9	110	<5	0.6
5	6.8	94	30	5.0	1.6	9.9	<0.1	16.1	2.2	0.08	0.1	<0.05	0.2	<0.05	115	~160	0.6	2.4	<4	0.6	<1	<5	2.2
6	7.0	90	35	8.2	0.4	9.2	0.8	9.8	4.3	0.06	0.15	<0.05	0.2	<0.05	15	13	1.6	<1	<4	0.6	3	<5	1.3
7	6.9	92	40	13.4	0.9	5.2	0.2	9.1	3.5	0.03	<0.05	<0.05	0.09	<0.05	10	7.7	0.6	<1	<4	1.2	3	5	0.6
8	7.0	69	27	5.6	0.2	9.2	1.4	8.0	3.6	0.04	0.1	<0.05	0.14	<0.05	<1	<0.5	0.2	<1	<4	<0.5	<1	<5	0.3
9	6.7	88	19	6.5	1.4	8.8	<0.1	19.7	4.0	0.06	0.12	<0.05	0.2	<0.05	1.4	11.2	0.7	<1	<4	1.2	3	5	4.3
10	7.6	1400	485	38	34	220	1.7	171	36	0.006	1.8	<0.05	0.31	0.6	57	16.7	0.2	<1	<4	<0.5	<1	<5	0.7
11	7.0	92	36	7.4	1.6	10.2	<0.1	13.4	0.5	0.03	0.1	<0.05	0.2	<0.05	15	7.0	0.3	<1	<4	<0.5	19	<5	0.5
12	6.7	435	9	1.5	0.6	4.4	<0.1	11.1	3.5	0.04	<0.05	<0.05	0.09	<0.05	154	11.2	0.8	1.1	<4	<0.5	20	<5	0.5

FROM: Isquith and Winters, 1981

TABLE 6: Analyses of Water of St. Thomas

(From: Jordan and Cosner, 1973)

* Locations -----	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Date--------- Year---------	9-29 1964	11-19 1963	10-14 1963	1-2 1964	12-22 1964	8-29 1963	11-24 1963	7-22 1964	11-16 1963	8-22 1964	12-17 1963	1-24 1964	12-7 1963	5-11 1965	5-20 1964
	Milligrams per liter														
Silica (SiO_2)	33	23	28	36	32	20	27	--	26	25	29	26	20	33	20
Iron (Fe)	0.00	0.00	0.04	0.00	0.00	0.13	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.32
Calcium (Ca)	14	48	59	48	38	20	46	30	34	40	52	74	48	94	4
Magnesium (Mg)	15	45	57	46	34	11	61	77	36	39	43	108	39	68	4.9
Sodium-Potassium (Na and K)	245	464	372	293	295	81	477	519	363	353	488	718	355	359	25
Bicarbonate (HCO_3)	524	726	730	758	668	188	1,010	1,028	772	704	935	848	798	772	36
Sulfate (SO_4)	37	90	131	32	35	17	60	80	81	86	27	120	37	142	4
Chloride (Cl)	112	432	305	200	200	70	360	440	235	275	405	962	255	362	36
Fluoride (F)	.4	1.2	.9	1.0	.8	.3	1.0	1.3	.5	.8	.8	.5	.4	1.0	.1
Nitrate (NO_3)	3	17	28	9.4	10	.6	3.9	1.8	3.8	2.3	0	15	.0	0.3	.2
Dissolved solids	727	1,440	1,300	963	994	--	1,480	1,700	1,110	1,150	1,510	2,380	1,080	1,470	160
Hardness ($CaCO_3$)	96	305	382	309	235	95	366	392	233	260	306	628	280	514	30
Specific conductance (micromhos at 25°C)	1,210	2,490	2,200	1,670	1,680	541	2,500	2,780	1,820	1,910	2,500	4,240	1,870	2,400	193
pH	8.1	8.0	7.9	7.9	7.7	7.4	7.4	8.1	8.1	7.9	8.3	7.8	7.8	7.7	6.8

* Locations of sites listed above are given below:

1. Well 3 in volcanic rock of Louisenhoj Formation.
2. Well 10 do
3. Well 18 do
4. Well 19 do
5. Well 12 do
6. Turpentine Run near Mt. Zion storm runoff discharge 1,700 gpm.
7. Turpentine Run near Mt. Zion, base-flow discharge 9 gpm.
8. Turpentine Run near Mt. Zion, base-flow discharge 1 gpm.
9. Bonne Resolution Gut at Bonne Resolution, base-flow discharge 15 gpm.
10. Same as above—base-flow discharge 5 gpm.
11. Well 23 in shallow alluvium, Lower Turpentine Run Valley.
12. Well 24 in deep alluvium and bedrock, Lower Turpentine Run Valley.
13. Well 2 in shallow alluvium of coastal embayment.
14. Well 16 in Outer Brass Limestone.
15. Hoffman Pond, Upper Turpentine Run basin.

TABLE 6: Analysis of Water of St. Thomas

(From: Jordan and Cosner, 1973)

* Locations -----	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Date---------	9-29	11-19	10-14	1-2	12-22	8-29	11-24	7-22	11-16	8-22	12-17	1-24	12-7	5-11	5-20
Year---------	1964	1963	1963	1964	1964	1963	1963	1964	1963	1964	1963	1964	1963	1965	1964
	Milligrams per liter														
Silica (SiO_2)	33	23	28	36	32	20	27	--	26	25	29	26	20	33	20
Iron (Fe)	0.00	0.00	0.04	0.00	0.00	0.13	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.32
Calcium (Ca)	14	48	59	48	38	20	46	30	34	40	52	74	48	94	4
Magnesium (Mg)	15	45	57	46	34	11	61	77	36	39	43	108	39	68	4.9
Sodium-Potassium (Na and K)	245	464	372	293	295	81	477	519	363	353	488	718	355	359	25
Bicarbonate (HCO_3)	524	726	730	758	668	188	1,010	1,028	772	704	935	848	798	772	36
Sulfate (SO_4)	37	90	131	32	35	17	60	50	51	56	27	120	37	142	4
Chloride (Cl)	112	432	305	200	200	70	360	440	235	275	405	962	255	362	36
Fluoride (F)	.4	1.2	.9	1.0	.8	.3	1.0	1.3	.5	.8	.8	.5	.4	1.0	.1
Nitrate (NO_3)	3	17	28	9.4	10	.6	3.9	1.8	3.8	2.3	0	15	.0	0.3	.2
Dissolved solids	727	1,440	1,300	963	994	--	1,480	1,700	1,110	1,150	1,510	2,380	1,080	1,470	160
Hardness ($CaCO_3$)	98	305	382	309	235	95	366	392	233	260	308	628	280	514	30
Specific conductance (micromhos at 25°C)	1,210	2,490	2,200	1,670	1,680	541	2,500	2,780	1,820	1,910	2,500	4,240	1,870	2,400	193
pH	8.1	8.0	7.9	7.9	7.7	7.4	7.4	8.1	8.1	7.9	8.3	7.8	7.8	7.7	6.8

* Locations of sites listed above are given below :

1. Well 3 in volcanic rock of Louisenhoj Formation.
2. Well 10 do
3. Well 18 do
4. Well 19 do
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6. Turpentine Run near Mt. Zion storm runoff discharge 1,700 gpm.
7. Turpentine Run near Mt. Zion, base-flow discharge 9 gpm.
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9. Bonne Resolution Gut at Bonne Resolution, base-flow discharge 15 gpm.
10. Same as above—base-flow discharge 5 gpm.
11. Well 23 in shallow alluvium, Lower Turpentine Run Valley.
12. Well 24 in deep alluvium and bedrock, Lower Turpentine Run Valley.
13. Well 2 in shallow alluvium of coastal embayment.
14. Well 16 in Outer Brass Limestone.
15. Hoffman Pond, Upper Turpentine Run basin.

The normal habitat of fecal streptococci is intestines of man and animals, therefore, these organisms can also be used as an indicator of fecal pollution. The data in Table 2 show that many of the cisterns had become contaminated with fecal streptococci. Some of the cistern waters showed the presence of coliform bacteria, but not the presence of fecal streptococci, while others were positive for fecal streptococci and negative for coliform. This may well be due to the long survival time of coliform bacteria (Klebsiella sp. and Aerobacter sp.) in the dark and in association with organic sediments.

The presence of coliform bacteria and fecal streptococci in cistern waters was only an indicator of fecal pollution and suggests the possible presence of pathogenic bacteria.

Many of the cistern waters showed the presence of Salmonella spp. and Shigella spp. in great numbers. Salmonella sp. may have long survival times and some can cause a variety of diseases, such as typhoid, in humans. These findings confirm those of Isquith and Winters, 1981 (Table 6 Phase I).

The high level of coliform bacteria, fecal streptococci and Salmonella spp. in many of the cisterns suggested the possible presence of pathogens in these waters. In addition to Salmonella and Shigella spp., these waters also contained species of Proteus, Aerobacter, Serratia, and Pseudomonas, which were noted but not counted. These are secondary pathogens, which means that they may initiate an infection if a person has been weakened or exposed to a primary pathogen, which has caused a disease.

CONCLUSIONS

1. The level of major ions in cistern water on St. Thomas is within acceptable safe drinking water standards.

2. The majority of cisterns tested failed to meet minimum safe drinking water standards in terms of coliforms.

3. The majority of the cisterns tested showed potential pathogens _whether or not E. coli_ was present. These pathogens were most often fecal streptococci, _Salmonella_ spp., _Shigella_ spp., _Proteus_ spp., _Klebsiella_ spp., _Aerobacter_ spp., etc.

4. Most of the cistern water in public housing or in Bovoni and Tutu fails to meet EPA and USPHA bacterial standards.

5. The current situation in the Virgin Islands is critical with a high potential for disease. Existing laws, standards, and methods of treatment and/or enforcement are inadequate and need review, and in some cases, changing.

6. Cisterns represent a unique ecosystem with their own colonization patterns, energy contamination vectors, sources, internal niches, and population dynamics that require detailed study.

RECOMMENDATIONS

Based on this study, a number of practices for the use of household cistern water supplies are recommended and enumerated below.

1. Paint used for rooftop collection systems should have as low a level of heavy metals, such as mercury and lead, as possible. During the time of painting, and until the paint is thoroughly dry, any rainwater that should fall on the collection surface should be diverted to the ground.

2. Local health authorities should carefully evaluate the sanitary and chemical contaminant quality of all alternate water supplies which are used to supplement cistern supplies, especially private supplies, to ensure that they meet U.S. EPA drinking water guidelines and regulations.

3. Initially at quarterly intervals, and eventually at semiannual to annual intervals, the local health authorities should provide low-cost testing of the sanitary quality of each cistern supply. If the cistern supply is found to contain fecal coliform in excess of one fecal coliform organism per 100 ml of water, the amount of chlorine added to the system each night should be increased so that the total residue each morning is about 1 mg Cl^-/L. The local health authorities should also provide users of household cistern

water supplies with low-cost analytical services, at annual to biannual intervals, to analyse the cistern supplies for heavy metals and other contaminants of potential concern. Particular emphasis should be given to those contaminants included in the U.S. EPA National Interim Drinking Water Regulations (1976a).

4. Every household with a cistern water supply should practice chlorination of their cistern storage water; sufficiently strong solutions of chlorine such as "Clorox", should be added to the cistern each night so that the residual total chlorine the next morning is on the order of 0.5 mg Cl^-/L or greater, based on measurements with a DPD chlorine colorimetric test kit. New cistern water supply systems should be required to be constructed to filter debris and to facilitate the addition of chlorine to the storage tanks. One way to accomplish this would be to provide plastic piping which would allow the addition of chlorine from the main part of the house, and which would preferably distribute the chlorine to several locations within the tank. A water depth indicator in the cistern supply tank would also be desirable to aid in determining how much chlorine is needed. It is realized that the addition of chlorine in this manner will increase the chlorinated organics content of the cistern water supply. However, in the opinion of the authors, the health risk of the increased concentrations is small when compared to the risk of promoting entric disease if the chlorine were not added.

5. At about yearly intervals, and more frequently if necessary, a substantial part of the leaf debris sludge present in the bottom of the cisterns should be carefully siphoned off or pumped out with a flexible hose so as not to drain the tank. If excessive amounts of debris accumulate, neccessitaing frequent cleaning, then all trees and shrubbery that overhang the rooftop collection area should be removed from that area. If leaves are a problem, it may be appropriate to place screens on the intakes. These screens would have to be cleaned at frequent intervals to make certain that they did not impair water collection.

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