RECONNAISSANCE OF GROUND-WATER QUALITY IN THE U.S. VIRGIN ISLANDS

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THE RESEARCH ON WHICH THIS REPORT IS BASED WAS FINANCED IN PART BY THE UNITED STATES DEPARTMENT OF THE INTERIOR AS AUTHORIZED BY THE WATER RESEARCH AND DEVELOPMENT ACT OF 1978 (P.L. 95-467).

DISCLAIMER

ABSTRACT

The U.S. Virgin Islands are faced with ever increasing demands for water and the response to these demands is calling into production groundwater supplies of dubious quality. To evaluate the seriousness of this problem, a cooperative study between the Caribbean Research Institute and the U.S. Geological Survey was done during 1984-85.

In this study, 26 wells were sampled for physical, chemical, and microbiological parameters including salinity, temperature, ionic species, heavy metals, 128 critical organic pollutants, and the major microbiological species present.

Results of this study indicate that the chemical quality of the groundwater, except for nitrate and total salinity in three wells, was acceptable. None of the 128 "priority pollutants" analyzed exceeded national standards. However, microbiological status of all wells were found to be very dubious. Three wells on St. John could pass the EPA coliform standard; however, five wells on St. Thomas-St. Croix met legal standards and only one well each on St. Thomas and St. Croix were found free of potentially pathogenic bacteria.

Conclusions of the study were that:

1. Chemically, the groundwater of the V.I. is of acceptable quality or can be treated to become acceptable.
2. Microbiologically, the groundwater is of dubious to poor quality due to contamination with feces and/or pathogenic bacteria.
3. Current standards, using fecal coliforms as indicators, are probably not useful in the V.I. and may be misleading.
4. Standards for both groundwater use and sewage (septic tank) facilities are not protecting the water and should be reviewed and revised.

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INTRODUCTION

The U.S. Virgin Islands are a group of three major islands and 27 smaller islands or cays clustered around the 18th parallel North. The islands are about 1100 miles southesast of Miami (Figure 1). Only the three larger islands, St. Thomas, St. John, and St. Croix (Figure 2) support any significant permanent populations. In 1984, about 140,000 permanent residents occupied the 60 odd square miles of land. In addition, over 1 million persons a year visit the islands.

Located in the trade winds zone, the islands have a high humidity but low rainfall. Annual rainfall varies from 20 inches to 70 inches per year in different parts of the islands. With this rainfall and population demand, water becomes a major commodity. The 4-5 million gallons per day required comes principally from three sources; The use of rainwater, desalinated sea water, and groundwater is increasing rapidly. The demand for groundwater in the Virgin Islands, especially for domestic use, has increased markedly in recent years. In 1982, groundwater withdrawals for public and domestic use in the U.S. Virgin Islands were about 1.1 million gallons per day. Recent investigations show that additional withdrawals might be possible (F. Gomez-Gomez, USGS personal communication, 1984). In the case of groundwater, there

is a great economic pressure to use some aquifers which may have water of marginal quality.

In spite of increasing demands for groundwater, data on its quality is very scarce. The lack of data constitutes a major gap in the knowledge of the U.S. Virgin Islands' hydrologic environment. There are no active water-quality monitoring networks and the most recent reconnaissance was conducted nearly two decades ago (Cosner, 1972; Jordan, 1975; Jordan and Cosner, 1973; Robinson, 1972). Furthermore, the profile of the topography has only shallow top soil over the alluvial or fractured rock aquifers (Figure 3). Only 5-6% of the occupied land has soil suitable for septic tank leaching fields, yet 80% of the homes use septic tanks. This situation is aggravated by direct deposition of wastes near poorly sealed wells and failing public sewage systems.

Being mindful of the current U.S. problems with contamination of groundwater, it was determined that a survey should be made of the water quality in representative wells from major aquifers. A grant was obtained from the V.I. Water Resources Research Center for this purpose. It was determined to evaluate 26 wells for 128 chemical and "priority pollutant" parameters and the microbial population of coliform and other bacteria of potential significance (Bordner and Winter, 1978). This study was

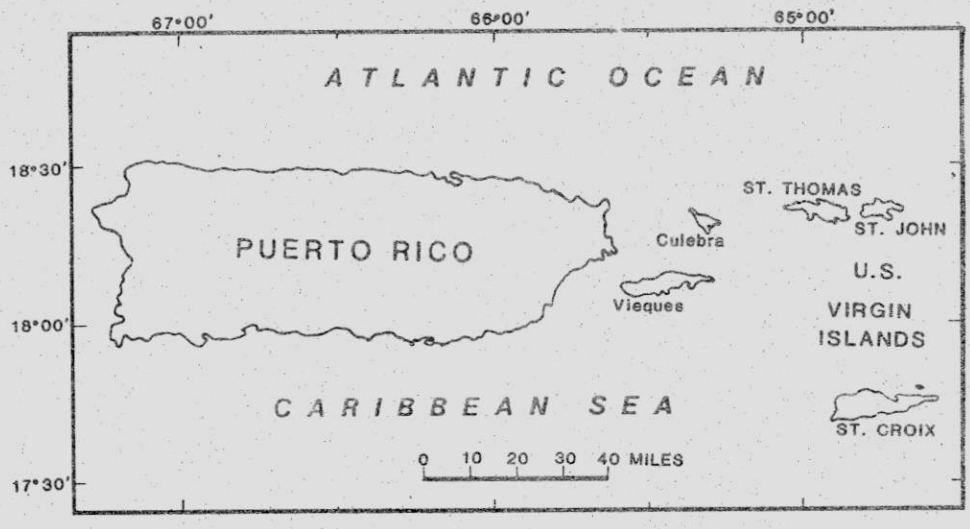
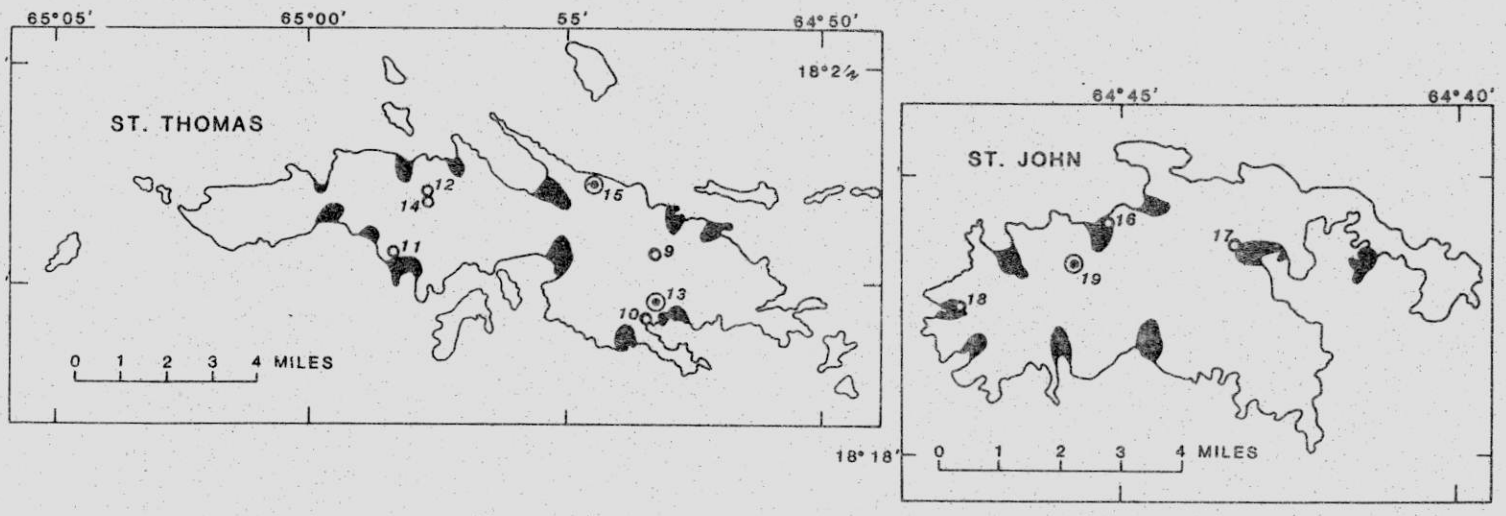


Figure 1.--Geographic location of the U.S. Virgin Islands.



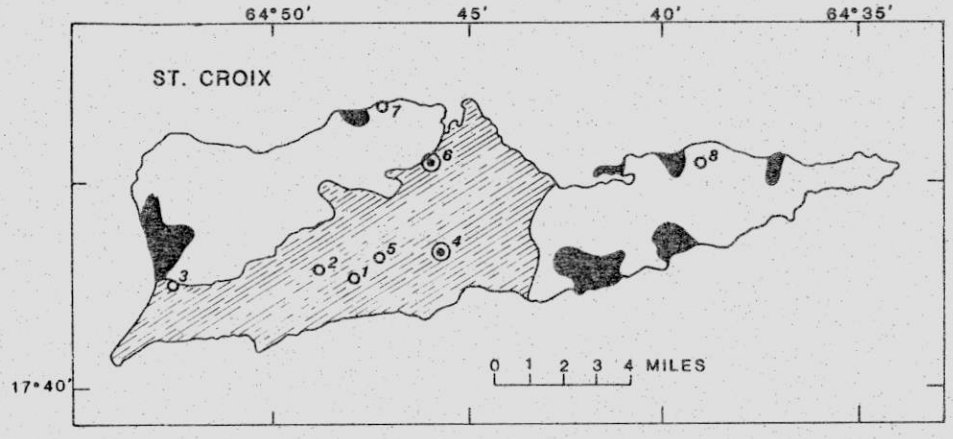


Figure 2.--Principal aquifers and selected wells sampled in the U.S. Virgin Islands.

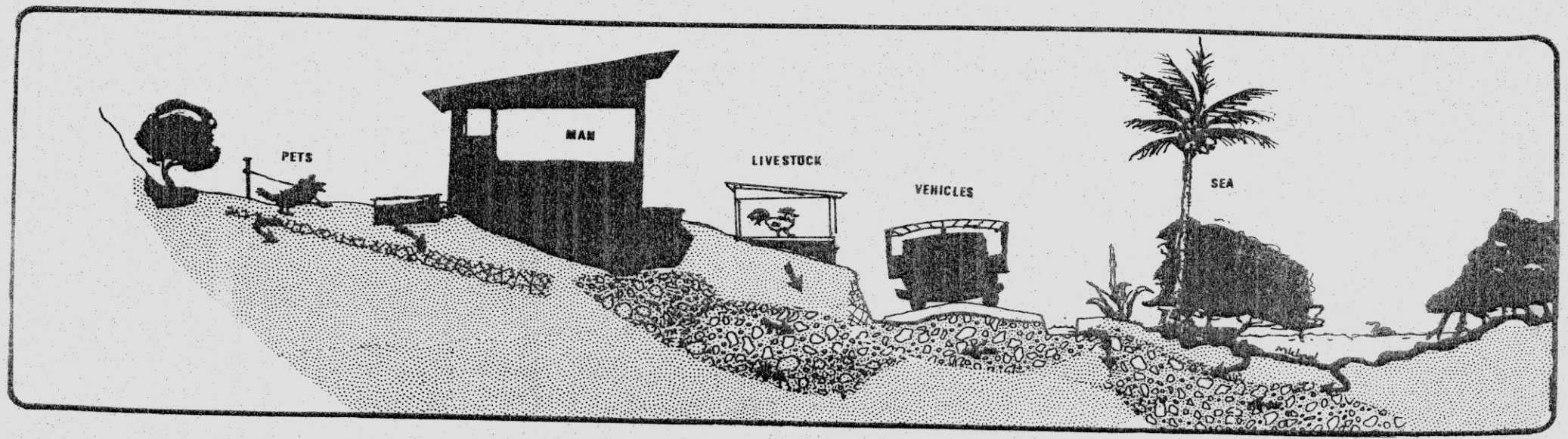


Figure 3

Diagram of A Typical Virgin Islands Aquifer Illustrating
Major Sources of Contamination

conducted in cooperation with the U.S. Geological Survey, Water Resources Division (Puerto Rico).

METHODS AND PROCEDURES

Twenty-six wells in the U.S. Virgin Islands were sampled as follows: ten wells on St. Croix, twelve wells on St. Thomas, and four wells on St. John. The wells were selected to represent the current most important pumping centers, or those of longest historic use. The samples were collected as close as possible to the well casing. Methods described by Classen (1982), and Bordner and Winter (1978), were used for the collection of the samples.

The depth of the water level below land surface was determined at each site and measures taken of temperature, conductance, pH and alkalinity were taken. Samples for chemical analysis of trace elements, common ions and nutrients were collected, filtered, and preserved in accordance with procedures described by Skougstad and others (1979), and Goerlitz and Brown (1972). Samples for the determination of priority pollutants were collected at five wells (map numbers 4, 6, 13, 15, and 19), and preserved in accordance with methods established by Brown and others (1970). The samples were shipped to the U.S. Geological Survey National Water-Quality Laboratory in Doraville, Georgia, for chemical analyses. Determinations of fecal coliforms and fecal streptococci bacteria were completed from water samples using the membrane filtra-

Table 1

Media Used In Isolation and Identification

---

mEndo-less Agar
mFC-Agar
mStaphylococcus Broth
mBrilliant Green Broth
mBismuth Sulfite Broth
mTetrathionate Broth Base
Phenol Red Lactose Broth
Plate Count Agar
Brain-Heart Infusion Broth
Brain-Heart Infusion Agar
Brain-Heart Infusion Agar w/5% blood
Nutrient Broth
Simmons Citrate Agar
MR-VP Medium
Tryptone
Urea Disk
Lauryl Tryptose Phosphate Broth
Brilliant Green Bile Broth 2%
EC Broth
Oxidation-Fermentation Glucose Medium
Levine EMB Agar
Bismuth Sulfite Agar
S/S Agar
Pseudomonas Isolation Agar
Motility GI Medium
Rabbit Plasma w/EDTA

Table 2

Quality Control Confirmation: Type Cultures

Difco Bactrol Disk, (Lot # 1628-32-2 and Lot # 1656-32-7)

ATCC # 8100 - *Serratia marcescens*

ATCC # 13315 - *Proteus vulgaris*

ATCC # 27853 - *Pseudomonas aeruginosa*

ATCC # 23355 - *Enterobacter cloacae*

ATCC # 13048 - *Enterobacter aerogens*

ATCC # 25922 - *Escherichia coli*

ATCC # 13883 - *Klebsiella pneumonia*

ATCC # 8090 - *Citrobacter freundii*

ATCC # 19606 - *Acinetobacter calcoaceticus*; var. *anitratus*

ATCC # 14028 - *Salmonella typhimurium*

ATCC # 19615 - *Streptococcus pyogenes*

ATCC # 25923 - *Staphylococcus aureus*

ATCC # 12228 - *Staphylococcus epidermitis*

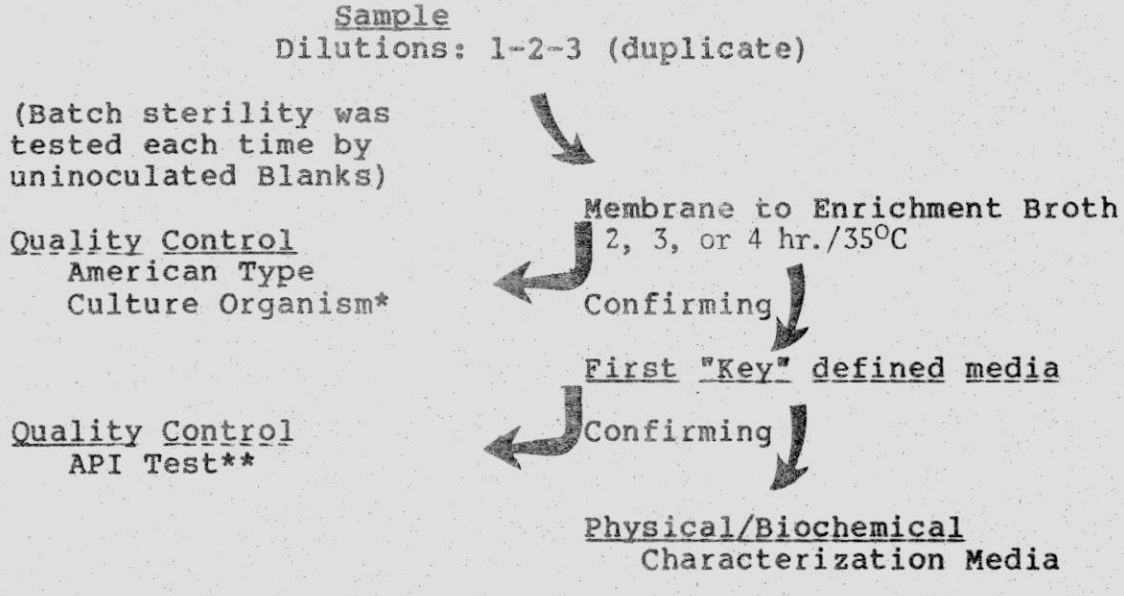
tion method (Greeson et al; 1977; APHA, 1983) and by standard incubation on a variety of special media. (Table 1)

Two one liter samples were taken from each well. Except for those samples which were preserved and forwarded to the U.S.G.S. lab, all samples for analyses and microbiological set-ups were kept at ambient temperature and tests were begun immediately upon return to the laboratory. Samples were divided into aliquots for microbiological, nitrate, turbidity, pH and dissolved solids (conductance) determinations.

While three dilutions of duplicate microbiological samples were being filtered for membrane culture, the chemical tests were completed. The completed membrane filrations were incubated at 35 C on an enriched broth for 2-4 hours and then transferred to the first of a series of media (APHA, 1980; Bergley, 1984; Analabs, 1984) for definitive separation of the families (Figure 4). Quality control tests were run by (A) uninoculated media, (B) running American Type Culture (ATC) (Table 2), pure cultures with test samples, and (C) running simultaneous biochemical tests on commercial media (Table 3) and on Analytical Profile Index (API) screening kits. Anomalous tests were repeated, and if the tests were not clear on a second run, they were queried via the API computer.

Figure 4

Generalized Flow Diagram of Microbiological Samples.



*ATCC organisms were inoculated on the appropriate media to confirm reactions.

**The API multiple factor test strip 20E was inoculated simultaneously with the standard test media to expand and confirm species identification.

TABLE 3

Family Separation by Differential Media

Isolation Media	Identification by Family	Percent Typical Colony Forming Units	Percent Atypical (CFU)
mEndo-Less Agar	Enterobacteriaceae	94%	6%
	Vibrionaceae	10%	90%
	Pseudomonadaceae	---	100%
	Neisseriaceae	---	100%
mFC Agar	Enterobacteriaceae	95%	5%
	Neisseriaceae	---	100%
KF-Streptococcus Agar	Streptococcaceae	100%	
mEnterococcus Agar	Streptococcaceae	100%	
mStaphylococcus Broth	Micrococcaceae	81%	19%
TCBS Agar	Enterobacteriaceae	77%	23%
	Vibrionaceae	41%	59%
	Pseudomonadaceae	---	100%
mBrilliant Green Broth	Enterobacteriaceae	---	100%
	Vibrionaceae	49%	51%
	Pseudomonadaceae	---	100%
	Neisseriaceae	---	100%
mBismuth Sulfite Broth	Enterobacteriaceae	13%	87%
	Vibrionaceae	---	100%
	Pseudomonadaceae	7%	93%
	Neisseriaceae	---	100%

RESULTS

Microbiology

It was found that 99% of the identified bacteria in Virgin Islands' wells were members of six families; Enterobacteriaceae, Vibrionaceae, Pseudomondaceae, Neisseriaceae, Streptococcaceae, and Micrococcacea. These families have both pathogenic and non-pathogenic species for man, animals, or cultivated plants. The normal habitats for these families as well as their potential pathogenicities are given in Table 4 (modified from Geldreich, 1975).

From the six families, 38 species of bacteria were positively identified and confirmed. Of these, 19 species or fifty percent are reported to have caused disease in man or animals. In spite of the relatively high occurrence of pathogens, only three wells were confirmed to have Escherichia coli present and eight were confirmed for fecal Streptococcus spp. (Table 5). Two of the three wells with E. coli also had fecal Streptococcus present. Under the present rules for indicator organisms in drinking water, only three of the tested wells (8.5%) would be listed as "contaminated". However, 14 wells, or 55% were in fact contaminated with potentially pathogenic bacteria. In this case, use of standard indicators, as proposed by EPA, would result in closing three wells as potentially

TABLE 4

Family Groups Encountered, Normal Habitat, and Pathogenicity

Microorganisms: Identified to Family.	Habitat: Free living, Saprophytic & Parasitic	Potential Pathogenicity: For primary or secondary diseases. In: Man(M), Animal(A), Plant(P)
Enterobacteriaceae	Man and animal intestines. Feces, sewage, soil and water. Healthy carrier possibility	Urinary tract infections (M) Respiratory tract infections(M) Gall bladder infection (M) Middle ear infection (M)
Vibrionaceae	Soil and water	Pneumonia (A) Gastrointestinal infections (M)
Pseudomonadaceae	Man and animal intestines. Feces, sewage, soil, air, and water	Urinary tract infection (M) Ear and lung infection (M) Secondary burn and wound infection (M) Onion bulb rot (P)
Neisseriaceae	Soil and Water	Secondary infections in debilitated individuals (M)
Streptococcaceae	Man and animal intestines. Feces, sewage, soil and water	Urinary tract infections Subacute endocarditis Respiratory infection
Micrococcaceae	Water and air. Mucous membrane and skin	Respiratory infection Osteomyelitis, meningitis, arthritis. Skin infections (boils and pimples)

hazardous, where 14 should have been closed or treatment required (7% success rate/cf for E. coli with all others, Table 5.)

The genera of bacteria found most often were Aeromonas, Staphylococcus, Pseudomonas, and Enterobacteria. Closely following these were Salmonella and Klebsiella (Tables 4 & 5). All of these species are known to be opportunistic pathogens; an opportunistic pathogen being one which may or may not cause disease, depending on the age and general health of the individual. The species of bacteria commonly found in cisterns (Canoy and Knudsen, 1983) were very simply being Aeromonas, Pseudomonas, Streptococcus.

Over 90% of the wells sampled showed excess "total coliforms" (i.e. gave a positive reaction on the presumptive tests) but only about 60% were confirmable as fecal coliforms. In contrast, 90% of the wells had high populations of fecal streptococcus. However, the wells low in fecal streptococcus, with two exceptions, were different from those with elevated total coliforms. In every case where total coliforms ratio to fecal streptococcus was 9:1 or greater, the well was located in an area of high population.

TABLE 5.

IDENTIFICATION OF TYPICAL AND ATYPICAL CFU OF MEDIA EMPLOYED, BY API SYSTEM

Source/Location	ST.CROIX Fair Plains	Prosperity	Barren Spot	Golden Grove	Adventure	Catherine Hope	Near Airport	Concordia	Mahogany Rd.	Rust-up Twist
No. Supplementary Biochemical tests	39	41	29	21	42	89	38	69	95	91
Escherichia coli*		+								
Escherichia coli H2S+*						+	+		+	
Salmonella spp.*								+	+	
Citrobacter freundii H2S+								+		
Citrobacter spp.										
Klebsiella pneumonia*										
Yersinia pseudotuberculosis	+									
Serratia odorifera										+
Serratia liquefaciens		+								
Enterobacter aerogens*										
Enterobacter agglomerans										
Enterobacter cloacae*						+		+	+	
Aeromonas hydrophila										+
Vibrio fluvialis*		+	+	+	+	+	+			+
Pseudomonas aeruginosa*								+		
Pseudomonas fluorescens gro			+		+	+				
Pseudomonas maltophila	+									
Pseudomonas stutgeri	+	+								
Psuedomonas putrefaciens*									+	+
Pseudomonas putida*										
Pseudomonas cepacia*										
Other Pseudomonas spp.		+			+				+	
Providencia rettgeri										
Acinetobacter calco.Var. anitratus	+									
Acinetobacter calco. Var. Lwoffi						+				+
Streptococcus faecalis*								+		+
Streptococcus faecium*									+	
Streptococcus Mgintermedius					+	+				+
Staphylococcus warneri	+		+	+	+		+			
Staphylococcus sciuri*										
Staphylococcus stimulans								+	+	
Staphylococcus saprophyticu						+	+			+
Staphylococcus capitis										
Staphylococcus hemolyticus*										
Staphylococcus epidermitis*										
Staphylococcus aureus*		+						+		

* Species which have been reported to cause disease in man or animals

Table 5 (Cont.) **IDENTIFICATION OF TYPICAL AND ATYPICAL CFU OF EMPLOYED MEDIA, BY API SYSTEM**

Source/Location	St. Thomas	Lovenlund	Crown Mt. Rd.	Dorothea #1	Brewers Bay	Lindberg Bay	Turpentine Run	Estate Tutu	Dorothea #2	Bovoni
No. Supplementary Biochemical tests		21	26	30	41	14	73	119	84	86
Escherichia coli*										
Escherichia coli H2S+*										
Salmonella spp.								+		
Citrobacter freundii H2S+*										
Citrobacter spp.			+							
Klebsiella pneumonia*			+							
Yersinia pseudotuberculosis*										
Serratia odorifera				+						
Serratia liquefaciens										
Enterobacter aerogens*		+								
Enterobacter agglomeraus										
Enterobacter cloacae*				+		+			+	
Aeromonas hydrophila							+		+	
Vibrio fluvialis*									+	
Pseudomonas aeruginosa*					+					+
Pseudomonas fluorescues group										
Pseudomonas maltophila				+						+
Pseudomonas stutgeri										
Pseudomonas putrefaciens*										
Pseudomonas putida*										+
Pseudomonas cepacia*					+					
Other Pseudomonas spp.							+		+	
Providencia rettgeri										
Acinetobacter calco. Var anitratus					+		+			
Acinetobacter calco. Var. lwoffi		+					+			
Streptococcus faecalis*										
Streptococcus faecium*	+	+								+
Streptococcus avium*										
Streptococcus Mgintermidius										
Staphylococcus warneri										
Staphylococcus sciuri*										
Staphylococcus stimulans										
Staphylococcus saprophyticus										
Staphylococcus capitis					+			+		
Staphylococcus hemolyticus*										+
Staphylococcus epidermitis*					+	+	+			+
Staphylococcus aureus*										

*Species which have been reported to cause disease in man or animals

Table 5 (Cont.) IDENTIFICATION OF ATYPICAL AND TYPICAL CFU OF MEDIA EMPLOYED, BY API SYSTEM

Source/Location	No. Supplementary Biochemical Tests	ST.JOHN Carolina	Cruz Bay	Adrian	Lameshur Bay	Cinnamon Bay
		16	14	9	12	6
Escherichia coli*						
Escherichia coli H2S+*		+	+			
Salmonella spp.				+		
Citrobacter freundii H2S+						
Citrobacter spp.			+			
Klebsiella pneumonia*						
Yersinia pseudotuberculosis*						
Serratia odorifera						
Serratia liquefaciens						
Enterobacter aerogens*						
Enterobacter agglomeraus						
Enterobacter cloacae*			+			
Aeromonas hydrophila						
Vibrio fluvialis*						+
Pseudomonas aeruginosa*					+	
Pseudomonas fluorescens (group)				+		
Pseudomonas maltophila						
Pseudomonas stutgerii						
Pseudomonas putrefaciens*						
Pseudomonas putida*						
Pseudomonas cepacia*						
Other Pseudomonas spp.		+				
Providencia rettgeri						
Acinetobacter calco. var. anitratus						
Acinetobacter calco. var. lwoffi						
Streptococcus faecalis*		+	+	+		
Streptococcus faecium*						
Streptococcus avium*		+			+	
Streptococcus Mgintermidius					+	
Staphylococcus warneri						
Staphylococcus sciuri*		+				
Staphylococcus stimulans				+		
Staphylococcus saprophyticus						+
Staphylococcus capitis						
Staphylococcus hemolyticus*						
Staphylococcus epidermitis*						
Staphylococcus aureus*						

*Species which have been reported to cause disease in man or animals.

Groundwater Chemistry

Extensive analyses were run on 19 of the 26 wells; including temperature, pH, conductance, and alkalinity of the wells at the time of sampling (Table 6). In addition five wells were sampled for the Environmental Protection Agency "priority pollutants". These wells were numbered 4, 13, 15, and 19 (Figure 2). Data are expressed as miligrams per liter (mg/L) interchangeable with parts per million, except in the case of dissolved solids (umhos/cm conductance).

Specific conductance in 17 wells ranged from 435-2700 umhos/cm. Two wells, Fair Plains and Catherines Hope in St. Croix, exceeded 4,000 umhos (salinity calculated as 0.10-1.25 /00) (Table 6). No correlation could be found between the dissolved solids, pH, or nitrate, and bacteria.

Chloride levels, chiefly as sodium chloride, ranged from 150-700 mg/L. At 21 wells, chlorides exceeded EPA drinking water standards (Nat'l Sci. Acad's. of Sci. and Eng. 1973). Chlorides as such are less critical than their associated metal ions such as sodium.

Nitrates exceeded 1.0 mg/L in sixty percent of the wells tested. Nitrates at and above this level are considered cause for concern, particularly in conjunction

TABLE 6

PHYSICAL, CHEMICAL AND BIOLOGICAL CHARACTERISTICS FROM SELECTED WELLS IN THE U.S. VIRGIN ISLANDS, JULY 1984.

WELL NUMBER ON MAP	LOCATION (LAT/LONG)	WELL NAME	OPERATED BY	DWL (FT)	T (DEG C)	SC (UMHOS /CM)	pH (UNITS)	ALK	FC	FS	NO2	NO2-NO3	PO4	TOC
1	174245644758	Golden Grove #1	DPW	36,75	29.0	1725	7.4	574	K 8	1	0.255	0.750	0.040	1.0
2	174308644841	Adventure #16	DPW	40.74	33,0	1750	7.6	531	< 1	< 1	.190	.710	.014	3.4
3	174258645222	Prosperity #I	DPW	34.83	28,5	1325	7.0	316	< 1	K 4	.025	1.1	.001	1.2
4	174329644547	Barren Spot #5	DPW	70,96	27,5	3175	7.6	597	< 1	K 2	.016	1.0	.015	.8
5	174225644719	Fairplains #6	DPW	58.07	27.5	5750	7.0	489	< 1	< 1	.016	.687	.071	9
6	174527644601	Concordia #1	DPW	25,27	27,5	2975	7.0	458	< 1	40	,015	,710	.013	.9
7	174659644716	Rust-up-twist	PO	32.13	27.0	2550	7,4	500	K 4	5800	.030	,850	.052	.8
8	174526643713	Zell's Well	PO	78,93	32,5	4675	7,2	446	38	2300	,016	.940	.014	.9
9	182033645312	V,I,H,A. #2	VIHA	73.86	29.0	1150	7,0	602	1	65	.008	ND	.009	1.7
10	181913645307	Bovoni #2	PO	24,37	28,5	2350	7,2	554	< 1	370	.011	8,0	.009	2.4
11	182036645813	C.V.I #2	CVI	46.83	29.0	1250	7.4	485	1	94	.007	5,8	.011	1.1
12	182141645746	Agriculture Sta.	USDA	65.15	25.5	1900	7.1	448	1	23	.009	3,1	.054	1.0
13	181945645257	Polycarib #3	PO	118.27	28.0	2425	7.2	580	1	488	.016	2,3	.003	3,8
14	182130645745	Bryan's Well #2	PO	ND	25,5	1250	6,9	251	36	4	.006	2,8	.065	.7
15	182142645427	Mohagany Run #9	PO	81,70	28.0	2230	6.8	580	< 1	4700	<.001	< .010	<.001	2.0
16	182112644519	N.P.S. #9	USNPS	ND	27.0	1925	6.8	518	< 1	10	.005	.597	.009	1.2
17	182058644322	Carolina Well	DPW	5.82	27.5	2000	6.8	287	6	109	.008	1.2	.012	1.2
18	182010644728	N.P.S. #2	USNPS	27.75	29.0	2500	7.0	560	30	3900	.011	4.9	.012	2.0
19	182043644546	Susanaberg #5	DPW	62.89	25.5	1450	7.0	538	5	8	<.001	1.6	.007	1.7

EXPLANATION

DWL - Depth to water level below land surface, in feet
T - Temperature, in degrees Celsius
SC- Specific conductance in micromhos per centimeter
ALK - Total alkalinity as calcium carbonate, in milligrams per liter
FC - Fecal coliform bacteria, in colonies per 100 milliliters
FS - Fecal streptococci bacteria, in colonies per 100 milliliters
DPW - Virgin Islands Department of Public Works
VIHA - Virgin Islands Housing Authority
USDA - United States Department of Agriculture

NO2 - Nitrate as nitrogen, total
NO2 + NO3 - Nitrate plus nitrate as total nitrogen
PO4 - Phosphorus, orthophosphate
TOC - Total Organic Carbon
TDS - Total dissolved solids
-- - No data
PO - Privately operated
CVI - College of the Virgin Islands
USNPS - United States National Park Service

with nitrite producing bacteria in the closed methemoglobin formation in fetuses and young babies ("blue babies").

Sulfates for most wells were below the EPA standard for drinking water of 250 mg/L. They may contribute to other problems such as odor, iron deposition, or "slime" production when associated with "iron" or "sulphur" bacteria (Thiobacillus).

Trace elements and organics were below the detection limits of the tests used (Appendix A). This places V.I. groundwater well below the national average for EPA drinking water standards for "trace metals of concern" and "priority pollutants" (Appendix A).

SUMMARY AND CONCLUSIONS

Sources Of Contamination

The major aquifers of the Virgin Islands occur in fractured rock, alluvial deposits or marl (St. Croix). Most aquifers seem to be renewed within the watershed in which they occur. Because of the steep terrain in most areas, the majority of the rainfall simply runs off or is evaporated. Only the water able to infiltrate the dense clayey soil, or that encountering an outcrop of fractured rock or alluvial layer, is able to percolate down to the aquifer. Very little has been done to "feed" aquifers by digging galleries or injection wells. On the contrary channelizing water courses ("guts") and wide spread development of houses and roads has probably greatly decreased the water available to the aquifers. Figure 3 illustrates the V.I. groundwater situation.

The unfilled or "undernourished" aquifers are left open to contamination from several sources (Figure 3). These sources chiefly are:

1. Human and animal wastes deposited on the ground and percolated down or washed into inadequately constructed wells.
2. Septic tanks with inadequate leach fields.
3. Sewage released directly into water courses.

4. Failure of private and public sewage plants and concomitant releases to the watercourses or shores.
5. Excessive pumping which causes intrusion of brackish or seawater components.
6. Careless or deliberate fouling of wells where sealing is inadequate.

This study, surveying 11% of all wells in the V.I., has produced five highly significant results. These are:

1. There is only minor contamination by organic chemicals in V.I. groundwater.
2. Except for salt intrusion, 90% of the wells sampled were below the limit allowed for inorganic chemicals.
3. There are large populations of bacteria in the water, even in water judged "uncontaminated" by current standards.
4. Among the bacteria present are a number of obligate or opportunistic human pathogens.
5. No correlation exists between the coliform water quality standard and the presence of pathogens in V.I. groundwater.

Because of the dense population of the Virgin Islands, the over 1.0 million visitors each year, and the ready access by immigrants each year from the eastern

Caribbean and South America, the Virgin Islands are "at risk" relative to epidemics. Further, there exists the possibility that an epidemic started in the V.I. would "hitch-hike" to the metropolitan areas of the U.S.. The majority of the common pathogens are opportunistic and most often attack the very young, very old, or persons already ill ("compromised") through some other cause. This causes debilitating or possibly fatal complications which may never be detected as originating in the water.

RECOMMENDATIONS

In light of this research, the authors recommend the following actions:

1. Formation of a group under the V.I. Water Resources Commission, composed of relevant governmental agencies, citizens, and experts to develop and seek implementation of a plan to control the quality and use of groundwater in the U.S.
2. A study of the factors involved in groundwater contamination and evaluation of various means of treatment.
3. Study the etiology and ecology of groundwater pathogens and select an alternate index to coliforms as indicator species.

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APPENDIX A

Table A.1 Concentrations of Priority Pollutants (trace metals) At Selected Wells In the U.S.V.I.

Table A.2 Organochlorine Insecticides, Polychlorinated Biphenyls and Polychlorinated Napthalens for Which Analyses were Performed in Samples From Five Wells in the U.S.V.I.

TABLE A-1

CONCENTRATIONS OF PRIORITY POLLUTANTS (trace metals) AT SELECTED WELLS IN THE U.S. VIRGIN ISLANDS, JULY 1984.

WELL NUMBER ON MAP	Al	Sb	As	Be	Cd	Cr	Cu	Fe	Pb	Li	Mn	Hg	Mo	Ni	Se	Ag	Zn	CYANIDE
4	70	< 1	2	< 10	< 1	< 10	< 1	< 10	1	10	< 10	0.1	2	< 1	4	< 1	10	< 0.01
7	< 10	< 1	< 1	< 10	< 1	< 10	< 1	10	2	50	< 10	0.3	< 1	2	6	< 1	10	< .01
14	10	< 1	--	<0.5	1.2	--	11	7.7	<10	< 4	180	--	< 10	--	--	2	13	< .01
16	10	1	--	<0.5	1.5	--	<10	230	<10	< 4	17	--	< 10	--	--	1	190	< .01
19	20	< 1	< 1	< 10	< 1	< 10	1	< 10	1	< 4	< 10	< .1	< 1	1	1	< 1	21	< .01

EXPLANATION

Concentrations in micrograms per liter

Al- Aluminum	Be - Beryllium	Cu - Copper	Li - Lithium	Mo - Molybdenum	Ag - Silver
Sb- Antimony	Cd - Cadmium	Fe - Iron	Mn - Manganese	Ni - Nickel	Zn - Zinc
As- Arsenic	Cr - Chromium	Pb - Lead	Hg - Mercury	Se - Selenium	-- - No data

Concentrations in milligrams per liter

Cyanide

TABLE A-2

ORGANOCHLORINE INSECTICIDES, POLYCHLORINATED BIPHENYLS & POLYCHLORINATED NAPTHALENES FOR WHICH ANALYSES WERE PERFORMED IN SAMPLES FROM FIVE WELLS IN THE U.S. VIRGIN ISLANDS, JULY 1984.

Minimum detection level 0.91 micrograms per liter	Minimum detection level 0.1 micrograms per liter	Minimum detection level 1.0 micrograms per liter
ALDRIN	CHLORDANE	TOXAPHENE
DDD	GROSS POLYCHLORINATED BIPHENYLS (AS PCB)	
DDE	GROSS POLYCHLORINATED NAPHTHALENES (AS PCN)	
DDT	AROCHLOR 1016	
DIELDRIN	AROCHLOR 1221	
ENDRIN	AROCHLOR 1232	
ENDOSULFAN	AROCHLOR 1242	
HEPTACHLOR	AROCHLOR 1248	
HEPTACHLOR EPOXIDE	AROCHLOR 1254	
LINDANE	AROCHLOR 1260	
METHOXYCHLOR	PERTHANE	
MIREX		