LAND USE, RUNOFF AND RECHARGE ON SELECTED WATERSHEDS IN THE U.S. VIRGIN ISLANDS

by

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ABSTRACT

Three watersheds with different land use characteristics on St. Thomas, Virgin Islands were instrumented and monitored to study the effects of various land use patterns on runoff and groundwater recharge. The water crop (combined runoff and groundwater recharge) for each watershed was calculated using two different methods and the runoff determined independently using a Soil Conservation Service method. While results illustrated the effect of different land uses on recharge, the wide discrepencies in results according to the method applied highlighted the need for extensive data collection for such a study to be conclusive.

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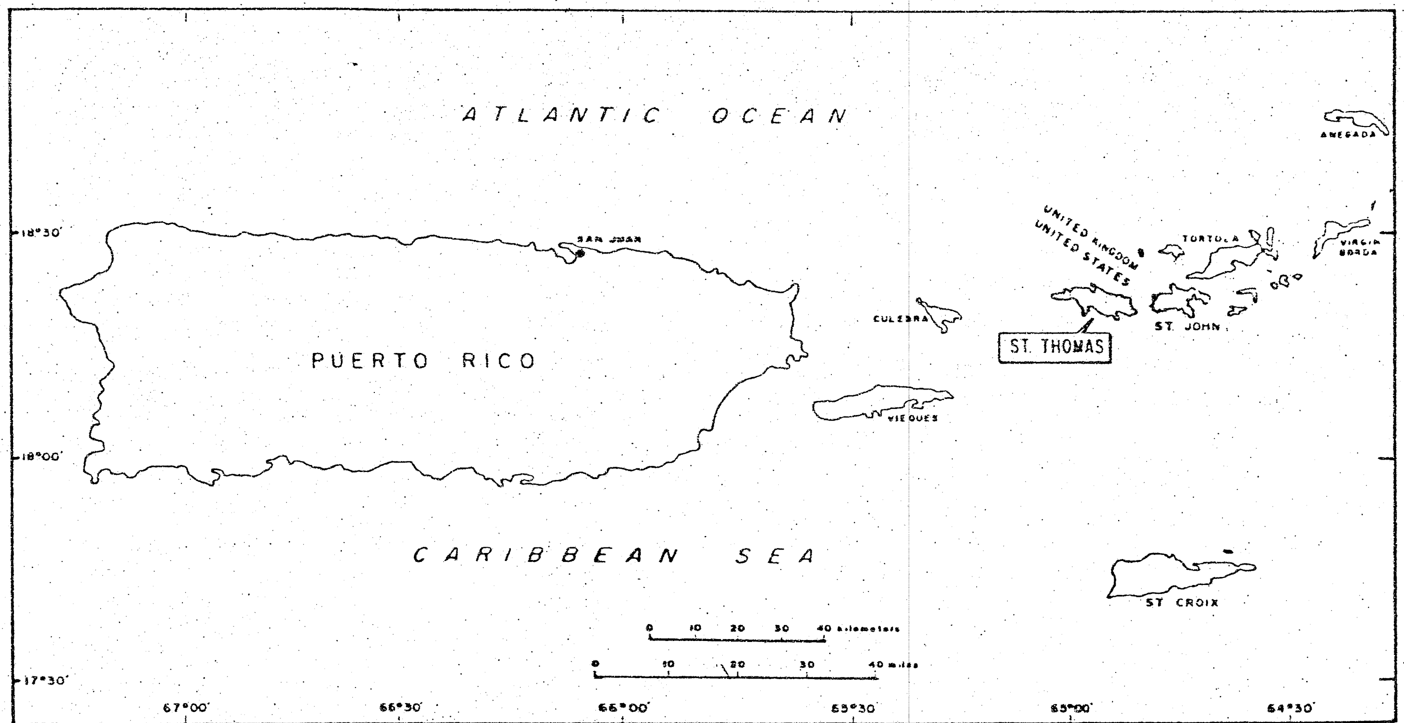
INTRODUCTION

Location

The United States Virgin Islands is an unincorporated territory of the United States located in the Caribbean Sea, approximately 1,100 miles east-southeast of Miami, Florida and 500 miles northeast of Caracas, Venezuela. The U.S. Virgin Islands consists of three large islands and more than forty small islands and cays. The three largest inhabited islands; St. John, St. Thomas, and St. Croix, have respective land areas of approximately 19, 32, and 84 square miles. All of the islands are characterized by steep rocky mountains of volcanic origin. The islands also display diverse ecological systems ranging from beaches and dry thorn scrub of the lowlands to the deciduous forests of the higher elevations.

St. Thomas is the second largest of the three major islands of the U.S. Virgin Islands and is located 50 miles east of Puerto Rico, (See Figure 1). The island is approximately 19 miles long and 2 to 3 miles wide. Flat land is generally rare on St. Thomas for most of the land surface is sloping and extends seaward

Figure 1



Location of St. Thomas, Virgin Islands

from a central ridge, 800 to 1,200 feet high, that runs almost the entire length of the island. The flat areas are found for the most part in Charlotte Amalie, the seat of government of the Virgin Islands, and a few alluvial-filled embayments. These embayments are seldom more than a few acres in area with the thickness of the alluvial deposits at a maximum being generally less than 50 feet.

In addition to rain water harvesting, groundwater is the only other significant "natural" water source on St. Thomas. Surface water supplies are negligible. As a result of the topography none of the streams in St. Thomas are truly perennial. Bonne Resolution Gut and Turpentine Run in the north and eastern parts of the island respectively, although often described as perennial, have been known to go dry during extreme drought periods. It has been estimated that in the perennial reaches of these streams about one-half to three-fourths of the flow is storm runoff and the remainder is base flow contributed by groundwater.(1)

Groundwater, though not abundant, is withdrawn throughout the island in varying amounts. In St. Thomas most of the groundwater occurs in fractured rocks, joints and fault zones. The major portion of the island is underlain principally by fractured volcanic tuff and breccia of the Louisenhoj Formation. Soil depths of one to two feet have developed in this formation. While the underlying bedrock, especially in the flat areas, has been tapped and can be a reliable source of water, extreme care must be exercised due to the ever present danger of salt water intrusion if over-pumping occurs.

Although slopes along the central ridge commonly exceed 35 degrees, at one time (during the early 1800's), almost all of the land on St. Thomas was under cultivation. Because of the decline in profitability of producing the principal crops (sugar cane and cotton) agriculture has declined now to the point where only small areas on the north central portion of the island are used for farming. Furthermore, tourism has replaced agriculture and livestock production as the mainstay of the economy and the once cultivated land has reverted to brush and secondary forest.

An ever increasing population brought on by an influx of retirees from the U.S. mainland, workers in the tourist trade from the U.S. mainland and other Caribbean islands, increased water use by businesses and increased standards of living have caused water demands to often exceed available supply. Since groundwater was a major source of water when the island was under cultivation attempts are being made to incorporate it into the urban supply as well. Such efforts have met with little success leading to the speculation that changes in land use have adversely affected the available quantity of water from this source.

Examination of available records reveals that streamflows in St. Thomas have declined over the years. The change in availability of groundwater is not readily apparent as groundwater records are rare. This is the primary objective of the present study. The effects of various land use practices in the Virgin Islands on groundwater availability will be examined.

Results are expected to be useful in the determination of appropriate management practices for rural areas in the island that are presently not under cultivation.

Need For Study

With rising energy costs and increasing demand for potable water, desalination of salt water is becoming a less economic option than groundwater for the supply of potable water. Rain water on the other hand is fairly unreliable. Consequently efforts are being directed towards improving both the quantity and quality aspects of groundwater as a source of water supply.

Several researchers have studied the effects of changing land use practices on groundwater availability. Filippini and Krothe(2) studied the impact of urbanization on a flood aquifer while Affleck(3) studied the effects of phreatophyte management on water levels in Arizona. While no study along these lines have been conducted recently in the Virgin Islands, Jordan(4) analyzed hydrologic data collected over several years to quantify the effect of land use on the water regimen of the U.S. Virgin Islands. In a later publication Jordan and Fisher(5) attributed the historical decline in groundwater levels to changes in land use. The authors also discussed the effects of transpiration by the dense growth of brush and trees along a stream channel on the north side of St. Thomas. Peeblés and others(6) suggested that the loss of water to recharge and streamflow be reduced by controlling the vegetation growth on watersheds.

All the above studies done in the Virgin Islands formulated conclusions based on either results of the Jordan(7) study or were not confirmed by field data. Thus there is a need for efforts directed to field determination of the effects of land use on groundwater in St. Thomas. This study was undertaken in this regard.

Methodology

Three small basins were investigated as part of this study. However, the available data are extremely limited. Although long-term daily rainfall and temperature records were available either on-site or at adjacent locations, corresponding water level records were generally not available. In the case of the two basins with pumping wells, daily water production records were not available. Estimates of total production were made from periodic readings.

Groundwater level monitoring at all three basins was initiated as part of this study in order to establish correlation between groundwater recharge and rainfall events. Evaporation data collected at one of the three basins are inadequate for use in computing water balances using hydrometeorological methods. Consequently daily water balances could not be obtained.

The <u>water crop</u>, defined as combined surface runoff and groundwater replenishment, is calculated using the equations[8]

$$\bar{R} = \bar{P} - \frac{\bar{P}}{(0.9+\bar{P}^2/L^2)^{1/2}} \qquad \text{(i)}$$

$$L = 300+25\bar{T}+0.05\bar{T}^2 \qquad \text{(ii)}$$

where:

$\bar{R}$ = average annual water crop (mm/yr)

$\bar{P}$ = average annual precipitation (mm/yr)

$\bar{T}$ = average daily temperature (centigrade)

Recharge calculated using (i) is converted to inches by using the conversion factor 1 inch = 25.4 mm

Runoff for various storm events have been calculated using methods suggested by the Soil Conservation Service[9, 10], based on the equations:

$$Q = \frac{(P-0.25)^2}{P+0.85} \qquad \text{(iii)}$$

$$S = \frac{1000}{CN} - 10 \qquad \text{(iv)}$$

where:

Q = runoff (in)

P = precipitation of runoff producing event (in)

S = potential abstraction, (in)

CN = curve number, (dimensionless)

The water crop defined as

$$R = Rs + Rg = P - Ea \quad (v)$$

where:

R = water crop (L/T)

Rs = surface runoff (L/T)

Rg = groundwater replenishment (L/T)

P = precipitation

Ea = evapotranspiration

is also used to estimate groundwater recharge.

II FACTORS INFLUENCING RECHARGE

Rainfall

The average annual rainfall of 44 inches is the principal natural source of potable water in St. Thomas. Table 1 shows a comparison of the sources of water supply on St. Thomas in 1979. This table is intended to provide an indication of the relative amounts of water available from various sources. In Figure 2 the ten-year running averages, accumulated departure from the average and annual rainfall for the period 1920 to 1967 at Charlotte Amalie are presented.

Evapotranspiration

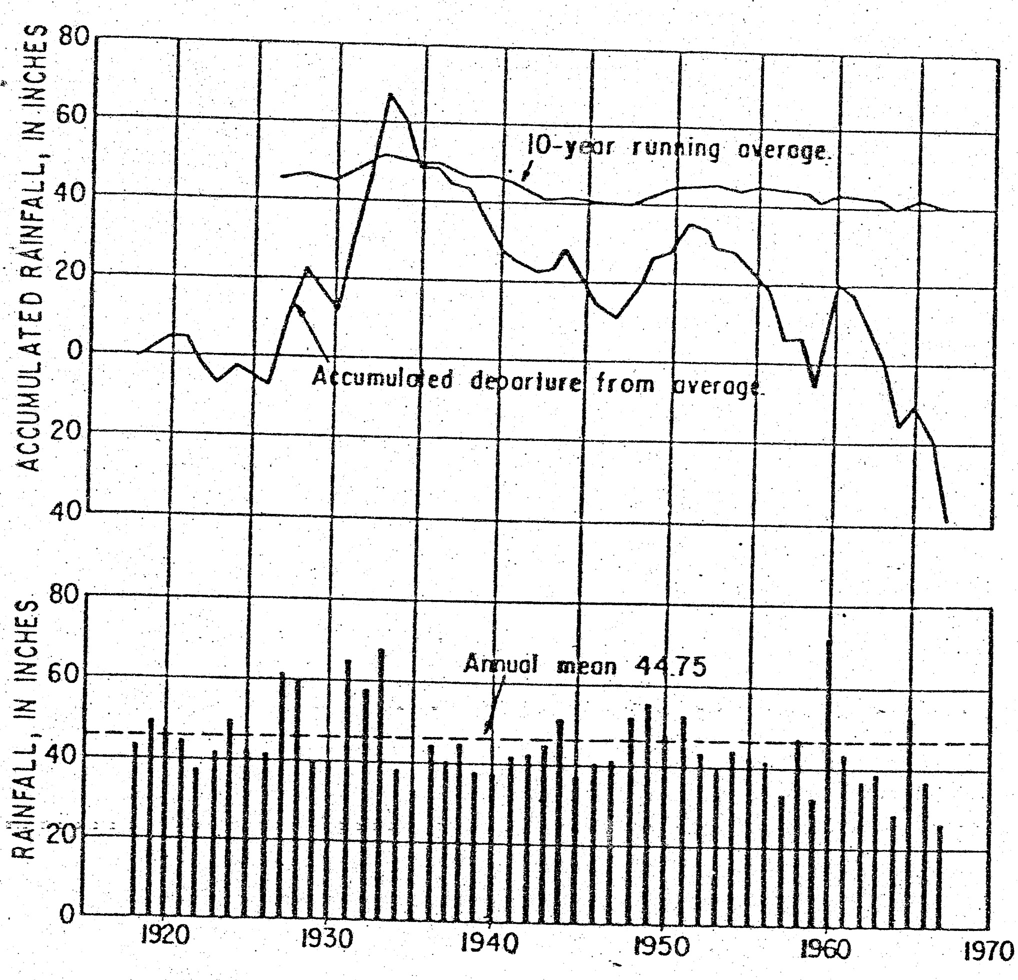
The climate in the Virgin Islands promotes a very high rate of evapotranspiration. Rainfall showers are often intense, of short duration followed by sunshine and the continual trade winds. Since the vegetation and upper soil layers generally hold water for a long time without percolation, the exposed water is evaporated directly while the capillary action within the upper soil layers acts like a wick to bring the percolating water back to the surface for evaporation. Concomitantly, the vegetation moves soil water by transpiration through leaves while deep-rooted plants withdraw and transpire water from the lower depths.

Table 1

Supply of Water Available from Various Sources in St. Thomas, 1979 (11)

Source	Amount (MGD)
POTABLE	
IMPORTED	
Barged	0.50
MANUFACTURED	
Desalted	1.50
NATURAL	
Surface	.00
Ground Water	0.40
Rain Harvesting	0.50
SUBPOTABLE	
NATURAL	
Ground Water	.00
Salt Water	1.00
MANUFACTURED	
Recycled	0.01

Figure 2



Rainfall Running Average, Accumulated Departure from the Average and Annual Rainfall at Charlotte Amalie, St. Thomas (12)

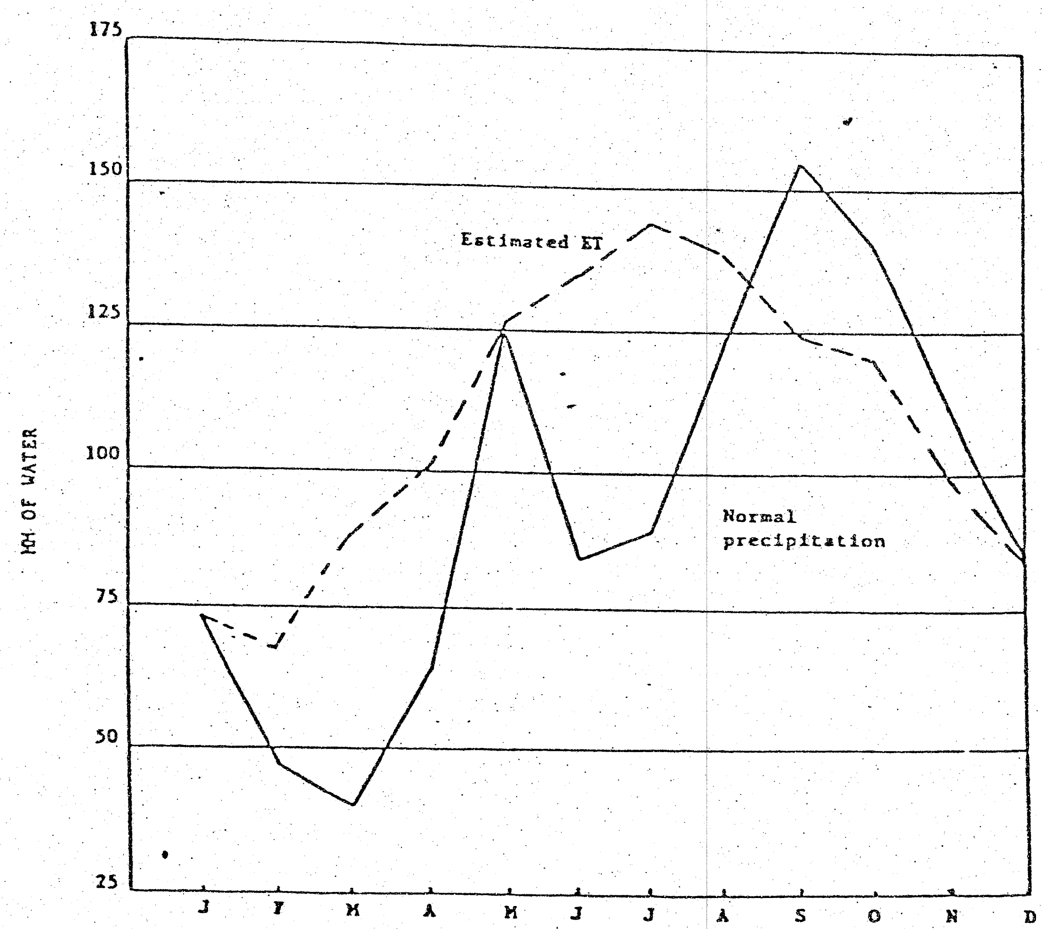
Using 20 years of data, Buzdugan[13] determined average monthly values of evapotranspiration for Charlotte Amalie (Figure 3). The ultimate disposition of rainfall on nearby St. Croix is compared with that of the continental United States in Table 2.

Groundwater and Geology

Groundwater is the only other significant natural source of potable water and is withdrawn throughout the island in varying amounts. A generalized map of the geology of St. Thomas is shown in Figure 4. The principal groundwater supplies are contained in a mantle of fractured and weathered rock, approximately 300 feet thick. Fractures beneath this mantle are very few and small and thus contain very little water. For most of the island the estimated storage capacity of the rock is one percent or less.[14]

The bedrock aquifer is estimated to receive recharge only about three times a year and varies from location to location because of the variability in rainfall quantity and in the characteristics of the rocks and soil throughout the island. On the east and west ends of the island, annual recharge to the bedrock aquifer is estimated to be 0.2 inches while in the Outer Brass Limestone in the Lovenlund Valley in the north, recharge has been estimated to more than five inches annually. Jordan and Fisher[15] estimated recharge to groundwater areas in St. Thomas as shown in Figure 5.

Figure 3



M O N T H

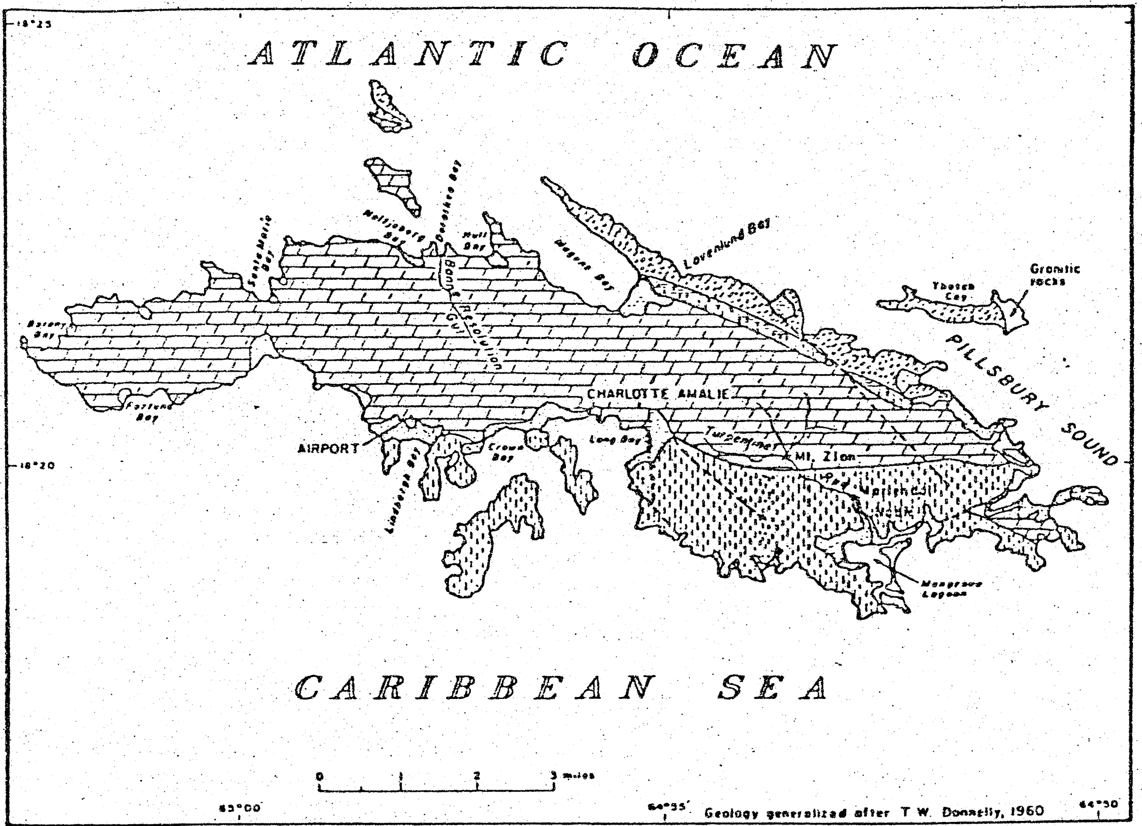
Precipitation and Evapotranspiration at Charlotte Amalie, St. Thomas (16)

Table 2

Ultimate Disposition of Rainfall[17]

Location	Evapotranspo-ration (%)	Runoff (%)	Ground-water (%)
St. Croix's Central Coastal Plain	96	1	3
Continental USA	70	20	10

Figure 4



EXPLANATION

Pleistocene (?) and Holocene

ALLUVIUM - Silt, clay, and thin, discontinuous beds of sand and gravel. Includes beach sand. Estimated maximum thickness 50 ft.

TUTU FORMATION - Tuffaceous conglomeratic mixture derived from older rocks. Contains some limestone, especially near the top. Maximum thickness greater than 6,000 ft.

OUTER BRASS LIMESTONE - Thin-bedded siliceous limestone and a few thin beds of tuff. Estimated maximum thickness 600 ft.

LOUISENHOJ FORMATION - Water-laid tuff, breccia, and a few thin beds of limestone. Maximum thickness known 13,000 ft.

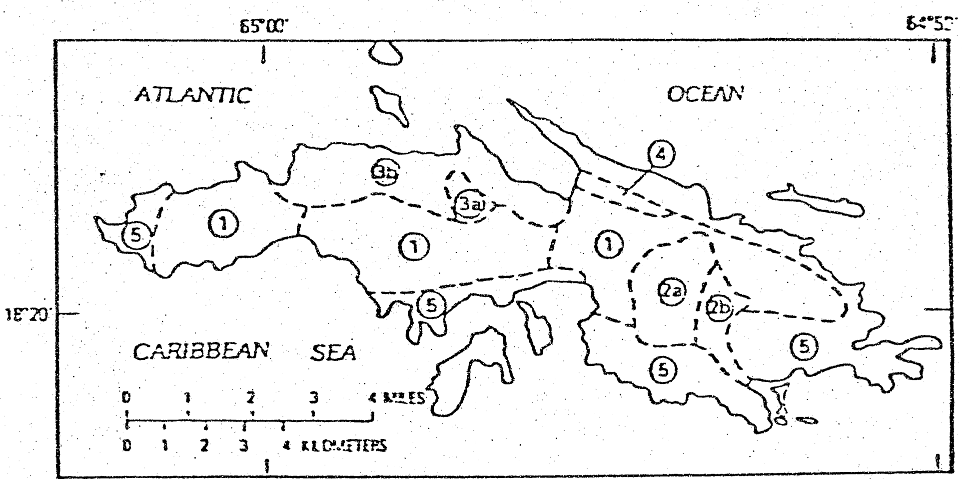
WATER ISLAND FORMATION - Lava flows, flow breccia, and water-laid tuff intruded by dikes and plugs. Maximum thickness greater than 15,000 ft.

Contact

Inferred fault, dotted where concealed

Generalized Geologic Map of St. Thomas (18)

Figure 5



AREA		RECHARGE	
Map No.	Square miles	10^6 gallons per year	Inches per year
1	13.6	164	0.7
2a	2.3	130	3.3
2b	1.1	16	1.0
3a	.6	20	2.3
3b	4.1	81	1.1
4	.4	36	5.3
5	10.0	36	.2

Estimated Recharge to Groundwater Areas in St. Thomas(19)

These estimates of recharge rates were determined based on the geology, soil, topography, rainfall and exposure of the regions.

Soils

A detailed discussion of the soils of St. Thomas will not be presented here. Comprehensive descriptions of the soils of the United States Virgin Islands are described elsewhere.[20, 21] The soil characteristics of areas of particular interest in this report will be discussed in detail at the appropriate places.

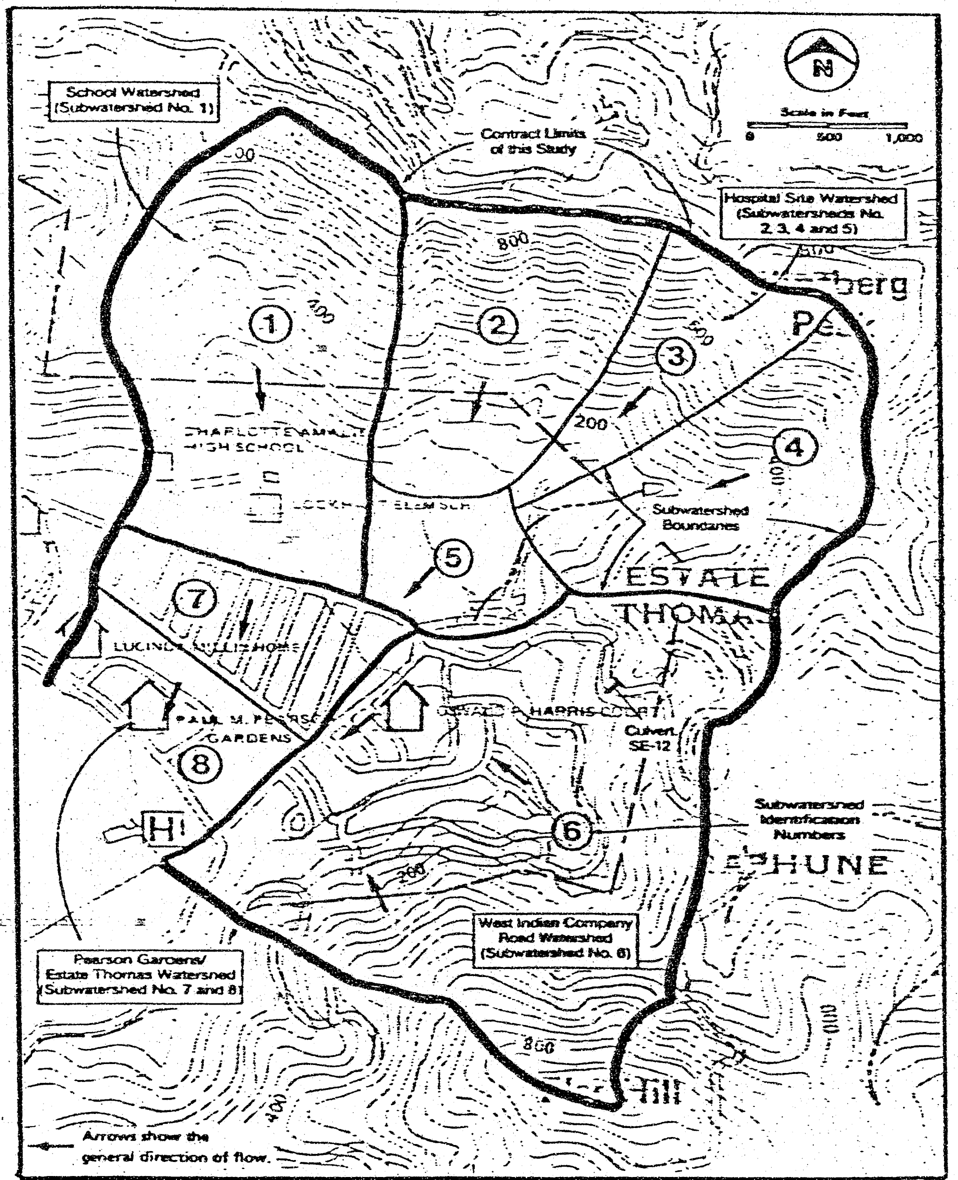
III STUDY SITES

The Lockhart Elementary School Study Site

The Lockhart Elementary School (LES) study site is located at latitude 18°20'38" and longitude 64°55'03". It is a subwatershed of 110 acres within the Sugar Estate Basin (Figure 6) which covers a total area of approximately 530 acres. Only the areas most likely to influence recharge to the observation well are included for rainfall-runoff calculations. Consequently downstream watershed Areas 7 and 8 in Figure 6 have been excluded as are the rest of the subwatersheds within the basin.

The study site may be separated into two distinct regions for descriptive purposes; the flat lower area in which the observation well is located and the upper hilly region which serves as the principal catchment area. The observation well is drilled and cased to an unknown depth with six-inch PVC (plastic) pipe. The well is owned by the Department of Public Works. It is situated midway in a small flat meadow located between the rearmost buildings of the Lockhart Elementary School and the Raphael O. Wheatley Vocational Training Center. The meadow is about 150 feet wide, covered principally with guinea grass, giant milkweed (*Calotropis procela*) and wild tamarind (*Leucaena Glauca*). It is mostly dry

Figure 6



Lockhart Elementary School Study Site (22) except for periods after heavy rainfall when ponding occurs and the area becomes temporarily swampy. The soil in this meadow is predominantly GyB (Glynn clay loam) which occurs on gently sloping alluvial fans where the upland drains have deposited their sediments on the coastal plain. The water holding capacity of this soil is high and it absorbs water readily. Glynn clay loam typically is classed as a moderately permeable soil with a plastic, slowly permeable layer at 4 to 6 feet.

The area of the upper hilly region draining onto the meadow is about 105 acres with a 34% slope. The maximum elevation in this area is 960 feet and is located 2,800 feet away from the observation well. The lower third of this region is covered with thick shrub consisting principally of false or wild tamarind (Leucaena glauca), Casha (Acacia sp.), Maran (Goton discolor), Cactus (Cephalocereus royeni), Yucca (Yucca sp.), Century plant (Agacie sp.), Thistle (Argemove mexicana), Catch-and- Keep (Anthacanthus spinosus), and Sage (Lantana sp.).

The upper two thirds of the area is dense forest, devoid of buildings, roads, or any other man-made intrusion. The dominant soils in this area are summarized in Table 3 along with pertinent properties. Of the soils the most dominant is Cramer gravelly clay loam. This soil is generally found in 12-40 percent slopes of strongly rolling to steep hills, foot slopes, narrow ridges and hilltops in the mountainous areas

Table 3

Engineering Classification and Estimated Soil Properties In Lockhart Elementary School Study Area[23,24]

Soil Series, Type and Phase	Depth To Hard Rock	Flood Hazard Freq. Duration	Water Table (Seasonally High) Depth Duration	Percolation Rate (Min./In.)	Classification: Layer Depth	Classification: USDA Texture	Permeability Rate (In./Hr.)	Available Water Capacity (In./In.)	Shrink-Swell Potential
Cramer Gravelly Loam									
CRC	Shallow	None -	Deep -	90	0-14"	GR.CL.Lm.	1.0	0.15-0.20	Moderate
CRE	Shallow	None -	Deep -	90	14-20"	Clay	1.0-0.63	0.15-0.20	Moderate
CRF	Shallow	None -	Deep -	90	20-32"	Rock+Clay	1.0	-	-
Cramer-Isaac Gravelly Clay Loam									
CVE	Mod. Deep	None -	Deep -	90	0-8"	GR.CL.Lm.	1.0-0.63	0.15-0.20	Low
					8-21"	Clay	0.63	0.15-0.20	Moderate
					21-27"	GR. Loam	1.0-0.63	0.10-0.15	Low
San Anton Clay Loam									
SAA	Very Deep	Freq. V. Brief	Deep -	50	0-9"	Clay Loam	1.0-0.63	0.15-0.20	Low
					9-21"	GR.CL.L	1.0-0.63	0.15-0.20	Low
SAC	Very Deep	None -	Deep -	50	21-50"	GR.CL.LM.	1.0-0.63	0.15-0.20	Low

throughout St. Thomas. Though it absorbs water readily, because of its shallow depth it has a low water holding capacity and is subject to rapid runoff and severe erosion where the surface is not protected by vegetation.

The forest consists for the most part of phraeatophytes common to such areas; Mampoo (Corcho blanco), White and Yellow Cedar (Roble blanco and Roble amarillo), Turpentine (Bursera simaruba), Tamarind (Tamarindus indica), Genip (Milicoccus bijugatus), Calabash (Crescenta cujete) and Silk Cotton (Ceiba pentandra).

Along the lower western portion of the drainage area is a small perennial north-south gut which is intersected by an even smaller channel which runs parallel to the training center and the elementary school and between the observation well and the training center. Between the larger gut and the observation well (a distance of about 50 feet) is a capped six inch well. Aside from the capped well the closest well known to be in the vicinity is located on the grounds of the adjacent public high school, about one quarter of a mile away from the observation well.[25] This well is inactive.

Data

Water levels in the observation well were monitored monthly from March 1982 until April 1983. Weekly observations were made from April 1983 until June 1983 when a continuous water level recorder was installed and hourly water levels could be obtained.

Rainfall was not monitored directly at the study site. However daily rainfall records for an area adjacent to the study site (about one mile north east) are used. Rainfall data are available for much longer than the groundwater level data.

In Table 4, water level data collected at the study site and rainfall data are presented for the period January 1, 1983 to September 30, 1983. This data is also plotted in Figure 7.

Analysis and Results

The response of the water level to rainfall input in the Lockhart School study area is shown in Figure 7. The first portion of the plot, January 1, 1983 to April 5, 1983 cannot be meaningfully used in this analysis because of the gap between water level data points which were measured monthly in this case. It is not possible to determine with any confidence whether at any point, the water level was rising or falling between data points. Data points are too widely spaced to suggest any trends. This portion of the plot is useful in that it

Table 4

Water Level and Rainfall Data for Lockhart Elementary School Study Site

Date	Water Level (Feet below ground surface)	Rainfall (Inches)
1-19-83	23.50	0.00
2-22-83	29.47	0.01
3-22-83	27.42	0.00
4-06-83	32.00	0.13
4-13-83	31.90	0.41
4-16-83	34.47	0.00
4-18-83		14.33
4-20-83	15.82	0.26
4-22-83	13.50	0.00
4-23-83	14.44	0.02
4-24-83	13.46	0.00
4-26-83	13.95	0.00
4-27-83	14.12	0.00
4-28-83	14.46	0.00
5-03-83	15.70	0.00
5-05-83	16.06	0.01
5-10-83	17.00	0.00
5-13-83	17.02	1.71
5-14-83	16.72	0.00

continued...

Date	Water Level (Feet below ground surface)	Rainfall (Inches)
5-16-83	15.20	0.07
5-19-83	13.85	0.96
5-24-83	11.19	0.66
5-26-83	11.70	0.00
5-28-83	12.22	0.00
5-31-83	13.28	0.13
6-02-83	14.00	0.00
6-04-83	14.51	0.07
6-07-83	15.09	0.00
6-08-83	15.46	0.19
6-11-83	16.55	0.00
6-14-83	18.16	0.04
6-18-83		6.34
6-27-83	11.68	0.46
6-28-83	11.65	0.16
6-29-83	11.66	0.00
6-30-83	11.76	0.00
7-01-83	11.90	0.04
7-02-83	12.04	0.04
7-03-83	12.15	0.03
7-04-83	12.25	0.03

continued...

Date	Water Level (Feet below ground surface)	Rainfall (Inches)
7-05-83	12.34	0.43
7-06-83	12.24	1.59
7-07-83	11.66	0.83
7-08-83	10.97	0.01
8-01-83	14.49	0.42
8-02-83	14.51	1.16
8-03-83	14.22	0.02
8-04-83	14.14	0.12
8-05-83	14.33	0.12
8-06-83	14.55	0.14
8-07-83	14.76	0.00
8-08-83	14.97	0.00
8-09-83	15.18	0.01
8-10-83	15.40	0.00
8-11-83	15.59	0.05
8-12-83	15.77	0.00
8-13-83	15.92	0.57
8-14-83	16.05	0.17
8-15-83	16.18	0.01
8-16-83	16.31	0.04
8-17-83	16.43	0.18

continued...

Date	Water Level (Feet below ground surface)	Rainfall (Inches)
8-18-83	16.53	0.91
8-19-83	16.62	0.00
8-20-83	16.70	0.00
8-21-83	16.70	1.92
8-22-83	16.22	0.01
8-23-83	15.89	0.00
8-24-83	15.99	0.00
8-25-83	16.08	0.00
8-26-83	16.26	0.00
8-27-83	16.46	0.00
8-28-83	16.61	1.08
8-29-83	16.63	0.06
8-30-83	16.62	0.02
8-31-83	16.67	0.00
9-01-83	16.74	0.05
9-02-83	16.86	0.00
9-03-83	17.97	0.03
9-04-83	17.08	0.06
9-05-83	17.19	0.00
9-06-83	17.31	0.11
9-07-83	17.44	0.00

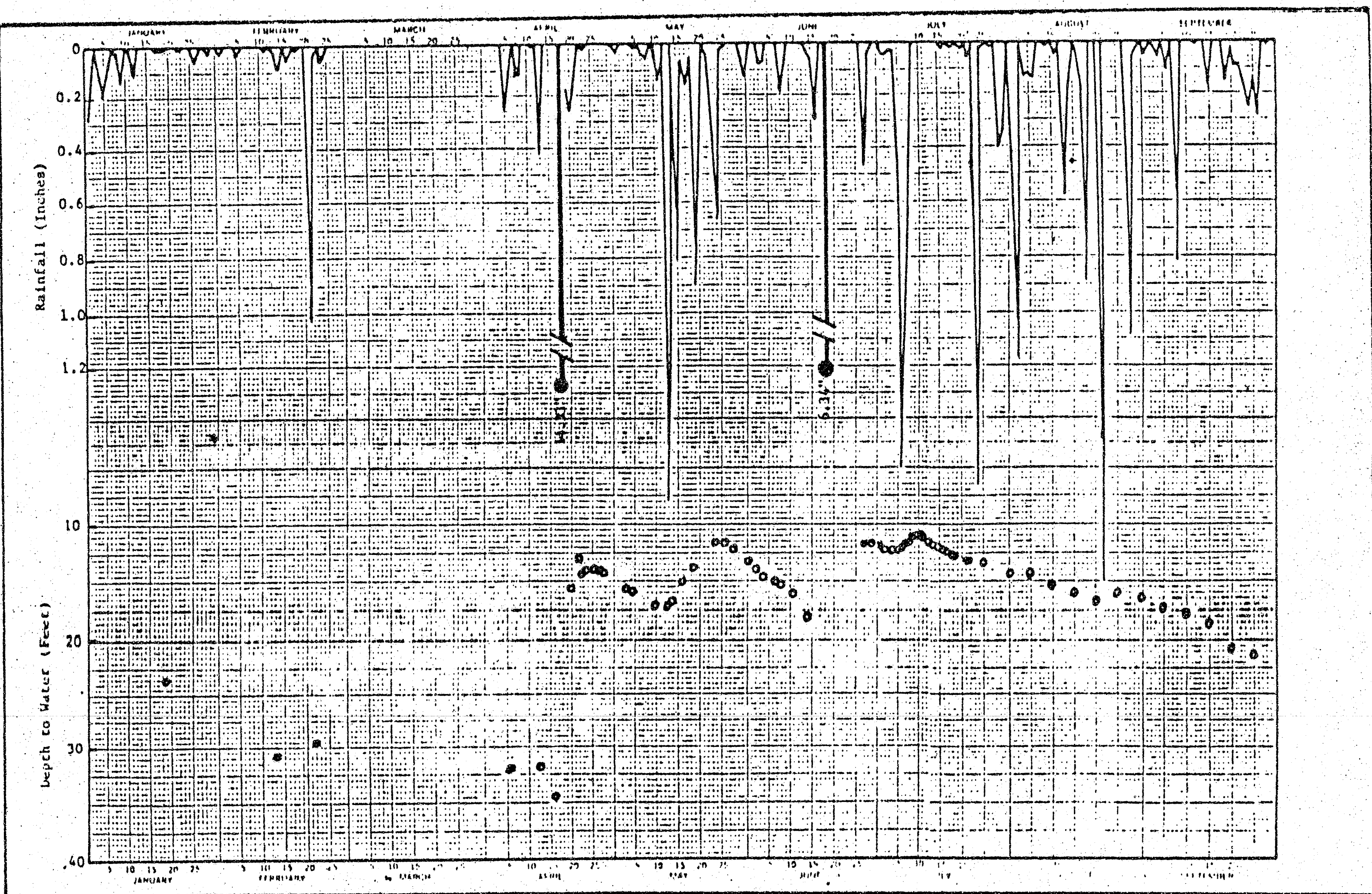
continued...

Date	Water Level (Feet below ground surface)	Rainfall (Inches)
9-08-83	17.57	0.81
9-09-83	17.76	0.00
9-10-83	17.90	0.00
9-11-83	17.99	0.00
9-12-83	18.10	0.05
9-13-83	18.22	0.00
9-14-83	18.37	0.00
9-15-83	18.60	0.19
9-16-83	19.20	0.01
9-17-83	19.74	0.00
9-18-83	20.20	0.00
9-19-83	20.54	0.15
9-20-83	20.82	0.03
9-21-83	21.04	0.09
9-22-83	21.22	0.09
9-23-83	21.36	0.16
9-24-83	21.46	0.26
9-25-83	21.53	0.14
9-26-83	21.61	0.29
9-27-83	21.70	0.00

continued...

Date	Water Level (Feet below ground surface)	Rainfall (Inches)
9-28-83	21.79	0.01
9-29-83	21.84	0.00
9-30-83	21.93	0.00

Figure 1



Rainfall and Groundwater Levels at Lockhart Elementary School Study Site points to the need, in a study such as this, for water level measurements to be taken more frequently, at least weekly, throughout the study period.

Water level monitoring continued twice every week after April 5,1983. On April 18, 1983 a storm dumped over 14 inches of rain on the study area and on April 20, 1983 when the water level was measured it had risen over 18 feet above the previously known level. There were 0.64 inches of rain on April 19 through April 20, 1983 and a corresponding 0.3 foot rise in the water levels in the well. Subsequent to that, until May 13, 1983 there was very little rain and the groundwater level dropped at a rate of approximately 0.12 feet per day. On May 13, 1983 nearly two inches of rain fell and the groundwater level immediately started to rise again. It can be noticed that because of the antecedent moisture conditions since the April 18th rainfall event, the water level responds quickly to subsequent rainfall events.

On June 18, 1983, another major rainstorm deposited over 6 inches of rain on the study area and the water level rose to nearly 7 feet above its former height. Examination of the plot in Figure 7 shows that the water level following June 18, 1983 continued to respond to rainfall events until the July 6, 1983 rainfall of approximately 1.60 inches. After this time the water level continued to fall even though there were several significant rainfall events. There may be several reasons for this. Among these are:

a. The rainfall events occurred at the site being monitored but not at the Lockhart School site.

b. Failure of the water level recorder.

Total rainfall for the period January to September 1983 from Table 5 is 32.16 inches. Estimated rainfall for the three-month period from October 1982 to September 1983 is 19.62 inches based on correlation with data from the Harry S. Truman International Airport, for a total rainfall of 51.78 inches for the period October 1982 to September 30, 1983. The average temperature during this period as recorded at the airport for 1981 is 81.1°F or 27.3°C.

Using the figure of 51.78 inches derived above for annual rainfall and the average annual temperature of 27.3°C as recorded at the Harry S. Truman Airport in equation (i) yields a water crop of 19.44 inches for the one year period, October 1, 1982 to September 30, 1983.

Runoff is calculated from daily rainfall for the period of record from January 1, 1983 to September 30, 1983 using equation (iii). The runoff for the previous three months is estimated from the cumulative rainfall estimates as a fraction, using the same fraction calculated from the period January to September 1983. From experience of storms in this area, only rainfall of

0.75 inches or more during a 24-hour period are included in the computations for runoff. The results are shown in Table 5.

The water crop (combined runoff and groundwater recharge) calculated for the LES study area using equation (i) is 19.44 inches. If we substitute the actual evapotransporation for St. Thomas, estimated at 43 inches a year [26] in equation (v), we obtain a value of 8.78 inches for the water crop for the LES subbasin.

Remarks

Two methods were used to estimate the water crop (combined runoff and groundwater recharge) in the LES. One method gave an estimate of 19.44 inches while the other method gave an estimate of 8.78 inches. Neither method gave an estimate which would account for the runoff estimate which was calculated using SCS methods. SCS methods yield a runoff estimate of 22.74 inches.

The discrepancy in the water crop estimates can be attributed to the "global" nature of the formulas, neither of which has been proven to be valid locally in the study area. Another factor affecting the estimates of the water crops is the lack of actual data on both evaporation and runoff. These observations point to the need for more direct observations of these parameters.

The rainfall-runoff plot of Figure 7 indicate the influence of groundwater levels by rainfall. However, lack of data on porosity and extent of the groundwater

Table 5

Lockhart Elementary School Runoff Calculations and Estimates, January-September 1983

Date	Rainfall	In	Af	Ft^3 (1000)	Gals (1000)
4-18-83	14.33	12.00	110.0	4,783.2	35.8
5-13-83	1.71	0.47	4.3	185.8	1.4
5-19-83	0.96	0.10	0.9	39.8	0.3
7-06-83	1.59	0.40	3.6	157.9	1.2
7-07-83	0.83	0.06	0.5	23.6	0.2
8-02-83	1.16	0.18	1.6	71.1	0.5
8-18-83	0.91	0.08	0.8	33.2	0.2
8-21-83	1.92	0.60	5.5	237.9	1.8
8-28-83	1.08	0.14	1.3	57.8	0.4
9-08-83	0.81	0.05	0.5	21.4	0.2
10-01-82	25.22	14.08	129.0	5,611.6	42.1
12-31-82	15.51	8.66	69.4	3,458.0	25.8
Totals	40.73	22.74	208.4	9,069.6	67.9

(1) Annual rainfall 51.78 inches

Average annual temperature 27.3°C

Total rainfall January 1, 1983-September 30, 1983 = 32.16 inches

Runoff producing rainfall January-September = 25.22 inches.

continued...

Fraction $\frac{25.22}{32.16}$ = 0.78

Total rainfall October 1, 1982-December 31, 1982 = 19.62

Runoff producing rainfall = 19.78 x .78 = 15.51

basin again preclude direct estimation of recharge. This observation reflects the need for geological and geophysical studies to delineate the extent of the aquifers, as well as hydrogeological studies to determine the water-bearing characteristics of the subsurface formations in the area to enable a reliable determination of groundwater recharge in the area.

College Of The Virgin Islands Study Sites

Groundwater recharge in two small watersheds in the vicinity of the College of the Virgin Islands (CVI) was investigated as part of this study. These are the Reichhold watershed, Area I, covering approximately 165 acres and part of the Brommer Hill watershed, the Gulf Course watershed, Area II, covering approximately 140 acres. The Brommer Hill watershed itself covers approximately 350 acres. However, the basin boundaries are such that the Golf Course area can be isolated for study of rainfall-runoff-recharge as shown in Figure 8.

The CVI study sites are located in the vicinity of the College of the Virgin Islands, north of the Harry S. Truman International Airport, approximately latitude 18°20' north and 64°58' east. The elevation of the watersheds range from sea level to nearly 1,400 feet at the top of Hawk Hill.

Site I is mostly undeveloped in the upper reaches except for a few homes and a radio station and tower at the top of Hawk Hill. The area has steep gradients; a 1,400 feet rise in elevation from sea level in less than 4,000 feet. Consequently, the area is characterized by rapid runoff following significant storm events. There

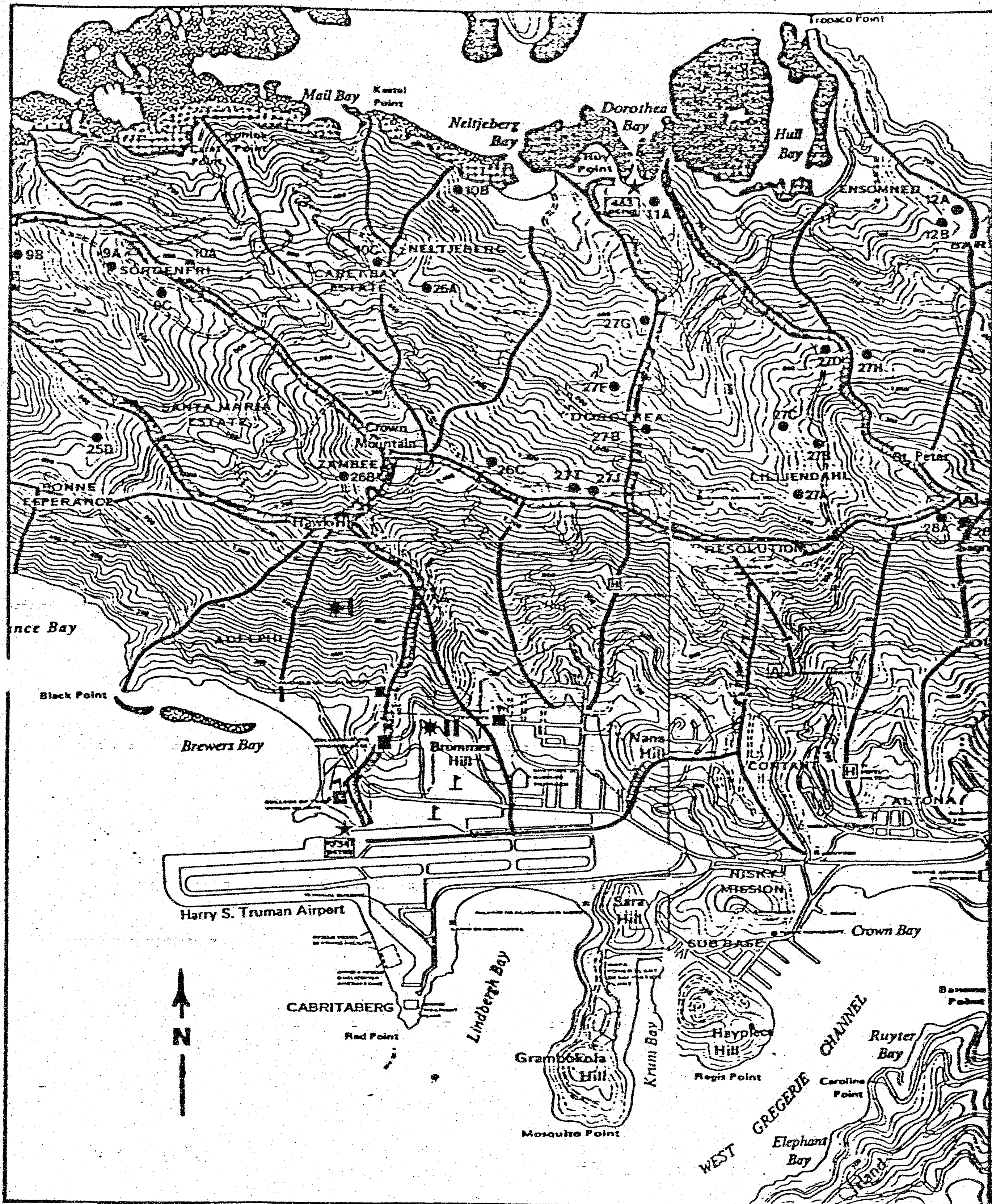


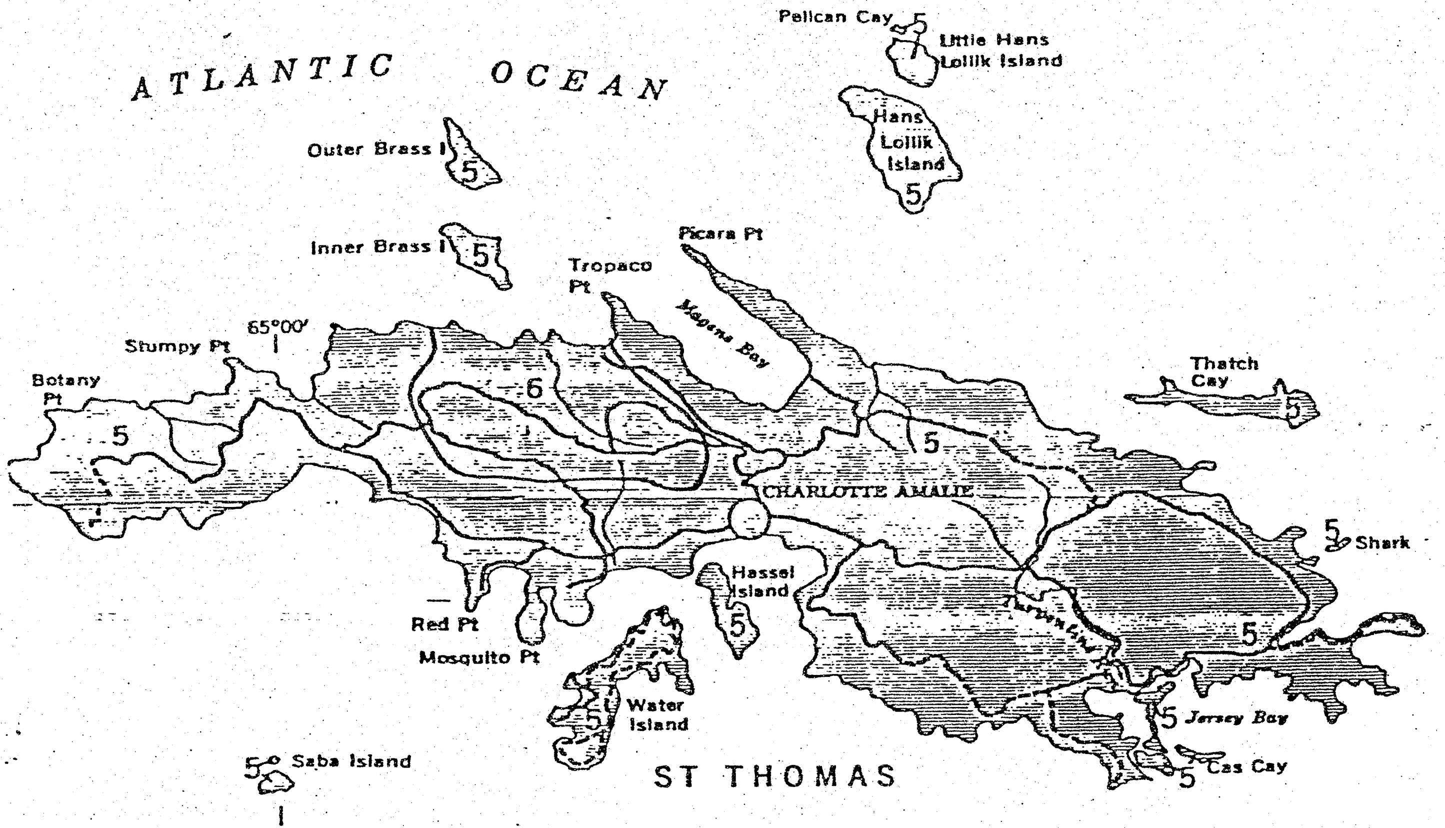
Figure 8

Location Map of the College of the Virgin Islands Study Sites (27) is a beach in the lower reaches. The Reichhold Center for the Arts is located in the valley.

The vegetation of the area is predominantly water mampoo (Corcho blanco), tamarind (Tamarinous indica) cactus (Cephalocereus royenii) and genip (Milcoccus bijugatus). The area around the Reichhold Cultural Center has been landscaped and planted with ornamental trees and shrubs.

The soils belong to the Cramer Isaac Association, Figure 9. The soil characteristics are shown in Table 6. The predominant soil type is Cramer Gravelly clay loam covering approximately 90% of the area. Sixty percent of the area is covered by this soil type on 40-60% slopes while the eroded variety of the same soil type is found on the lesser slopes of 10-40%. The rest of the flat area, approximately ten percent, is covered by Jaucas beach sand found on less than 10% slopes formed in marine deposits of sand-sized particles of corals and seashells.

Site II contains most of the campus development of the College of the Virgin Islands. It includes a grass covered golf course on approximately thirty percent of the site. About ten percent of the site, mostly on the ridges, is built up and consists of office buildings, classrooms and dormitories. The developed area is landscaped and covered with ornamental trees and other vegetation. The rest of the area is covered with water mampoo (Corcho blanco), tamarind (Tamarindus



SOIL ASSOCIATIONS

1	Descalabrado-Jacana association: Strongly sloping to steep, well-drained soils; clay loam to clay subsoil; shallow and moderately deep over volcanic rock; on mountainsides and foot slopes
2	Aguilita-Fredensborg-Sion association: Gently sloping to steep, well-drained soils; clay loam and silty clay loam material below the surface layer; shallow over soft marly limestone; on hills, foot slopes, and terraces
3	Fraternidad-Aguirre-Glynn association: Nearly level to gently sloping, well-drained to poorly drained, deep, mainly clayey soils on alluvial fans
4	Southgate-Parasol association: Steep to sloping, well-drained soils; gravelly loam to clay subsoil; shallow and deep over weathered granitic rock; on mountainsides, foot slopes, and alluvial fans
5	Cramer-Isaac association: Very steep to strongly sloping, well-drained soils; clayey in subsoil; shallow and moderately deep over volcanic rock; on mountainsides and foot slopes
6	Dorothea-Victory-Magens association: Steep and very steep, well-drained, deep soils; clay to clay loam subsoil; on mountainsides
7	Cornhill-Coamo-San Anton association: Nearly level to gently sloping, moderately well drained and well drained, deep soils; clay to clay loam subsoil; on alluvial fans and flood plains

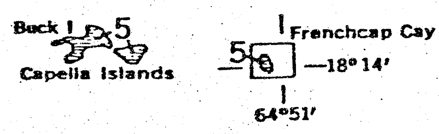


Figure 9

General Soils Map[28]

Table 6

Engineering Classification and Estimated Soil Properties in College of the Virgin Islands Study Area (29,30)

Soil Series, Type and Phase	Depth To Hard Rock	Flood Hazard Freq. Duration	Water Table (Seasonally High) Depth Duration	Percolation Rate (Min./In.)	Classification		Permeability Rate (In./Hr.)	Available Water Capacity (In./In.)	Shrink-Swell Potential
					Layer Depth	USDA Texture			
Cramer Gravelly Clay Loam									
CRE CRE	Shallow Shallow	None - None -	Deep - Deep -	90 90	14-20" 20-32"	Clay Rock+Clay	1.0-0.63 1.0	0.15-0.20 -	Moderate -
Cramer-Isaac Gravelly Clay Loam									
CVE	Mod. Deep	None -	Deep -	90	0-8" 8-21" 21-27"	GR.CL.Lm. Clay GR. Loam	1.0-0.63 0.63 1.0-0.63	0.15-0.20 0.15-0.20 0.10-0.15	Low Moderate Low
Jaucasi JuB	Very Deep	Freq. V Brief high tide	Mod. V. brief Shallow high tide	50	26-29"	Saprolite	6.30-20.0	0.05-0.10	Very low
San Anton Clay Loam									
SAA	Very Deep	Brief	Deep	50	0-9" 9-21" 21-50"	Clay Loam GR.CL.L GR.CL.LM	1.0-0.63 1.0-0.63 1.0-0.63	0.15-0.20 0.15-0.20 0.15-0.20	Low Low Low

indica), cactus (cephalocereus royenii), and genip (Milcoccus bijugatus) trees. Other unidentified species also occur.

The area is characterized by a flat "U"-shaped valley on which the golf course is situated. The upper reaches of the basin contain steep slopes of over 40%, and rises to nearly 1,400 feet at Hawk Hill. Rapid runoff from the steep slopes recharges the groundwater in the valley. There are several wells on the golf course, two of which are used by the College for water supply.

The soils on this site also belong to the Cramer-Isaac Association, Figure 9. The soil characteristics are shown in Table 6. The predominant soil type is Cramer Gravelly clay loam covering approximately ninety five percent of the area. The other five percent is covered by soils of the Jaucas beach sand.

Data

Daily rainfall and temperature data are available from the adjacent Harry S. Truman International Airport for nearly 20 years. The College of the Virgin Islands also maintained daily rainfall data during 1982-83. Rainfall data at the College of the Virgin Islands during 1982-83 and at the adjacent Harry S. Truman International Airport are shown in Table 7. However, water level records are only available for the last two years. Groundwater production records for wells in the area are also available and are shown in Table 8.

Table 7

Rainfall at the College of the Virgin Islands, St. Thomas
October 1982-September 1983

DAY	1982 Oct	Nov	Dec	1983 Jan	Feb	Mar	Apr	May	June	July	Aug	1983 Sept
1	0.01	0.21		0.62				0.05	0.03	0.14		
2	0.04	0.07	0.24	0.02				0.08	0.22		0.81	
3		0.07	0.02		0.01			0.01	0.01	0.25	0.02	
4		0.01	0.03	0.05	0.02						0.02	0.15
5		0.04	0.07	0.14	0.01	0.08	0.28		0.02	0.12	0.01	
6		0.76		0.18		0.07				0.96	0.04	0.05
7				0.02		0.11	0.05		0.21	0.30		
8			0.01	0.29	0.01	0.27	0.06	0.02	0.14	0.20		0.25
9		0.05		0.03		0.01		0.80	0.31			
10				0.01		0.01						
11		0.47			0.05	0.06						
12		0.25		0.05		0.20				0.27	0.07	0.02
13		0.03				0.45	0.25	0.04				
14	0.06	0.02			0.03		0.05	0.16	0.35		0.07	
15	0.06		0.54			0.01			0.10		0.04	0.06
16		0.59	0.06		0.09	0.01		0.04		0.06	0.03	
17		0.02		0.10				0.02			0.19	
18	0.88	0.32								0.06	0.35	0.20
19	1.44	0.16			0.01		15.80	0.02	5.52			0.03
20	0.66	0.16	0.88				0.25	0.50		0.03	0.05	0.14
21	0.03	0.01			3.50		0.24	3.43			1.41	0.48
22	0.08	0.05			0.02			0.44		0.04	0.01	0.04
23	0.49	2.20	0.11		0.02			0.33				
24	0.01	0.68	0.05							0.93		
25	0.07	0.01	0.02		0.01			0.88		0.01		1.02
26	0.05		0.02	0.05			0.01	0.09	0.02			0.23
27	0.12	0.13	1.40						0.70			
28			0.90	0.04		0.02			0.01		0.30	
29		0.38	0.09	0.01						0.68	0.14	
30	0.57	0.23	0.02							0.05		
31	0.03									0.30		
	4.60	6.92	4.46	1.61	3.78	1.30	16.99	6.91	7.64	4.40	3.56	2.67

TABLE 8

GROUNDWATER PRODUCTION AT CVI STUDY SITES, 1982-83

Year	Month	Total Production ($X10^6$ gals.)	
		Site I	Site II
1982	October	0.29	0.36
	November	0.13	0.28
	December	-0-	0.40
1983	January	-0-	0.34
	February	0.06	0.13
	March	0.02	-0-
	April	0.02	0.40
	May	0.47	0.54
	June	-0-	0.24
	July	-0-	0.56
	August	-0-	0.67
	September	-0-	0.61
	TOTALS	0.99	4.53

Analyses And Results

Site I: Reichhold Center Area

The total rainfall during the year (October 1, 1982-September 30, 1983) as recorded at the College is 68.98 inches. During this period, the total rainfall producing significant runoff amount to 39.47 inches. The water crop (combined runoff and groundwater recharge) calculated using equation (i) is 34.30 inches.

The runoff calculated using SCS-methods[31] is 16.48 inches, Table 9, or about 210 acre-feet per year over the area. The groundwater recharge therefore is 17.82 inches (34.30-16.48). The influence of rainfall on groundwater levels in the area is shown in Figure 10. Water production from wells at the site during the same period is shown in Table 8.

Site II: Golf Course Area

The total rainfall for Site II is assumed to be equal to that of Site I, and is taken as 68.98 inches. Rainfall producing significant runoff is also 39.47 inches. The water crop (combined runoff and groundwater recharge) is also 34.30 inches.

The runoff calculated using SCS-methods[32] is 18.65 inches, Table 10, or nearly 220 acre-feet per year over the area. The amount of water available for groundwater recharge is 15.65 inches. Groundwater production during this period is shown in Table 8.

TABLE 9

SITE I: REICHHOLD CENTER RAINFALL - RUNOFF CALCULATIONS OCTOBER 1982-SEPTEMBER 1983

	Date	Rainfall	Runoff			
			INS	AF	Ft^3 10^3	Gals. (X10[6])
1.	10-01-82	0.01 (1)	0	0	0	0
2.	10-18-82	0.88 (1)	0	0	0	0
3.	10-19-82	1.44	0.07	0.96	41.7	0.3
4.	11-06-82	0.76 (1)	0	0	0	0
5.	11-23-82	2.20	0.32	4.41	191.6	1.4
6.	02-21-83	3.50	1.01	13.86	603.0	4.5
7.	04-19-83	15.80	11.61	159.67	6,945.6	52.0
8.	05-09-83	0.80 (1)	0	0	0	0
9.	05-21-83	3.43	0.97	13.30	577.3	4.3
10.	06-19-83	5.52	2.43	33.41	1,453.3	10.9
11.	07-06-83	0.96 (1)	0	0	0	0
12.	07-24-83	0.93 (1)	0	0	0	0
13.	08-02-83	0.81 (1)	0	0	0	0
14.	08-21-83	1.41	0.06	0.87	37.8	0.3
15.	09-25-83	1.02	0.01	0.08	,003.6	(0.03) (2)
16.	09-30-83	0.00	0	0	0	0
	TOTALS	39.47	16.48	213.65	9,853.9	73.7

Notes (1) Insignificant runoff generated by this storm event

(2) Omitted from totals

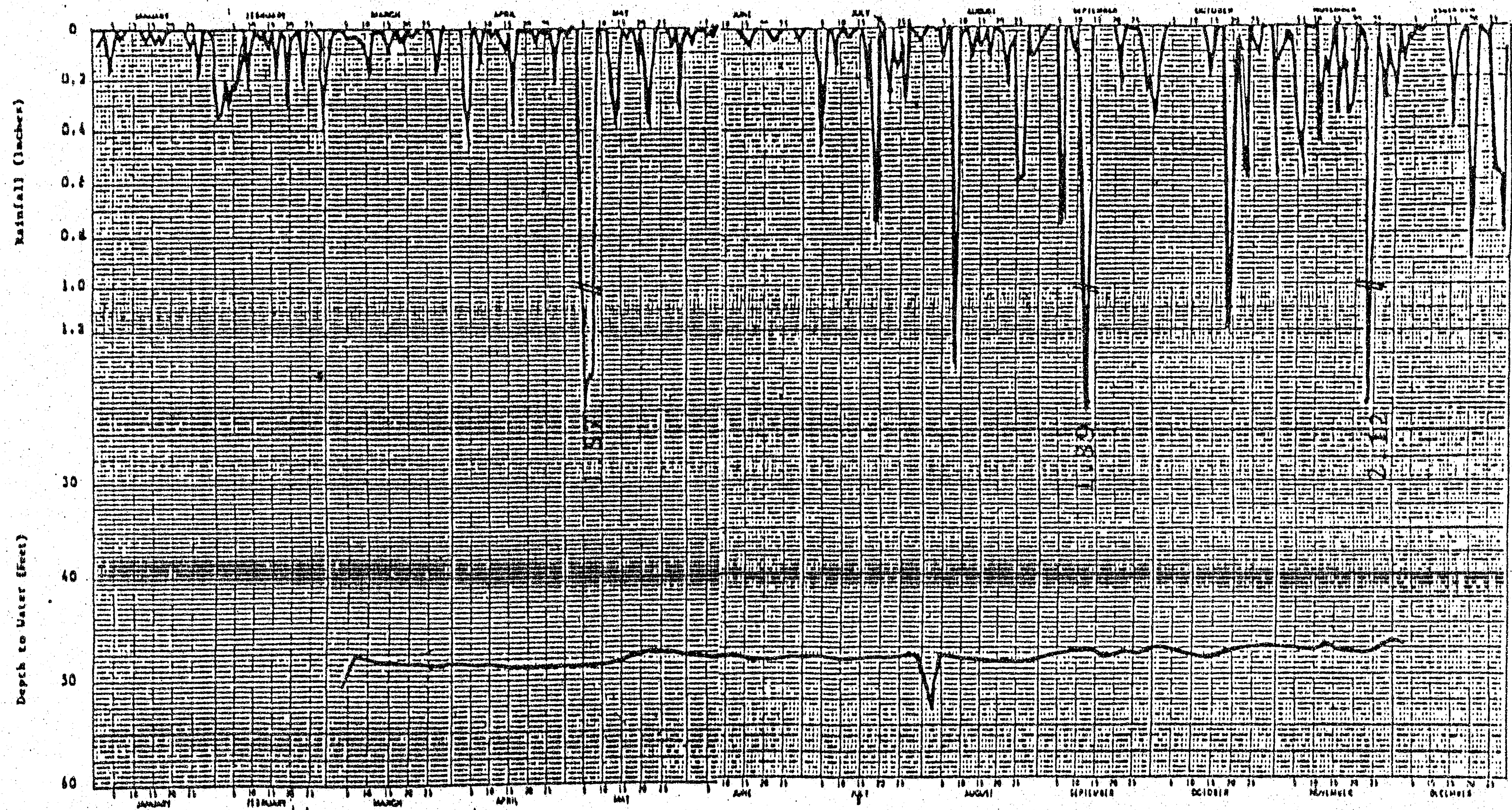


Figure 10

Rainfall and Groundwater Levels at CVI Study Area

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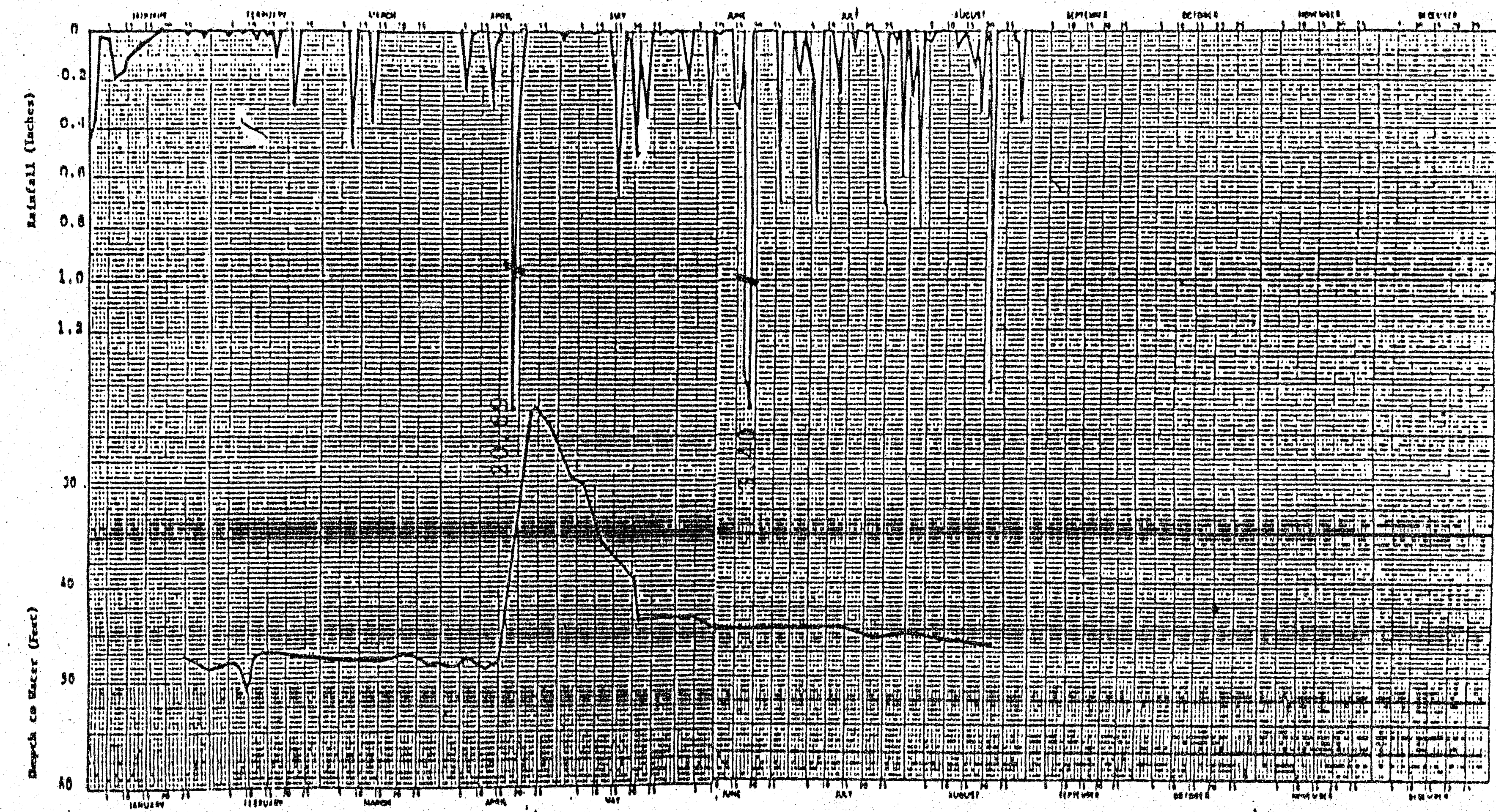

Figure 10 (continued)

Rainfall and Groundwater Levels at CVI Study Area

TABLE 10

SITE II: GOLF COURSE RAINFALL - RUNOFF CALCULATIONS OCTOBER 1982-SEPTEMBER 1983

	Date	Rainfall	Runoff			
			INS	AF	Ft^3 10^3	Gals.(X10^6)
1.	10-01-82	0.01	0	0	0	0
2.	10-18-82	0.88 (1)	0	0	0	0
3.	10-19-82	1.44	0.15	1.70	73.9	0.6
4.	11-06-82	0 (1)	0	0	0	0
5.	11-23-82	2.20	0.48	5.64	245.2	1.8
6.	02-21-83	3.50	1.30	15.19	660.7	4.9
7.	04-19-83	15.80	12.40	144.69	6,293.9	47.1
8.	05-09-83	0 (1)	0	0	0	0
9.	05-21-83	3.43	1.25	14.61	635.6	4.8
10.	06-19-83	5.52	2.88	33.57	1,460.2	10.9
11.	07-06-83	0.96	0.02	0.28	12.0	0.1
12.	07-24-83	0.83 (1)	0	0	0	0
13.	08-02-83	0.81 (1)	0	0	0	0
14.	08-21-83	1.41	0.14	1.58	68.8	0.5
15.	09-25-83	1.02	0.03	0.40	17.2	0.1
16.	09-30-83	0.00	0	0	0	0
	TOTALS	37.81	18.65	217.66	9,471.40	70.8

(1) Insignificant runoff generated by this storm event

Remarks

The summary of rainfall-runoff-recharge conditions during 1982-83 at the two study sites adjacent to the College of the Virgin Islands are shown in Table 11. The available data indicate approximately 69 inches of rain was recorded during the past year. This is significantly much more than the average annual rainfall generally expressed in the literature as 45 inches. Consequently, it can be concluded that 1982-83 was a wet year in the historical record. Using a global formula, equation (i), the water crop defined as combined runoff and groundwater recharge, is calculated to be 34.30 inches for the year. Assuming the validity of this formula for the Virgin Islands, approximately half of the incident rainfall resulted in runoff and groundwater recharge.

Runoff is calculated using established SCS methods.[33] Runoff calculated for Site II is 19 inches and slightly more than runoff calculated for Site I which is 16 inches, despite similarities in topography and a smaller area for Site II. This result can be attributed to greater development on Site II as compared with Site I.

Water available for groundwater recharge in Site II is 16 inches and in Site I is 14 inches. Potential groundwater recharge at Site I is approximately 81

Table 11

Summary of Hydrological Conditions at the College of the Virgin Islands Study Sites

		*Area		Rainfall		Runoff				Recharge				Evapotranspiration Losses	
Site No	Location	(Mi^2)	(Acres)	Total (In)	Runoff Component (In)	(In)	(Acre-ft.)	(Ft^3) (10^6)	Gallons (10^6)	(In)	(Acre ft.)	(Ft^3) (10^6)	Gallons (10^6)	(In)	In. (per acre)
I	Reichhold Center	0.3	165	69	39	16	214	9.9	74	18	248	11	81	35	4.7
II	Golf Course	0.2	140	69	38	19	281	9.5	71	16	187	8	61	34	4.1

million gallons, whereas less than 1 million gallons were pumped during the year. Potential groundwater recharge at Site II is 61 million gallons whereas less than 5 million gallons were pumped. Consequently, there is significantly more groundwater in each area than is presently being withdrawn.

These results would indicate that the slightly more developed Site II receives less water for groundwater recharge and generates more runoff than the less developed Site I. This result is to be expected. However, more definitive research needs to be undertaken in order to establish the role of different vegetative cover on the groundwater regime in the area.

IV CONCLUSIONS AND RECOMMENDATIONS

The Virgin Islands are undergoing changes in land use patterns from predominantly rural to urbanized. These changes are bound to affect the groundwater regime. Three small basins were investigated in order to determine the effects of changes in land use on the availability of groundwater. These basins, while being similar in area, topography, and geology and subject to the same hydrologic influences were not all similarly developed.

All methods applied in using the collected and very limited available data, though not in agreement as to the magnitude, did concur that urbanization negatively affected the quantity of groundwater recharge.

One of the principal difficulties encountered in ths undertaking was the lack of basic hydrologic data not intrinsic to this study. Estimates had to be made of soil porosities, long term values of annual evaporation, rainfall and runoff. The latter parameters are routinely monitored by local and state and federal agencies on the mainland of the United States. This is not the case in the United States Virgin Islands.

While an extensive data collection program may seem expensive, the worth of it will be realized when studies such as this one are conducted. Studies of this nature are crucial in formulation of plans and policies for land and water usage.

It is recommended that further research be conducted to more specifically define the role of not only land use effects on groundwater recharge but also the effects of various types of vegetative cover on groundwater recharge in the Virgin Islands. When these effects are known, proper management strategies for undeveloped areas in the islands will result in substantial enhancement of the already scarce and precious groundwater resources.

It is strongly recommended that priority be given to establishment of an extensive basic hydrologic data collection network in the Virgin Islands. Without data from this source, water resources planning efforts are pointless.

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