CHAPTER 4 INLAND FLOODING

4.1 INTRODUCTION

Inland flooding can cause significant damage when natural drainage channels overflow their banks. Flooding of this nature results from prolonged intense rainfall which is normally associated with hurricanes and tropical depressions or from stationary cold front systems. In order to determine the existing potential for inland flooding throughout the larger islands of the BVI, a drainage analysis was carried out.

The study was conducted by Dr. Hernan Solis, a hydrologist and water resources consultant from Costa Rica between April and November 1996, and involved field trips and extensive use of the US Corps of Engineers Hydrologic Engineering Center (HEC) Hydrologic and Hydraulic software (HEC-1 and HEC-2 models). The study also involved a detailed topographic survey of the three main drainage channels in Road Town.

The main objects of this study were:

X To characterize the Hydrologic behavior of the islands, to establish the general climatic and geomorphological features that control the drainage system.

X To analyze in detail the hydrologic behavior of three of the more important watersheds, in order to estimate the peak discharges for different return periods. The Huntums, Long Bush and Johnson Ghut watersheds studied in detail.

X To analyze the hydraulic capacity of the ghuts and their bridges, and to establish flooding risks along the their courses.

X To recommend preventive and corrective measures to alleviate present and future flooding conditions.

The final report of the study was presented in three parts

1) BVI Hydrologic Description and Behavior which outlines the general drainage conditions of the BVI

2) Hydrologic Modeling which describes the hydrologic behavior of the three Ghuts of Road Town and

3) the Hydraulic Modeling of the lower reaches of the three Ghuts, which determined areas prone to flooding and the channel sections requiring improvement.

The main aspects of the final report presented here are edited versions of the final report which is available at the BVI Office of Disaster Preparedness.

4.2 BVI HYDROLOGIC DESCRIPTION AND BEHAVIOR

4.2.1 GENERAL BVI HYDROLOGIC CONDITIONS

This chapter will focus on the larger BVI islands: Tortola, Virgin Gorda, Jost Van Dyke and Anegada. For the analysis two groups are proposed, based on the geomorphologic characteristics. In the first group Tortola, Virgin Gorda and Jost Van Dyke are included. In the second group only Anegada is considered.

In the first group we find irregularly shaped mountainous islands, with very steep average slopes. Pronounced backbone ridges and peaks, attain relatively high altitudes in very short distances, offering a first and dominant feature in the drainage system. As an example, we can mention that the Huntums Ghut, in Tortola, has an average slope of about 15 %, which is high, from the hydrological point of view. In fact, these steep slopes will be responsible for very high water velocities and tiny times of concentration, of only about 20 minutes for the larger watersheds of the islands, which will lead to pronounced and quick runoff hydrographs, if precipitation is big enough.

In general it can be said that the hydrology is dominated by evapotranspiration, limited surface runoff of torrential type and also small underground runoff, which can not sustain permanent streams.

The ghuts are generally dry and present discharges only after infrequent heavy rainfall. Drainage is lateral off the flanks of the ridges and the intermittent ghuts fall abruptly along deep and steep valleys to the sea, where local coastal flats often present a contrasting morphologic feature. These small flats are formed by alluvial deposits, with very varied fine and coarse textures, laid irregularly, restricted horizontally but can attain a deep thickness and occur at the basal flats of the more important ghuts. In these flat areas are found the only significative aquifers.

Soils in the islands are very shallow, with a thickness of about three feet, underlaid by impermeable fractured rocks. This characteristic was clearly observed in road cuts in the steep areas. It is estimated that these soils can infiltrate initially, if previously dry, about one inch of precipitation. If it rains during successive days, infiltration capacity is sharply reduced. The capacity of infiltration of such shallow soils is very limited during heavy rainfall, so that here we have another crucial geologic feature that increases greatly the amount of runoff, specially for storms of more than 1 inch of precipitation.

The vast majority of development occurs, of course, in the flats. They have, unfortunately, a high risk of flooding, aggradation and degradation which is not uniform along the flats and that has not been properly evaluated. Here a first systematic effort is presented in that direction.

The vegetative cover, typically semiarid, is relatively dense, with grasses, bushes and small trees. This vegetation leads to an intense evapotranspiration, which helps to keep the soil relatively dry. Steep slopes, with active surface and underground drainage, and small amounts of average annual precipitation also contribute to soil dryness. This condition promotes infiltration and reduces runoff. For small precipitation events, the infiltration capacity is big enough to prevent significant runoff. For large amounts of precipitation, however, the shallowness of the soils leads to a quick soil saturation and encouragement of runoff.

The geographic position of the BVI is highly related to hurricane hazards, of long duration and intensity, and other events of rainfall, of short duration but characterized by even higher intensities. On the other hand, the small amount of the watersheds, permits a total coverage of the watersheds during the storms, with the highest possible intensities, due to the short lag and concentration times.

As a summary, total spatial coverage of watersheds during storms, high risk of hurricane and rainfall with very high intensities, very steep average slopes, low infiltration capacity and deforestation explain the occurrence of not common but disproportionately high discharges. This from the hydrologic point of view.

From the hydraulic point of view, the presence of flats just at the outlet of the watersheds, reduces abruptly the energy availability, having as a consequence a significative reduction of water velocity, increase of water level and risk of flooding. So, natural conditions are difficult. Development of these flat areas have, very often, deteriorated the already conflictive situation. In fact, the ghut courses have suffered a notorious strangulation, with bridges of insufficient capacity blockage of piers, and marine reclamation have reduced even more the hydraulic capacity of the ghuts.

As an example of the modification of natural drainage conditions, it is mentioned that the outfall of Long Bush ghut was filled during reclamation works, and its course was diverted into Huntums ghut. The course of the latter was extended across reclaimed land, reducing its gradient near the outfall. Finally, its capacity was also restricted by a new bridge. Moreover, the reclaimed area slopes back from the sea to the old shoreline and thus adds to the storm runoff. As an obvious consequence, flooding risk has been artificially and significantly increased. The offensive conditions caused by stagnant sewage effluents during dry times and extensive flooding during times of heavy rainfall, have increased as a consequence of the Wickhams Cays and Port Purcell reclamation works in Road Town, Tortola.

Another undesirable factor is the accumulation of debris in the ghut courses, specially troublesome when they accumulate at the bridges, reducing dangerously the already insufficient hydraulic capacity of these structures. The unnecessary presence of piers underneath some of these bridges increases significantly the possibility of blockage.

The BVI, unfortunately, have a sparse network of meteorological stations. The majority of the gauges is limited to daily precipitation measurements. Besides, records are often incomplete. It is just now that a more sophisticated system has been installed by the Office Of Disaster Preparedness, with recording gauges that will provide important information about time distribution and amount of precipitation during short extreme storms.

The majority of the information is related to Tortola. In spite of the vicinity of the islands, the marked difference of mountain elevations has a significant influence on the orographic component of precipitation, so that the pattern of precipitation is very irregular. The accepted tendency, for the range of altitudes present in the BVI (from 0 to 1700 feet above sea level), is of a gradual increase of precipitation with altitude. As a consequence, and according to the information provided by residents of the different islands, Tortola has the highest amount of precipitation and Anegada the lowest.

The rainfall pattern in the BVI presents long dry periods and short heavy rains, occurring at any time, but more frequently between September and December. Some annual maximum 24 hr. rainfall is available for two Tortola rain gauges: Chalwell and Road Town. There is also some data in regard to maximum short duration intensities in Road Town, but, in general, the scarce information regarding rainfall intensity is definitely constraining.

In the East and West ends of Tortola, comparatively lower vegetation, with typically semiarid species, indicate a reduction of the precipitation in comparison with the more humid central sector of the island. These ends present lower elevations, with the consequent reduced orographic effect in the precipitation pattern.

There are no useful records of runoff measurements in the BVI. Because of the small size of the watersheds, hurricane surge waves due to reduced barometric pressure will happen at different times than flooding events. As a consequence, the coincidence of high surge levels, reducing available energy gradient for the outfall of discharges produced by heavy rainfall events can be discarded. In fact, the eye of a hurricane has a large diameter with low pressure, high surge waves and typical clear skies. So, if a hurricane passes over the BVI, firstly it is possible to have heavy precipitation, then high surge hurricane waves and finally again heavy precipitation.

4.2.2 TORTOLA

Tortola is a typical BVI island, irregularly shaped, elongated east-west. A pronounced spine ridge runs along the island and reaches a maximum height of 1780 ft. at Mount Sage. The coastline is very steep, indented with bays. Some of the bays present sandy beaches. In more sheltered bays the shores are often muddy and support mangrove and other wetland vegetation. Natural drainage channels or ghuts run from the ridge down to these bays. The ghuts are dry and only flow after heavy rainfall. On these infrequent occasions, flooding may be present in the low flats.

Tortola is the only BVI island with significative and reliable meteorologic information. Annual statistical computation of rainfall data collected by the BVI Water and Sewerage Department in Tortola indicates that the annual rainfall in 95 years of measurements has ranged between 24 and 94 in., with a mean value of 50 in. Details are presented in **Table 4.1** and **Figure 4.1**. This value is a higher than the world average annual precipitation on the land surface which is about 32 in. The average for this period is of about 50 in. with a standard deviation of 8.9 in which is relatively small, indicating that rainfall is fairly uniform along the period of measurement, which is very long. The records vary from a maximum value of 94.26 to a minimum value of 24.11. These values, on the other side, show that large variations can occur.

TABLE 4.1: TORTOLA MEAN ANNUAL PRECIPITATION (1901-1994)

YEAR	PRECIPITATION (in)	ORDER	PRECIPITATION (in)
1901	59.09	1	94.26
1902	57.69	2	88.52
1903	53.2	3	75.03
1904	50.54	4	71.52
1905	59.28	5	70.64
1906	53.66	6	69.65
1907	38.26	7	67.11
1908	53.37	8	65.68
1909	70.64	9	64.31
1910	42.4	10	63.63
1911	53.85	11	63.14
1912	46.41	12	63.04
1913	43.28	13	62.82

1914	46.58	14	62.77
1915	63.04	15	62.02
1916	69.65	16	60.88
1917	38.6	17	60.08
YEAR	**PRECIPITATION (in)**	**ORDER**	**PRECIPITATION (in)**
1918	52.55	18	60.05
1919	50.36	19	59.28
1920	42.11	20	59.09
1921	45.95	21	58.96
1922	50.72	22	57.69
1923	39.98	23	56.42
1924	55.01	24	56.26
1925	38.39	25	56.25
1926	31.01	26	55.78
1927	63.63	27	55.42
1928	51.82	28	55.02
1929	43.25	29	55.01
1930	49.52	30	53.99
1931	75.03	31	53.85
1932	88.52	32	53.66
1933	94.26	33	53.37
1934	52.81	34	53.2
1935	48.89	35	53.18
1936	65.68	36	52.81
1937	56.25	37	52.55
1938	56.26	38	51.82
1939	46.56	39	51.82
1940	46.18	40	51.31
1941	35.47	41	51.2
1942	62.82	42	51.09
1943	48.98	43	50.82
1944	51.31	44	50.72
1945	44.09	45	50.54
1946	45.93	46	50.36
1947	53.99	47	50.18
1948	50.82	48	49.52
1949	58.96	49	48.98
1950	60.08	50	48.89
1951	56.42	51	48.38
1952	63.14	52	48.26
1953	47.71	53	48.07

1954	51.2	54	47.86
1955	43.31	55	47.85
1956	45.23	56	47.71
1957	36.8	57	46.58
YEAR	**PRECIPITATION (in)**	**ORDER**	**PRECIPITATION (in)**
1958	60.88	58	46.56
1959	37.76	59	46.41
1959	37.76	59	46.41
1960	71.52	60	46.18
1961	41.98	61	45.95
1962	47.85	62	45.93
1963	42.65	63	45.54
1964	31.75	64	45.23
1965	48.38	65	44.81
1966	51.09	66	44.09
1967	34.82	67	43.31
1968	51.82	68	43.28
1969	67.11	69	43.25
1970	62.02	70	43.02
1971	42.85	71	42.85
1972	36.58	72	42.65
1973	30.66	73	42.4
1974	55.42	74	42.11
1975	55.78	75	41.98
1976	39.1	76	39.98
1977	48.07	77	39.1
1978	55.02	78	38.97
1979	62.77	79	38.6
1980	36.33	80	38.39
1981	64.31	81	38.26
1982	43.02	82	37.76
1983	48.26	83	36.8
1984	44.81	84	36.58
1985	38.97	85	36.58
1986	53.18	86	36.33
1987	60.05	87	35.74
1988	45.54	88	35.47
1989	50.18	89	34.82
1990	36.58	90	31.75
1991	31.34	91	31.34
1992	47.86	92	31.01
1993	35.74	93	30.66

1994	24.11	94	24.11
AVERAGE	50.39	MAXIM	94.26
AVEDEV	8.91	MINIM	24.11

Figure 4.1

Temperature, relative humidity, sunshine, mean wind speed and evaporation measurements are available for Tortola, recorded at the Paraquita Bay Agricultural Station from 1971 to 1977. Although the record is not as long as desirable, it is a satisfactory and important set of data for this parameter and the values are a good estimation of these parameters. An effort should be made to resume these measurements. **Table 4.2** summarizes climatic data for Tortola.

TABLE 4.2: PARAQUITA BAY CLIMATIC DATA

MONTHS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVE
PARAMETER													
MAX.TEMP (1F)	82	82	83	84	85	85	86	87	88	87	86	83	85
MAX.TEMP 1C)	28	28	28	29	29	29	30	31	31	31	30	28	29
MIN. TEMP (1F)	73	72	72	73	76	77	78	76	76	76	74	72	75
MIN TEMP (1C)	23	22	22	23	24	25	26	24	24	24	23	22	24
AVE.TEMP (1F)	77	77	77	78	80	81	82	82	82	81	80	77	80
AVE TEMP (1C)	25	25	25	26	27	27	28	28	28	27	27	25	26
REL. HUM (%)	78	72	72	75	78	77	69	79	79	84	85	81	77
SUNSHINE(hr)	250	235	256	270	292	265	291	276	232	236	265	238	259
WIND (kn/day)	136	116	116	116	124	124	122	124	97	93	101	113	115
WIND (km/day)	252	215	215	215	230	230	226	230	180	172	187	209	213
PAN EVAP (in)	7.5	6.9	8.5	9.3	10.1	9.3	10	9.2	8.4	8	8.3	6.6	8.5
PAN EVAP (mm)	188	173	213	233	253	233	250	230	210	200	208	165	213
POT EVAP (in)	5.6	5.2	6.4	7.0	7.6	7.0	7.5	6.9	6.3	6	5.8	5.0	6.38
POT EVAP (mm)	140	130	160	175	190	175	188	173	158	150	145	125	160

There has been no systematic long term collection of data for Virgin Gorda, Anegada and Jost van Dyke. It is obvious that temperature, sunshine and humidity of the BVI islands must be very similar. Wind speed and potential evaporation must be very similar for the BVI mountainous islands. Precipitation, however, for Virgin Gorda and Jost van Dyke must be smaller in comparison with Tortola, due to comparatively smaller land mass and low level mountains. However, all the islands are affected by the extensive cloud systems associated with tropical weather conditions of low pressure. Anegada should show the more homogeneous rainfall precipitation pattern, spatially and temporarily, because of the absence of orographic effects.

It has been reported that runoff occurs only when there is heavy precipitation, over 1 in of 24 hr. precipitation, or a series of rainy days, so that soils may get saturated. In general precipitation in the BVI is not heavy, with small amounts of 24 hr. rainfall. On the contrary, they can be very frequent, during the rainy season. As a consequence, runoff and deep percolation are expected to be low, in comparison with evapotranspiration. Evapotranspiration is increased by relatively high temperatures all year around.

4.2.1.1 MONTHLY PRECIPITATION

Average monthly precipitation presents a dry season, from January to August, May showing an isolated rainy peak, and a rainy season, from September to December (**Table 4.3** and **Figure 4.2**). It can be noticed that precipitation is relatively homogeneous. This situation is favorable to evapotranspiration, because droughts tend to decrease it.

TABLE 4.3: BVI MONTHLY PRECIPITATION

MONTH	**PRECIPITATION (in)**
JAN	2,56
FEB	2,46
MAR	1,82
APR	3,77
MAY	5,07
JUN	2,75
JUL	3,28
AUG	4,55
SEP	5,06
OCT	6,44
NOV	6,57
DEC	5,78

Figure 4.2

4.2.1.2 WATER BALANCE

The monthly water balance (**Table 4.4** and **Figure 4.3**) indicates that there is a significant deficit of precipitation during the first nine months, and a very small excess during the last three months. This table explains why it is very difficult to have runoff. In fact, during the first nine months precipitation is significantly smaller than evapotranspiration, so that the soil will be very dry, with the exception of short periods of time, during wet days. During the last three months, there is almost equilibrium between precipitation and evapotranspiration, creating more favorable conditions for runoff. But average rainfall excess is less than 1 in. while average rainfall deficit is frequently over 4 in.

TABLE 4.4: BVI AVERAGE MONTHLY WATER BALANCE

MONTH	PRECIPITATION (in)	POTENTIAL EVAPOTRANSPIRATION (in)	DEFICIT (in)
JANUARY	2,56	5,6	-3,04
FEBRUARY	2,46	5,2	-2,74
MARCH	1,82	6,4	-4,58
APRIL	3,77	7	-3,23
MAY	5,07	7,6	-2,53
JUNE	2,75	7	-4,25
JULY	3,28	7,5	-4,22
AUGUST	4,55	6,9	-2,35
SEPTEMBER	5,06	6,3	-1,24
OCTOBER	6,44	6	0,44
NOVEMBER	6,57	5,8	0,77
DECEMBER	5,78	5	0,78

4.2.1.3 TEMPERATURE

Temperature data of maximum, minimum and average temperature indicate a very uniform behavior and a tendency to have mild and pleasant values with a small reduction during the winter months and the corresponding increase during the summer months.

Figure 4.3

The minimum average temperature is 751F, the average temperature is 801F and the maximum average temperature is 851F (**Table 4.2** and **Figure 4.4**). Maximum average temperature tends to increase from January to September, then decreases until December. Average temperature has a similar behavior. Minimum average temperature has a slightly different tendency: it starts to increase from March to July, and then decreases until March. This relatively high sustained level of temperature favors plant growth and evapotranspiration.

4.2.1.4 RELATIVE HUMIDITY

Relative humidity is very constant and relatively high (**Table 4.2** and **Figure 4.5**). As expected, the records show low values during the dry season, with a contrasting minimum value in July, and higher values during the rainy season. This behavior is closely related to the evaporation data, because it is known that the lower the relative humidity, the higher the evaporation and vise versa.

4.2.1.5 SUNSHINE

Sunshine also tends to present high values during summer and spring, and lower values during fall and winter (**Table 4.2** and **Figure 4.6**). The average value, 259 hours per month, i.e. 8.6 hours per day, indicates that cloudiness is very low. Again, we have here a factor that favors evapotranspiration. The higher the sunshine time, the higher the evaporation.

4.2.1.6 WIND SPEED

Mean wind speed presents more contrasting values. In fact, the highest value is recorded in January and during summer time. The lowest data is recorded during the fall (**Table 4.2** and **Figure 4.7**). Wind speed is a factor that controls significantly the amount of evapotranspiration. In fact, the higher the wind speed, the higher the evaporation.

Figure 4.4

Figure 4.5

Figure 4.6

Figure 4.7

4.2.1.7 EVAPORATION

Evaporation, measured as pan evaporation, is higher, as expected, during the summer months, and lower during the winter time (**Figure 4.8**). If a pan coefficient of 0.75 is adopted, potential evapotranspiration is presented in **Table 4.2**. Average potential evaporation is 6.38 inches per month. This is a relatively high value, and supports the predominance of evaporation over runoff in the BVI water cycle.

4.2.1.8 UNDERGROUND WATER

Taking into account the type of soils, steep slopes and limited precipitation, groundwater resources must be very scarce and limited to the small flat low areas. As these areas are often populated, there is the risk of domestic pollution. Another problem is the low level of these areas, so that they are exposed to salt water pollution, when the water table is lowered by pumping. Ground water supply could be considered in Road Town, Paraquita Bay, Long Look and the West End, but in limited amounts and with possible quality problems. **Table 4.5** and **Map 4.1** presents the more important Tortola island watersheds, with different essential parameters used to estimate runoff.

TABLE 4.5: TORTOLA WATERSHED CHARACTERISTICS

GHUT NAME	ORIENTATION	LENGTH (feet)	ELEVATION (feet)	SLOPE (%)
TWO GHUT	NS	6400	1550	24
BUNTIN GHUT	NS	6000	1648	27
BROWN GHUT	NS	6000	1550	26
VALLEY GHUT	WE	10000	1710	17
NIBBS GHUT	NS	8800	1506	17
LONG BUSH GHUT	WE	8000	1244	16
HUNTUMS GHUT	NS	8800	1228	14
JACKASS GHUT	NS	5600	1023	18
JOHNSON GHUT	NS	5200	1023	20
JAMES GHUT	NS	5200	1091	21
SPRING GHUT	NS	9200	1263	14
BOMIE GHUT	NS	5000	667	13
GREY GHUT	SN	4800	1263	26
THOUSAND GHUT	SN	3600	1050	29
JOHNNY CAKE GHUT	SN	6400	1228	19
RIVER GHUT	SN	5600	1337	24
GARDEN GHUT	EW	4400	1506	34
SHANNON GHUT	EW	5600	1300	23
OLD GROUND GHUT	EW	4400	1684	38
CAPOONS BAY GHUT	EW	3200	750	23
AVERAGE		6110	1281	22

DRAINAGE DENSITY

122200/22 = 5554 (ft/mi^2)

Map 4.1

Figure 4.8

4.2.2 VIRGIN GORDA

Virgin Gorda is situated to the East of Tortola, at approximately 181 29= North latitude and 641 24= West longitude. It has a rectangular central block, with two branches. The first extends westwards and the second southwards. Spanish Town is located in the latter. The central block is dominated by the Virgin Gorda peak (1359 feet). This peak imposes a radial drainage system, with the typical BVI steep slopes and short distances. The eastern branch is elongated and hilly, with low elevations. Both the central block and the eastern branch are typical of the steep BVI physiography, with an extremely efficient surface runoff system. The southern branch, in contrast, presents a rather flat physiography, producing a slower runoff condition. This island presents flatter areas than other BVI islands, and the average slope of the larger watersheds is about 20 %, which, in spite of being high, is smaller than the slopes found in other islands. The main ghut water courses are shown in **Table 4.6 and Map 4.2**.

TABLE 4.6: VIRGIN GORDA GHUT CHARACTERISTICS

GHUT NAME	ORIENTATION	LENGTH (feet)	ELEVATION (feet)	SLOPE (%)
WINDY HILL	WE	1600	251	16
CRAB HILL	WE	2400	175	7
PLUM TREE BAY	EW	4800	1348	28
TURN GHUT	SN	2800	725	26
GREAT GOVERNOR	SN	5600	1359	24
CINNAMON GHUT	NS	4000	825	21
BLACK ROCK GHUT	WE	4800	1250	26
LITTLE BAY GHUT	WE	5200	1050	20
VALLEY GHUT	WE	2800	750	27
OIL NUT BAY	WE	2800	225	8
AVERAGE		3680	796	20

DRAINAGE DENSITY

36800/9 = 4089 (ft/m^2)

Map 4.2

The more developed area of this island is Spanish Town. This town has very favorable drainage conditions:

- The population is not densely concentrated.

- The slopes are moderate, facilitating a quick runoff disposal without high energy levels.

- The watersheds are very small in the town.

- Runoff is divided into two components: the eastern side of the town drains towards St. Thomas Bay, and the western side towards Taylor=s Bay.

- Elevations in the Spanish Town area are low (maximum 448 feet in the Cow Hill), so that precipitation is expected to be low, having a very small orographic effect. This conclusion is supported by the presence of low vegetation, typical of arid climates, like cactus.

Drainage problems in this area should not be serious, and are caused by insufficient capacity of drainage works, and debris blockage of ghuts and bridges.

A very interesting situation occurs in the South Sound flat. This is an attractive site, with an area of about 0.2 mi^2 (0.5 km^2), with practically no development at all. There are a few similar situations in the BVI, such as the Paraquita Bay flat, where development could be safer, from the surface drainage and stability points of view. In fact, in South Sound, slopes are moderate, nor very low nor very steep, and four different small watersheds are identified, so that runoff is not concentrated. There are no meteorological measurements in this island. Low and semiarid vegetation, such as scrubs, predominate. This is an indicator of lower levels of precipitation in comparison with the precipitation recorded in the central part of Tortola.

4.2.3 JOST VAN DYKE

Jost van Dyke island is situated to the West of Tortola, at approximately 181 27= North latitude and 641 45= West longitude. The island has a West-East elongated shape and is dominated by two summits: Mahonny Hill (1054 ft) and Roach Hill (1026 ft). Like the rest of the BVI islands, Jost van Dyke is very hilly, with steep slopes and a few small coastal flats. The average slope of the more important watersheds is about 36 %, which is very high. This island presents only one significant developed area: the Great Harbour flat. The watersheds are steep but small. Development has occurred at the seashore, with a road and bridges that makes the surface runoff more difficult.

There is also some development at the foot of the hills. A mangrove wetland is located in the center of the flat, preventing development in this area. A great deal of the runoff from the watersheds is not channelized directly into the ocean, but spreads out into the mangrove wetland. There are no meteorological measurements in this island. Low and semiarid vegetation, and relatively low mountain elevations, of just above 1000 feet, are indicators of a more reduced precipitation, as compared to the Tortola precipitation record. The principal watercourses are presented in **Table 4.7 and Map 4.3**.

Map 4.3

TABLE 4.7: JOST VAN DYKE WATERCOURSE CHARACTERISTICS

GHUT NAME	ORIENTATION	LENGTH (feet)	ELEVATION (feet)	SLOPE (%)
Old Mill Round Ghut	WE	2160	596	28
Cherry Ghut	WE	2240	1054	47
Brown Ghut	EW	4800	950	20
The Ghut	WE	4000	1026	25
Great Ghut	SN	1600	950	59
Garner Bay	NS	2400	1026	43
Spring Hill	NS	2400	800	33
AVERAGE		2800	914	36

DRAINAGE DENSITY
19600/3.2 = 6125 ft/mi^2

it can be observed from **Table 4.7** that the average length of the ghut courses is very small, in contrast with the elevation, resulting into an extremely high average slope.

4.2.4 ANEGADA

Anegada is a very low and flat limestone island, formed by the elevation of a coral reef. The island is entirely composed of limestone. Bedrock is exposed over 60 % of the island, and typically is characterized by a modified karst topography.

Anegada can be divided into five physiographic subdivisions: 1. Bedrock Ridge, 2. Bedrock Flat, 3. Stabilized Dune and Beach Ridge Complex, 4. Salt Ponds and 5. Mangrove Marsh. (**Map 4.4**). Sands are common in the West, and in the East upraised coral limestone predominates, with rock outcrops.

Map 4.4

Climate in Anegada must be significantly drier, with rainfall estimated to be about 40 in per year, due to its flat topography. Vegetation is very low and typically semiarid (cactus, century, low bushes). In fact, localized clouds tend to pass over the island without precipitation, in the absence of cooling effect from forested high mountains. Limestone rocks have an heterogeneous infiltration behavior, with a general tendency to low infiltration rates but, isolated sink holes, where infiltration is very high. The amount of precipitation, however, is so small, and the topography so flat, that concentrated surface runoff should be limited.

The sandy areas of the West and North coasts present higher rates of infiltration. In the areas of limestone outcrops, there is so little infiltration and so small slopes, that water tends to accumulate in topographic shallow depressions forming ponds and puddles that can last for several weeks. Some large ponds are permanent and are predominantly brackish, but fresh water ponds are also found. When rainfall is very heavy some localised ponding will occur, with low depths, and very slow rate of flow, not presenting a real danger to the communities. However, this is a nuisance and can lead to mosquito related health problems.

The extensive salt pond system has only one outlet to the sea, in the place called The Creek, in the Point Peter pond. Unfortunately, a bridge was built there with very small culverts that can be easily obstructed by debris and sand bars. The culverts should be substituted by a bridge with a higher hydraulic capacity.

In Anegada, it is not possible to define any watershed. Water flows in a disperse way to the sea, where the slope favors this option, or accumulates in ponds or puddles, and in this case water extraction is mainly due to evaporation.

There is an important contrast in the flood problems of the mountainous BVI islands, and Anegada. Runoff in the mountainous islands is concentrated, with high energy, in very small valleys and flats and can be very destructive. On the contrary, in Anegada, topography does not favor runoff concentration, water flows everywhere, with little energy, and, as a consequence, is much less damaging.

4.3 HYDROLOGIC MODELING

4.3.1 INTRODUCTION

In order to determine the flood potential of natural channels, detailed investigation of the watersheds which drain through these channels is required. Because of the limitations of time, the project investigated the three main watersheds and associated ghuts which run through Road Town, which are the Huntums, Long Bush and Johnson Ghut watersheds. These watersheds were selected because they are located at the most populated and important area of the BVI, and have traditionally presented flooding problems. These studies would then serve to develop a methodology which could be used to assess other watersheds in the BVI if required.

The main aim of the hydrological modeling process is to determine the nature of flow or discharge through the drainage channels. This requires a detailed analysis of the nature of precipitation, the configuration and surface covering of the watersheds and other features. The actual modeling process involved using these parameters as inputs in the HEC-1 hydrologic modeling software.

Because of the absence of stream flow records in the BVI and the lack of data on extreme precipitation events in the BVI, the hydrologic modeling of the Road Town watersheds involved using some data from similar watersheds in the US Virgin Islands. Details of the modeling process are presented in the final report. The important findings are summarised below.

4.3.3.1 PRECIPITATION

An important part of the hydrologic study relating to flood hazard is to establish the overall pattern of precipitation but more importantly to estimate the magnitude of extreme events and the frequency of occurrence. Data from the US Virgin Islands was used extensively to obtain these estimates for the BVI. The close proximity and similarity in size geomorphology and watershed conditions in the BVI and USVI makes it possible to derive crucial data to characterize the BVI watersheds. The estimates of 24 hour precipitation and their return periods produced by this analysis is summarised in **Table 4.11**. The details of the precipitation analysis are available in the final report.

TABLE 4.11: 24 HR. RAINFALL ESTIMATES FOR DIFFERENT RETURN PERIODS IN TORTOLA

RETURN PERIOD (years)	PRECIPITATION (in)
2	5.6
5	7.9
10	9.4
25	11.4
50	13.4
100	15.0

4.3.4 HUNTUMS GHUT HYDROLOGIC MODELING RESULTS

The Huntums Ghut and Long Bush Ghut are modeled in the same process, taking into account that these ghuts were artificially joined and can be seen to represent two adjacent sub-watersheds, (**Map 4.5**). The Huntums Ghut sub-watershed characteristics are presented in **Table 4.12**.

TABLE 4.12: HUNTUMS GHUT SUB-WATERSHED CHARACTERISTICS

SUB-WATERSHED	AREA (mi^2)	MAX. ELEV. (ft)	MIN. ELEV. (ft)	LENGTH (ft)	LAG TIME (hr)
EVA TOWN	0.16	721.93	0.00	3116.0	0.11
LONG BUSH1	0.47	1310.69	0.00	7708.0	0.25
LONG BUSH2	0.02	2.95	0.00	656.0	0.15
BOTANIC GARDEN	0.14	49.00	0.00	8134.4	0.95
PICKERING	0.12	1228.00	49.20	2788.0	0.08
GORDON	0.67	1155.00	85.28	5018.4	0.16

The HEC-1 output files provide the maximum discharges for the different reaches of the Huntums and Long Bush Ghuts. The main results, which will be used for the HEC-2 hydraulic modeling are presented in **Table 4.13**.

MAP 4.5

TABLE 4.13: HUNTUMS AND LONG BUSH GHUTS MAXIMUM DISCHARGES (cfs)

SUB-WATERSHED	**RETURN PERIOD (years)**					
	2	5	10	25	50	100
LONG BUSH1	384	569	688	846	988	1128
LONG BUSH2	517	764	924	1135	1325	1514
GORDON	552	815	985	1210	1411	1612
PICKERING	652	962	1162	1427	1664	1901
BOTANIC GARDEN	746	1105	1388	1646	1922	2196
HUNTUMS OUTLET	1279	1894	2291	2817	3289	3758

4.3.5 JOHNSON GHUT HYDROLOGIC MODELING RESULTS

The Johnson Ghut characteristics are presented in **Table 4.14** and **Map 4.5**. and the peak discharge estimates in **Table 4.15**.

TABLE 4.14: JOHNSON GHUT SUB-WATERSHED CHARACTERISTICS

SUB-WATERSHED	**AREA (mi^2)**	**MAX. ELEV. (ft)**	**MIN. ELEV. (ft)**	**LENGTH (ft)**	**LAG TIME (hr)**
PURCELL	0.33	1055.18	82.00	3116.00	0.10
BUTU	0.06	1091.00	45.92	3280.00	0.10
JOHNSON PORT	0.25	946.00	6.56	3444.00	0.11

TABLE 4.15: JOHNSON GHUT MAXIMUM DISCHARGES (cfs)

SUB-WATERSHED	**RETURN PERIOD (years)**					
	2	5	10	25	50	100
PURCELL	273	403	486	597	696	795

BUTU	323	476	575	705	822	939
JOHNSON PORT	530	781	943	1157	1350	1541

4.3.6 MAXIMUM DISCHARGE ESTIMATION FOR BVI WATERSHEDS

Based on the hydrologic modeling results it is possible to estimate the maximum discharges for the bigger watersheds, in the main islands of the BVI. The basic parameters are taken from the Huntums and Long Bush hydrologic modeling (**Table 4.13**). It is assumed that the unit discharge, or the discharge per unit area of watershed, for the different return periods, is constant for the various islands, and watersheds.

Of course, this is only an approximation, but taken into account the similarity of geomorphology and climatic conditions of the BVI, this estimation is reasonable as a first approximation. Of course, Anegada is excluded from this analysis, because its drainage pattern is completely different and undefined.

Unit discharges and the corresponding return periods are presented in **Table 4.16**, and indicates discharge at the watershed outlet.

TABLE 4.16: UNIT DISCHARGES FROM HUNTUMS GHUT

RETURN PERIOD (years)	DISCHARGE (cfs)	AREA (mi^2)	UNIT DISCHARGE (cfs/mi^2)
2	1279	1.58	809
5	1894	1.58	1199
10	2291	1.58	1450
25	2817	1.58	1783

50	3289	1.58	2082
100	3758	1.58	2378

The discharge estimations for 2, 5, 10, 25, 50 and 100 years return periods, are presented in **Table 4.17** for the main sub-watersheds of Tortola, **Tables 4.18** and **Table 4.19** present data for Virgin Gorda and for Jost Van Dyke island respectively.

TABLE 4.17: TORTOLA WATERSHED MAXIMUM DISCHARGES

WATERSHED	PERI M.	AREA	DISCHARGE (cfs)					
	(mi)	(mi^2)	RETURN PERIOD (years)					
			2	5	10	25	50	100
Two Ghut	5.06	0.75	602.96	893.63	1080.70	1328.89	1551.74	1772.35
Buntin Ghut	3.15	0.33	270.83	401.38	485.41	596.89	696.98	796.07
Brown Ghut	3.90	0.49	398.50	590.60	714.24	878.27	1025.55	1171.35
Valley Ghut	5.48	1.05	847.24	1255.67	1518.54	1867.27	2180.41	2490.40
Nibbs Ghut	5.18	0.97	786.88	1166.21	1410.35	1734.25	2025.07	2312.98
Long Bush G.	4.76	0.48	390.28	578.42	699.51	860.16	1004.40	1147.20
Huntums G.	5.03	0.93	751.80	1114.23	1347.48	1656.94	1934.80	2209.87
Jackass G.	2.96	0.21	166.22	246.36	297.93	366.35	427.79	488.60
Johnson G.	3.83	0.64	517.95	767.64	928.34	1141.54	1332.97	1522.48
James Ghut	3.60	0.48	388.38	575.61	696.11	855.98	999.52	1141.63
Spring Ghut	5.70	1.09	882.00	1307.19	1580.84	1943.89	2269.87	2592.58
Bomie Ghut	4.50	0.62	504.04	747.03	903.42	1110.89	1297.18	1481.61
Grey Ghut	3.00	0.27	217.42	322.23	389.69	479.18	559.54	639.09
Thousand G.	3.30	0.40	325.50	482.41	583.40	717.38	837.68	956.77
Johnny Cake	3.49	0.40	322.97	478.66	578.87	711.81	831.17	949.34
River Ghut	4.35	0.71	572.30	848.20	1025.76	1261.33	1472.85	1682.25

Garden Ghut	3.15	0.36	295.16	437.45	529.02	650.52	759.60	867.60
Shannon Ghut	3.38	0.43	346.35	513.32	620.78	763.35	891.36	1018.08
Old Ground G.	2.81	0.25	204.15	302.56	365.90	449.93	525.38	600.07
Cappoons Bay	1.80	0.15	119.45	177.04	214.10	263.27	307.42	351.13

TABLE 4.18: VIRGIN GORDA MAXIMUM DISCHARGES

WATERSHED	PERIM.	AREA	DISCHARGE (cfs)					
	(mi)	(mi^2)	RETURN PERIOD (years)					
			2	5	10	25	50	100
Plum Tree Bay	2.66	0.22	177.16	262.56	317.53	390.45	455.93	520.74
Valley Ghut	1.84	0.11	86.53	128.24	155.08	190.70	222.68	254.33
Little Bay Ghut	2.91	0.21	167.90	248.84	300.93	370.04	432.10	493.53
Black Rock G.	3.06	0.31	247.09	366.21	442.87	544.58	635.90	726.31
Cinnamon G.	2.66	0.18	145.56	215.73	260.89	320.80	374.60	427.85
Great Governor	3.34	0.41	333.21	493.84	597.22	734.37	857.52	979.44
Turn Ghut	2.31	0.20	158.42	234.79	283.94	349.15	407.70	465.66
Oil Nut Bay G.	1.66	0.08	63.99	94.84	114.70	141.04	164.69	188.10
Crab Hill Ghut	1.28	0.06	51.35	76.11	92.04	113.18	132.16	150.95
Windy Hill G.	1.16	0.05	43.07	63.84	77.20	94.93	110.85	126.61

TABLE 4.19: JOST VAN DYKE MAXIMUM DISCHARGES

WATERSHED	PERIM.	AREA	DISCHARGE (cfs)					
	(mi)	(mi^2	RETURN PERIOD (years)					
			2	5	10	25	50	100
Cherry Ghut	1.20	0.05	37.42	55.45	67.06	82.46	96.29	109.98
Old Mill G.	1.95	0.14	114.78	170.11	205.72	252.96	295.38	337.38
Great Ghut	1.48	0.08	62.57	92.74	112.15	137.90	161.03	183.92
The Ghut	3.28	0.37	301.23	446.44	539.90	663.89	775.22	885.43
Brown G.	2.98	0.30	246.11	364.76	441.12	542.42	633.38	723.43
Garner G.	1.98	0.16	130.07	192.78	233.13	286.67	334.75	382.34

4.4 HYDRAULIC MODELING

4.4.1 INTRODUCTION

The outputs of the hydrologic modeling process was used as inputs for the hydraulic modeling which involves an assessment of the water flow conditions of the drainage channel itself. This requires an understanding of the channel configurations, the type of channel surface and the nature of channel obstructions.

A detailed topographic survey was commissioned to obtain data on channel configuration. This involved the production of several cross sections of the drainage channels which are crucial inputs for the hydraulic modeling. Field surveys were carried out to determine the other parameters.

In general the model determines the capacity of the channel to handle flow discharge of varying magnitudes. The US COE HEC-2 model was used for this analysis. HEC-2 is a computer program intended for calculating water surface profiles for steady gradually varied flow in natural or man made channels. Effects of various obstructions such as bridges, culverts, and other structures in the drainage channel are considered in the computations. The program also has the capability for assessing the effects of channel improvements and levees on water surface profiles and can determine flood prone areas.

4.4.2 FLOOD PRONE AREAS

The final report presents a series of maps produced by GIS analysis that show the areal extent of over-bank flow that can result from discharges with return periods of 25, 50 and 100 years. One of these maps is shown in **Map 4.6**. The small quantities of flood water, the lack of detailed topography of the low lying areas, and the presence of many buildings and roads, does not allow us to produce an accurate delineation of the areas which might be affected from an extreme flood event.

These maps show the areas with elevations below the level of the water in the channel for a given discharge. The maps therefore indicate that in general terms over-bank flow

Map 4.7 (Cont.)

can extend over much of the flat low lying areas adjacent to the drainage channels as a result of even a 25 year flood event which would represent 24 hour rainfall of 11.4 inches. However the relatively low discharge through the channels results in small changes of water surface elevation and therefore the depth of inundation is shallow and the entire area would not be inundated simultaneously.

The HEC-2 model analysis did allow us to identify the sections of the drainage channels, **Map 4.7**, which are most inefficient in conveying large discharges. Based on the position of these sections, the areas most prone to flooding in Road Town is indicated in **Map 4.8**.

4.4.3 CHANNEL IMPROVEMENT

Channel improvement work involve steps to introduce geometric modifications of the channel course, in order to improve the hydraulic capacity and ideally transport all the amount of flow within the boundaries of the channel, so that no overbank flow will occur. **Map 4.7** indicates the reaches of the ghuts which should be modified to reduce the possibility of flooding.

The model provides a series of options to improve the flow capacity of these reaches. One option is to increase the area of the channel section. If this is attempted in the low lying areas, the width of the channels become very large, because the low slope and tides do not permit deepening the channel bed.

In order to keep the dimensions small it is necessary therefore to improve the hydraulic energy efficiency of the channel. This can be achieved by a good quality concrete lining of the channel, including the walls and the channel bed.

Map 4.8

4.5 CONCLUSIONS

The general drainage study indicates that only Tortola, Virgin Gorda and Jost Van Dyke possess drainage systems capable of causing flood hazards and the results of the precipitation analysis suggest that these events are quite infrequent. The return period for rainfall amounts of 11.4 inches in 24 hours for example, was estimated at 25 years. In general the hydrologic study suggests that the watersheds will produce relatively small discharges because of their small size, and the presence of abundant vegetation.

The hydraulic study of the Ghuts in Road Town indicates that the banks of the drainage channels can be overtopped as a result of a 25 year rainfall. However the water level would be very low and the presence of buildings and other obstructions will limit any significant damage to structures and or their contents to those located immediately adjacent to the drainage channel.

The areas of greatest susceptibility was also identified. In addition the hydraulic study identified areas for channel improvement to reduce flood hazard. In general the flooding hazard associated with the Ghuts in Road Town is not significant. However localised blockage of the drainage channels by debris for example can result in localised inundation.

The entire study provides important background data relating to the hydrological and hydraulic characteristics of the Ghuts which were studied in detail. This data could be very useful for more detailed study and for site specific design purposes.