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:

- To characterize the Hydrologic behavior of the islands, to establish the general climatic and geomorphological features that control the drainage system.
- 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.
- To analyze the hydraulic capacity of the ghuts and their bridges, and to establish flooding risks along the their courses.
- 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 significative 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)

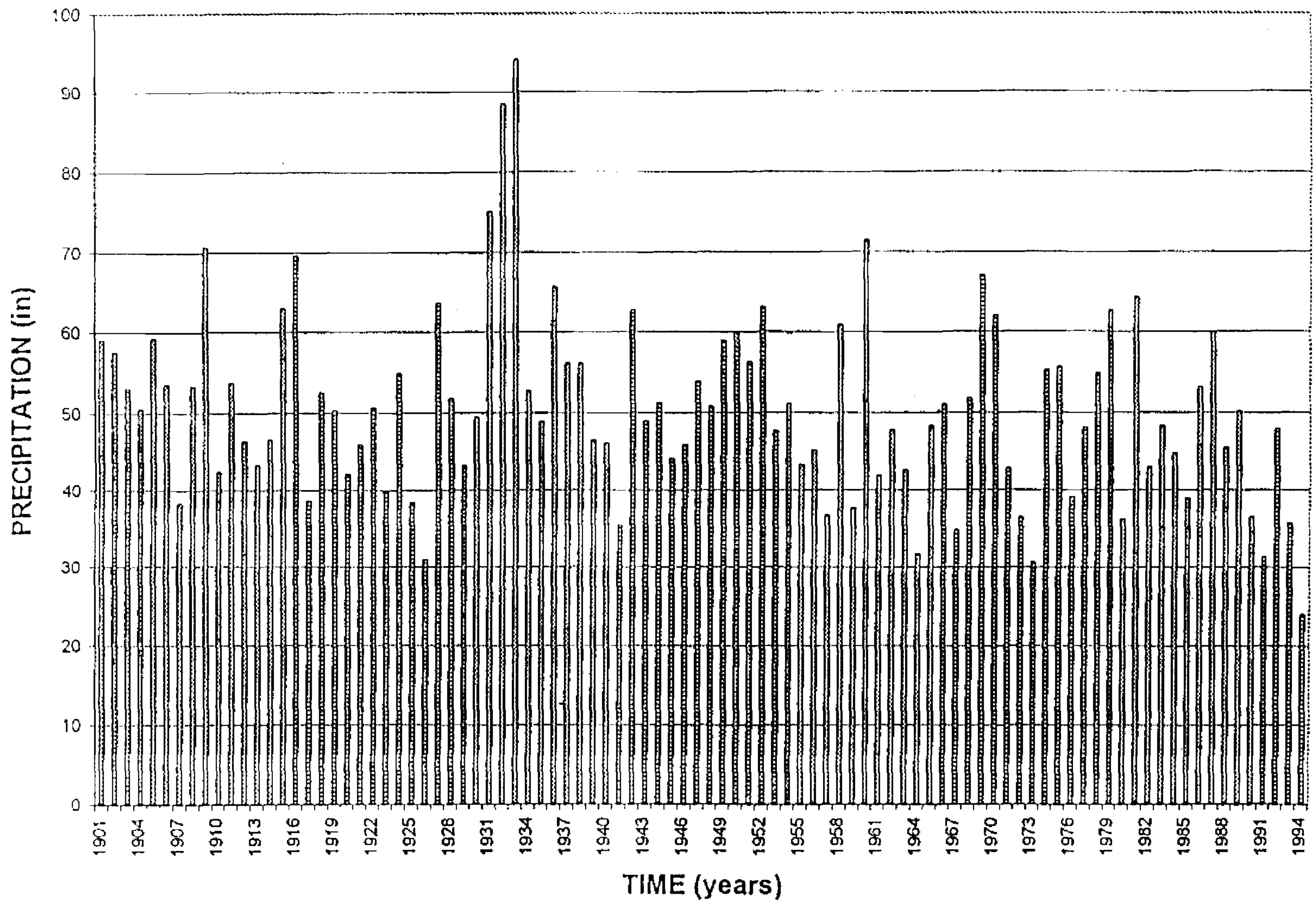
YEAR	PRECIPITATION (in)	ORDER	PRECIPITATION (in)
1901	59.09	1	94.26
1902	57.69	2	88.52
1903	53.2	3	75.03
1904	50.54	4	71.52
1905	59.28	5	70.64
1906	53.66	6	69.65
1907	38.26	7	67.11
1908	53.37	8	65.68
1909	70.64	9	64.31
1910	42.4	10	63.63
1911	53.85	11	63.14
1912	46.41	12	63.04
1913	43.28	13	62.82
1914	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

BVI MEAN ANNUAL PRECIPITATION



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 (ºF)	82	82	83	84	85	85	86	87	88	87	86	83	85
MAX.TEMP ºC)	28	28	28	29	29	29	30	31	31	31	30	28	29
MIN. TEMP (ºF)	73	72	72	73	76	77	78	76	76	76	74	72	75
MIN TEMP (ºC)	23	22	22	23	24	25	26	24	24	24	23	22	24
AVE.TEMP (ºF)	77	77	77	78	80	81	82	82	82	81	80	77	80
AVE TEMP (ºC)	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.

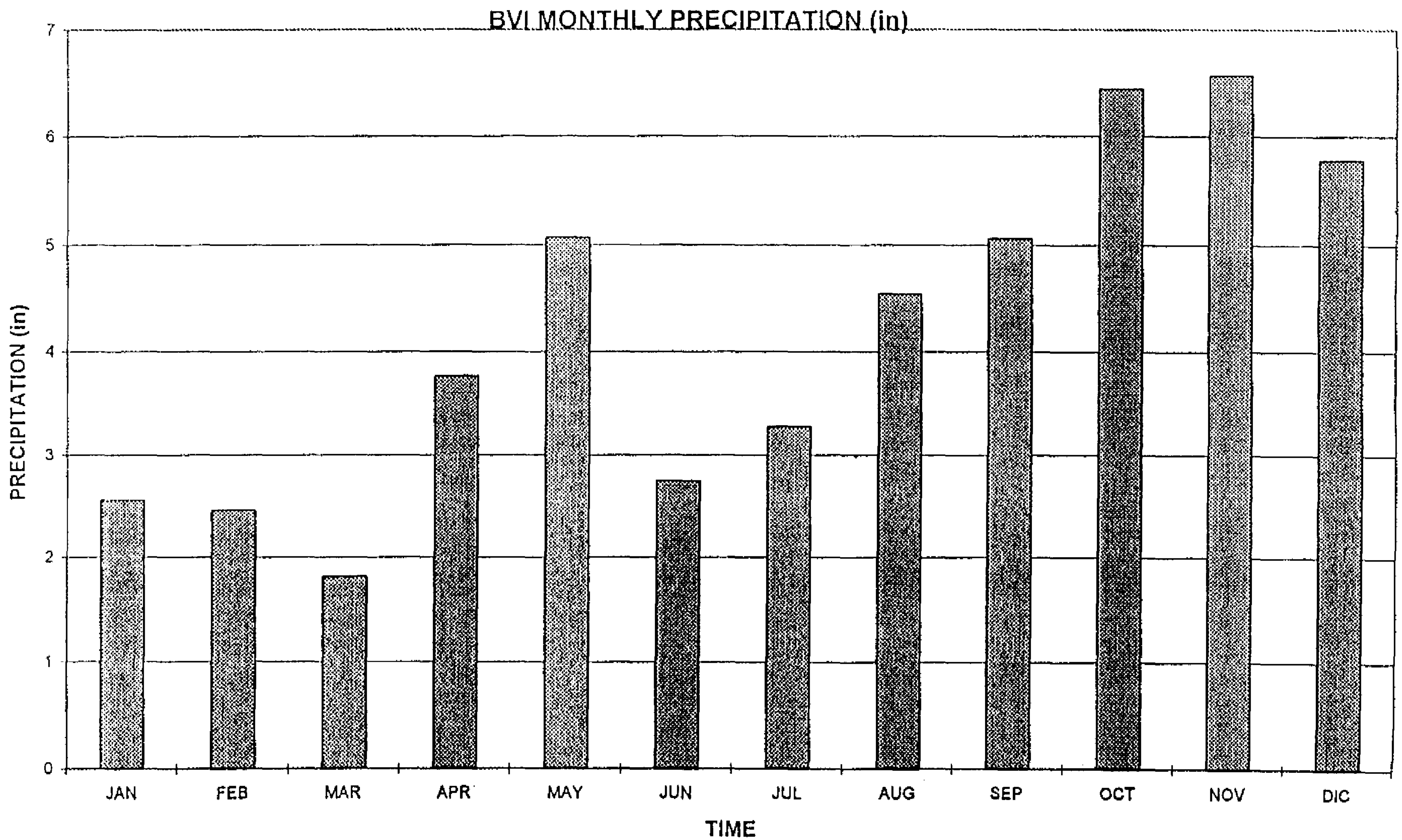
4.2.1.1 MONTHLY PRECIPITATION

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


BVI MONTHLY PRECIPITATION (in)
PRECIPITATION (in)
0
1
2
3
4
5
6
7
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DIC
TIME

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

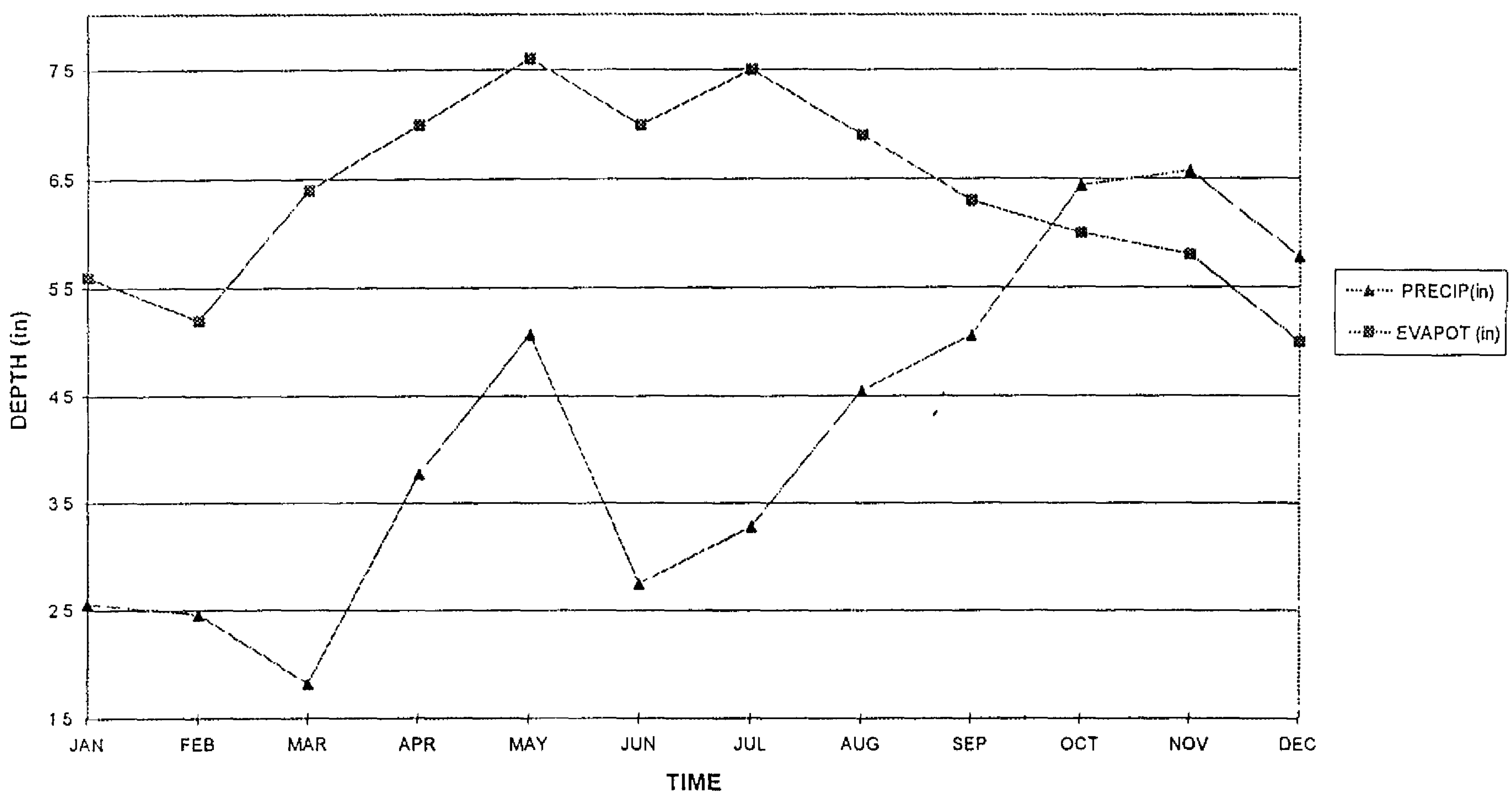
MONTH	PRECIPITATION (in)	POTENTIAL EVAPOTRANSPIRATION (in)	DEFICIT (in)
JANUARY	2,56	5,6	-3,04
FEBRUARY	2,46	5,2	-2,74
MARCH	1,82	6,4	-4,58
APRIL	3,77	7	-3,23
MAY	5,07	7,6	-2,53
JUNE	2,75	7	-4,25
JULY	3,28	7,5	-4,22
AUGUST	4,55	6,9	-2,35
SEPTEMBER	5,06	6,3	-1,24
OCTOBER	6,44	6	0,44
NOVEMBER	6,57	5,8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

WATER BALANCE



The minimum average temperature is 75ºF, the average temperature is 80ºF and the maximum average temperature is 85ºF (**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

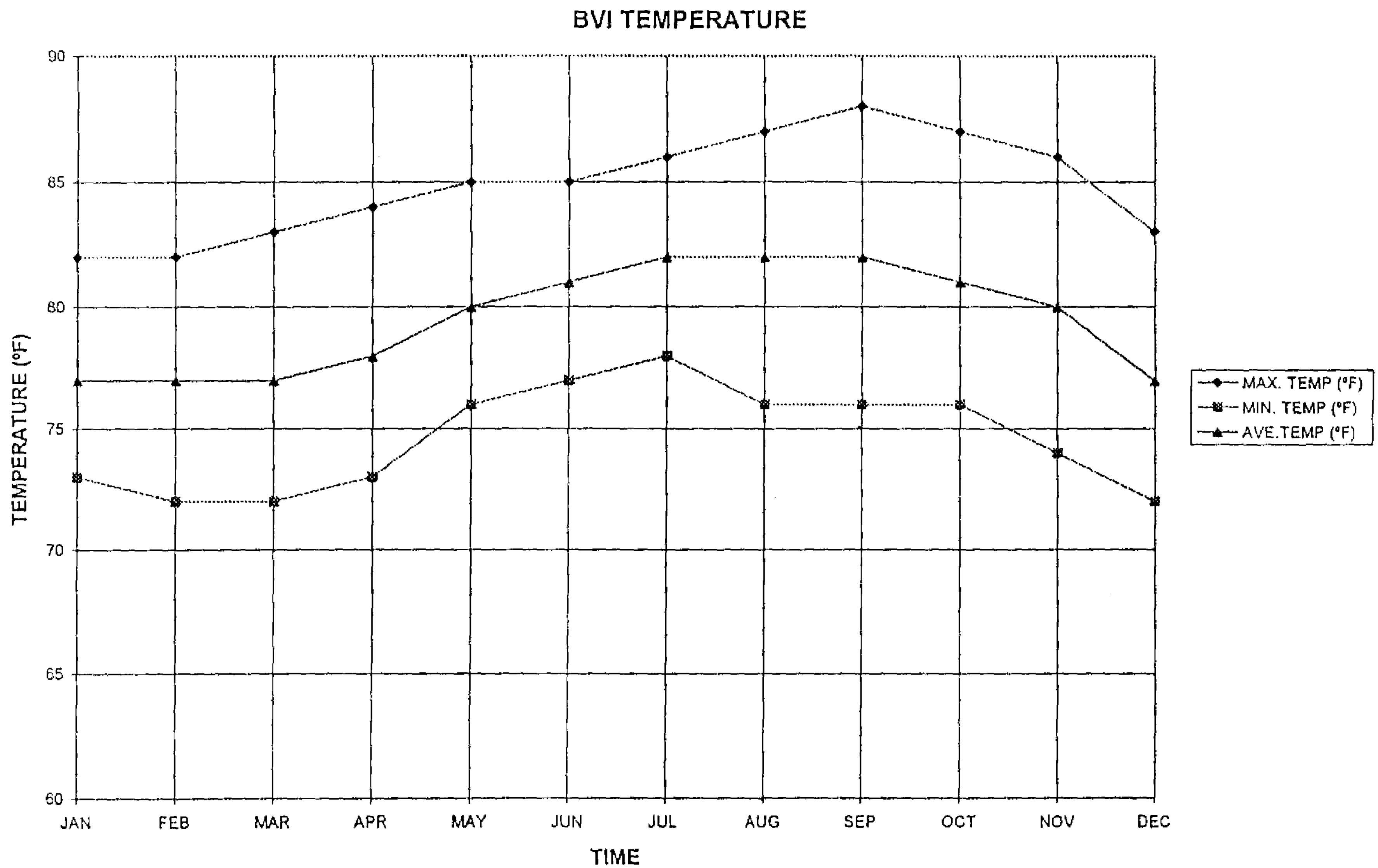

BVI TEMPERATURE
90
85
80
75
70
65
60
TEMPERATURE (ºF)
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
TIME
MAX. TEMP (°F)
MIN. TEMP (°F)
AVE.TEMP (°F)

Figure 4.5

BVI RELATIVE HUMIDITY

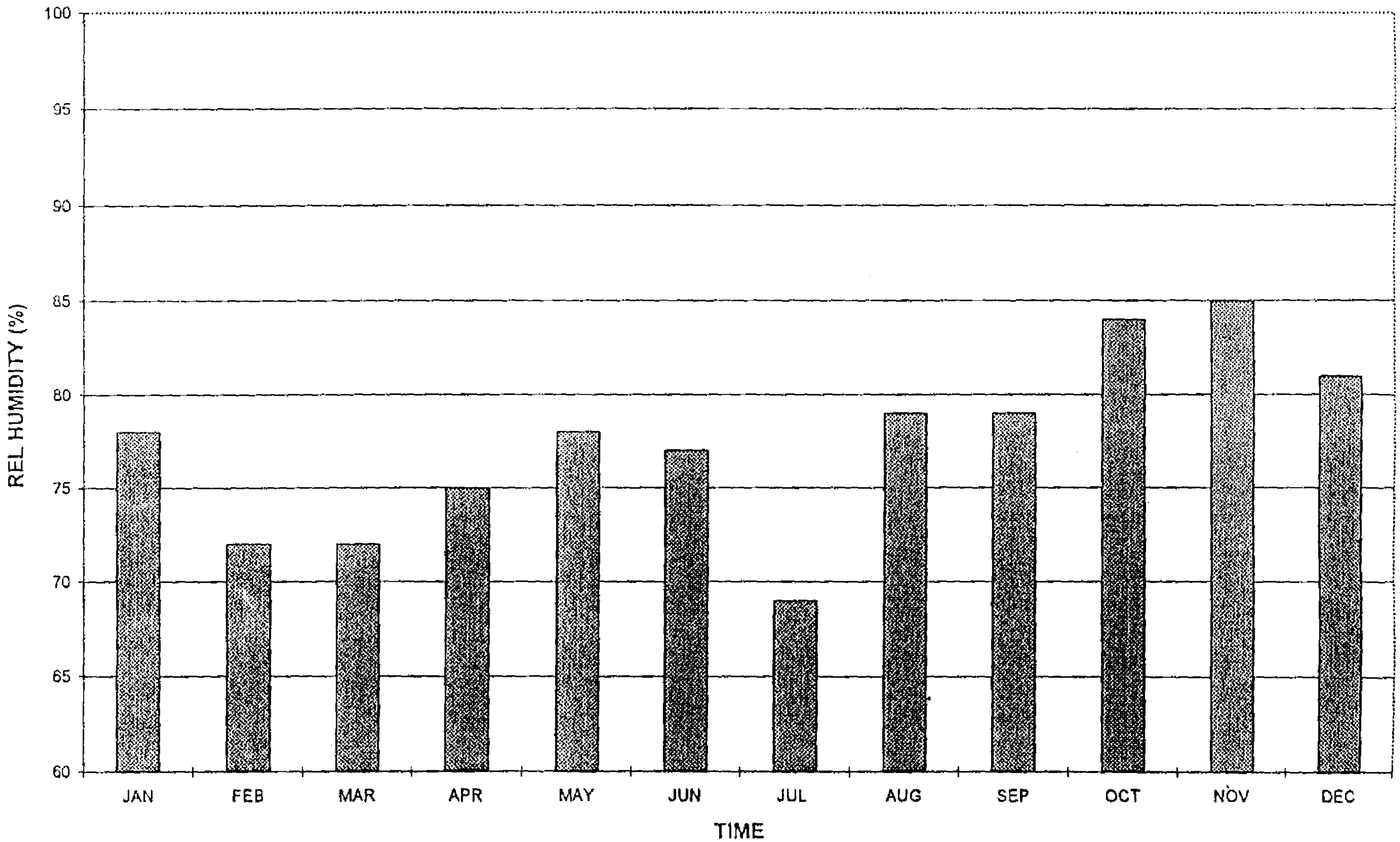


Figure 4.6

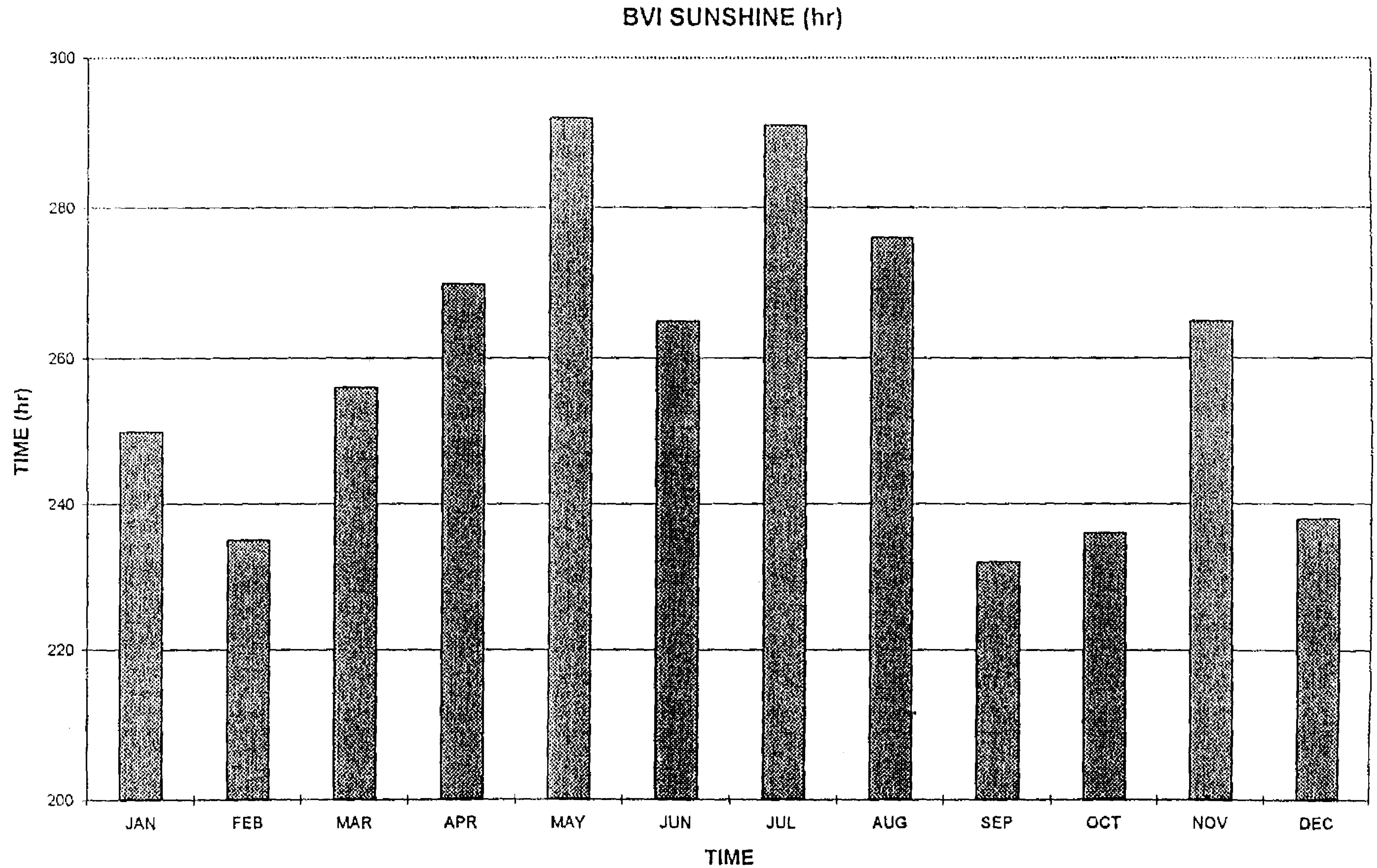
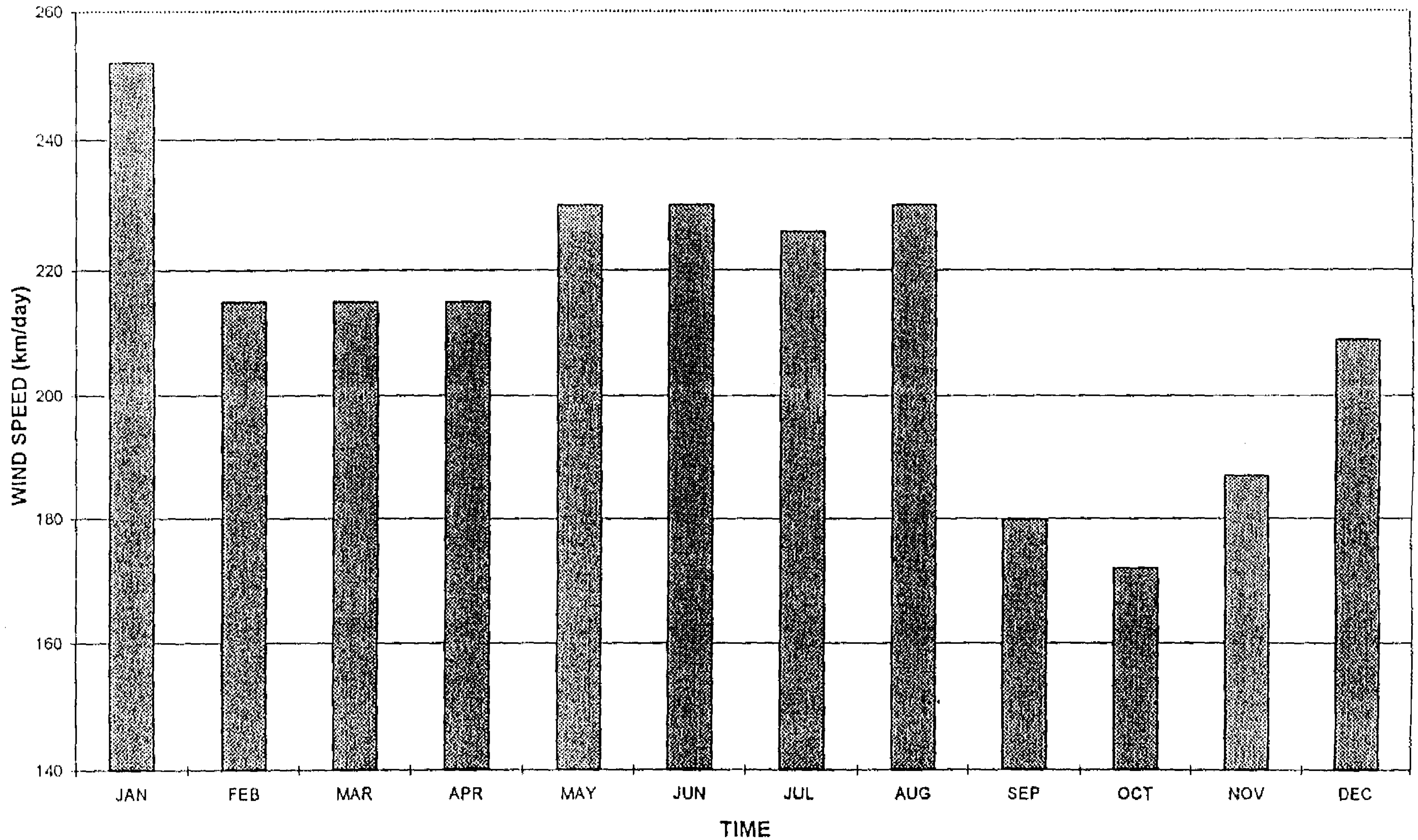

BVI SUNSHINE (hr)
TIME (hr)
300
280
260
240
220
200
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
TIME

Figure 4.7

BVI WIND SPEED



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)

Figure 4.8

BVI PAN EVAPORATION