A GENERAL OVERVIEW OF HYDROLOGY AND THE ANALYSIS OF RAINFALL DATA

by

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Introduction

Hydrology can be defined in general terms as the science which deals with the waters of the earth, their distribution on the surface, underground and the cycle involving evaporation, precipitation and flow to the seas. All components of this cycle are of equal importance. The linkages between subsystems in the hydrologic cycle are illustrated in Figure 1 while the hydrologic cycle and associated water quality parameters are illustrated in Figure 2.

The hydrologic cycle is perhaps the best vehicle to use in a general discussion on hydrology. However, it is erroneous to give the impression that water moves at a constant rate through this cycle. It is instead, an erratic movement, both temporally and spatially. Furthermore, it is important to have more than a qualitative understanding of the cycle and knowledge of how to measure quantities of water at various stages in the cycle. It is necessary to be able to deal quantitatively with the iterations between the various fac-

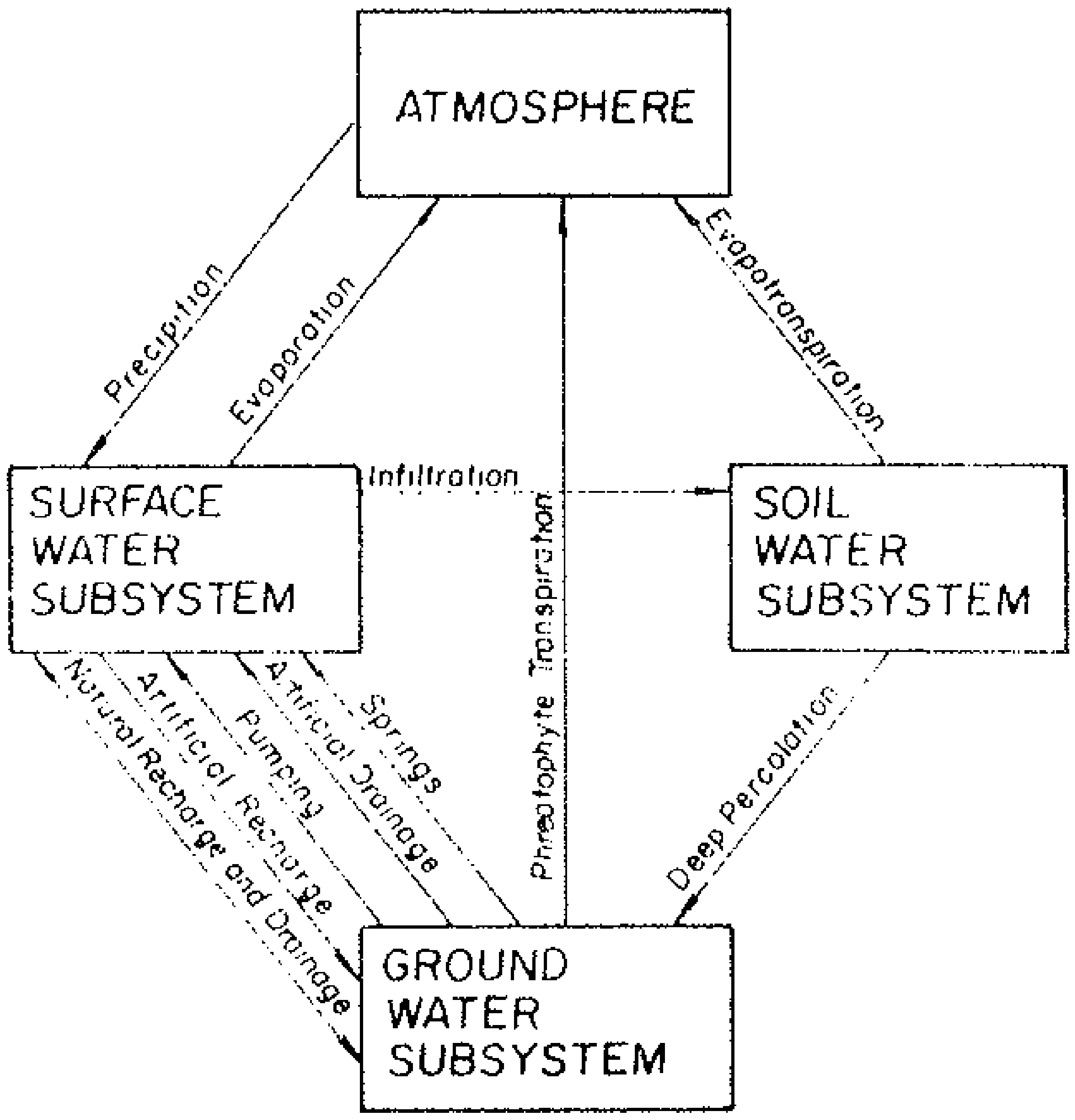

Figure 1. Linkages Between Subsystems in the Hydrologic Cycle
(From: McWorther and Sunada, 1981)

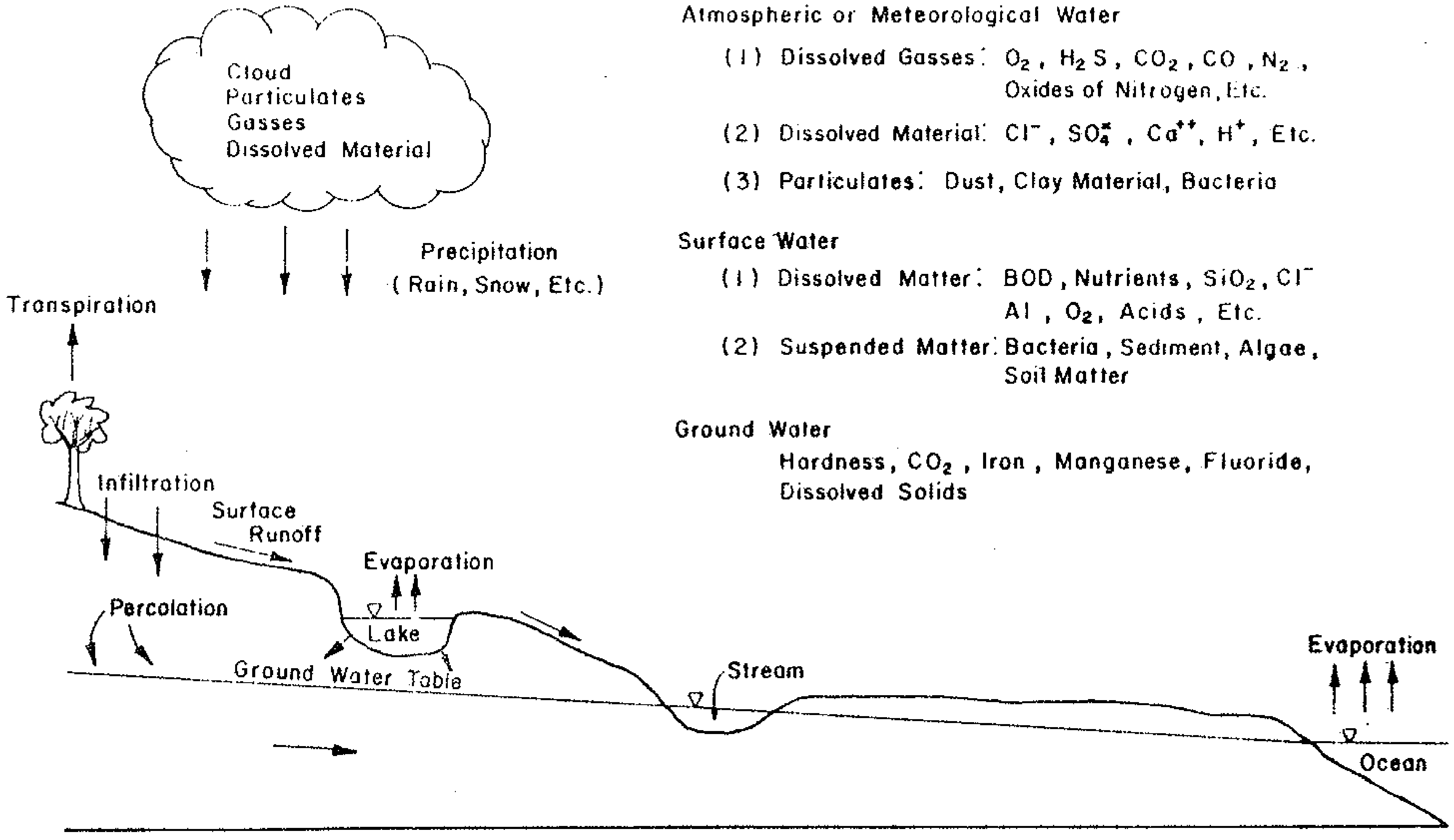

Figure 2. The Hydrologic Cycle and Associated Water Quality Parameters
(From: Sanders, 1980)

tors in order to make assumptions on the influence of man-made works on the relations. It is necessary to be familiar with methods for evaluating the frequency of various extermes of the cycle. The final section of this discussion will examine some of the methods relevant to us.

Of the average annual rainfall in the Virgin Islands, (38-45 inches), it has been estimated that 87% returns directly to the atmosphere as evapotranspiration, 5% goes to groundwater recharge and 8% occurs as runoff. In Figure 3 the movement of water through the hydrologic cycle for an average year in the Virgin Islands is illustrated. It is indeed a challenge then with our high slopes, cooling ever-present tradewinds and limited flat areas, to intercept for use as needed, the maximum possible amount of water that can be feasibly withdrawn from each source.

Rain Water Harvesting

When atmospheric water vapor condenses, hydrometeors are formed. These hydrometeors include damp haze, fog, ice fog, snow, frost, drizzle and rain. For purposes of clarification, drizzle consists of tiny liquid water droplets, usually with diameters between 0.004 and 0.02 inches, with such slow settling rates that they often appear to float. Drizzle rarely exceeds 0.04 inches/hour. Rain on the other hand consists of liquid water drops mostly larger than 0.2 inches in diameter.

Rainfall may be measured conveniently by any open receptacle with vertical sides. The standard gage of the U. S.

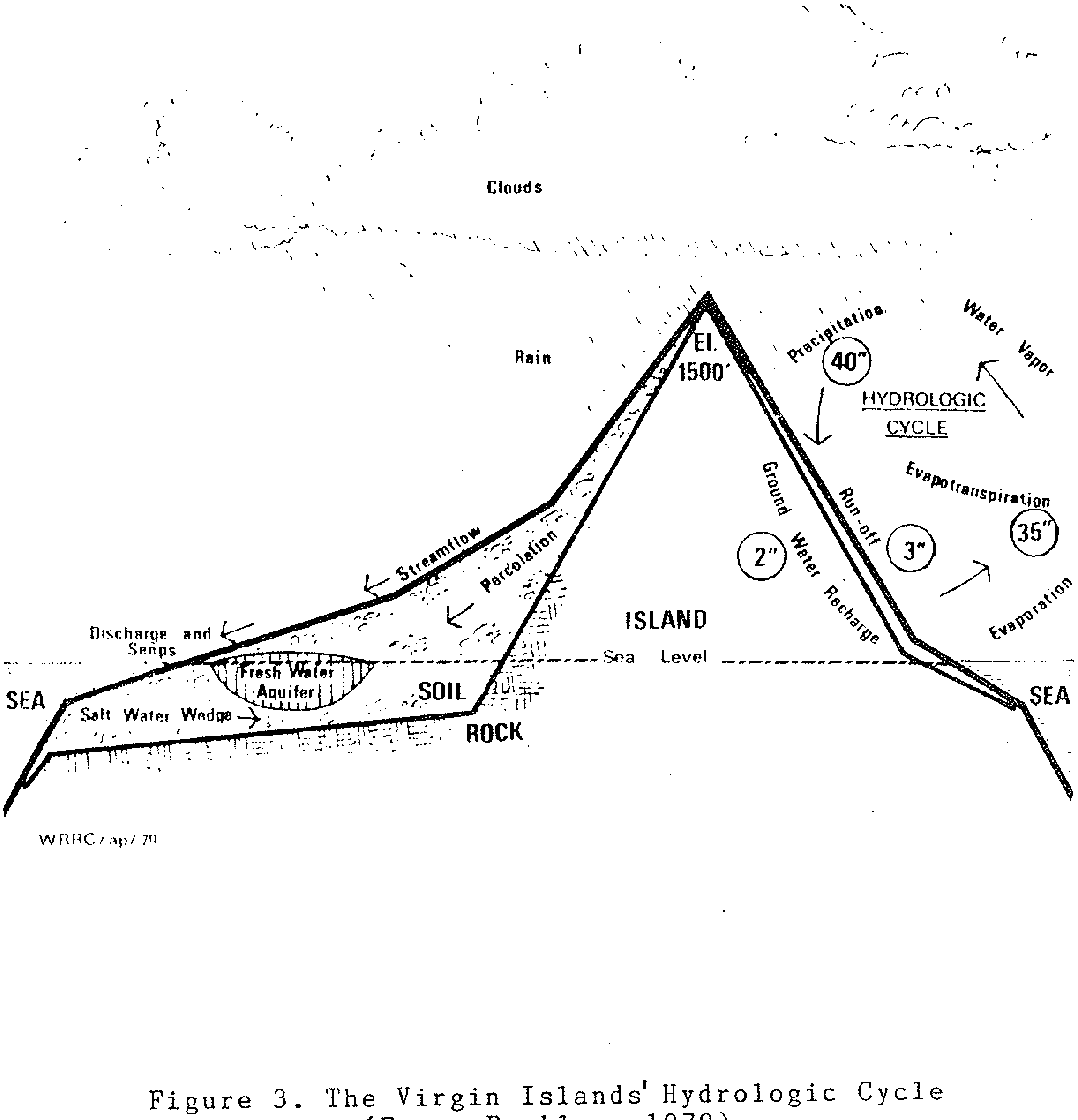

Figure 3. The Virgin Islands' Hydrologic Cycle
(From: Peebles, 1979)

National Weather Service consists of a collector which passes the collected rain into a cylindrical measuring tube which stands in an overflow can. The cross-sectional area of the measuring tube is one-tenth that of the collector. In this way, 0.1 inch of rain fills the tube to a depth of 1.0 inch. This makes it possible to measure rainfall to an accuracy of 0.01 inch with the calibrated measuring stick.

Other types of raingages in common use are the tipping bucket, the weighing type, and the float recording gages. These gages are all best suited for particular applications and, for the most part, used where a continuous record is desirable.

The preferable network density of rain gages in an area is highly dependent on the use to which the data will be put. The density recommended by the World Meteorological Organization for small mountainous islands with irregular precipitation is one station for each 10 square miles.

Rain water harvesting has been the traditional source of water in tne Virgin Islands and still is the preferred source of water for most residents. On each of the islands the greatest annual rainfall occurs in the northwest and the least on the southeastern coasts. As can be seen from Figure 4, which shows average rainfall data for a location in St. Croix, February and March are the driest months and September is the wettest. Almost half of the average annual rainfall occurs between August and November. Generally, rainfall occurs as brief intense showers of less than a few tenths of an inch.

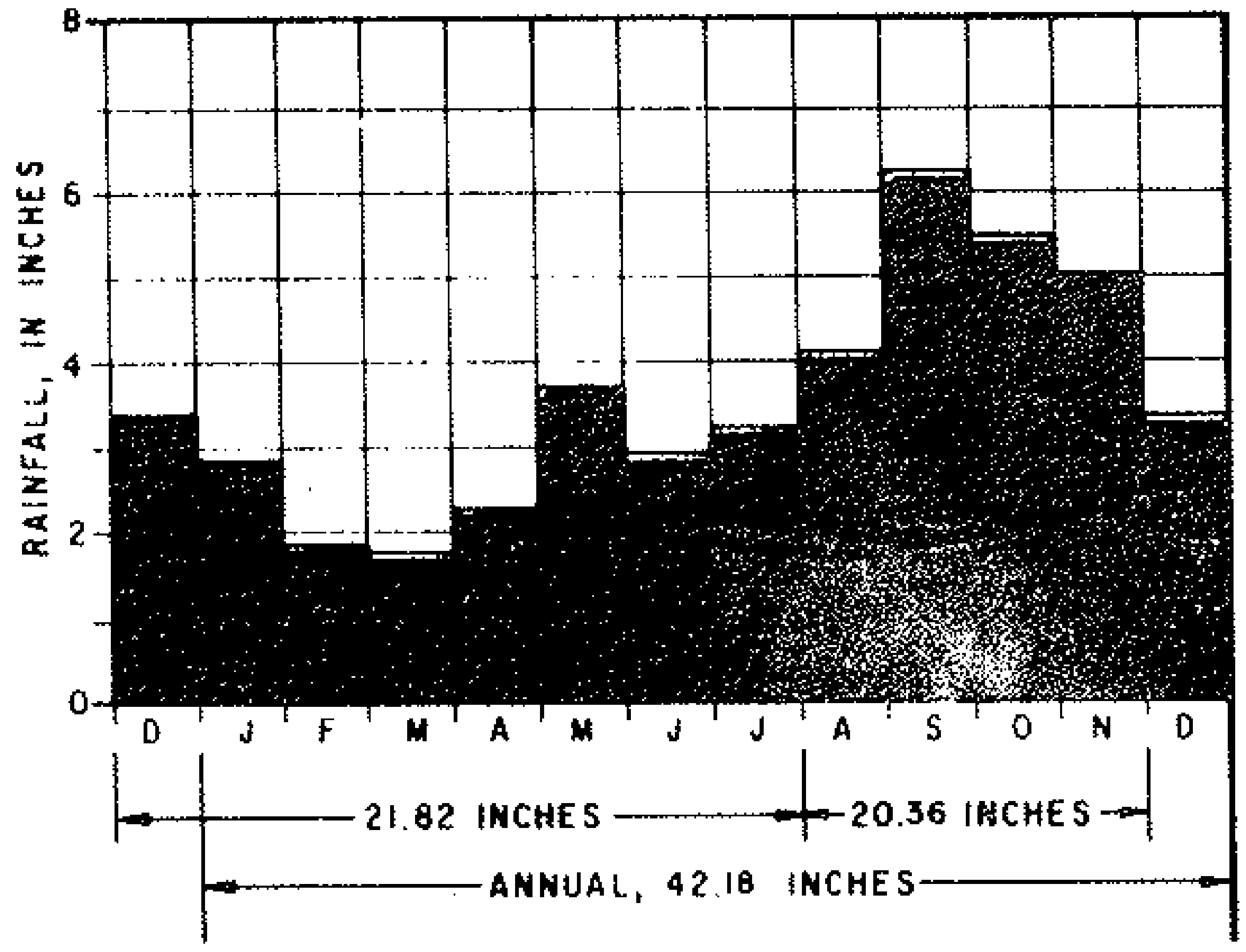

Figure 4. Mean Monthly Rainfall at Anna's Hope, St. Croix, 1920 - 1967)
(From: Jordan, 1975)

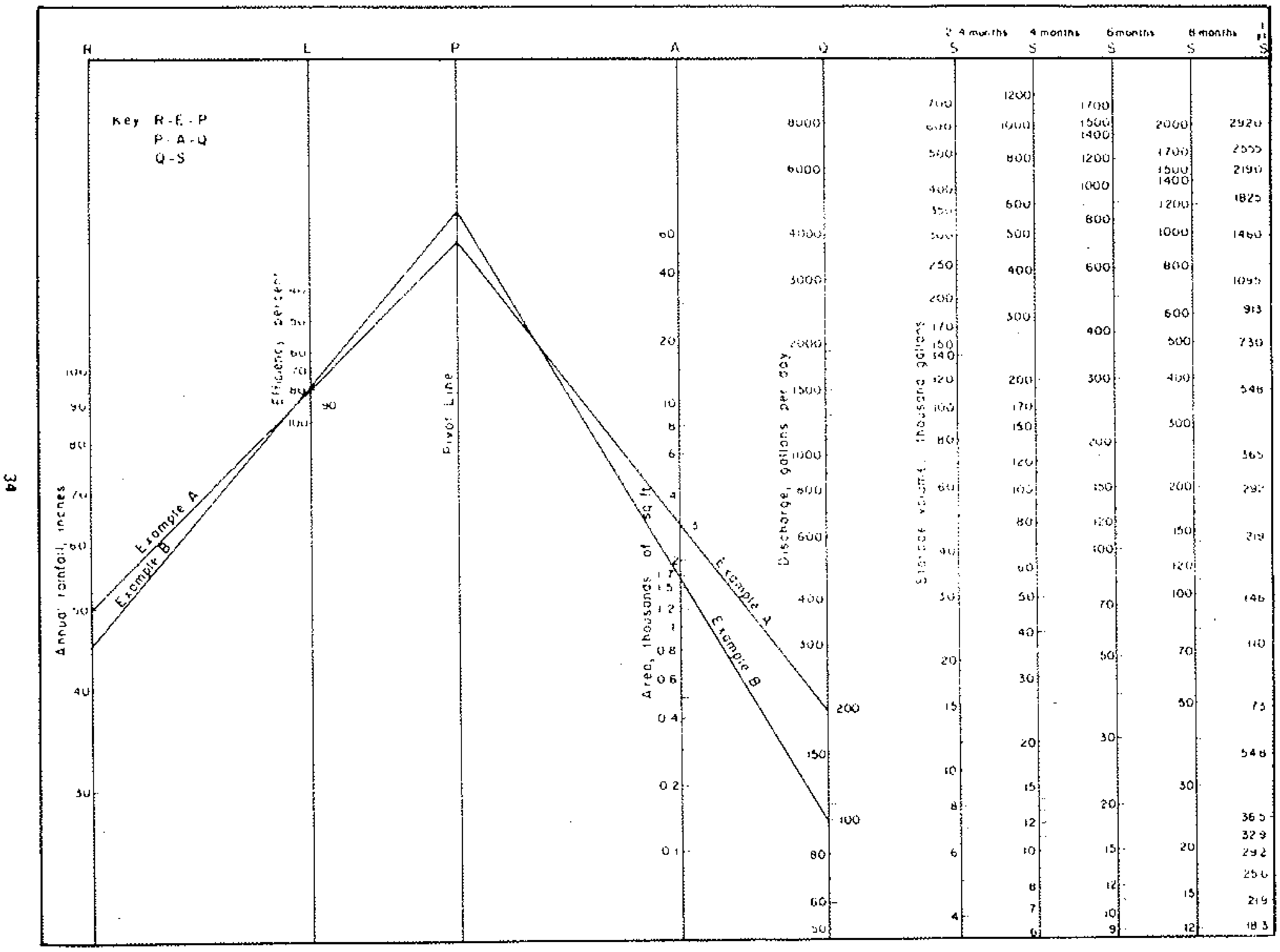

Figure 5. Nomograph of Rainfall and Runoff from Catchments
(From: Cosner, 1972)

Methods utilized to determine the amount of rainfall that may be harvested from a purpose built catchment use essentially the same approach as those to determine runoff from other surfaces (Explained further below). Results obtained are often expressed in nomographs (Figure 5) or design curves (Figure 6).

Cisterns are required by law in the Virgin Islands and sizing requirements are presented in the table below.

Table 1. Cistern Sizing Requirements in the Virgin Islands

Type of Structure	Required Cistern Size*
Single story dwelling	10
Multi-story dwelling	15
Churches and warehouses	4.5
Other buildings	Exempted

* gallons per square foot of roof area

In St. Thomas, rainfall harvesting satisfies 20% of the daily potable water demands and in St. Croix and St. John 13% and 75% of the respective demands are satisfied by rainfall harvesting.

Surface Water

During a rainfall event, certain abstractions occur before there is any direct runoff from the ground surface. These initial abstractions include interception storage by the covering vegetation and depression storage due to surface unevenness. A schematic representation of this process is presented in Figure 7. Because of the mountainous relief and high evaporation rates, surface water in the Virgin Islands is very limited. Streams are for the most

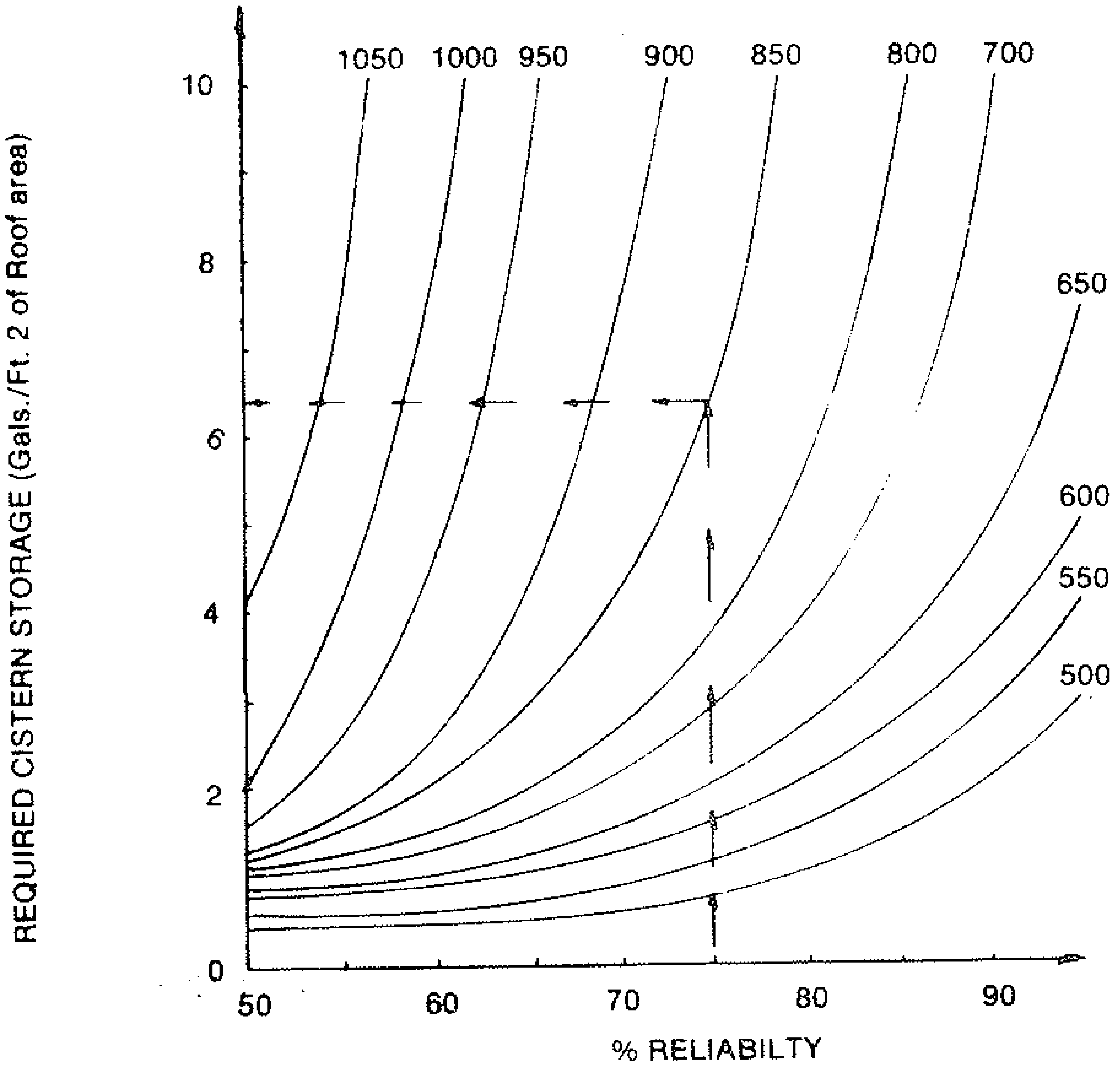

Figure 6. Cistern Sizing Curves for Sprat Hole, St. Croix (From Smith, 1981)

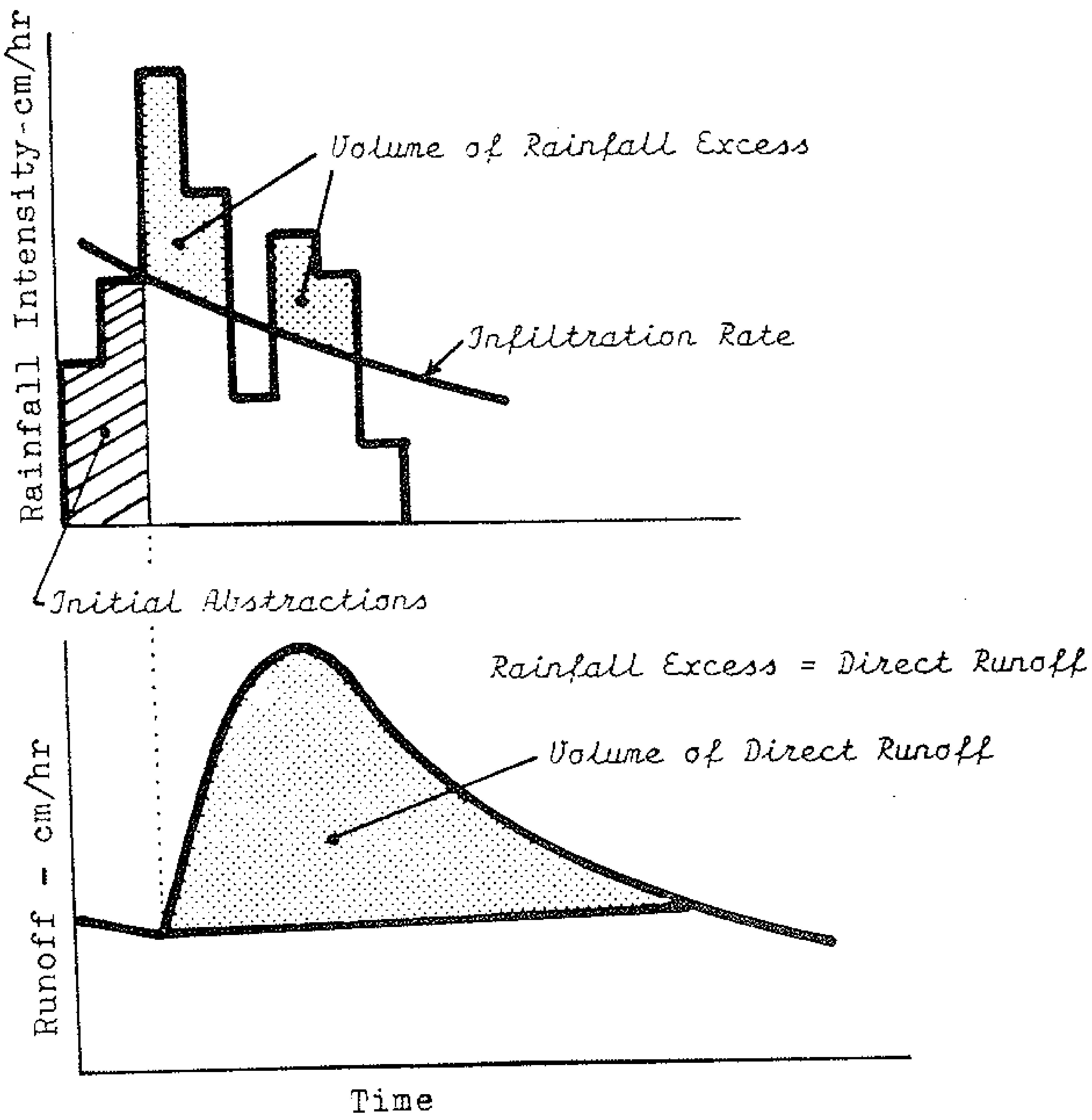

Figure 7. Relationship of Rainfall, Runoff, Infiltration and Initial Abstractions
(From: Schulz, 1978)

part ephemeral - they go dry during periods of little or no rain. Steep slopes and clayey soils lead to rapid runoff.

Several methods are used to estimate discharge of water from an area. For the most part they are all based on the rational formula

$$Q = ciA$$

where Q is the discharge in cubic feet per second (cfs), c is a runoff coefficient, i is the rainfall intensity in inches per hour and A is the watershed area in acres.

While the rational method provides an easily computed estimate of discharge from an area, there are certain factors associated with its use that must be considered. Most importantly, results obtained are greatly influenced by the size of the watershed being considered. Both the rainfall intensity and the runoff coefficient can be expected to vary as the size of the area increases. Values used in the formula then should be an average value and thus the estimated discharge is significant only as an estimate for the whole area and results should not be used to approximate conditions for a smaller area in the watershed. A commonly used `Rule of Thumb' is that the rational method should not be used for watersheds greater that 200 acres or where there is a great variation in the value of the runoff coefficient.

Runoff from an area may also be be calculated using methods suggested by the Soil Conseravtion Service and described in a publication popularly referred to as Technical

Bulletin No. 55. This method depends principally on the use of runoff curve numbers. Runoff curve numbers for land use and treatment practices for hydrologic soil groups were developed from daily rainfall records for small agricultural watersheds. By using land use patterns found in various areas and accounting for the impervious areas, a weighted curve number representing runoff potential for the watershed can be determined. When only some sections of the watershed is urbanized, peak discharge downstream is determined through combining the component hydrographs and routing then to the outlet at the discharge point.

Flow discharge in an open channel may also be estimated using the Manning formula

$$Q = (1.49/n)AR^{(2/3)}S^{(1/2)}$$

where Q is the flow discharge in cubic feet per second, n is a roughness coefficient available from several handbooks, A is the cross-sectional area of the channel, R is its hydraulic radius and S is the slope.

While there are several small livestock ponds in the islands, Creque Dam on St. Croix is the only dam in the Virgin Islands constructed to serve for municipal supply. This dam was constructed by the U.S. Navy in 1920 and is a concrete arch dam with a design capacity of 9 million gallons. Creque Dam is 40 feet high and 200 feet long. It is presently not in use.

Steep slopes also make erosion a concern. Estimates can be made of the potential soil losses from these slopes using the universal soil loss equation

$$A = R\ K\ LS\ C\ P$$

where:

A = average annual soil loss (tons/acre)

R = rainfall factor expressing the soil erosion potential of average annual rainfall in the vicinity.

K = soil erodibility factor. The average soil loss per unit R and is a function of soil type and percent organic material. K ranges from 0.02 for sand with 4 percent organics to 0.60 for silt with less than 0.5 percent organics.

LS = a dimensionless topographic factor that represents the combined effects of slope length and steepness. For a slope length of 300 feet, LS varies from 0.18 for a 1 percent slope to 31 for a 50 percent slope.

C = cover and management factor. A ratio of the soil quantities eroded from land that is cropped under specific conditions to that which is eroded from clean tilled farrow under identical conditions. C ranges from 0.001 for a well managed woodland to 1.0 for tilled continuous fallow.

P = factor for supporting practice. No supporting practice, i.e. contouring or contour terracing, P = 1.0.

Use of this equation will give an estimate of soil erosion per year due to rill and sheet erosion but should not be used as an estimate of the sediment delivered to the channel since much of the eroded material will be redeposited before reaching the channel. To determine the amount of sediment reaching the channel, the sediment eroded is multilpied by a sediment delivery ratio factor which has been found to be a function of drainage basin area. Detailed discussion on this process can be found in the manual "Control of Water Pollution from Cropland" by W. C. Walton.

Groundwater

The process by which water sinks into the soil is known as infiltration. The rate of infiltration is dependent on the characteristics of the soil material and the type and density of the vegetation growing or lying on the soil surface. Because there are larger spaces between the grains, sandy soils tend to have higher infiltration rates than silty or clay loams which are fine grained.

As a soil becomes wetter during a rainfall event, the infiltration rate (measured in units of inches per hour) decreases. The first reason for this is that wetting of the soil causes granules of silt or clay to expand and close some of the pore spaces between granules. The second reason is that the film of water that surrounds each grain is more or less continuous and forms a three-dimensional network of interconnected viens of water. The liquid continues to flow downward through the network but encounters frictional resistance that increases as the depth of the network increases. The rate of downward movement is slowed with the increase in frictional resistance as the depth of wetting increases and thus the rate of entrance of new water from the surface is impeded.

Rainfall that enters the soil suffers from one of three fates:

a. It may evaporate directly from the soil
b. It may be transpired by vegetation
c. It may enter the saturated zone

In the upper strata of the soil, the openings are only partially filled with water. This zone of aeration is divided into three belts - the belt of soil water, the intermediate belt, and the capillary fringe. The belt of soil water furnishes most of the water for plant growth. The intermediate belt is principally a passage for water from the soil belt to the capillary fringe. The capillary fringe holds water above the zone of saturation by capillary force acting against the force of gravity. Phreatophytes, which grow without dependence upon the belt of soil water, get their water from the capillary fringe and the water table. In the saturated zone, the pores spaces are filled with water. The transition between these belts and zones is gradual and their thickness varies according to local geology, the availability of pores or openings in the formations, the recharge and movement of water within the zones from areas of recharge toward points or areas of discharge. The general subsurface distribution of water is illustrated in Figure 8.

In the Virgin Islands, soils are for the most part relatively shallow with high clay contents and cap a rock base. Groundwater recharge on an average amounts to 5% of the annual rainfall. The occurence of feasible extractable water is summarized in the following table.

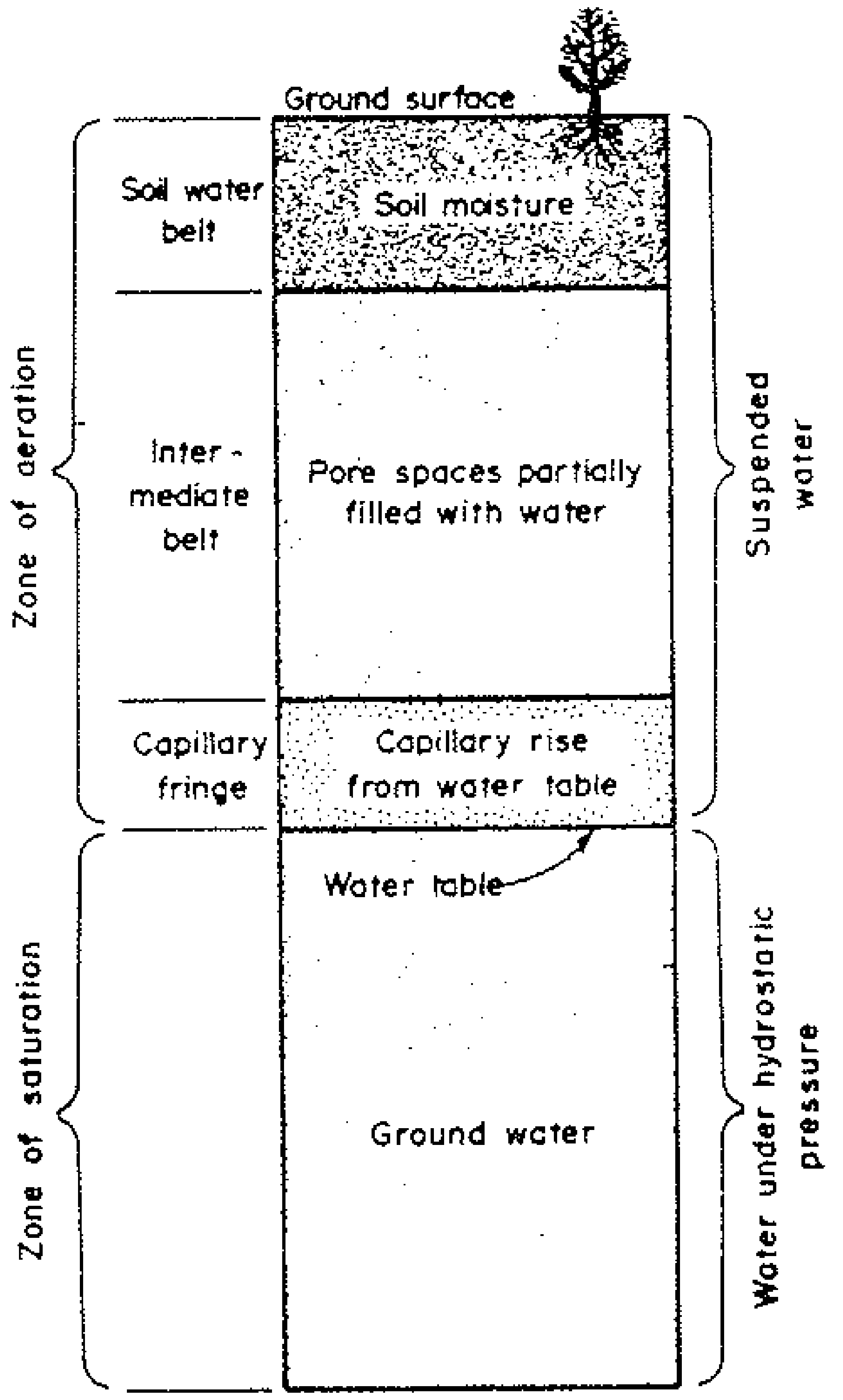

Figure 8: Subsurface Distribution of Water
(From: Johnson Division, UOP Inc., 1982)

Table 1. Estimated Yeild of Virgin Islands Aquifers

Aquifer Characteristics	Potential Yield *
Thin sand and gravel bed	10 - 30
Solution cavities	20 - 60
Fractured rock	2 - 5

* gallons per minute

It is useful to examine the definition of several of the terms most commonly used in discussions of groundwater. The <u>porosity</u> of a soil is the proportion of its volume not occupied by solid material. An <u>aquifer</u> is a water saturated geologic unit that will yield water to wells or springs at a sufficient rate so that the wells or springs can serve as practical sources of water supply. While porosity represents the amount of water an aquifer will hold, it does not indicate how much water the porous material will yield. The <u>specific yield</u> of a soil is the quantity of water that a unit volume of the material will give up when drained by gravity, while the corresponding volume retained is its <u>specific retention</u>. The capacity of a porous medium for transmitting water is its <u>permeability</u>. The rate at which water may be withdrawn from an aquifer without depleting the supply to such an extent that withdrawal at this rate is no longer feasible is the <u>safe yield</u>.

In their initial development, wells are tested by pumping under controlled and well monitored conditions to determine the productive capacity of the completed well and to provide data on which the selection of the pumping equipment to be used can be based (Refer to Figure 9). The

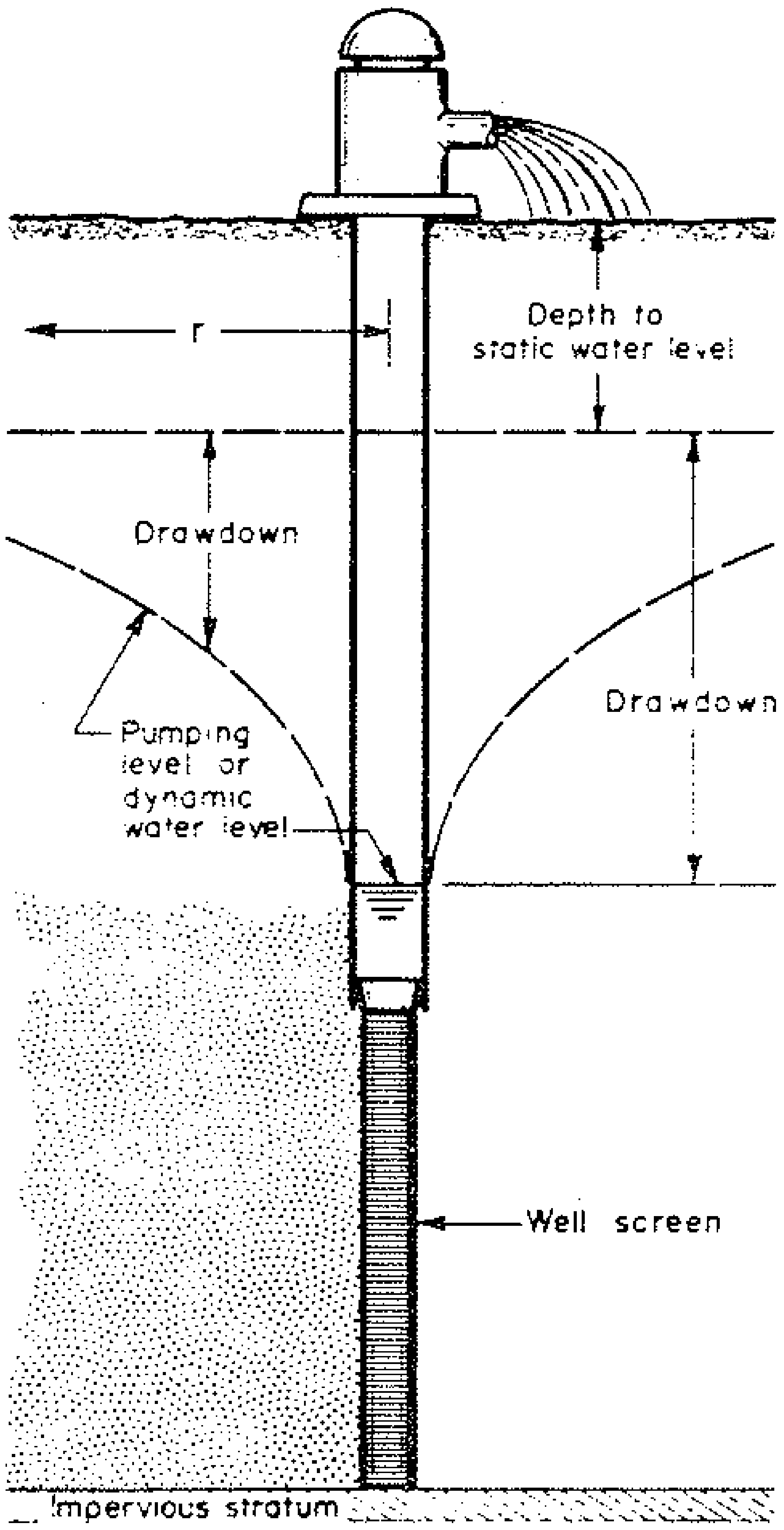

Figure 9. Measurements Related to Well Performance and Pumping Tests of Wells and Aquifers
(From: Johnson Division, UOP Inc., 1982)

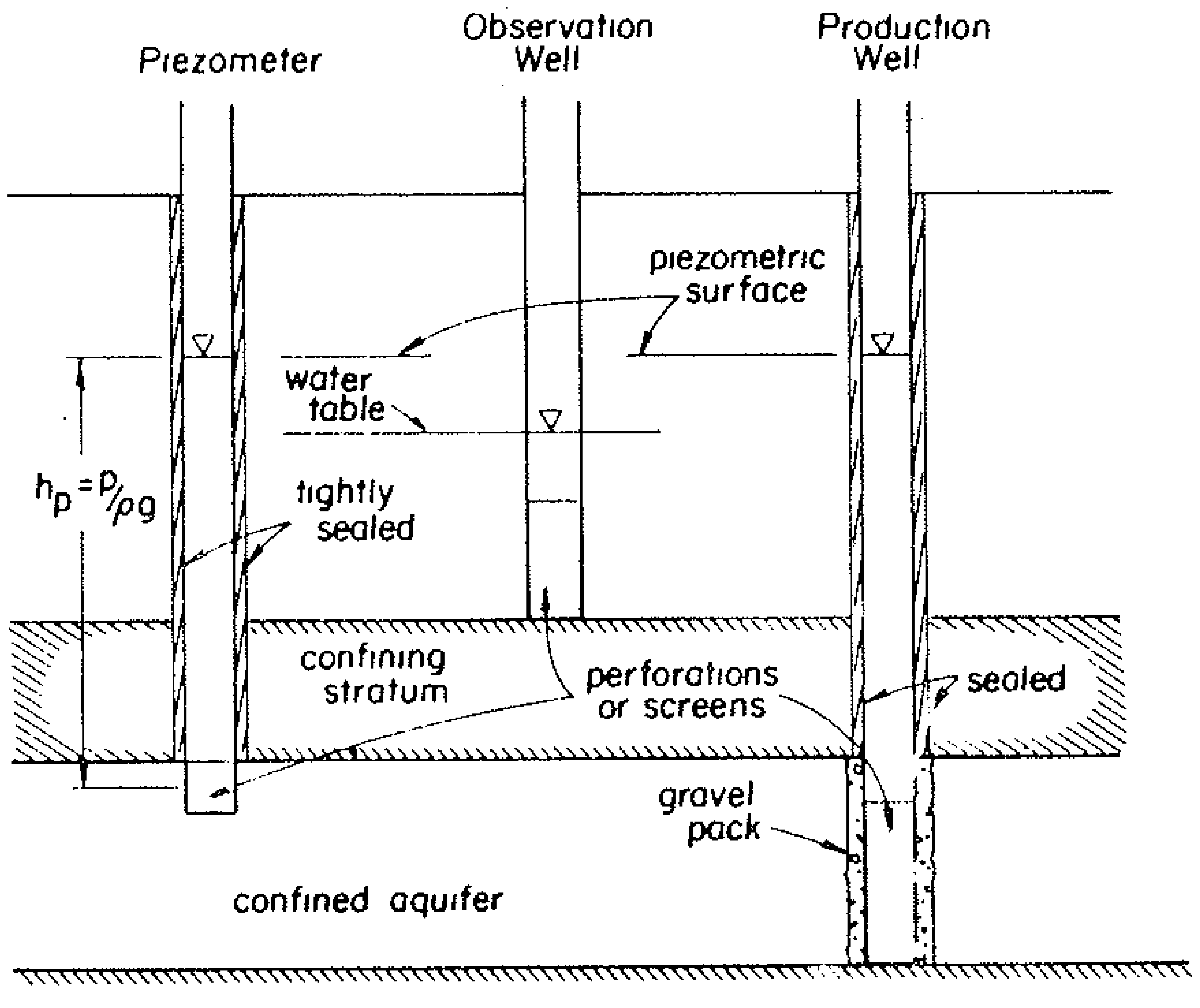

Figure 10. Common Facilities for Observing Water Levels in Aquifers
(From: McWorther and Sunada, 1981)

static level of the well is the level at which water stands in the well when no water is being removed from the aquifer. This level is normally expressed as the distance from the ground surface to the water level in the well. The pumping dynamic level is the level at which water stands in the well when pumping is in progress. When pumping stops, water in a well rises and approaches the static water level. At any particular time during this recovery period, the distance at which the water level is found is the residual drawdown. The volume of water per unit of time discharged from a well is the well yield. The yield of a well per unit of drawdown is known as the well's specific capacity.

Groundwater levels are commonly monitored by piezometers, observation wells and production wells. These are shown in Figure 10. A piezometer consists of a casing, perforated near the terminal point only, that is installed in such a way that the casing fits tightly against the geologic formation. The height to which water rises in the piezometer is the water-pressure head at the terminal point of the piezometer. The observation well is a perforated casing simply placed in a bore hole with no attempt to provide a seal in the aquifer. In installing the observation well, care is taken not to penetrate the underlying confined aquifer in order that the observation well properly indicates the position of the water table. The production well may penetrate any confined layers present and indicates an average water-pressure head.

Elementary Statistics in Hydrology

In hydrology a hydrologic variable is defined to be any variable which measures or defines the magnitude or quantity of some element in the hydrologic cycle. The mean is an estimate of the most likely observed value, the average. It is a measure of central tendency as are the median, mode and the weighted mean. The middle value of a set of observed values arranged in order of magnitude is the median while the mode is the value which occurs most commonly. The weighted mean is derived based on the association of weighting factors to the observed values. The mean (X_m) is computed as

$$X_m = \sum_{i=1}^{N} X_i \Big/ N$$

where N is the number of observations.

The standard deviation (S_X) is a measure of the dispersion of various values about the mean. It is computed as

$$S_X = \sqrt{\Sigma (X_i - X_M)^2 / N}$$

Since the mean was used in the equation above we would have a biased estimate of the standard deviation. When there are only a few observations or when there is a great variability in the values, the effect of this bias is great. The unbiased standard deviation is preferred and is calculated as

$$S_X = \sqrt{\Sigma (X_i - X_M)^2 \big/ N-1}$$

Multiplication of the biased estimate by the ratio

$$N / (N - 1)$$

will produce the unbiased standard deviation.

The <u>coefficient of variation</u> (C_v) is measure of the dispersion of a variable about the mean expressed in dimensionless units. It is calculated as

$$C_v = S_x / X_m$$

It is often desirable in hydrology to determine if there is some change (<u>trend</u>) in the value of observations over a period of time (<u>time series</u>). This may be difficult to observe because commonly there is a high variability and a large scale random variation about the mean value in most hydrologic time series. Variations may be seasonal or diurnal resulting in cyclic components in the long term record.

<u>Stationarity</u> in a hydrologic time series occurs when the statistical parameters (mean and variance) do not change with respect to the origin. <u>Nonstationarity</u> occurs when a trend or cyclic component is present. Nonstationarity also results when there is a sudden change in the hydrologic eco-system or in the method of observation or reduction of the data (<u>nonhomogeneity</u> or <u>inconsistency</u>).

One way to determine trends is by plotting the data on a scatter diagram as well as the mean of the full time record and observing if there any obvious trends. If a trend is suspected the data should be divided into two or three segments of equal length and the mean for each segment computed.

The moving mean is another method of determining trends. The mean is calculated for periods of consecutive data of equal length but with successively different starting points. While periods of different length may be used, in the analysis of precipitation records the five-year moving mean is usually satisfactory in damping out the effects of random variation. Use of the moving mean method to examine 80 years of annual precipitation data for the British Virgin Islands is illustrated in Figure 11.

Probability analysis may be used to determine the probability that an event may be equaled or exceeded in any year. The <u>return period</u> or recurrence interval is used to signify the average number of years within which a given event will be equaled or exceeded. The return period and the exceedence probability are reciprocals. To determine the return period the data is first ranked according to magnitude and assigned an order number (Table 3). The plotting position of the data is determined using a chosen plotting position formula. The one most commonly used is Weibull's

$$n = m / (n + 1)$$

where n is the number of years of record and m is the rank. The data and the corresponding exceedence probabilities may then be plotted on probability paper (Figure 12).

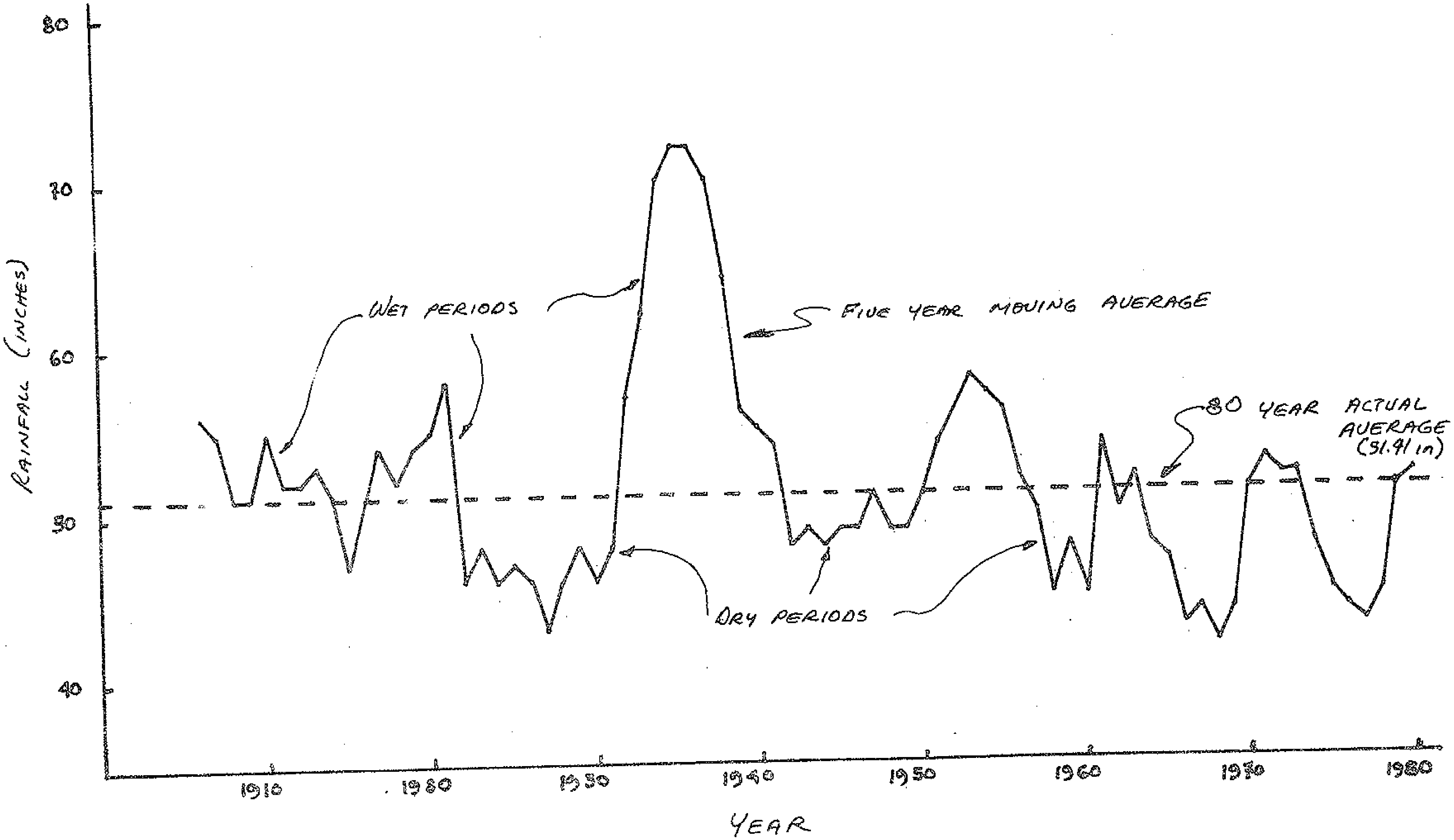

Figure 11. Use of 5-Year Moving Averages to Determine Wet and Dry Periods for the British Virgin Islands

Table 3. Determination of Return Periods and Exceedence Probabilities for the British Virgin Islands

YR	RAIN	ORDER	RET. PER.	EX. PR.
1933	94.26	1	81	1.23
1932	88.52	2	40.5	2.47
1931	75.03	3	27	3.7
1960	71.52	4	20.25	4.94
1909	70.64	5	16.2	6.17
1916	69.65	6	13.5	7.41
1969	67.11	7	11.57	8.64
1936	65.68	8	10.13	9.87
1927	63.63	9	9	11.11
1952	63.14	10	8.1	12.35
1915	63.04	11	7.36	13.59
1942	62.82	12	6.75	14.81
1979	62.77	13	6.23	16.05
1970	62.02	14	5.79	17.27
1958	60.88	15	5.4	18.52
1950	60.08	16	5.06	19.76
1905	59.28	17	4.76	21.01
1901	59.09	18	4.5	22.22
1949	58.96	19	4.26	23.47
1902	57.69	20	4.05	24.69
1951	56.42	21	3.86	25.91
1938	56.26	22	3.68	27.17
1937	56.25	23	3.52	28.41
1975	56.11	24	3.38	29.59
1974	55.41	25	3.24	30.86
1978	55.02	26	3.12	32.05
1924	55.01	27	3	33.33
1947	53.99	28	2.89	34.6
1911	53.85	29	2.79	35.84
1906	53.66	30	2.7	37.04
1908	53.57	31	2.61	38.31
1903	53.2	32	2.53	39.53
1934	52.81	33	2.45	40.82
1918	52.55	34	2.38	42.02
1928	51.82	35	2.31	43.29
1968	51.82	36	2.25	44.44
1954	51.8	37	2.19	45.66
1944	51.31	38	2.13	46.95
1966	51.09	39	2.08	48.08
1948	50.82	40	2.03	49.26

(Table 3 Continued)

YR	RAIN	ORDER	RET. PER.	EX. PR.
1922	50.72	41	1.98	50.51
1904	50.54	42	1.93	51.81
1919	50.36	43	1.88	53.19
1930	49.52	44	1.84	54.35
1943	48.98	45	1.8	55.56
1935	48.89	46	1.76	56.82
1965	48.38	47	1.72	58.14
1977	48.07	48	1.69	59.17
1962	47.85	49	1.65	60.61
1953	47.71	50	1.62	61.73
1914	46.58	51	1.59	62.89
1939	46.56	52	1.56	64.1
1912	46.41	53	1.53	65.36
1940	46.18	54	1.5	66.67
1921	45.95	55	1.47	68.03
1946	45.93	56	1.45	68.97
1956	45.23	57	1.42	70.42
1945	44.09	58	1.4	71.43
1955	43.31	59	1.37	72.99
1913	43.28	60	1.35	74.07
1929	43.25	61	1.33	75.19
1971	42.87	62	1.31	76.34
1963	42.65	63	1.29	77.52
1910	42.4	64	1.27	78.74
1920	42.11	65	1.25	80
1961	41.98	66	1.23	81.3
1923	39.93	67	1.21	82.64
1976	38.89	68	1.19	84.03
1917	38.5	69	1.17	85.47
1925	38.39	70	1.16	86.21
1907	38.26	71	1.14	87.72
1959	37.76	72	1.13	88.5
1957	36.8	73	1.11	90.09
1980	36.33	74	1.09	91.74
1972	35.56	75	1.08	92.59
1941	35.47	76	1.07	93.46
1967	34.82	77	1.05	95.24
1964	31.75	78	1.04	96.15
1926	31.01	79	1.03	97.09
1973	30.66	80	1.01	99.01

MEAN RAINFALL: 51.41 STD. DEV.: 11.81

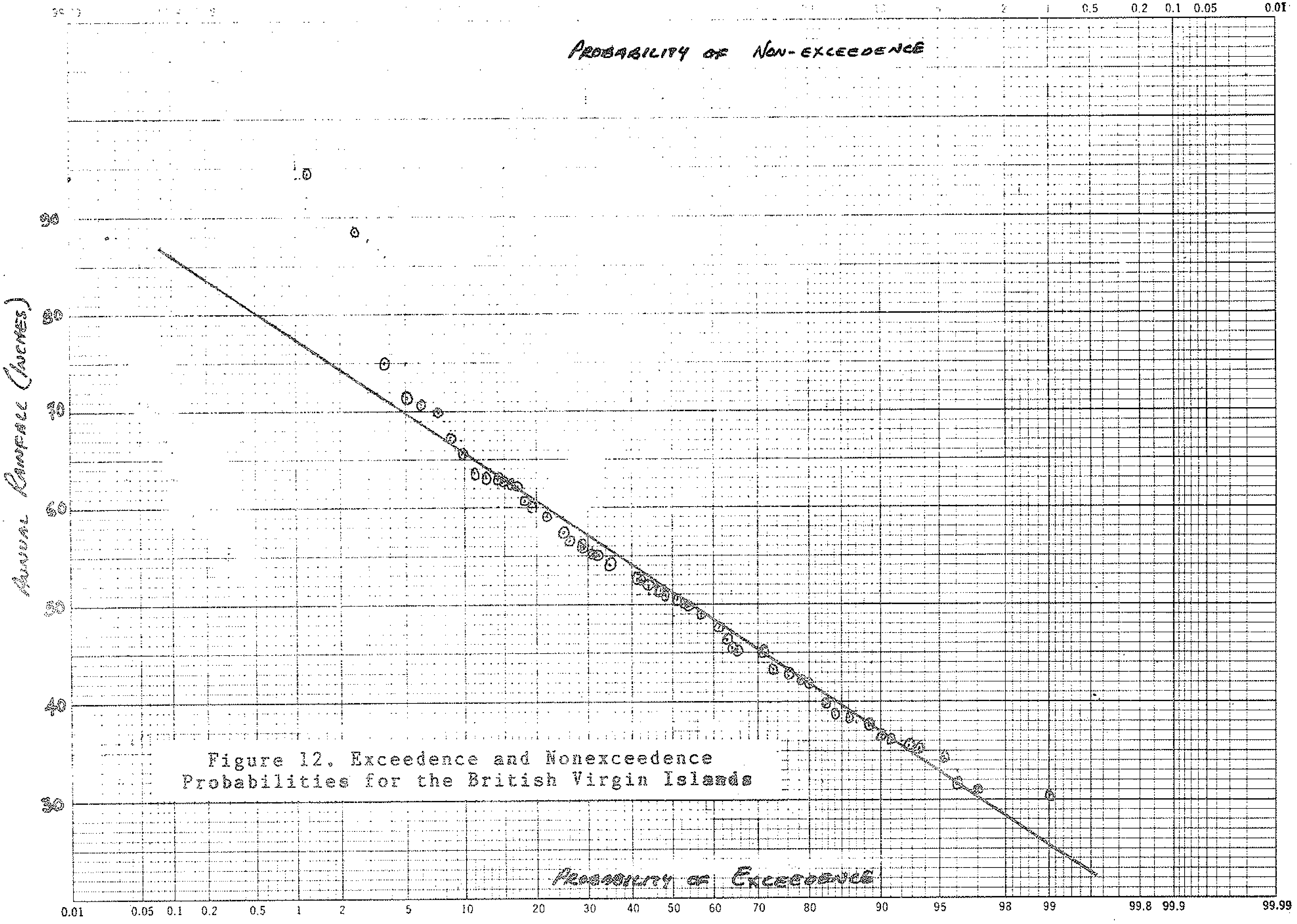

Figure 12. Exceedence and Nonexceedence Probabilities for the British Virgin Islands

Conclusion

The basics of hydrology relevant to the Virgin Islands were presented. While this examination was not exhaustive, it is expected to serve as an overview and source of general information to persons with interest in the development and management of our critical water resources. A list of suggested readings is included for use if more detailed discussions are required.

Useful References

Ajayi, O. and Smith, H. H. 1981. Compendium of Water Resources Data for the U. S. Virgin Islands. Technical Report No. 12, Caribbean Research Institute, College of the Virgin Islands, St.Thomas, Virgin Islands.

Bowden, M. J., et. al. 1970. Climate, Water Balance and Climatic Change in the North-West Virgin Islands. Caribbean Research Institute, College of the Virgin Islands, St. Thomas, Virgin Islands.

Chow, V. T.(ed.) 1964. Handbook of Applied Hydrology - A Compendium of Water-resources Technology. McGraw-Hill, New York.

Cosner, Oliver J. 1972. "Water in St. John, United States Virgin Islands." United States Geological Survey, Caribbean District Open-File Report.

Davis, S. N. and DeWiest, R. J. M. 1966. Hydrogeology. John Wiley & Sons, New York.

Fisher, D. W. and Jordan, D. G. 1977. "Relation of Bulk Precipitation and Evapotranspiration to Water Quality and Water Resources, St. Thomas, Virgin Islands." U. S. Geological Survey, Caribbean District Open File Report.

Hem, J. D. 1970. Study and Interpretation of the Chemical Characteristics of Natural Water. U. S. Geological Survey Water Supply Paper 1973.

Hydrology Subcommittee 1982. Guidelines for Determining Flood Flow Frequency, Bulletin #17B. U. S. Geological Survey, Reston, Virginia.

Johnson Division, UOP Inc. 1982. Ground Water and Wells. Saint Paul, Minnesota.

Jordan, D. G. 1972. "Land-Use Effect on the Water Regimen of the Virgin Islands." U. S. Geological Survey Professional Paper 800-D.

Jordan, D. G. and Cosner, O. J. 1973. "A Survey of the Water Resources of St. Thomas, Virgin Islands." U. S. Geological Survey, Caribbean District Open File Report.

Jordan, D. G. 1975. "A Survey of the Water Resources of St. Croix, Virgin Islands." United States Geological Survey, Caribbean District Open-File Report.

Linsley, R. K. et. al. 1975. Hydrology for Engineers. McGraw-Hill, New York.

McWhorter, D. and Sunada, D. K. 1981. Ground-Water Hydrology and Hydraulics. Water Resources Publications, Fort Collins, Colorado.

Office of Water Research and Technology, "The A-B-C of Desalting" U. S. Department of the Interior, Washington, D.C.

Peebles, R. W. et. al. 1979. Waterplan: A Comprehensive Water Management Framework for the U. S. Virgin Islands. Technical Report No. 2, Caribbean Research Institute, College of the Virgin Islands, St.Thomas, Virgin Islands.

Rivera, L. H. et. al. 1970. Soil Survey, Virgin Islands of the United States. Soil Conservation Service, Washington, D.C.

Rivera, L. W. et. al. 1966. Soils and Their Interpretations for Various Uses - St. Thomas and St. John, American Virgin Islands." Soil Conservation Service, Washington, D.C.

Robinson, T. M. 1972. "Ground Water in Central St. Croix, United States Virgin Islands." U. S. Geological Survey, Caribbean District Open File Report.

Robinson, T. M. et. al. 1973. "Water Records of the United States Virgin Islands." U. S. Geological Survey, Caribbean District Open File Report.

Sanders, T. G.(ed.) 1980. Hydrology for Transportation Engineers. U.S. Department of Transportation - Federal Highway Administration, FHWA-IP-80-1.

Schulz, E. F. 1978. Problems in Applied Hydrology. Water Resources Publications, Fort Collins, Colorado.

Science and Education Administration 1979. Field Manual for Research in Agricultural Hydrology. Agriculture Handbook Number 224, U. S. Department of Agriculture, Washington, D.C.

Smith, H. H., 1981. Effects of Various Factors on the Sizing of Rain Water Cistern Systems. Technical Report No. 19, Caribbean Research Institute, College of the Virgin Islands, St.Thomas, Virgin Islands.

Smith, H. H.(ed.) 1984. Proceedings of the Second International Conference on Rain Water Cistern Systems. Caribbean Research Institute, College of the Virgin Islands, St.Thomas, Virgin Islands.

Smith, H. H. and Ajayi, O. 1981. Land Use, Runoff,and Recharge on Selected Watersheds in the U. S. Virgin Islands. Technical Report No. 13, Caribbean Research Institute, College of the Virgin Islands, St.Thomas, Virgin Islands.

Soil Conservation Service . Urban Hydrology for Small Watersheds, Technical Release No. 55. U. S. Department of Agriculture.

Torres-Sierra, H. and Dacosta, R. 1984. Technical Report No. 21, Caribbean Research Institute, College of the Virgin Islands, St.Thomas, Virgin Islands.

Walton, W. C. 1970. Groundwater Resource Evaluation. McGraw-Hill, New York.

Yevjevich, V. 1972. Probability and Statistics in Hydrology. Water Resources Publications, Fort Collins, Colorado.