PROCEEDINGS OF

UNIVERSITY SEMINAR ON POLLUTION AND WATER RESOURCES

COLUMBIA UNIVERSITY

Volume V: 1971–1972

Second Edition (1980)

PROCEEDINGS OF

UNIVERSITY SEMINAR ON POLLUTION AND WATER RESOURCES

Volume V 1971-1972

Second Edition (1980)

Edited by

George J. Halasi-Kun

and

Kemble Widmer

COLUMBIA UNIVERSITY

in cooperation with

U.S. DEPARTMENT OF THE INTERIOR,
GEOLOGICAL SURVEY

The New Jersey Department of Environmental Protection Bureau of Geology & Topography

BULLETIN 72 - D

PREFACE

Over two-thirds of the earth's surface is covered with water but only a fraction of it is suitable for immediate consumption and this fraction is endangered by pollution through our growing urbanization and industrialization. Therefore, it is of utmost importance to watch and improve our water quality. With the help of our modern technology, we should introduce standards which will insure that there will be a return in the form of clean water through the investment of vast sums of money being spent for surface water and groundwater research including pollution control, water purification and flood management not only inland but also in the ocean.

New Jersey is the most densely populated State in the Union. Because of the great importance of the water management in allocation of available water, the State of New Jersey is encouraging and supporting all efforts in achieving these goals. The University Seminar on Pollution and Water Resources with its interdisciplinary character has an ambitious program exploring the problems of utilization of the usable water resources and improving its quality. The results of the effort are presented in these Proceedings.

David J. Bardin, Commissioner
New Jersey Department of
Environmental Protection

CONTENTS

Volume V: 1971–1972

INTRODUCTION

Water is something usually taken for granted. In recent years, increased demands for clean water and impurity of the available one, stimulated development of water supply from new sources by various means. Inevitably, the complexity of the development, the variety of the problems and the wealth of alternates to meet these demands necessitated quite often an interdisciplinary approach which is the aim of our Seminar.

The fifth academic year was distinguished in emphasizing the interdisciplinary and international character of the Seminar and in consolidating its program and membership list. Besides the regular meetings and meetings in Ocean Engineering, the Seminar participated on the "Annual December Meeting in Washington, D. C." with the World Bank as host in both academic years. These December meetings became traditional yearly reviews of the world situation in water resources planning including financing.

The Seminar also organized several international conferences on water resources or participated in them. On June 6–12, 1971 in Paris, France, the Water Resources Section of the International Congress of Civil Engineers of France, sponsored by UNESCO, was initiated and the Seminar participated in it with one speaker.

On September 11–16, 1972 in Ft. Collins, Col. the Second International Symposium in Hydrology at Colorado State University was held and two papers were delivered by our Seminar members.

In Spring 1972 "The Encyclopedia of Geochemistry and Environmental Science", New York: Van Nostrand Reinhold Co., was published. The Seminar took part in this undertaking by ten of its members, the editor Rhodes W. Fairbridge included, by contributing almost 20 percent to its 1300 pages content.

Finally, the editors of the proceedings wish to express their appreciation to all members contributing articles and lectures to foster the Seminar. Their valuable contribution and unselfish dedication produced this volume of the Proceedings. The publication was made possible only by the generous help and cooperation of the U.S. Department of the Interior and the State of New Jersey, Department of Environmental Protection. In addition to the articles of local, interstate and international interest on pollution and water resources, they also include the first results of research activities on hydrology of smaller watersheds and their application in New Jersey. This research started as a joint program with the Technical University Brunswick, West Germany and echoed a great interest at various local, State and international forums.

George J. Halasi-Kun
Chairman of the University Seminar
on Pollution and Water Resources
Columbia University

LOW FLOW HYDROLOGY OF AUSTRALIAN STREAMS

T. A. McMahon[1]

[1] Dr. McMahon is Associate Professor, Department of Civil Engineering, Monash University, Clayton, Victoria, Australia.

INTRODUCTION

In terms of rainfall or streamflow, Australia is the driest continent. In addition, its streams are generally more variable than those observed elsewhere. The purpose of this review is to examine this latter observation and to relate variability of Australian streams to other low flow characteristics. Where possible, comparisons are made with Northern Hemisphere rivers.

Flow characteristics are defined in terms of variability, persistence and yield. Variability is characterized both by the coefficient of variation as well as the shape of the streamflow distribution, expressed through the coefficient of skewness. Persistence – the effect of a previous flow on the present flow – is measured by serial correlation. Catchment yield, which encompasses the overall effects of all these factors, is the required reservoir capacity expressed as a ratio of the mean flow for given releases from the reservoir. Another measure of yield which is examined is the monthly flow equalled or exceeded 90 percent of the time. All these characteristics and their interrelationships are dealt with herein under the headings given in figure 1.

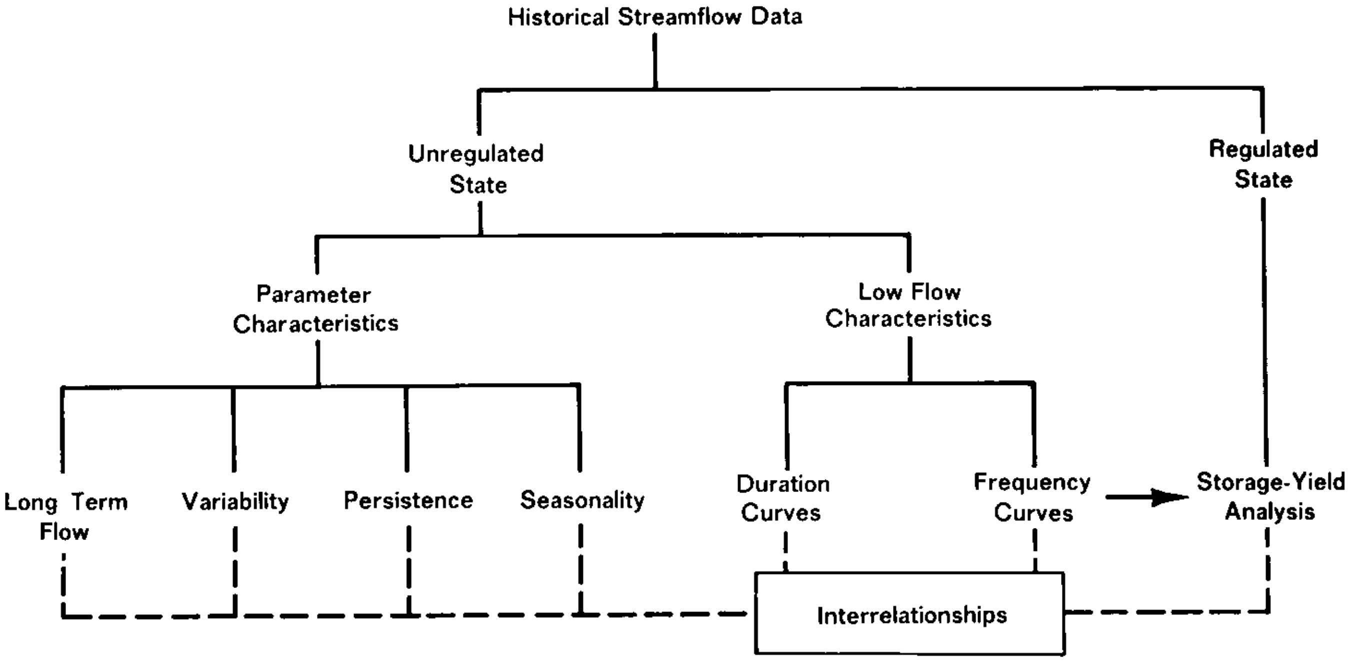

Figure 1.—Analysis for characterizing low flow hydrology.

STREAMFLOW DATA

The major drainage divisions in Australia are shown in figure 2. In the largest of these – the Western Plateau – the drainage is uncoordinated and ungauged but runoff is believed to be minimal. The gauged proportions in the other drainage basins vary from 3 percent to 76 percent. Full details can be found in an Australian Department of National Development publication (1965).

At December 1969, there were 3,047 streamgauging stations in Australia (Department of National Development, 1971), of which about 2,275 were current. Of those with more than 15 years of data, 93 percent were located in the North-east, South-east, Tasmanian and Murray-Darling drainage basins, which cover only 25 percent of Australia's surface area.

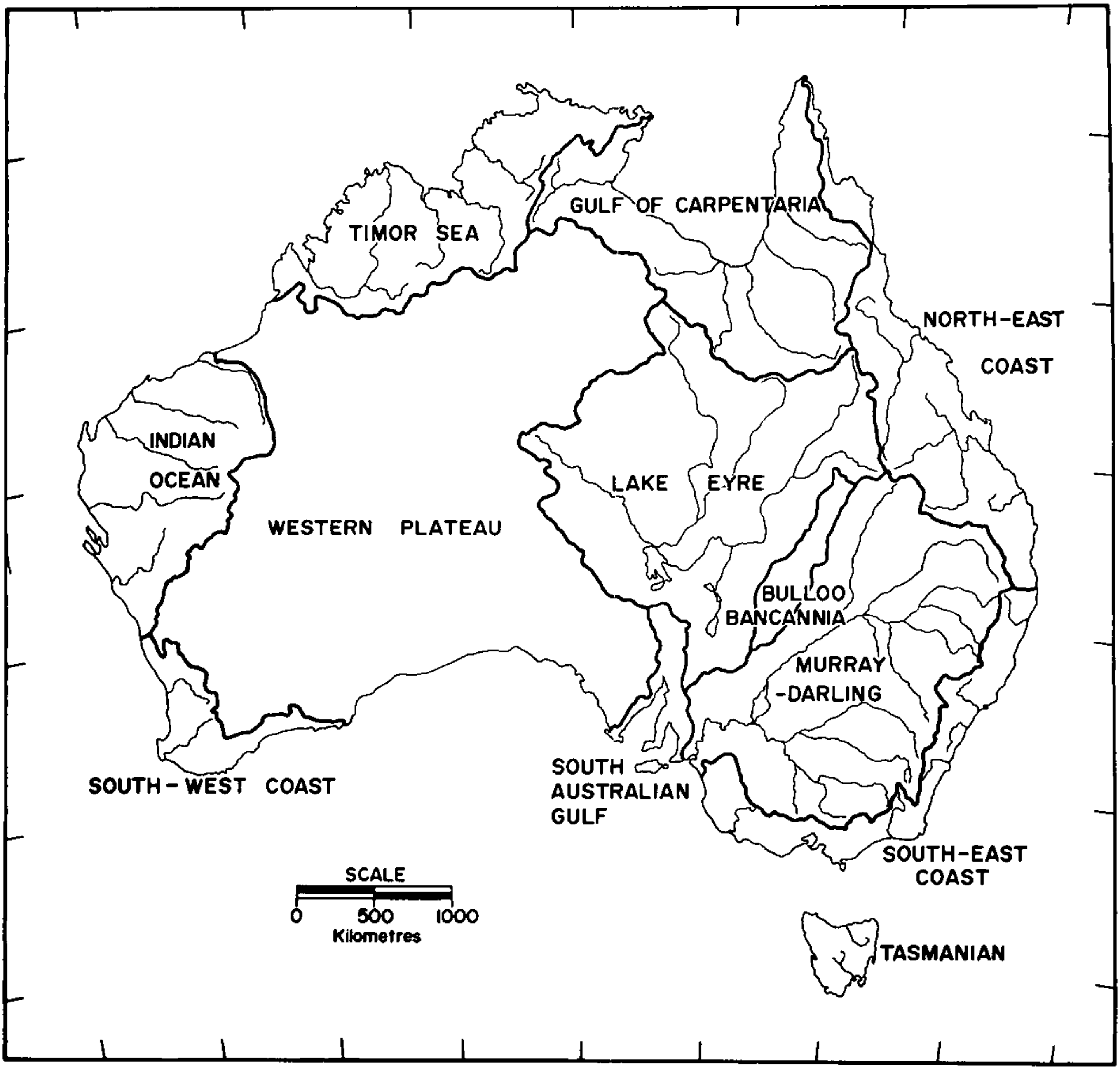

Figure 2.—–Major drainage divisions in Australia.

Within this framework, 156 catchments covering a wide range of conditions were chosen for quantitatively assessing the low flow characteristics of Australian streams. The locations of the catchments in relation to the general rainfall patterns as defined in table 1 are shown in figure 3. The rainfall zones are extracted from a map produced by the Department of National Development (1969). Catchment areas and record lengths are given in table 2. Streamflows used in the study either were not significantly affected by regulation or were adjusted to represent natural conditions. Ninety five percent of the data was measured, the remainder being estimated by correlation techniques.

Table 1.—*Classification of Climatic Zones*

Symbol in figure 3	Description	Median annual rainfall (mm)
LS	Low Summer	380 – 635
MS	Medium Summer	635 – 1,400
HS	High Summer	> 1,400
LU	Low Uniform	254 – 508
MU	Medium Uniform	508 – 890
HU	High Uniform	> 890
LW	Low Winter	254 – 508
MW	Medium Winter	508 – 890
HW	High Winter	> 890
AZ	Arid Zone	> 254 in uniform and winter areas > 380 in summer areas

A winter rainfall area is one where the ratio

$$\frac{\text{median rainfall May to October}}{\text{median rainfall November to April}}$$

is greater than 1.4.

A summer rainfall area is one where the ratio

$$\frac{\text{median rainfall November to April}}{\text{median rainfall May to October}}$$

is greater than 1.4.

A uniform seasonal rainfall area is one where neither of the above ratios are greater than 1.4.

(Extracted from Department of National Development, 1969.)

Table 2.—*Catchment Areas and Record Lengths*

Area (km^2)	Record length (years)							
	10–19	20–29	30–39	40–49	50–59	60–69	70–79	Total
< 10		2						2
10 < 20		2			1			3
20 < 50	1	5	3					9
50 < 100	2	7		1	3			13
100 < 200	1	5	3	3	3	1		16
200 < 500	3	8	10	5	4		4	34
500 < 1,000	3	8	5	5	2	2	1	26
1,000 < 2,000	1	9	2	4	3		1	20
2,000 < 5,000		4	4	1	3		2	14
5,000 < 10,000	1	1	3	3		1	2	11
10,000 < 20,000				2				2
20,000 < 50,000				1	1	1		3
> 50,000	1		1	1				3
Total:	13	51	31	26	20	5	10	156

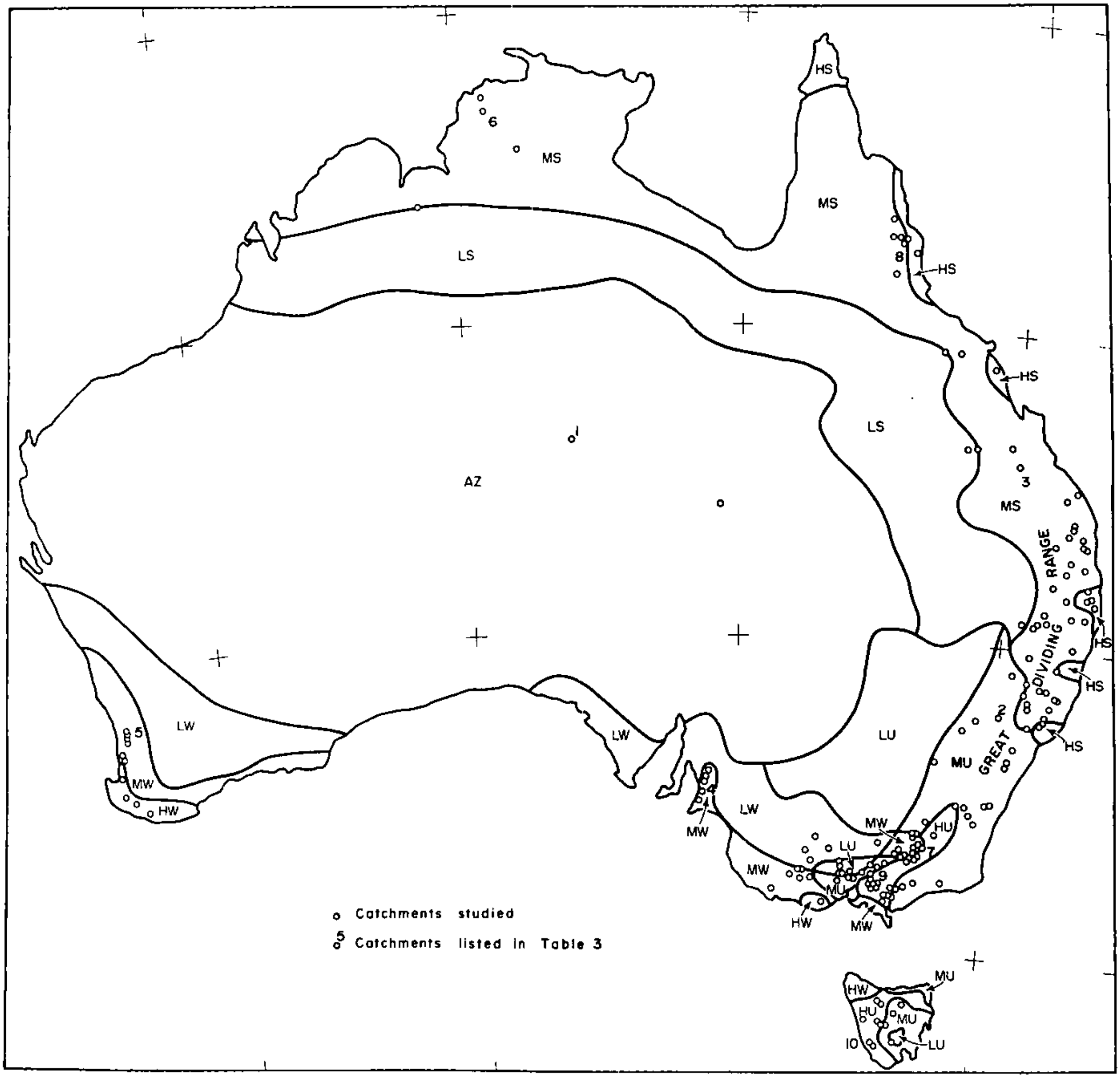

Figure 3.––Location of catchments and climatic zones.

HYDROLOGIC ANALYSES

Several analytical techniques were used to specify the flow characteristics. These are briefly outlined below.

The first relates to determining the parameters which define the flow distribution and its time series features. The mean was adopted as the measure of central tendency and was calculated from the annual historical data. For both annual and monthly data, three other statistics – flow variability, skewness of data and persistence – were computed. The parameters calculated were respectively the coefficient of variation, the coefficient of skewness and the lag one serial correlation. Any reference text, for example the *Handbook of Applied Hydrology* (Chow, 1964), gives details of these computations. Some typical results for ten selected Australian streams are given in table 3.

Variability was further examined by determining the maximum and minimum annual, monthly and seasonal flows and also the seasonal maximum coefficients of variation, skew and serial correlation. Again the magnitude of these characteristics is set out in table 3.

Flow duration curves are the second technique adopted. These are cumulative frequency curves that show the percentage of time which specified discharges were equalled or exceeded during the period of record. The low flow portion of the curve is an index of the amount of groundwater being contributed to streamflow from natural catchment storage. Flow values at 50 percent and 90 percent were used to examine this aspect. If the slope of the curve in the low flow portion is flat, groundwater contributions are significant. On the other hand, a steep curve indicates poor base flows and probable 'cease to flow' conditions. The 90 percent to 50 percent flow rate and the percentage of non-zero monthly flows are used to define these characteristics. The procedure for flow duration analysis is set out in Searcy (1959). Some results are given in table 3.

The third analytical tool adopted takes into account the fact that individual flow items are non-random and non-homogeneous.[2] Because of this, a flow duration curve should not be used to determine the probability of an event not being exceeded, as the probability is dependent on the preceding value and on the time of the year. However, a frequency curve can be interpreted as a probability curve because each item is unrelated and homogeneous.

Frequency computations were based on three duration periods, but only results of low flows for 36 months' duration and a 10 percent probability of occurrence are considered in this paper (table 3). The frequency values were found by computing the steady State distribution from the transition matrix of consecutive overlapping flow events. A similar approach was adopted by Joy (1970).

A reservoir storage capacity estimate by itself tells us little about the flow characteristics of the catchment or the stream used to obtain the estimate. If, however, the estimate is related to the mean flow, the magnitude of this ratio indicates the inability of the catchment to provide water without storage. This value is a function of flow variability and therefore related to physical and climatic catchment characteristics. In many ways, storage-yield estimates are the most useful measure of low flows as they take into account all the separate characteristics isolated by the other flow parameters.

In this analysis two procedures based on monthly flows were used to compute storage-yield values. The first procedure is commonly known as a behaviour or simulation analysis which is carried out by examining the changes in the stored content of a finite reservoir by adding inflow and subtracting releases from the water in store. Analysis was made assuming the reservoir to be first initially empty and then re-run for the situation in which the reservoir was assumed to be initially full. Probability of failure was expressed as the proportion of months that the storage is empty to the number of months of historical flow run through the storage.

The second procedure was based on Gould's solution (Gould, 1961) to Moran's steady state storage analysis (Moran, 1959). Using discrete time units, Moran set up a simple flow continuity equation of water in storage as follows:

$$Z_{t+1} = Z_t + X_t - Y_t$$

where Z_t, Z_{t+1} are the reservoir contents at the beginning and end of t^{th} discrete time period,
X_t is the inflow during the t^{th} time period, and
Y_t is the release during the t^{th} time period.

[2] Time homogeneity requires that identical events in a series are equally likely to occur at all times.

Table 3.—*Hydrologic characteristics of selected Australian streams*

	River (AWRC No.)	Lat. S Long. E °	′	Area (sq. km.)	Records (yrs.)	Mean annual runoff	Annual totals C_v	C_a	r	Max Mean	Min Mean	Monthly (seasonal) means Max Mean (month)	Min Mean (month)	Max C_v	Max C_a	Max r	Low flows $\frac{D_{90}}{D_{50}}$	$\frac{F^{10}_{36}}{F^{50}_{36}}$	Percent non-zero monthly flows	Storage 5% Prob. of failure (yrs.) Regulation 90%	50%
(1)	(2)	(3)		(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)
1	TODD (006009)	23 133	42 52	443	14	18	0.97	1.05	-0.14	2.7	0.07	4.1 (FEB)	0.01 (SEP)	3.7	3.7	0.70	0.00	0.63	28	3.30	0.79
2	GOULBURN (210006)	32 150	21 07	3,340	56	27	1.79	3.58	.18	9.7	.03	2.1 (FEB)	.49 (SEP)	4.1	7.3	.84	.16	.00	98	17.4	1.71
3	DON (130306)	24 150	06 04	6,860	27	44	1.36	2.02	.12	5.0	.01	4.8 (FEB)	.02 (SEP)	4.2	5.1	.96	.00	.00	70	11.9	1.73
4	TORRENS (504501)	34 138	51 44	347	72	145	.78	1.45	.02	3.9	.04	3.0 (AUG)	.05 (MAR)	2.1	6.2	.70	.11	.51	96	3.17	.54
5	WUNGONG CK. (615071)	32 116	12 04	132	60	214	.50	.64	.21	2.2	.08	2.8 (AUG)	.08 (MAR)	.8	1.6	.95	.14	.68	100	1.70	.24
6	ADELAIDE (817002)	13 131	14 07	632	17	325	.63	1.02	.06	2.4	.13	4.4 (FEB)	.01 (SEP)	2.3	3.9	.97	.05	.49	99	2.11	.40
7	SNOWY CK. (401210)	36 147	34 25	407	33	480	.54	1.27	.03	2.8	.33	2.0 (AUG)	.32 (FEB)	1.8	5.4	.88	.39	.85	100	1.71	.15
8	BARRON (110003)	17 145	16 33	220	43	622	.45	.27	-.01	2.0	.28	2.8 (MAR)	.24 (NOV)	1.8	5.6	.92	.37	.70	100	1.10	.17
9	WATTS (229129)	37 145	28 34	96	59	838	.32	.71	.16	1.7	.41	1.6 (AUG)	.41 (FEB)	.7	3.3	.76	.38	.73	100	.90	.06
10	GORDON (308007)	42 145	44 58	1,280	36	1,400	.24	-.08	.06	1.4	.58	1.5 (JUN)	.40 (JAN)	.9	1.6	.39	.25	.85	100	.40	.07

Symbols: C_v is the coefficient of variation

C_a is the coefficient of skewness

r is the coefficient of serial correlation

$\frac{D_{90}}{D_{50}}$ is the monthly flow equalled or exceeded 90% of the time divided by the 50% flow.

$\frac{F^{10}_{36}}{F^{50}_{36}}$ is the minimum expected flow of thirty six months' duration for a 10% probability of occurrence divided by the equivalent median flow.

By neglecting seasonality and serial correlation and dividing the reservoir and streamflow regimes into a number of equally sized zones, Moran obtained a system of equations and a transition matrix describing the cumulative probability of reservoir contents. The solution of these equations provided the steady state probability distribution of water in store. In Gould's technique, the transition matrix of storage contents is obtained by running each year of the historical record through a given storage size, a month at a time. Thus seasonality and monthly serial correlation are automatically taken into account. However, annual flows are assumed independent. By recording the starting zone, finishing zone and the number of failures, the transition matrix of storage contents and the conditional probabilities of failure within the year, subject to the reservoir contents at the start of the year, is built up. As applied by Gould, the conditional probabilities of failure were based on annual failures determined from monthly flows. This results in overestimation of the required storage size (Joy, 1970). In the procedure adopted here, the method is modified so that the conditional probabilities of failure are determined using monthly failures from monthly flows. Space precludes a detailed description of Gould's procedure. It is set down clearly in example form in Appendix I of the original paper (Gould, 1961).

Both storage procedures adopted herein have limitations. These are summarized below.

Aspect	*Behaviour Analyses*	*Gould Analysis*
1. Historical flows:	Based on historical sequencing of flows. If not representative of population sequences, then storage estimates will be atypical.	Procedure samples all yearly flows without reference to historical sequencing.
2. Annual serial correlation:	Taken into account.	Assumed zero (but results may be adjusted – however, correction factor is limited in range).
3. Initial condition of storage:	Assumed initially full or empty. (Sometimes empty case does not allow probability condition to be met).	Storage estimates are independent of initial condition.
4. Non-continuous flow record:	Results may be unreliable.	Results unaffected.

Because of these limitations in methodology, the two behaviour procedures and the Gould procedure were used to calculate storage estimates for a 5 percent probability of failure and for constant drafts or releases from the reservoir equivalent to 90 percent and 50 percent of the historical mean monthly flow. From these results, a 'best estimate' of storage was determined according to a set of guidelines which took into account the above factors. These are set out in detail in McMahon (1973).

MEAN ANNUAL RUNOFF

The starting point for any discussion about the hydrologic characteristics of streams is the mean flow. Figure 4 shows isolines of mean annual runoff. This is reproduced from the Atlas of Australian Resources (1967). By way of comparison, it has been estimated that mean annual runoff over Australia is about 40 mm compared with runoff of more than 320 mm over North America, 260 mm over Europe and 170 mm over Asia (Kalinin, 1971).

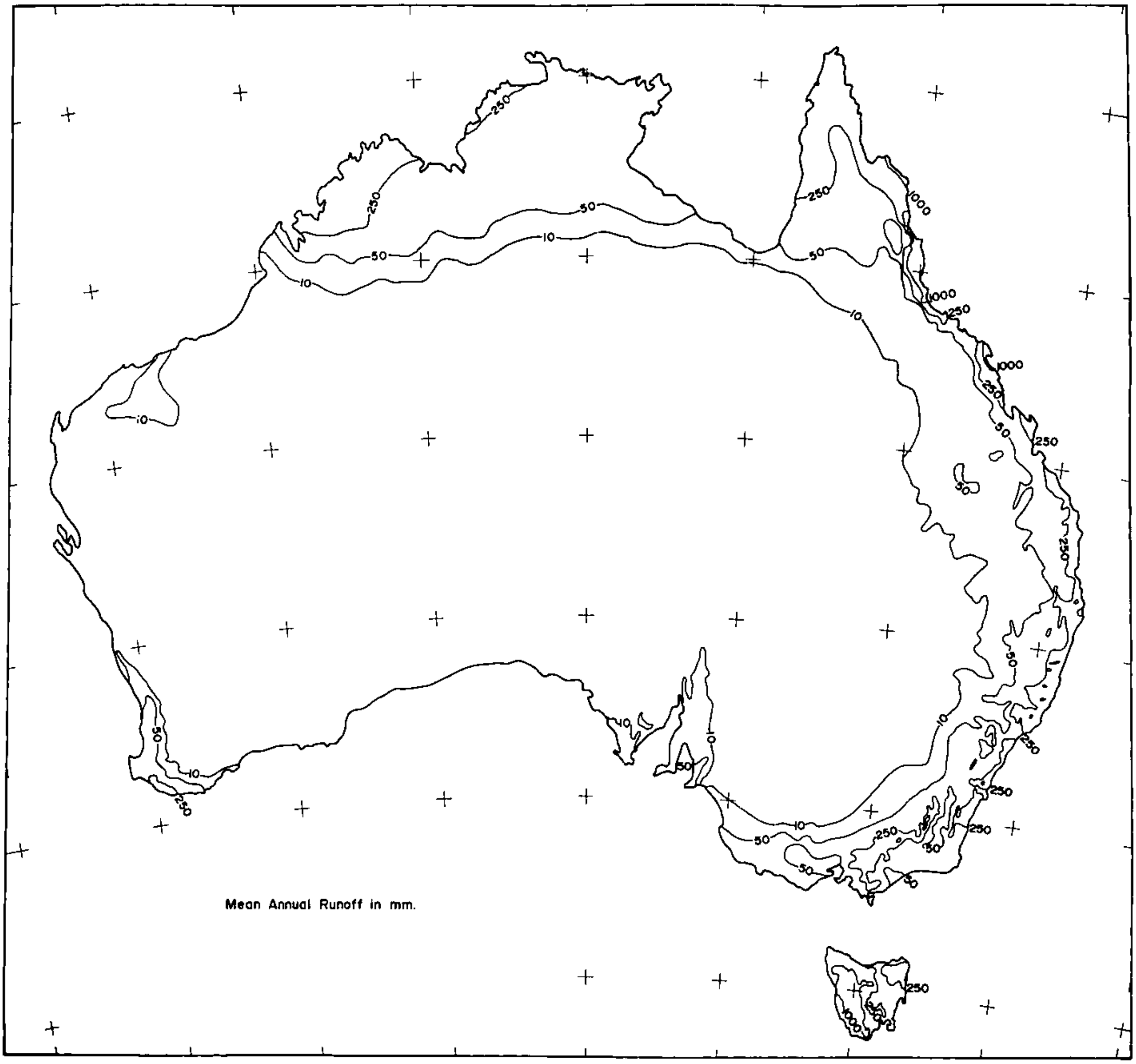

Figure 4.——Mean annual runoff.

One inadequacy with the catchments used in this study is that those located in the higher rainfall areas are relatively smaller in size than those located in the more arid regions. Although some of the hydrologic variables were found to be a function of catchment area, it is believed that the conclusions reached in the study are not affected by this.

VARIABILITY

A frequency histogram of the annual values of the coefficient of variation is given in figure 5, and their spatial distribution is shown in figure 6. Comparing this figure with figure 3, most variable

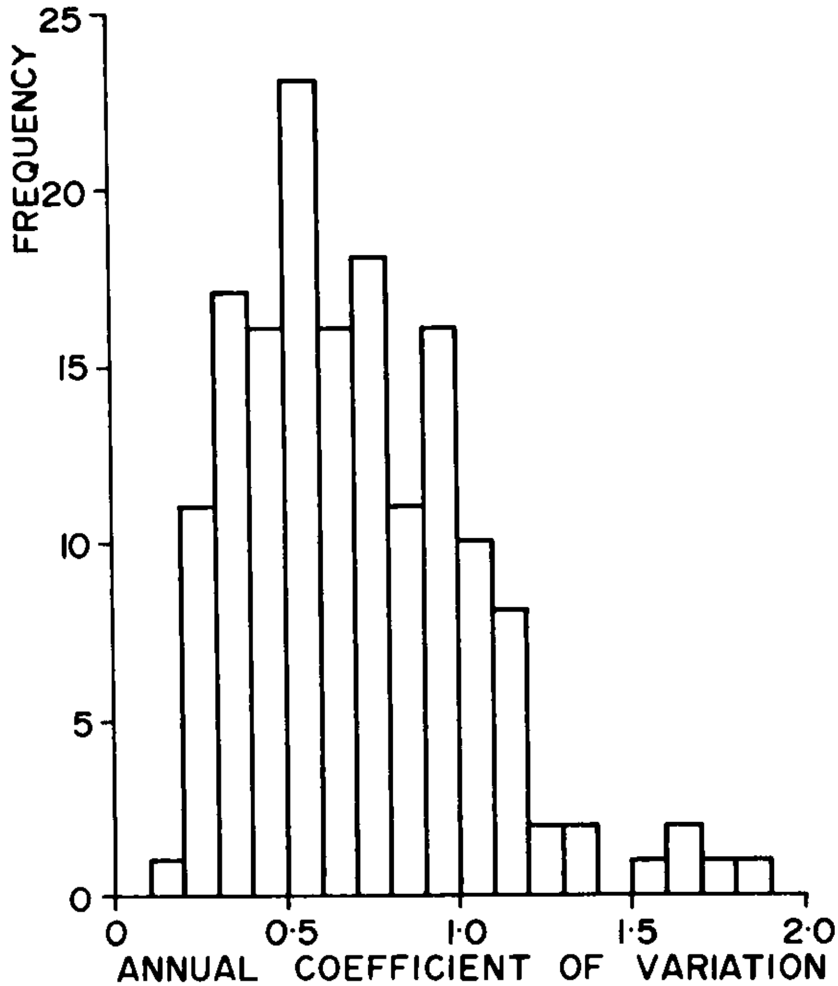

Figure 5.—–Histogram of annual coefficients of variation.

streams, those with values greater than 1.2, are located in the medium summer or uniform rainfall zone (MS or MU). The least variable streams are mainly found in the high uniform rainfall zone (HU).

The median value of the coefficient of variation for the 156 streams is 0.67. This contrasts with median values of 0.3, 0.2 and 0.2 for the North American continent, Europe and Asia respectively (data from Yevdjevich (1963) and Kalinin (1971)). Furthermore, of the streams sampled in the Northern Hemisphere, only 5 percent exhibit variability greater than the Australian median.

As a general rule areas of high rainfall yield more runoff and exhibit lower streamflow variability than low rainfall areas. It will be shown later that this general relationship holds for Australian catchments. However, with regard to the most variable Australian streams, it is observed that their headwaters are located on the slopes of the Great Dividing Range, they drain both inland and seaward, and are located in the medium summer or uniform rainfall climatic zones. In contrast, data from the catchments located in the arid or low winter zones indicates that they are not as variable.

Only recently have hydrologists accepted that the coefficient of skewness is a useful parameter in hydrologic analysis, particularly in data generation procedures. Annual values for the 156 streams

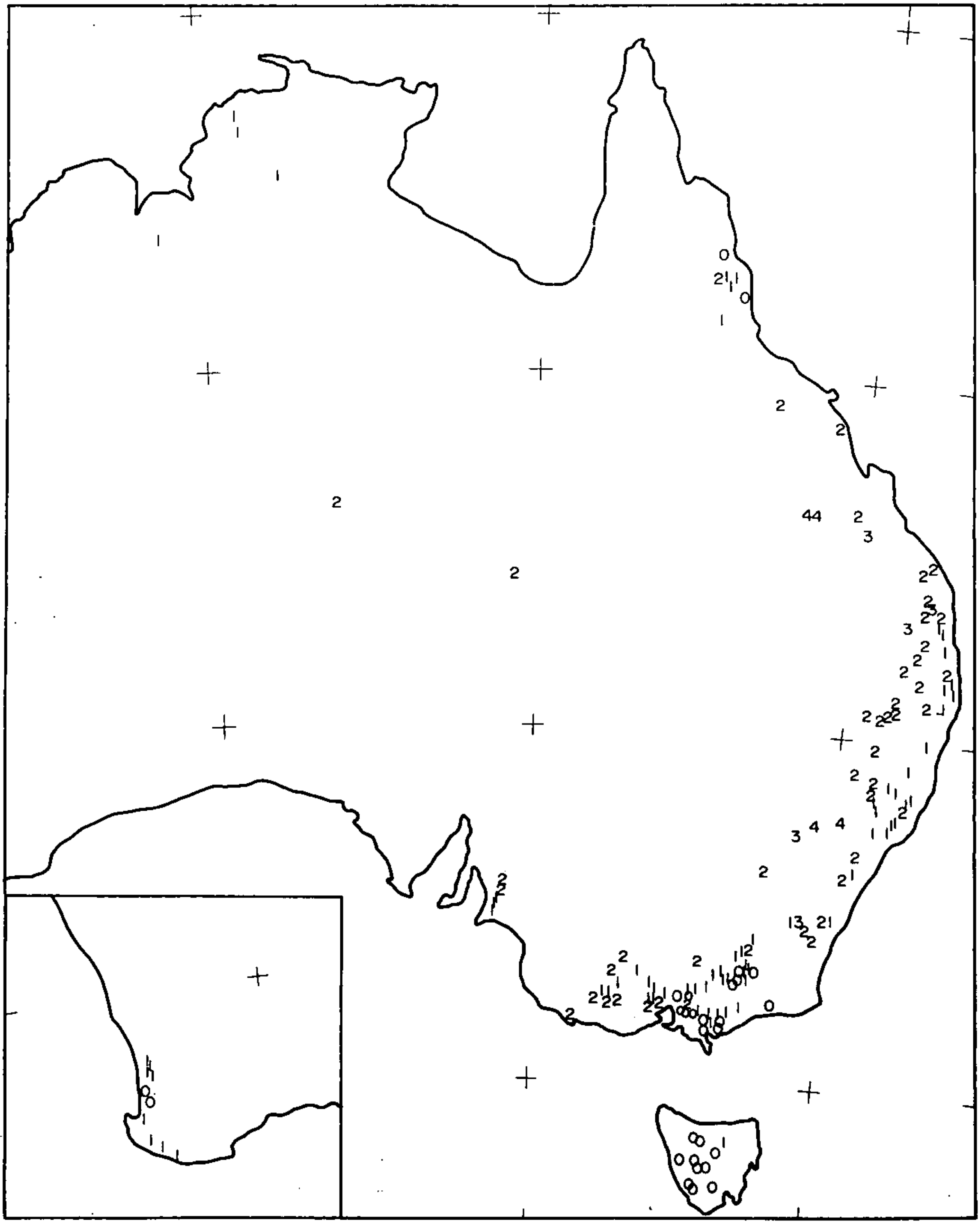

Figure 6.––Spatial variability of annual coefficients of variation (legend: 0 = 0 to 0.4; 1 = 0.4 to 0.8; 2 = 0.8 to 1.2; 3 = 1.2 to 1.6; 4 = ≥ 1.6)

are presented in histogram form as figure 7. Their spatial variation is similar to that displayed by coefficients of variation. In addition the Australian median value of 1.1 is larger than the equivalent value of approximately 0.4 for the other continents.

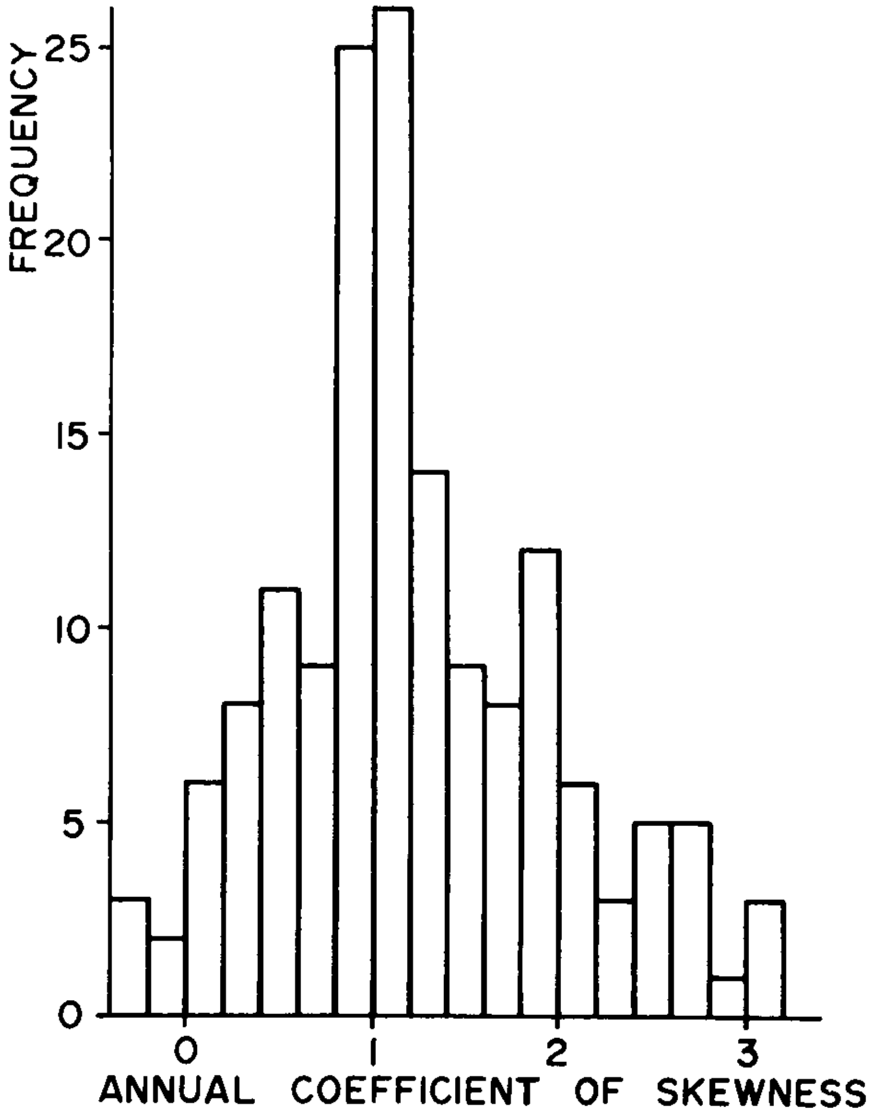

Figure 7.--Histogram of annual coefficients of skewness.

As a consequence of the higher skews in Australia than elsewhere, analysis involving statistical techniques is more difficult because non-Gaussian methods must be employed. Based on the coefficient of skewness as a measure of normality, approximately 70 percent of the streams sampled by Yevdjevich (1963) and Kalinin (1971) may be considered normal, whereas only 22 percent of those sampled in this survey are normal.

Another indicator of variability is the ratio of the annual maximum or minimum to mean annual flow. Typical values are given in columns (10) and (11) of table 3. These are alternative but less satisfactory ways of expressing variability because the parameters are a function of the length of record. Figure 8 illustrates graphically the variable nature of a low yielding Australian river.

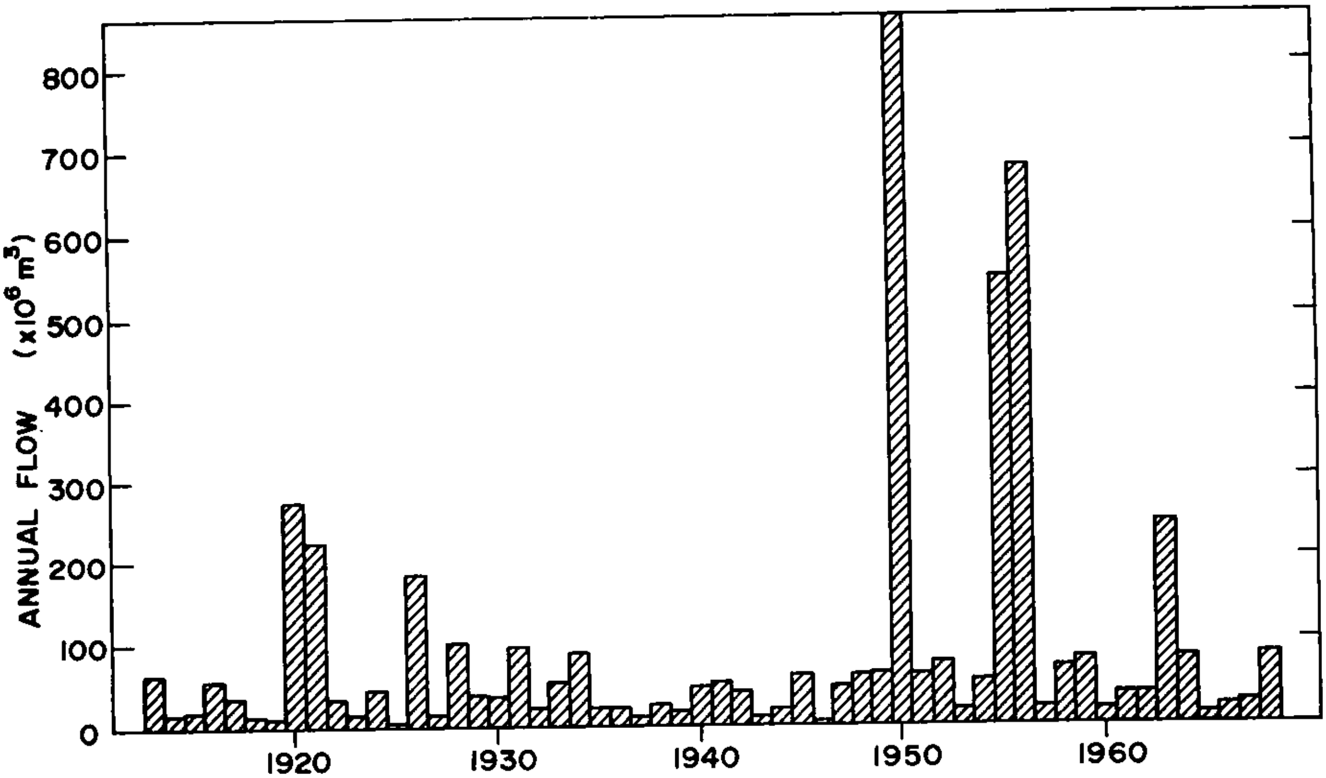

Figure 8.—–Annual hydrograph for Goulburn River at Coggan (AWRC No. 210006).

Within-year variation is another factor to be considered under the heading of variability. Columns (12) and (13) of table 3 indicate the range within which the seasonal means vary. Rivers 1, 3 and 6 are typically extremely seasonal with runoff associated with summer tropical rains. On the other hand, the less seasonal streams show winter maxima and summer minima.

PERSISTENCE

Persistence is the effect of one event on a following event in a time series. It is quantitatively defined in this paper by the annual lag one serial correlation coefficient. Again the results are plotted in histogram form as figure 9 and their spatial variation is given in figure 10. One question which arises in computing serial correlation is whether the results are significantly different from zero. Using Anderson's test (Anderson, 1941), 26 percent of the values are significantly different from zero at the 5 percent level of significance.

Compared with Northern Hemisphere data, Australian serial correlation appears to be slightly weaker. Corresponding median values are 0.15 compared with 1.12.

LOW FLOWS

Based on flow duration curves, the continental variations of low flow are examined in terms of the flows equalled or exceeded 90 percent of time. The 90 percent level is usually adopted as an indicator of the contribution of base flow to catchment yield. Values expressed as ratios of mean monthly flow are shown in figure 11. Of the 156 catchments analysed, 25 percent recorded flows 1 percent

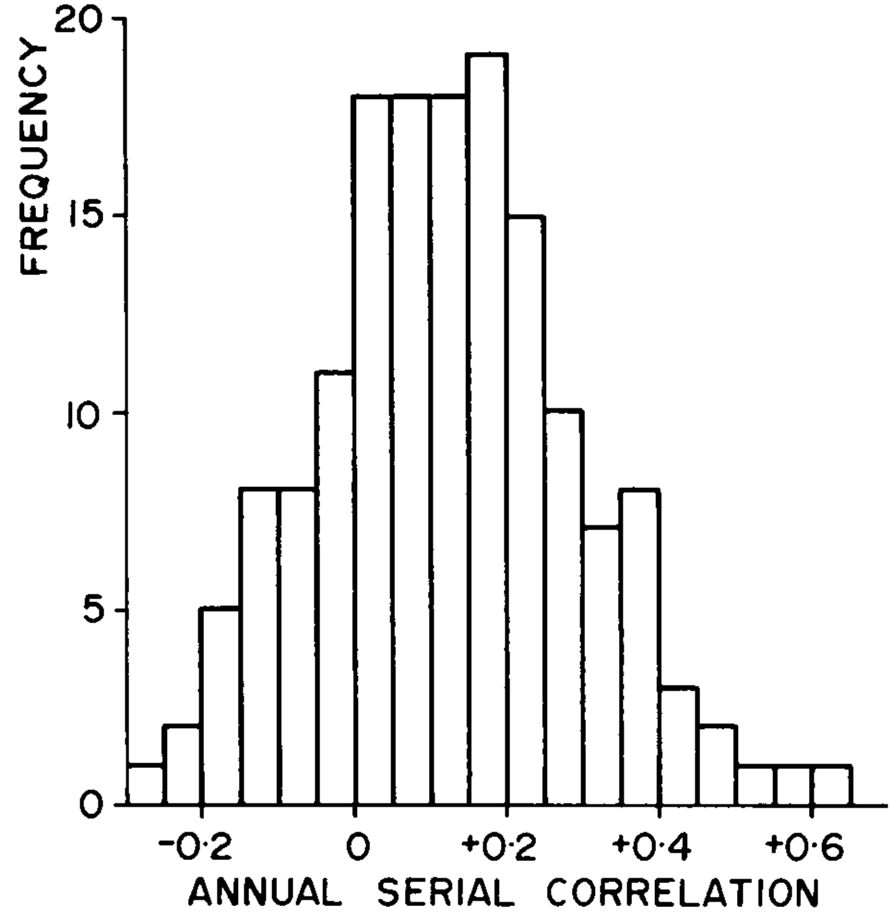

Figure 9.—Histogram of annual lag one serial correlation coefficients.

or less of the mean flow. The spatial distribution of low flow values is presented in figure 12. Nearly all the poor yielding streams are located in the low and medium rainfall zones.

The poor yielding characteristic of many Australian streams is further indicated by the observation that 41 percent exhibited 'cease to flow' conditions for at least one month during their recorded period.

Some low flow values for 36 months' duration which are based on frequency analysis are given in column (18), table 3. The characteristics that can be observed in such estimates are also contained in storage-yield values and, therefore, the frequency data is not examined in further detail. However, values for 1, 12 and 36 months' duration for the 156 catchments are given in a report by the writer (McMahon, 1973).

STORAGE-YIELD

The final method adopted to study the storage-yield characteristics of Australian streams was based on the storage capacities per mean flow required to meet given conditions of regulation and reliability. As noted earlier two procedures were used to compute storage estimates. Each utilized monthly flow data. One method was a slightly modified version of Gould's transition matrix

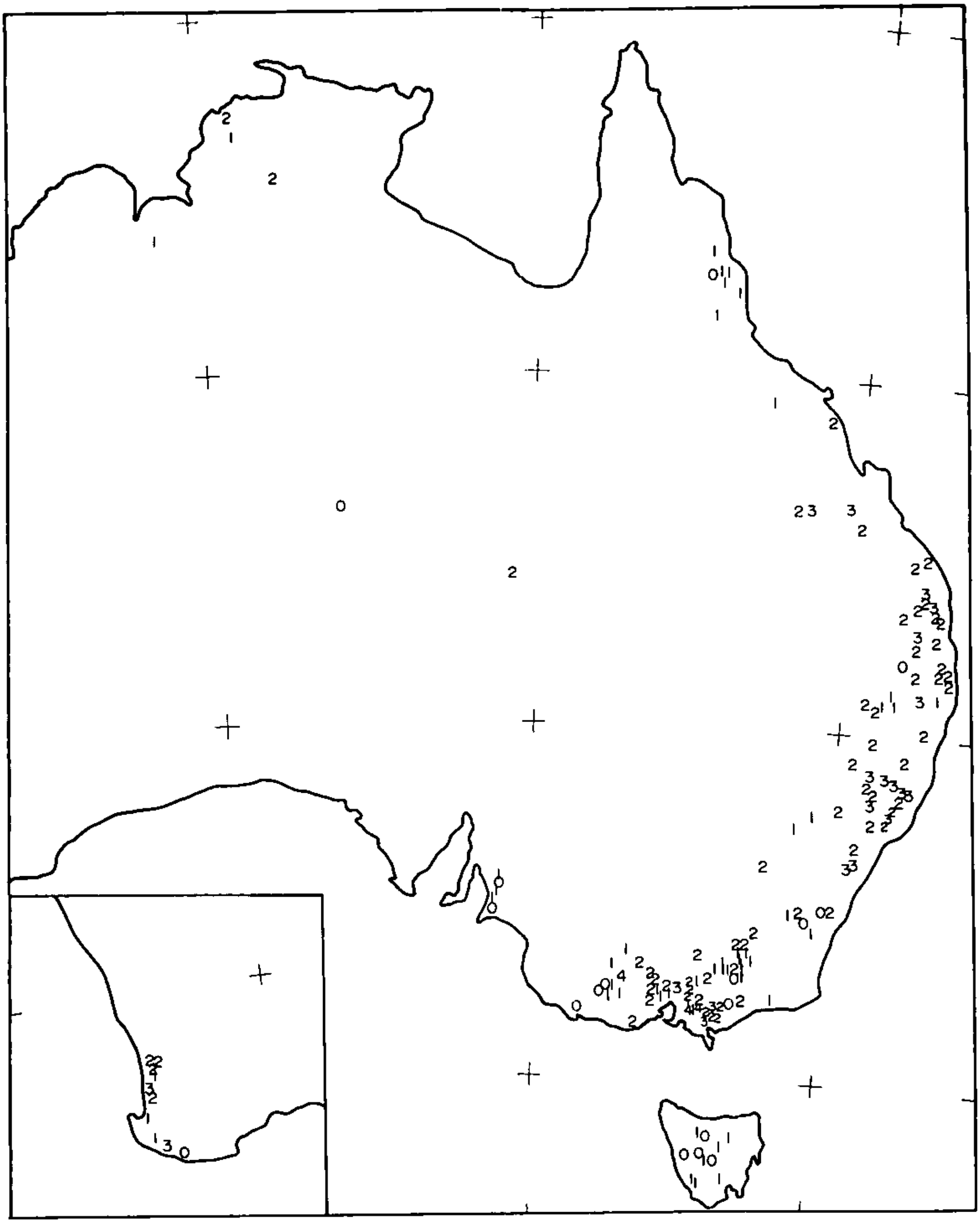

Figure 10.—–Spatial variability of annual lag one serial correlation coefficients (legend: 0 = -0.3 to -0.1; 1 = -0.1 to +0.1; 2 = 0.1 to 0.3; 3 = 0.3 to 0.5; 4 = ⩾ 0.5).

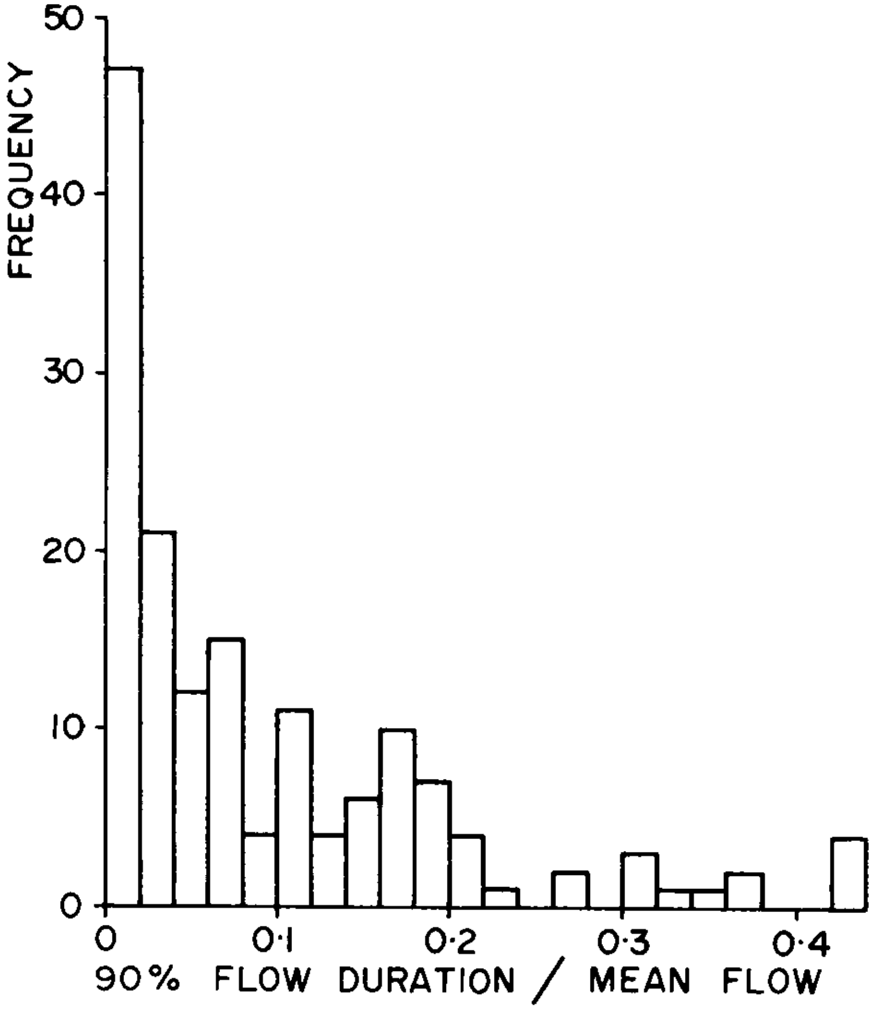

Figure 11.—Histogram of flows equalled or exceeded 90 percent of time.

procedure (Gould, 1961). The behaviour diagram was the basis of the other procedure; in one case the reservoir was assumed to be initially full, in the other, it was assumed initially empty. The storage sizes finally adopted were based on a set of rules which were devised after all the results were reviewed and anomalies noted.

Storage sizes were computed for 50 percent and 90 percent draft rates, which are constant amounts released from the reservoir and are expressed as percentages of the mean annual flow. A 95 percent reliability was also adopted in the analysis. Reliability is defined as the number of months, expressed as a percentage of the number of months of flow run through the reservoir, that the constant draft could be maintained.

The analysis was based on the 50 percent and 90 percent drafts as they represent respectively a reasonably short critical period, up to 12 months, and a long critical period,.in excess of 2 to 3 years. The 95 percent reliability value was considered to be typical and suitable for comparative studies.

Figure 13 shows in histogram form the computed storage capacities as ratios of mean annual flow for 90 percent draft. In addition, the spatial variation of this parameter is given in figure 14.

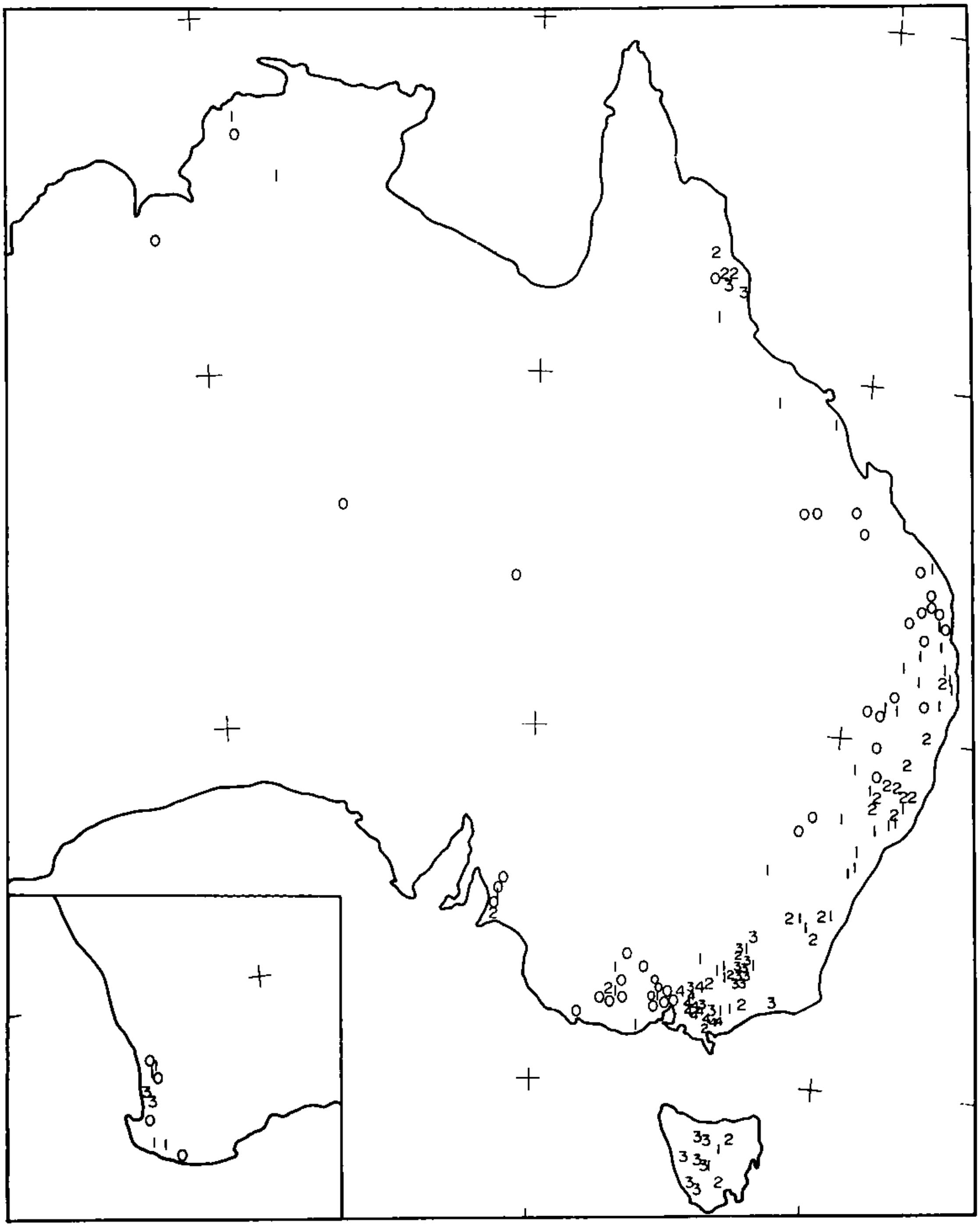

Figure 12.—–Spatial variability of flows equalled or exceeded 90 percent of time (legend: 0 = 0 to 0.01 monthly flow per mean monthly flow; 1 = 0.02 to 0.07; 2 = 0.08 to 0.15; 3 = 0.16 to 0.29; 4 = ⩾ 0.3).

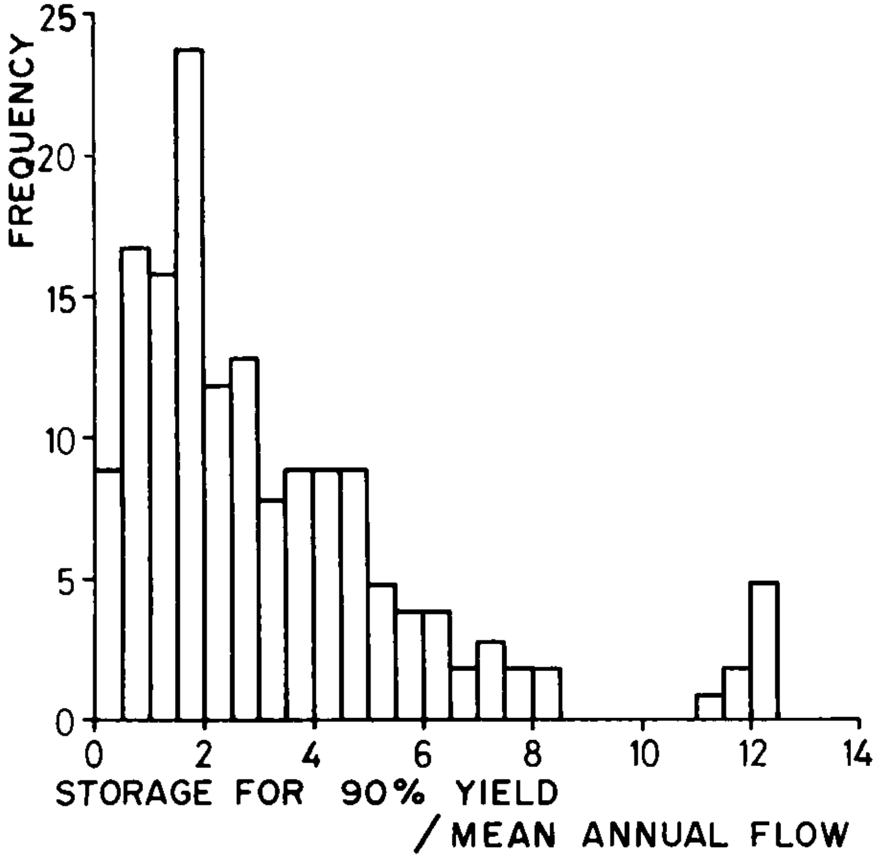

Figure 13.—Histogram of storage capacities for 90 percent draft and 95 percent reliability.

A storage estimate integrates all the streamflow characteristics of a catchment and is therefore particularly useful in classifying it. By expressing the storage size in terms of mean flow, direct comparisons may be made among streams. In figure 14, it can be seen that the catchments with the least relative yield, that is, those requiring the largest relative storage, are not those located in the arid or low rainfall zones, but are those found in the medium summer and uniform zones where the largest streamflow variabilities occur. The specific relationship between storage and variability is examined later.

Results from the analysis shown that for the streams examined there is a 70 to 1 range in the required storage at 90 percent draft, and a range of 190 to 1 at 50 percent draft. These values are indicative of the wide range of hydrologic conditions existing across the Australian continent.

As noted in the next section, the required storage capacity of a catchment is a function of approximately the square of the coefficient of variation. Using the median values for European and North American streams, (Kalinin, 1971 and Yevdjevich, 1963), and the median value for Australian streams found in this study, we estimate the relative storage requirements per mean annual flow (τ) for each continent as follows:

$$\frac{\tau \text{AUST}}{\tau \text{EUROPE}} = \frac{C_V^2 \text{ AUST}}{C_V^2 \text{ EUROPE}} = \frac{(0.67)^2}{(0.20)^2} = 11$$

$$\frac{\tau \text{AUST}}{\tau \text{NTH. AMER.}} = \frac{C_V^2 \text{ AUST}}{C_V^2 \text{ NTH. AMER.}} = \frac{(0.67)^2}{(0.30)^2} = 5$$

where C_V is the coefficient of variation.

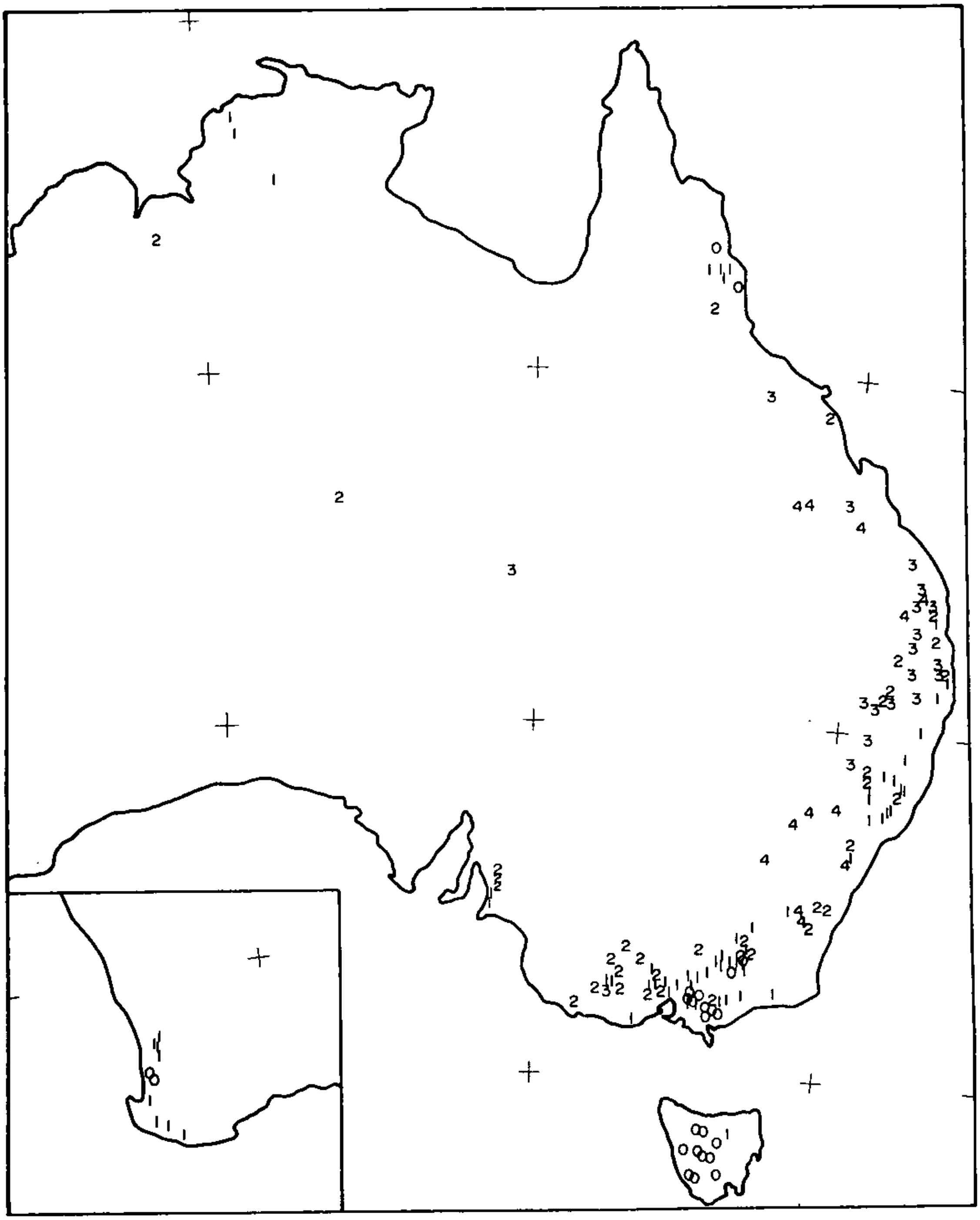

Figure 14.—–Spatial variability of storage capacities for 90 percent draft and 95 percent reliability (legend: 0 = 0 to 1.0 years; 1 = 1 to 3; 2 = 3 to 5; 3 = 5 to 10; 4 = ≥ 10).

These ratios quantitatively illustrate the poor-yielding characteristics of Australian streams compared with European and North American ones.

RELATIONSHIP AMONG CHARACTERISTICS

In addition to the characteristics noted above, many other flow parameters were computed during the project. The processed results are tabulated in McMahon (1973).

In table 4 linear relationships computed amont various pairs of parameters are given. Four of the correlations (nos. 1, 5, 6 and 7) could be spurious as the same variables appear on both sides of the equations. From the tabulation, it can be seen that the coefficient of variation accounts for more of the variance in the dependent variables than does the mean annual runoff. An unexpected result was that no relationship was found between flows equalled or exceeded 90 percent of time and mean annual runoff. This partly arises because of the large number of zero or near zero 90 percent flows which are found in most regions of the Australian continent. One can conclude from the analyses that it may be difficult to devise regional techniques which rely only on the mean flow for estimating characteristics of ungauged catchments, although the writer found it to be a satisfactory parameter in an earlier study (McMahon, 1969).

Because of their practical significance, four of the relationships are shown graphically, as figures 15, 16, 17 and 18. The purpose of figure 15 is to further illustrate the variability of Australian streamflow. The annual coefficients of variation are plotted against mean annual flows along with a generalised curve from Kalinin (1971, figure 29) and data from Rosenberg (1971). For climatic regions with more than 100 mm of runoff, the larger variability of Australian data compared with world data is clear. In the more arid regions, the results are compared with Rosenberg's data for nine catchments in Israel. Again the larger variability of Australian data is noted.

Table 4.—*Relationship between flow characteristics*

No.	Independent variable (X)	Dependent variable (Y)	Coeff. of deter. r^2 (%)	Equation
1	Mean annual run-off (mm)	Annual coeff. of variation	61[1]	Y = 1.9-0.51 log X
2	Mean annual run-off (mm)	Annual coeff. of skewness	33[1]	Y = 3.3-0.87 log X
3	Mean annual run-off (mm)	Annual serial correlation	0	Y = 0.13-0.005 log X
4	Mean annual run-off (mm)	Flows equalled or exceeded 90% of time (>500 $m^3 km^{-2}$ per month)	0	Y = 8500 + 0.48 X
5	Mean annual run-off (mm)	Storage capacity, 50% draft (years)	50[1]	log Y = 1.1-0.66 log X
6	Mean annual runoff (mm)	Storage capacity, 90% draft (years)	57[1]	log Y = 1.8-0.58 log X
7	Annual coeff. of variation	Monthly coeff. of variation	72[1]	Y = 0.28+2.0 X
8	Annual coeff. of variation	Annual coeff. of skewness	61[1]	Y = 0.06+1.8 X
9	Annual coeff. of variation	Annual serial correlation	0	Y = 0.09+0.03 X
10	Annual coeff. of variation	Storage capacity, 50% draft (years)	79[1]	log Y = -0.09+2.0 log X
11	Annual coeff. of variation	Storage capacity, 90% draft (years)	93[1]	log Y = 0.73+1.7 log X
12	Annual coeff. of skewness	Annual serial correlation	3	Y = 0.072+0.040 X
13	Annual serial correlation	Monthly serial correlation	1	Y = 0.46 - 0.089 X

[1] Significant at 5% level of significance.

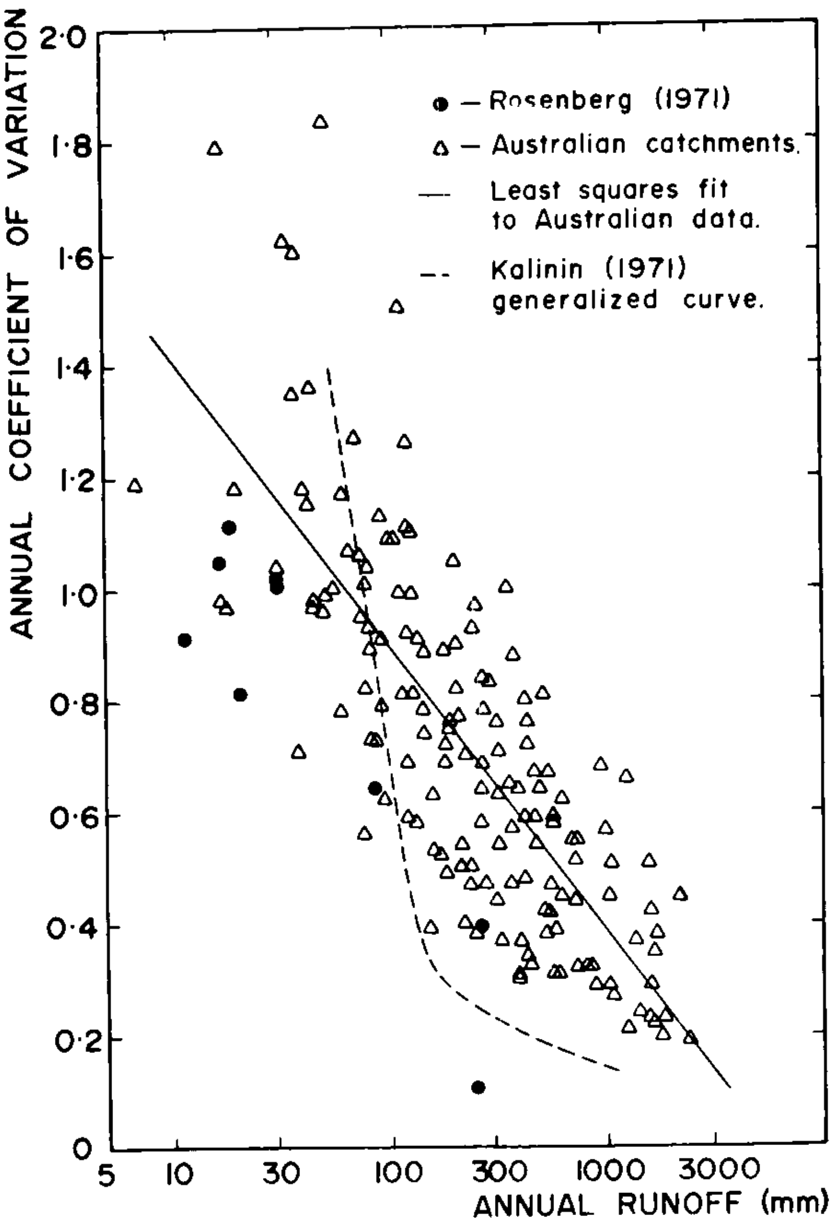

Figure 15.—–Relationship between annual coefficients of variation and mean annual runoff.

Figure 16 relates the annual coefficient of variation to the annual coefficient of skewness. Superimposed on the plot is the following theoretical relationship between the coefficients of skewness (C_S) and variation (C_V) for a two-parameter lognormal distribution (Chow, 1964):

$$C_S = 3\,C_V + C_V^3$$

It is seen that, except for coefficients of variation less than 0.6, the relationship as given in this equation is outside the 95 percent confidence limits of the empirical data. This indicates that as a general rule a two-parameter lognormal distribution does not adequately represent annual flows of Australian streams. The empirical relationship between the coefficients of variation and skewness given as Eqn. 8 in table 4 is very similar to that found by Kalinin (1971) for Northern Hemisphere streamflow data.

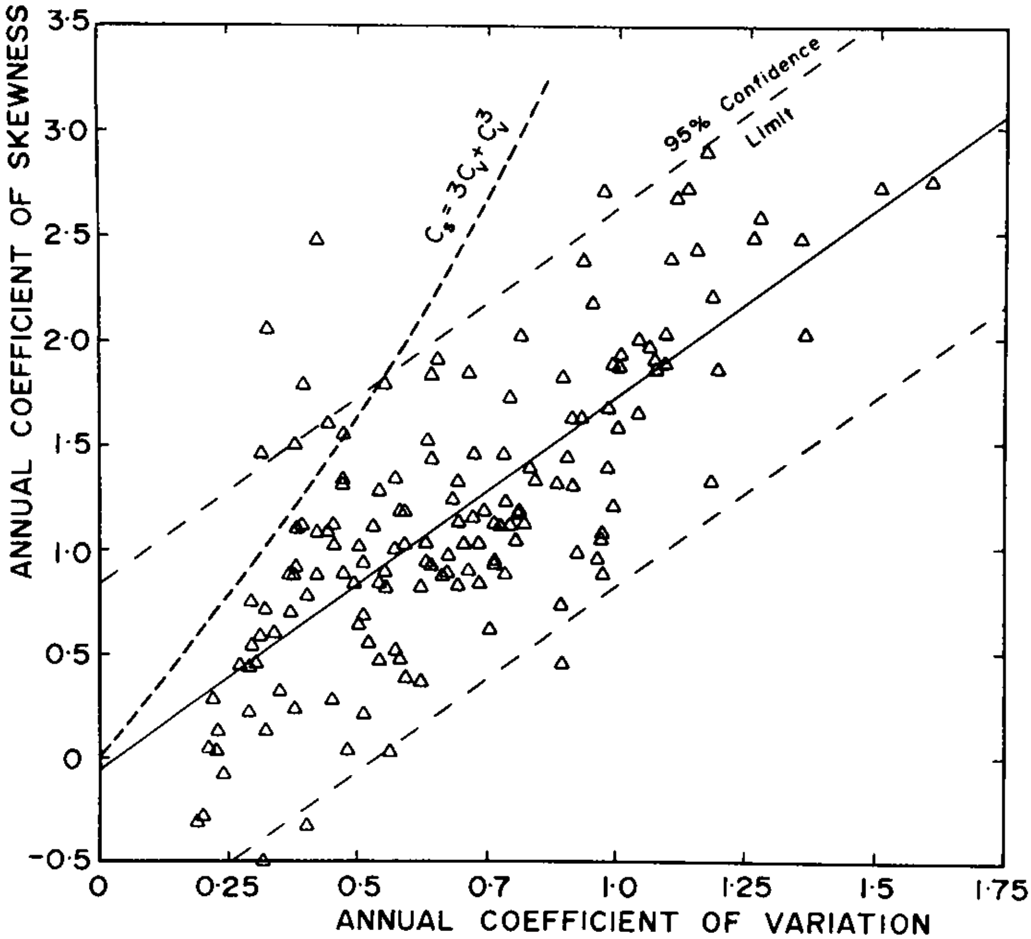

Figure 16.—–Relationship between annual coefficients of skewness and annual coefficients of variation.

Figures 17 and 18 are of specific practical interest not only because they are based on empirical data, but also because the dependent storage estimates are related to only one explicit independent variable – the coefficient of variation. Assuming annual flows are approximately normally distributed and independent, the required storage capacity (S) per mean annual flow ($\bar{Q}$) is related to constant draft (D) (expressed as a ratio of mean annual flow ($\bar{Q}$)), the coefficient of variation (C_V) and the standardized normal variate (t) as follows:

$$\frac{S}{\bar{Q}} = \frac{t^2}{4\ (1\text{-}D)} C_V^2$$

For 95 percent reliability (t = 1.64), and for D = 0.5 and 0.9 respectively, the theoretical relationships are shown on figures 17 and 18. The relationship fits the 90 percent data, but overestimates storages for 50 percent draft. This arises because the theoretical analysis is based on annual flows assumed normally distributed, whereas the empirical estimates are based on monthly data. It is seen that this effect is particularly significant for short critical periods.

Based on the empirical data in figures 17 and 18, the following reservoir capacity-flow variability equations were computed. It should be noted that the 50 percent storage equation is slightly different to that shown in table 4 as only storage estimates greater than 0.05 years in size were utilized.

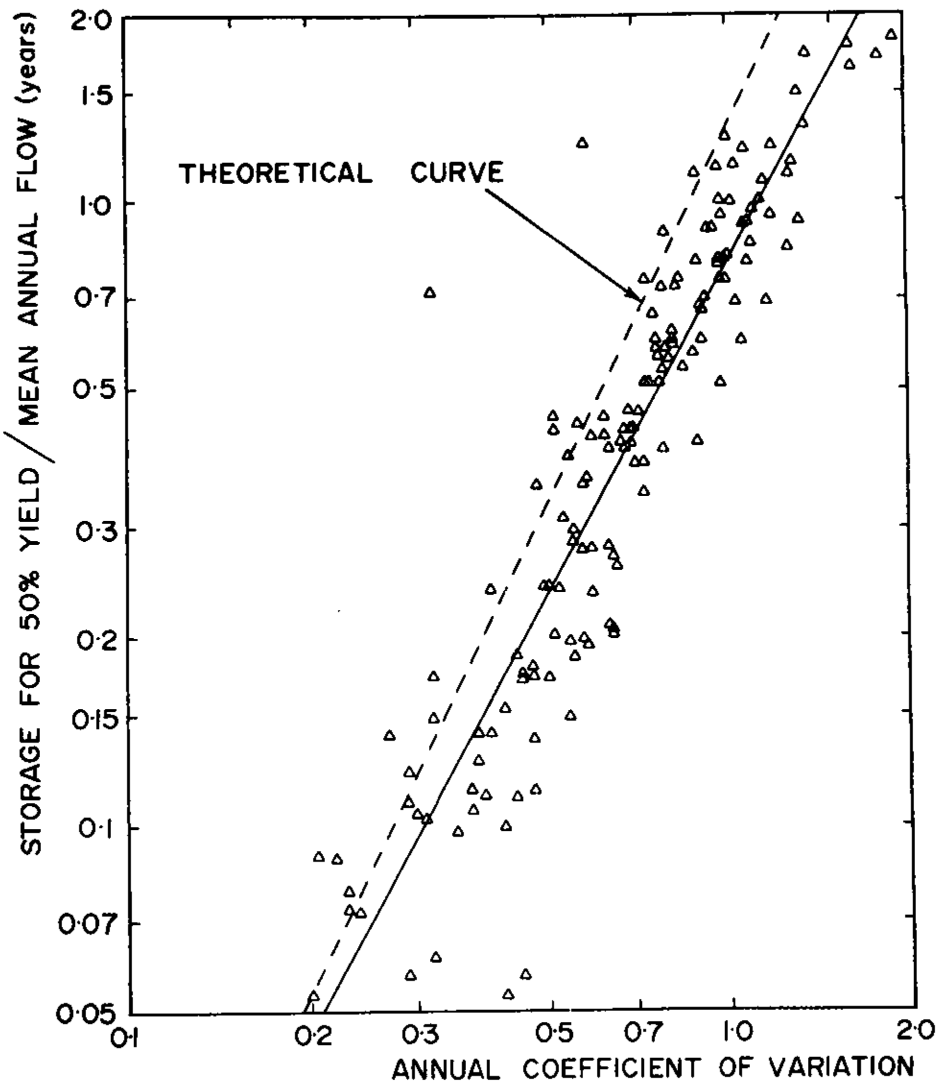

Figure 17.—Relationship between storage capacities for 50 percent draft and annual coefficients of variation.

$$\tau_{50} = 0.80\ C_V^{1.8},\ \tau_{50} > 0.05$$

$$(N = 148,\quad r^2 = 0.86,\ SE = +41\%, -29\%)$$

$$\tau_{90} = 5.3\ C_V^{1.7}$$

$$(N = 156,\quad r^2 = 0.93,\ SE = +26\%, -21\%)$$

where τ_{50}, τ_{90} are reservoir storage sizes per mean annual flow (years) for 95 percent reliability of providing a constant draft of 50 percent and 90 percent of the mean annual flow, C_V is the annual coefficient of variation, N is the number of items used in the regression, r^2 is the coefficient of determination and SE is the standard error of estimate.

These empirical equations allow perliminary estimates of storage capacity at 95 percent reliability of yield to be computed for Australian streams.

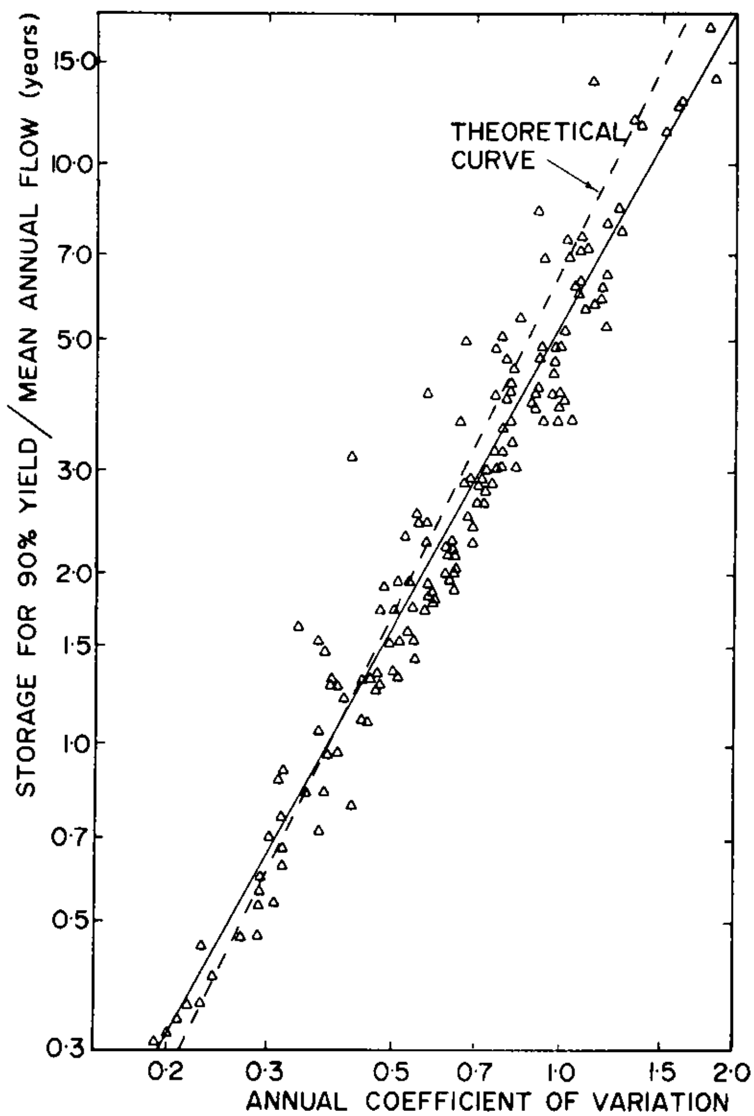

Figure 18.—Relationship between storage capacities for 90% draft and annual coefficients of variation.

CONCLUSIONS

The major conclusion from the study is that Australian streams are considerably more variable than Northern Hemisphere ones. Median values of the annual coefficient of variation is 0.67 compared with 0.2. Skewness values are nearly three times larger. On the other hand, annual lag one serial correlation coefficients are very similar – 0.12 (Australia) compared with 0.15 (Northern Hemisphere).

No comparative storage yield values are available. But based on the simple relationship that storage is directly proportional to the square of the coefficient of variation, it is estimated that for similar conditions of draft and reliability reservoir storage requirements per mean annual flow in Australia are eleven and seven times larger than that required in Europe or North America respectively.

Simple linear least squares relationships between hydrologic characteristics show that the coefficient of variation accounts for more variance in the other characteristics than does the mean annual flow. This is a significant observation with regard to regional analysis.

Empirical equations relating reservoir storage capacity per mean annual flow to the coefficient of variation are developed.

ACKNOWLEDGEMENT

The author wishes to acknowledge the financial support for the project provided by the Water Research Foundation of Australia. Streamflow records were supplied by all Australian water authorities. The School of Civil Engineering, University of Melbourne and the Commonwealth Bureau of Meteorology also provided information. Data processing was carried out by Mrs. Nancy Stone in the Department of Civil Engineering, Monash University.

REFERENCES

Anderson, R.L. (1941): "Distribution of the Serial Correlation Coefficient." *Ann. Math. Stats.*, Vol. 13, p. 1.

Chow, V.T. (Ed.) (1964): *Handbook of Applied Hydrology*, McGraw-Hill.

Department of National Development (1965): *Review of Australia's Water Resources 1963*, Canberra.

——— (1967): *Surface Water Resources*, (Scale 1:6,000,000), Atlas of Australian Resources, Commonwealth Government Printer, Canberra.

——— (1969): *The Representative Basin Concept in Australia*, Australian Water Resources Council Hydrological Series No. 2.

——— (1971): *Stream Gauging Information*, Canberra.

Gould, B.W. (1961): "Statistical Methods for Estimating the Design Capacity of Dams", *Jour. I.E. Aust.*, Vol. 33, No. 12, pp. 405–406.

Joy, C.S. (1970): *On the Relationship Between Reservoir Capacity and Yield*, M. Eng. Sc. Thesis, Monash University.

Kalinin, G.P. (1971): *Global Hydrology*, Israel Program for Scientific Translations, Jerusalem.

McMahon, T.A. (1969): "Water Resources Research: Aspects of a Regional Study in the Hunter Valley, New South Wales." *Jour. Hydrology*, Vol. 7, pp. 14–38.

——— (1973): *Low Flow Hydrology of Selected Australian Streams*, Civil Engineering Research Report 3/1973, Monash University.

Moran, P.A.P. (1959): *The Theory of Storage*, Methuen, London.

Rosenberg, M. (1971): *Modèles explicatifs de précipitation et d'écoulement de surface. Etude hydrologique et statistique du régime des cours d'eau d'Israel, Thèse:* L'Université Scientifique et Medicale de Grenoble.

Searcy, J.K. (1959): *Flow Duration Curves*, Geological Survey Water Supply Paper 1542A, Washington.

Yevdjevich, V.M. (1963): *Fluctuations of Wet and Dry Years Part I Research Data Assembly and Mathematical Models*, Hydrology Papers No. 1, Colorado State University.

COMPUTATION OF EXTREME FLOW AND GROUND WATER CAPACITY WITH INADEQUATE HYDROLOGIC DATA IN NEW JERSEY

Dr. George J. Halasi-Kun

Chairman, Columbia University Seminars on Pollution and Water Resources, New York, USA

Summary

In smaller watersheds with an area less than 100 sq. mi. (~ 260 km^2), the recorded hydrologic data are scarce or nonexistent because observation-stations with longer period of records are available only at random. Correlating the extreme runoff data with the characteristic permeability of the different geological formations can not only enrich the various methods for simulation or interpretation of hydrologic information from other areas but also secures additional improvement in hydrological data gathering. The data collection extended to the adjacent areas gives a much larger scale and variation of available information which, based on similar geologic subsurface, can be evaluated more efficiently.

An account is given about tentative average values in millidarcys for permeability of different geological formations based on selected bibliography and previous experience. Further correlation of peak runoffs and hydrogeologic conditions in Central Europe and in the Northeastern coastal area of the United States with their specific geological subsurface is discussed. It is pointed out that the geological subsurface as a characteristic of the peak runoff does not apply at all for watersheds with an area over 120 sq. mi. (~ 310 km^2). A similar but less clearly defined correlation can be found between the lowest runoff and the geological formations within a watershed area less than 40 sq. mi. A detailed description of the hydrogeologic conditions of Central Europe and that of New Jersey preceeds the ground water capacity computation. The practical upper limit for ground water availability estimate can be set at 80 sq. mi. which limit may be extended for calculations of greater area with uniformed geological subsurface.

*Based on articles:

Halasi-Kun, G.J., "Improvement of Runoff Records in Smaller Watersheds Based on Permeability of the Geological Subsurface," *Symposium on the Design of Water Resources Projects with Inadequate Data, International Hydrologic Decade,* Madrid: UNESCO-WMO-IAHS, June 1973.

———, "Data Collecting on Water Resources and Computations of Maximum Flood for Smaller Watershed," *International Symposium on Water Resources Planning, Papers,* Vol. I, Mexico, 1972.

———, "Computations of Peak Floods with Inadequate Hydrologic Data," *Decisions with Inadequate Hydrologic Data,* Proceedings of the Second International Hydrology Symposium, Sept. 1972, Ft. Collins: Colorado State Univ., 1973.

INTRODUCTION

A water resources conscious society is well aware of the importance of surface and ground water records and data collecting from drainage basins in gathering information either to prevent floods (peak flow data) or to find out how much water is available in periods of droughts for consumption, for industrial use and to mix with polluted or treated effluents (minimum flow data). In accordance with the circumstances, how valuable property should be protected against flood damage or for how long a period is it acceptable to have lower flow, and by how much, than is needed for purposes of consumption, different schemes were worked out. In the case of flood prevention, 100-year peak flood flow records are desirable. Less demanding are the requirements for minimum flow where, generally, 20- to 50- year minimum flow records for 355-day/year are accepted.

In both cases, we have abundant information for larger rivers – especially of peak flood magnitudes – because plans for preventing flood damages have always been of great concern to the public. Therefore, longtime gage records of streams as indicators of flood flows, including historic records, are almost always available. For lowest-flow of the rivers, the data are more scarce. On the other hand, for smaller streams (drainage basins of less than 260 km^2 ~ 100 square miles) either peak or low flow data observations are, or may be, either non-existent or cover only short periods and, therefore, information is extremely limited.

Generally, no data for longer periods is at hand, when the area is planned for development. In accordance with various studies conducted at moderate climatic conditions in Central Europe and in the Northeastern United States of America, it seems that the peak runoff values of these drainage basins are highly dependent on the geologic subsurface where the permeability of the rock formations secures the ground water storage, or their impervious surface preconditions the extent of the lake and swamp areas of the region.[1] Both these characteristics directly influence the drainage density in the areas with different permeability factor of the geological formations, as can be demonstrated, for instance, by the hydrographical map of Southwest Germany from the Upper-Danube region (fig. 1).[2]

Another classic example can be the river training and flood control program of 1840–1950 in the Carpathian Basin in Central Europe where – even in a greater watershed like the Danube at Orshova, Romania (222,250 sq. mi. or 576,240 km^2 area of drainage basin with a yearly average rainfall of 36 inches or 900 mm) – the diminishing of lake and swamp area by extensive drainage and flood control, the maximum annual flood increased by 15 percent in the observed 110 year period (fig. 2) while the lake and swamp area decreased from 11 percent to 3 percent of the watershed.[3] In the Carpathian Basin (123,500 sq. mi. or 318,030 km^2 of the Danubian drainage basin related to the observation station Orshova, Romania) 15,700 sq. mi. or 39,000 km^2 agricultural land was reclaimed in the flood and marshland region. (Figure 3 shows the reclaimed area for the 110 year period including the two major lakes of that basin.)

A similar effect on peak runoff was observed in the State of New Jersey, USA in a territory of 7,836 sq. mi. or 20,295 km^2. This observation is based on 67 gauging stations for watershed of

[1] Halasi-Kun, G.J., "Data Collecting on Water Resources and Computations of Maximum Flood for Smaller Watersheds," *Simposio Internacional Sobre la Planificacion de Recursos Hidraulicos – Ponencia*, Volume I, Mexico, 1972, p. 16.

[2] Herak, M. and Stringfield, V.T., *Karst*, Amsterdam-London-New York: Elsevier Publishing Co., 1972, p. 207.

[3] In Hungary decreased even to 1.41 percent according Degen, I., *Vizgazdalkodas* (Water Resources Planning), Volume II, Budapest, 1972, p. 49.

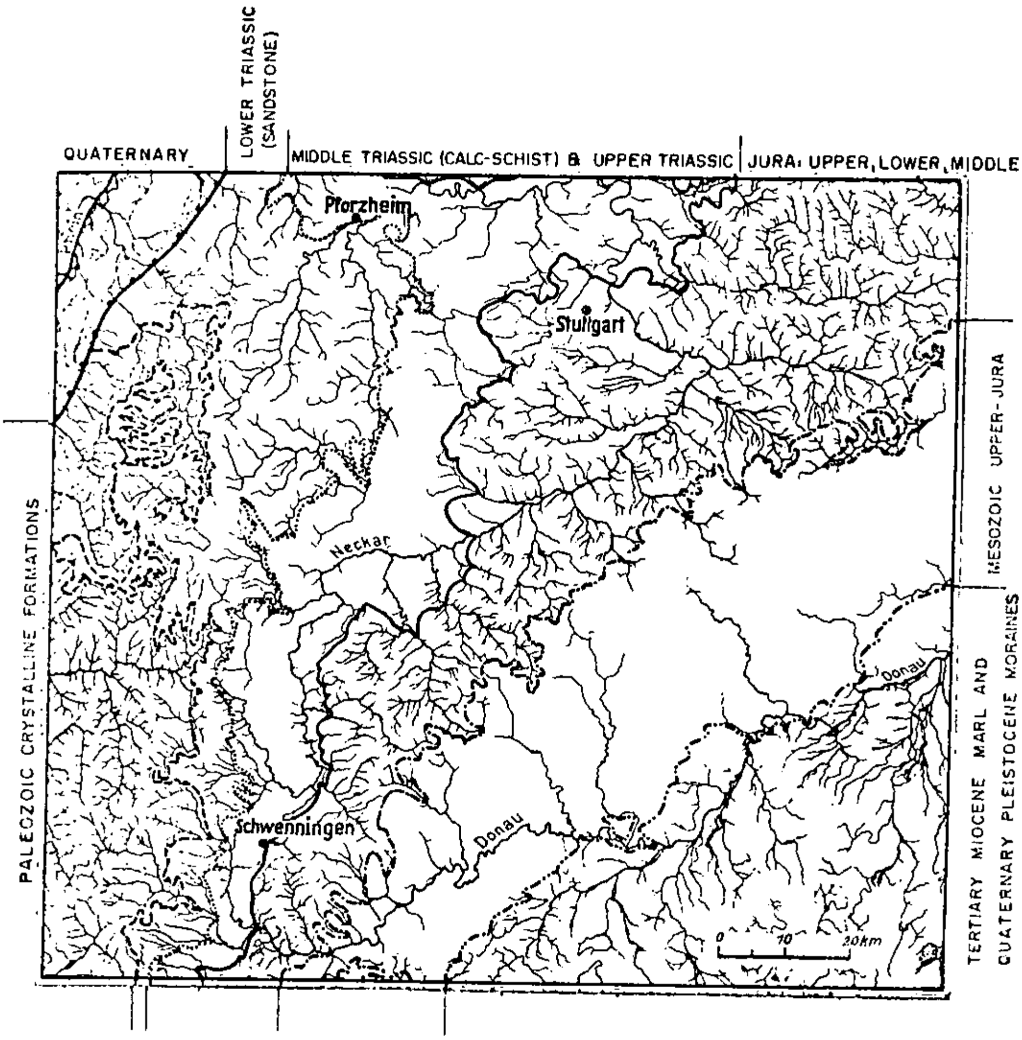

Figure 1.—–Hydrographical map of southwest Germany from the Upper-Danube Region.

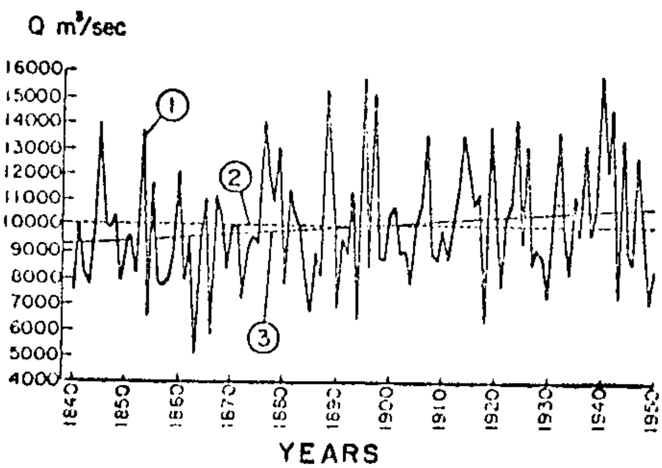

Figure 2.—–Maximum annual flood of the Danube River at Orshova, Romania, 1840–1950.
1. Series of peak flood discharges.
2. Average peak flood.
3. Trend of the average peak flood.

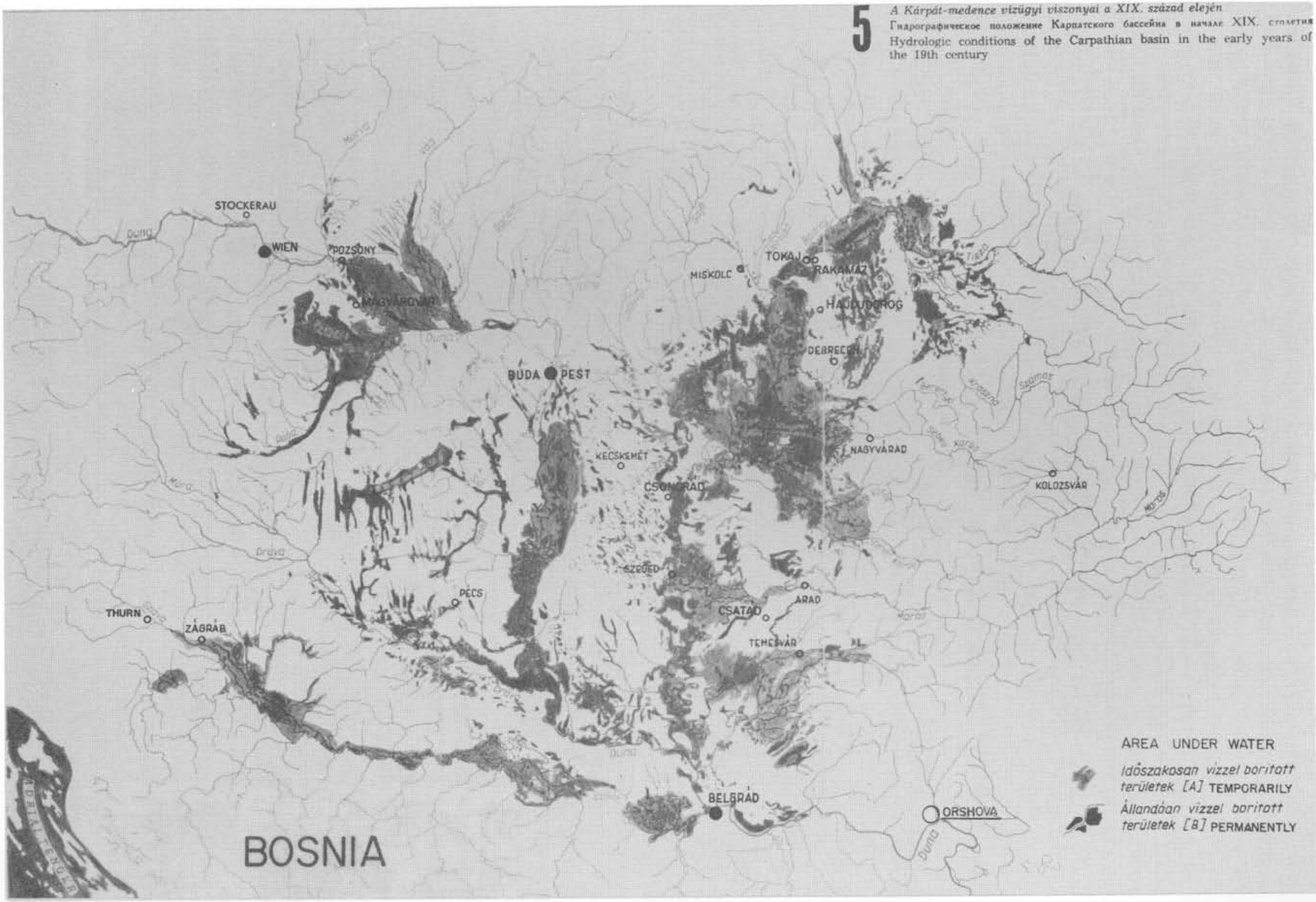

Figure 3.—–Land reclaimed in the Carpathian Basin, Europe 1840–1950, (from the report of the Intergovernmental Economic Committee of Europe for Rational Utilization of Water Resources, October 1964—–shaded area also includes Lake Balaton and Lake Fertő).

from 10 sq. mi. (25.9 km²) to 200 sq. mi. (518 km²) with an average yearly rainfall of 45 inches (1,125 mm) (figure 4: Adjustment factor for effect of lakes and swamps on peak runoff in New Jersey 1897–1972 compared with data developed from the Danubian basin at gauging station Orshova, Romania 1840–1950).

Because of the insufficient data available on flood-peak discharge of smaller watersheds, different methods have been used for computation of flood flows. General practices for estimating discharges from various sizes of watersheds, according to *Hydrology Handbook* of the American Society of Civil Engineers, (New York, 1948) are as follows:

Catchment area sq. mi.	*Present practice*
Less than 1	Overland flow hydrograph; rational method.
1 – 100	Rational method; unit hydrograph; flood frequencies; flood peaks vs. drainage area.
100 – 2,000	Unit hydrograph; flood frequencies; flood peaks vs. drainage area.
Over 2,000	Flood routing; flood frequencies; flood peaks vs. drainage area.

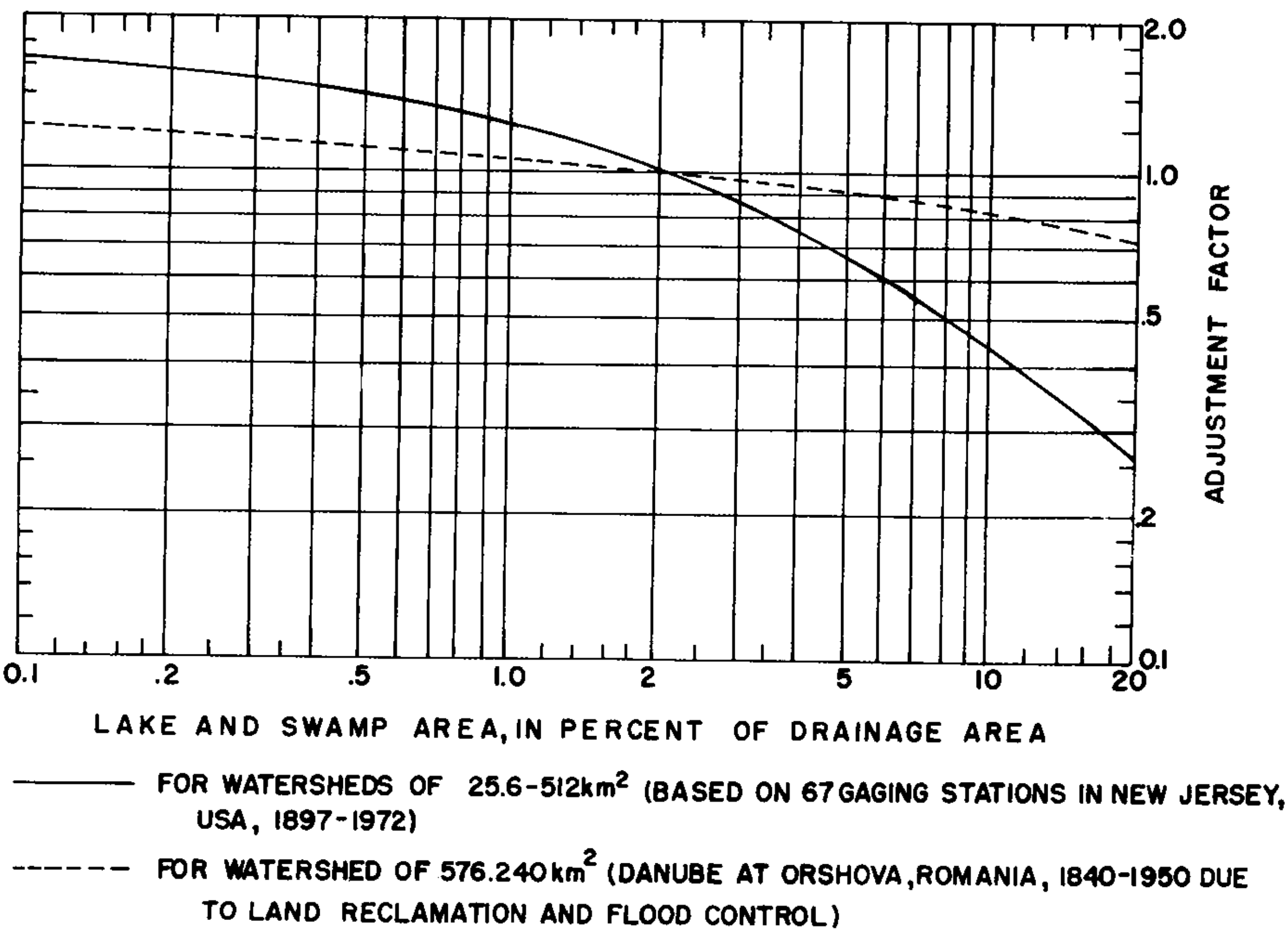

Figure 4.—–Adjustment factor for effect of lakes and swamps on peak runoff in New Jersey, U.S.A. and Danube at Orshova, Romania.

Analyzing the methods for areas less than 100 sq. mi. where records of floods are insufficient, the most frequently used computations are:

A. Less than 1 sq. mi. area: $Q = ARC$ or $Q = ARC\sqrt[5]{\frac{S}{A}}$

Q = peak flood in cft/sec.
A = drainage area in sq. mi.
R = rainfall rate in inches/hour.
C = coefficient depending on permeability of the artificially improved surface of the drainage area (such as pavement, roof, etc).
S = slope of the watershed in ft/1,000 ft.

This method is based on rainfall intensity and permeability of the surface. It also takes into consideration the slope of the terrain. This rational method is widely applied for storm sewage design and for peak flood of areas less than 1 sq. mi.

B. For 1–100 sq. mi. watersheds, especially in range of 1–80 sq. mi. the flood peaks vs. drainage area method was recommended and the formulas used are similar to Myer's:

$Q = 100\,C\sqrt{A}$
Q = peak flood in cft/sec
A = drainage area in sq. mi.
C = coefficient determined by observations of many flood flows with a value of from 15 to 1,300 depending on the geographic location of the watershed.

C. Methods using the unit hydrograph and flood frequencies (multiple regression methods) have the same "basic" problem as the above-mentioned method, since basic information from the watershed is needed to predict flood flows. Time is an important element in the procedure of the unit hydrograph method because rainfall data must be available from a drainage area of 20–100 sq. mi. for unit times shorter than 2–4 hours, and this data will be available only by accident.[1,2] Similar difficulties are encountered with the flood frequency method (multiple regression method or flood index), since flood records of at least 50 years are needed to establish reliable results.[3]

With various methods of computation based on probability (flood rooting, flood frequency, unit hydrograph, etc.) and other sophisticated ways, the available data can be interpreted with a workable accuracy only for a time no longer than twice the period of observation. This means that for computation of 100-year extreme flow it is necessary to have at least 50-year observation which is, or may be, available for larger rivers in many regions but almost non-existent for smaller streams in most of the countries. The need for data on peak and lowest flow occurs at random and in emergency conditions; therefore, there was no collected data nor is there time to collect data for longer periods. It is essential to find similar watersheds where data are available and can be applied. On what basis should a similarity be established? What influences the peak and the lowest flow in smaller watersheds? The peak flow data of smaller drainage basins are mainly influenced by the permeability of the geologic subsurface, the regional configuration of the terrain, the peak point rainfall intensity with the size of storm center, and the yearly average rainfall; while the lowest flow depends generally on the length of drought, the frequency and the size of rain, the storage capacity of the geologic subsurface, the evapo-transpiration, the temperature of the atmosphere and of the soil, the retardation effect of forest and of lake, and the elevation of the watershed. In both extreme flow values, the causative circumstances and influencing factors have also extreme values.

[1] Fair, G.M., Geyer, J.C., Okun, D.A., *Water and Wastewater Engineering*, Vol. 1, New York: J. Wiley & Sons, 1966, pp. 7–21.
[2] Meinzer, O.E., *Hydrology*, New York: McGraw-Hill Co., 1942, p. 524.
[3] Davis, D.V., *Handbook of Applied Hydraulics*, New York: McGraw-Hill Co., 1952, p. 1,196.

DATA COLLECTING

The basic data collecting for evaluation and water resources planning in smaller watersheds consists of descriptive surveying of surface – and groundwaters of the area in question. The survey must be based on and carried out from a broad view-point because gradual extension and completion can be very expensive. It is necessary that the water resources planner and the geologist collaborate very closely and carefully in their survey. In the field, they should use topographical and geological maps, made to scale at least 1:50,000 (preferable 1:25,000). The report about their findings can be summarized at a scale 1:250,000 to 1:1,000,000. Questionaires distributed and filled out in advance by local authorities give the surveying team a wealth of information, but its reliability depends on the professional background, educational level and local knowledge of the persons involved—not to mention the length of time spent for filling out the forms—therefore, their value is dubious as it was in the case in gathering data for water resources planning of the first Five-Year Plan of highly developed Czechoslovakia in 1948–1949. On the other hand, such a preliminary survey saves time for the surveying team and enables it to be more efficient in data collecting, also from a local view-point.

The listings and the geographical descriptions of the springs, rivers, lakes, swamps, glaciers and groundwater conditions are accompanied by the necessary geologic information, and above all with respect to the permeability of the subsurface. The meteorologic records should include not only the extreme and average rainfall data with the information of characteristic storms (their precipitation data, intensity, duration, size of storm center, etc.) but also temperature, evapotranspiration and peak point rainfall intensity data. The extent of the wooded region and that of urbanized area with the type of the impervious land-use surface (which will be discussed later) is another essential piece of information, along with the mean elevation of the drainage area, soil classification and slopes of terrain. The groundwater data can be secured by available studies, if such exist, and by surveying existing wells of the area (depth, capacity, quality, etc.). Special difficulties are encountered in the relief of Karstic waters and particularly of the underground streams, as for example in Yugoslavia. Finally, permits for constructions across a stream (bridges, bank protection and other encroachments) can reveal valuable information about the stream conditions.

The hydrographic description of a region has very limited value if it is not supported by numerical evaluation of runoff, precipitation, intensity, evapotranspiration, and dates of occurrence. Further improvement of the water resources data collecting would be to put all the information in workable form in a "Data Bank" (computerized electronic data processing or other type of mechanized data compilation) so that the water resources planner and other governmental agencies, institutions, researchers, corporations and citizens can have a quick reference to help them coordinate their activity or problems with the available water resources data for making the necessary and appropriate decision. This "Data Bank," set up properly, would also eliminate any duplication or omission of the available records. Furthermore, it would improve the quality and standard of the "Environmental Impact Statements" prepared to solve environmental problems including future use of water resources in the various planning stages. To reduce the installing cost of the data processing, only the point-type of informations should be computerized. The area-type data need to be prepared in map form for the different records which can be easily stored with the help of microfilms and the access to them is easier and quicker in many instances than that of computerized systems and is substantially more economical. The disadvantage of this kind of set-up is that the transfer of information from the regional (state-wide) data bank to a centralized (nation-wide) one is more time-consuming, not mentioning the difficulties in handling. On the other hand, to computerize area-type data, it is necessary to prepare map-type records as the first step of data collecting. Therefore, the regional data bank should have computerized point informations and microfilmed areal data in their preliminary organization which can be expanded in more sophisticated fully computerized electronic data processing at a later date.

Generally, the need for peak flood flow computations of smaller watersheds occur at random and with inadequate information. Therefore, the collected data from different areas, despite their scarcity, can be utilized if the runoff records based on similar surface flow conditions are enriched and extended by such additional values as the similarity of the geological subsurface. The significance of the runoff formula based on hydrogeologic conditions (a suggested method for extending and improving informations) is that the available peak flow data can be generalized and used for areas where data are not available, except for geologic and meteorologic ones. The reliable flow data based on long-time records, computed by flood frequency (multiple regression) methods or flood index and grouped in accordance with the geologic formations give sufficient information to establish the peak flood values for smaller drainage basins (1 to 260 km^2 ~ 1 to 100 sq. mi.) also in regions where observations are limited and only geologic and meteorologic data have been collected.

Before discussing further the groundwater availability and the surface runoff formulas based on geological conditions, we should take a look at the hydrogeologic evaluation of Eastern Czechoslovakia and New Jersey including the urbanization effect since the developed formulas are based on observations of runoff conditions in these regions.

HYDROLOGIC EVALUATION OF EASTERN CZECHOSLOVAKIA

The yearly average rainfall varies from 24 inches (600 mm) in the South to 64 inches (1,600 mm) in the mountains with extremes of 20 inches (500 mm) in Southwest Slovak Plains and 84 inches (2,100 mm) on the peaks of High Tatra.

The peak floods are caused either by transcontinental cyclones or by local torrential rains. In accordance with van Bebber's observation, there are two paths of lowest barometric pressure where the cyclones occur in the summer: one from South to North, from the Adriatic Sea (Trieste) through the Alps of Lower Austria, Valley of Morava in Czechoslovakia to the Delta of Vistula on the Baltic Sea; the other one from West to East, weaker than the previous, from the Bay of Biscay in South France, North of Switzerland, across Czechoslovakia along Plzen-Brno-High Tatra line.[4] The point rainfall intensity reaches 4–5 inches/day (100–125 mm/day) value. The observed extreme values are listed in figure 4. The recorded storm pattern is an ellypsoid 9 miles by 33 miles (15 km by 50 km), with the highest intensity in its focus.[5] The higher values in rainfall intensity (4–5 inches/day or 100–125 mm/day) are characteristic more for the Morava, Middle-Vag Valley and for High Tatra than for the Central Slovak Mountains and the Slovak Plains in the South. The later region shows a similarity to the European Soviet Union's Plains with 1.2–1.6 inches/day or 30–40 mm/day peak value.

The relief of Eastern Czechoslovakia (Slovakia) is of Paleozoic, Mesozoic and Tertiary origin, built by different rock units (metamorphic rocks, Mesozoic and Tertiary rocks, volcanics of various types and ages etc.), they are divided into units defined primarily by their tectonic position. The

[4]Smetana, J., *Hydrologie a úprav toku* (Hydrology and River Traning), Prague: VUT, 1952.
[5]Halasi-Kun, G.J., *Hydrologia*, Kosice, 1949, pp. 7–9.

reason for this is that the rock sequences and complexes are very intricately folded, faulted, and overthrust (nappe structures) and their original relations considerably obscured. The following main units may be encountered:

(1) The mountain belt, typical Alpine formation with eroded slopes and valleys to the South:

(a) Outer or Teritiary Paleogene or Flysch Carpathians with very high water confining quality.

(b) Central Slovak Carpathians, mostly of Paleozoic Crystalline formations, Granite, Gabbro, Sandstones in the North and Mesozoic Basalt, Tuff and Andesite in the South interwoven and surrounded mainly in an arc form from West to East in the northern half of the massive by Mesozoic Triassic or Cretaceous limestones and dolomites.

(2) Region of South Slovakia covered by Tertiary Neogene in the center, which is unfolded and represents either more or less post-tectonic phase of sedimentation. Quaternary sediments, mostly as River Drift, adjoin the Neogene zone, and intrude deeply into the mountain region with the wide eroded valleys.

On the whole, Eastern Czechoslovakia can be characterized as a relatively small area (18,922 sq. mi. or 49,008 km^2) with a great variety of geological formations, relief, precipitation extremes which have an unusually well preserved hydrological record about floods from smaller watersheds, and for a longer period.

In accordance with the findings, the value of the coefficient "C" of the peak runoff formula showed a very close relation to the geological character of the watershed as it is described in detail in Volume II of these Proceedings.[11] The highest values were found in the Paleozoic formations,

Figure 5.—Characteristic peak point rainfall intensity recorded in the areas of East-Czechoslovakia in 1871–1963.

Date	Origin of storm	Location	Rainfall intensity in inches/day	Rainfall intensity in mm/day
Aug. 22, 1938		Lipt. Hradok	4.02	[6] 100.6
June 29, 1958	Cyclonic	Oravice	4.41	[6] 113.3
June 29, 1958	Cyclonic	Skalnate Pleso in High Tatra	7.55	[6] 191.7
June 7, 1873	Cyclonic	Trencin	10.51	[7] 267.0
June 26, 1875	Cyclonic	Budapest, Hungary	4.12	[8] 103.0
July 25, 1960	Cyclonic	Neszmely near Komarom, Hungary	4.63	[9] 117.6
May 25, 1948		Dobersberg, Lower Austria	4.20	[10] 105.0
Sept. 20, 1926		Grosssiegharts, Lower Austria	4.02	[10] 100.5
July 4, 1955		Pinkafeld, Burgenland, Austria	4.44	[10] 111.0
Aug. 12, 1960		Waidhofen a/Th., Lower Austria	5.24	[10] 131.0
Aug. 12, 1960		Weikertschlag a/Th., Lower Austria	4.67	[10] 117.0

[6] Pacl, J., "Katastrofalna povoden v oblasti Tatier v juni 1958," *Sbornik Prac o Tatranskom Narodnom Parku* (Catastrophic Flood in Region of Tatra in June, 1958 – Work Report on National Park Tatra), High Tatra, Czechoslovakia, 1959, Volume III, pp. 26–30.
[7] Smetana, J., *Hydrologie a upray toku* (Hydrology and River Training), Prague: VUT, 1952.
[8] *Pallas Nagy Lexikon* (Pallas Great Encyclopedia), Vol. VII, Budapest, 1894, p. 28.
[9] *Vizrajzi Evkonyv 1960* (Hydrographic Yearbook 1960), Vol. LXV, Budapest, 1961, p. 277.
[10] *Hydrographisches Jahrbuch von Osterreich 1962*, 70. Band, Wien, 1963, pp. 26–28.

[11] Halasi-Kun, G.J., "Computation of peak discharge from smaller watersheds in East-Czechoslovakia," *Proceedings of University Seminar on Pollution and Water Resources*, Vol. II (1968/69), New York-Trenton: C.U. & State of N.J.

where the permeability is comparatively low because the formations are usually well indurated rocks. The Mesozoic formations are better aquifers (more permeable), and therefore their coefficient has a smaller value. The Tertiary formations, being usually only slightly lithified, have an even smaller coefficient, and the Quaternary sediments have the smallest. Exceptions from this rule are the early Tertiary formations of the "Flysch" type, which have a very high content of silt, which gives them an extreme water confining character, and therefore the highest runoff values occur in this region. Any igneous rocks will have values similar to the impermeable Paleozoic sedimentary rocks, except for the tuff which is very close, hydrogeologically, to the low magnesium carbonate formations. As a further observation: the prevailing winds influence the peak flow quantities in conformity with the rules of the "snow-fence"––"windshield" phenomenon.[12] As a conclusion from the observation, it appears that the rule of surface runoff must be related in an inverse way to the permeability of the geologic subsurface of the watershed, and that the groundwater storage capacity is directly dependent on these conditions.

HYDROGEOLOGIC CONSIDERATIONS IN RUNOFF CALCULATION OF NEW JERSEY

According to the U.S. Weather Bureau's description, the storms which occur over the State of New Jersey have their origin in or near the Pacific and the South Atlantic Oceans and may be classified, generally, as thunderstorms, cyclonic (transcontinental) storms and extratropical storms. These last are due to rapid convective circulation (usually in July), are limited in extent and cause local flooding or flashy streams. The cyclonic storms are due to transcontinental air mass movements with attendant "highs" and "lows." These occur usually in the winter or each spring, and are potential flood producers over large areas because of their widespread extent. The extratropical storms, due to rapid convective circulation when a tropical marine air mass is lifted suddenly on contact with hills and mountainous terrain, cause heavy rains––usually in the summer and fall seasons. The West Indies hurricanes of tropical origin proceed northward along the coastal area accompanied by extremely violent winds and torrential rains of several days duration.

The maximum point rainfall intensity thus far recorded in the Garden State (fig. 6) shows a trend of 8–10 inches/day (200–250 mm/day) with a heavily affected area up to 20 miles by 70 miles (30 km by 105 km) in the center of the storm.[13] On the other hand, the previously studied region of Central Europe has a typical 4–5 inches/day (100–125 mm/day) peak point rainfall intensity (fig. 5) with an intensively affected surface up to 9 miles by 33 miles (15 km by 50 km) surrounding the focus of the storm. For further information, the geographic pattern of the precipitation of the most recent West Indies hurricane "Doria" in New Jersey, August 26–28, 1971, is demonstrated in figures 7–9.

HYDROGEOLOGIC CATEGORIES OF NEW JERSEY*

Most of the geologic formations in New Jersey are sedimentary rocks where the age of sedimentation has a reverse relation with permeability and a direct one with the surface runoff capacity. Therefore, the Paleozoic formations have the highest value in runoff coefficient. The

[12] Halasi-Kun, G.J., "Correlation Between Precipitation, Flood and Windbreak Phenomena of the Mountains," *Proceedings of University Seminar on Pollution and Water Resources,* Vol. I (1967/68), New York-Trenton: C.U. & St. N.J. pp. 77–87.

[13] Dunlop, D., *Hurricane Doria, Data of Storm Precipitation – New Jersey August 26–28, 1971* (Preliminary Report), New Brunswick, N.J.: Weather Bureau Office for State Climatology, Rutgers State University, 1972.

*Excerpts from article: Halasi-Kun, G.J., "Computations of Peak Floods with Inadequate Hydrologic Data," *Decisions with Inadequate Hydrologic Data,* Proceedings of the Second International Hydrology Symposium, Sept. 1972, Ft. Collins: Colorado State University, 1973.

Figure 6.—Characteristic maximum point rainfall intensity recorded in the State of New Jersey in 1882–1973[1]

Date	Origin of storm	Location	Rainfall intensity in inches	Rainfall intensity in mm
Sept. 20–24, 1882	Extratropical	Paterson	11.40	290.0
July 29, 1897	West Indies hurricanes	Elizabeth	8.73	222.0
Feb.–Mar., 1902	Cyclonic	Hanover	3.30	83.5
Oct. 7–12, 1903	Extratropical	Paterson	11.45	291.5
Do	...do	Perth Ambey	6.09	155.0
Mar. 9–22, 1936	Cyclonic	Millburn	4.56	116.0
Sept. 17–21, 1938	West Indies hurricanes	Plainfield	3.06	77.5
Do	...do	Dover	4.50	114.0
Do	...do	New Brunswick	4.81	122.0
Do	...do	Newark	4.14	105.0
Do	...do	Irvington	4.14	105.0
Do	...do	Belvidere	3.60	91.5
Do	...do	Burlington	4.64	118.0
Do	...do	Flemington	3.08	78.0
July 15–23, 1945	Extratropical	Little Falls	7.60	193.0
Do	...do	Freehold	3.61	92.0
Aug. 11–13, 1955	West Indies hurricanes	Orange	5.73	146.0
Aug. 17–20, 1955	...do	Clinton	4.75	120.5
Do	...do	Wanaque Dam	4.92	125.0
Do	...do	Canister Res.	6.24	158.5
Oct. 14–18, 1955	Extratropical	Princeton	4.49	113.5
Sept. 11–12, 1960	West Indies hurricanes	Freehold	5.19	132.0
Sept. 21–22, 1966	...do	Plainfield	5.33	135.5
May 28–29, 1968	...do	...do	5.75	146.0
August 27–28, 1971	...do*	Mt. Holly	8.80	224.0
Do	...do	Glassboro	7.93	202.0
Do	...do	Burlington	7.83	199.0
Do	...do	Trenton	7.55	192.0
Do	...do	Windsor	9.10	231.0
Do	...do	Hightstown	9.10	231.0
Do	...do	Bound Brook	9.70	247.0
Do	...do	McGuire over[2]	10.00	254.0
Do	*(24 hours point rain-	Freehold	8.00	204.0
Do	fall intensity only)	Rahway	7.90	200.5
Do	...do	Elizabeth	9.15	233.0
Do	...do	Clinton	7.55	192.0
Do	...do	Watchung	8.41	214.0
Do	...do	Springfield	9.02	230.0
Do	...do	Newark	7.83	199.0
Do	...do	Wanaque	7.28	182.0
Do	...do	Woodcliff Lake	7.06	179.0
Do	...do	Little Falls over	10.00	254.0
Do	...do	New Milford	5.93	150.5
Do	...do	Newton	5.50	140.0
Aug. 2–3, 1973	Extratropical	Bound Brook+	5.25	134.5.
Do	...do	Cranford+	6.74	171.0
Do	+(24 hours point rain-	Plainfield+	7.09	180.0
Do	fall intensity)	Chatham	7.08	180.0
Do	...do	Green Brook	9.71	247.0
Do	...do	Springfield	6.70	170.0

[1]*Climatological Data,* U.S. Dept. of Commerce, NOAA, Environmental Service, Volumes 1–78, 1973; *Survey Report for Flood Control* (Passaic, Raritan, Rahway and Elizabeth Rivers), U.S. Corps of Engrs., New Yori, 1972; *A Summary of Peak States and Discharges for the Flood of Aug. 1973 in New Jersey,* Trenton: U.S.G.S., 1973.

[2]Information from U.S. Air Force.

(See figures 6–9 for

Station	Precipitation in inches: August 26–27									
	20–24	00–01	01–02	02–03	03–04	04–05	05–06	06–07	07–08	08–09
Cape May 1NW*	0.10	0.40	1.60	0.20	0.50	.....	.....	.....	.....	.....
WSO Atlantic City	.04	.13	.18	.34	.37	0.06	0.12	0.01	0.02	0.03
WSO Wilmington, Da	.29	.16	.27	.33	.03	.09	.10	.22	.32	.47
Glassboro	.06	.25	.60	.11	.15	.....	.04	.06	.26	.33
WSFO Philadelphia, Pa	.02	.14	.28	.47	.19	.39	.43	.26	.17	.51
Laurelton	.05	.01	.10	.12	.12	.14	.08	.31	.22	.33
Mt. Holly*	.....	.....	.....	.10	.40	.30	.50	.90	.40	.80
WSO Trenton	.05	T	.02	.15	.34	.23	.52	.31	.06	.25
Windsor*	.....	.....	.....	.20	.30	.70	.80	.90	.30	.20
Freehold*	.10	.....	.....	.10	.20	.10	.20	.30	1.30	1.70
Hightstown*	.....	.....	.....	.40	.20	.40	.40	.80	.60	.10
New Brunswick	.....	.01	.19	.16	.15	.25	.34	.70	.25	.26
Palley 2E Neshanic*	.10	.....	.....	.10	.10	.30	.30	.30	.40	.30
Bound Brook*	.....	.....	.....	.....	.10	.10	.20	.50	.30	.40
Rahway	.....	.30	.01	.01	.04	.12	.02	.05	.23	.56
Clinton*	.10	.....	.....	.....	.....	.10	.20	.30	.10	.80
WSO Allentown, Pa	.07	.07	.14	.09	.14	.40	.25	.13	.05	.13
Watchung	.....	.....	.....	.....	.02	.17	.11	.13	.15	.50
Springfield	.....	.....	.....	.....	.04	.12	.06	.10	.08	.43
Elizabeth	.....	.....	.07	.01	.05	.11	.04	.03	.18	.33
Columbia*	.....	.....	.....	.10	.10	.10	.10	.20	.20	.10
WSO Newark	.04	.02	T	.02	.04	.05	.01	.12	.21	.40
Essex Falls	.....	.....	.....	.04	.02	.04	.06	.07	.33	.43
New Milford	.....	.....	.....	.....	.12	.08	.....	.03	.09	.18
Woodcliff Lake	.....	.....	.....	.....	.05	.07	.02	.10	.02	.18
Newton	.....	.....	.....	.01	.07	.07	.15	.11	.29	.15
Wanaque	.....	.....	.....	.....	.....	.....	.12	.08	.15	.40

NOTES:
*Fischer-Porter punch tape data.
T – traces.
Time – E.S.T.

hourly rainfall data from selected stations

further information)

Precipitation in inches: August 26–27														
09–10	10–11	11–12	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24
....	....	....	....	....	....	....	....	....	....	....	....	0.30	0.50	1.50
0.11	0.05	T	T	....	....	....	....	....	....	....	....	....	.22	1.18
.20	.43	0.10	0.21	0.06	0.09	0.04	....	0.14	T	....	0.01	.10	.13	.27
.36	.85	.96	.65	.27	.03	.03	0.10	.11	....	0.01	....	.02	.15	.37
.13	.90	.30	.08	.11	.04	.02	.01	T	0.01	.03	....	T	.06	.24
.03	.06	T	....	....	....	....	....	....	....	....	....	....	T	.14
.70	.40	.90	.70	.80	.30	.30	....	.10	....	....	....	....	....	....
.24	.82	1.11	.31	.04	.26	.01	.01	.02	T	.01	T	T	.01	.07
.40	.70	1.50	.60	.10	....	.10	....	....	....	....	....	....	....	.10
.70	.30	.30	....	.10	.80	....	.10	....	.20	....	....	....	....	....
.40	.50	1.20	1.40	.40	.20	.10	....	.10	....	....	....	....	....	.10
.74	.94	1.39	.07	.09	.27	....	....	....	....	....	.01	....	.01	....
.40	.80	.70	1.50	.20	.10	.10	....	....	....	....	....	....	....	....
.40	.30	.80	1.00	.50	.10	.10	.10	....	.10	....	.10	....	.10	....
.83	.40	.75	1.75	1.30	.18	.06	....	.08	....	....	.02	.01	.01	.01
.30	.20	.30	.40	.30	.10	.10	.10	.10	....	....	....	....	....	....
.27	.22	.18	.17	.12	.02	.08	.18	.08	T	.11	.04	T	.05	.20
.66	.35	.53	.70	.95	.15	.06	.11	.06	....	....	.01	....	....	....
.76	.37	.70	1.15	1.36	.18	.06	.04	.09	....	....	....	....	....	....
.76	.78	.78	1.40	1.68	.48	.08	.06	.04	....	.14	....	....	....	....
.20	.20	.50	.20	.20	.10	.10	.10	.10	.20	.10	....	....	....	....
.57	1.03	.74	1.35	.94	.07	.01	.06	T	.01	.26	.01	.01	T	....
.48	.35	.93	.99	.40	.02	.04	.20	....	.05	.03	....	.02	.03	.08
.26	.11	.35	.53	1.90	.10	.11	.04	....	....	....	.10	....	....	....
.23	.07	.45	.95	1.40	.07	.03	.09	.01	.01	.03	.13	.06	.01	.01
.33	.76	.46	.31	.23	.16	.09	.01	.11	.02	....	.02	....	....	.10
.15	.15	.30	1.25	.10	.07	.08	.10	.03	.02	.03	.05	.02	.02	.02

Hurricane Doria, New Jersey, August 26–28, 1971 hourly rainfall data for selected stations

(See figures 6–9 for further information)

Station	Percipitation in inches: August 28							24 hrs rainfall intensity in inches
	00–01	01–02	02–03	03–04	04–05	05–06	06–07	
Cape May 1NW*	.....	0.10	.....	.....	.....	.....	.....	5.00
WSO Atlantic City	0.38	.08	0.01	T	0.01	T	.....	2.99
WSO Wilmington, Da	.28	.49	.14	0.12	T	.....	.....	4.11
Glassboro	1.15	1.80	.23	.08	.....	0.01	.....	7.80
WSFO Philadelphis, Pa	.60	.73	.38	.07	T	.....	.....	5.68
Laurelton	.53	.67	.08	.04	.02	T	.....	2.75
Mt. Holly*	.10	.60	.60	.10	.20	.....	.....	8.80
WSO Trenton	.39	.92	1.60	.28	.06	.....	.....	7.53
Windsor*	.60	1.20	.60	.....	.30	.....	.....	9.10
Freehold*	.30	.90	.50	.....	.10	.....	.....	8.00
Hightstown*	.40	1.10	.70	.10	.10	.....	.....	5.10
New Brunswick	.....	.....	.....	.....	.....	.....	.....	over 6.00
Palley 2E Neshanic*	.20	.40	1.20	1.70	.30	.10	.....	8.90
Bound Brook*	.....	.30	.80	2.20	1.40	.20	.....	9.50
Rahway	.01	.10	.47	.90	.13	.05	0.02	7.89
Clinton*	.90	.70	.60	.70	.70	.60	.10	7.30
WSO Allentown, Pa	.19	.30	.32	.39	.25	T	.....	3.88
Watchung	.01	.14	.70	1.45	1.12	.63	.04	8.41
Springfield	.....	.10	.76	1.53	1.12	.37	.03	8.90
Elizabeth	.....	.07	.53	1.00	.70	.10	.04	9.15
Columbia*	.10	.10	.30	.30	.50	.50	.10	4.30
WSO Newark	.04	.38	.90	.62	.06	.04	T	7.83
Essex Falls	.09	.45	.....	.....	.....	.....	.....	over 5.15
New Milford	.....	.11	.69	1.01	.21	.11	.....	5.93
Woodcliff Lake	.01	.16	1.13	.89	.68	.34	.01	7.06
Newton	.19	.17	.28	.72	.78	.21	.04	5.50
Wanaque	.01	.05	.15	1.00	2.25	.55	.....	7.28

NOTES:
*Fischer-Porter punch tape data.
T – traces.
Time – E.S.T.

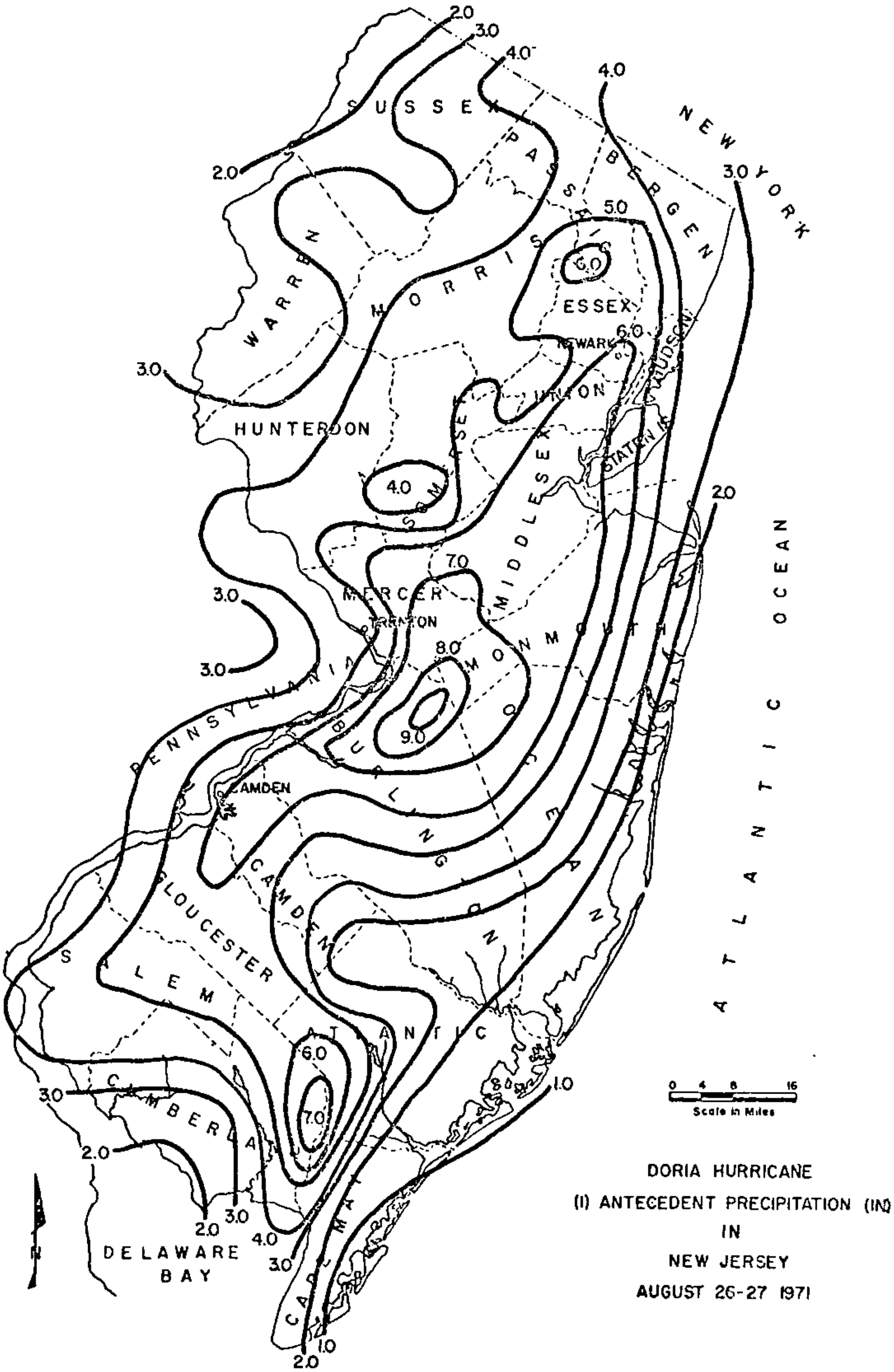

Figure 7.—Doria Hurricane in New Jersey, August 26–27, 1971.

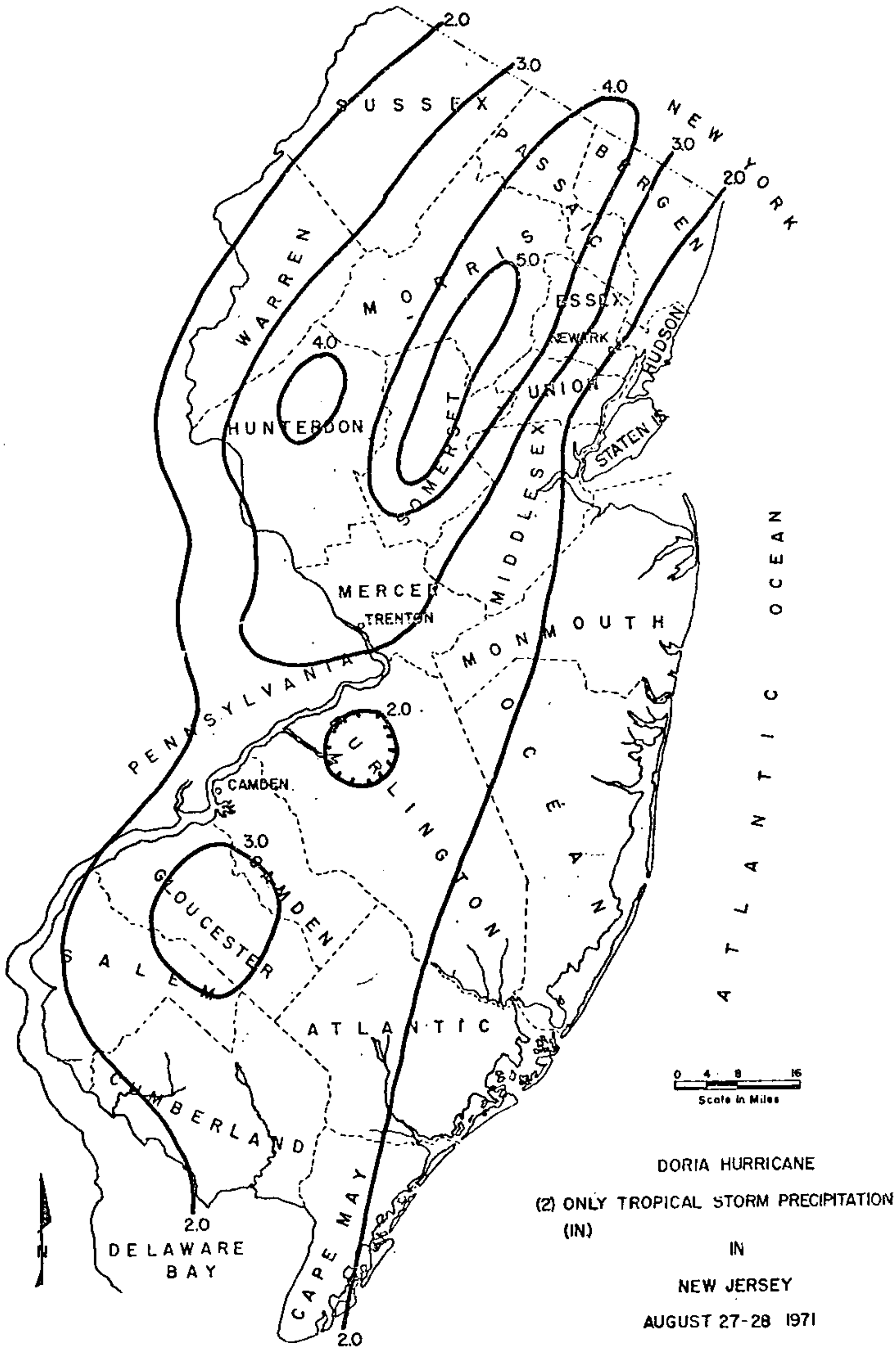

Figure 8.—Doria Hurricane in New Jersey, August 27–29, 1971.

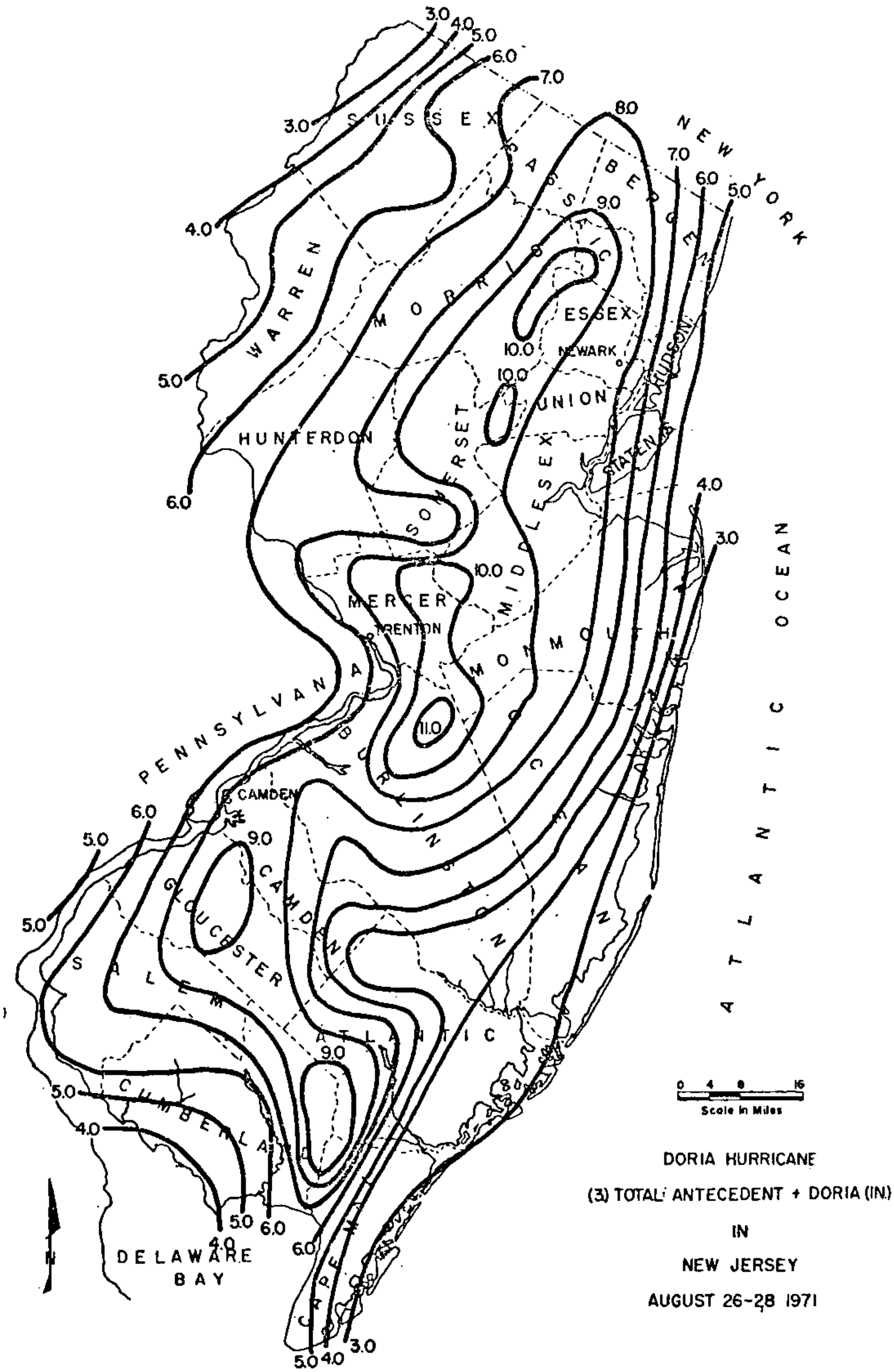

Figure 9.—–Doria Hurricane in New Jersey, August 26–28, 1971.

Mesozoic formations are distinguished by higher permeability and lower value of flood flows. The Tertiary formations have even more groundwater storage capacity and less surface runoff, and the lowest runoff coefficient is attributed to the Quaternary sediments. The igneous rock formation's hydrologic character can also be categorized according to the age. In New Jersey the Cambrian and Precambrian igneous rocks belong to the Paleozoic sedimentary formations, from the viewpoint of surface runoff. The Triassic igneous rocks, together with the Triassic Stockton sedimentary formations, constitute a separate runoff category. The general geologic pattern of the Garden State is depicted in figure 10.

Though we may deem hydrologic classification to be very simple, reality is to the contrary. Special attention is needed to establish the proper categories for the formations of the following groups.

Carbonate formations are the first type of rocks which should be analyzed carefully. They are characterized by calcium and magnesium content. These sedimentary rocks are similar to the crystalline rocks in that they have almost no primary porosity. However, owing to earth movements and destructive weathering processes, they commonly contain numerous secondary openings in the weathered zone near the surface. Solution is the chief weathering agent in carbonate rocks. Limestone (less than 50 percent magnesium content) and dolomite (more than 50 percent magnesium content) are relatively soluble in slightly acid water. Rainfall contains carbon dioxide dissolved from the atmosphere making it a weak carbonic acid which is increased by more carbon dioxide and organic acids from the soil. Natural water is an effective solvent of carbonate rocks and it may erode channels or openings of considerable size and extent. The occurrence of the solution openings is extremely irregular. At a later stage these increased openings, cavities and caves, have a tendency to collapse. Concerning the runoff coefficient values, the rule of age applies to these formations in the Garden State, too, because in New Jersey the Karst formations are almost nonexistent. Precambrian limestone has a higher runoff coefficient than the Devonian one. The lowest runoff coefficient can be observed at the Mesozoic formations. It must be menthioned that a high content of magnesium particles has a water confining tendency which is quite important. For example, in the upper layer of Kittatinny limestone formations in some areas, as in Lopatcong Valley in Warren County, this can be the explanation for the higher surface runoff values.

The other characteristic formations which do not follow the previously set pattern are the clay and marl formations. The basic characteristic of these two groups——especially that of clay——is that they contain a high percent of silty particles (smaller than 1/16 mm) of crystalline origin (composed of hydrous aluminum, magnesium, iron or similar silicates) with plastic properties, and they have a water confining quality. The marl formations are essentially calcareous clay (silt) or intimate mixture of clay (silt) and particles of calcite or dolomite, usually fragments of shells, fine-grained calcareous sands, and sands containing glauconite. Both groups have an upgrading effect on the runoff coefficient at the formations in which they occur.

Finally, the uppermost subsurface layers: the soil horizons, their thickness, permeability or water confining character can completely alter the hydrogeologic conditions as in the region of Gloucester and Salem counties, Southern New Jersey. In this region an extensive accumulation of clay in the soil horizon is the primary cause of peak floods.

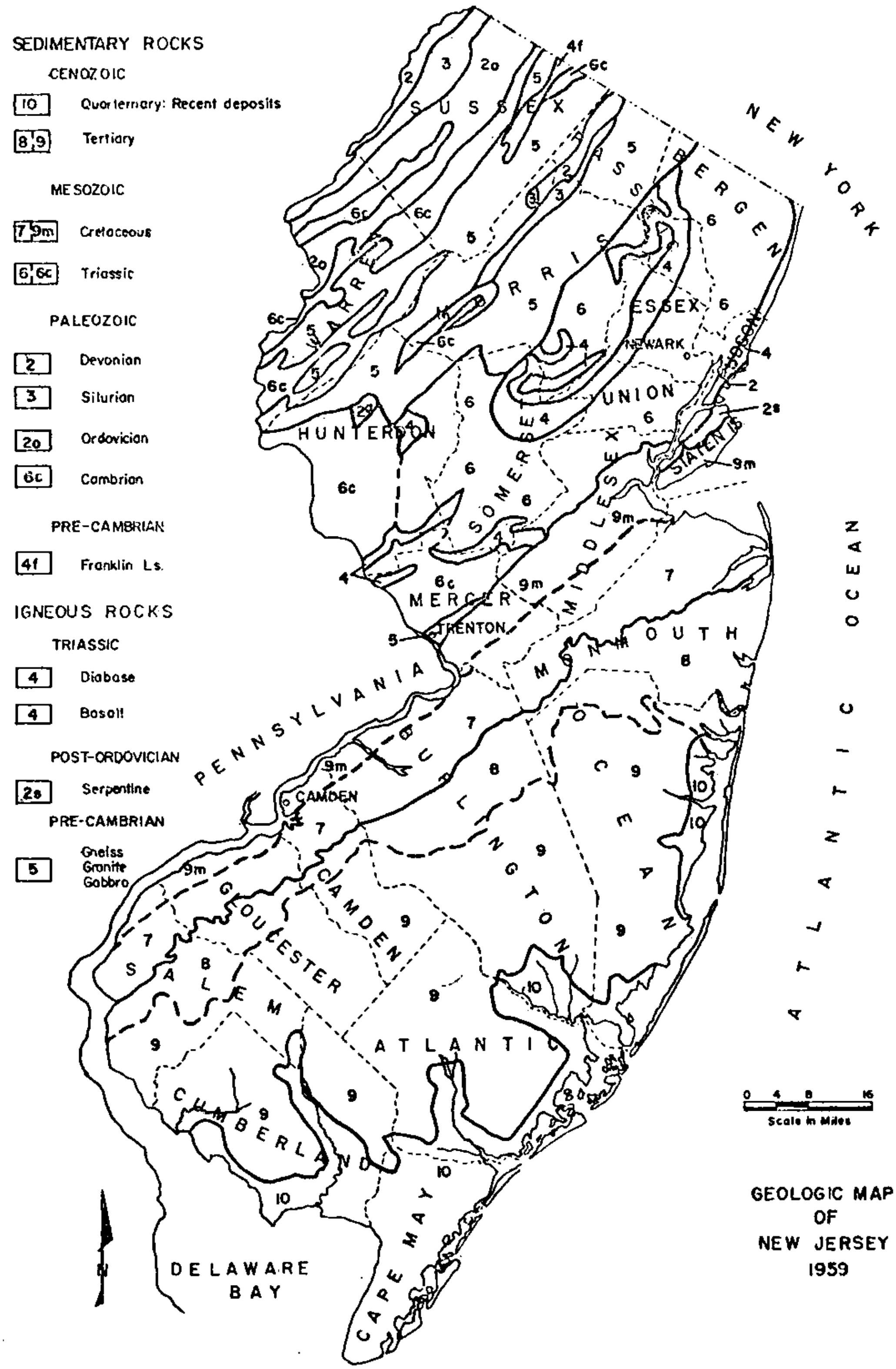

Figure 10.—Geologic Map of New Jersey, 1959.

In accordance with the hydrologic characteristics of the geologic formations and based on collected peak runoff data in the years 1882–1972, it seems that ten 100-year peak flood flow regions can be established in New Jersey (fig. 11).[16]

These generalized regions are the followings:

(1) Region of Kaolinite, very argillaceous limestone or *clay* as in Salem County.

Paleozoic: Cambre-Ordovician Kittatinny Limestone in Warren County, where Lepatcong Valley including Buckhorn Creek drains the adjacent area (especially Lower Pohatcong Valley).

Mesezoic: Triassic argillaceous Brunswick Formation in Hunterdon and Mercer Counties.

Tertiary Clay in Salem County.

Runoff coefficient values: (1,400–2,600) 2,000 (or 147 for runoff formulas given in metric system).

(2) *Shales and Schist. Lockatong* Formation and *Cretaceous Clay.* Less 16 percent porous limestone or clayey area in Monmouth and Salem Counties (part not included in Region number 1).

Paleozoic: Ordovician – Martinsburg Shale, Manhattan Schist; Silurian – Green Pond and Shawangunk Conglomerates; Devonian – Esopus Grit and Skunnemunk Conglomerates; Igneous – Precambrian Gabbro and Post–Ordovician Serpentine.

Mesozoic: Triassic Conglomerates, Lockatong Formation and silty Brunswick Formation in the Saddle River Valley; Cretaceous Clays (Woodbury Clay and Marshalltown Marl) highly glaucenitic and micaceous (similar to Flysch).

Runoff coefficient values: (1,200–1,400) 1,300 (or 100 for runoff formulas given in metric system).

(3) Paleozoic: *Unweathered Igneous Rocks* (Precambrian Gabbre, Granite, Byram, Losee and Pochuck Gneiss: Biotite Gneiss, Amphibolite, Microcline Gneiss, Sillimanite Gneiss, Pyroxene Granite, Skarn, Syenite––see also Region number 5); Silurian and Devonian shales and *slates; Sandstones* of Cambro-Devonian origin (Hardyston Sandstones; Longwood Shale, High Falls Formation; Kanouse Sandstone, Bellvale Sandstone, Pequanac Shale).

Mesozoic: *Cretaceous Marls* (Merchantville Clay, Navesink Marl); *Diabase Dikes.*

Runoff coefficient values: (1,000–1,200) 1,100 (or 81 for runoff formulas given in metric system).

(4) Paleozoic: *Igneous Rocks* (Precambrian Granite, Byram, Losee and Pochuck Gneiss: Alaskite, Hornblende Granite, Hypersthene-Quartz-Andesine Gneiss, Quartz-Oligoclase Gneiss, Granodiorite Gneiss, Pyrexene Syenite); Precambrian Franklin Limestone (marble); *Dolomitic* Kittatinny Limestones: especially Cambrian Allentown and Ordovician Epler Formations in Sussex County; Late Silurian Formations (Decker Limestone, Bossardville, Manlius, Rondout, Pexono Island); Devonian (Marcellus Shale, New Scotland and Stormville Formations, Port Ewen Beds).

Mesozoic: *Triassic Stockton* Formation and silty Brunswick Sandstones (in Essex and Union Counties); Igneous rock formations of Triassic origin (Diabase, *Basalt*) and Velcanic Breccia, Wissahicken Gneiss; *Cretaceous sandy clays* (Red Bank and Tinton Sands).

[16] Thomas, D.M., *Floods in New Jersy, Magnitude and Frequency,* Water Resources Circular 13, Trenton: U.S. Geological Survey-State of New Jersey, 1964.

Water Resources Data for New Jersey: Part 1: Surface Water Records, Trenton: U.S. Geological Survey – State of New Jersey. Published each year from 1961 to 1973.

Floods of August and September 1971 in New Jersey – open File Report. Trenton: U.S. Geological Survey – State of New Jersey, 1972.

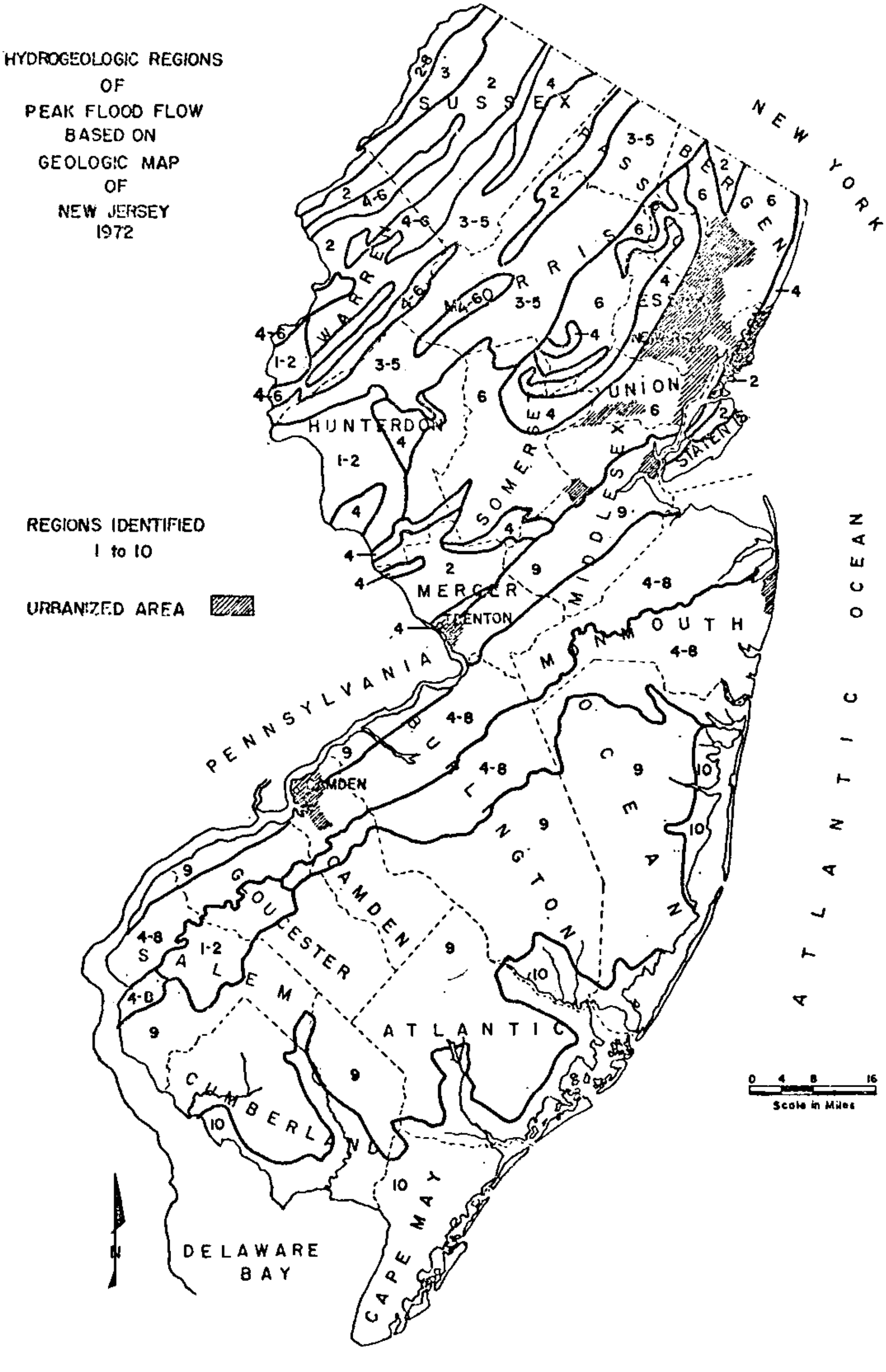

Figure 11.––Hydrogeologic regions of peak flood flow based on geologic map of New Jersey, 1972.

Tertiary: *Paleogene* (Eocene) *Marls* (Hornerstown, Manasquan, Shark River).

Runoff coefficient values: (850–1,000) 950 (or 70 for runoff formulas given in metric system).

(5) Paleozoic: *Weathered Igneous Rocks* (Precambrian Granite, Byram, Losee and Pochuck Gneiss: Biotite Gneiss, Amphibolite, Sillimanite Gneiss, Pyroxene Granite, Skarn, Graphite Schist – see also Region number 3); Ordovician-Devonian *Limestones; Tuff* (Jacksonburg Limestone, Oriskany, Becraft Limestone, Coeymans Formation and Onondaga Limestone); Dolomitic Kittatinny Limestones: especially Cambrian Lower Allentown and Ordovician Rickenbach Formations (see also Regions number 4 and number 6).

Runoff coefficient values: (600–850) 800 (or 59 for runoff formulas given in metric system).

(6) Paleozoic: Kittatinny Limestones: especially Cambrian Leithsville Formations in Hunterdon and Warren Counties (see also Regions number 4 and number 5).

Mesozoic: *Triassic Brunswick Formation* (see also Regions number 1, 2 and 4).

Quaternary: Early Drift?

Runoff coefficient values: (450–600) 500 (or 37 for runoff formulas given in metric system).

(7) Mesozoic: *Cretaceous clayey sands* (Englishtown, Mt. Laurel-Wenonah).

Tertiary: *Eocene clayey sands* (Vincentown Sand, Beacon Hill Gravel).

Runoff coefficient values: (375–450) 400 (or 30 for runoff formulas given in metric system).

(8) Tertiary: Miocene sand: *Kirkwood Sand.*

Quaternary: Bridgeton and Pennsauken Formations, Terminal and Recessional Moraines (?)

Runoff coefficient values: (250–375) 350 (or 26 for runoff formulas given in metric system).

(9) Mesozoic: *Cretaceous Magothy and Raritan* Formations.

Tertiary: Neogene *Cohansey Sands.*

Quaternary: Stratified and River Drifts, Cape May Formation.

Runoff coefficient values: (150–250) 160 (or 12 for runoff formulas given in metric system).

(10) Tertiary: *Cohansey Sands.*

Quaternary: *Cape May* Formation and *Beach Sand* and Gravel.

Runoff coefficient values: (100–150) 100 (or 7.3 for runoff formulas given in metric system).

The runoff coefficient values include not only the hydrogeologic but also the point rainfall intensity and the storm center characteristics. Further detailed description of the peak runoff formula is offered in Chapter number 7: Maximum Surface Flow. In the same formula, the influence of the slope of the terrain (configuration of the surface and stream-bed slope) on the drainage basin is expressed by the exponent of the watershed-area (according to its topographic character: 0.37 for plains up to 0.48 for mountains) as it will be described in the above mentioned chapter. The permeability of the soil was taken into consideration in the geologic runoff coefficient values.

OUTLINE OF THE URBANIZATION EFFECT ON SURFACE FLOW AND GROUND WATER

Extreme values (peak and lowest flow) are influenced significantly when land is converted from forest or agricultural use into a highly developed metropolitan area. It was already demonstrated by the flood control management of the Carpathian basin of the Danube River in 1840–1950 that extensive land-reclamation program including drainage and river training works of big proportion decreases substantially the retention ability and the storage capacity of the watershed not only for surface flow but also for groundwater potential. By eliminating swamp and lake areas, diminishing flood hazard regions, the peak flow increases (figures 2-4) and the length of the low flow period is extended because the surface flow is speeded up and the amount of the stored water in lakes, swamps and aquifer layers of the immediate geological subsurface is reduced drastically during periods without any precipitation.

The additional percentage of paved or improved surface including the buildings' roof area in connection with urbanization causes further changes in hydrogeologic character of the watershed. Modifying the slope characteristic by extensive landscaping and creating green belts, straightening meandering river beds to gain land and augment stream-slope by various river training programs, the surface flow conditions are even more altered.

Therefore, it is important to mention that New Jersey is the most densely populated State in the United States of America where surface flow factors due to urbanization are rapidly changing. Most recent studies based on New Jersey census, 1970 found a direct relation between the impervious land area, land-use categories and population density.[17] The findings can be interpreted that the hydrogeologic (peak runoff) coefficient due to urbanization ought to be reclassified in accordance with land-use categories. Based on surface water records for New Jersey metropolitan area in 1897–1972,[18] the peak runoff coefficient in watershed less than 100 sq. mi. (~ 260 km^2) is therefore modified as follows:

Land-use category:	*Percent impervious land area:* (according Stankowski) Low	Average	High	*Geologic runoff co-efficient* at Least
Single-family residential	12	25	40	400
Multiple-family resident	60	70	80	1,050
Commercial	80	90	100	1,300
Industrial	40	70	90	950
Public and quasi public	50	60	75	900
Conservational, recreational and open: no change.				

The runoff coefficient in a given urbanized area should be chosen either by the geologic subsurface or by the reclassified coefficient in accordance with the urbanization grade——whichever has the higher value.

On the other hand, the thermal effect of the built-in metropolitan region increases the evaporation possibilities and diminishes not only the surface flow but also the available groundwater recharge.[19] Similarly, the increased porosity of the backfilled area around constructions can have a temporary or permanent reverse effect on the peak flow.

[17] Stankowski, S.J., Population Density as an Indirect Indicator of Urban and Suburban Land-surface Modification (Manuscript), Trenton: U.S. Geol. Survey – State of New Jersey, 1971.

[18] *Water Resources Data for New Jersey:* Part 1: Surface Water Records, Trenton: U.S.G.S. – State of New Jersey, 1961 to 1972.

[19] Pluhowski, E.J., "Urbanization and Its Effect on the Temperature of the Streams on Long Island, New York," Washington, D.C.: U.S.G.S. Professional Paper 627-D, 1970.

Seaburn, G.E., "Preliminary Results of Hydrologic Studies at Two Recharge Basins on Long Island, New York," Washington, D.C.: U.S.G.S. Professional Paper 627-C, 1970.

It must be stressed that especially in watershed greater than 50 sq. mi. (~ 130 km^2), the extreme surface flow (peak and lowest) is bound rather on the land-reclamation program than on direct urbanization as I stated previously.

Finally, special attention should be paid to the effect of various water diversion rights, river training programs, regional sewage systems (trunk lines, treatment plants etc.), water supply networks, artificial flood retention areas and dam or reservoir constructions. Such water works can transform whole regions, several adjacent watersheds even of greater areas and create completely different basic conditions in surface flow and ground water management and availability as it occurred in the area of Hong-Kong, Asia[20] or that of Hamburg, West Germany.[21]

MAXIMUM SURFACE FLOW

Because of the insufficient data available on flood-peak discharge of smaller watersheds, a variety of methods have been used. However, all these methods need basic information from the watershed to predict flood flows. Time is an important element in the procedure of the unit hydrograph method because rainfall data must be available from drainage area of 20–100 sq. mi. (~ 50–260 km^2) for unit times shorter than 2–4 hours, and these data will be available only by accident. Similar difficulties are encountered with the flood frequency method (multiple regression method or flood index), since flood records of at least 50 years are needed to establish reliable results. In New Jersey, records are available for 30–40 years or less in a few watersheds and in most of the smaller drainage basins there are no records at all. Furthermore, in developing flood frequency curves for 100 year peak flood from 50 years data can have a deviation up to ± 30 percent from the experienced one. Thus the computation of flood flow for these smaller drainage basins can not give better results than the various empirical flood formulas used by hydrologists for the past century because they are based on observations and records of short duration. Therefore, the calculations based on probability and records of short periods are producing unreliable results for this size watershed.

The significance of a runoff formula based on hydrogeologic conditions is that the geologic formations give sufficient information to establish the peak flood flow value for smaller drainage basins if a direct relation between the peak flood flow and the hydrologic character of the geologic subsurface can be established. Findings in Austria and Czechoslovakia showed that the difficulties—because of the inadequate or non-existent information from the surface runoff gauging stations—can be overcome by this method with a ± 4-7 percent accuracy. In New Jersey it is convenient because the geologic information is available even for smaller areas to compute the runoff on this basis.

Researches conducted in the past decades concerned maximum flow in watersheds with area 100 sq. mi. (260 km^2) or less, where the geological conditions, topographic characteristics and rock formations permit an evaluation of peak rates of runoff from smaller watersheds, such research revealed a clear influence of these factors on the peak runoff.

[20] Wilmot-Morgan, E.P., "British Corwn Colony of Hong-Kong," *Water for Peace,* Vol. I, Washington, D.C.: International Conference on Water for Peace – May 23–31, 1967, pp. 193–204.

[21] Maniak, U., "Hydrology and Computation Methods of Flood Retention Reservoirs," *Symposium of Flood Retention Reservoirs,* March 1–3, 1967, Braunschweig, 1967.

In accordance with the findings abroad (in Central Europe in an area of 18,922 sq. mi. or 49,008 km^2)[22] and in the Northeastern United States (in an area of 7,836 sq. mi. or 20,295 km^2)[23] the correlation of the 100 year peak flow with the geologic subsurface, the topographic conditions (slopes) and the size of the watershed can be put in the following simplified equation:

$$Q = C.A^{-e} \quad \text{, where}$$

Q = 100-year peak runoff value in cft/sec. sq. mi. (or m^3/sec.km^2)

A = area of watershed in sq.mi. (or km^2)

C = coefficient depending on the geological subsurface with value:

In Central Europe at 4–5 inches/day (100–125 mm/day) point rainfall intensity and 9 miles by 33 miles (15 km by 50 km) recorded storm pattern – from 13.6 to 248 (or from 1 to 18.2 in formula given in metric system) –– figure 12.

In Northeastern United States of America at 8–10 inches/day (200–250 mm/day) point rainfall intensity and 20 miles by 70 miles (30 km by 105 km) recorded storm pattern – from 100 to 2,000 (or from 7.3 to 147 in formula given in metric system) –– figures 12 and 13.

e = topographic (slope) exponent of the watershed area depending on the topographic character of the watershed (0.32 – plains; 0.37 – slightly hilly plains; 0.44–0.46 – steeper hills and moderate mountains; 0.50 – Alpine type mountains).

The above equation can have also the following detailed form (values given in metric system):

$$Q = (P_1 \,.\, P_2) \,.\, (i_1 \,.\, i_2) \,.\, A^{-e} \,.\, (c_v \,.\, c_c) \quad \text{, where}$$

Q, A, e are given as in equation above.

P_1 = permeability factor of the soil and of the geologic subsurface with a value from 1.0 to 18.2

P_2 = urbanization factor from 1.0 to 14.0 in accordance with the impervious land-use and permeability of the geologic subsurface

i_1 = twenty four hours point rainfall intensity from 0.5 to 2.0 (0.5 for 35 mm/day; 1.0 for 125 mm/day; 2.0 for 250 mm/day)

i_2 = storm characteristic from 1.0 to 4.1 depending on the size and pattern of the extreme storms and on the wind velocity)

c_v = coefficient of vegetative cover from 0.95 to 1.05 (from 40 percent to 70 percent of watershed area covered by forest)

c_c = concentration coefficient from 0.90 to 1.05 (0.90 for elongated shape or at least 1:5; 0.95 for horse shoe-shape and 1.05 for fan-shaped watersheds)

[22] Halasi-Kun, G.J., *Die Ermittlung von Hochstabflussen fur Einzugsgebiete kleiner als 300 km^2 im Bereich der Slowakei,* Braunschweig: Leichtweiss-Institut, 1968.

[23] –––––, "Data Collecting on Water Resources and Computations of Maximum Flood for Smaller Watersheds," *Simposio Internacional Sobre la Planificacion de Recursos Hidraulicos – Ponencias,* Volume I, Mexico, 1972.

Herak, M., Stringfield, V. T., *Karst,* Amsterdam-London-New York: Elsevier Publishing Co., 1972.

Figure 12.—Peak runoff coefficient in various hydrogeologic regions

Hydrogeologic regions (formations)	Peak runoff coefficient in Central Europe* for peak runoff values in cft/sec. sq. mi.	m³/sec. km²	in New Jersey, U.S.A. cft/sec. sq. mi.	m³/sec. km²
(1) Kaolinite, Clay including argillaceous Triassic or Tertiary Paleocene Flysch.	248	17.5–18.2	2,000	147
(2) Paleozoic Shales, Schist and Mesozoic Marl . .	190	14	1,300	100
(3) Igneous Rocks (except Basalt, Diabase), Sandstones, Mesozoic Triassic Stockton Formation.	136	10	1,100	81
(4) Dolomite, Basalt and Tertiary Marl	?	?	950	70
(5) Weathered Igneous Rocks, Limestone, Tuff . .	82	6	800	59
(6) Mesozoic Triassic Brunswick Formations	?	?	500	37
(7) Mesozoic Cretaceous Clayey Sands, Tertiary Eocene Clayey Sands.	?	?	400	30
(8) Tertiary Miocene Sands and Quaternary Moraines.	34.1	1.9–2.5	350	26
(9) Tertiary Neocene Sands, Mesozoic Cretaceous Magothy-Raritan Formations, Quaternary River Drift.	25.8	1.9–2.5	160	12
(10) Quaternary Beach Sands (Cape May Formation).	13.6	1	100	7.3

*Ratio of combined effect for point rainfall intensity and size of storm pattern in the two observed regions (Halasi-Kun, G.J., "Data Collecting on Water Resources and Computations of Maximum Flood for Smaller Watersheds," *Simposio Internacional Sobre la Planificacion de Recursos Hidraulicos – Ponencias,* Volume I, Mexico, 1972, pp. 20–27).
1 to 8.2 = Eastern Czechoslovakia to New Jersey, U.S.A.

The roughness of the surface and its retardation effect on the flow is not treated separately because this phenomenon is bound on the geological formation. Therefore, this effect is part of the geological runoff coefficient "C" in the simplified equation and of permeability factor "P_1" in the detailed formula.

Analyzing the figures of the geological runoff coefficient for abroad and the Northeastern United States, the result seems to be identical in both areas studied, if we assume that the point rainfall intensity and the size of recorded storm patterns have a direct influence on the peak runoff (fig. 12). Furthermore the vegetative cover showed a ± 5 percent effect on the peak flood. Similar influence was observed concerning the form of watershed (+5 percent for fan-shaped and -10 percent for elongated form of drainage basin).[24] The urbanization causing impervious surfaces due to various construction alters the geological character of the surface and has a direct relation in increasing the surface peak flows as it was already discussed.

GROUND WATER STORAGE CAPACITY

Ground water is an important source of water supply throughout the world and it occurs in permeable geologic formations known as aquifers (water bearing formations), that is, formations

[24] Halasi-Kun, G. J., "Computation of Peak Discharge from Smaller Watersheds in East-Czechoslovakia," *Proceedings of University Seminar on Pollution and Water Resources,* Volume II, New York – Trenton: Columbia University – State of New Jersey, 1973.

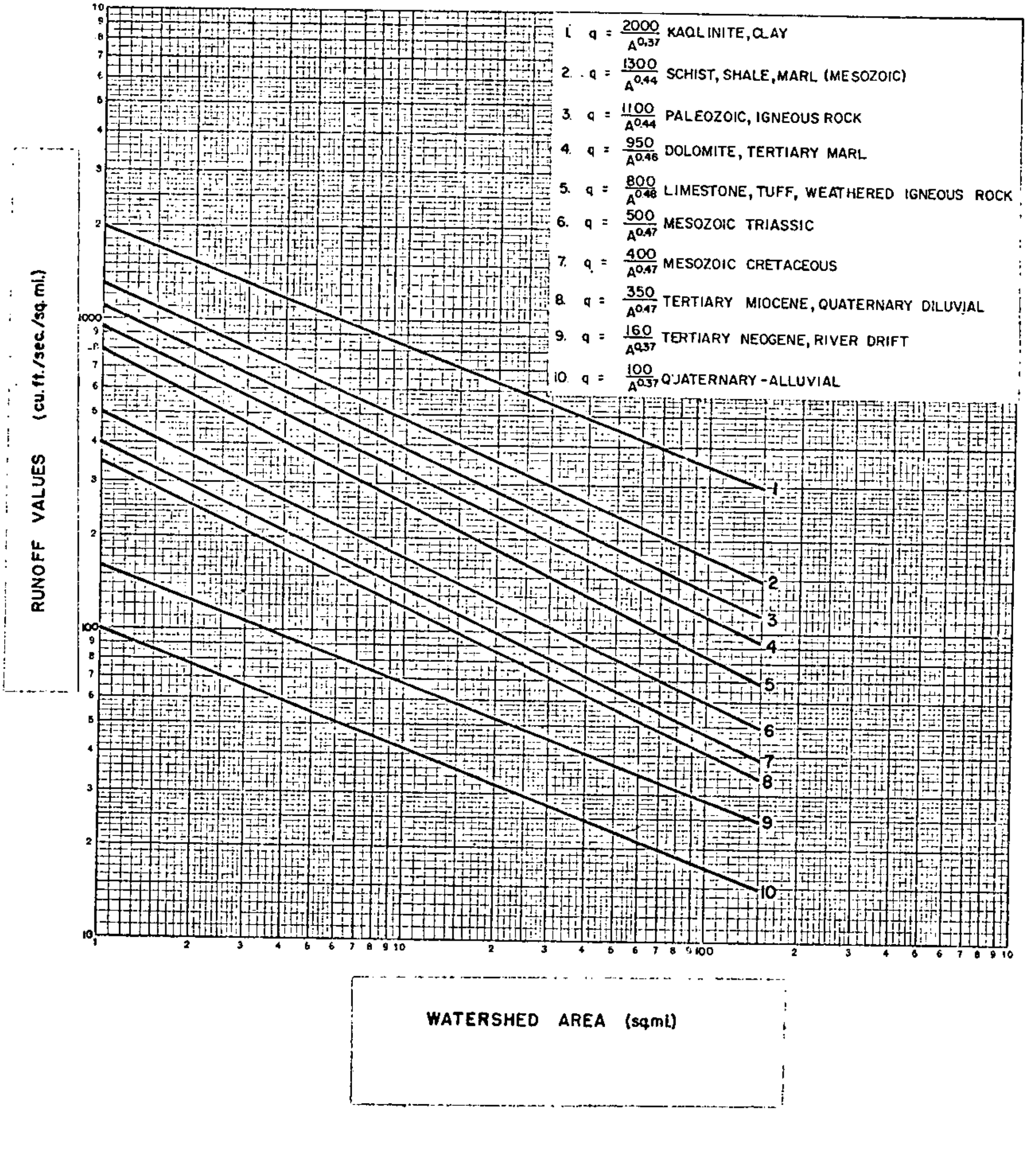

Figure 13.—-Peak runoff expected once in 100 years in New Jersey, U.S.A.

having structures that permit appreciable amounts of water to move through them under general field conditions.

From our view point, that portion of a rock or soil not occupied by solid mineral matter may be occupied by ground water. These spaces are known as voids, interstices, pores, or pore spaces and they are characterized by their size, shape, irregularity, and distribution. The original or primary voids had been created by geologic processes governing the origin of the geologic formation and are found in sedimentary and igneous rocks. After the rocks were formed, secondary voids developed as joints, fractures, faults, solution openings, and openings formed by plants and animals or pores caused by man's activity—earth works (excavation and backfill) and mining operations. Capillary and subcapillary voids will be not treated here because their influence on water storage capacity is less significant.

It is estimated that 97.54 percent of all fresh water on the Earth is ground water and half of this amount is available at a depth of less than half mile under the surface.[25]

Ground water constitutes one portion of the Earth's water circulatory system called the hydrologic cycle. Water-bearing formations (aquifers) of the Earth's crust act as conduits for transmission and as reservoirs for storage of water. Water enters these formations from earth's surface or from bodies of surface water, after which it travels slowly for varying distances until it returns to the surface by action of natural flow, pressure, plants, or man.

Water within the ground moves downward through the unsaturated zone under the action of gravity, whereas in the saturated zone it moves in a direction determined by surrounding hydraulic situation. Ground water discharge occurs either by gravitation, under pressure (artesian wells, etc.) or by pumping from wells. The latter constitutes the major artificial discharge of subsurface water.

Shortages of ground water in areas of excessive draft emphasize the importance of correct estimates and proper development, regulation, and protection of supplies in order to insure the continued availability of this key natural resource. Ground water usage has increased at an accelerating rate in recent years, and indications are that the trend will continue. For example, in accordance with U.S. Geological Survey, 600 million gallons per day ground water was registered in New Jersey in 1965.[26] This quantity was only about 10 percent of the total fresh water use but shows a 24 percent increase for the past decade.

Before discussing the ground water storage estimate in New Jersey, it has some merit to review the hydrogeologic, rainfall and storm conditions of both observed areas (East-Czechoslovakia and New Jersey) governing the peak and low surface flows.

Research conducted by the author in Czechoslovakia and West Germany in the 1950's and 1960's confirmed the principle that in rural areas the 100-year peak runoff of smaller watersheds has up to a 90–95 percent dependence on permeability of geologic subsurface of the watershed and in addition on point rainfall intensity and configuration of the terrain. The influence of vegetative cover and the form (concentration) of the watershed were already mentioned. Local configuration

[25] Doxiadis, C. A., "Water and Environment," *Water for Peace,* Volume 1, Washington, D.C.: International Conference on Water for Peace – May 23–31, 1967, pp. 33–60.
[26] Todd, D.K., *The Water Encyclopedia,* Port Washington: WIC, 1972, p. 232.

of the terrain, elevation above sea level, and average yearly rainfall values of the drainage basin had far less influence on the 100-year flood flow.

Further importance of these basic formulas is that they were established according to the geologic subsurface and the point rainfall intensity of Central Europe for watersheds less than 120 sq.mi. (310 km^2).[27] Finally, the basic formula is applicable not only for New Jersey conditions[28] but its validity was confirmed also for Australia.[29]

GROUND WATER ESTIMATE IN NEW JERSEY

It is obvious that the rate of surface runoff must be related in an inverse way to the permeability of the geological subsurface of the watershed; and the quality and quantity of ground water storage is directly dependent on these conditions. Based on over 90,000 well-record files of domestic and industrial wells throughout the State of New Jersey, USA (area 7,836 sq.mi. or 20,295 km^2) from a period of 1947–1973, the ground water availability in rock formations from Precambrian through Triassic in age and from unconsolidated sediments from the Cretaceous to the present, can be estimated. Comparison of large statistical samples of well-records in the rock formations to a depth of as much as 1,600 ft (or 500 m) has provided a means of estimating the ground water potential of areas underlain by specific rock types.[30] Several of these estimates of ground water availability have been tested against the experience in areas of suburban development during times of drought which occurred 1961–1966. There is sufficient consistency in the results so that underlying rock and sediment types may be determined from well data where they are otherwise concealed by soil and overburden.

Areal distribution of ground water in New Jersey may be described in accordance with the physiographic provinces of the Garden State:

(1) The Appalachian Highland and Valley Province in the North is the poorest region for ground water supply. The Paleozoic igneous rocks yield about 120,000 gallons day per sq.mi. and even in case that these rocks are extremely weathered, they do not give more than 300,000 gallons day per sq.mi. In the valleys in the area of Kittatinny Limestone, the yield is varying from 170,000 to 450,000 gallons day per sq.mi. according local conditions (calcium and magnesium content of the limestones, stratified drift, etc). The Paleozoic Shales' capacity is below 100,000 gallons day per sq.mi. The whole province is a region of rugged topography with numerous springs, shallow wells and widespread stratified deposits with various capacities.

[27] Halasi-Kun, G.J., "Computation of Peak Discharge from Smaller Watersheds in East-Czechoslovakia," *Proceedings of University Seminar on Pollution and Water Resources*, Vol. II (1968/69), New York – Trenton: Columbia University – State of New Jersey.

[28] ––––––, "Computations of Peak Floods with Inadequate Hydrologic Data," *Decisions with Inadequate Hydrologic Data*, Ft. Collins, Col.: Water Resources P., 1973, p. 57–73.

[29] McMahon, T.A., "Water Yield and Physical Characteristics of Catchments," *Civil Engg. Trans., Institution of Engrs. Australia*, Vol. CE 11 (1969), No. 1, pp. 74–81.

[30] Halasi-Kun, G. J., "Ground Water Computations in New Jersey, USA," *Nordic Hydrology*, I (1974).

Miller, J., *Geology and Ground Water Resources of Sussex County*, Geol. Bulletin No. 73, Trenton: New Jersey State, 1973.

Widmer, K., *Geology and Ground Water Resources of Mercer County*, Geol. Report No. 7, Trenton: State of New Jersey, 1965.

Rhodehamel, E.C., *A Hydrologic Analysis of the New Jersey Pine Barrens Region*, Water Resources Circular No. 22, Trenton: State of New Jersey and U.S.G.S., 1970.

Barksdale, H.C., Greenman, D.W., Land, S.M., Milton, G.S., Outlaw, D.E., *Groundwater Resources in the Tri-State Region Adjacent to the Lower Delaware River*, Special Report No. 13, Trenton: State of New Jersey, 1958.

Cost Analysis of Ground-Water Supplies in the North Atlantic Region, 1970, Geol. Survey Water-Supply Paper 2034, Washington, D.C., 1973.

(2) The Piedmont Province comprising the central part of the State (confined from the North by Ramapo Valley – Bernardsville – Clinton – Holland and from the South by Staten Island – New Brunswick N. – Trenton) is distinguished by higher yielding Mesozoic Triassic Brunswick Formation (350,000 gallons day per sq.mi.) and by lower yielding Basalt and Diabase including Triassic Stockton Formations in Hunterdon County and silty Brunswick Sandstones in Bergen, Essex and Union Counties (170,000 to 250,000 gallons day per sq.mi.). Extremely low yield of less than 100,000 gallons day per sq.mi. is characteristic for Lockatong and argillaceous Brunswick Formations in Hunterdon, Mercer and Middlesex Counties. Many drilled wells of moderate depth are supplied from joints in the crystalline rocks and in fault zones. Many shallow dug wells are supplied from surface deposits or from the upper decomposed part of the bedrock. Some wells in Triassic Sandstones yield rather large supplies. Special attention should be given to the geological "Lake Passaic" in the Upper Passaic Valley where large diluvial deposits of gravel (100–200 feet or 30–60 m deep) topped by heavy clayey layers (30–40 feet or 9–12 m) are potential ground water storage areas.

(3) In the Atlantic Coastal Plain Province the water is derived in rather large quantities from Mesozoic Cretaceous (Magothy-Raritan) Formations, Tertiary Neogene Sands and Quaternary deposits, chiefly sand and gravel interbedded with clay. Large supplies are obtained from Tertiary Cohansey Sands near the Atlantic Coast. The aquifers yield 500,000 to 850,000 gallons day per sq.mi. The large area of Pine Barrens including Wharton Tructs yield 610,000 gallons day per sq.mi. also for a longer period.[31]

This general description of the three physiographic provinces has no bearing on exceptional high capacity wells and the characteristic yields are given for the periods of drought. Further significance of these well-records is that they include the unsuccessful wells attempting to get amounts of water in excess of 100,000 gallons day. Approximately 15 percent of the total recorded number of wells—especially in Northern New Jersey—fell in this category and gives valuable information about the ground water conditions of the different geological formations. Many of these wells in Northern New Jersey have been completed in the thick Pleistocene outwash deposits and most of the rock wells also have relatively thick covers of Pleistocene sands, gravels, and tills. The Pleistocene wells that have been unsuccessful (107 wells) have been drilled in thick tills, or silt-clogged outwash. Rock wells were unsuccessful (112 wells) because of a thick till cover over the underlying rock.[32]

Finally, the general location of the watershed has a decisive influence on the ground water availability. In the head water area the ground water quantity has a decreasing tendency due to the adjacent lower lying regions. In lower courses area the ground water capacity may be increased by the additional ground water flowing from the abutting higher watertable area.

The gathered statistical data on ground water availability in New Jersey is based also on pumping tests and records of the wells, and their figures can be accepted on the assumption of an average yearly rainfall 45 inches (1,125 mm)—which value can drop for two consecutive years of drought even to a yearly 34 inches (850 mm). The ground water is available in the northern half (rock country) of the area studied only to a depth of 550 feet (180 m) below the surface. Boring tests proved that below that level there is a very marked decrease in fractures and fissures from which

[31] Rhodehamel, E.C., *op. cit.*, p. 27.

[32] Widmer, K., "Study of Groundwater Recharge in Santa Clara Valley, Calif. and Its Application to New Jersey," *Journal American Water Works Association*, Vol. 58, No. 7 (1966), pp. 893–904.

water can be obtained. There is also evidence, of course, that certain fracture zones may give abundant water at great depth, but these fractures are those such as the Triassic border fault or others that have been mapped for years. In the coastal half (coastal plains) of this examined region, the limit in accordance with the aquifer layers is from 600 to 3,000 feet or 190 to 1,000 m (from West to East) below the sea level.[33]

It must be stressed that along fracture zones and faults, there is always a possibility for more ground water due to a greater permeability in the formations even for longer distances. The same principle applies for border lines delineating the different geologic formations since the contact of these formations is never uniform and in most cases has greater voids than the adjacent area. Consequently, this permits easier mining or outcrop of ground water. Generally, these zones include the regions of springs and wells of greater capacity. Therefore, the boundary lines in figure 11 (indicating the various main hydrogeologic regions) are also the zones of greater ground water potential, especially in water poor regions. Similar attention should be given to the limestone areas with numerous secondary openings and caverns as is the case along the Kittatinny formations in Northwestern New Jersey.

The evapotranspiration and interception average 18–22 inches (450–560 mm) yearly, and the yearly average runoff is up to 22 inches (550 mm) from the annual precipitation. The ground water availability indicator has a value from 0 to 18 inches (0 to 450 mm) yearly, depending on the permeability and storage capacity of the geological formations.[34]

Despite the fact that the estimate of the regional availability is complicated by factors such as recharge or transmissability from adjacent areas, there is clear evidence in correlation of permeability of geological formations with surface peak runoff and ground water availability. The comparison can be based only on average values of permeability because they are measured under difficult conditions and in various geological formations which are commensurate to formations used in establishing of runoff formula coefficients and ground water availability indicators (fig. 14). It must be pointed out that the various formations are also, in general, already mixed or interwoven even in smaller drainage areas. The uneven surface weatthering, artificial impervious surface due to urbainzation, the disintegrated underlying rock formations at various depths and the possible present faults add to the difficulty of establishing a practical average value of permeability, ground water availability or surface runoff even for a smaller watershed.

The minimum ground water availability in 1,000 gallons day per sq.mi. given in figure 14 is based on records of longer period of drought such as the 1961–1966 drought of New Jersey. For years with average rainfall, these values may be increased by 50 percent. On the other hand, the available quantity of ground water for practical planning purposes can be augmented further by additional 50 percent to total 200 percent, assuming that the ground water will be "mined" (taken out more than the natural supply). This type of planning can run into the danger of exhausting the stored ground water quantity, lowering the ground water table, and causing additional problems.

The various studies about surface flow showed that the geological subsurface has an effect only on smaller watersheds with an area of 100 sq.mi. (260 km^2) or less. By increasing the watershed,

[33] Barksdale, H. C., *op. cit.*

[34] Halasi-Kun, G. J., "Aspects hydrologiques de la pollution et des ressources en eau, dans les domaines urbains et industriels," *Actes du Congres: Sciences et Techniques An 2000,* Paris: SICF, 1971.

Figure 14.—Ground water availability in various hydrogeologic regions and their average permeability

Hydrogeologic regions (formations)	Ground water availability in New Jersey, U.S.A. in 1,000 gallons day/sq. mi.	mm/year	Average permeability in millidarcys (1 millimeinzer = 18.2 millidarcys)
(1) Kaolinite, Clay including argillaceous Triassic or Tertiary Paleocene Flysch.	34–50	17–25	[2]1
(2) Paleozoic Shales, Schist and Mesozoic Marl . .	less than 100	less than 47	[2]1–1.9
(3) Igneous Rocks (except Basalt, Diabase), Sandstones, Mesozoic Triassic Stockton Formation.	120	63	[2]2.5
(4) Dolomite, Basalt and Tertiary Marl	170–250	87–125	[2]4
(5) Weathered Igneous Rocks, Limestone, Tuff.	300	150	[2]4–6
(6) Mesozoic Triassic Brunswick Formations . . .	350	175	[2]6
(7) Mesozoic Cretaceous Clayey Sands, Tertiary Eocene Clayey Sands.	500	250	[2]6–10
(8) Tertiary Miocene Sands and Quaternary Moraines.	600	300	[2]10–14
(9) Tertiary Neocene Sands, Mesozoic Cretaceous Magothy-Raritan Formations, Quaternary River Drift and Cape May Formation.	700	350	[2]10–14
(10) Quaternary Beach Sands, Tertiary Cohansey Sands (Cape May Formation).	850	425	[2]18.2

Values are based on over 90,000 well-record files of domestic and industrial wells of the State of New Jersey from the period of 1947–1973. Further information, especially for regions (2), (3), (4), (5), (6), (7), (8) and (9), is in references already mentioned: articles and books of Miller, J. Jr.; Widmer, K.; Rhodehamel, E.C.; Kasabach, H.; Barksdale, H.C. In regions (2), (4) and (5) compare also: Hobba, W.A. Jr., Friel, E.A. and Chisholm, J.L., *Ground-water Hydrology of the Potomac River Basin, West Virginia*, Washington, D.C.: U.S. Geol. Survey, 1973. The form of data on average permeability makes easy comparison with figure 12. (See also: Davis, St. N., DeWiest, R.J.M., *Hydrogeology*, New York-London-Sidney: J. Wiley & Sons, 1966 and Linsley, R.K. Jr. Kohler, M.A., Paulhus, J.L.H., *Hydrology for Engineers*, New York-Toronto-London: McGraw-Hill, 1958.

the flow curves of the various hydrogeologic regions are convergent. The "geologic" character of the runoff coefficient starts to "fade away" and for a watershed of over 130 sq.mi. (340 km^2) the computations show already more than ± 20 percent error comparing with the observed values of the same area. Therefore, the use of formulas for greater drainage basins based on geologic conditions is not recommended because other factors affect the flood flow, and the influence of geological factors is less important or becomes inferior in value. Even more confined in area is the ground water availability estimate where the practical upper limit may be less than 80 sq.mi. (~ 200 km^2), depending on the surface conditions and on the complexity of the subsurface rock formations. The limit can be extended only for calculations of greater area with uniform geological subsurface.

Note that runoff—the water that appears in streams—also includes ground water discharge as well. This means that ground water is not something to which we can look as an entirely new source of water once we have fully developed the streams, but instead that is part of the same supply and must be computed and utilized accordingly.

Ground water availability in the Coastal Plains of New Jersey is quite different from that of the Appalachian Highland and of the Piedmont in the same State since several water-bearing geologic formations – topping each other and having a seaward slope – give a uniform pattern for the whole area. The ground water availability values given in figure 14 are valid in general also for the Coastal Plains if the formations in question are close to the surface. All of the Atlantic Coastal Plain Province is underlain by layers of sands, gravels, and clays which dip gently to the Southeast. Some of the aquifer layers reach from the surface in the Northwest to a 4,000 feet (1,220 m) depth at the Atlantic coast. Therefore, the water demand generally can be satisfied everywhere in this region by selecting the appropriate water-bearing formation. The selection of the aquifer depends on the accessibility and the subsurface elevation of the water-containing layer. On the other hand, along the coast any large-scale lowering of artesian pressures in the deeper aquifers and even small-scale lowering of water levels in the shallow deposits may result in salt-water contamination.

LOWEST SURFACE FLOW

The lowest flow in smaller watershed – which is important to find out the pollution effect of various polluting sources – depends, similarly, on the permeability of the geological subsurface (lithology and structure of the rock formations), the length of drought, the frequency and the amount of rain, the storage capacity of the aquifer layers, the evapotranspiration, the temperature of the atmosphere and of the soil, the retardation effect of forest and of lake and the elevation of the watershed – not to mention transfer of available water from one watershed to the other. From these few factors is also evident that reliable data about lowest flow are even more scarce for smaller watersheds than the peak ones. In general, the surface water records contain very limited amount of data pertaining lowest flows.

Most recently, several attempts were made to develop methods of defining the low-flow characteristics of streams by frequency curves of annual or seasonal minimum flows, by duration curves and by base-flow recession curves among others. Generally, it is agreed that the lowest flow characteristics are even more dependent on the geologic conditions than those of peak flows. A reliable uniformed procedure to compute these values are not yet established because of insufficient data.[35]

Despite these circumstances, there is sufficient evidence to develop a preliminary formula for lowest runoff based on records from both areas collected especially from the drought periods 1921 and 1947 in Czechoslovakia[36] and 1961–1966 in New Jersey[37] as it follows:

$$Q = C.A^{-e} \text{ where}$$

Q = lowest runoff (50 years ?) value in gallons minute per sq.mi. (or $1/\text{sec.km}^2$)
A = area of watershed in sq.mi. (or km^2)
C = coefficient depending on the geological subsurface (fig. 15):

[35]Riggs, H.C., "Low Flow Investigations," *Techniques of Water Resources Investigations of the U.S.G.S.*, Book 4, Chapter B1, Washington, D.C.: Dept. of the Int., 1972.

Sauer, St. P., "Factors Contributing to Unusually Low Runoff During the Period 1962–1968 in the Concho River Basin Texas," Washington, D.C.: U.S.G.S., Water-Supply Paper 1999–L, 1972.

[36]Dub, O., *Hydrologia, hydrografia, hydrometria*, Praha-Bratislava: SVTL, 1957.

Halasi-Kun, G.J., *Hydrologia, Kosice, 1949.*

------, *Voda v polnohospodarstve* (Water in Agriculture), Bratislava: SPN, 1954.

[37]Miller, J., *Geology and Ground Water Resources of Sussex County*, Geol. Bulletin No. 73, Trenton, 1973.

Widmer, K., *Geology of the Ground Water Resources of Mercer County*, Geol. Report No. 7, Trenton, 1965.

Rhodehamel, E.C., *A Hydrologic Analysis of the New Jersey Pine Barrens Region*, Water Resources Circular No. 22, Trenton, 1970.

Water Resources Data for New Jersey: 1961–1971, Part 1: Surface Water Records, Trenton, 1962–1972.

Kasabach, H.F., *Geology and Ground Water Resources of Hunterdon County*, Special Report No. 24, Trenton, 1966.

Figure 15.—Lowest runoff coefficient in various hydrogeologic regions

Hydrogeologic regions (formations)	Lowest runoff coefficient		
	in Central Europe	in New Jersey, U.S.A. for lowest runoff values in	
	1/sec. km^2	1/sec. km^2	gallons/min. sq. mi.
(1) Kaolinite, Clay including argillaceous Triassic or Tertiary Paleocene Flysch.	0.3–0.5	0–0.26	less than 0.8 (0–1.6)
(2) Paleozoic Shales, Schist and Mesozoic Marl . .	0.3–0.5	0–0.26	1.0 (0–1.6)
(3) Igneous Rocks (except Basalt, Diabase), Sandstones, Mesozoic Triassic Stockton Form.	less than 0.7* (0–1.1)	less than 0.4 (0–1.70)	less than 2.6 (0–10.5)
(4) Dolomite, Basalt and Tertiary Marl.	1.0 (0.5–1.5)	0.6 (0.17–0.79)	3.8 (1–4.75)
(5) Weathered Igneous Rocks, Limestone, Tuff . .	2.0 (1–2.0)	0.9 (0.62–0.91)	(3.7–5.6) (3.7–5.6)
(6) Mesozoic Triassic Brunswick Formations	4–5.58**	3.5 (2.71–5.75)	20.0 (16.5–35.0)
(7) Mesozoic Cretaceous Clayey Sands, Tertiary Eocene Clayey Sands.	less than 0.3^+	$0–10.40^+$	$0–66.0^+$
(8) Tertiary Mocene Sands and Quaternary Moraines.	less than 0.3^+	$0–10.40^+$	$0–66.0^+$
(9) Tertiary Neocene Sands, Mesozoic Cretaceous Magothy-Raritan Formations, Quaternary River Drift.	less than 0.3^+	$0–10.40^+$	$0–66.0^+$
(10) Quaternary Beach Sands (Cape May Form). .	less than 0.3^+	$0–10.40^+$	$0–66.0^+$

* Excluding the Alpine type region.
* Including the Alpine type region.
\+ Explanation for values also on next page.

In Central Europe from 0 to 34 (or from 0 to 5.58 for runoff formulas given in metric system).

In New Jersey, U.S.A. from 0 to 35 (or from 0 to 5.75 for runoff formulas given in metric system).

$e = 0.065$;

the exponent indicates an almost even distribution of the lowest runoff regardless of the size of watershed and the available data and values were not sufficient evidence to evaluate the influence of slopes and topographic configuration of the drainage basins in further details.

On the other hand, the constant value of the exponent "e" and the different values of the coefficient "C" in the two surveyed areas indicate that the lowest runoff depends more on the evapotranspiration effect (percent of yearly rainfall) than on the slope characteristics since the minima occur at the end of the drought period when the stored ground water is bound rather on evapotranspiration effect than on the surface topography of the watershed. Springs function as an overspill from the stored ground water and are – of course – at their lowest capacity. This latest phenomenon may explain why the lowest runoff curve flattens and why any increase in size of the watershed has a direct linear effect on the quantity of the available ground water.

The developed formula is based on watershed with an area less than 20 sq.mi. (52 km^2) in general but not more than 40 sq.mi. (104 km^2). For catchbasin larger than 40 sq.mi., this computation method is not recommended because of complexity of factors influencing the lowest flow.[38]

In both examined areas in the plain region, where the aquifer sediments prevail and reach considerable depth as far as 3000 feet (1000 m) below sealevel, the runoff coefficients decrease in value because the surface runoff is absorbed by these highly permeable layers. As a contrast to this phenomenon in areas such as these along the Atlantic Coast in New Jersey or the valley of the Danube and the Tisza in Southern Czechoslovakia and in Hungary, the ground water collected, even from distant area, "spills over" from its subsurface storage and keeps the surface runoff values up to 66 gallons minute per sq.mi. (10.4 l/sec.km^2) in periods of drought. This outcropping of the ground water can be observed also in the surface streams of the "Pine Barrens" area of Southern New Jersey. Unfortunately, the data concerning of low runoffs is far less available than that for peak runoffs or of well-records. This makes further evaluation and calculation extremely difficult. not to mention the artesian phenomena along the Coast and inland of Burlington and Ocean Counties.

Finally, the lowest runoff values in figure 15—similarly to figure 14: Ground Water Availability—are based on observations of longer period of drought. For general planning purposes, the available lowest runoff values may be increased by 100 percent in supposing that yearly about 5 days there will be less amount of water available. On similar basis—for a year with average rainfall—the lowest runoff for 355 days per year can be even 300 percent of the values given in figure 15. This latest assumption is very important in planning waste treatment plants with their effluents including water pollution control of the streams.

CONCLUSION

The clear correlation of precipitation-evapotranspiration-surface runoff-ground water availability, and the previously mentioned wealth of data from surface runoff and well-records of the studied area, showed a reliable pattern for computation not only of ground water capacity but it also improves surface water runoff records based on geological subsurface. Correlating the extreme runoff data, ground water availability with the characteristic permeability of the different geological formations, can not only enrich the various methods for simulation or interpretation of hydrologic information from other areas but it also secures additional improvement in hydrological data gathering in watershed area less than 100 sq.mi. where data are hardly available.

[38]Compare with Vladimirov, A.M., Chebotarev, A.I., "Computation of Probabilistic Values of Low Flow for Ungauged Rivers," *Symposium on the Design of Water Resources Projects with Inadequate Data,* Madrid, June 1973, UNESCO, Volume II, pp. 561–569, discussing the problems based on experience gained in the Soviet Union.

TROPICAL HYDROLOGY

Jaroslav Balek
Institute of Hydrodynamics,
Academy of Science
Prague, Czechoslovakia

1974

TROPICAL HYDROLOGY IN GENERAL

Tropical regions are bounded by parallels located 23° 27′ north and south of equator, called the Tropic of Cancer and the Tropic of Capricorn, respectively. From the meteorological point of view, the boundaries of the tropics are sometimes considered as the dividing lines between easterlies and westerlies. The tropics are among the most significant and promising water resources regions. Unfortunately, knowledge of tropical hydrologic regimes is still very limited.

The sun culminates between Cancer and Capricorn within the angles 43°–90°; the duration of a day is 10.75–13.25 hours. The sun is overhead in the tropics twice a year. The water circulation known as the hydrologic cycle is driven by solar activity; one can assume that in the tropics the sun is an even more decisive factor than for other regions. The relationship between the sun and water cycle is far from simple. The sun does not manifest itself unambiguously on the whole earth surface, rather it evokes circulations of many different types. The fluctuation in solar activity itself highly influences the hydrologic regimes; such as unequivocality, however, is not demonstrable by easily accessible methods. For instance, the frequencies in the sequences of various hydrological and meteorological phenomena are affected not only by solar activity, but by other mediating agents which themselves can act as influencing factors. If the hydrologic regime is considered as a part of the environment, then any study concerned with the variability of that regime in time has to consider not only the hydrosphere of the basin, but also the hydrosphere of the whole region, the troposphere and perhaps even higher layers which mediate between the sun and the basin. In the basins of big rivers there is more opportunity for solar activity to be asserted as most significant, particulary in climatologically homogeneous areas. In small basins there are other factors more or less as important as the sun; frequently the local ones play a very decisive role. Anomalies caused by local situations, such as bush fires, man's activities etc. may influence the cycle and rise above the direct compact of solar activity.

Various combinations of mutually interacting factors can decrease or increase the direct influence of the sun. A basin itself is influenced by the sun because its biological part, soil and rock formation, erosion etc. are under the direct impact of solar activity.

In the vicinity of the equator, the solar periodicities of some big rivers, such as the Niger are more pronounced (1), or in otherwords, more statistically significant then in moderate regions. Sometimes, as in the case of the Nile, an exceptional period of 14 years is found (2) requiring further explanation.

Continental parts of tropical regions are sources of considerable but irregulary distributed resources of various kinds. Most of them are still imperfectly known and the prospect of raising living standards depends primarily on the search for, discovery and development of new resources. Water resources are especially important because the exploitation of other resources depends on the availability of water. The designers of various projects in the tropics often require hydrological data for their work, data which is unavailable because of the lack of solid knowledge of the behavior of hydrological systems.

A main object of this study is to provide general review of the present knowledge of the hydrology of tropical regions. Actual regional hydrologic data can be found in various reports resulting from a considerable effort which has been carried out by numerous international agencies working under the United Nations Development Programme and by national institutions as well.

The quality and quantity of data available hinders the advancement of tropical hydrology and hydrometeorology. These data originate in regions with many natural and sociological differences, occasionally even political problems are involved when the data are to be collected from the international basins and regions. So far, tropical climatology as a source of information on one of the most significant parts of the hydrologic cycle, is most advanced as compared with other scientific disciplines related to the tropical hydrology. With few exceptions, the regimes of many tropical rivers are still very much unknown. Very little is known also on the water regimes retained in the rocks and subsoils of tropics, although in this field experience from the moderate zones can be applied much more easily. The evapotranspirational process and its variability has become a matter of intensive studies in the tropics, because of its importance for tropical agriculture.

Still, however, present knowledge of the hydrology of tropical regions does not reach a comparable level with the hydrology of moderate regions. Many interesting and challenging problems remain to be solved.

CLIMATOLOGY AND METEOROLOGY OF TROPICAL REGIONS

Rivers are products of the climate. A classification of the climate is therefore one of the basic indicators for the hydrologic classification of the basic indicators for the hydrologic classification of the river systems. In hydrologic classification another factor such as geomorphology, vegetation, soil and rock types play important roles even though all of them are themselves influenced by the climate.

Many attempts have been made to classify the earth climates. Voejkoff (3), Penck (4), Köppen (5), Herbertson (6), Trewarth (7) and many others have presented different types of classification. Köppen's classification (8) gives probably the most complex account on the variety of the climatical regimes in tropics. Köppen recognizes (fig. 1):

Tropical rain climate—(A type) with the mean annual temperature during all months above 18°C. For the temperatures at 20°C at least 600 mm, at 25°C 700 mm of annual rainfall should be available. Three subtypes exist, defined as:

- rainfall tropical forest climate (Af) in permanently wet regions with minimum monthly rainfall of 60 mm,
- monsoon climate (Am)
- periodically dry savanna climate (Aw). Here at the annual rainfall of

1,000	1,500	2,000	2,500 mm the driest month should have
60	40	20	0 mm or less of precipitation.

Dry climate—(B type) with two subtypes found in tropics:

- steppe climate (Bs), where at the mean annual temperature of

25	20	15°C is maximum annual rainfall of
700	600	500 mm,

- desert climate (Bw) were at the mean annual temperature of

25	20	15°C is maximum annual rainfall of
350	300	250 mm.

Warm rainfall climate—(C type) the temperature of the coolest month is between -3 and 18°C and at the mean annual temperature of

5	10	15	20°C is the mean annual rainfall more than
300	400	500	600 mm.

Three subtypes are found in relatively small tropical localities:

- warm climate with dry winter (Cw),
- warm climate with dry summer (Cs),
- warm wet climate.

Ice climate—(ET, particulary the tundra subtype is found in narrow mountainous belts.

Tropical rainfall forest climate is characterized by a uniform high temperature, with the coolest month above 18°C. Table 1 is an example of the monthly mean temperature at Cotonou, Dahomey:

Table 1.—*Monthly mean temperature at Cotonou, Dahomey*

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
t°C	27.5	28.3	28.9	28.9	27.9	26.3	26.1	26.0	26.4	26.7	27.9	27.7

Two rainfall peaks and two dry periods are frequently found, and although there is no pronounced winter period, there are occasional fluctuations of cool and hot days. The rains come in the form of convectional storms, usually between noon and midnight. The intensification of chemical and biological decomposition by high humidity is another factor typical for this climate, which explains an enormeous thickness of lateritic red soils. The precipitation regime at Georgetown (fig. 2) illustrates this type of climate. As can be seen from the map of climate distribution (fig. 1) the type is found in Malaysia, Phillipines, New Guinea, Melanesia, Polynesia, Congo basin, northern Guinea Bay, eastern Malgassy, Amazon and tributaries, eastern Brazil, West India and eastern coast of Central America. Under the influence of trade winds, the climate is found at an elevation of 1,000 m at Cordilleras. The highest annual rainfall observed in the region is 12,500 mm at Kauai (Hawai), daily maximum 1,168 mm at Baguio, Phillipines. The trade winds occur in the tropics as a result of the difference between the high air pressure above subtropics and low pressure above the equator. Monsoons are developed as a result of the difference between the temperatures of the continents and oceans. During summer the continents become warm and under a low pressure; the summer direction of the monsoons is from the ocean toward the continents. During winter the reverse movement occurs. Monsoon forest climate is limited to rather narrow strips along the coast. The forest in these belts contains more species of the deciduous character. Typical is a higher difference between the coolest and warmest months (up to 8°C). The climate is distributed even parts of Indian coast, Thailand, Vietnam, southwestern Ceylon, western coast of Burma, Malaysia, northern Australia and Sierra Leone. Typical monthly rainfall for this climate is shown in figure 3. The world record of annual rainfall under the influence of monsoons, 16,300 mm is held by Cherapandji, with daily maximum 1,037 mm.

The savanna climate is sometime also called the trade-winds climate. Dry periods are sharply bounded, occuring during the winter; annual rainfall is between 1,000 and 2,500 mm and the temperature amplitude reaches 12°C. The summer rain peak comes after the sun has reached the

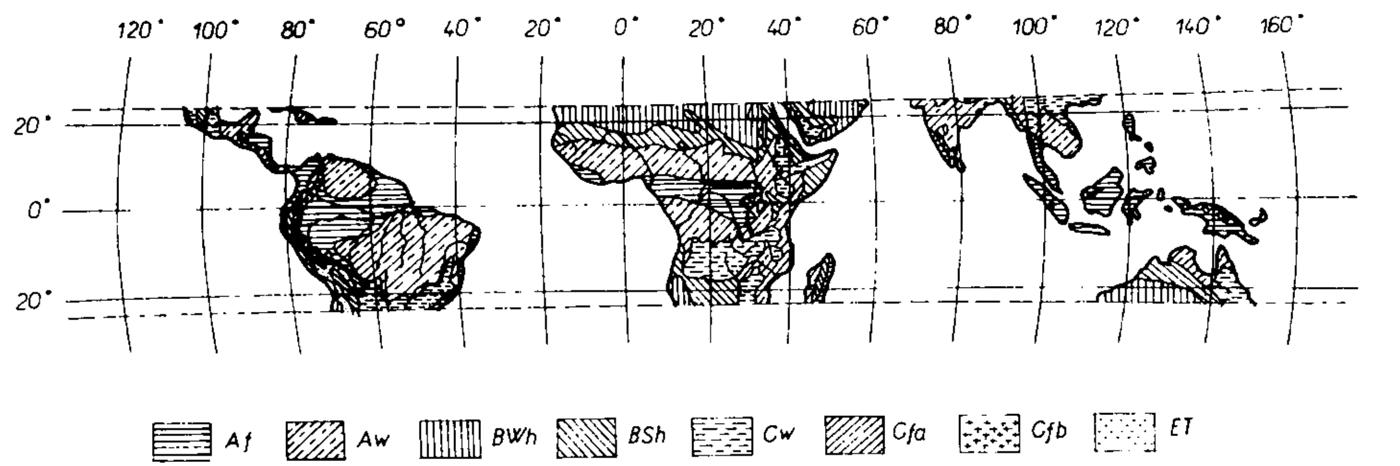

Figure 1.—Köppen's classification of tropical climates. Af = rainfall tropical forest climate, Am = trade wind climate (not seen in this scale), Aw = periodically dry savanna climate with dry winter, Bwh = desert climate with mean annual temperature over 18°C, Bsh = steppe climate with mean annual temperature over 18°C, Cw = warm temperature climate with dry season in winter, Cfa = warm temperature climate with sufficient precipitation in all months and warmest month over 22°C, Cfb = warm temperature climate with sufficient precipitation in all months, warmest month below 18°C and at least four months over 10°C. ET = ice climate with warmest mean monthly temperature between 0° -10°C.

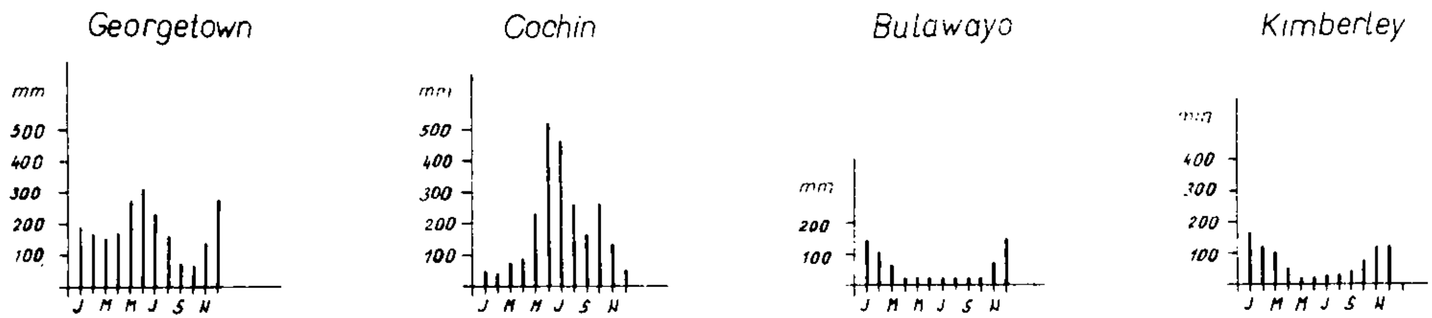

Figure 2 Figure 3 Figure 4 Figure 5

Figure 2.—Monthly rainfall at Georgetown, Guyana, 7°N, 58°W, Af region.
3.—Monthly rainfall at Cochin, India, 10°N, 73°E, Am region.
4.—Monthly rainfall at Bulawayo, S. Rhodesia, 20°S, 29°E, Aw region.
5.—Monthly rainfall at Kimberley, S. Africa, 29°S, 25°E, Bs region.

zenith. The dry period is the product of the trade winds. Because savanna (in South America llano) is a typical ecological product of such a type of climate, the name savanna climate prevails. The climate is found in Africa from Ethiopia and Somalia to Southern Rhodesia (fig. 4), Sudan, eastern part of Guinea Bay, Congo and western Malagasy. In South America it covers the central part of Brazil, northeastern coast of Venezuela, Yucatan and Cuba. It is found in India, Thailand and eastern Australia.

Dry climate regions according to the prevailing vegetation are also called steppe climate regions. Owing to an intensive thermal exchange between the surface and air masses, there is a high fluctuation of daily temperatures. Soils are intensively decomposed. Generally there are recognized two subtypes, steppe climate and desert climate. The steppe climate has two subgroups, one with dry and the second with a wet winter period. The subtype is widely distributed in southern parts of Africa, Iraque, Iran, part of tropical Australia and Sahara margins. Desert climate, typical for Sahara, is found also in tropical Arabia and India. The regions are almost without any rainfall, the mean temperature of the hottest month is over 26°C and the annual mean temperature is over 18°C. A high fluctuation of the temperature during a day and frequent sand storms are typical for the region (fig. 5).

Warm, moderate rainfall climate is not widely distributed in tropics, except the subtype Cw with dry winter and wet summer and low difference between summer and winter temperatures. The climate is found on the tropical plateau of Central Africa, southern Brazil, western Mexico and Eastern Australia.

Ice climate is found in small localities on the slopes of tropical mountains in the forms of so called tundra climate, and tropical highland climate. The second form can be characterized as a climate with dry winter and wet summer, accompanied by storm activities. A great variety of temperature regimes is found, depending on the altitude and latitude. The warmest month has 10–22°C, the coolest 6–18°C. The highlands of Mexico, Lake Titicaca, Bolvia (tierra templada), southeastern Brazil, southern Africa, Ethiopia and East Africa are the localities of the tropical highland climate, while the tundra climate is found in narrow strips around Cordilleras.

From the hydrological point of view, rainfall is the most significant meteorological phenomenon. Owing to the increased temperature in tropics much more rain is needed to keep the fields saturated. Unfortunately tropical rainfall largely stems from cumulus clouds and thus the rainfall intensities are high more frequently then the intensities of the middle latitude rainfalls, staging from the stratus and altostratus decks. At Djakarta the annual rainfall falls within a total of 360 hours, according to Riehl (9). As has been proven experimentally (10), distribution of the tropical rainfall is highly nonuniform even within small areas. In figure 6 there is a graph indicating the fluctuation of the annual rainfall within an area of 16 km^2 situated on the Central African Plateau. For single storms such a variability is even more pronounced. Thus a significant part of the tropical rainfall is lost to the vegetation. Most of the water is evaporated before penetrating the ground, owing to the high evapotranspiration rate. Afternoon showers particularly are of a very limited use in agriculture; plant ecologists consider as a minimum effective rainfall within a day 2.5 -6 mm, otherwise all the water is evaporated.

Reliable rainfall records are available elsewhere in tropics, most commonly on daily basis. The number of autographic recorders is much smaller and processed data can seldom be found. However, the probability of occurence of tropical rainfalls requires a complex study for each

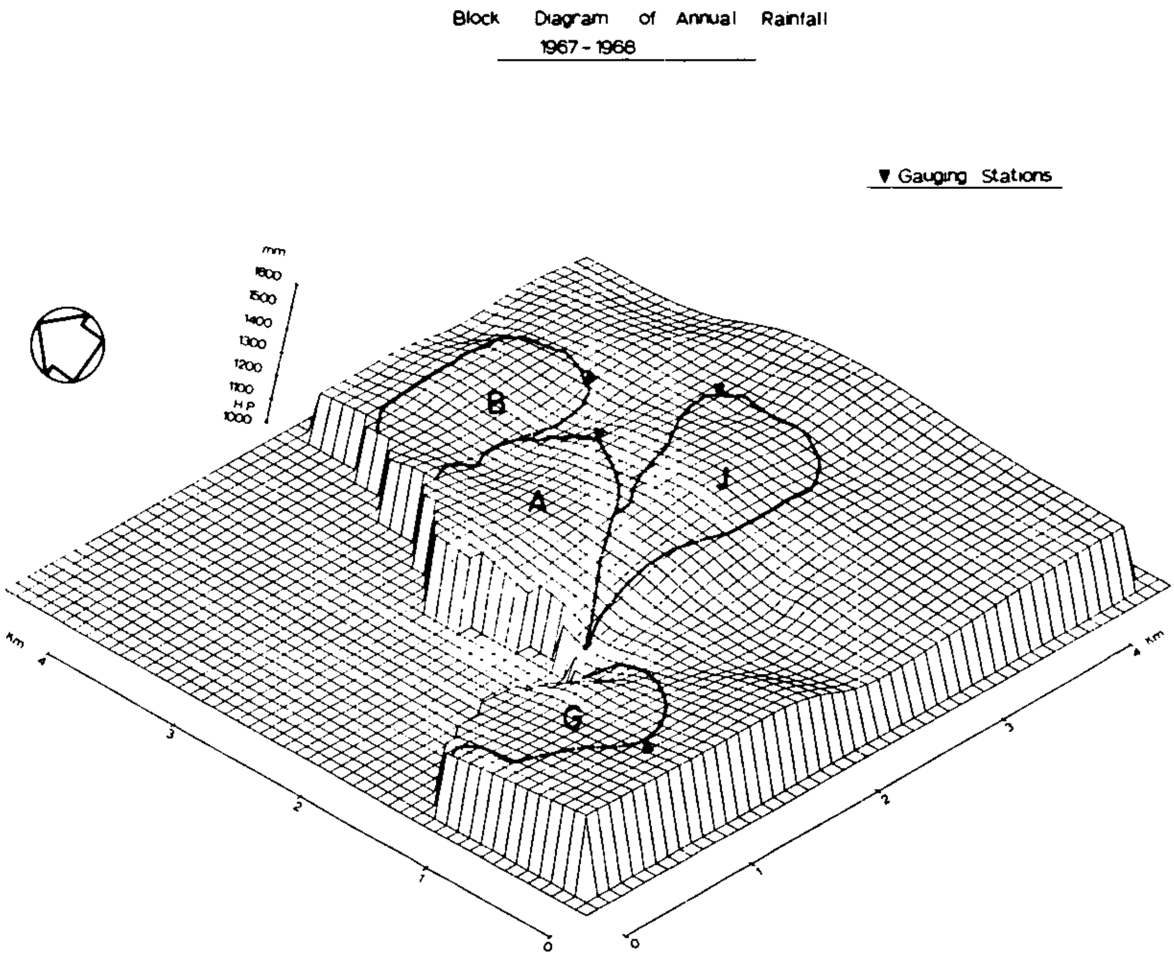

Figure 6.—Areal fluctuation of the annual tropical rainfall.

particular region. Bailey (11), suggests the use of Fisher-Tippett's type I distribution for the tropical rainfall analysis. Limits obtained for Zambian territory are shown in table 2:

Table 2.—*Probability of occurence of the maximum daily rainfall, Zambia*

Return periods (years)	2	5	10	25	50	100
Max daily rainfall (inches)	2.3-3.7	2.8-4.7	3.3-5.6	3.4-7.0	3.6-8.3	3.9-9.8

Other important climatological phenomena are the potential evaporation and actual evapotranspiration. Following the definitions of Aune (12) the potential evaporation is the quantity of water vapor that could be emitted by a surface of pure water per unit area and per unit time under the existing atmospheric conditions; the actual evapotranspiration is the sum of the quantities of water vapour actually evaporated from the soil and watershed surface and from plants under existing atmospheric, soil moisture, groundwater level and vegetational conditions. Sometimes the term potential evapotranspiration is introduced, defined as the maximum quantity of water capable of being lost as water vapor from an unbroken stretch of vegetation in a given climate and where the soil is kept saturated. There are several methods available for calculating the potential evaporation; direct observations of actual evaporation also can be made. However, differences between the calculated potential evaporation and measured evaporation exist and are variable. Also the materials used in the construction of evaporation pans also significantly influence the measured values. For instance, the galvanized pan is exposed to an intensive heat in tropics and the results are not comparable with those obtained in moderate regions. Fiberglass pans are preferred in the tropics by some hydrologists. The pan has to be screened. Otherwise animals use it as a watering place.

Penman's method, (described elsewhere), is widely used in tropics for the calculation of the potential evaporation. Generally, there is a choice of using either sunshine records or not radiation records in the calculations. It has been assumed that the net radiation is a more sensitive indicator of potential evaporation, although sunshine records are more frequent in tropics. Table 3 compares monthly evaporation calculated using Penman's formula by McCullech interpretation (13), from sunshine and radiation records. Data are calculated for the Copperbelt area near Zambia/Zaire borders.

Table 3.—*Monthly potential evaporation calculated by using Penman's formula and sunshine or radiation records, for the area near Zambia/Zaire border*

Month of 1968/69	Sunshine used	Radiation used
	mm	mm
10	201.1	192.0
11	160.0	152.6
12	128.6	133.8
1	156.0	150.5
2	124.0	126.5
3	146.6	137.0
4	149.6	138.7
5	132.4	126.5
6	110.8	105.4
7	118.7	112.0
8	141.0	133.3
9	167.5	159.5
Year	1,736.3	1,667.8

For the same year the direct measurements of evaporation were made using galvanised and screened fiberglass pans, with the following results (table 4):

Table 4.—*A comparison of the actual monthly evaporation from the galvanized unscreened and fiberglass screened pan*

Month of 1968/69	Unscreened galvanised pan	Screened fiberglass pan
	mm	mm
10	254.96	229.58
11	173.07	142.17
12	103.85	81.61
1	124.33	103.11
2	113.64	87.63
3	118.73	99.53
4	132.95	113.86
5	131.21	117.40
6	117.56	104.64
7	130.19	113.46
8	143.15	125.32
9	187.98	161.95
Total	1,731.62	1,480.26

Finally, the daily fluctuation of the potential evaporation as calculated by Penman's (14) formula is plotted in figure 7.

There are other meteorological phenomena such as winds, pressure, humidity, storms etc. related to the hydrological cycle. It is beyond the scope of this paper to discuss them and a special literature such as (9) should be reviewed.

TROPICAL RIVERS

Seven of the ten largest rivers of the world originate in the tropics, namely Amazon, La Plata, Congo, Madeira, Orinoco, Tocantins and Rio Negro. The total outflow from the Amazon basin far overreaches the outflow from any of the other streams. Mighty streams of Madeira, Tocantins and Rio Negro are the tributaries of Amazon. All these big rivers are products of very complicated river regimes. Several attempts have been made to classify tropical river regimes. The term "typical river regime" can be related only to small and medium streams, although some deviations should always be expected.

Pardé (15) recognized in the tropics:
Tropical rainfall regimes characterized by a minimum discharge during the winter season and maximum during summer months (July, August, September north of the equator; February, March, April to the south).
Equatorial regimes characterized by the occurence of two annual peaks.

Lvovich (16) classified following tropical groups:
Rivers fed only during autumn
Rivers fed mostly during autumn
Rivers fed during summer

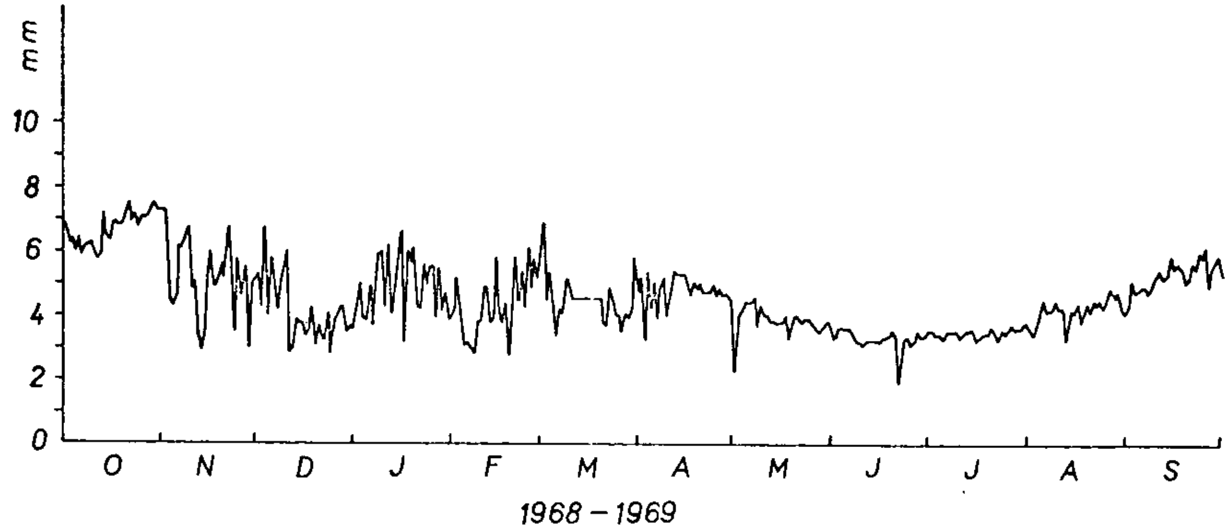

Figure 7.—Daily fluctuation of the potential evaporation in the region of periodically dry savanna climate.

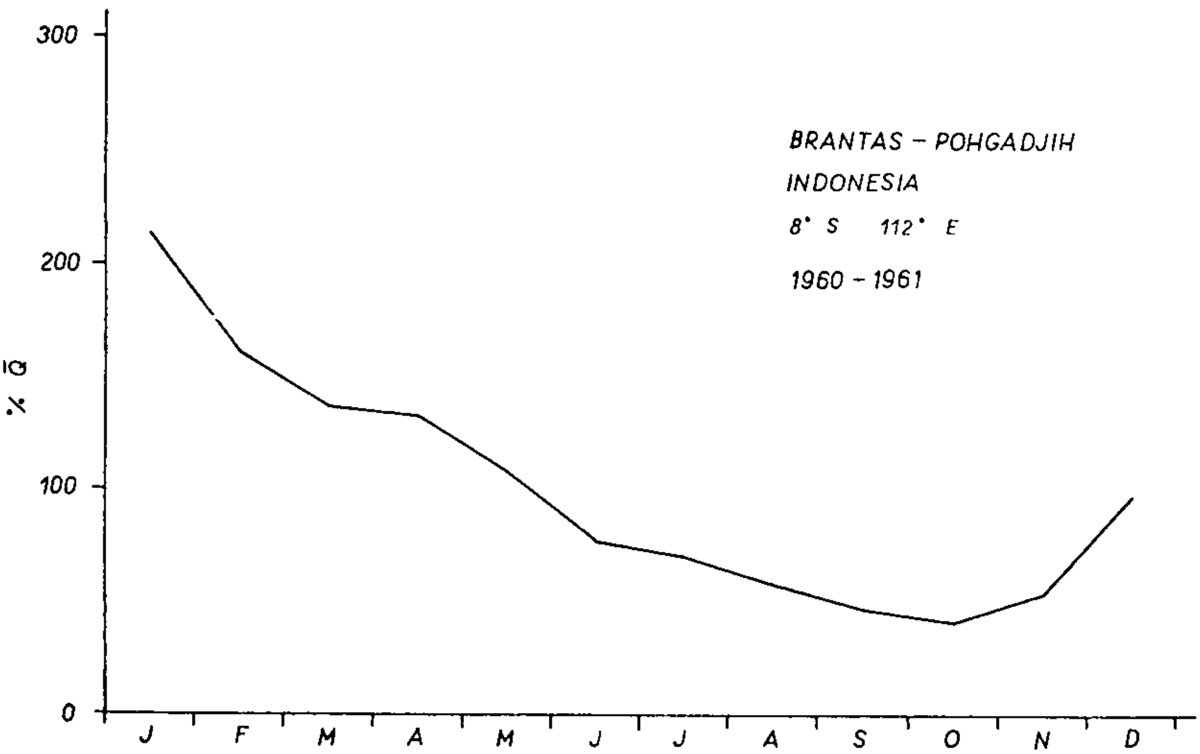

Figure 8.—Hydrograph of the Brantas river at Pohgadjih, Indonesia.

These classifications are greatly simplified. The following classification developed for African streams can perhaps be extended in general, for tropical regions.

1. Equatorial rivers with one peak produced by heavy precipitation of 1,750–2,500 mm without a marked dry season. Even if some stations have recorded two rainfall peaks, the result is one high flow peak corresponding with the most pronounced rainfall period. In figure 8 there is an example of such a regime, the Indonesian river Brantas.

2. Equatorial rivers with two peaks produced by the precipitation regimes with monthly totals over 200 mm. The basins of these rivers are mostly covered by the equatorial forest; annual rainfall is well above 1,750 mm. River Ogowé (Gabon) represents this group (fig. 9). In this case the two peaks are almost equal, which however, is not a rule.

3. Tropical rivers under the influence of wet and dry type of climate. Such a climate produces numerous combinations of river subregimes which are mainly influenced by the seasonality of the rainfall distribution. River Mangkoky on the west side of the Malagasy island is an example of such a river (fig. 10). The regime is under the influence of seven dry months, although some rain is always observed. There is enough precipitation during the rainy season but the discharge decreases toward the end of the dry season very rapidly. Vegetation influences which type of subregime will develop; many combinations of forest and savanna, both wet and dry type exist. The basins with dry type of vegetation are situated in the margins of dry climate zones, receiving 500–750 mm of precipitation which is more typical of semidesert areas, on the other side of the extremes in some basins the annual rainfall may exceed 1,500 mm.

4. Dry climate rivers. Several type of dry climate rivers are recognized depending on the vegetation prevailing. Ecologists differ on the definitions of wooded steppe and grass steppe; for the rivers the degree of intermittency is a better characteristic. Intermittent streams, however, can be found in the previous group, even in the areas with more the 1,200 mm of annual rainfall, here owing to special geomorphological and geological conditions. Such an intermittency usually is not of a periodical character. River Gwai in Southern Rhodesia (fig. 11), with the drainage area more than 100,000 km^2 is an example of this group.

5. Desert rivers. Rivers of a wade type originate in pure deserts or deserts covered by ephemeral grass and shrubs in the areas of 200 mm and less of the annual rainfall. Although there is some drainage area ocassionaly traceable, usually it has been developed before the present stage of aridity. The latter desiccation has resulted in change for intermittent, perhaps perenial regimes to ephemeral ones. Thus the present stage of the desert network represents an adjustment to the desert environment.

6. Tropical highland rivers. The drainage areas are rather limited in size, with the exception of South American tropics and Ethiopia. The regimes are always products of special conditions. Their behavior is generally similar to the rivers of the surrounding environment but under the influence of the altitude, slope prevailing wind and precipitation. It should be recalled that about 1,000 km^2 of tropics are covered by the glaciers. There is no representative river for all tropical highlands. The river Pangani is an example (fig. 12), flowing from the slopes of the mountains Kilimanjaro and Mweru. Figure 13 shows the vegetational belts from which the river and its tributaries flow.

7. Swamps. They are not limited to a certain climatic region and can be found anywhere in tropics. It can be said that the vegetational cover and hydrological regime are more closely related than for the previous types. Because of their economical importance, the swamps are discussed in a special chapter.

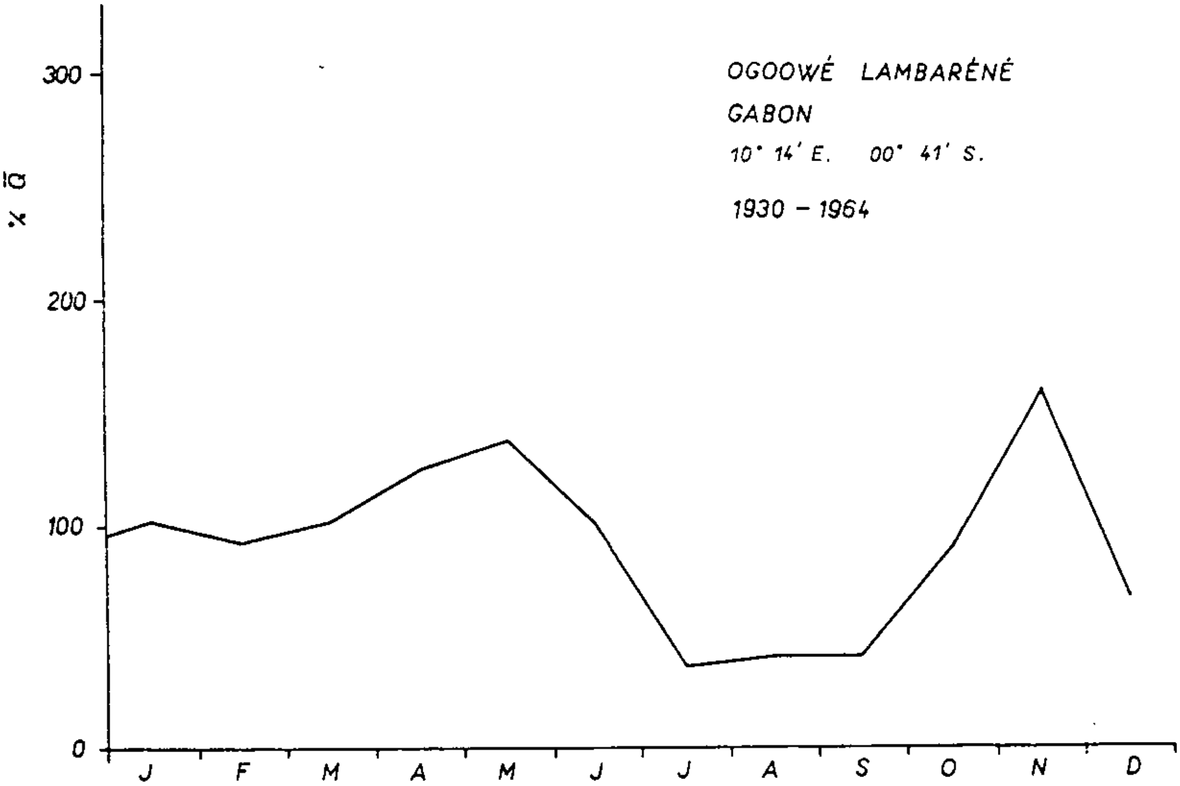

Figure 9.—Hydrograph of the Ogowé river at Lambarrene, Gabon.

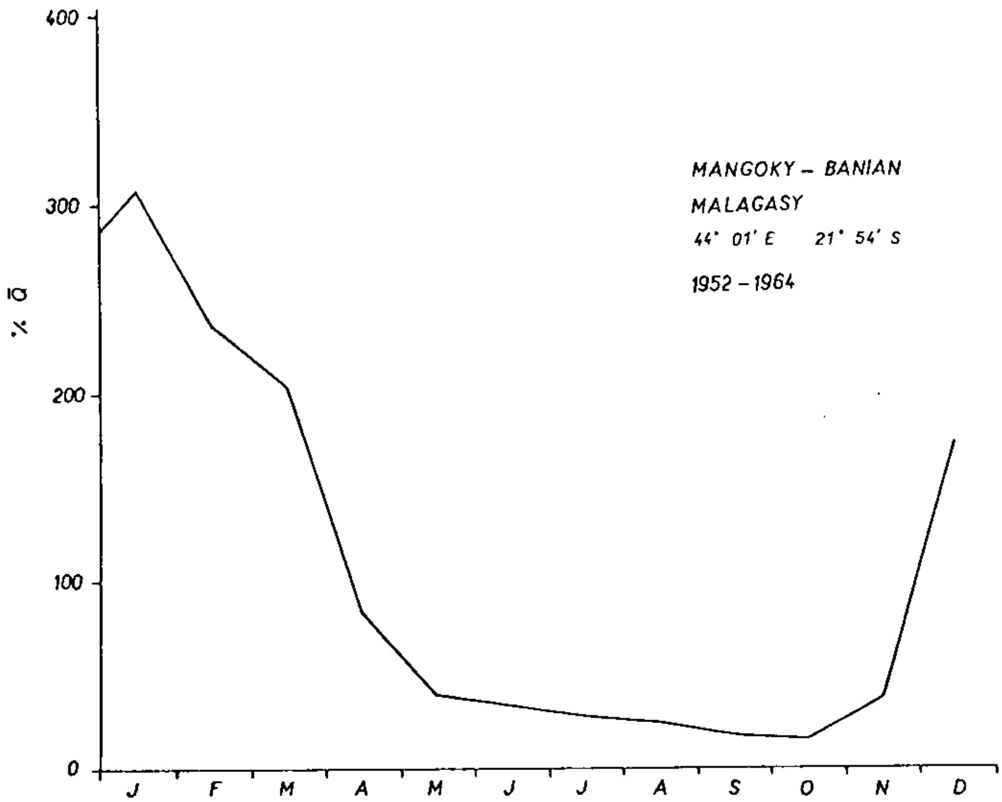

Figure 10.—Hydrograph of the Mangkoky river at Banian, Malagasy.

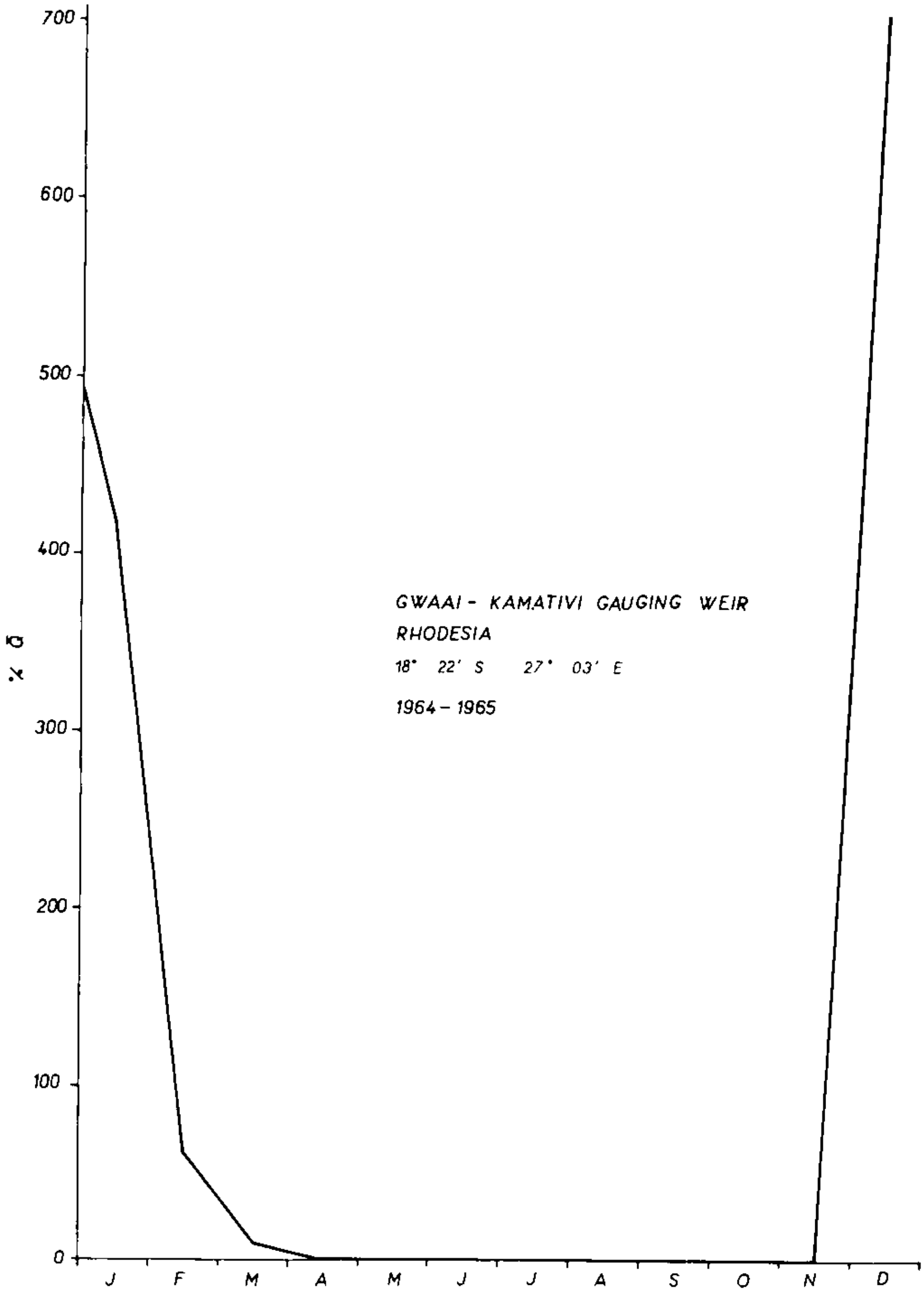

Figure 11.––Hydrograph of the Gwai river at Kamativi, Southern Rhodesia.

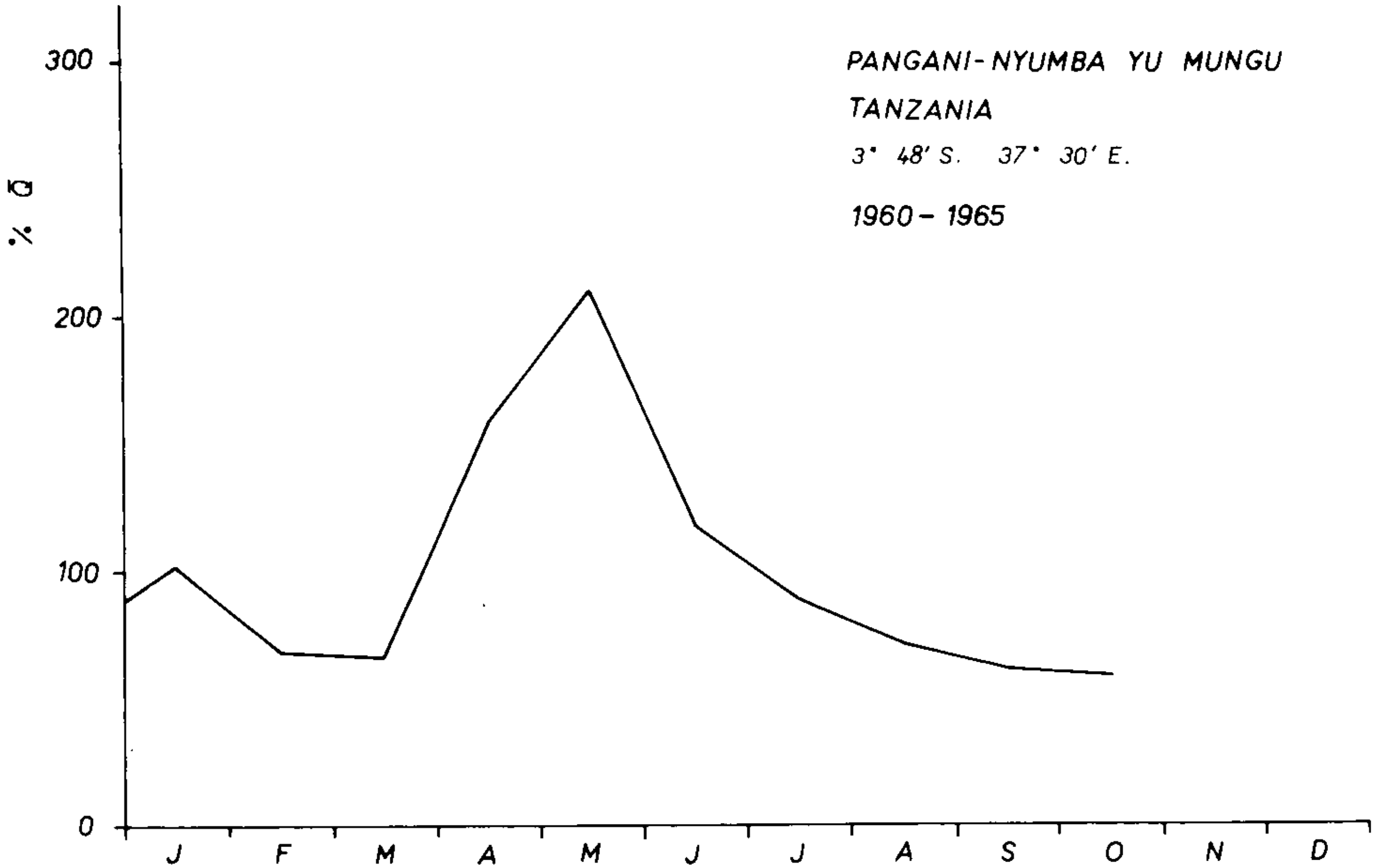

Figure 12.—Hydrograph of the Pangani river at Nyuma Yu Mungu, Tanzania.

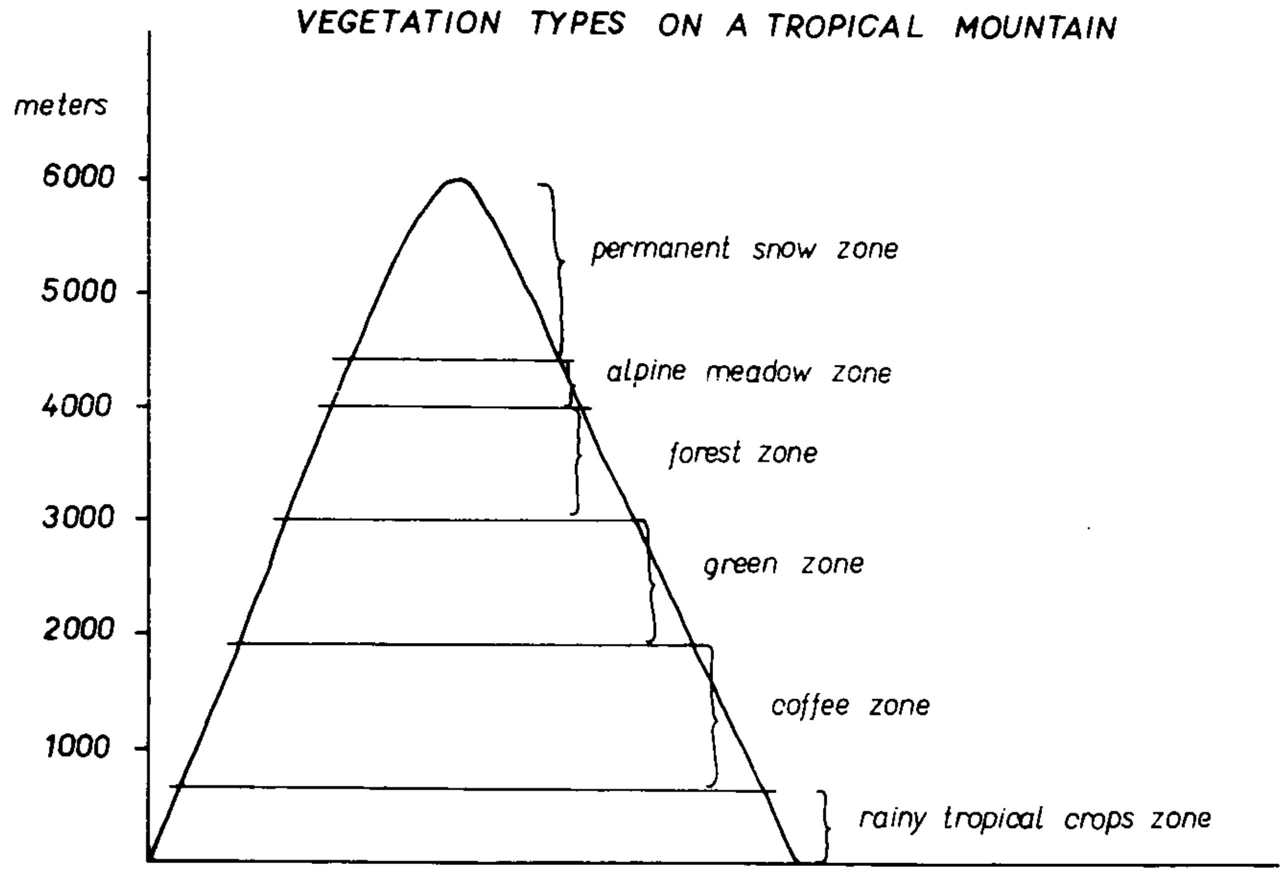

Figure 13.——Vegetational belts on the slopes of tropical mountains.

As can be seen in table 5, South American continent produces the greatest tropical rivers. Two different sets of data are given for the Amazon, representing certain limits of present knowledge. A remarkable effort has been put into the survey of the river. The search for the source has been intensified in the second part of this century. The river Santiago flowing from the glacier Uacra has been located as the ultimate source. The total length was estimated in 1962 to be 7,025 km, which makes Amazon the longest river of the world (Mississippi-Missouri 6,730 km, Nile 6,700 km). The river is called Amazon from the cofluence of Rio Solimoes and Rio Negro. The width of the river varies from 1.5 km upstream to 80 km at the mouth. The river flows through a wide braided valley, the typical cross-section of which can be seen in figure 14. The depth of the river is 12 meters at the mouth and 90 m inland. Because the slope of the river is only 0.000022, the bottom is below ocean level. Complex result of the river regimes appears very simple (fig. 15). The rise continues from November till June; the decreasing period is much shorter and the lower stages occur only for a short time. According to the latest measurements, the mean annual discharge may be 244,000 m^3/s, which is almost 20 percent of the total outflow from the all continents. Thus the yield is estimated by 34.5 $l/s/km^2$. The ration maxima/minima is only 3 for the mean and 5 for the extremal year.

Madeira, a tributary of the Amazon, rises as a joint stream of the rivers Mamoré, Guaporé and Beni. The level elevation of Madeira during a year is relatively high, about 12 meters of the water stage. The level rises between October and May as a result of the combined effects of the rains on the flat part of the basin and snow melting in Andes. River Tocantins flows into the Atlantic ocean at Belem, however, it is partly connected with the Amazon system. In the recent balance calculations the drainage area has been considered as a part of the Amazon basin. Rió Negro, the left tributary of Amazon, rises in flat swampy areas producing dark water. Xingu and Tapaos are other tributaries of the world's largest river.

Another large system, that of the, La Plata, originates in South America. It does not belong entirely in the tropics, although most of it originates there. La Plata is developed as a confluence of the rivers Paraná and Oruguay. Paraná rises in southern Brasil as a confluence of the rivers Paraíba and Rió Grande. Numerous rapids and waterfalls exist in the basin, the largest ones Iguassu on the river of the same name (elevation of the falls in 70 m). The level of the lower reaches is influenced by the fluctuation of the atmospheric pressure and wind as well as by the discharge. Under the combined effect of these three components, the level fluctuation may reach 400 cm within 24 hours. The river regime is a product of the river regimes of several tributaries. For instance, the culmination in the headwaters of Paraná is delayed by one to two months after the heavy rainfall in December and January; river Iguassu has three periods with increased discharge under the influence of tropical summer rains and trade winds. A fluctuation of the rivers in the Paraná system is shown in figure 16a.

Another mighty stream of South America is the Orinoco. It flows from the Andes parallel to and north of the Amazon. The source of the river was not known prior to 1951. The upper waters of the Orinoco are united with those of Río Negro by a natural river Casiquiare. The culmination of Orinoco occurs in August (fig. 16b).

The largest river of Africa, the Congo, rises south of Lake Tanganyika as a Chambeshi river, flowing into the Bangweulu swamps, which drain into the Luapula system. The Congo system includes the rivers Lualaba, Ubangi, Shanga, Lulonga and Kasai, as well as drainage from Lake Tanganyika. The central part of the basin is formed by a great pan surrounded at the margins by numerous waterfalls, cataracts and rapids. The waterfalls in the lowest stream, called Livingstone's, are the largest in the world based on discharge. Because the basin is located symetrically along the equator, the regime of the river is a combination of the regimes characteristical for southern and

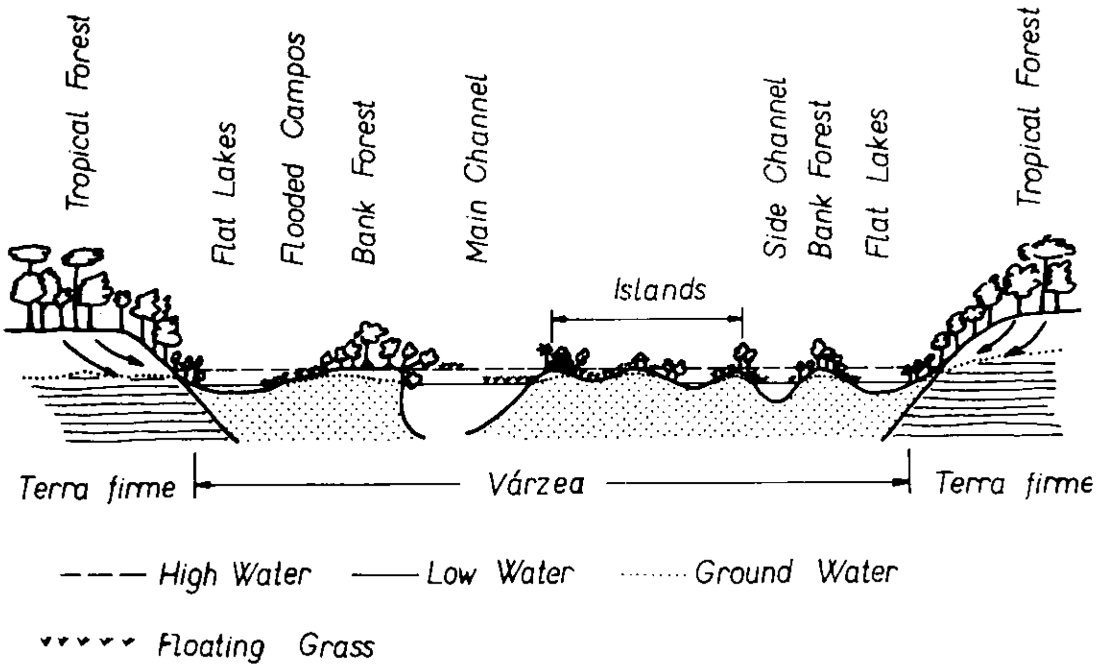

Figure 14.—–Cross-section of the Amazon valley.

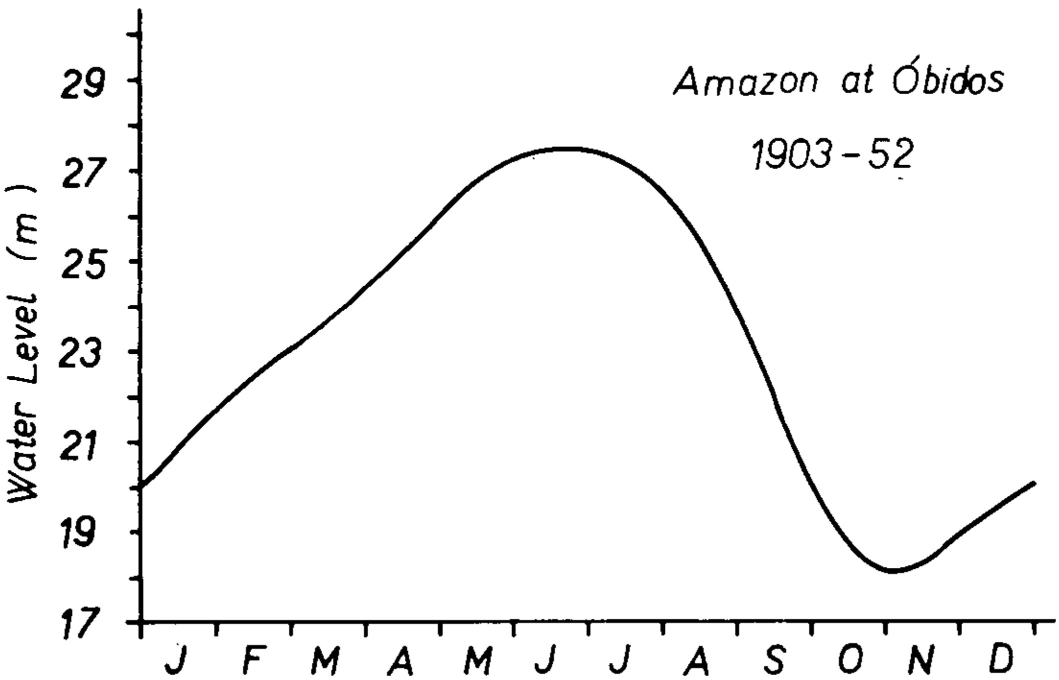

Figure 15.—–Hydrograph of the Amazon river, Brazil.

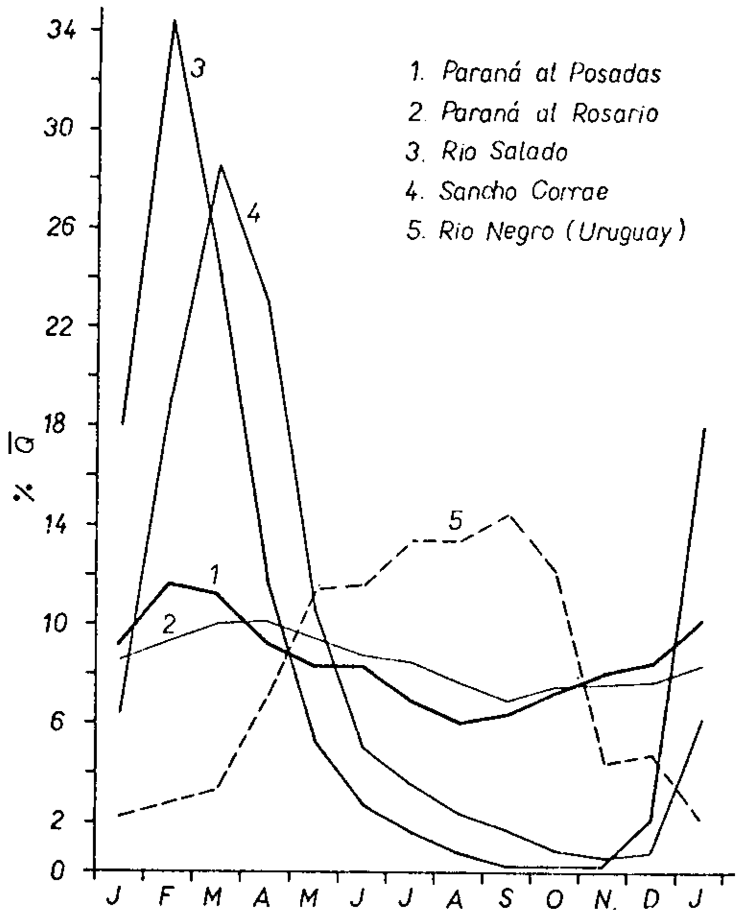

Figure 16a.—Fluctuation of some rivers in the Parana system.

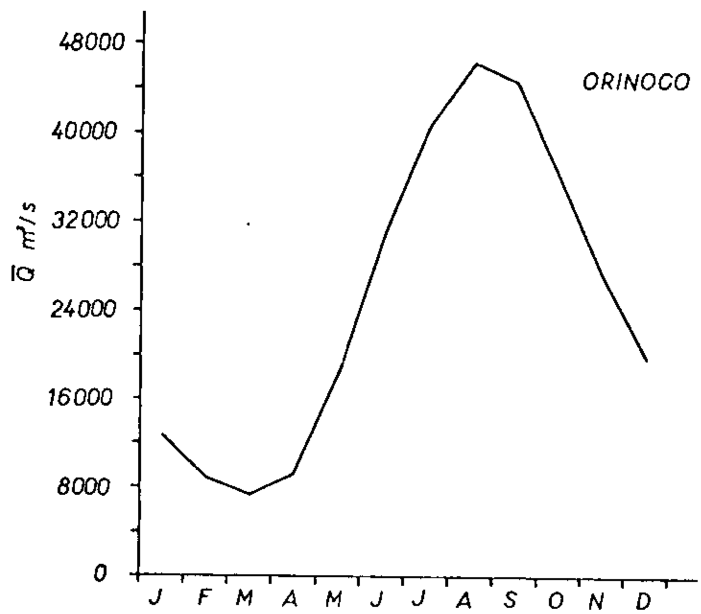

Figure 16b.—Fluctuation of the Orinoco river, Venezuela.

northern tropics. The fluctuation can be seen in figure 17. About 50 million tons of sediments are carried by the river within a year.

The Niger river rises in Foutha Djallon Highland and flows into the flat and frequently flooded country at Segou. The lower part confluences with Benue, headwaters of which are connected with Chad system during the flood period. The Niger delta starts 130 km inland as Oil rivers.

The Nile system can serve as an example that there is nothing like a typical tropical regime (fig. 17b). Although the lower part is not within the tropics, the river is a product of the tropics, particularly of the arid parts. The ultimate source in the headwaters of Kagera river was found in 1937. From Lake Victoria, after passing Lake Kyoga, it enters Lake Albert and from there flows as the Albert Nile; downstream the White Nile, (so called because of the lack of suspended loads). The river flows 560 kilometres through swamps and is joined by Bahr el Ghazal which drains another extensive swampy area. The tributaries Sabat and Atbara are rather nonsignificant. The Blue Nile originates from Lake Tana in the Ethiopian Highland; sometimes a tributary of Tana, Abbai is considered as a true source. On the way to the Mediterranean, most of the water is evaporated.

Zambezi, the largest African river flowing into the Indian ocean, is 2,600 km long, originating in the Central African Plateau. There is an intermittent connection between Zambezi and the Western Kalahari drainage system through the Chobe river, which makes the drainage area of Zambezi very uncertain (17). Victoria Falls (1,658 m of wide, 98 m deep, and 1,180 m^3/s mean annual discharge) is among the largest falls in the world. In the lower part is the river regime is influenced by the Kariba Dam. Lake Nyassa drains into Zambezi through the river Shire.

River Mekong is the largest stream of Asian tropics, although it is tropical only in the middle and lower part. Its regime is influenced by the tributaries from the Tibetian Plateau; owing to a great slope, the culmination moves with a great velocity. The highest peak in the tropical part comes in September.

Table 5 gives an approximate account of the water balance of the largest tropical streams. Information found on the maps (figs. 18, 19, 20) includes mean annual rainfall, runoff and evaporation (18).

Very little is known of long term fluctuations of tropical rivers. The existence of periodicity has been proven (19). For the Niger, for instance, a period of 25.5 years was proven; periods of 7.3 and 3 years were also found significant. In the Nile, periods of 21, 7.6, 4.3 and 2.7 years were traced. Taking into the account the unequal lengths of the sequences and shapes of the periodographs, a period of 22.6 years has been found as significants for both rivers, obviously in the coincidence with the period of sunspots categorized by some authors within 22 ± 2 years (20). For the River Paraná, the periodicity of 4.8 years was found as most significant. Also periods of 2.7 and 14.5 years were traced. Actual river sequences and a modeled one, based on the three significant periods, are shown in figure 21.

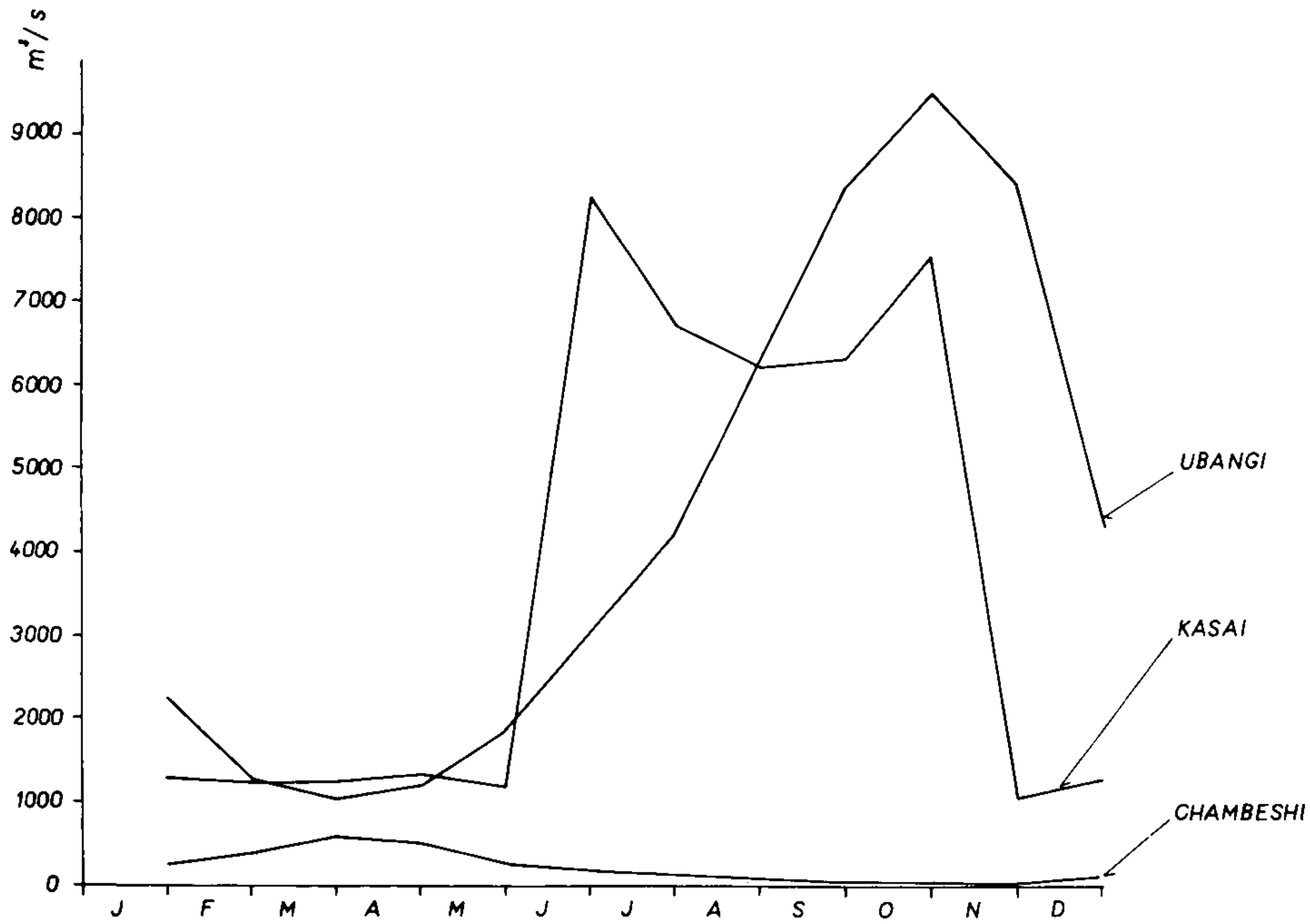

Figure 17a.––Fluctuation of some rivers in Congo system.

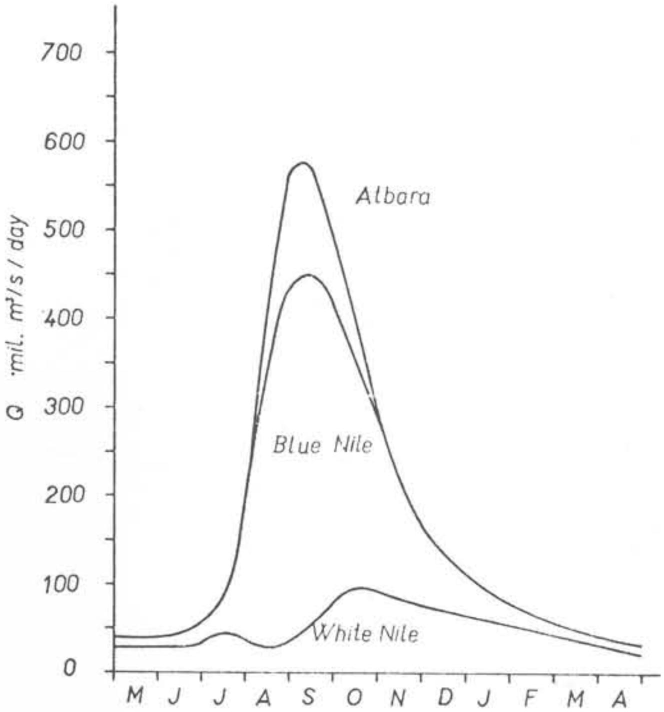

Figure 17b.—–Fluctuation of some rivers in Nile system.

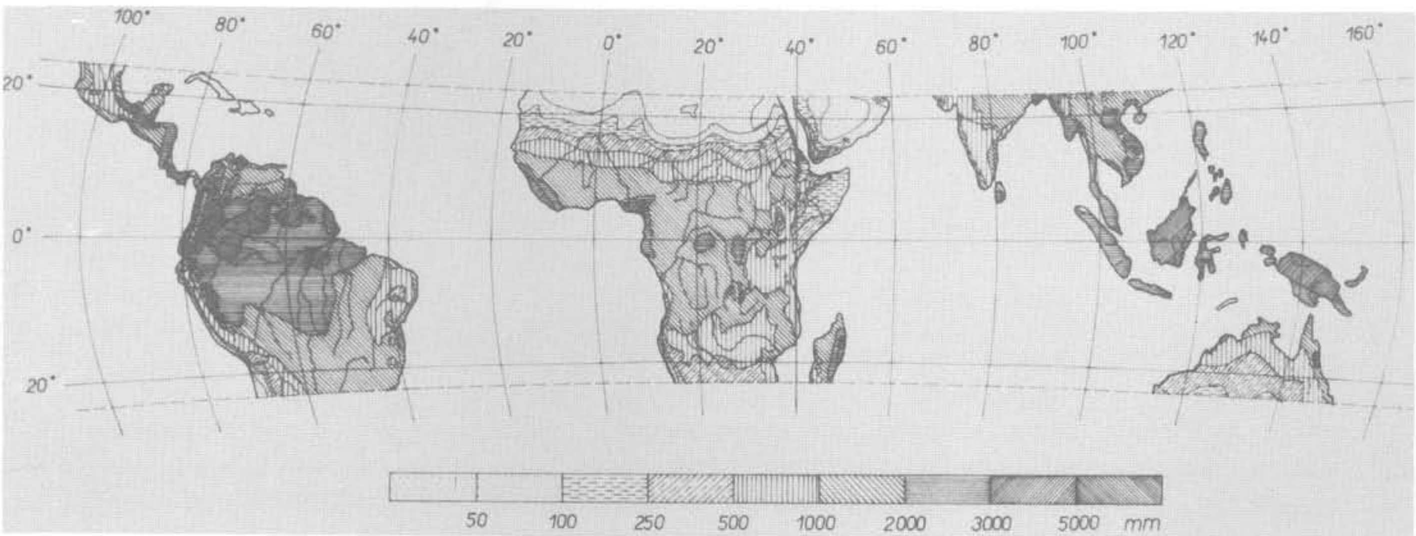

Figure 18.—–Distribution of the annual precipitation in tropics (after Soviet Physiographical World Atlas, 1964).

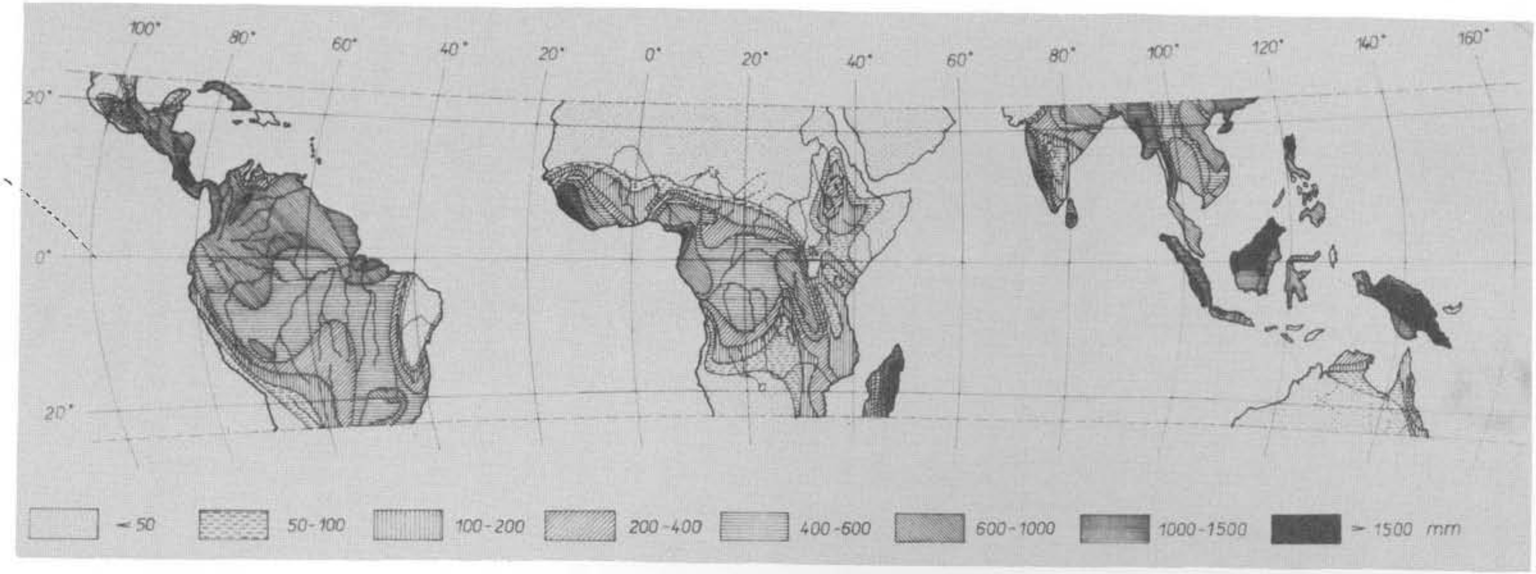

Figure 19.—–Distribution of the annual runoff in tropics (after Soviet Physiographical World Atlas, 1964).

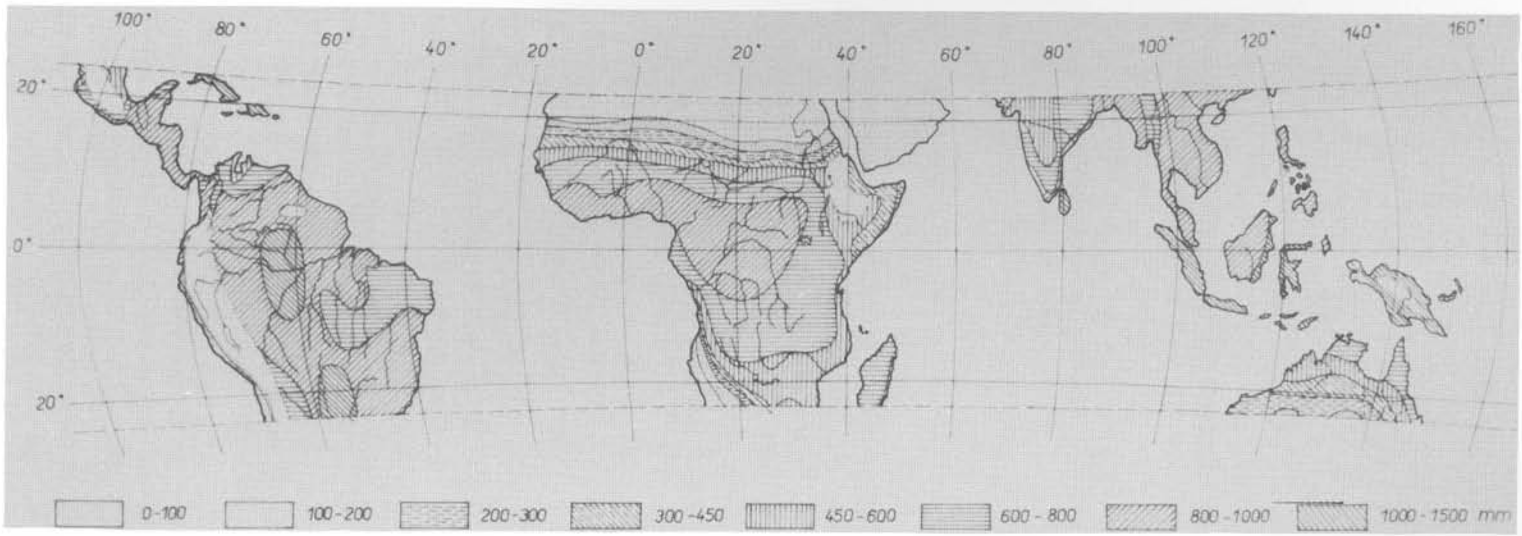

Figure 20.—–Distribution of the annual evapotranspiration in tropics (after Soviet Physiographical World Atlas, 1964).

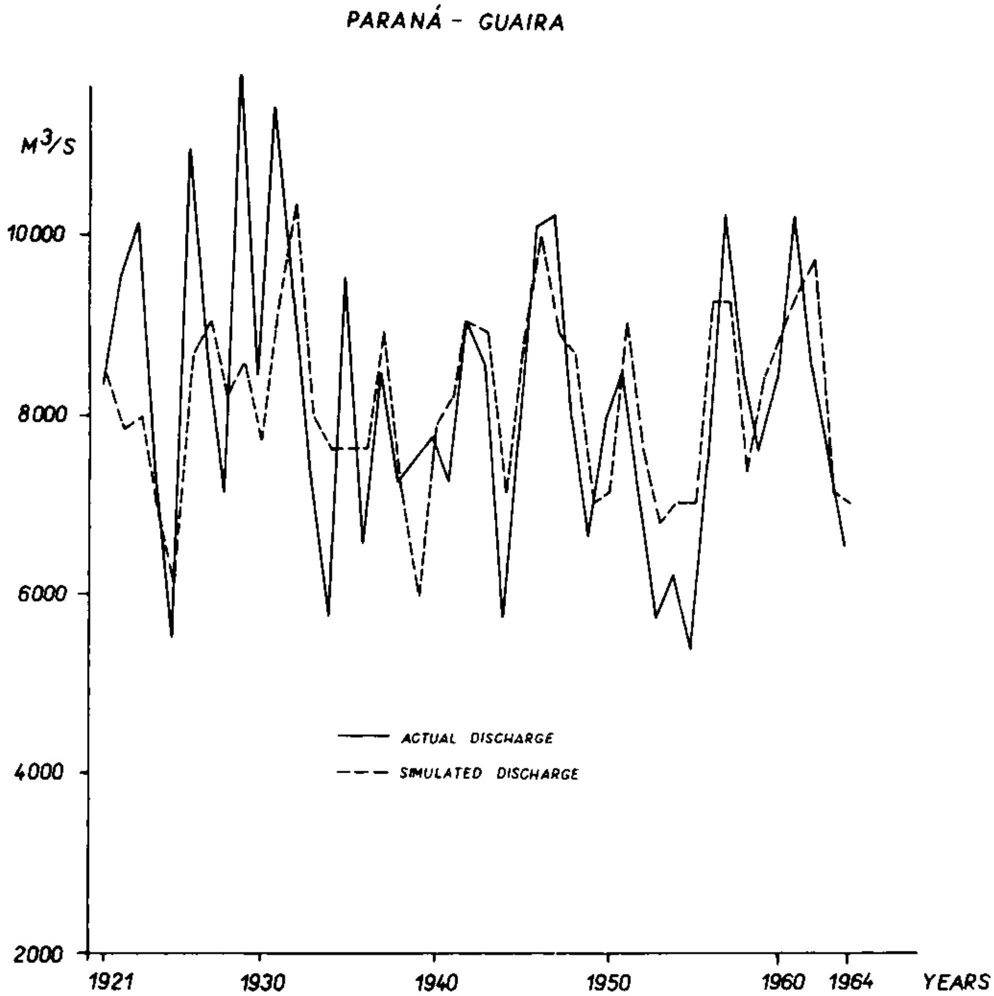

Figure 21.—Actual and simulated sequences of the mean annual discharge of the river Paraná.

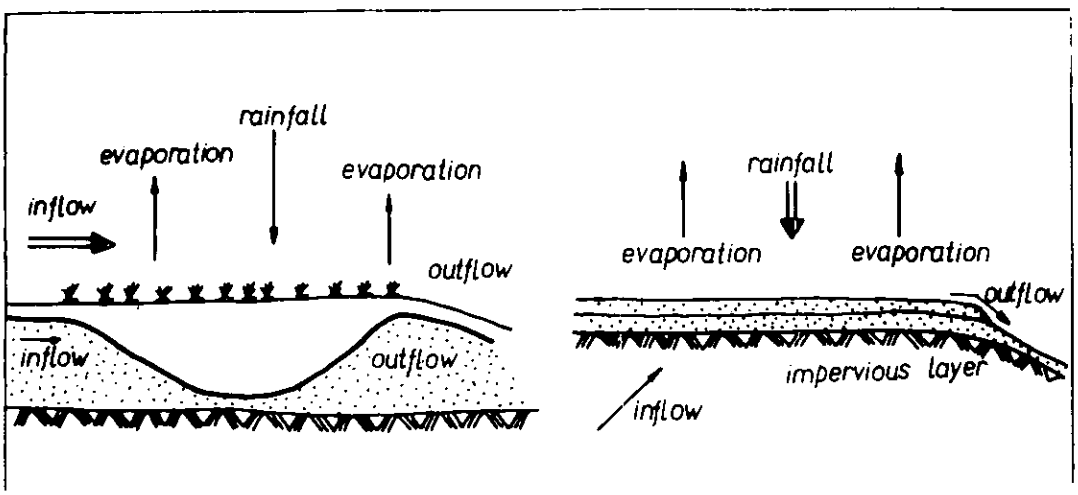

Figure 22.—Simplified diagram of tropical swamp and dambo.

Also analysed were the longest hydrological records in existance, the sequences of minima and maxima of the Nile, commencing in 622 A.D. and continuing for more than 800 years (21). Periods of 6.6 and 14.1 years were found as very significant and also 77 years and longer periods were traced.

Interesting results were achieved by analysing Lake Victoria levels. Periods of 35.5, 70.8, 11.8, 23.6 and 17.7 were found in the sequence of low levels.

Table 5.—*Water balance data for the largest tropical rivers*

River	Cross-section	Drainage area	Precipi-tation	Runoff	Evaporation	Runoff coef.	Yield	Mean annual discharge
		km^2	mm	mm	mm	o/o	$L/s/km^2$	m^3/s
Amazon[1]	Mouth	7,179,500	1,626	483	1,143	293	15.2	109,000
Amazon[2]	Mouth	7,179,500	2,340	1,080	1,260	46	34.5	244,000
La Plata	Mouth	3,104,000	1,200	431	769	36	13.4	42,200
Congo	Mouth	3,607,450	1,561	310	1,251	20	9.8	35,300
Orinoco	Mouth	1,000,000	?	883	?	?	27.9	27,900
Paraná	Rosario	2,341,750	961	217	744	24	6.8	15,900
Tocantins	Mouth	836,570	1,499	508	991	34	16.0	13,400
Madeira	Mouth	1,249,670	1,346	330	864	24	10.4	13,000
Mekong	Mouth	810,000	1,499	508	991	34	16.0	13,000
Río Negro	Mouth	999,750	1,168	279	889	24	8.8	8,800
Xingú	Mouth	600,880	1,321	381	940	29	12.0	7,200
Niger	Mouth	1,091,000	1,250	207	1,048	16	6.4	7,000
Tapajos	Mouth	429,940	1,295	406	889	31	12.8	5,500
Nile	Mouth	2,881,000	479	28	451	6	.9	2,600
Blue Nile	Mouth	324,530	1,082	159	923	14	5.0	1,630
Zambezi	Below Luangwa	[3]1,722,233	799	44	755	6	1.4	1,120
Zambezi	Mouth	[4]1,866,730	850	?	?	?	?	?
White Nile	Above Blue N	1,435,000	710	21	699	3	.7	1,000
White Nile	Below Albert L	281,500	1,309	81	1,228	6	2.5	700
Vict. Nile	Rippon Falls	269,000	1,302	81	1,221	6	2.5	670

[1] After Keller 1962.
[2] Recent measurements.
[3] With Western Kalahari.
[4] With Western Falahari.

TROPICAL SWAMPS AND LAKES

An important part of tropical water resources is formed by swamps and lakes. They contribute significantly to the economy of many tropical countries, acting as storage reservoirs and centers of the fishing industry. The swamps, occupying a much greater area than the lakes, are particularly significant. Unfortunately, no classification of the tropical swamps has been made regarding their geomorphology, origin or hydrological regime. Also the total size of the tropical swamps is not known. In Africa, the size has been estimated at 340,000 km^2, one quarter of which is formed by seasonally inundated swamps. Many of the lätter are rather small in size; their total number has been estimated between 10^4 and 10^5. One can expect that the distribution would be similar elsewhere in tropics. More data exist on tropical lakes. In table 6 there is a list of the largest ones:

Table 6.—*Largest tropical lakes*

Name	Size	H max	H min	Volume	Altitude
	km²	m	m	km²	m.s.l.
Victoria	66,400	80	40	2,656	1,135
Tanganyika	32,900	1,435	572	18,940	773
Nyassa	26,500	706	273	7,000	472
Chad	18,000	12	1.5	27	240
Maracaiba	13,000	250	....	....	0
Rudolph	9,000	72	....	....	427
Titicaca	9,000	400	....	....	4,100
Nicaragua	8,000	77	....	....	32
Albert	5,300	117	....	....	620

The lakes are of different origins. For instance, many of the African lakes are related to the tectonic activities associated with the Western Rift or with the downwarping during the Middle Pleistocene, as in the case of Victoria Lake, where a reversal in the direction of the inflowing system has occurred. Other lakes are results of exogenous activities. Frequently the hydrological regime is influenced by the origin.

Lake Victoria, the third largest lake in the world, fills a shallow pan. Some authors estimate the lake area up to 70,000 km² Because the lake margins are formed by swamps, it is a matter of consideration whether to attach the swamps to the lake or to the land. The water balance of the Lake Victoria was intensively studied during 1967–72 as a regional project of WMO. Preliminary balance figures are (in mm):

Precipitation	Inflow	Runoff	Evaporation
1,476	241	316	1,401

In the course of the first six decades of this century, the fluctuation of the lake was rather smooth with seasonal fluctuation below 70 cm. Commencing in 1960, a sharp rise of water levels was recorded, not only in Lake Victoria, but in the whole system of lakes Albert and Kyoga.

Tanganyika lake fills part of the Great Rift. It is the deepest lake in the world (1,435 m), third in the amount of storaged water. Water balance has been estimated:

Precipitation	Inflow	Runoff	Evaporation
950	1,640	172	2,418

The lake is occasionally intermittent. During wet periods it drains into the Congo system through Lukuga river. Nyassa Lake, belonging to the Great Rift system, drains into Zambezi through Shire river. Balance values are as follows:

Precipitation	Inflow	Runoff	Evaporation
2,000	2,272	2,194	2,078

It is believed that the periodic lake variations are caused by a blockage of the outflow by aquatic vegetation.

Lake Chad is drained only occasionally into the Nile system, after the level reaches a very high stage. The size, estimated at a mean of 18,000 km^2, may reach up to 32,260 km^2 when the area of the swamps is occassionally flooded.

Maraciba, a lagoon lake in Venezuela, fills a tectonic depression near of the Tablazo Bay, connected with the ocean through a short channel. Salinity of the lake fluctuates owing to a frequent exchange of water between the lake and ocean.

Titicaca is the highest large tropical lake. It fills a tectonic depression and is a relict of former much greater lake. The lake drains through the river Desaguadero into Lake Poopo'.

Lake Nicaragua fills the depression formed by a volcanic activity.

Lake Albert occupies an area formed by tectonic activity associated with Western Rift. Water balance for the lake is:

Precipitation	Inflow	Outflow	Evaporation
766	6,910	6,300	1,376

The numbers indicating the seasonal fluctuation of the evaporation from the lake are of interest as compared with the monthly precipitation:

	J	F	M	A	M	J	J	A	S	O	N	D	
Evaporation	144	134	112	120	111	107	95	89	100	114	110	140	mm
Precipitation	14	32	58	102	95	54	66	83	75	84	73	30	mm

A comparison of the salinity of the lake with the salinity of the other African lakes is also of interest:

Albert	Edward	George	Kyoga	Victoria	
480	600	100	200	65	p.p.m.

The balance of tropical swamps is much more difficult. For example, Bahr el Ghazal joins the Nile at the Lake No above the river Sabat as an outflow from the extensive swamp area into which flow many Congo streams from the basin with 800–1,200 mm of precipitation, however, almost all the precipitation is evaporated on the way through swamps; the contribution to the Nile is almost negligible. The flooded plains are covered by grass, bush and savanna forest. The area of the swamps depends on the local rainfall and regime of the inflows. During some periods, many areas may be completely covered by water. In addition to the areas seasonally flooded, there are permanent swamps with papyrus, reed and aquatic plants. In an exceptionally dry season, even the permanent swamps dry out.

Debenham (22), studying the tropical swamps in Africa, defined them as products of vegetational covers of such types which tend to hold backwater. Thus he considers morphological conditions to be secondary. Kimble (23) has differentiated between perenial and seasonal swamps, the latter including a special type called dambos or mbugas in Africa.

The following are characteristics pertaining to tropical swamps:

a. Runoff regulating systems acting as reservoirs with an increased rate of evapotranspiration.
b. Fluctuation of the size year by year, in some cases period by period.
c. Three clearly marked zones; at the margin of a swamp there is a zone under water only short part of a year, usually at the end of the rainy season, second is the area waterlogged for much a longer period and third the area with water all year round.
d. High ratio of the surface area to the depth of the water.

In many cases the seasonal swamps are of the same origin as the perenial ones, arising where ever the climatological and morphological conditions are favourable to make rainy season water accumulate in a depression faster than it can disperse. These swamps differ only in size and in the role of vegetation. There are in tropics swamps genetically different from ordinary swamps. According to Ackermann (24), these swamps are streamless grassy depressions periodically inundated and grasscovered at the headwater end of a drainage system in a region of dry forest or bush vegetation. However, some swamps of such a type have a simple stream network detectable by infrared photography and may behave as perenial after a heavy rainy season (25).

A simple scheme gives an idea of the tropical swamps classification:

Lake
Pond
Stream-perenial swamp-intermittent swamp-land

Headwater lake
and/or stream -perennial headwater swamp (dambo)-intermittent headwater swamp-land

The dambos are unlike ordinary swamps. They are formed in the upper parts of stream networks where valleys are cut by erosion, through thin soil deposits to rock. Dambos are recharged mostly by precipitation, since the subsurface inflow into is relatively small, and passes through them into the drainage network; surface runoff from the bush area is also negligible. A thin surface layer of water on the swamp can be considered as a temporary stream draining the area. A simplified version of the two types of swamps is shown in figure 22. The overland flow occurs very regulary year by year, shortly after the rainy season has started; it is developed as an excess of the groundwater storage after the groundwater space has been filled.

A monthly distribution of total and surface runoff is given in the following table, according to the observation of the headwater swamps in Central Africa. Two catchments, one with 10.8 percent of the headwater swamp, second with 4.9 percent are compared table 7. The table indicates how the increasing size of the headwater swamp increases the surface runoff. One can assume that in an area without any swamp, a negligible runoff would be observed, providing that the bush cover is of the same type as in the studied catchments.

Obviously the vegetation plays an important role in the hydrology of swamps and dambos. A general conception of swamps is related by some authors to so called static environment, or to the standing water series. Welch (26) has supported such a conception.

Table 7.—*Total and surface runoff as depending on the forestation of the catchment*

Month	Catchment with 10.8% of dambo		Catchment with 4.9% of dambo	
	Total Runoff	Surface	Total Runoff	Surface
	mm	mm	mm	mm
October	0.03	0.00	0.00	0.00
November	.00	.00	.00	.00
December	69.98	68.04	16.15	1.20
January	114.92	111.93	72.78	31.43
February	97.97	93.52	108.01	68.17
March	81.60	75.99	85.72	31.11
April	37.92	32.16	64.95	17.30
May	15.42	10.11	36.41	.80
June	7.62	2.99	25.13	.00
July	5.17	.90	12.11	.00
August	3.30	.00	10.15	.00
September	2.26	.00	4.60	.00
Year	436.10	395.64	441.02	140.01

Debeham (22) established the vegetational concept on the principle of running water, because the aquatic vegetation requires flowing water. Thus the life of swamps is more permanent than that of lakes, because the vegetation can adapt itself to many physical changes with the exception of continuous drought. Apparently both concepts are valid under certain circumstances.

Little aquatic vegetation is found in areas flooded once in several years, while in the seasonally inundated areas the conditions for aquatic vegetation are very favourable.

Vegetation influences the hydrological regimes of swamps in many ways. It developes permanent changes in the depth and direction of the channels. Even animals can influence the cycle in swamps. For example, hippopotami consume large quantities of vegetation. If they leave the environment, vegetation becomes more dense, creating opportunities for channel blockage. Differentiation of vegetation in perenial and intermittent swamps also influences the evapotranspirational process. According to recent measurements, the evapotranspiration from a swamp is higher than the evaporation from a free water surface. Hurst (27) concluded that transpiration from the Nile papyrus may exceed the evaporation from the free water surface. Similar results have been reported from East and Central Africa. In figure 23 can be seen how much of the area is covered by papyrus in Bangweulu, a typical swamp. Water balance calculation for this swamp (28) indicates how many factors participate.

Bangweulu swamps from a hydrological unit with Bangweulu Lake (Zambia) in the upper part of Congo basin. Because there is no way to separate lake and swamp, the balance was

THE ENTRANCE OF LULINGILA INTO LAKE CHAYA

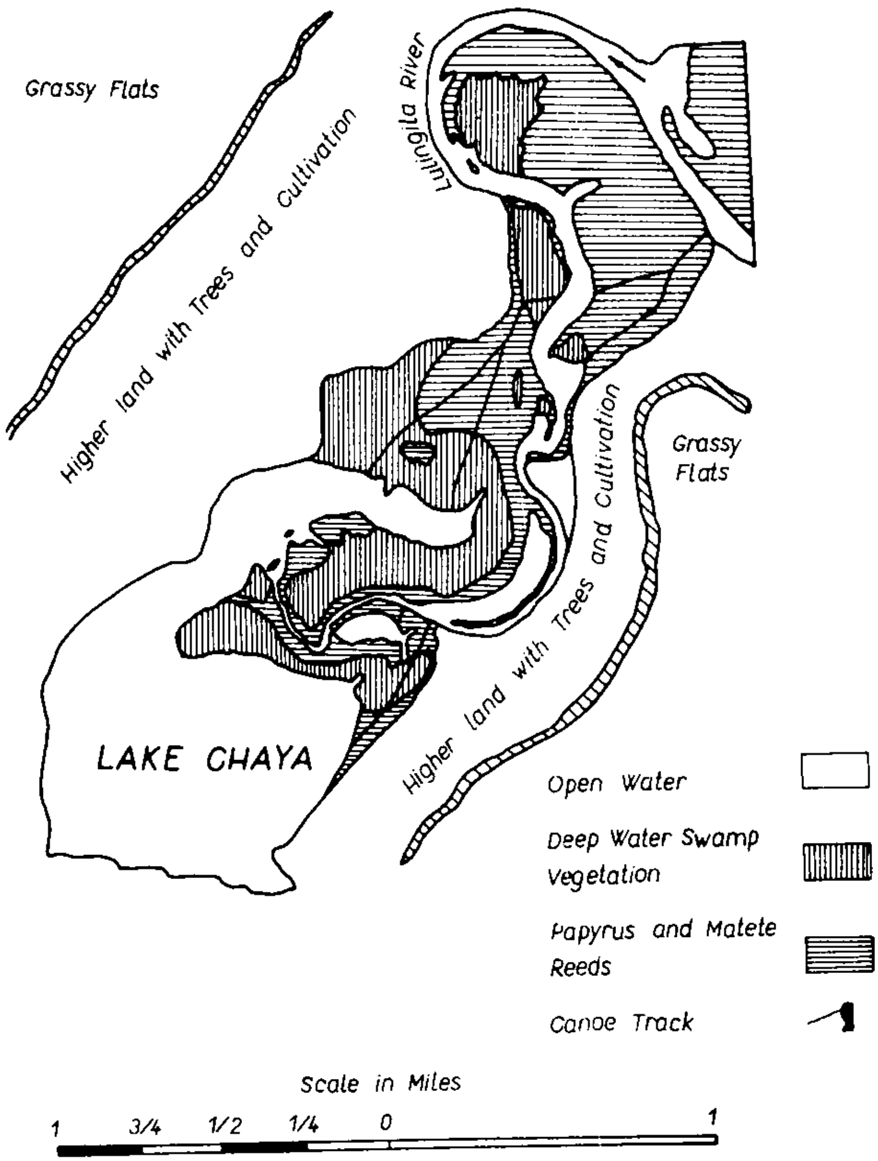

Figure 23.—Map of part of the Bangweulu swamps.

provided for the whole unit, area of 15,875 km². Observed evaporation from the free water surface in the lake area is 2,340 mm/year. The evapotranspiration in the drainage area outside the lake and swamps has been based on the observation of the rainfall and discharge in several river basins inside of the drainage area and estimated at 890 mm. Mean annual precipitation is 1,190 mm in the Chambeshi river basin (which flows into the swamps) and 1,165 mm for the whole Bangweulu basin at the outflow point (River Luapula). By correlation of rainfall and runoff, an additional loss of 167 mm for the whole basin as compared with Chambeshi basin is apparent. Thus the whole swamp/lake area evaporates 2,000–2,160 mm, depending on the size of the swampy area taken into the calculation. Even the upper limit is below the free water surface evaporation, 60 percent of the total inflow into the swamps is transpired.

Table 8 provides an interesting comparison between the evapotranspiration and percent of annual evapotranspiration for an intermittent and a perenial swamp. Both are located 160 km south of the equator.

Table 8.—*Evaporation from an intermittent and perennial tropical swamp*

Month	Intermittent		Perenial	
	Evapo-transpiration	Percent of annual evapo-transpiration	Evapo-transpiration	Percent of annual evapo-transpiration
October	28	5.7	114	5.3
November	90	18.2	261	12.1
December	94	19.1	249	11.5
January	97	19.7	250	11.6
February	69	14.1	261	12.1
March	53	10.7	276	12.9
April	26	5.4	208	9.6
May	10	2.0	122	5.8
June	9	1.8	97	4.4
July	6	1.2	101	4.6
August	5	1.0	107	5.0
September	5	1.0	109	5.1
Year	494	100.0	2,156	100.0

A function of the perenial swamps differs in the middle and lower parts of the basins. These swamps contribute to the reduction of the total and surface runoff instead of increasing it as indicated in table 7. An attempt to find a relationship between percentage of swamps within a basin and outflow from the basin is shown in table 9. The values in the table represent total outflow in mm.

The relationship was developed for the tropical plateau covered by woodland-savanna in dry-wet region.

Table 9.––*Relationship between the swamp extension within a basin, annual rainfall and annual runoff*

Areal extent of swamps as a percentage of total catchment area	Annual rainfall (mm)		
	1,250	1,000	750
1	357	182	56
2	315	155	41
3	275	127	31
4	243	107	23
5	220	91	20
6	203	76	15
7	188	71	10
8	177	68	8
9	172	66	5
10	167	63	3

Recently a few attempts have been made to simulate the regimes of swamps using mathematical models (29). Hutchinson and Midgley (30) simulated the regime of lower reaches of Okavango. Despite such difficulties as limited data available and recent earth tremors which made the past data unapplicable, the result is an example of the application of modern methods in tropical hydrology.

HYDROLOGIC CYCLE AND WATER BALANCE IN TROPICS

The general function of the hydrologic cycle in the tropics is similar to the function of the cycle elsewhere. However, there are some factors which may produce rather unexpected deviations from the water cycle existing in middle latitudes. One of the most decisive factors producing such deviations is vegetation. Vegetation itself is influenced by the climate on a large scale, a good correlation can be found between meteorological phenomena and vegetation cover. However, a great variety of vegetation is found in the subregions. For instance, in British Guayana there have been found within an area of 8 km^2, 163 tree species, three types of palms, 80 types of shrub, 83 lianas and 98 types of epiphytes (31). In Zambia (28), in an area of 16 km^2, there have been found 60 species of grasses.

From the ecological viewpoint, a classification of the vegetation developed by Kimble (23) for tropical Africa can be extended as valid for tropics in general Kimble recognizes:

1. *Pereniallv well-watered regions* with the subtypes
   a. rainforest,
   b. perenial swamps
   c. great lakes

2. *Seasonally well-watered regions* divided into
   a. savanna
   b. dry forest
   c. seasonal swamps

3. *Perenial ill-watered regions* with
   a. semidesert
   b. desert

Equatorial or rain forest is found in areas where the annual rainfall is in excess of plant needs, even if it is not in the place where there is more water than the forest can use. The area is characterized by a continuous downward movement and transport of water, high infiltration which reduces the runoff and intensive transpiration. The effect of natural forest is fully seen after a part of it has been destroyed by a fire, exposing soil to erosion and solar radiation. Most of the large tropical streams are fed from the rainfall forest regions, such as the Amazon, the Congo and part of the Niger.

Perenial swamps have been discussed in the previous chapter, here their function as runoff regulating systems is to be discussed. During the dry period, they are able to release more water than they receive. Although not limited to a single climatical zone (however, they tend to be more frequent and extensive near the tropical margins), they are considered as vegetational units.

The tropical lakes occupy much less area than the swamps and frequently they are saline or brackish, which reduces their utility for agriculture. The hydrologic cycle is not fully known in the marginal areas between lakes and land.

Savanna and dry forest cover at least half of the tropics, which indicates that approximately the same amount suffers from alternating surpluses and shortages of water. Regarding numerous types of savanna itself or in combination with dry forests, one can see that the ratio of surpluses and shortages is very different in different places. The dominant vegetational cover, bush, grass and trees can adapt themselves to extensively alternating conditions and the presence of water is indicated by a higher degree of greeness.

Seasonal swamps differ from the perenial ones by the duration of the outflow, type, size and role of the vegetation and duration of the water level. Some developed even on steep slopes, where deep vegetation slows the surface movement.

Semideserts obtain rain only occasionally; only vegetation such as thorny shrubs and ephemeral grasses, which can adapt to such a condition, are found there. Debenham estimated that about 50 percent of the rainfall infiltrates in semidesert soil. The porous sand layer inhibits evapotranspiration so the density of vegetation is reduced.

Desert water is considered as being of an exotic origin. There are very few deserts without water storage of some depth. In some desert areas, as between the Orange and Cunene rivers in southwest Africa, fog is a dominant part of the hydrological cycle, the amount of which is sufficient for short lived plants to live there. In the Sahara, nightly falls of dew during the cooler months of the year are sufficient for similar purposes.

An interesting classification of the vegetation has been carried out by Troll (35) for tropical Andes (table 10).

A simplified classification according to Blumenstock and Thornthwaite (32) is presented in figure 24.

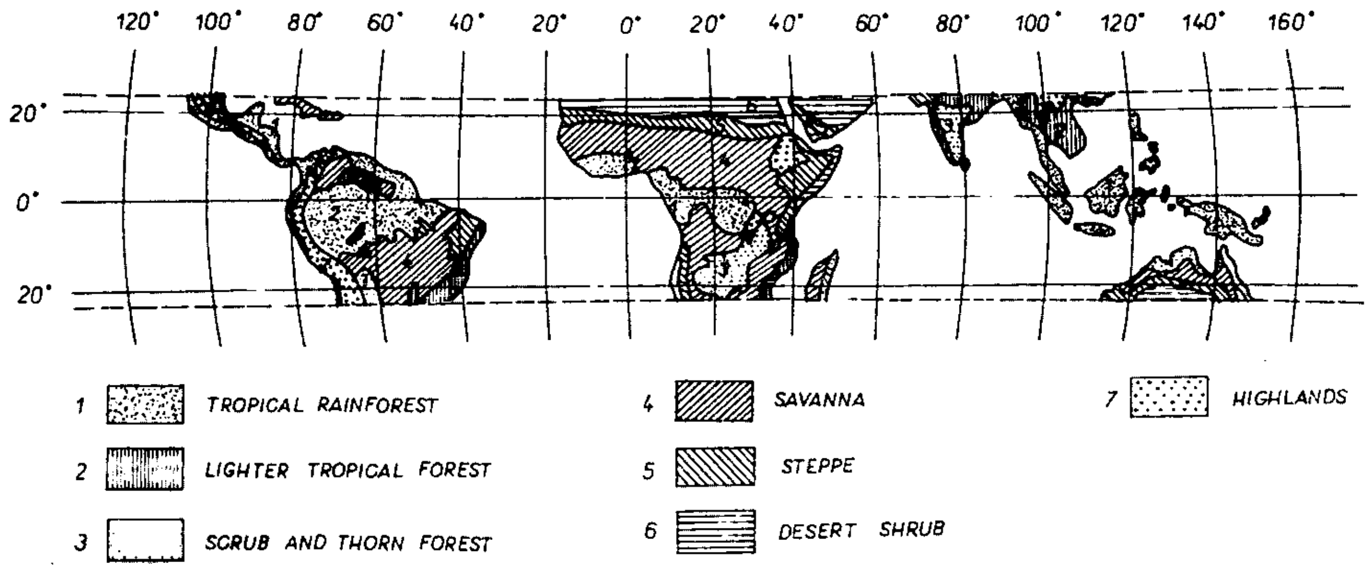

Figure 24.—Vegetational belts in tropics, according to Blumenstock and Thornthwaite, 1941. 1 = tropical rainfall forest, 2 = lighter tropical forest, 3 = thorn forest, 4 = savanna, 5 = steppe, 6 = desert shrub, 7 = highlands.

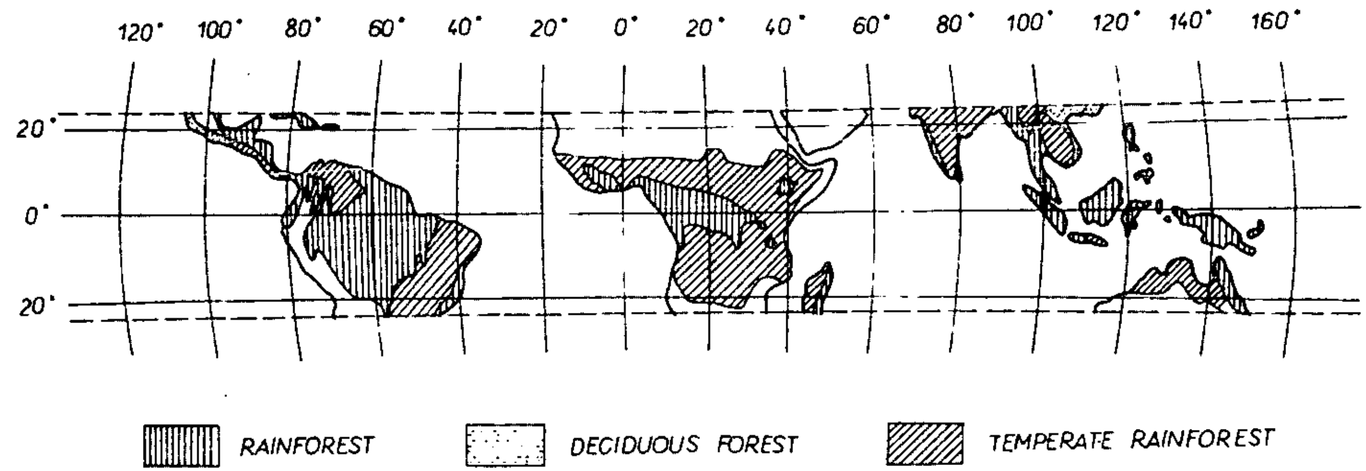

Figure 25.—Distribution of tropical forest according to Matějka, 1971.

Table 10.—*Classification of the vegetation in tropical Andes*

Months with rainfall	Warm land	Moderate land	Cold land	Frost land
12				
11	Tropical rainforest	Tropical forest	Tropical mountain forest	Paramo
10				
9				
8	Wet savanna	Vegetation of wet valleys	Wet sierra vegetation	Wet puna
7				
6				
5	Dry savanna	Vegetation of dry valleys	Dry sierra	Dry puna
4				
3	Shrubbed savanna	Shrubbed valley vegetation	Shrubbed sierra	Shrubbed puna
2				
1	Semidesert	Valley semides	Dry sierra	Desert puna
0	desert	Valley desert	Dry sierra	Desert puna

Studying the role of tropical vegetation, Wicht concluded (33):

a. Plantations of exotic trees require approximately the same amount of water as indigeneous forest,
b. forests use more water than grasslands,
c. swamps will be dried out if trees are planted in them,
d. the consumption of water by forests depends primary on the amount of water available in the soil,
e. the removal of vegetation will cause an increased discharge. However, there has not yet been a definite answer to the question as formulated by Bernard: Is the high rainfall of Congo a result of the forest or is the forest a consequence of the high rainfall? There is no doubt that the forest plays a significant role as a part of tropical water resources and is itself an important component in the formation of the water resources. This double function is even more pronounced in tropics where about 52 percent of the total acreage of productive forest on the earth is found; according to Weck (34) almost 1.3 millions of hectars. Figure 25 indicates the distribution of world forests in the tropics.

Pereira (36), in evaluating the evapotranspiration in the Kenya Rift Valley catchments, concluded that even if the deep permeable soils are covered by heavy forest, the seasonal streamflow fluctuation is 1:20. However, the forest cover makes such a type of catchment almost imune against stormflow. Similar conclusions have been made by Balek and Perry (29) from the areas near Zaire-Zambia borders.

The most difficult of the hydrological cycle components to be studied is the evapotranspiration. Here in addition to vegetation, soils play an important role. A simplified map of tropical soils is shown in figure 26.

The most frequent soils of the tropics are the so called latosols or lateriti soils. They are developed by laterization, a chemical and mechanical decomposition of the parent rock, under the influence of moisture and heat. Silica (SiO_2) is almost entirely leached and oxides of iron,

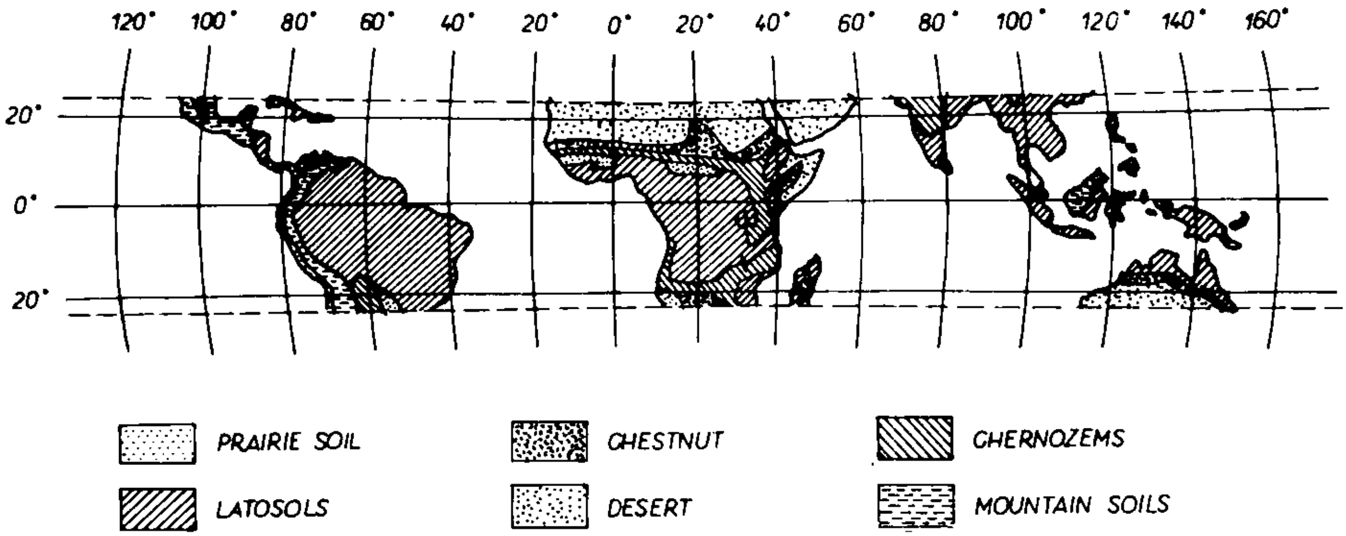

Figure 26.—Distribution of tropical soils according to Kutílek, 1963.

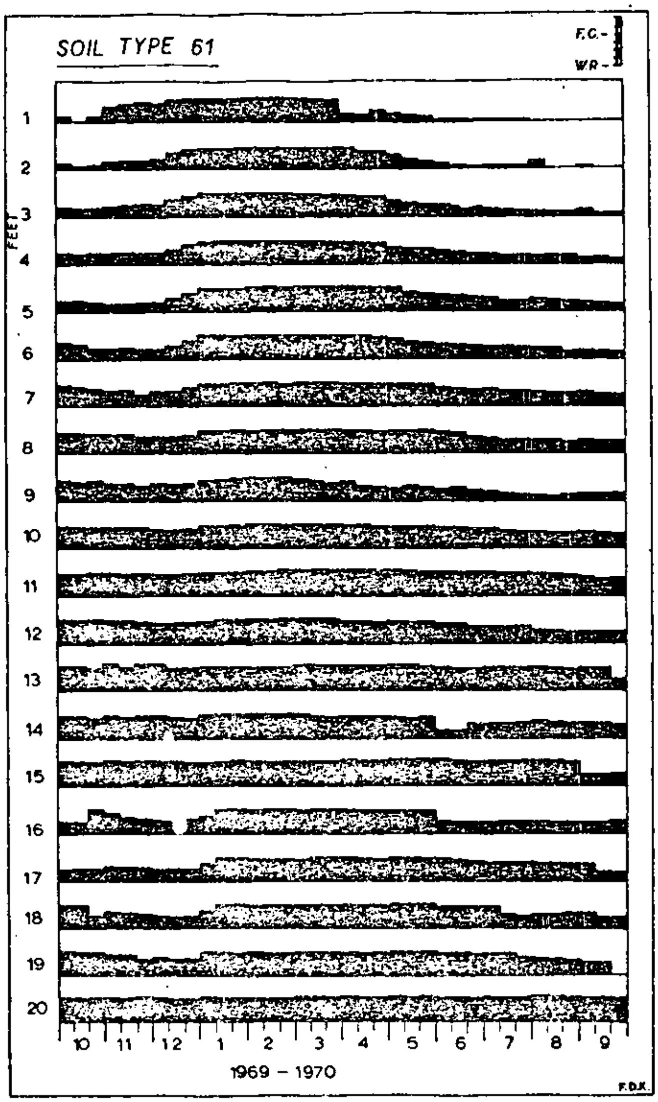

Figure 27.—Soil moisture fluctuation in tropical poorly drained soil of wet and dry region with woodland cover.

aluminum and manganese have accumulated, giving a distinctive reddish brown colour to the soil. Because of the rapidity of bacterial action, humus is entirely lacking. These soils correspond closely with the equatorial rainforest and savannas. They lose their fertility quickly, because plant nutrients are available only in a thin surface layer. The accumulation of oxides goes to such an extent that the layers known as laterites are formed.

Prairie soils are found in tropics in transitive areas between the red soils and chernozems. They require 25–40 inches of rainfall and they are similar to chernozems, lacking only calcium carbonate.

The chernozems consist of two layers. The black layer, two to three feet thick, is rich in humus and grades into a yellow-brown horizon; both are divided by a sharp line from a light colored horizon. The soil is rich in calcium appearing also as calcium carbonate. Chernozem requires more aridity in the climate with hot summer and cold winter and strong evaporation. Grasses flourish there instead of forest.

Chestnut soils and brown soils are developed in the semiarid areas of tropical Africa. Soils of a prismatic structure contain less humus. A fluctuation of dry and normal years is favourable for them. Brown soils, compared with chestnut soils, indicate a higher degree of aridity.

Desert soils occur in a grey or red colour and contain little humus because of the limited vegetation. Horizons are very slightly differentiated. Calcium carbonate, in the form of lime crust, appears as a hard rock layer, owing to the slow evaporation of water near the surface. In the depressions where there is no outlet for the intermittent streams, the evaporation is so intensive that the soils contain an excess of salts appearing as saline soils.

The relationships between soils, vegetation and evapotranspiration has become an object of various studies. They were discussed widely at the Symposium on tropical soils and vegetation at Abidjan in 1959. Aubrecht (38) pointed out that vegetation and climate are the most active factors in the formation of tropical soils. Under savanna and forest, organic matter in drained tropical soils is of the soft variety and the humus characteristics vary according to climatic conditions, primarily as a function of rainfall. Lang's factor, (L) defined as:

$$L = \frac{S}{t},$$

is frequently used as a climatological characteristic of the soil formation. Here S means the mean annual precipitation (mm), t is mean annual temperature (°C). Areas with different L are favourable for various processes of soil formation according to the following table:

Table 11.—*Relationship between the Lang's factor and soil formation*

$L >$	160	process of podzolization
160–	100	chernozem process
100–	60	brown soil forming
60–	40	forming of laterits
$<$	40	desert soils

Initial studies on the water uptake by plantations were concerned with the water in the areation zone. Observations on Central African catchments (29) indicated that the groundwater storage participates in this process to a great extent; particular tropical trees are supplied during the dry period from the groundwater storage, through the zone of capillary rise. The trees of tropical highlands can transpire practically any amount of water available. In some years following a wet period, the total amount of transpired water may exceed total annual precipitation. The root density and distribution analysis as well as direct water balance calculations gives information on the transpirational process. The root studies of Maxwell (37) clearly indicate the relationship between the roots and moisture in the soil. A record of soil moisture movement in poorly drained, slowly permeable, very strongly to strongly acid soil (fig. 27) demonstrates that supplementary water for transpiration during a period of deficit in the upper layer is provided from groundwater sources. Grasses use water from only upper soil layers because of their short root systems. A correspondence between root density and soil moisture fluctuation can be seen by a comparison of figures 27 and 28. In figure 28 a second peak in the root density can be seen in the vicinity of the groundwater level.

Such experiments are possible for single species; the function of vegetation as a complex system is much more difficult to study. A classicial approach, based on a comparison of the discharge and precipitation and considering the fluctuation of the soil moisture and groundwater storage is presented below (39). Values of monthly evaporation and the potential evaporation calculated by using Penman's method are presented in table 12.

Table 12.—*Evapotranspiration from the forest and grassland*

Month	Potential evaporation	Precipitation	Evapotranspiration	
			Grassland	Woodland
	mm	mm	mm	mm
October	190.97	95	29.13	66.98
November	171.11	169	124.00	152.73
December	145.98	244	65.86	145.98
January	146.42	358	99.64	146.42
February	152.87	161	71.25	162.95
March	161.63	241	55.30	197.69
April	150.93	7	26.59	127.89
May	130.22	0	10.34	87.45
June	101.38	0	9.02	63.36
July	114.75	0	6.65	61.38
August	136.40	0	5.56	55.04
September	159.87	0	5.13	46.71
Year	1,762.53	1,277	508.47	1,314.58

The table indicates that in the studied area the trees consume approximately two to three times more water than the grassland. From further analysis it follows that in the mixed gress and tree cover total evapotranspiration depends on the ratio of grass and trees. During wet periods the total amount of evapotranspiration exceeds the value of potential evaporation. Also, in a given year the

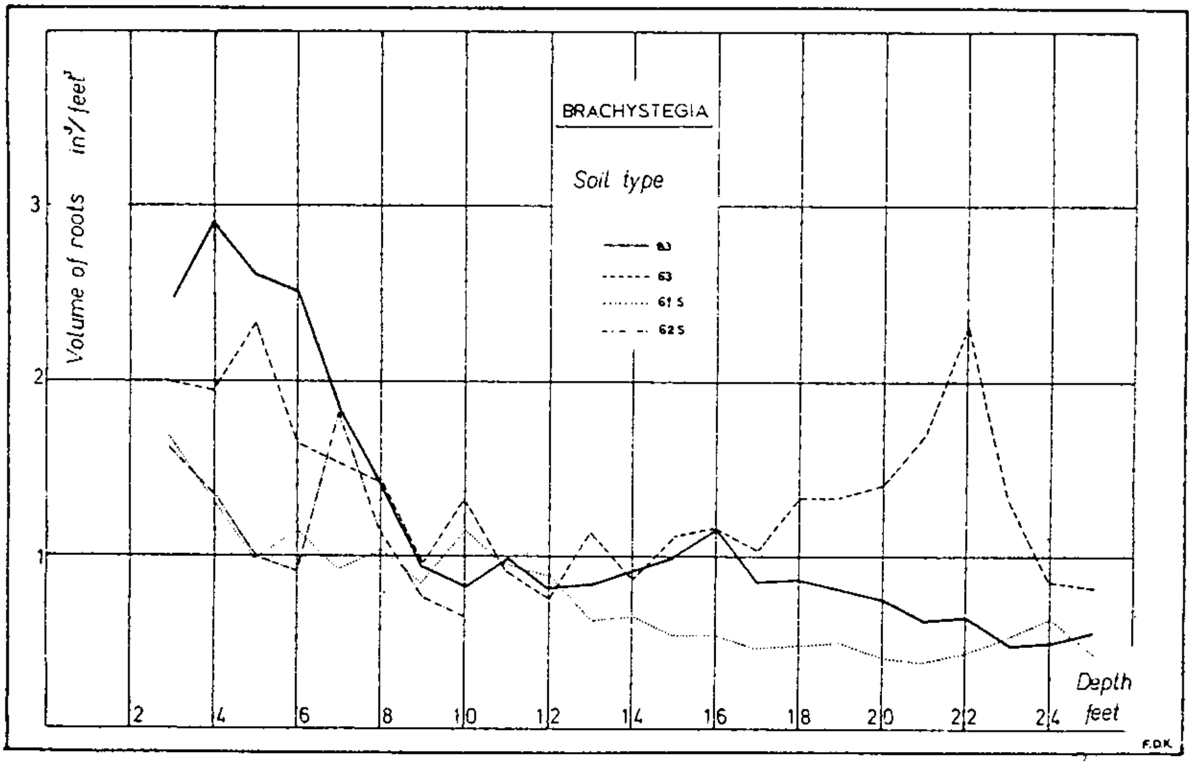

Figure 28.——Relationship between soil moisture availability and root density.

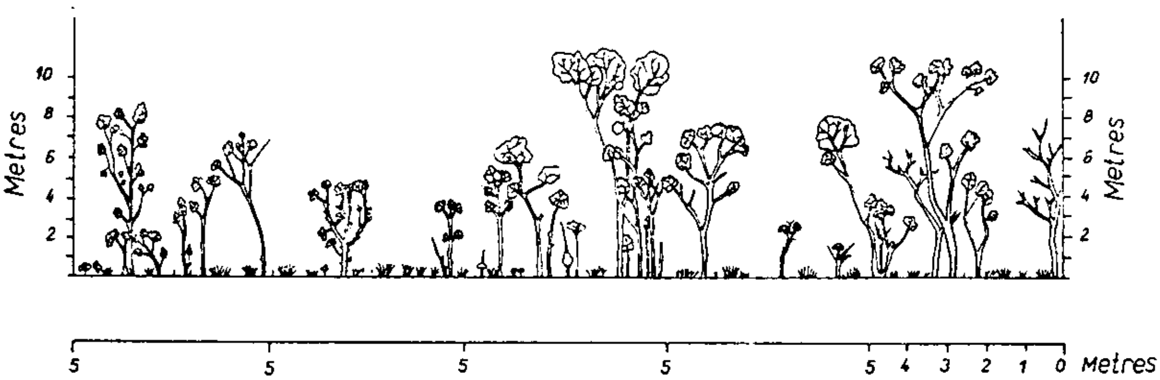

Figure 29.——Profile diagram of a 50 m strip in the middle slope savanna, Ghana.

evapotranspiration from the forest exceeds the annual precipitation, which indicates that the previous year was wet. Similar observations were made by Hurst (27) on the Sudanese papyrud and recently in Uganda by Bulek (40). Very likely the leaf area index, defined as a ratio of the total leaf area to the area covered by the plant, plays an important role. This can be also traced on the profiles of various tropical species (41) as can be seen in figure 29 on an example from Ghana's savanna. Some studies, however, have been based on the presumption that the ratio of potential evaporation/actual evapotranspiration (E_t/E_o) is fairly constant and more or less typical for certain species. Pereira et al. (42) estimated the ratio for bamboo to be 0.9, vegetable in Kenya 0.51, maize 0.72, coffee 0.5–0.8 and tropical forest 0.86.

The hydrologic cycle is also affected by interception. The process may be considered a bridge between the rainfall and soil infiltration. Few interception measurements have been made in the tropics. Jackson (43) established experimental plots in west Usambaras (Tanzania). In an intermediate forest community exposed to the humid climate on mountainous slopes he found the following relationship between gross rainfall and percentage of intercepted water:

Gross rainfall	1	2.5	5.0	7.5	10	15	20	40	mm
Percent intercepted	80	44	28	21.3	17	12	9.5	5.5	

Jackson demonstrated that the high variability of the tropical rainfall rate makes accurate determination of interception difficult, even for small areas. The intercepted water probably increases significantly the evapotranspiration and increases the ratio E_t/E_o during the rainy season. Kutilek (44) concluded that for a precipitation duration of 15 minutes, interception intensity is similar to that in moderate region; increasing the duration of precipitation produces higher interception intensities in the tropics.

In the absence of detailed knowledge of the interception process, the hydrologic studies concerned with various phases of the tropical hydrologic cycle deal with simple rainfall-runoff relationships similar to the Wundt' diagrams (45), developed as limits for tropics and subtropics. These can serve as a first approximation of the runoff which can be expected from a certain river basin, assuming that the precipitation is known. After some period of observation, deviations for each particular river are found. Some tropical rivers behave within the limits for the tropics; others act subtropical, such as the rivers of high altitude plateaus. In an attempt to categorise the rainfall-runoff relationships a set of curves has been plotted (fig. 30), based on the observations of various catchments in East and Central Africa.

A formula for the calculation of the annual amount of water deficit was developed by Pike (50):

$$E_t = \frac{R\,E_o}{\sqrt{R^2 + E_o^2}} \quad \text{mm/year}$$

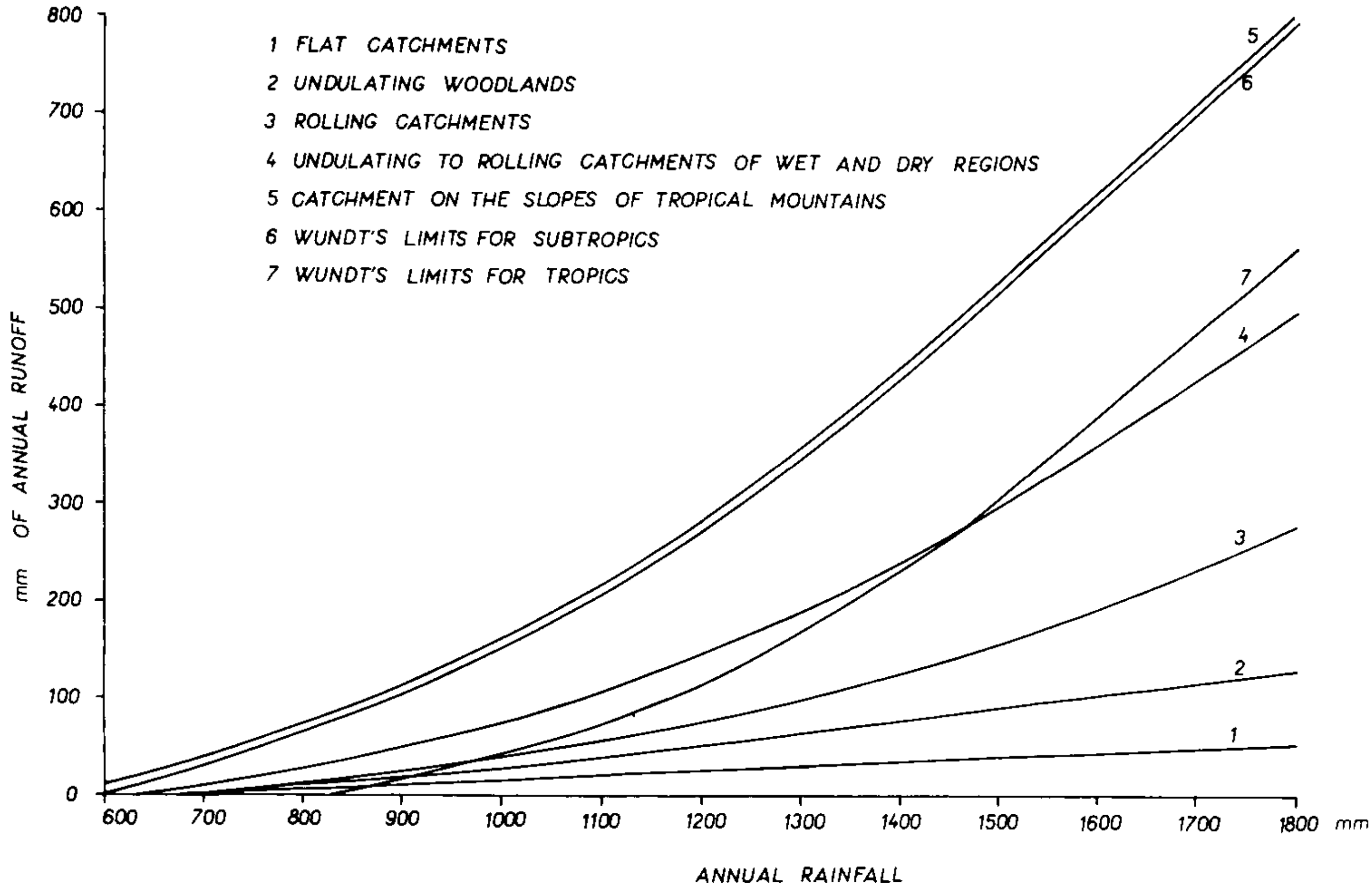

Figure 30.—Rainfall runoff relationships based on the observations of the catchments in East and Central Africa.

where E_t is the annual evapotranspiration, R is the annual rainfall and E_o is the open pan evaporation or corresponding Penman's estimate. The formula has been considered as an improvement of Turc's formula, occasionally used in tropics as well:

$$E \quad \frac{P}{\left\{0.9 + \left(\frac{P}{L}\right)^2\right\}^{1/2}} \quad \text{mm/year}$$

Here P = annual precipitation in mm,
L = $300 + 25T + 0.05T^3$ mm,
T = mean temperature in °C.

UTILIZATION OF TROPICAL WATER RESOURCES

The alternation of seasonal surpluses and deficits of water creates problems for many tropical countries. In some cases, according to Kimble (23), simple solutions, such as prevention of flooding by lowering erosion rates, are sufficient. More frequently, however, rather expensive schemes have to be provided.

There is an extensive power potential in tropical water resources. For instance, about 37 percent of the world's water power potential is in tropical Africa, 10 percent in tropical South America, 8 percent in tropical Asia and 3 percent in Oceania. In otherwords, more than half of the world's water power is in the tropics. The Congo river is a good example; in a stretch of 350 km, it descends almost 300 meters through 32 falls and cataracts and develops a potential of 114 million horsepower, about half of the total potential of the North American continent.

Tropics are also extremely rich in fish, this source of nutrition is far from being exhausted because of the small scale of trade and small number of varieties fished. The transport problem is a barrier to extensive exploiatation.

Recently much attention has been paid to the complex development of the international river basins which are numerous in tropics. In many cases rivers form natural boundaries. In Africa alone, 48 river basins have international status.

A substantial portion of water resources is still needed for agriculture, because agricultural prosperity will create a sound basis for further development. Irrigation, drainage and flood control have become major parts of the water resources development. Basically, the potential food supply in the tropics is adequate, but there appears to be serious nutritional imbalances and quantitative seasonal deficiences in certain rural areas owing to severe droughts, diseases etc. On the contrary, in the arid areas and heavy rainfall zones only a limited intensification and extension of the agricultural production can be provided without rather expensive water control measures. Therefore the extension of irrigated agriculture will have to be related in various stages to the climatological-ecological zoning. The extension of the irrigated agriculture can be foreseen:

i. in arid areas where no settled agriculture is possible without irrigation,
ii. in the intensification and diversification in semi-arid areas to ensure safe and high yields of cash crops,

iii. in the areas where the rain is so erratic that supplemental irrigation is needed for the production of high values export crops,

iv. in the areas with higher water requirements.

The extension of the flood control measures and drainage is generally required in the high rainfall zones and the flood plains and coastal area of tropics.

Numerous sociological problems are created by technical rearrangements; frequently they have to be accompanied by various settlement and resettlement schemes. Plans for development must be reconciled with the traditional law.*

A present stage of irrigation is given in table 13:

Table 13.—*State of irrigation in tropics*

Continent	Arable land	Harvested annually	Irrigated annually	Comments
	million hectars	million hectars	million hectars	
Africa south of Sahara . .	152	64	1.1	Excluding Laos Indonesia,
Asia	211	211	44	Burma Cambodia, Vietnam.
Latin America	130	71	·11	Excluding Central America.

Water resources planning for irrigation, drainage, flood control, hydropower and navigation in a region requires a qualitative and quantitative assessment of the available resources and prospective needs. Past failures in planning development and limitations of financial resources have led to integrated development projects within which the water resources development is seen in a much wider concept than before and constitutes a part of the overall framework of development planning. In water resources development planning, successive stages can be identified leading from the inventory of available resources to their full scale utilization:

1. Reconnaisance surveys to determine priorities,
2. Resources survey and appraisal,
3. Overall development, planning and identification of objectives and constraints,
4. Development of plan alternatives,
5. Selection of means and methods by successive selection of
   i. projects for early implementation,
   ii. implementation of pilot schemes and feasibility studies,
   iii. realization of large scale improvement and development.
6. Utilization, maintenance and conservation.

*After a dam on one of the tributaries in Zambezi basin was swept away by an exceptional flood, the village elders declared that it happened because the local council had not slaughtered a black cow as a ritual to the spirits and insisted on such a slaughter before the reconstruction started.

One of the main problems in tropical water resources management is a very limited availability of data and information on existing and potential use of land and water resources. Therefore, the continuous study and survey of hydrological regimes is needed. After preliminary reconnaisance surveys, the potential of river basins, general planning and the implementation of the projects are to be determined. Finally a detailed survey is justified for selected projects for which the financing has been assured.

Surveys of a basin potential should cover the entire river basin. However, because of the international status of many basins and the competition of the water resources schemes with forms of investment which may be more productive in the short run, none of the large schemes proposed in tropics has been fully developed.

Flooding, waterlogging and salinity are the three main problems arising from the excess of water which restrict agricultural production. Drainage and flood control techniques are two basic measures of controlling excess water. On the other hand, floods frequently develop fertile flood plains with good quality agricultural soils. In some regions regular floods are of such a great importance that they are celebrated as national holidays.*

In order to drive optimum water management, problems have to be tackled from both sides i.e. the potential and effective exploitation of available resources as well as the specific requirements at the field level, otherwise social disasters can be developed. Kariba, one of the largest man made lakes, constructed for the benefit of the people living along the Zambezi river is an example. Traditionally fertile areas occupied by Ila Tonga people were flooded and the tribe was resettled in a hostile country of Gwembe, where insufficient water supply caused suffering less then five miles from the lake.

The effect of the water control in various stages is shown in table 14:

Table 14.—*Effect of water control in tropics*

State of water control	Inputs	Rice yeilds obtained		Obtainable
		tons/ha		
No water control	Nil	Laos	0.8	1.0
Successive introduction of water control:				
a. Elimination of floods	Nil	Cambodia	1.2	2.5
b. Elimination od drought	Low fert.	Burma	1.4	2.5
		India	1.5	2.5
c. Water table control	. . . .do	Thailand	1.8	2.5
		Vietnam	2.0	2.5
d. Full control (irrig and drainage).	. . . .do	Ceylon	2.3	
Sophisticated water management	High fert., impar. seeds	Malaysia	2.7	4.0
Experimental cond.				8.0

*On the middle Zambezi, the King of Barotse Litunga is welcomed twice a year by cheering crowds at so called Kuomboka, which is a celebration of the moment at which the Zambezi increases or decreases to a certain level at which the king can sail from or to his winter palace in the middle of the Zambezi flood plains.

Some areas of the tropical regions are exposed to intensified soil erosion. Insufficient reforestation and grazing control are main factors which influence this intensification. For example, savanna soils have a great structural instability when overcultivated. According to some authors only two years of highly mechanized cultivation are sufficient to degrade the structure of savanna soil. Starmans (46) presented a graph (fig. 31) on the relationships between various tonages of suspended loads and vegetational cover of the basins in Africa and Asia. The graph indicates how the rainfall and its distribution plays an additional role. Systematic reforestation, contour tillage and gently sloping ridges have proved themselves as profitable measures. The plant cover in plant rotation is also very effective, particularly when grass-legume mixtures and proper fertilization are used. The flood control projects and dam constructions belong to the difficult parts of the erosion control and river training because the observation of the extremes are not long enough to permit the effective design. There are also many gaps in the already existing sequences. In some cases the validity of theoretical curves must be verified by field surveying and interviewing local people.*

In figure 32 the relationship between the yield of 1 percent flood and the drainage area has been developed for African tropical streams (47), however to some extent it can be applied toward other tropical basins. The following are basic characteristics for the plotted curves:

1. Insufficiently forested mountainous areas of Mediterranean.
2. Mountainous tropical areas with scarce vegetation and parts suffering from advanced soil erosion.
3. Mountainous areas with high rainfall and high proportion of exposed rocks and selerophyllous vegetation.
4. Basins of savanna or savanna/forest type of vegetation with pronounced rolling character of the country.
5. Basins of tropical lowlands and highlands containing a small percentage of swamps.
6. Flat basins significantly influenced by swamp regimes.

Local utilization of water resources is rather simple and inexpensive; local labor and materials can be used. Water for domestic purposes is obtainable from

i. springs and wells,
ii. pans,
iii. river beds,
iv. boreholes,
v. dams,
vi. catchment tanks.

Perenial springs are rare where the demand for water is high. Tradition often virtually prohibits piping of water from springs and wells.

Pans are shallow, natural depressions, filled with water during the rain periods. Frequently they are filled with mud and coarse grasses. Because no grazing control is practised in the vicinity, the quality of water becomes doubtful without further treatment, although local people are frequently adapted to it.

*As in the case of the catastrophic flood in Luangwa valley bordering Malawi and Zambia "nothing like these floods has happened during the past years" according to the chief of the tribe. Since it has been known that the tribe is living within the area for about 100 years, such an information is extremely valuable when carefully interpreted.

RELATIONSHIP OF VEGETATION AND SOIL EROSION SELECTED RIVERS AFRICA AND ASIA

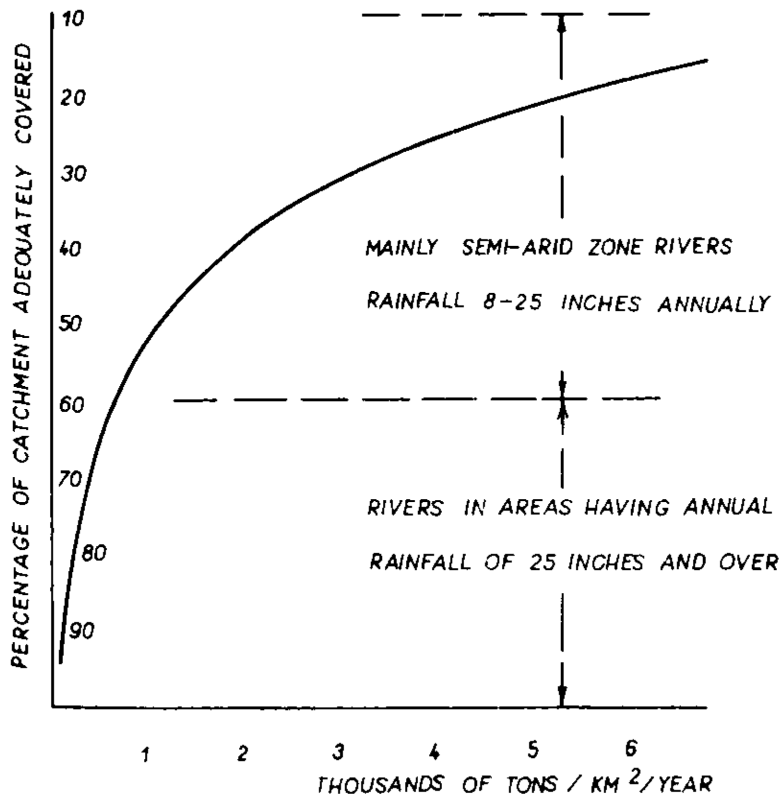

Figure 31.—Soil erosion as depending on the amount of vegetational cover of various Asian and African basins.

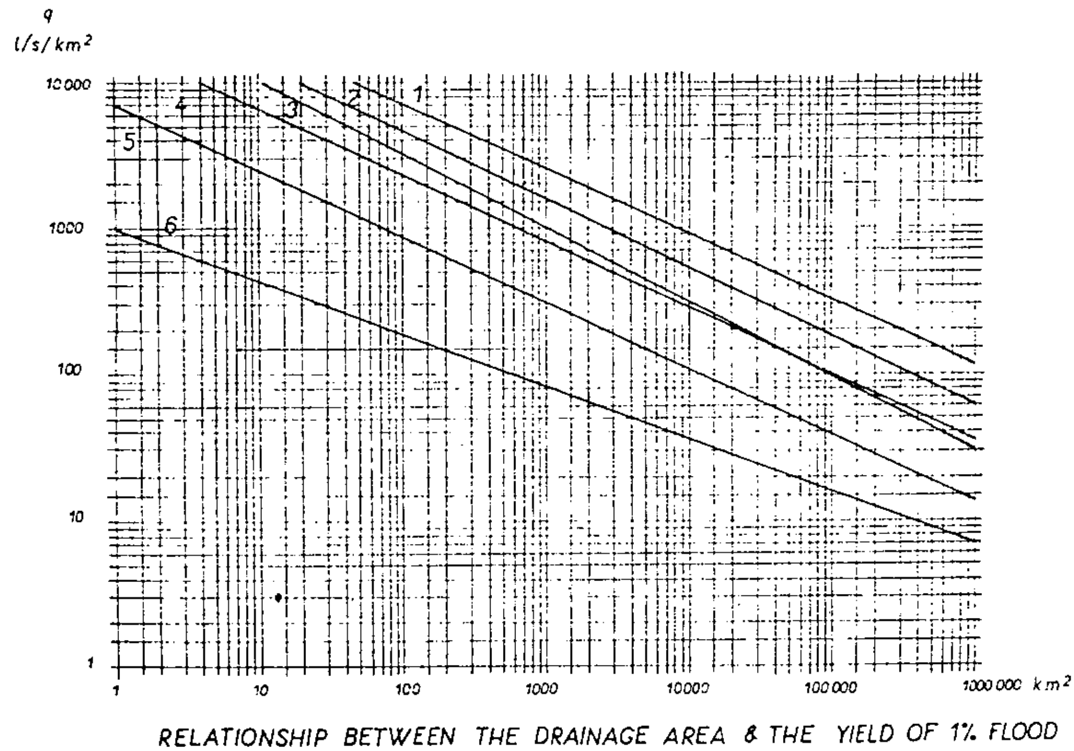

Figure 32.—Flood diagram of 1 percent flood yield as depending on the drainage area.

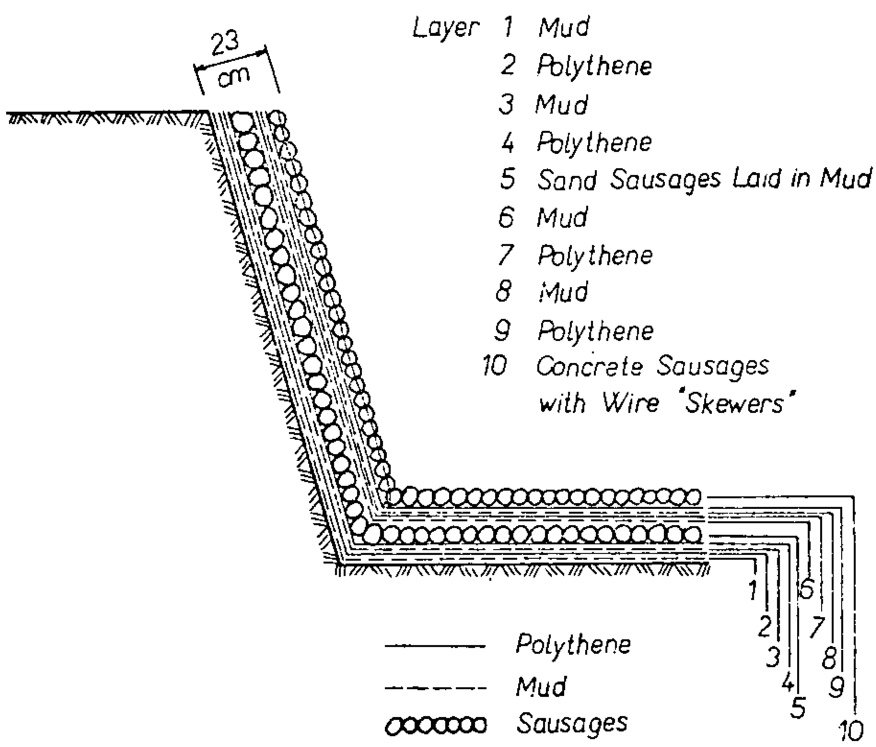

Figure 33.—Water tank cross-section.

Most rivers in semiarid zones run water only during and shortly after a heavy rain. The river beds are filled with sand and gravel to a great depth. The sand contains fresh water in large quantity and it is a common practice to dig a hollow in the sand and allow it to fill with water seeping from the sand. A subsurface concrete dam can increase the amount of water available so that at the end of dry season the hollow does not have to be too deep.

A true dam in arid and semiarid regions will be able to provide some water only if the amount of rainfall and the pertaining catchment are sufficient to fill the reservoir regularly. Water depth of the reservoir has to be large enough to survive the evaporation.

Catchment tanks are popular in countries like Botswana and Sudan. Their function is similar to that of a dam reservoir. They catch the excess of water falling above them and/or on the catchment and store it for the dry periods. Mud and plastic bags filled with sand or with sand and cement mixture are frequently used as a building material, so that the construction is less expensive than of a dam. More advanced construction contains some sort of cover to minimize evaporation. A simple example is shown in figure 33. Obviously, a good appraisal of the local hydrometeorological regime is necessary for successful constructions.

Although the rural water supplies are rather small in scale and require little ingenuity and engineering skill, they are frequently more important than big water schemes. As stated by Wood (48) "... there is no single measure that can so improve the health and well being of the rural dwellers than provision of an ample supply of safe water." Planning and surveying for the rural water supplies may be, under certain circumstances even more difficult than for big international schemes. For example, the so called "Punta del Este", a treaty signed by 19 Latin American countries establishing general objectives in health, set a target for potable water to supply at least 70 percent of urban and 50 percent of rural population.

Water treatment for rural supplies in tropics should be as simple as possible and within the capacity of local skill. Many tropical streams are not yet heavily polluted and in most cases no treatment or simple filtration process will be found sufficient. However, because of the possibility of the occurrence of tropical born diseases such as typhoid, bilharzia, diarrhoea etc. a specialist should be consulted before any water source is to be tapped.

A proper utilization of tropical water resources requires well qualified manpower. The situation is still far from satisfactory on all levels of education. There is a shortage of professional personnel, subprofessional workers such as assistants, foremen and supervisors, skilled workers such as mechanics, machinists, observers etc. and administrative personnel. A great number of trainees disappear in administrative positions instead of being put in this field. During the International Decade, some progress has been made by organising numerous engineering and subprofessional courses, although most of the top technical positions and many at the general level are still occupied by expatriates. Because education is a time consuming process, an output from the educational stream will continue for a long time before the needs of water resources development will be fully satisfied.

The preparation of various water resources projects in tropics is also difficult because very limited data from many tropical basins are available. Where the extension of the existing network and improvement of the quality of the records is not technically possible, at least the system of representative and/or experimental catchments within the main basins should be established, supplying the data and information on the regionally specific phenomena which cannot be obtained as a result of experiments from the catchments of moderate regions. Then among other factors of the hydrologic cycle, the role of the vegetation, soil moisture movement and geomorphological conditions should be intensively studied. A systematic field survey, particularly during the occurrence of the extremes, together with the tracing of the historical records supply additional and most valuable information (40, 49).

LIST OF THE LITERATURE

1. Anděl, J., Balek, J., 1971. Analysis of periodicty in hydrological sequences. Journal of Hydrology 13.
2. Anděl, J., Balek, J., Verner, M., 1971. An analysis of the periodicty in the hydrological sequences of Nile maxima and minima. ECA Hydrological Symposium Addis Ababa.
3. Voejkoff, A., 1883. Flüsse und Landseen als Produkte des Klimas. From "Die Klimate des Erdballes", St. Petersburg 1883.
4. Penck, A., 1910. Versuch einer Klimaklassifikation auf Physiographischen Grundlage. Bei. d. Preuss. Akad. d. Wiss., Phys-math.
5. Köppen, W., 1900. Versuch einer Klassifikation der Klimate, vorzugsweise nach ihren Beziehungen zum Pflanzenwelt. Geogr. Zeitschr. 6.
6. Herbertson, A.J., 1905. The major natural regions. Geogr. Journal I, pp. 300–312.
7. Trewartha, G.T., 1955. An introduction to climate. McGraw-Hill, New York, 402 pp.
8. Köppen, W., Geiger, R., 1954. Klima der Erde. J. Perthe, Darmstadt, Germany.
9. Riehl. H., 1954. Tropical Meteorology. McGraw Hill, N. York 1954.
10. Balek, J., 1973. Use of representative and experimental catchments for the assessment of hydrological data of African tropical basins. UNESCO Symp. on Water Res. Projects with Inadequate Data, Madrid.
11. Bailey, M., 1969. On extreme daily rainfall in Zambia. Met. Notes, Serie A, No. 4, Lusaka.
12. Aune, B., 1970. Tables for computing potential evaporation for the Penman equation. Dept. of Meteorology Rep. No. 3, Lusaka 1970.
13. McCulloch, J.S.G., 1965. Tables for rapid computation of the Penman estimate of evaporation. Est. Af. Agric. and For. Jour. 30 (3).
14. Balek, J., 1971. Daily fluctuation of the potential evaporation. Water Resources research Rep. WR 9, N.C.S.R. Lusaka.
15. Lvovich, M.I., 1945. Elements of earth's river regimes (In Russian). Moscow.
16. Balek, J., 1971. Water balance of the Zambezi basin. Lusaka N.C.S.R. WR Report No. 8.
17. ———Physiographical atlas of the world (Russian), 1964. Leningrad.
18. Anděl, J., Balek, J., 1970. Mathematical-statistical analysis of the hydrological sequences (In Czech, English resume). Vodbhospodársky časopis No. 1, Bratislava.
19. Willet, H.C., 1964. Long-term indices of solar activity. Scient. Rep. No. 1 NSF Grant 5931. Cambridge Mass.
20. Verner, M., 1972. Periodical water-volume fluctuations of the Nile. Archiv orientální 40/1972, Prague.
21. Debenham, F., 1952. Study of an African swamp. Colonial Office, London.
22. Kimble, G.T., 1960. Tropical Africa. Twentieth Cent. Fund, New York.
23. Ackermann, E., 1936. Dambos in Nordrhodesia. Wiss. Veroff. Leipzing, 4:149–57.
24. Balek, J., Perry, J., 1973. Hydrology of seasonally inundated African headwater swamps. Journal of Hydrology 19:227–249.
25. Welch, J.S., 1952. Limnology. McGraw Hill, New York.
26. Hurst, H.E.Le Nil, Paris 1954.
27. Balek, J., Water Balance of Luapula and Lake Tanganyika Basin. 1970 WR6 N.C.S.R. Lusaka.
28. Balek, J., Perry, J., 1972. Luano catchments, first phase final report. N.C.S.R. WR 20, Lusaka.

29. Hutchinson, I.P.G., Midgley, D.C., 1973. A mathematical model to aid management of outflow from the Okawango swamp, Botswana. Journal of Hydrology 19, pp. 93–112, Amsterdam.
30. Matějka, V. et al., 1971. Forest management in tropics and subtropics. (In Czech), Prague.
31. Blumenstock, D.C., Thornthwaite, C.W., 1941. "Climate and Man" from the U.S. Dept. of Agriculture Yearbook 1941.
32. Wicht, C.C., 1949. Forestry and water supplies in South Africa. Dept. of Agric. S. African Bulletin 33, p. 58.
33. Wëck, J., 1957. Die Wälder der Erde, Berlin.
34. Troll, C., 1948. Die assymetrische Aufbau der Vegetation Zonen und Vegetation Stufen auf der Nord un Südhalbkügel. Bez. über d. Geobot. Forschung. Zurich.
35. Pereira, H.C., 1962. Hydrological effects of changes in land use in some East African catchment areas. East Afr. Agric. For. Journal 24.
36. Maxwell, D., 1972. Root range investigation. N.C.S.R. Report WR 16, Lusaka.
37. Aubrecht, G., 1959. Influence de divers types de vegétation sur les caracteres et l evolution des soils en regions équatoriales et subéquatoriales ainsi que leurs bordures semi-humides. UNESCO Symposium Tropical Soils and Vegetation, Abidjan.
38. Balek, J., 1974. Water balance of tropical forest (In Czech, English resume). Vodohospodársky časopis No. 1, Bratislava.
39. ———, 1972. An evaluation of the index catchments and extension of the data to the ungauged areas in the Hydromet. Survey of Lakes Victoria, Kyoga and Albert. Interim report to W.M.O., Entebbe.
40. Jeník, J., Armstrong Mensah K.O., 1968. A study of a vegetation catena in Guinea savanna at Mole Game Reserva. J. Ecol 56, 505–522.
41. Dagg, M., Hosegood, P.H., 1961. An intensive method of catchment basin study. Proceedings of the hydrological symposium Nairobi.
42. Jackson, I.J., 1971. Problem of throughfall and interception assessment under tropical forest. Journal of Hydrology 12, Amsterdam.
43. Kutílek, M., 1963. Tropical and subtropical soil science. Prague (In Czech).
44. Wundt, W., 1953. Gewässerkunde. Heidelberg.
45. Starmans, G.A.N., 1970. Soil erosion on selected African and Asian catchments. International Water Erosion Symp. Prague.
46. Balek, J., 1971. On extreme flood in Zambia. N.C.S.R. Report WR 11, Lusaka.
47. Wood, W.R., 1970. National rural water supply programmes. ECA working group of experts on water resources planning. Addis Ababa 1970.
48. Balek, J., 1972. An application of the inadequate hydrological data of the African tropical regions in engineering design. Second International Symposium on Hydrology, Fort Collins 1972.
49. Pike, J.G., 1964. The estimation of annual run-off from meteorological data in a tropical climate. Journal of Hydrology 2, pp. 116–123.

ASBESTOS POLLUTION

by
Steven A. Hartman, M.S. in Marine Biology
Columbia University Seminar on Pollution and Water Resources

INTRODUCTION

Asbestos comes from the Greek Adjective (asbestos), meaning inextinguishable or unquenchable. Chrysotile asbestos the variety of the mineral making up ninety-five percent of the world's production, geologically had its origin millions of years ago. There were subterranean upheavals causing fractures in serpentine rock that were penetrated by water heated by the earth's interior. Some of the serpentine rock dissolved by this water and the solution then cooled, and fibrous silicate crystals then grew within the fractures. Asbestos was first used by man in the Stone Age pottery. It was first mined commercially in the late eighteen seventies.

"It seems as perishable as grass, but by virtue of being almost immune to the forces of corrosion and decay under almost every condition of temperature and moisture (and of being resistant as well to the action of most acids, alkalies, and other chemicals) it is just about indestructible. It looks extremely fragile yet its fibres have a tensile strength equal to that of piano wire. Apparently as light and feathery as thistle-or eiderdown, it is actually as heavy and dense as the rock from which it is extracted. In one sense, then, it is fibre of stone. In another sense, however, it is a mineralogical vegetable whose fibres are so soft and flexible that . . . Asbestos is the only mineral that can be woven into cloth . . . asbestos is fibrous . . . for there are approximately a million individual fibrils lying side by side in a linear inch of chrysotile asbestos, whereas only thirty-eight hundred glass fibrils, such as those found in various insulation materials, or six hundred and thirty hairs can be aligned along the same distance."[1]

Since that first commercial asbestos mine the world production of asbestos has increased from five hundred tons in 1880, to three hundred and thirty thousand tons in 1925, to four hundred and forty-six thousand metric tons in 1938, to over two million tons in 1958, while today the production is more than four million tons (Hueper, 1965). The main producing country is Canada, while the principal consuming country is the United States, which consequently should have the largest number of individuals exposed for occupational and nonoccupational reasons to an inhalation of asbestos dust from an increasing number of sources and from a growing number and variety of products.

There are many types of asbestos and related asbestos compounds. These are: chrysotile, amphibole, amosite, crocidolite, tremolite containing magnesium, aluminum, calcium, iron, silica. The chief cause of asbestosis and cancer in this country is chrysotile. Not only are the people

[1] Brodeur, P. 1968. A Reporter at Large. The New Yorker. Oct. 12, 1968 Reprint p. 2.

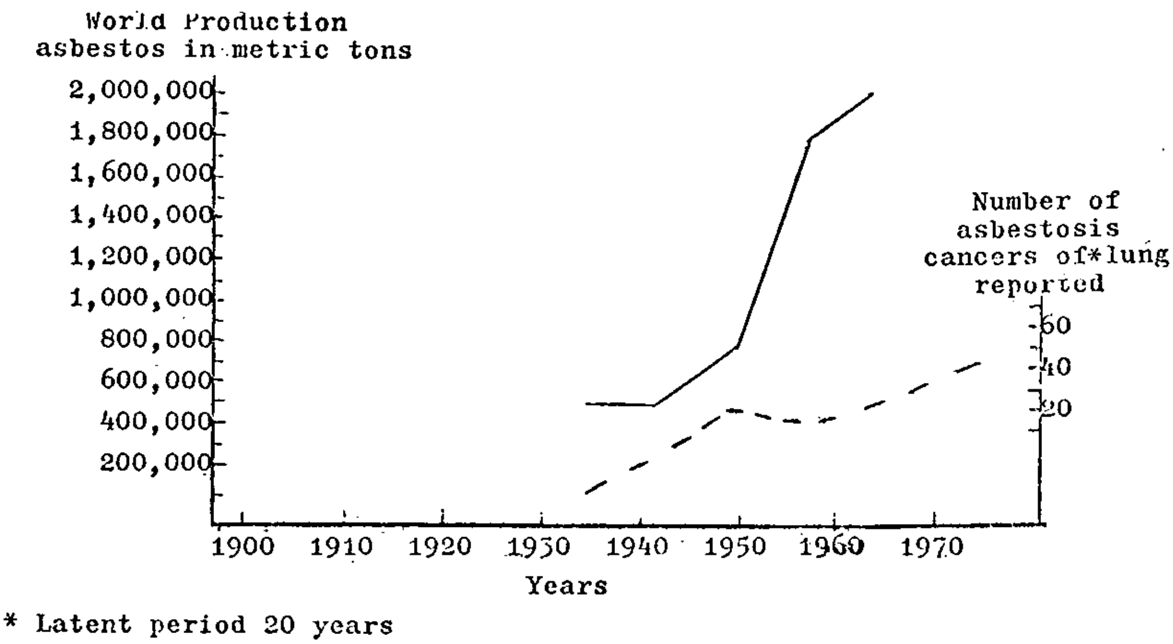

Figure 1.––World production of asbestos and asbestosis carcinoma of the lungs, (Hueper, 1965).

directly involved in asbestos production, handling, processing, and using asbestos containing materials, but for those people who may have an occasional exposure to asbestos dust (laboratory technicians, construction workers, shipyard workers, railroad workers, truckers, office workers, automobile plant and garage employees, repairmen, mechanics, engineers, maintenance men, and others). It has been conservatively estimated that between fifty thousand and one hundred thousand people are unsuspectingly exposed to harmful asbestos dust. The asbestos industry in the U.S. and Canada employs about fifty thousand people. Asbestos products and by-products are very numerous and varied, thereby increasing the number of people who come in possible contact with asbestosis conditions. The asbestos cement and plaster industry uses the most quantity of this material. The asbestos cement can be applied like a mortar or plaster, it may be sprayed on walls, insulating material, cables, pipes, boilers, roofing shingles, tiles siding shingles, flat and corrugated sheets, clapboard, wall board and automobile undercoating. Asbestos with animal or vegetable fibers and synthetic fibers or alone can be found extensively in the manufactoring of sheets, cloths, threads, wicks, cords, yarns, blankets and products in the aircraft and automobile industries in the form of friction material, fireproof safety clothing, brake linings, curtains, life jackets, gaskets, and clutch facings.

According to Dr. Selikoff there are about three thousand different items made of or with asbestos.

The average private motor vehicle wears out three or four sets of brake linings and one or two clutch linings in its life time, and commercial and public transport vehicles wear out many more. These linings consist largely of asbestos which is ground to dust as the linings wear, and most wear occurs in built-up areas. This alone in most cities would involve the discharge of many tons of asbestos dust and fibers in the streets each year. A further contribution is from those car mufflers (silencers) which contain asbestos packing, and from car under-body coating which may contain up

Table 1.—*Major uses of asbestos*

	Short tons	Approx. value dollars
Asbestos textiles	66,000	26,400,000
Asbestos cement products	2,190,000	328,500,000
Friction materials & gaskets	111,000	11,100,000
Asbestos paper	220,000	19,800,000
Floor tile	307,000	13,200,000
Paints, roof coatings, caulks, etc.	85,000	3,740,000
Plastics	21,000	924,000
Miscellaneous	220,700	19,670,000
Total	3,220,700	423,334,000

Estimated from private information (Hendry, 1965).

to fifty percent asbestos. The disintegration by natural weathering of asbestos-containing products used in buildings such as roofing materials, asbestos cement ect., must result in some asbestos fibers getting into the air of towns and cities, but at the moment we have no means of knowing whether these are significantly contributory or not.

It is probable, however, that the amounts available for city air contamination are very small and could be ignored if asbestos dust had transient effects or a limited life, but unfortunately asbestos is virtually indestructible. It resists heat, alkalis, acids, oxidation and reduction, and other means by which materials are altered chemically or physically, and mechanical disintegration of asbestos-containing products mearly results in the liberation of asbestos dust and fibers liable to be inhaled . . . The half-life of the asbestos fiber could be described as an infinity of years. The two and one-half million tons of asbestos used annually are added to the millions of tons used in previous years, and even if an infinitesimal proportion becomes available as an air contaminent in towns, the actual amount will increase, as more asbestos accumulates on the surface of the earth. (See Thomson, 1965).

The threshhold for asbestos dust in the U.S. is five million particles per cubic foot of air for a daily eight hour exposure, forty hours per week. A short exposure of very much higher readings can overwhelm the lungs and be more harmful than long term exposures at lesser values. About fifty percent of those individuals who come to autopsy in New York City have asbestos bodies in their lungs. (Information given by Environmental Science Laboratory, Mt. Sinai Medical School, New York City.)

The Department of Air Resources of New York City has been involved in a program for watching this potential problem. They have set up stations for measuring asbestos levels in lower Manhattan, especially in the area of construction sites. There are 38 permanent air quality monitoring stations. Periodic samples were taken at 11 of these stations in all five boroughs of New York, in a recent study. The staff of Mount Sinai's Environmental Sciences Laboratory supplemented the samples with other samples from other urban, suburban, and rural sites. These samples were then analyzed by electron microscope at Mount Sinai. These samples were scanned at 42,000 x magnification (Nicholson, Rohl, Ferrand, 1970).

Tables 2, 3, and 4 show the results of this study indicating the distribution of chrysotile asbestos in different locations in New York. In some cases, the levels of chrysotile asbestos were approximately 10 times greater than the ambient values. In table 4, the samples in Philadelphia were taken near a construction site while those from Ridgewood and Port Allegany were near no obvious source of asbestos emission. It is important to realize that 10^{-9} grams of chrysotile asbestos could contain as much as a million fibrils.

There have been occasional references to asbestos in the literature since the nineteen-hundreds. The first documented reports of lung dust related to asbestosis appeared in the ninteen-twenties. In 1924 the first case of death due to asbestosis was recorded by Dr. W.E. Cooke, an English physician who gave the disease its name. These first studies were done on victims whose exposure period was twenty years and whose ages were in the thirties, with an interval of one year or less between the end of their exposure and death. The autopsy showed pulmonary fibrosis with dense strands of abnormal fibrous tissue that was attaching the lungs and the pleural membranes surrounding them. Cooke made notes of the presense of solid yellowish brown particles which he called "curious bodies" found in the area of fibrosis. He wrote; "We have never seen anything parallel to this in pneumoconiosis (the general term for all dust diseases of the lungs) due to other dusts, nor have we been able to find such occurrence in literature . . . We cannot think there is any reasonable doubt that the particles in the lung are the heavy, brittle, iron-containing fragments of asbestos fibre." [1]

These "curious bodies" described by Cooke were found to be so abundant in the lungs of autopsied asbestos workers—literally billions of bodies in many cases—that they became known as "asbestos bodies".

Table 2.—*Chrysotile content of ambient air in N.Y.C. preliminary results*

Sampling locations	*Asbestos air level in 10^{-9} grams/m^3*
Manhattan	25–60
Bronx	25–28
Brooklyn	19–22
Queens	18–29
Staten Island	11–21

Table 3.—*Chrysotile content of N.Y.C. air in vicinity of spray fireproofing with asbestos-containing materials*

Site	*Asbestos level in 10^{-9} grams/m^3*
1 (downwind from source)	45–180
2 (45° from source)	15–30
3 (upwind from source)	20
4 (downwind from source)	45
5 (upwind from source)	20

[1] Brodeur, P. 1968. A reporter at large. The New Yorker. Reprint Oct. 12. p. 5.

Table 4.—*Chrysotile content of air in three selected locations*

Location	*Asbestos level in 10^{-9} grams/m^3*
Philadelphia, Pa.	45–100
Ridgewood, N.J. (suburban)	20
Port Allegany, Pa.*	10–30

*They have also found amosit fibers in the air of this community; a factory using this material is present.

A very significant report done by Dr. E.R.A. Merewether in 1928 to 1929 brought much awareness to the hazard of asbestos dust. He examined three hundred and sixty-three asbestos workers in a plant in Great Britain and found ninty-five workers, or 25 percent, showed evidence of suffering from pulmonary fibrosis. He showed that fibrosis increases in direct proportion to the number of years of exposure, with eighty-one percent occurance in workers employed for twenty years or more. Because of Mereweather's report, the Parliament passed legislation in 1931 requiring improved methods of exhaust ventilation and dust suppression in asbestos-textile factories. (Brodeur, 1968).

It is very important to determine whether urban dwellers have asbestos present in their lungs. There is a high percentage of asbestos workers that have been shown to have asbestos in their lungs, but greater concern will be generated if a high percentage of urban dwellers are found to be effected as well.

Table 5.—*Observed and expected number of deaths among 632 asbestos workers exposed to asbestos dust 20 years or longer. (Selikoff, Churg, Hammond, 1964).*

Cause of death	1943–1947	1948–1952	1953–1957	1958–1962	1943–1962
Total, all causes	28	54	85	88	255
Observed (asbestos workers)					
Expected (US white males)	39.7	50.8	56.6	54.4	203.5
Total cancer, all sites	13	17	26	39	95
Observed (asbestos workers)					
Expected (US white males)	5.7	8.1	13.0	9.7	36.5
Cancer of lung and pleura	6	8	13	18	45
Observed (asbestos workers)					
Expected (US white males)	.8	1.4	2.0	2.4	6.6
Cancer of stomach, colon, and rectum	4	4	7	14	29
Observed (asbestos workers)					
Expected (US white males)	2.0	2.5	2.6	2.4	9.4
Cancer of all other sites combined	3	5	6	7	21
Observed (asbestos workers)					
Expected (US white males)	2.9	4.2	8.4	5.0	20.5
Asbestosis	0	1	4	7	12
Observed (asbestos workers)					

It has been observed that chrysotile asbestos will readily break down chemically and physically in the presence of various ranges of environments. Even in distilled water there is a degradation. Magnesium will be leached from the asbestos in aqueous solutions with a ph below 10.8. It has been demonstrated that magnesium was quickly leached from chrysotile fibers in rats (Morgan and Holmes, 1969).

The bundled fibrils also appear to splinter in biological residence. There is a thinning of the fibril walls, indicating a loss of material *in vivo.* Of the unit fibers present, some are in the range of 300 to 400 A in diameter, and are invisible to the research eye through the light microscope. This factor is important in the consideration of qualitative determinations when using the light microscope.

All varieties of asbestos fibers, in an organic environment, will induce the formation of asbestos bodies (Langer, Selikoff, 1970). There are several reasons why the detection of chrysotile asbestos in human lung tissue is difficult and marked so when the tool of detection is the light microscope. Some of the reasons are: 1) the chrysotile fibers break up into very small unit fibrils always smaller in diameter than 0.1 microns, which is beneath the resolution of the light microscope; 2) Even those particles inhaled in the larger fiber size, once in the biological environment may separate into the unit fibrils very easily and become "invisible"; 3) the nature of this asbestos makes it readily subject to attack by body fluids; 4) the inhalation of asbestos fibers will tend to leave the amphibole fibers visible to the light microscope while the chrysotile fibers disappear (Langer, Selikoff, 1970).

It has been proven by several researchers that the precise detection of chrysotile asbestos is unlikely to be successful. Rather, a direct search for the fibers and fibrils should be made with the electron microscope. The estimates of chrysotile in tissues has been underrecorded (Pooley, Oldhan, Chang Hyun, Wagner, 1969).

The data on table 6 indicates the results of a comparison identification study of chrysotile fibers and fibrils between the light microscope and electron microscope (Langer, Selikoff, 1970).

The method for separating asbestos, free and inside bodies, has still to be improved over the present methods for more accurate studies.

One method that has been used is to first mince, dry, and ground the lung sample. This is then ashed at 380 degrees centigrade, this is treated with 0.1N hydrochloric acid, washed with water then dried to give a mineral sample to be used for determination of minerals by light and electron microscope as well as X-ray diffraction. The hydrochloric acid is used to remove endogenous salts from the lungs while affecting the asbestos fibers as little as possible.

Another method used for chrysotile, the commonest type of asbestos, is electrophoresis at 0.001 molar sodium chloride at pH 5 because this mineral has a strong positive charge whereas the other types of asbestos and silica are negatively charged (see Nagelschmidt, 1965).

The study of asbestosis has recently been carried out by the Safety in Mines Research Establishment (S.M.R.E.), because of the view that the causation of the disease asbestosis may be dust, dissolved in the lungs and producing a dissolution product of silica, thereby causing lung fibrosis, much as silica dust from the atmosphere of mines causes silicosis.

Table 6.—*Light microscope and electron microscope study of 28 random autopsy cases from New York City*

	Light microscopy			*Electron microscopy*	
Case	*Asbestos bodies*	*"Thick"*	*"Thin"*	*Chrysotile Asbestos (Fiber + Fibril)*	*Fiber*
1	3	8	1	54	8
2	1	4	0	9	15
3	0	2	0	4	5
4	3	8	0	3	31
5	3	6	2	16	3
6	0	1	0	212	4
7	0	1	0	133	1
8	3	3	0	344	23
9	0	4	0	37	63
10	1	1	0	25	11
11	9	2	1	107	50
12	1	4	0	119	25
13	0	2	0	20	0
14	0	0	0	79	5
15	1	2	0	57	13
16	0	3	0	70	8
17	0	3	2	57	2
18	0	2	0	16	9
19	1	10	0	7	4
20	1	4	0	28	3
21	0	4	0	23	4
22	2	5	6	21	10
23	0	2	0	16	28
24	0	3	0	50	2
25	1	7	0	270	13
26	0	5	0	26	9
27	1	4	0	81	1
28	0	6	0	186	16
Ratio (+)	14/28	27/28	5/38	28/28	27/28

Berger (1933) studied sections, lung juice smears, and one piece of lung tissue of an asbestos worker who had died aged thirty-five years after twenty years of dust exposure, followed by one year out of dust. He found many asbestos bodies and few needles of free asbestos and identified the latter as chrysotile on the basis of their optical properties . . . Berger made many measurements of the frequency and dimensions of the asbestos bodies and fibers and estimated that one cubic centimeter of lung contained 0.02 mg. of asbestos. This would be equivalent to forty mg. for a volume of two litres for both lungs. He gave the average dimensions of the free fibers as fifty microns long and 0.5 microns wide. (See Nagelschmidt, 1965).

In 1961 Beattie and Knox found that in the severe cases of asbestos the proportion of longer fibers (about fifteen microns) to all fibers was much lower than in less severe cases. The quantity of

Table 7.—*Lung dust analyses in asbestosis (Nagelschmidt, 1965)*

	Grade of asbestosis			
	None	*Minimal*	*Moderate*	*Severe*
Number of cases	16	14	8	11
Mineral content mg./gm. dried lung*	4.1	4.3	6.9	5.2
Dust exposure, years	16	18	27	24
Survival, years	3	7	6	10
Dust accumulation, mg./gm. per year exposed	0.27	0.24	0.25	0.21

*Five mg./gm. equals 1 gm. in a pair of lungs of 200gm. dry weight.

dust found in the lungs rises slightly as the degree of fibrosis increases, though there was a slight difference in dust quantity between the moderate and severe degrees of asbestosis.

In many of the studies of asbestos victims there have been very small amounts of the mineral present. This is a basic problem in the discovery of the cause of death due to fibrosis. It seems that the asbestos dissolves in the lungs. Due to the structural characteristics of some types of asbestos chrysotile is most easily dissolved, crocidolite being intermediate, and amosite the most resistant to dissolution since it appears in only some lung residues.

The most common type of fibrosis found in asbestosis is interstitial fibrosis rather than the nodular lesions found initially in other forms of fibrosis. In diffuse interstitial fibrosis, as in aluminosis and asbestos is, the amounts are not large and do not seem to relate to the grade of fibrosis, dissolution of these fibers seems to be the reason.

The guinea pig lung is a very good indicator of asbestos dust because their lungs react to it very quickly, even to those particles too small to be seen by the light microscope. An infection of the

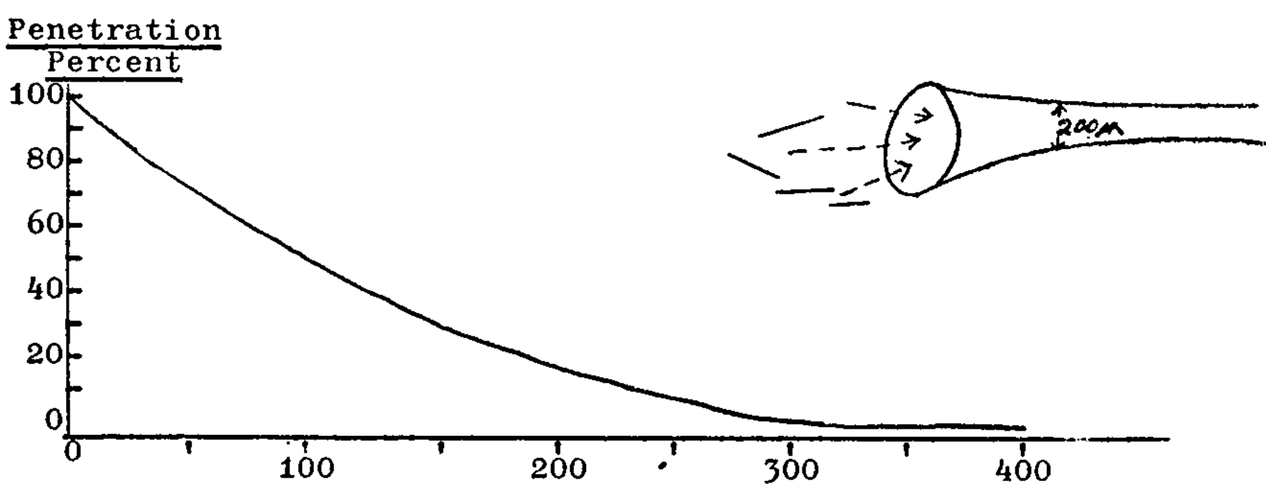

Figure 2.—Calculated penetration curve for fibers into a respiratory bronchiole (Timbrell, 1965).

Calculated penetration curves for fibers through branching of a respiratory bronchiole, for cases of two, four or eight branches (Timbrell, 1965).

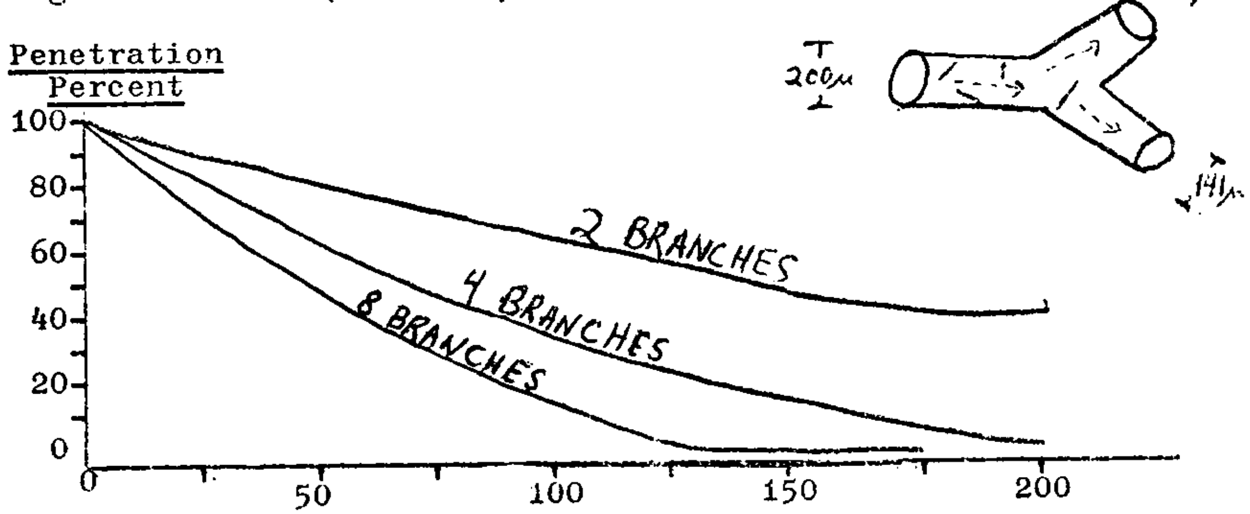

Figure 3.——Fibre length in microns.

bronchial tubes occurs, which then causes an inflamation of the adjacent alveoli. The later stages show a widespread and increased fibrosis of the lung bronchiolar epithelium as well as a fibrosis of the tracheal lymph glands. After as few as seven days of asbestos infiltration into the lungs asbestos bodies form in which the fibers become coated with iron-containing protein (see Holt, Mills, Young, 1965).

The pathological changes and progressions of asbestosis in guinea follow three stages. First, there is the formation of small nodules of cell lesions in the walls of, usually, the terminal bronchioles. Next is a fibrosing interstitial pneumonia throughout the lung, later followed by consolidations in some lung sections. There are alveolar macrophages that were found to have chrysotils dust within them, lending credence to the idea that no other cell types could phagocytose this type of material. The size of the fibers was: ten microns long and two microns in diameter to one micron long and only about two hundred angetroms in diameter. After a few months there appears a structural change in the fibers indicated some dissolving by body fluids. (Davis, 1965).

Most of the capillary walls in the dusted lungs were normal in structure, but in a few cases the blood-air barrier was found to be much thicker than normal. Where this occurred the basement membrane was found to be very uneven in outline, and numerous impocketings were seen in the cytoplasm of both the epithelial and endcthelial cells.

It was found that giant cells were formed by the aggregation of dust-containing macrophages, and it was also found that these macrophages could undergo conversion to fibroblasts. After only a few days' dusting, the surfaces of dust-carrying macrophages showed large numbers of elongated processes, and where such macrophages occurred together, the processes interdigitated, binding the cells together, to form a giant cell. Fibrosis frequently occurred in the lungs used in these experiments, and it was found that most of the fibroblasts in these areas contained chrysotile dust. As this dust was found only in macrophages and giant cells apart from fibroblasts, the transformation of dust-carrying macrophages to fibroblasts was indicated, and it was possible to

Table 8.—*Comparison of clinical findings*

Survey	Hunter, 1930–34	Wyers, 1949	Williams & Hugh Jones, 1958, Thomson et al., 1959	1960–64
Cases	30	53	26	26
Mean exposure years	7	10.4	14.5	17.5
Dyspnea	100%	100%	92%	69%
Morning cough	Nearly all	Noticeable	73%	77%
Sputum	40%	Usual	58%	57%
Chest pain	53%	Occasional	–	27%
Basal crepitations	Sometimes	Generally	100%	96%
Clubbing	20%	50%	84%	69%
Cyanosis	Occasionally	Has been noted	15%	4%
Mean DLCO	–	–	13.9	19.3

demonstrate the various stages in this process. It was also found that the macrophages making up giant cells were capable of being converted into fibroblasts. Some giant cells appeared capable of total conversion to fibrous tissue, but in large ones only the macrophages on the surface were capable of transformation to fibroblasts. (Davis, 1965).

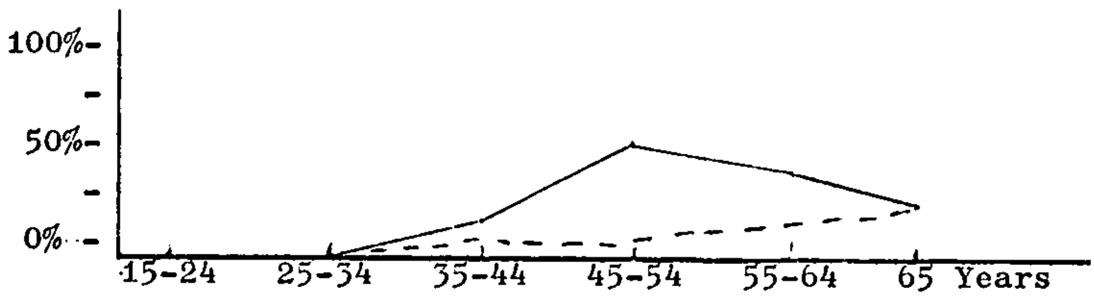

Figure 4.—Percentage of cases positive for asbestos bodies in age groups in Miami (Thomson, 1965).

When human lung tissue was examined it was found to have lesions similar to those found in the animals. The asbestos bodies were found in the alveolar macrophages, in fibroblasts or among collogen fibers.

In human material, the asbestos body coating was found to consist mainly of ferritin granules approximately sixty angstroms in diameter as was the case in guinea pigs. The initial deposit may be sparse, but a thick coating is usually built up and the diameter of human asbestos bodies can be as much as five microns. Two structural variations in the body coating were, however, occasionally seen in human material. The first was a clumping of the ferritin material in the innermost layer of some bodies. This clumping appears to be most marked close to the asbestos fiber. The second variation was the inclusion of fine needle-like particles among the ferritin granules. These needles vary from fifty angstroms to two hundred and fifty angstroms in diameter and are from 0.05

microns to 0.5 microns in length. They appear scattered fairly evenly throughout the body coat but almost invariably have their long axis parallel to the surface of the body.

In addition to normal asbestos bodies, the irregular bodies with no definite core of asbestos dust that were reported from guinea pigs have also been found in the human material. It is commonly thought that the tissue damaged from the harmful effects of the dust, and if this is true it is logical to suggest that it is the dust that is not coated that causes the damage. If this is so then further work should be concentrated on the chemistry of ferritin deposition onto asbestos dust (see Davis, 1965).

There is an increasing number of reports continually being presented to the public and scientific communities, shedding more light on the asbestosis danger from its many different sources. These investigations have demonstrated the process of asbestosis infection and development. Harington (1965) is one of many researchers that consider many metals to be carcinogenic. Nickle, chromium, and iron are just some of the metals found in asbestos. Harington also has suggested that radioactivity in asbestos can be a cause of tumors. One of the widely accepted causes of malignant change is the irritating effect of sharp asbestos fibers on tissues (see Smith, Miller, Elsasser, Hubert, Wagner, 1965).

A fine report of an in depth study of seven patients was done on asbestos in the lungs and a mesothelioma in the pleura or peritoneum (see Godwin, Jagatic, 1969). In table 9 we can clearly follow the patients condition relevent to his occupational history in contact with industrial asbestos. They found asbestos bodies in macrophages, lying free and in fibrous tissue. The bodies appeared small, brown with a round mass at one end and small bead-like particles along a small tracking fiber. Some macrophages were found multinucleated as well as others that had only one nucleus. Inside the lymphatic channels in the pleura of the lung also lie macrophages containing asbestos bodies. Great detail has been supplied in this report of the clinical aspects of each patients histological condition of asbestosis.

The importance of submicroscopic particles in the causing of asbestos bodies has been widely recognized. Davis (1965) found, while working with animals, that these particles quickly accumulated in alveolar macrophages. He observed the formation of ferritin coating around these smallest dust particles thereby producing asbestos bodies. He noted that human tissue showed the same formation and that these very minute dust particles must be investigated further. Harington states, in his discussion of another study (see Pernis, Vigliani, Selikoff, 1965), that these submicroscopic fibers may be the most important clue in the carcinogensis of asbestos. He found a very large number of fibers, a few Angstroms in size in macrophages.

Several researchers support the findings that asbestos bodies, fragments, particles, and especially dust are transported throughout the body and are concentrated in the lymph nodes, spleen and liver (see Godwin, Jagatic, 1969). These researchers also considered it probable that carbon, silica particles, asbestos material, and tumor cells pass through the thoracic and abdominal lymph nodes and finally enter the blood's vascular system. In the liver and spleen localization of carbon and silica occurs. These researchers used ashing and polarized light to identify the asbestos. Other researchers who came out with similar reports on quantity and quality aspects of asbestos particles used ashing technique as well as fluorochrome taggin (see Newhouse, Thompson, 1965; Berkley, Churg, Selikoff, 1965).

There was an estimated total of about seven hundred cases of asbestosis in Germany in 1946, among a total of approximately eight thousand employees of the asbestos industry. Wagelius found

Table 9.—*Asbestos and mesotheliomas*

Site(s) of origin of tumor	Site of metastases	Extrapulmonary asbestos bodies	Exposure to asbestos	Time of exposure to death
43 (1) Abdominal mesothelioma; (2) 2nd mesothelioma	Metastasis to abdominal nodes	Asbestos bodies in hilar nodes	Coated submarine engines 1942–45 in Germany	24 years
82 (1) Pleura left & pericardium; (2) squameopidermoid carcinoma right upper lobe	1. Hilar and mediastinal 2. Hilar nodes	Asbestos bodies in mediastinal nodes	Stockman & superintendent, Asbestos plant 1931–52, 21 years	25 years
57 Abdomen	None	Asbestos bodies in hilar nodes	Brake hand weaven from 1930–1943, 13 years	34 years
55 Pleura mesothelioma	Left		Cut asbestos lined drums with torch 1950–1966, 16 years	Died: 16 years exposure
66 Abdominal mesothelioma	None	Asbestos bodies Hilar nodes	Not known	Not known
42 Pleural mesothelioma bilateral	Mediastinal nodes intestine	Asbestos bodies in hilar nodes Abdominal tumor jejunal mucosa	Laborere in asbestos factory 1939–41, 2–3 years	25 years
55 Left pleura	Peritoneum	Asbestos bodies in hilar nodes	Asbestos factory for 6 weeks at age 14	41 years

one hundred and twenty-five cases of asbestosis of the lung in examination of four hundred and seventy-six asbestos workers of one company in Finland. Of one hundred and thirty-two asbestos workers examined by Bohme, twenty-nine percent showed evidence of asbestosis.

The morbidity rate of asbestosis in members of this worker group rose, moreover, with the duration of employment, being five percent in workers exposed to asbestos for less than three years; fifty-six percent for those employed for five to ten years, and seventy-nine percent for those with over ten years exposure. A similar morbidity rate of eighty percent among English asbestos workers with over twenty years of employment, was reported by Merewether and Price in ninteen hundred and thirty (Hueper, 1965).

There has been some very significant work demonstrating that airborne asbestos particles can be present even in areas not involved in its mining or processing. One of these experiments were done

Table 10.—*Asbestos workers union survey 1963–1964*

Year from onset	Deceased	Retired	Ill	Withdrawn	Working members	Total alive
50+	25	22	8	1	5	36
40–49	79	35	17	10	43	105
30–39	107	6	5	22	185	218
20–29	39	0	2	7	75	85
10–19	9	0	2	24	385	411
0–9	5	0	0	11	393	404
	264	63	34	75	1,086	1,258

1,522 members January 1, 1943–December 31, 1962 (Selikoff, Churg, Hammond, 1965).

in the asbestos producing region of Avren (Bulgaria), where asbestos outcrops were present but significant processing was not taking place. Significant numbers of endemic pleural plaques in this area would lead one to doubt that industrial asbestos air pollution was unique in its deleterious effects, or a principal factor in the development of endemic pleural asbestosis (see Zolov, Burilkov, and Babadjov, 1967). The main reason for these doubts would be:

1. The very small amount of underground asbestos mining which begun in 1948, which produced very little airborne asbestos;
2. The fact that the minimal time lapse period of dormancy had hardly elapsed, and the contrasting large numbers of instances of calcification in relationship to age dependency of frequency;
3. The very definite demarkation of pleural plaque occurrences between those families working in one tobacco field compared to those families working in another field.

They expressed their hypothesis, that pleural asbestos among the populations in these regions were not only caused by industrial air pollution, but also merely by the daily farm activities of soil cultivation in which asbestos fibers naturally occurred.

Stimulated by these studies, a similar investigation began in the regions of the Rhodope Mountains where asbestos occurs naturally in the soil. The results of their findings (see Burilkov, Michailova, 1970), which were ascertained by X-Ray survey examinations, were first reported to the 2nd International Conference on the Biological Effects of Asbestos, Dresden 1968. Their results clearly showed a much higher number of persons with pleural plaques as well as a higher frequency of pleural adhesions in comparison with a control group in the Balkan Mountains. To continue their study to the logical manner, they then investigated the mineralogical character of the soil in the area of greater pleural plaque occurrences as well as the soil in the area of the control group.

The region of higher pleural plaque frequency had natural outcrops of anthophyllite asbestos which was not exploited due to its dispersion and low fiber content. The control region had no endemic asbestos and was without anthophyllite outcrops. The samples were fractionated and differenciation of mineral components was accomplished by using phase-contrast microscopy and the immersion method with polarized light microscopy.

The results of the size determination of particles is given in figure 5. Particles under 1 micron were examined with the electron microscope, and by X-Ray diffraction. The most common

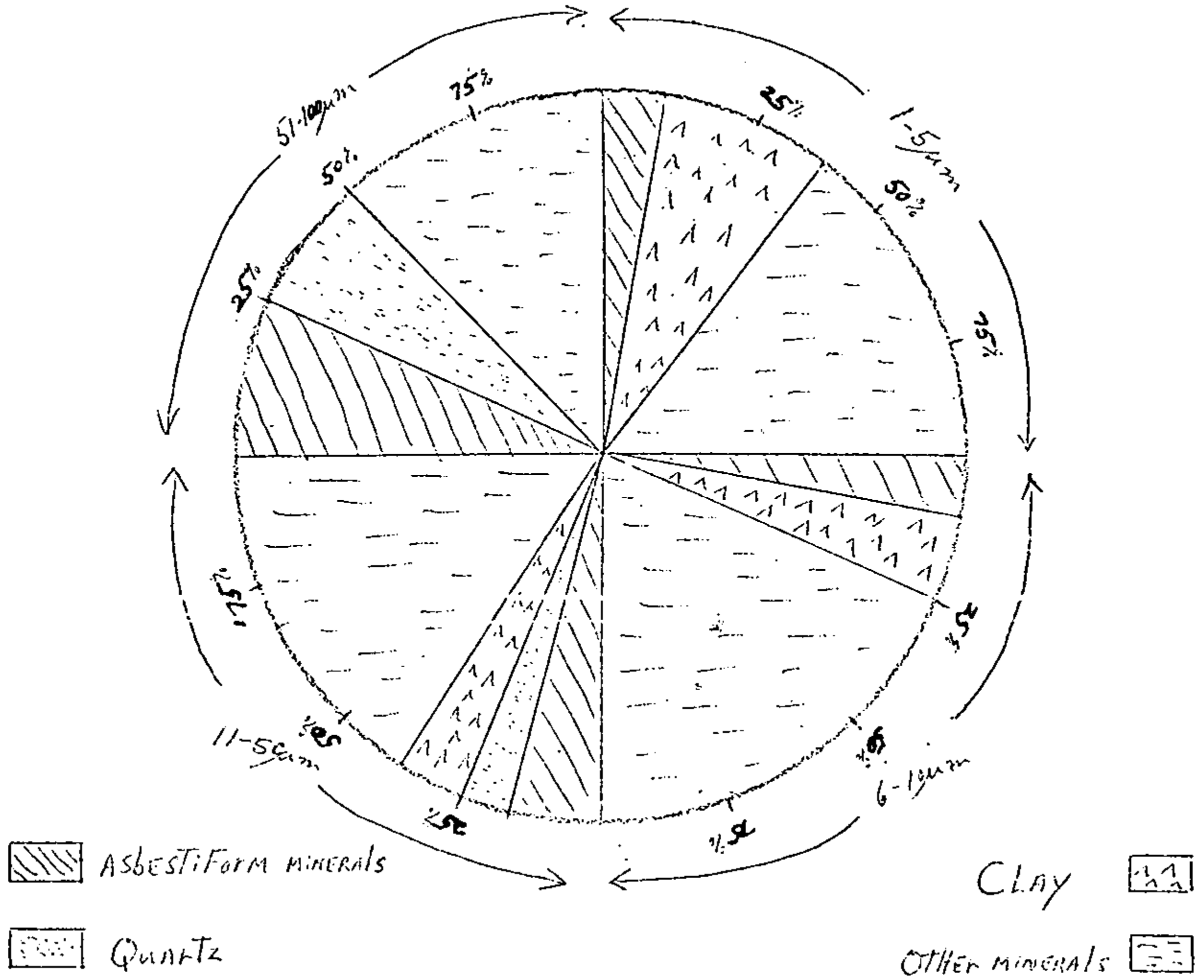

Figure 5.—Mineral compositions of soil samples from the region of higher pleural plaque frequency.

minerals of interest found were kaolinite montmorilonite, as well as anthophyllite and tremolite. The mineral sepiolite was found in all samples. This material is a weathered product of serpentine rocks and has an amphibole structure.

This study supports the concept that an area devoid of industrial processing of asbestos can cause pleural plaques to develop in the human population. Therefore, weathering serpentinities makeup an important source of potential asbestos air pollution originating from its natural soil residence. When the soil content is high in asbestos forms, coupled with intensive erosion, fine dispersion of the soils, dry or hot climate, the formation of dusts with a considerable content of fibrous particle results.

Their study (see Burilkov, Michailova, 1970), could not demonstrate fibrous minerals in the soil of the control region where no pleural plaques appeared in the residents. Pleural plaques were found only in those regions with outcrops of asbestos—anthophyllite, tremolite and sepiolite.

The asbestos fibers readily form the asbestos bodies after being in the lungs a short time. These asbestos fibers before forming the bodies move down to the base of the lungs due to gravity and lung movement. This movement will be faster in younger and more active lungs. Once the asbestos body forms it is improbable that it will move any more and due to its large size it won't be able to be phagocytosed or transported by the lymph system.

The inhalation of these fibers even in small quantities accumulates and concentrates in a small portion of the lungs, so that an inhalation over a long period, a life time, can cause considerable fibrogenic and carcinogenic concentrations that if dispersed would be ineffective. (See Hueper, 1965.)

Table 11.—*The concentration of asbestos bodies in basal lung smears (Cape Town and Miami figures combined) (Thomson, 1965)*

	Male	Female	Total
1 Asbestos body in 31–300 L.P.FS	122	67	189
1 Asbestos body in 10–3– L.P.FS	31	8	39
1 Asbestos body in 2–9 L.P.FS	29	4	33
More than 1 asbestos body in 2 L.P.FS	7	0	7
Negative for asbestos bodies	421	311	732
Total	610	390	1,000

L.P.FS. = Low-power fields.

The most dramatic development of connecting asbestos exposure to another disease was the discovery of an association with mesthelioma. Mesothelioma is an almost always malignant tumor of the delicate membrane that encases the lungs, the pleura, or the peritoneum which is a similar membrane that lines the abdominal cavity.

The disease of mesothelioma is so infrequent that it has not yet been classified in the International Classification of Causes of Death. In general population, death due to asbestosis is about only one in 10,000 (see Selikoff, Churg, Hammond, 1965). After industrial exposure, the frequency of occurrence increases to about one in 10 individuals (Selikoff, Hammond, Churg, 1968). If the spray techniques of industry are not effectively controlled in view of the mounting information, the public may face a time-bomb asbestos infliction.

Mesothelioma was so rare prior to the increase of asbestosis that it was considered a pathological curiosity. It had been found in only one out of every ten thousand autopsies. Dr. Wagner in South Africa during an outbreak of mesothelioma where sixteen cases appeared showed how the asbestos might have played a part. There were two reasons for this link, one was that asbestos bodies were found in an autopsy of the first case. Then by 1961 there were eighty-seven of the cases and they were all in areas where asbestos dust was in abundance (see Brodeur, 1968).

In October 1964 in order to discuss the data of the past as well as the problems awaiting the future the New York Academy of Science sponsored an international conference on the biological effects of asbestos.

Dr. Selikoff and Dr. Hammond found a correlation between asbestos dust and cigarette smoking. They determined that those asbestos workers who smoked cigarettes are ninty times more likely to die of lung cancer than those that don't smoke. There seems to be an important cocarcinogenic

Table 12.—*Mesothelioma in 2,500 consecutive autopsies 1953–1964 (Selikoff, Churg, Hammond, 1965)*

Classification	*Number of cases*
Total autopsies	2,500
Cases with asbestos	26
Pleural mesothelioma	4
Peritoneal mesothelioma	3
Bronchogenic carcinoma	7
All other	12

Table 13.—*Presence of asbestos bodies in lung sections among 45 cases of pleural and peritoneal mesothelioma (Selikoff, Churg, Hammond, 1965)*

Location of mesothelioma	Number of cases	Asbestos bodies	
		Found number of cases	Not found number of cases
Pleura	19	5	14
Peritoneum	26	7	19
Totals	45	12	33

Table 14.—*Underlying cause of death in 307 consecutive deaths among asbestos insulation workers, Jan. 1, 1943 to Aug. 31, 1964 (Selikoff, Churg, Hammond, 1965)*

Cause of death	Number of deaths	Percentage
Bronchogenic carcinoma	53	17.3
Gastrointestinal cancer	34	11.1
Pleural mesothelioma	4	1.3
Peritoneal mesothelioma	6	1.9
All other neoplasms	27	8.8
Asbestosis	17	5.5
All other causes	166	54.1
Total	307	100.0

effect between asbestos exposure and cigarette smoking. Since asbestos fibers are so absorbent as well as so indestructible they may retain the substance known as benzo(a) pyrene from the cigarette smoke for long periods of time in lung tissue, this then producing lung cancer by a synergistic effect. Nobody knows for sure about this tie, more information is needed.

Of all the industrial uses of asbestos the one which potentially can have the greatest effect on the general public are the construction uses. Those construction uses in which the asbestos is locked-in by plastic or cement, contribute very little ambient air pollution. Probably the worst contributor to the asbestos air pollution is the spray applications. The use of spray asbestos insulation has the advantages of being more economic and gives the builder the freedom of design more pleasing to the eye. The public gains by a lower cost as well as enjoying a safe building. The cost may be very high, because these immediate advantages might be outweighed by the large volumes of asbestos put into the air. There are generally two methods of spraying asbestos insulation; 1) A prepared dry mix is put into a hopper and pneumatically conveyed to a nozzle. At this point the material is mixed with water and the slurry is sprayed upon the surface; 2) the material is mixed with water and then the slurry is pumped to the place of application (see Reitze, Fenner, Romer, Holaday, 1970).

In April of 1970 New York City introduced stringent regulations governing these spray activities. According to the Assistant Commissioner Department of Air Resources, Mr. Harold Romer, paragraph 2 of the orders issued by his commission read as follows:

2. The entire floor, or the part of the floor to be insulated shall be enclosed with plastic tarpaulins in a manner which shall preclude the escape of asbestos–containing material from the enclosure. All interior open areas, such as elevator shafts, stairwells, ect., shall be enclosed in a manner which shall prevent the escape of asbestos containing material from the working area. "Stack effect" of the shafts, stairwells ect., shall be considered in providing proper enclosures. An enclosure will be considered satisfactory only if visible insulating material cannot escape from the enclosure.

Even though these regulations don't control invisible particles they take a big step in the process of effective control of asbestos.

The legal prohibition of the dangerous uses of asbestos in high population areas is showing steady gains. The City Department of Air Resources has strongly urged the State Department of Environmental Conservation to adopt Subchapter A, Part 196, of the City Commissioner's Orders on containment and clean-up on April 13, 1970. A challenge to the power of the Commissioner of the Department of Air Resources to regulate spraying operations using asbestos arose in the case of LaMonica vs. Jerome Kretchmer, Administrator of the Environmental Protection Administration (Romer). In the New York Law Journal of Nov. 18, 1970 commented on this case by stating, "A State Supreme Court Justice ruled yesterday that the Commissioner of the Air Resources Department could bring criminal proceedings against a firm charged with spraying asbestos coating on buildings in violation of the Air Pollution Code." They continued by stating, "Relying on powerful evidence of the disastrous medical effects of asbestos in the air, Justice Xavier C. Riccobono held that the Commissioner's Orders to the firm to end the practice were valid and within his authority as contained in the Air Pollution Control Code." "The plaintiffs asked for a temporary injunction to prevent the Commissioner from enforcing the Code, contending that his orders to cease spraying asbestos coating on buildings under construction, as well as the Air Pollution Control Code, were unconstitutional. The plaintiffs had received 19 summonses for violations of the Code." The Judge denied the injunction.

Dr. Irving Selikoff, researcher and pioneer in the field of asbestos diseases, is the Director of Environmental Science Laboratories at the Mt. Sinai School of Medicine in New York City. He was one of the expert brought to this case to describe the medical effects of asbestos inhalation. During that case he stated, "In Manhattan ambient levels far removed from construction sites are now 20-60x1-$^{-9}$ grams per cubic meter of air, up to 6 times more than in, say, Staten Island, or Ridgewood, N.J. Indeed, ambient air levels about construction sites are even several times higher than these background levels. At these levels the average person might inhale 10 to 15 million asbestos fibrils in one 24 hour day." "In New York City, the construction industry is a major source, of airborne asbestos particles. Three-quarters of all asbestos used, is used in the construction industry."

There have been many summonses for violations by spraying contractors and these violations and summonses have been increasing. A very disturbing example of a violation occurred on Dec. 4, 1970. Twelve summonses were served on two construction sites this windy day. Dozens of complaints had been made to the effect that it was "snowing asbestos." It was observed on personal inspection that all vertical rises, curb, steps and storefronts for about a three block area of the two construction sites had accumulated as much as 3 inches of asbestos. The air was heavy with asbestos, surfaces of cars were covered, and pedestrians had to brush the asbestos from their clothes (Romer, 1971). It is easy to appreciate the large job it is to provide adequate surveillance over the New York City area, considering there are 25 to 40 skyscrapers asbestos insulation spray operations in progress each day. A cooperative State and National effort is necessary for a program of protection to be completely successful.

CONCLUSIONS

The rise of the occurrence of asbestosis can be directly correlated with the rise in production. The prime problem involved with the increase of the mineral asbestos in our atmosphere is the fact that it is virtually indestructable. The real problem for us is the constant accumulation, still continuing, to a possibly human lethal level. The asbestos fibers once in the lungs readily form "asbestos bodies" which are yellowish-brown protein-ferritin masses. These settle in the basal part of the lungs eventually causing the failure of these alveoli and a deterioration of the membranes. Asbestosis has been linked to diseases such as tuberculosis, cancer, and mesothelioma.

There is certainly a great difference in the quantity of asbestos inhaled by an asbestos worker and the average urban dweller. We will not know the consequence of the urban dweller's health until more studies are completed. One cannot assume that low levels of asbestos will cause the same conditions as large doses, nor can we be just as quickly convinced it will have no effect.

The hazard of asbestos inhalation must be contained soon or man may succeed in self-destruction. The number of people exposed unneccesarily is increasing at an alarming rate. In as many as three thousand different industrial products the presence of asbestos has become threatening. More work is needed to bring fourth the impact of proof that would sway the tide of political interest from talk to action.

BIBLIOGRAPHY

Berkley, C., Churg, J., and Selikoff, I.J. 1965. "The Detection and Localization of Mineral Fibers in Tissue." *Annals of the New York Academy of Science.* 132:48–63.

Brodeur, P. 1968. "A Reporter at Large." *The New Yorker.* Reprint Oct. 12. pp. 1–21.

Burilkov, T., and Michailova, L. 1970. "Asbestos Content of the Soil and Endemic Pleural Asbestosis." *Environmental Research 3,* pp. 443–451.

Davis, J.M.G. 1965. "Electron-Microscope Studies of Asbestosis in Man and Animals." *Annals of the New York Academy of Science.* 132:98–111.

Godwin, M.C., Jagatic, J. 1969. "Asbestos and Mesotheliomas." *Environmental Research 3,* pp. 391–416.

Harington, J.S. 1965. "Chemical Studies of Asbestos." *Annals of the New York Academy of Science* 132(1), 31–47.

Hendry, N.W. 1965. "The Geology, Occurrences, and Major uses of Asbestos." *Annals of the New York Academy of Science.* 132:12–22.

Holt, P.F., J. Mills, D.K. Young. 1965. "Experimental Asbestosis with Four Types of Fibers: Importance of Small Particles." *Annals of the New York Academy of Science.* 132:87–97.

Hueper, W.C. 1965. "Occupational and Nonoccupational Exposures to Asbestos." *Annals of the New York Academy of Science.* 132:184–195.

Langer, A.M., Selikoff, I.J. 1970. "Chrysotile Asbestos in the Lungs of Residents of New York City." *Second International Air Pollution Conference,* Washington, D.C.

Morgan, S. and Holmes, A. 1969. *Proceedings of the International Conference on Pneumocniosis,* Johannesburg 1 in press.

Nagelschmidt, G. 1965. "Some observations of the Dust Content and Composition in Lungs with Asbestosis Made During Work on Coal Miners Pneumoconiosis." *Annals of the New York Academy of Science.* 132:64–76.

Newhouse, M.L., Thompson, H. 1965. "Epidemiology of Mesothelial Tumors in the London Area. Discussion by G.W.H. Schepers and Selikoff." *Annals of the New York Academy of Science.* 132(1) 579–588.

Nicholson, W.J., Rohl, A.N., Ferrard, E.F. 1970. "Asbestos Air Pollution in New York City." *Second International Air Pollution Conference,* Washington, D.C.

Permis, B. and Vigliani, E.C. Selikoff, I.J. 1965. "Rheumatoid Factor in Serum of Individuals Exposed to Asbestos." *Annals of the New York Academy of Science.* 132 (1) 575–578.

Pooley, F.D., Oldham, P.D., Chang-Hyun Um, Wagner, J.C., 1969. *Proceedings of the International Conference on Pneumoconiasis,* Johannesburg, in press.

Reitze, W.B., Holaday, D.A., Romer, H., and Fenner, E., "Control of Asbestos Fiber Emissions from Industrial and Commercial Sources." *Second International Clean Air Conference,* Washington, D.C. 1970. (to be published.)

Romer, H., "Banning of Sprayed Asbestos," Statement before State Dept. of Environmental Conservation, N.Y. 1971.

Selikoff, I.J., J. Churg, E.C. Hammond. 1964. "Asbestos Exposure and Neoplasia." *The Journal of the American Medical Association.* 188:22–26.

Selikoff, I.J. J. Churg, E.C. Hammond. 1965. "The Occurrence of Asbestosis Among Insulation Workers in the United States." *Annals of the New York Academy of Science.* 132:139–153.

Selikoff, I.J., J. Churg, E.C. Hammond, *Journal of American Medical Association,* 204:106, 1968.

Smith, Wm. E., Miller, L., Elsasser, R.E., and Hubert, D.D. 1965. "Tests for Coreinogenicity of Asbestos." *Annals of the New York Academy of Science,* 132 (1) 456–488.

Smither, W.J. 1965. "Secular Changes in Asbestosis in an Asbestos Factory." *Annals of the New York Academy of Science.* 132:166–183.

Thomson, J.G. 1965. "Asbestos and the Urban Dweller." *Annals of the New York Academy of Science.* 132:196–214.

Timbrell, V. 1965. "The Inhalation of Fibrous Dust." *Annals of the New York Academy of Science.* 132:255–273.

Wagner, J.C. 1965. "Epidermiology of Diffuse, Mesothelial Tumors: Evidence of an Association from Studies in South Africa and the United Kingdom." *Annals of the New York Academy of Science.* 132(1), 575–578.

Zolov, C. Burilkov, T., and Babadjov, L. 1967. "Pleural Asbestosis in Agricultural Workers." *Environmental Research 1,* 287.

FLUORESCENCE SPECTROSCOPY IN THE STUDY OF AIR AND WATER POLLUTION

Akhtar Yaseen, Ph.D.
New York Medical College
Center for Chronic Disease
Bird S. Coler Hospital
Welfare Island, New York

Luminescene Spectroscopy includes the spectral analysis of both fluorescene and phosphorescence radiation material. The distinguishing feature of this technique is its high sensitivity. Fluorescence Spectroscopy is 10 to 1,000 times more sensitive than absorption spectroscopy and permits us to assay in the concentration range from nanograms to milligrams per milliliter quite easily, especially with compounds containing an aromatic ring. A properly designed fluorescene spectrophotometer provides measurement selectivity unique to spectroscopy. One can take a mixture of fluorescent materials, and by properly selecting the excitation wavelengths, obtain the spectrum of each component in the mixture, relatively free from interferences from the other components.

Fluorescent spectroscopy has become a prime analytical tool in the areas of Clinical Chemistry, Biochemistry, Polymer Chemistry, Petroleum and Petrochemical Analysis, Air and Water Pollution Study, Pharmaceuticals and Inorganic Phosphor Research. The rapid growth in the application of fluorescent spectroscopy is emphasized by the excellent review articles by White (1) and Weissler (2).

FLUORESCENT EMISSION OF RADIATION

A cell containing the material under investigation is placed in a source of continous radiation. If the light absorption lies in the banded region of the spectrum, there are several options open to an excited molecule. (a) It may re-emit a quantum of either the same or different frequency. This emission is called fluorescene or phosphorescene. (b) It may collide with other molecules and pass on to them some or all of its excitation energy. This energy either can cause reaction in the other molecules or can gradually degrade into heat. (c) It may collide with another molecule and react with it. (d) It may spontaneously decompose if the excitation energy reaches a bond that can be broken (predissociation).

Fluorescene is the emission of light which has been absorbed by the molecules. It should not be confused with the scattering of light which has not been absorbed. The distinction between fluorescene and phosphorescene was formly made on the bases of the duration of the after-glow, a slow decay of luminescence being called phosphorescence. Current usage of these items, however, based the distinction on a difference in the mechanism for re-emission of light.

INSTRUMENTATION

There are two types of fluorometers: filter fluorometers and fluorescence spectrophotometer. Filter fluorometers usually contain a mercury lamp and require filters to set emission and excitation wavelengths. This type of instrument is suitable for quantitative assays, if excitation and emission wavelengths are known. Fluorescene spectrophotometers usually consist of grating excitation and emission monochromators. The wavelength is linear from 200nm to 780nm, with Xenon light source and capability of manual and automatic scans at fixed or variable speeds. Both filter fluorometer and fluorescene spectrophotometers consist of a photometer with transmittance scale (0 to 100) for reading fluorescence intensity. The photometers have sensitivity control and meter multiplier, which is a step amplifier control. Cell compartment is usually equipped to take fluorescence-free quartz cells (10mm) or flow-through micro cell.

The major feature of fluorescence spectroscopy making it a potentially powerful tool is a high "degree of freedom" steming from the design requirement for fluorescence spectrophotometers, which make two monochromators necessary. Two monochromators functioning independently of each other and a source (a xenon arc) whose out-put pass into the first (excitation) monochromator that disperses the light and provides monochromatic light to excite the sample. The excited sample becomes the source for the second (emission) monochromator. The collecting optics for emission monochromator is arranged to take fluorescence from the sample at an angle other than 180° relative to the exciting light, usually 90° or 45°. This arrangement makes it possible to achieve high sensitivity, selectivity, and ease of sampling.

The fluorescence spectrophotometer described in figure 1 can provide two kinds of spectra,—excitation and emission.—from and fluorescent sample. By adjusting the excitation

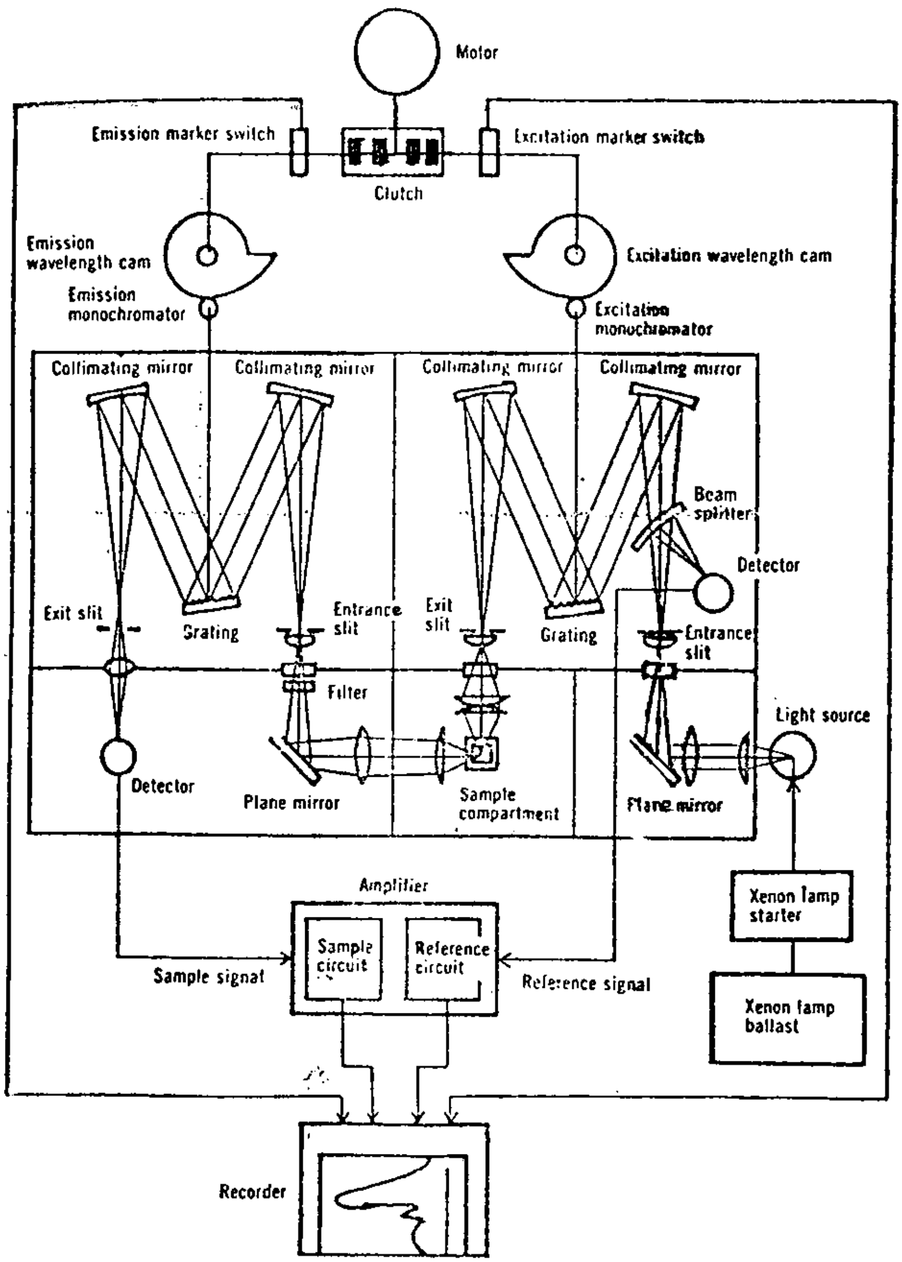

Figure 1.—–Schematic of a fluorescene photometer.

monochromator to appropriate excitation wavelength for a given sample and causing the emission monochromator to scan, the emission spectrum of the sample will be recorded. On the other hand, the emission monochromator can be set to an emission wavelength of the sample and the excitation monochromator caused to scan, thereby producing on excitation spectrum (fig. 2).

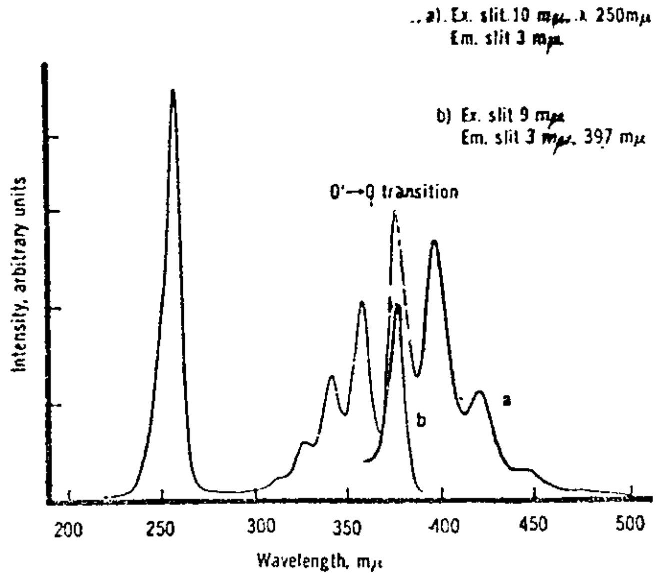

Figure 2.—Emission spectrum (a) of anthracene shows minor image relationship with excitation spectrum (b).

The instrument described above is called scanning spectrofluorometer. There are several scanning spectrofluorometers available on the market. Some of them are Perkin-Elmer MPF-2A Fluorescence Spectrophotometer, Aminco-Bowman Spectrofluorometer and Turner. For routine pollution chemistry these instruments are too sophisticated. However, there are many less expensive models available. These fluorometers (e.g. Turner Model 110 or Model 111, G.K. Turner Associates, Palo Alto, California) do not have Xenon arc as a light source and require filters (Corning or Illford) for setting excitation and emission wavelengths before reading fluorescence radiation of a material.

TESTING FLUOROMETER

Before measuring relative fluorescence, the instrument must be checked with quinine sulfate solutions. The evaluation of calibration measurements is particularly difficult because of the fact that the data on the radiation capacity of standard emitters are based in part on the radiation density and in part on the irradiation intensity. Therefore measurements should be made as quickly as possible to avoid errors due to the lamp fluctuation and sample deterioration. In order to monitor the instrument we need the following solutions:

(a) *Stock Solution*

Prepare a 10 microgram per ml solution by transferring 10 milligrams of pure quinine sulfate into one liter volumetric flash and add 0.1N H_2SO_4 to dissolve quinine sulfate and add acid to one liter mark.

(b) *Working Solutions*

Prepare 1, 0.1, 0.01, 0.001 and 0.0001 micrograms per milliliter solutions by successive dilution of stock solution in 0.1N H_2SO_4.

(c) *Measurement of Relative Fluorescence Intensity*

Turn on the fluorometer according to the instruction manual. Pour suitable volume (one to three milliliters) of 10 micrograms per milliliter stock solution into the cell and insert it in the cell holder. Adjust excitation wavelength 350mn and emission wavelength 450mn until maximum reading is obtained on the photometer for both. (For filter fluorometers, insert appropriate filters). Adjust slit arrangement and sensitivity settings until photometer reads between 30 to 100 on the transmittance scale. Relative intensity is the product of meter reading and meter multiplier, with all parameters fixed. Remove the cell containing 10 micrograms per milliliter solution and pour suitable volume of solvent blank (0.1N H_2SO_4) into another cell. Insert the cell in cell holder and adjust the meter multiplier until photometer reads between 30 to 100. If reading is below 30 when meter multiplier is at lowest, record the reading and proceed with measurement of relative intensity of other solutions. Do not discard highly concentrated solution from a cell and replace with low concentration without a thorough cleaning of the cell.

Plot the data on log-log paper with or without blank substraction. When data differ by a factor of 100 or less, linear paper may be used to advantage. High concentrations, usually greater than 10 microgram per milliliter can cause apparent concentration-quenching due to absorption of excitation light by the highly concentrated solutions. Figure 3 illustrates a decrease in relative intensity with increasing concentration above 10 micrograms per milliliter.

DATA TABULATION

Concentration ug /ml	Relative Intensity	Meter Multiplier Setting	Relative Fluorescence Intensity
100	52	0.1	5.2
10	41	1	41
1	52	0.1	5.2
0.1	90	0.01	0.9
0.01	47	0.01	0.47
0.001	47	0,01	0.47
Blank	43	0.01	0.43

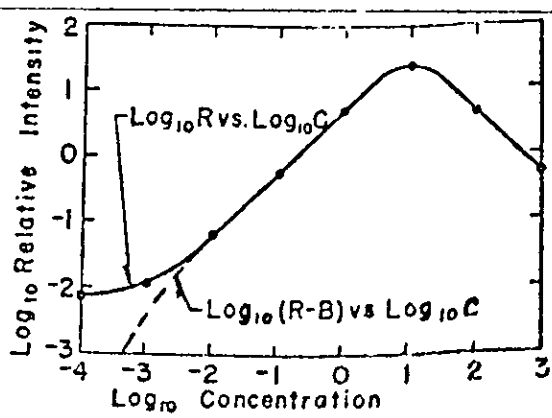

Figure 3.—Fluorescence of quinine sulfate in 0.1N H_2SO_4.

ULTIMATE SENSITIVITY

Ultimate sensitivity of compounds with fluorescent characteristics are usually listed in terms of concentration in micrograms per milliliter which will produce a useful (at least 10 percent of full scale) meter deflection at maximum sensitivity, with optimum arrangement of slits and correct choice of photomultiplier tube. This data differs from instrument to instrument; if the excitation and emission wavelengths, pH etc., are known, the ultimate sensitivity of a compound for a particular instrument can be determined by running a set of standards.

REMOVAL OF INTERFERING SUBSTANCES

Interfering substances in samples are usually removed (1) by solvent extraction and (2) by absorption of specific substances onto inorganic absorbents. Ion-exchange resins are also used in some determinations. Sometimes absorption chromatography by means of thin layer plates of many absorbents applied to glass plates has found wide application in separation of complex mixtures of organic compounds.

OBTAINING A FLUORESCENCE SPECTRUM

Let us assume that we have a compound and we wish to obtain a fluorescence spectrum when emission and excitation wavelengths are unknown. We proceed as follows:

(a) Insert suitable volume of sample solution into sample cell. Remove cell compartment cover, insert the cell into holder, replace the cover. (Sample cells for fluorometry are different in construction than photometric cells. They are made of quartz and transparent on all sides).

(b) Open the photomultiplier shutter, usually by pressing it down.

(c) Set the photometer to high sensitivity.

(d) Manually change excitation disc in steps of 10mu at completion of each emission scan (200mn to 750mn) until maximum deflection is indicated on photometer (transmittance scale). The magnitude of deflection will be governed by cell cleanliness. The region of greatest scatter is between 300 to 500mn.

(e) When excitation wavelength is located, stop the emission disc and adjust emission wavelength for maximum fluorescence indicated on the meter.

(f) Adjust the excitation wavelength disc for maximum fluorescence indicated on scale; meter reading is obtained.

Since we have located the excitation and emission wavelengths, it is possible to scan the fluorescence spectrum if the instrument is equipped with a recorder. Otherwise meter reading at one fixed excitation wavelength and various emission wavelengths may be plotted to construct an uncorrected fluorescence spectrum. Determination of the exact excitation and excitation spectra requires the use of correction curve or complex automatic electro-mechanical compensation. However, the spectra obtained are of great value and do not detract from quantification of determination as in the case with any filter instrument. Corrected spectra accessories usually consists of a special optical system using Rhodamine B, compensating potentiometers etc., which are attached to a spectrofluorometer. Emission and excitation wavelengths of some compounds are listed in table 1.

Table I

Compound	Activation maximum (millimicrons)	Fluorescent maximum (millimicrons)	pH	Ultimate sensitivity (micrograms per milliliter)
	List 1 *Insecticides*			
Guthione	250, 312	380	11	0.03
Indole acetic acid in methanol	285	345	....	.001
Naphthalene acetic acid	230, 282	325	11	....
Naphthalene acetamide in methanol	230, 286	327	11	0.1
Piperonyl butoxide in methanol	248, 292	320	....	0.1
Potasan (in methanol)	320	385	....	0.1
N-propylisome	248, 292	326	....	0.1
Warfrin in methanol	320	385	....	0.1
	List 2 *Carcinogens*			
8 Methyl fluorene	280, 290, 365	460, 480	....	....
1, 2 Benzpyrene in cyclohexane	290, 330	410	....	....
Naphthacenene	280, 390 415	480	....	....
	445	....	....	....
Naphthacene	290, 310	480, 515	....	....
Benzanthrene	245, 325, 340	385, 400	....	....
1, 2 Benzanthrene	280, 340	390, 410	....	....
Chrysene	310, 335, 390	480, 510	....	....
3, 4, 8, 9 Dibenzpyrene	410	....	....	....

QUANTITATIVE ASSAY

Before proceeding with the measurement of relative fluorescence intensity, it should be determined beyond reasonable doubt that the fluorescence is from the compound under assay and not from the interfering substances or from the blank. Fluorescence from the blank may be minimized by using clean disposable glassware and the reagents specially purified for fluorometery. Once the fluorescent peak for compound under assay has been found, this peak will thereafter serve as indicator for quantitative assay and with the same degree of facility as fluorescence spectrum. In some cases it is advantageous to use excitation spectrum. For example, when two compounds under assay exhibit the same fluorescence spectra but different excitation spectra (fig. 4).

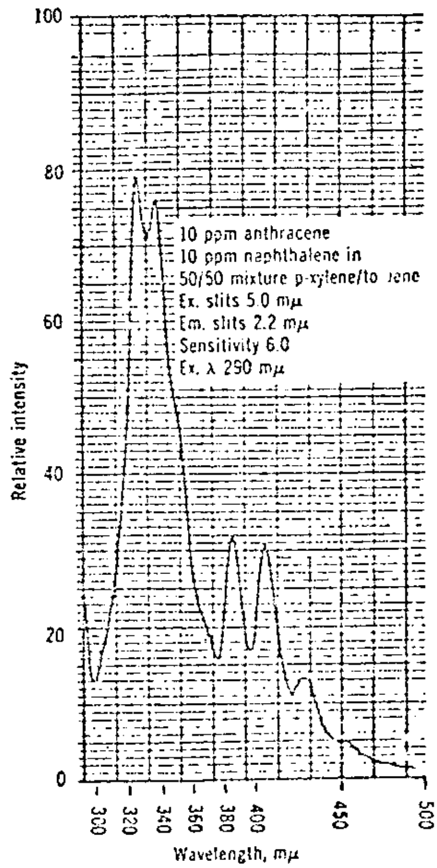

Figure 4.—Emission spectrum of sample containing equal parts of Anthracene and Naphthalene.

AUTOMATED TESTS

Chemical constituents in air and water samples can be determined by a continous flow instrument which is capable of handling and presentation, delivery of reagents in proper sequence, removal of interfering materials, heating or incubating mixtures, and measuring and recording data. A continous-flow automated instrument consists of a sampler, a manifold for addition of proper amount of reagents with the sample to be assayed, a fluorometer equipped with flow-cell, and a recorder for recording fluorescence intensity which is proportional to the concentration of unknown constituent in the samples. A calibration plot for an automated procedure is shown in figure 5. Applicablity of automated tests in any laboratory depends on the work load.

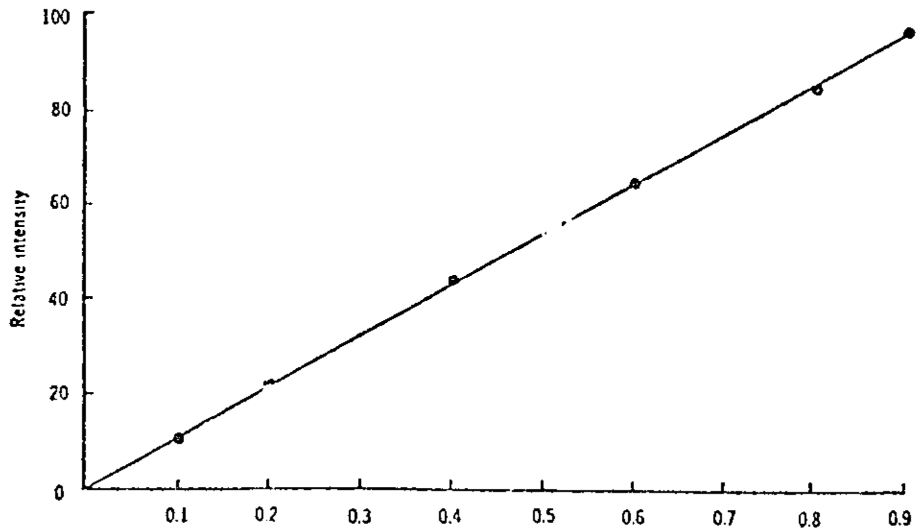

Figure 5.—Concentration (ppm) benz (d) Pyrene in iso-octane.

REFERENCES

1. White, E.C. and Weissler, A., "Anal. Chem." 36,5 (1964).
2. Weissler, A. and White, E.C., "Anal. Chem." 38,5 (1966).

THE WORLD PLAN OF ACTION FOR THE APPLICATION OF SCIENCE AND TECHNOLOGY TO DEVELOPMENT

Lecture presented at the Columbia University of the City of New York Seminar on Pollution and Water Resources, on 20 September 1972

by

Bertrand H. Châtel*
Chief
Science Applications Section
Office for Science and Technology
United Nations, New York

*The views expressed by the author do not necessarily reflect those of the United Nations.

Much has been said to complicate the problem of Development, but I would like to start by noting its main features and try to summarize it with a few figures. I think that the first figure is the Gross National Product (GNP): developed countries (DDC) have now a total GNP of $2,500 billion; developing countries (DGC) have roughly $500 billion; and the World total GNP is $3,000 billion. If we assume, for a moment, a growth rate of 5 percent for the GNP, developed countries will have, in the year 2000, $10,000 billion; developing countries: $2,000 billion; and the World $12,000 billion. The population of developed countries is at the moment roughly one billion persons; developing countries have 2.5 billion persons, and the World has 3.5 billion persons. In the year 2000, if we take the projections agreed upon in the United Nations, it is anticipated that the population of developed countries will be 1.4 billion while the developing countries will be 4.7 billion, making a World total of 6.1 billion.

To have an idea of the development problem, we have to divide the GNP by the population to obtain the GNP *per capita.* In developed countries, it is at the moment $2,500 *per capita;* in developing countries $200 *per capita*, i.e. 8 percent of what the developed countries have. In the year 2000 – with the previous assumptions for growth of GNP and population – the GNP *per capita* of developed countries will be around $7,000 while that of developing countries would be around $430 *per capita.* The latter percentage will have decreased to 6 percent (see table 1).

Table 1.—*The problem of development*

Countries	Gross national product (GNP) (billion $)		Population (billion persons)		GNP/per capita ($/person)		2nd UN developed decade target (billion $)	World plan of action targets (billion $)
	1970	2000	1970	2000	1970	2000		
Developed countries.	2,500	10,000	1	1.4	2,500	7,000	25	1.25 2.25
Developing countries.	500	2,000	2.5	4.7	200	430		5.00
Total world	3,000	12,000	3.5	6.1	900	2,000	25	8.5

In other words, there is a large discrepancy between the average standard of living of a man living in a developing or a developed country, and this will be worsening if no corrective action of great magnitude is undertaken. Why is it worsening? This is the result of a simple division. In the fraction GNP/Population, the numerator is increasing quickly in developed countries while the denominator (population) is increasing slowly (1.4 percent in developed countries). But in developing countries, the numerator GNP is increasing slowly while the denominator population is increasing quickly (2.8 percent, the double in developing countries). After 30 years, the curves of GNP/*per capita* will have therefore diverged considerably.

Does this discrepancy really matter? Many people in advanced countries believe it does not. For instance, in the Presidential elections, this matter is not mentioned. In Western Europe, it is the same: most people are not interested in development. So we have to answer this preliminary question: What is the importance of these diverging standards of living? Could not people live differently? In fact, great discrepancies in the standards of living do not necessarily matter. For instance, if people do not know each other: in 1491, before Columbus, the Indians of America had a very different standard of living from that of an Englishman, or a Parisian, or a Fiorentine, or an Egyptian, a Chinese or a Japanese. But this did not really matter because people ignored each other. From the 16th to the early 20th century, the rich have travelled to the poor countries; this did not matter so much either, because the poor nations continued to ignore what was going on in rich countries. But since the second half of this century, 20 years ago, this situation has changed: Representatives of the poor countries have started to travel; and the poor segments of the poor countries, while not yet travelling, have become aware of all that they do *not* have by the telecommunications, by the mass-media, by radio, broadcasting, by television, by films, by newspapers; and this large discrepancy can become a seed for violence and conflicts, and thereby a matter of concern to the United Nations.

The role of the United Nations is traditionally that of a peacekeeping organization. In the beginning, it was mainly involved in the political problems arising in the "club of the winners" of the World War II. But since 1952, a great number of countries have become independent and joined the United Nations, where developing countries actually have a large majority now. And the problems of these new countries are mainly economic and social. The discrepancy between the standards of living of developed and developing countries are now considered as a very important source of conflicts before the end of this century, and should be aleviated from the point of view of justice also. This is why the "Development problem" has become one of the major concerns of the United Nations: There are now proletarian and rich nations and it is to be hoped that a good co-operation can be organized between these two classes of nations before the end of this century, so as to avoid that the present worsening situations degenerate into conflicts.

We have here only mentioned the main concept of GNP/*per capita* in relation to Development and this should be obviously complemented by more sophisticated parameters such as the quality of life and all the non-monetary aspects of income, which are numerous in developing countries. We should also mention the large differences which exist between developing countries, ranging from $100/*capita* per year to $2,000/per capita/year and within a single country. Other considerations, such as the "limits to growth", the depletion of natural resources and the protection of the Human Environment have also to be introduced to build up a more comprehensive picture of the "System of Development".

All these variations intervene – as modulations around a bearer wave – around the trends of the GNP/*capita* which are considered as one of the main roots of the problem.

THE SECOND UNITED NATIONS DEVELOPMENT DECADE

Many people believe that the major activities of the United Nations are of a political nature, such as the conflicts in the Middle East or in Viet-Nam, but this is not the case. The United Nations devote only 20 percent of its activities to these, and 80 percent to the economic and social problems of developing countries.

We are now in the "Second Development Decade", which started in 1971, the main objectives of which are summarized in its "Strategy", a very military term for a peaceful organization.

This strategy recommends that the GNP of developing countries grow at a rate of 6 to 7 percent a year, while in the previous decade, it had grown at a rate of 4.5 to 5 percent a year. If the Population growth does not exceed 2.5 percent a year in developing countries (it is now 2.8 percent), the growth of the GNP/capita would be 4 percent per year, which would mean the doubling of the income of developing countries in 20 years. In other words, in 1990, developing countries would have a GNP/capita of $400 per year, and this would represent an advance of ten years vis-a-vis the figures given in the above introduction.

This rate of 6 to 7 percent is, of course, a mean figure which covers several diversified growth rates such as in agriculture (4 percent), in industry (8 percent), in domestic ratings (0.5 percent), in exports (7 percent), or decreasing rates such as in imports (7 percent).

The Second Development Decade Strategy defines many programs in the fields of population, employment, education, health, housing, youth, environment, industry, natural resources, transport, telecommunications, etc.

How to finance this strategy? The developed countries have agreed as a target to allot one percent of their GNP to aid the developing countries. For a GNP of $2,500 billion, this means a funding of $25 billion per year during the Decade. The flow of aid from the United Nations on a multilateral basis was roughly $1 billion in 1968, i.e. 4 percent of the total strategy. (It is now $3 billion). This means that the remaining amount, i.e. $22 billion, or 88 percent should be financed on a bilateral basis. This is not very well known: the United Nations advocate not so much a multilateral assistance but rather a bilateral channel for the aid of developed to developing countries.

THE APPLICATION OF SCIENCE AND TECHNOLOGY TO DEVELOPMENT

The Second United Nations Development Decade proposes economic goals. But how to implement them? By applying science and technology in developing countries. Science and Technology here are considered as the tools which can generate economic progress. This is based on the belief that the Western World has obtained its economic advances by these means, and that a similar medicine should be applied to the developing countries. The general philosophy which is behind this is not "Science for the sake of Science progress", but "Science for stimulating Development". Science policy, in this case, is therefore an answer to the following questions: How, when and how much funds should be invested in Science and Technology to create development by a catalytic effect?

This has been the idea which laid a basis for the convening, in 1963, in Geneva, of the International Conference[1] on this subject. This led the way to the creation of a Committee[2] of 24 members, scientists, engineers, economists, doctors, biologists, nutritionists from all over the world who gathered to advise the Secretary-General as regards the application of Science and Technology. One of their main tasks has been the preparation of the "World Plan of Action", with the assistance of all the specialized agencies of the United Nations System and many consultants, forming a team of about 150 persons. The report, originally 1,500 pages, was compiled and summarized by the Office for Science and Technology of the United Nations to arrive at the present, more readible, document of 280 pages which was approved by the Advisory Committee in February 1971. It is now being discussed by the Economic and Social Council and will later be submitted to the General Assembly.

[1] United Nations Conference on the Application of Science and Technology in the less developed areas.
[2] United Nations Advisory Committee on the Application of Science and Technology to Development (ACAST).

What are the main objectives of this Plan? They are derived from the basic observation that 98 percent of R and D facilities are located in developed countries and perform work on programs oriented towards the interests of developed people. This means that 2.5 billion persons – in developing countries – are now receiving products which have not been particularly designed to fit their own needs, but designed for 1 billion persons, living elsewhere, in different environmental conditions, with an income ten times higher and accordingly with different interests, tastes and needs. It is necessary, therefore, to build up an indigenous science and technology in developing countries, to create institutions and science policies, to foster education, and to prepare and also implement specific projects. This is the purpose of the World Plan of Action which also includes programmes in various sectors such as natural resources, food, agriculture, industry, housing, building, urban settlement, transport, telecommunications, health, population and recent technologies much as nuclear, space, and computer technologies.

HIGHLIGHTS ON WATER PROGRAMS

I will not go into the details of each of these programs, but would like to focus on those related to water, which are approached, in the Plan, from two points of view: that of Health and that of water resources.

A. *Health aspects of community water supply*

The World Health Organization, which prepared this program for the Advisory Committee, has observed that two-thirds of the World's population does not have appropriate water supply. In developing countries, correlations have been observed between imperfect water supply and certain diseases such as cholera, enteric fevers, bacillary or amoebic dysentry, and diarrhoeal diseases. For instance, cholera can assume epidemic proportions when there is a lack of good sanitation. Cholera EL TOR, for example, was affecting only Indonesia in 1930, but since 1961 it has spread through water and food, and in 1970 had reached the Middle East, North Africa and Eastern Europe. Crowding, overpopulation, and slums exacerbate the problem caused by inadequate water supply in urban areas. The Plan recommends that 100 percent of the urban dwellers be provided water supply: 40 percent by piped water connected to houses or courtyards; and 60 percent by giving an access to piped water connected to public fountains located within reasonable distances from the homes. This objective – although modest – would represent a doubling of the present status where only 50 percent of the urban dwellers have a satisfactory access to water supply.

As regards the rural areas, the Plan recommends that 20 percent of the population be served by adequate and safe water supply, while only 10 percent enjoy this service at present. This important world wide program of water supply will cost $9.1 billion, which will be scattered in Asia (60 percent), Latin America (25 percent), and Africa (15 percent). The urban piping will cost $7.5 billion and the rural part of the program $1.6 billion. It is estimated that one-fourth to one-third of this project should be financed by external sources. Pre-investment planning projects should be prepared: 50 projects at $800,000 would require a budget of $40 billion. These studies would formulate long range "National Master Plans" and also "bankable projects" for submission by Governments to the UNDP and, later on, to the World Bank.

The education and training of personnel should be supported by 100 fellowships per year, i.e., $5 million during the decade, to be given to engineers, managers and technicians.

As regards scientific and technical information, it is proposed to create an "International Reference Center for Community Water Supply" which would pool the information, store the data, organize seminars and training, and pursue research. This center would cost $2 million during the decade, which would be financed by developing (20 percent), developed countries (40 percent) and international sources (40 percent).

Five Engineering Research Institutes in the field of public health should also be established during the decade, in Africa, the Western Pacific and Southeast Asia, similar to the Center established at Nagpur (India). The cost estimate is $3.75 million during the decade for these five institutions.

Concerning the health aspects of water supply, I would like to mention in conclusion the obvious importance of the quality of the water. And to illustrate this, let me quote a story on the Ganges water. The river Ganges is very dirty. When it corsses the holy city of Benares, the inhabitants throw all their garbage into it, literally everything. And then the sick worshippers bathe in it, because they believe that they will be cured. So there are two miracles in Benares: one, is that the people do not get sicker, and the other is that some skin diseases are actually cured. People go away and thank Buddha or Rhama. But the Indian Government has started to investigate the matter and to analyze the water. It was found that bacteria, after they have passed, in the stream, the city of Benares, have been effectively killed. A study will be initiated to investigate the presence of radioactive particles, the chemical contents, the biological process and the operation of this eco-system. This report promises to be very interesting.

B. *Water Resources*

The programs related to water resources consist mainly in establishing a rational relationship between the existing and potential water available and the requirements of present and future utilization.

1. *Water Systems*

The central idea of water systems is to link the rivers of a country, so that one river can transfer water to another, and thereby create a "Water Grid" similar to the "electric grids". For example, in India, the rivers located in the North provide too much water, while the South is a very dry desert. Seasonal changes also increase the imbalances. As some rivers are inadequate to irrigate the lands in their areas, the remedy is to link rivers together by appropriate canals and pumps for the double purpose of water supply and navigation. This will be the largest water system in the World as it will cover the whole Indian sub-continent. It will cost $4 billion and will take 10 to 15 years to achieve. Similar projects are planned in USSR to divert northern water towards the south, in the United States where the Mississippi would feed Texas, and on a smaller scale in Israel.

2. *Underground Water*

The exploration of underground water involves opportunities for large-scale development of now arid or semi-arid lands in developing countries. Research has started with the "International Hydrological Decade" (1965–1974) which might be extended, in the framework of the Second United Nations Development Decade, to 1980. The construction of underground dams is envisaged. It has been estimated that the amount of water stored annually, half a mile below the surface of the earth, is equivalent to 130 years of annual flow of all the rivers of the World.

3. *River Basin Development*

The development of river basins is a multi-purpose enterprise which includes flood control, irrigation, electric power, navigation, recreation, and water supply for agriculture, industry and households. It has, most often, international aspects, as many basin-countries have become independent – for example those of the Mekong Basin. The United Nations can usefully participate in the economic, social and engineering planning of these vast projects. In 1969 in New York, a United Nations panel of experts has recommended that basin States train their nationals for research, planning and operation of river basins.

4. *Desalination*

The desalinization of water will also be a very important topic in the 1970's, as many developing countries have arid territories located near the sea. Intensive research should be pursued on the methods for desalinizing water such as distillation of sea or brackish waters, freezing and electrodyalisis. Research should also apply to nuclear desalinization and to the plants run by geothermal energy with a view to reducing the operating costs, as the dual-purpose generators produce electric power as well as water.

Several desalinating plants are already operating, such as in Kuwait (150.000 cubic meter per day); in Malta (45.000 cubic meter per day); in Tijuana, Mexico (28.000 cubic meter per day). A demonstration plant is operating in Mashabei Sade (Israel), using the electrodyalisis method.

The World Plan recommends that 20 demonstration pilot plants be created during the Second Decade: 10 in Asia, 7 in Latin America and 3 in Africa, for a total cost of approximately $40 million.

5. *Prevention of Water Losses*

The Plan advocates research on the prevention of water losses in agricultural and industrial utilization. In agriculture, studies should apply to water saving techniques to suit the soil, slopes and crops requirements. Industrial wastages, pollution and effluents discharges should also be the subject of research, including the re-utilization of water, the treatment plants and the dilution of effluents. An estimate of $18 million has been proposed for research purposes.

The Plan also recomments research on rain-making. It calls for the identification of 20 basins where experiments could be conducted in the field of rain modification and hydrological evaluation.

The United Nations could contribute to stimulate education and training by creating four centers in 1971–1980 similar to the Kuwait/UNDP Training and Development Center, for the purpose of evaluating projects, testing equipments and materials, training personnel, develop desalinization and irrigation techniques.

The Plan recommends the establishment of national, regional and interregional documentation centers to study, store, classify, retrieve and disseminate data concerning water. It has been estimated that the water resources documents will grow from 15,000 to 30,000 papers per year. The documentation center should be computerized, and a "World Thesaurus" should contribute to the codification of these documents.

It is considered advisable that a central authority for water be created in each country. This National Committee, or Council, could co-ordinate the action of various ministries concerned with electric power, agriculture, industry, navigation, health, etc. Its functions would include the inventory of water resources available, its existing utilization, an evaluation of future needs, economic and technical studies, the preparation of specific projects, the pooling of data and finally the elaboration of an overall "National Master Plan for Water Use and Supply", taking into account all the aspects of an integrated planning at the national level.

FINANCING

The financing of the World Plan of Action is to be insured by developed and developing countries directly as well as through the United Nations system. Three targets have been spelled out in the Plan:

1. Developing countries should spend by the end of the Decade one percent of their GNP on science and technology projects (R and D) and related services (STS). As the GNP of developing countries is $500 billion, this target would amount annually to some *$5 billion.* At the moment, developing countries spend around 0.2 to 0.3 percent of their GNP while developed countries spend 2.0 to 3.0 percent on science and technology.

2. Developed countries should allocate .05 percent of their GNP ($2,500 billion) to scientific and technical assistance for the benefit of developing countries. This target would amount to approximately *$1.25 billion.* It represents 5 percent of the total aid target of the Second United Nations Development Decade (one percent of the GNP).

3. Developed countries spend at present $60 billion on R and D, broken down into civilian ($45 billion) and military ($15 billion) purposes. The third target of the World Plan recommends that developed countries re-orient 5 percent of their non-military R and D expenditures and apply them to problems of specific interest to developing countries. This would amount to about *$2.25 billion.* This target is a re-orientation of activities inside the laboratories and does not imply transfers of funds.

The total of the three targets, i.e. $8.5 billion, represents the yearly financing of the Plan. It represents about one-third of the financing of the Strategy of the Second United Nations Development Decade ($25 billion).

This amount can be compared with the international flow of capital and grants from developing to developed countries, which was, in 1968, $12.5 billion. The United Nations had contributed up to $0.86 billion (including UNDP: $0.155 billion and IBRD: $0.634 billion). Since than, the participation of the United Nations system has substantially increased as the World Bank approved, in 1971, $3 billion in loans, thus implementing the promise of its president, Robert McNamara, to double the lending of the bank over the 1964–1968 level.

But there is a return flow from developing to developed countries (for payment of earlier loans, repatriation of foreign-owned capital and of profits and investments of developed in developing countries). This return flow was $10 billion in 1968, leaving a remaining amount in developing countries of $2 billion. The net remaining is anticipated to decrease, despite the increased loans, due to the increase of the annual debts of developing countries.

The United Nations contribution (one billion dollars in 1968) appears very significant, despite its small amount, as it represented half of the funds remaining in developing countries.

To put these figures in perspective other comparisons can be made to give a better idea of the magnitude of the sums envisaged to finance the Plan. Each year, $200 billion are spent in armaments in the World including $183 billion by developed countries and $17 billion by developing countries. The projects for the eradication of poverty in the United States – to provide $3,300 for each of the 30 million persons belonging to families whose incomes are below this level – would cost $10 billion. The New York City budget is $10 billion. The American industry spent in 1970 $7 billion in computers and it is anticipated that $30 billion will be spent in 1975.

Apart from the United Nations financial institutions (UNDP, IBRD) the regional development banks might play an important role in financing the World Plan of Action in the Asian, African, Latin American, Caribbean regions, as well as the European Funds for Development, and OECD.

But there is another source of funding which is the subject of many recent debates particularly at Santiago of Chile at the third UNCTAD Conference, and soon at the International Monetary Fund: it is the increase of the allocation of Special Drawing Rights (SDR) to developing countries. At the moment, the quotas of this new reserve-money, alloted to developing countries, are small as compared with those recently released for the benefit of developed countries. Here again, the World Plan of Action would play a useful role as a framework for justifying the allocation of SDR's to developing countries in order to realize programs agreed upon in the Plans.

Private investments should also contribute to the implementation of certain projects. On one hand, private investors require the safety of their capital and a fair return of the profits; on the other hand, governments of developing countries also require the fulfillment of certain conditions for foreign investments: the respect for political independence, opportunities for local employment, use of local resources, and, the provision of education and training for local staff.

IMPLEMENTATION OF THE WORLD PLAN

The Plan will be implemented in three steps:

(a) It stands now as an indicative plan, which outlines general guidelines and recommendations at the world level;

(b) The priorities set forth in the Plan on a global basis have to be reshuffled according to a regional approach; this is why *Regional Plans* are now under preparation with the assistance of the Regional Economic Commissions of Latin America, Africa, Asia and the Far East and also the Middle East;

(c) Then Regional Plans will, in turn, be submitted to Governments which will prepare their *country programs*, taking into account their own national priorities for science and technology, and also, hopefully, the general guidelines delineated in the World and Regional Plans. These programs will be submitted to the United Nations financial institutions such as the United Nations Development Programme (UNDP) and the World Bank (IBRD), for financing the pre-investment studies and, finally, the investments.

In the meantime, the work to be done is mainly one of promotion, public relations, press releases and articles, television, firms, seminars, fellowships, contacts with Governments, etc., to focus attention of decision makers and of the scientific and technological community on the ideas contained in the Plan.

The World Plan of Action has already raised considerable interest in several countries: for instance, Germany (FRG) has gathered 200 persons from Research Institutes and economic planning departments for a study of the Plan during a two-day discussion concerning its possible implementations. In Baden, (Austria) a similar seminar was organized to discuss the financial targets of the Plan. In Washington D.C., on 6 October 1972, a meeting was orgainzed, under the sponsorship of the National Academy of Science for a discussion of the World Plan by 60 representatives of Federal Agencies.

We are not pushing the Plan: we are presenting it to the member States who will have to decide whether to put it on the shelf or try to implement it for the benefit of developing countries.

CONCLUSIONS: THE IMPACT OF THE PLAN

I would like to conclude with a question: What can be the impact of the World Plan of Action? In my opinion, this mipact could be great from several points of view: (a) the scientific community; (b) business; (c) finance; (d) youth; and (e) developing countries.

(a) *The scientific community*

There is some uncertainty nowadays in the scientific community of the industrialized countries. What is the future? Governmental research contracts are being reduced; employment in industry has become more difficult; the need for reconversion has to be faced by many scientists and engineers who were working in nuclear weapons, aerospace industry, biological warfare or in industries where research budgets are being cut, due to a tougher competition. This uncertainty is reflected in the high degree of unemployment of Ph.D's and technologists who are now seeking for jobs, while, in the developing countries, there is, simultaneously, a lack of scientists and engineers and so many problems to solve. What does this situation mean? It means that there is at present an imbalance in the location of the scientific and technological staff in the world: in developed countries, most problems are being solved or have been already more or less solved, and scientists and engineers are in excess; in developing countries, where many problems are to be solved, there are very few engineers and scientists. It is quite understandable that some Ph.D's are unemployed here as they are often not located in the most appropriate place, and do not occupy themselves with the most critical problems of our times. They sometimes have to sell their talents reluctantly to the armaments laboratories or to the development of some trivial gadgets imagined to please sophisticated leisure-oriented countries, while leprosy waits for a research breakthrough. I believe that the challenge of this century is to solve the problems of developing countries, and that the present imbalance of world's staff has to be corrected. This is the purpose of the Plan. To fulfill this objective, the scientific community should become aware of these opportunities, and developing countries should create an appropriate local environment so that working conditions for scientists and engineers become attractive in the labs of these remote countries.

(b) *Business*

(i) Developing countries should be considered, from the point of view of businessmen, as one of the most important markets due to their increasing population (now 2.4 billion, growing at twice the rate of developed countries and reaching 4.7 billion in the year 2000) which will be three times the population of the developed countries. There is little purchasing power in these countries, this is true. There are uncertainties on the political side, this is also true. But when Ford and I began to design and erect his motor car in his barn, there were no cars in the United States, which could be considered at this time in many respects as a developing country. Nevertheless Ford, in an intuition full of genius, believed that the United States would become a market for his car, although not a single motor car was sold at that moment, because it did not exist and most people were poor. Now this market has somewhat grown. This might be also the case for developing countries where people at the moment do not have the purchasing power to buy many products from developed countries.

(c) *Finance*

In view of the depression which affects so many markets, in Europe as well as in the United States, it would seem logical that developed countries turn themselves towards the markets of developing countries. But they are inhibited from doing so because of the lack of purchasing power. There is a need, therefore, for a strengthening of the financial structures of the developing countries, so that the potential demand is adequately supported. The needs of developing countries are of a great magnitude, but the financial means to fulfill them have still to be found. What the United Nations is doing at present is only one of the streams to the sea. The continuous flow of finance has to come from private investments, business, banks and governments, Ways and means have to be found for raising the purchasing power of developing countries and transform their needs into a market.

In addition, the cost of technology is increasing: computers, education by television or by satellites, agro-industrial complexes, nuclear reactors, etc., could be of great assistance to development but the financial implications have still to be met. Another alternative is to implement an "intermediate" technology: "the appropriate technology", labor-intensive and capital saving – which would be less expensive and more adapted to the specific needs of these countries; this is now often called the "Chinese solution", which might contribute to reduce the cost of technological development.

(d) *Youth*

Youth needs a high goal, and also jobs. Youth wants to be utilized for something valuable and meaningful. In our generation, there have been a few valid goals, such as the liberation from Nazism, the fight for freedom, the advances in science and technology to liberate man from toils. The previous generation, in the United States had also a faith in success, in the achievement of an individual, through the capitalistic competition. But this is now called "the establishment" and these faiths are more or less fading away. But youth still needs its goal! I do not believe that in developed countries this goal exists, at the moment, because of the problems due to leisure, prosperity and the growing unemployment. Consequently, youth has less hope, and this is reflected in the Universities, in the Hippies movement and in the various troubles which are very apparent in developed countries, around the World.

I think that youth could find its "raison de vivre" in the creation of a good standard of living in developing countries, on the grounds of justice. This could be the great goal for youth for the end of this century, and it could also provide career opportunities and jobs, in developing as well as in developed countries.

(e) *Developing countries*

Now let us come back to the developing countries, the poor, the proletarian countries. Marx had a right analysis when he forecast that a high discrepancy in the standards of living was the seed for conflicts and violence – the class struggle – in the national framework. This vision of Marx has now become applicable to the World: There are proletarian countries and there are wealthy countries; and if something is not done there will be struggles. The problems of the end of this century will be generated, not only by pollution problems, as it is fashionable to say now, but by development problems. People of the world are now put suddenly face to face, by planes, by cars, by railroads; and the poor discover how far they are from the standards of living of the rich countries. The World Plan of Action does not propose so much to developing countries, in the way of assistance or gifts in the traditional sense. Its originality is to propose to the developing countries that they build up their own strength, their own science, their own education and institutions, their own staff of scientists and engineers, their own problem-solvers, their own decision-makers or resources-finders. This is a "Do-it-yourself" Plan. This is why it should be acceptable to developing countries, because it is a matter of pride. What is called for, in this exercise, is really a "Marshall Plan for the Third World", this time not by the United States alone, but on an international basis.

When one considers the depression which now exists, in so many cases, in developed countries – where unemployment and over-production are present nearly in every industrial nation – this plan could also be called "The New Deal for Development". This new deal would prepare the new structures required in science, business, finance and youth careers, and would take into account the needs of the new emerging countries.

APPLICATION OF THE PRODUCTION FUNCTION IN WATER MANAGEMENT

by

Prof. I. Degen
Undersecretary of State,
President, National Water Authority
Budapest, Hungary

The growing importance of economics in water management is a necessary consequence of evolution. The expansion of water management, the realization of projects, as well as the related production processes call for growing outlays in material, technical equipment and labour. The social desirability and most effective use thereof cannot be decided upon, unless a scientifically founded economic analysis is made. As in other branches of economic life, the national organization of technicoeconomic operations; the determination of the optimal ratio of objectives (desired results) and activities (means of achieving results) by the rational and economical use of the material resources and labour available assumes growing importance in water management as well. For promoting the practical realization of these requirements, an important domain of economic analysis, namely the relations between the volume of output and the factors affecting production (equipment, materials, labour, etc.), the methods of analysing the optimum application ratios of the factors of production and the application of these methods in water management will be considered here. Examples will be quoted to illustrate the uses of the cost function which can be examined by the methods of analysis used in connection with the production function.

1. *The analysis of production by functions expressing economic relations*

The productive and service functions in water management call for large volumes of live and mechanized labour (economic resources), as well as for water supplies (natural resources) of the required volume and quality. Both the resources of society and the natural water supplies are limited in magnitude. Owing to the continuing diminution of available water supplies, in some areas to the exhaustion of local water resources, to the pollution of waters and to the growing value of properties exposed to water damages, increasingly greater efforts are needed for meeting the demands for, and averting the potential damages by water.

In view of the great number of mutually interrelated natural and economic factors, such as water regime, water supplies, water demands, use of capacities, etc., many of which are subject to random variations, the determination of outlays resulting in the highest benefits presents a highly complex problem.

The choice of the optimal method of using productive facilities at a given outlay involves the maximization of objective, or for attaining a given level of objective, the minimization of the facilities, consequently the solution of extreme-value problems. From the economic point of view, the problem is to select from among a number of different, realistic, feasible potential alternatives the most effective one, i.e., the one which represents the optimal alternative in relation to the economic and natural resources to be used and to the objective to be attained.

The mathematical tool most widely used for preparing effective economic decisions and for justifying economic objectives is optimal programming. This consists essentially of describing the objective envisaged with the help of functional relations expressed in terms of quantities. The same procedure is adopted in the case of the conditions affecting the processes needed for attaining a particular objective. The set of expressions thus obtained forms the mathematical model representing a conditional extreme value problem, the solution of which provides orientation in formulating an economically optimum decision.

One method of formulating economic processes and decision problems by mathematical models leads to models of the production function type, while the approach to their solution involves marginal analysis (marginal programming in which differential calculus is applied for solving economic optimum problems).

In the case of marginal analysis partial derivation, familiar in mathematics, is applied to economic processes. If the dependent variable is the function of several independent variables and we are interested in finding the manner in which it changes with the variation of a single independent variable, then this particular independent variable is changed by an infinitely small amount and the resulting change in the dependent variable is determined. When applied to production, the volume thereof is the dependent variable, while the factors of production are the independent variables. The use of partial derivation in the domain of production presumes that the factors of production can be substituted for each other, although to a limited extent.

Marginal analysis applied to production has resulted in the marginal productivity theory. The marginal productivity of any one factor of production is measured in terms of the volume of product resulting from increasing that particular factor of production by one unit, assuming that the other factors remain unchanged.

Differential calculus as a method of marginal analysis can be used in many fields of economic life for the analysis and justification of economic decisions. The most commonly encountered functional relations in economics to which marginal analysis, differential calculus is applied are as follows:

1. The production function $Y = f_1\ (X)$ represents the relation between the factors of production (machines, raw materials, etc.) and the volume of commodity (Y), which can denote for instance the volume of earthwork, or of water produced.

2. The cost function $C = f_2\ (Y)$ represents all costs related to the level Y of production.

3. The demand function $P = f_3\ (Y)$ represents the relation between the volume Y of commodity produced and offered on the market, and the unit price P which can be realized. It indicates the demand of the consumers at different price levels of the commodity.

4. The income function $PY = Yf_3\ (Y)$ representing the total income when Y units are sold at the unit price P.

5. The profit function $N = PY - C = Yf_3(Y) - f_2(Y)$ indicates the profit attainable when the volume Y of the commodity produced at the cost C is sold at the unit price P.

The derivatives representing production and considered in marginal analysis are according to the terminology introduced as follows:

$\frac{dY}{dX}$ marginal product, or marginal productivity,

$\frac{dC}{dX}$ marginal cost

$\frac{dP}{dY}$ marginal demand

$\frac{d(P,Y)}{dY}$ marginal income,

$\frac{dN}{dY}$ marginal profit.

The discussion of the production and cost functions is justified primarily by the fact that the majority of decisions in water management is concerned with the organization of production, the determination of costs and the allocation of costs and expenditures among the uses of different character, to further the determination of the volume of water production and the ratio of uses for the different production opportunities. Problems of this type arise in the economic analyses of water management at enterprise and sectorial level, and in analyses and decisions at the level of the national economy. In the solution of such problems the production function, marginal analysis and the method of differential calculus proved useful tools.

2. *The production function*

In the analysis of production one of the most frequently applied economic relations, the production function, represents – as mentioned before – the relationship between the factors of production and the volume or value of commodities. The relations involved indicate the magnitude of diverse types of outlays (transportation, power, material, wages, etc.) to be devoted to the production of different volumes of commodities (values of production). In orgainzing production, in making decisions concerning the volume of production and in determining the magnitude of outlays to be used, it is advisable to know how the volume of production depends on the magnitude of outlays. It is of especial interest to obtain information on the increase of production resulting from increasing the quantity of a particular factor of production. Using general notations the production function is written formally as the functional relation

$$Y = f(X_1, X_2, X_i, X_n) \qquad /1/$$

where Y denotes the value of product and X_i the factors of increase, or of production.

Econometric analysis may be performed at diverse levels of aggregation. Accordingly production functions at enterprise, sectorial and national economy level can be distinguished. The functions at enterprise level represent technical relations governed largely by technology, whereas those at the level of national economy reflect general relations and conditions, which appear as trends rather than definite relations.

The production function is an expression of empirical relationships formulated on the basis of statistical data for the interrelations between production and the factors of production (labour, raw materials, machine work, transportation, etc.) which can be expended for the output Y of commodity. The optimization computations have already been performed beforehand by taking various technological processes into consideration that are potentially applicable in the production process. In other words the maximum output Y of commodity which can be attained at a particular combination of outlays has already been determined.

In the production function the output is usually expressed in terms of value, the labour expenditure in man hours, man days or in terms of the magnitude of the labour force, and the outlays either in natural units of measure, or as value.

Investigations performed into the productive processes with the help of the production function (1) have revealed that if one of the factors of production is increased in magnitude while the magnitude of the other factors remains unchanged, the production characteristics* (marginal productivity, average productivity, marginal elasticity) which can be derived from the production function vary as indicated in table 1 and figure 1. As will be perceived from the figure the output increases first progressively then at a decreasing rate as the factor of production is increased. However, once a maximum value of output is attained, any increase of the factor of production beyond this point will entail a decrease in the output. A similar examination of the other characteristics will reveal that the peak of average productivity is attained earlier. Marginal productivity displays a local extreme value, a maximum, or minimum at the points of inflection of the production function. Marginal elasticity diminishes at different rates as the factor of production is increased, and assumes the value of unity at the maximum of average productivity and becomes zero at the maximum value of output. The typical ranges of production corresponding to different values of the factor of production can be identified on the basis of the extreme values of the curves indicated. The characteristics thereof are shown in table 1.

The production characteristics can be used to determine the technical optimum of production from the point of view of the factor of production considered.

---

*The *marginal productivity* (or marginal product) of a particular factor of production, at a given combination of factors of production, is understood as the increment output which can be attained by a unit increase of the quantity used of the particular factor of production, while the other factors of production remain unchanged in magnitude ($\partial Y/\partial X$).

Average productivity is the output attained by a unit used of the factor of production (Y/X_i).

The *marginal elasticity* of the production function Y with respect to the factor of production X is defined as the percentage increase in output resulting from increasing the factor of production X by 1 percent

For additional details c.f. /2/.

$$\frac{\varepsilon}{X} = \frac{dY}{Y} : \frac{dX}{X}$$

Table 1.—*Variations in the characteristics derived from the production function*

	Range according to figure 1				
	1	2	3	4	5
Output /Y/	Rises Progressively	Rises Degressively	Rises Degressively	Falls Progressively	Falls Degressively
Marginal Productivity $/\partial Y/X_1/$	Rises Positive	Falls Positive	Falls Positive	Falls Negative	Rises Negative
Average Productivity $/Y/X_1/$	Rises	Rises	Falls	Falls	Falls
Marginal Elasticity $/\varepsilon_y, X_1/$	$\varepsilon > 1$	$\varepsilon > 1$ Falls	$1 > \varepsilon > 0$ Falls	$\varepsilon < 0$ Falls	$\varepsilon < 0$

For determining the technical optimum the change in average productivity resulting from a change in the factor of production, expressed in natural units, in examined. The technical optimum is situated at the boundary of the ranges 2 and 3 shown in figure 1, where the average productivity of the factor of production is highest. Besides the maximum of average productivity, the technical optimum is characterized also by the fact that here marginal productivity equals the average productivity, being higher and lower before and after this point, respectively. At the point of technical optimum the marginal elasticity equals unity, being higher and lower than unity before and after this point, respectively.

To operate rationally, an enterprise is logically restricted in choice to outlay magnitudes belonging to ranges 1, 2 and 3. As soon as the boundary of range 3 is reached, any further increase in the magnitude of the factor of production will decrease the output volume and is thus necessarily adverse in effect. The choice between the expenditure (input) volumes in ranges 1 to 3 will be governed by the cost of the outlay.

If the utilization of the factor of production and its average productivity are measured in physical units, then – as mentioned already – the use of the factor of production will attain technical optimum at the maximum value of the average productivity.

Such data are, however, alone insufficient to arrive at an economically optimal choice, since they contain no information whatsoever on prices. In other words, those responsible for decision making have no information on the economic value, expressed in monetary terms, of the individual outlays nor on the financial benefits accruing therefrom.

In studies on the *economic optimum,* besides the factors of production and products (commodities) measured in terms of physical units, the prices thereof must be taken into consideration. The use (combination) of the factors of production will be economically optimal if the highest output can be attained at a given price or conversely if a given output can be attained at minimal cost. Whichever criterion is adopted for the economic optimum of the production function, it is unavoidable to write the function representing the cost of inputs

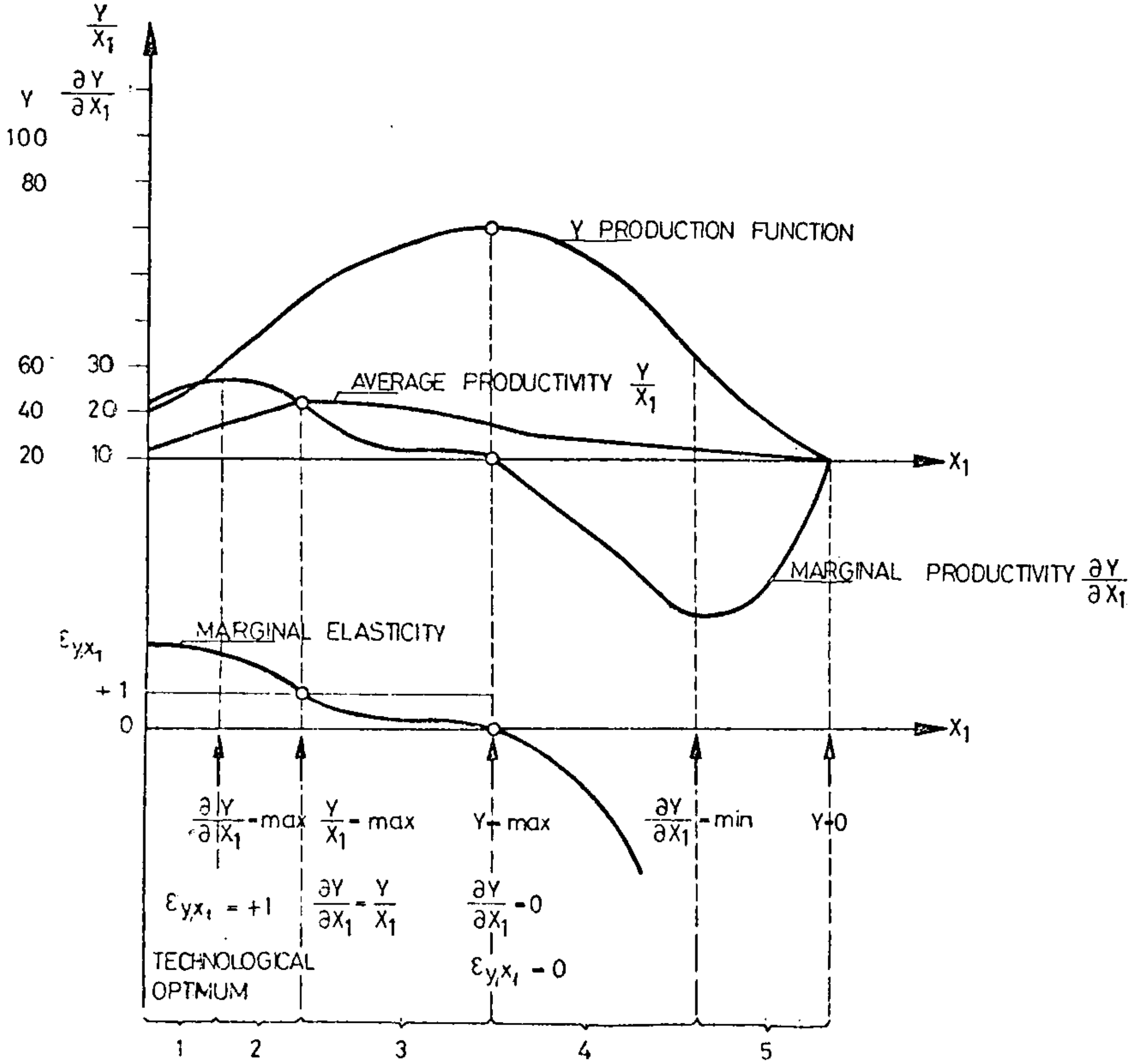

Figure 1.—Variations in the production characteristics and the technological optimum.

$$C = P_1X_1 + P_2X_2 + \ldots + P_nX_n \qquad /2/$$

where

C is the total cost,

$P_1, P_2, \ldots, P_n$ is the price of the factors of production, and

$X_1, X_2, \ldots, X_n$ are the factors of production.

For example, the water production function of a water works be

$$Y_{sz} = f(X_1, X_2, \ldots, X_n) \qquad /3/$$

where X_i denotes the magnitude of diverse inputs and Y_{sz} is the water volume (demand) to be produced annually. It is the interest of the water works to produce this volume of water at the lowest possible cost. This means that the cost C of inputs used for obtaining the output Y_{sz} is to be minimized (the cost is expressed by Eq. 2).

The economic optimum is given by the minimum value of function (2). Applying the Lagrangian function* to Eqs. /2/ and (3), the problem is to determine the extreme value of the function

$$L_c = P_1X_1 + P_2X_2 + \dots + P_nX_n + \lambda f(X_1, X_2, \dots, X_n) - Y_{sz} \qquad /4/$$

Setting the partial derivatives of the function equal to zero, the minima are obtained

$$\frac{\partial L_c}{\partial X_1} = P_1 + \lambda \frac{\partial f(X_1, X_2, \dots, X_n)}{\partial X_1} = 0$$

$$\frac{\partial L_c}{\partial X_2} = P_2 + \lambda \frac{\partial f(X_1, X_2, \dots, X_n)}{\partial X_2} = 0$$

$$\dots\dots\dots\dots\dots\dots \qquad /5/$$

$$\frac{\partial L_c}{\partial X_n} = P_n + \lambda \frac{\partial f(X_1, X_2, \dots, X_n)}{\partial X_n} = 0$$

$$\frac{\partial L_c}{\partial \lambda} = f(X_1, X_2, \dots, X_n) - Y_{sz} = 0$$

In the case of two variables the first two partial differential equations assume the form

$$P_1 = -\lambda \frac{\partial f(X_1, X_2, \dots, X_n)}{\partial X_1}$$

and /6/

$$P_2 = -\lambda \frac{\partial f(X_1, X_2, \dots, X_n)}{\partial X_2}$$

---

*With general notations the form of the auxiliary function knows as the Lagrangian function is

$$L/X_1, X_2, \dots, X_n; \lambda_1, \lambda_2, \dots, \lambda_m/ = f/X_1, X_2, \dots, X_n/ + \sum_{r=1}^{m} \lambda r \, [\phi_r / X_1, X_2, \dots, X_n/ - C_r]$$

where the number of condition equations ranges from 1 to m. The Lagrangian function is a function of the variables $X_1, X_2, \dots, X_n$ and the multiplyers λ.

The first term is identical with the function of which the extreme value is to be determined, while the second term represents the sum of the differences between the two sides (ϕ_r and C_r) of the balance equations of the restrictive conditions, weighted according to the multipliers $\lambda_1, \lambda_2, \dots, \lambda_m$ which are undertermined for the time being.

The solution of the function is obtained by differentiation with respect to the variables and multipliers. For additional details c.f. /2/.

whence the λ terms are eliminated to obtain the expression

$$\frac{P_1}{P_2} = \frac{\dfrac{\partial f(X_1, X_2, \ldots, X_n)}{\partial X_1}}{\dfrac{\partial f(X_1, X_2, \ldots, X_n)}{\partial X_2}} \qquad /7/$$

In view of the fact that $\dfrac{\partial f(X_1, X_2, \ldots, X_n)}{\partial X_1}$

is the marginal output of X_1, while

$\dfrac{\partial f(X_1, X_2, \ldots, X_n)}{\partial X_2}$ is that of X_2, on the basis of Eq. /7/ the condition of an economic optimum is that the ratio of the price of the factors of production be equal to the ratio of their marginal outputs.

In the case of two inputs the economic optimum can be represented graphically as well. For plotting the production function (fig. 2), the inputs X_1 and X_2 are entered on the axes of the system of coordinates. The points representing identical output levels Y_i attainable by different input combinations are then arranged along a single curve, the so-called isoquant curve. The isoquant (indifference) curve is thus the geometrical location of all input combinations resulting in the same output level. At the same time, the equation representing the cost of the two inputs

$$C = P_1X_1 + P_2X_2$$

is plotted as a straight line, referred to as the price line, each point of which cooresponds to input combinations of the same cost. At given prices P_1 and P_2 the input combination pertaining to the point of tangency of the price line and the indifference curve representing the corresponding output level Y_1 will yield the economic optimum. The particular combination of factors of production, at which a given production objective (level of production) can be attained at minimum cost, is indicated by the point of tangency G of the isoquant curve pertaining to a given output and the price, or balance line reflecting the relative.values of these factors.

Comparing the graphical and analytical methods it is found that the ratio of the marginal productivities on the right-hand side of Eq. /7/ is expressed by the indifference curve, while the slope of the price line by the price ratio on the left-hand side. Equality exists at the point of equal slope, i.e., at the point of tangency.

The method of economic optimum analysis described in connection with the production function can be applied readily to the cost function as well. The application of the analytical methods of the production – and cost function to the solution of decision making problems arising in the field of water management will be illustrated subsequently by a few typical examples.

3. *Examples for the application of the production and cost functions in water management*

There are numerous opportunities in water management for applying the production function. Without claim at completeness, a few examples will be presented subsequently.

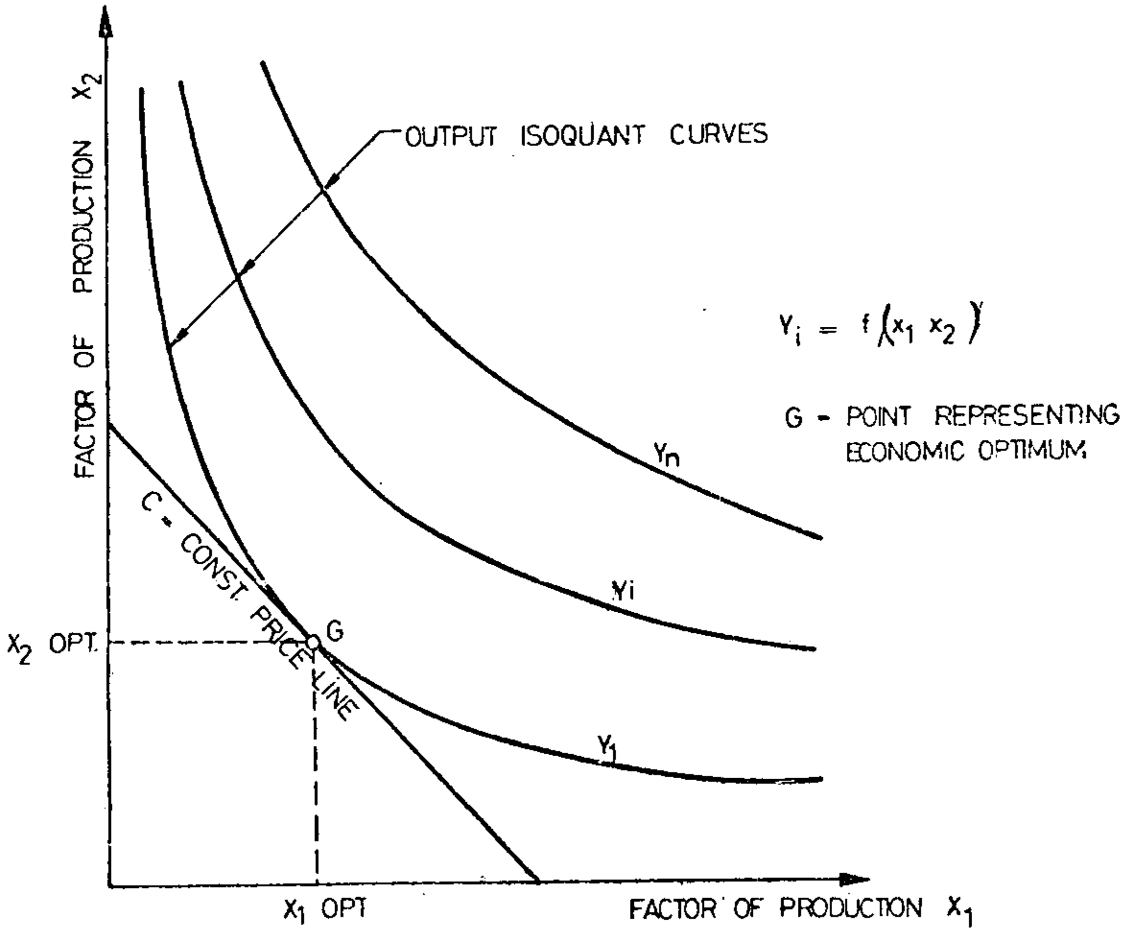

Figure 2.—–Determination of the economically optimal set of factors of production by means of the production function.

3.1 *Determination of the economical diameter of water conveying pipelines*

In dimensioning water conveying facilities the designer is frequently called upon to choose from a number of different alternatives. For finding the optimum solution of the particular problem and for checking the decision making process it is advisable to seek new ways by which the results of the competing solutions can be estimated. The production function appears to be a suitable tool for this purpose as it makes it possible to select the economic combination of the factors of production. A similar application of the production function will be considered subsequently /3/.

Let us for example determine the economical diameter of a water conveying pipeline. The economical diameter will be understood as one through which a given discharge, Q, cu.m/sec, is conveyed at minimum cost. The production factor X_1 is the annual power demand, in kWh units, per one meter run of pipe, while X_2 is the pipe diameter D. The pipe material be steel with a roughness coefficient k = 1.5 mm, the overall efficiency of the motor and pump be η = 0.75. The production functions pertaining to the discharges Q = 0, 5, 0.75, 1.2 and 1.5 cu.m/sec are illustrated in figure 3.

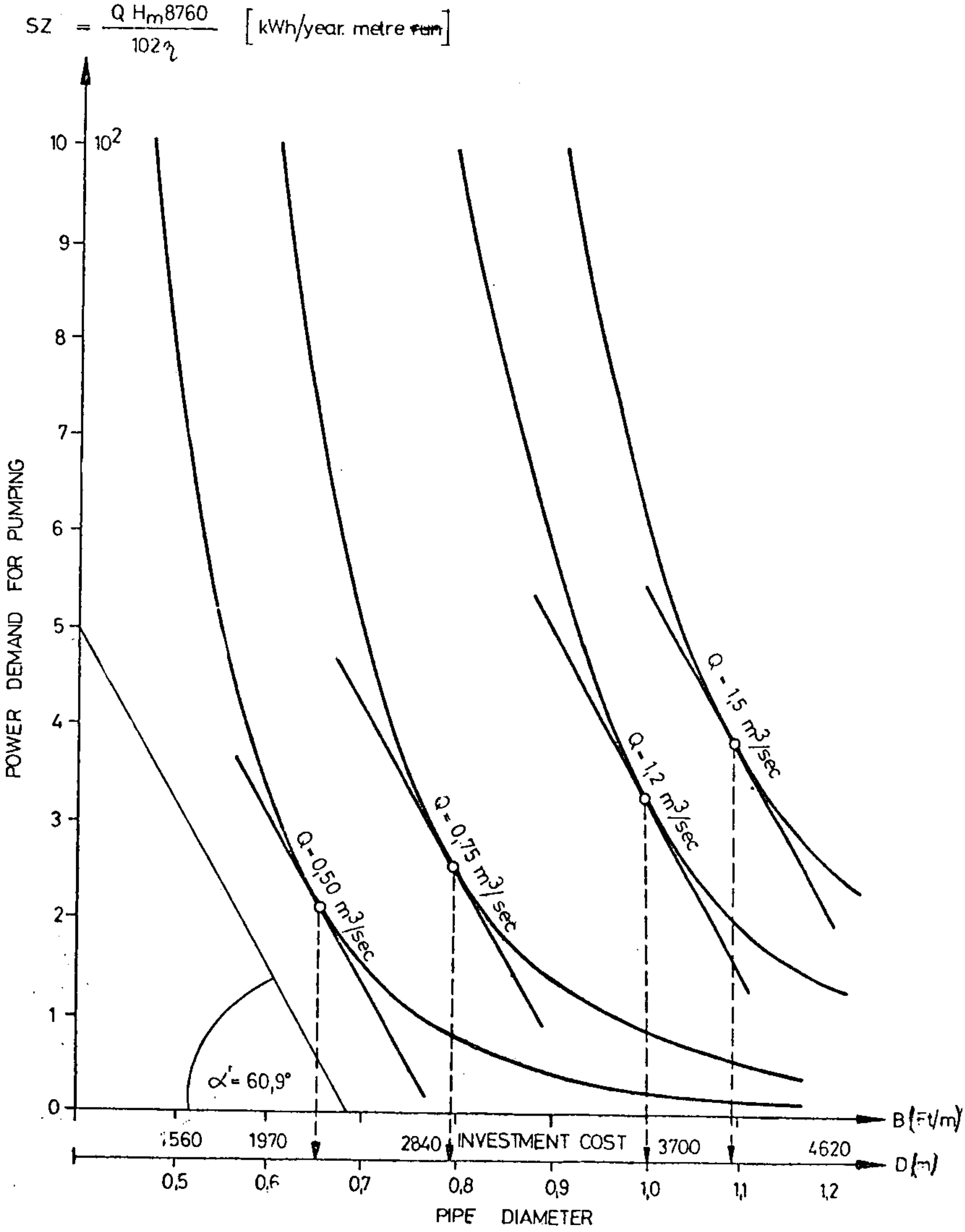

Figure 3.—Production functions pertaining to different water conveyance capacities.

Once these are available, for determining the economical pipe diameter the balance straight line representing the costs, too, must be constructed. The slope thereof will depend on the costs of the factors of production. These costs are composed of two parts, namely the costs of investment, the magnitude of which is a function of the pipe diameter and the operating costs, which include essentially the pumping costs. The total costs of water conveyance per year are made up of the annual investment costs (capital costs) and the annual operating costs.

The cost per year after the investment for the pipeline depends on the service life and the rate of interest considered in the computation:

$$b = B\left(\frac{1}{t} + \frac{P}{2}\right) \qquad /8/$$

where

b is the annual capital cost per metre of pipe,

B is the investment (capital) cost per metre of pipe,

t is the service life,

P is the rate of interest, which can be introduced with half-value in the case of cumulated interest and annual repayment.

The investment cost per metre of pipe (B) can be described under conditions prevailing in Hungary in term of the diameter D by the expression

$$D = 3700\ D^{1.21} \quad \text{(Forint/Metre)} \qquad /9/$$

As annual operating cost the annual of pumping, Sz, is introduced by the expression

$$Sz = \frac{Q\, H_{man}\ 8760}{102\ \eta}\, y \quad \text{(Forint/metre)} \qquad /10/$$

where

Q – the discharge conveyed (litres/sec),

H_{man} – the manometric delivery head (m),

y – the power cost (Forint/kWh),

η – the overall efficiency,

102 – constant for computing the dimension of kWh (1 kW = 1000 joule/sec = 102 mkp/sec),

8760 – constant, the number of hours within a year (365 days).

The pumping cost is used in combination with H_{man}, since the geodetic delivery head does not enter into the determination of the economical pipe diameter. This is because it represents a constant power demand shifting the isoquant in the vertical sense, while leaving its shape unchanged. On the other hand it does not affect the steepness (slope) of the balance straight line, the latter depending only on the price of the factors. Thus, regardless of the geodetic delivery head, constant intercepts are obtained on the axis of abscissae.

For determining the economical pipe diameter according to the graphical method shown in figure 2, remembering the relationship between pipe diameter and investment, it is advisable to plot on the horizontal axis on the basis of Eq. /3/ the investment cost and to find the slope of the price line in this way.

The angle α', or the slope of the price line is found from the expression

$$tg\ \alpha' = \frac{\text{scale of the axis } \chi_2 \bullet \frac{y}{\eta}}{\text{scale of axis } \chi, \text{ (by } B) \bullet (\frac{1}{t} + \frac{P}{2})} \qquad /11/$$

Writing Eq. /11/ on the basis of figure 3 and recalling that

t = 30 years

p = 7 percent

η = 0.75

y = 0.4 Ft/kWh,

the form

$$tg\ \alpha' = \frac{\frac{10\ .\ 10^2}{20}\ \frac{0.4}{0.75}}{\frac{4620\ -\ 1560}{14}\left(\frac{1}{30} + \frac{0.07}{2}\right)} = 1.759$$

is obtained, whence

$$\alpha' = 60,9°$$

Once the angle α' is known, it is possible to construct the straight line of prices. By drawing parallel tangents to the successive output curves, the points of tangency define on the horizontal axis the optimal pipe diameters pertaining to the different discharges. In the present example (fig. 3) the diameters 0.65 m, 0.8 m, 1.0 m and 1.1 m pertain as optimum values to the deliveries Q = 0.5, 0.75, 1.2 and 1.5 cu.m/sec, respectively.

The method described lends itself readily to the determination of the optimal combination of factors involved in other water management processes.

3.2 *Determination of the production value of reclamation*

By applying the production function it is possible to determine the production value of reclamation on the basis of partial marginal elasticities according to outlays serving different purposes (agriculture, drainage, etc.) implemented simultaneously for attaining a particular economic objective /4/.

Assume the production value created in agriculture to depend on outlays undertaken in the two fundamental branches, namely agriculture and water management, i.e.,

$$T = T_V + T_M = K_V + K_M + E \qquad /12/$$

where

T = the production value created in a particular area per year (or any other period of time),
T_V = the production value attributed to water management investments,
T_M = the production value attributed to agricultural investments,
K_V = the annual cost of drainage,
K_M = the annual costs of agricultural production,
E = the annual net benefit accruing.

From Eq. /12/ the annual net benefit is

$$E = T - (K_M + K_V) \qquad /13/$$

It is assumed subsequently that it is possible to allocate E in proportion to the outlays on the basis of the principle of "economic compensation". On the other hand, in order to discard in applying the "economic compensation principle" the principle of equal effectiveness, resorted to in the absence of more precise data, it is necessary to determine on the basis of the areal production function, the partial elasticities of outlays serving different purposes (agriculture, drainage).

The interpretation of the production function describing the cost-benefit relations in drainage-reclamation work is unconventional in that it measures in terms of the output created in a particular area, or of the net income, the effectiveness of such activities in water management. The majority of output in drainage work is known to be utilized in agriculture, but in the absence of direct market relations this is not reflected by the output costs of the beneficiary of such work. In such cases the economic efficiency analysis changes into a system-efficiency analysis, the objective of which is to determine the contribution by a component element of a system to the creation and enhancement of the output or net income from a particular area.

The areal production function is thus written into the following general form:

$$T = f(V, M) \qquad /14/$$

where

V = the aggregate value of equipment and work expended for drainage,
M = the aggregate value of equipment and work expended in agricultural production.

Since a given point of the production function, the present level, is known, the ratio of elasticities can be used in determining the key of allocation, which defines the allocation on the principle of actual efficiency in production. The partial elasticities for the given point of the production function characterized by the coordinates V and M are

$$\&_V = \frac{\frac{\partial T}{\partial V}}{\frac{T}{V}} = \frac{\partial T}{\partial V} \frac{V}{T}$$

and

$$\varepsilon_M = \frac{\frac{\partial T}{\partial M}}{\frac{T}{M}} = \frac{\partial T}{\partial M}\,\frac{M}{T}$$

where

ε_V = the partial elasticity between areal production value and drainage equipment,

ε_M = the partial elasticity between areal production value and agricultural equipment.

The ratio of partial elasticities of unit equipment, which is eventually the characteristic index of economic efficiency, is given by the expression

$$\alpha' = \frac{\varepsilon_V}{\varepsilon_M} = \frac{\frac{\partial T}{\partial V}\,\frac{V}{T}}{\frac{\partial T}{\partial M}\,\frac{M}{T}} = \frac{T'_V V}{T'_M M} \qquad /16/$$

where

α' = the ratio of partial elasticities according to the expressions

$$T'_V = \frac{\partial T}{\partial V} \quad \text{and} \quad T'_M = \frac{\partial T}{\partial M}$$

Since the net income realized in agriculture can be resolved into two components, i.e.,

$$E = E_V + E_M \qquad /17/$$

where

E_V = the net income attainable at the annual cost of drainage

and

E_M = the net income attainable at the annual cost of agriculture

and assuming that the net income is generated through the individual components in the proportion in which these contribute to the material-free output, the ratio of the two net income components satisfies the following conditions:

$$\frac{E_V}{E_M} = \frac{\varepsilon_V}{\varepsilon_M} = \alpha' = \frac{E_V}{E - E_V} \qquad /18/$$

Consequently

$$E_V = \alpha' (E - E_V), \qquad /19/$$

which can be rearranged into the form

$$E_V = \frac{\alpha'}{1 + \alpha'} \qquad /20/$$

The production value of drainage can thus be computed from the expression

$$T_V = K_V + E_V.$$

The application of the foregoing considerations will be illustrated subsequently by a numerical example related to one of the model operations in the Mirho-Gyolcs sub-catchment and based on a paper prepared at the Research Institute for Water Resources Development (VITUKI). The basic criteria characterizing the size of the operation apply to the combined drainage and agricultural activities of production conducted presently at the operation:

$$T = 1635 \text{ Ft/kh (Forints/hilohectare)},$$
$$V = 910 \text{ Ft/kh},$$
$$M = 7030 \text{ Ft/kh},$$
$$E = 445 \text{ Ft/kh}.$$

A feasibility study has been prepared for the development of the operation in which similar amounts are envisaged for increasing the equipment in each of the two branches. If development is implemented in agriculture in a form concentrated in a particular area (the creation of a hog farm is contemplated in the future) then – according to the report – the increase in production is characterized by the following indices:

$$\partial_T = 602 \text{ Ft/kh},$$
$$\partial_M = 3440 \text{ Ft/kh},$$
$$K_M = 2804 \text{ Ft/kh}$$

and thus

$$T'_M = \frac{\partial T}{\partial M} = \frac{602}{3440} = 0.175.$$

If in water management the technological development level of drainage capacity is increased from 20 lit/sec/sq.km to 30 lit/sec/sq.km, then the increase in crop yield due to reduction of damages would be characterized by the following data:

$$T = 41 \text{ Ft/kh},$$
$$V = 447 \text{ Ft/kh},$$
$$K_V = 65 \text{ Ft/kh},$$

and thus

$$T'_V = \frac{\partial T}{\partial V} = \frac{41}{447} = 0.092.$$

With the foregoing data it is possible to find the ratio of production elasticities:

$$\alpha' = \frac{T'_V}{T'_M} \frac{V}{M} = \frac{0.092}{0.175} \frac{910}{7030} = 0.068$$

and in the knowledge of α' the net income accruing from drainage is found from Eq. /20/

$$E_V = \frac{\alpha'}{1 + \alpha'} E = \frac{0.068}{1 + 0.068} 445 = 28.3 \text{ Ft/kh.}$$

Finally the production value of drainage is obtained from Eq. /21/ as

$$T_V = K_V + E_V = S5.1 + 28.3 = 98.5 \text{ Ft/kh.}$$

Summarizing the experiences gained from the foregoing computations it may be established that the computation method of elasticities may offer valuable guidance in the efficiency study of contemplated drainage development and in the economic evaluation at national economy level of existing drainage facilities. This is accomplished in the method by identifying the contribution of drainage to the total production value.

3.3 *Dimensioning reservoirs for economic optimum*

In the course of controlling natural water resources, realized by dimensioning single reservoirs, or storage systems the problem consists essentially of realizing the economically optimal cooperation of two systems, namely the water supply and water using systems. Under this approach the dimensioning of reservoirs presents an optimization problem, the aim of which is to realize the highest possible economic benefit by evaluating the combined economic effect of water supply and water utilization.

In the interest of optimizing the parameters of a system including the consumers and the supplier of water and regarded as a unit, as a first step it is necessary to determine the economic outlays,

$$R = \ddot{U} + aB + V, \qquad /21/$$

arising in connection with discharge regulation, where

$\ddot{U}$ = operating costs without amortization,
a = the amortization coefficient,
B = first, or investment costs,
V = economic losses due to water restrictions in the water management system and at the consumers connected thereto.

The magnitude of the investment and operating costs of the water supply system and of the economic losses resulting from restriction in supply depend substantially on the magnitude of the discharge that can be delivered and on the reliability of supply. Considering, rather than absolute magnitude, the relative magnitude of discharge that can be delivered from a reservoir with respect to the average mean streamflow rate, the magnitude of the economic outlay can be specified in terms of two fundamental parameters:

$$R = f(\beta, P) \qquad /22/$$

where

β = the degree of equalization representing the effect of the reservoir system. This is found from the expression $\beta = \dfrac{Q_t}{K\ddot{O}Q}$, there Q_t is the discharge that can be withdrawn from the reservoir ($0 < \beta \leq 1$),

P = the reliability of supply, represented by the probability at which the water volume desired by the consumers, or required for the most effective operation of their equipment is available.

Considering the cost function $R = f(\beta, P)$, the outlay of the total economy will be minimal, if the condition

$$\frac{\partial R}{\partial P}\, dP + \frac{\partial R}{\partial \beta}\, d\beta = 0 \qquad /23/$$

is satisfied.

In water management practice two methods have found recognition for solving the extreme value problem.

The essentials of the method suggested by Klemens can be summarized as follows [6]:

The analytical form of the function R is usually unknown, so that the optimal storage effect may be found by approximation opt. (β, P), by comparing the costs of several alternatives.

Using the relation $R = f(\beta, P)$ described in the foregoing the costs R_{ij} pertaining to different degrees of equalization $\beta = \beta_1, \beta_2, \ldots, \beta_i, \ldots \beta_n$ and to different reliabilities $P = P_1, P_2, \ldots P_j, \ldots, P_m$ are determined. The results are tabulated in the following form (cost matrix), whence the optimal storage effect

$$\text{opt}\,(\beta, P) = \min R$$

is obtained.

	P_1	$P_2 \ldots\ldots$	$P_j \ldots\ldots\ldots$	P_m
β_1	R_{11}	$R_{12} \ldots\ldots$	$R_{1j} \ldots\ldots$	R_{1m}
β_2	R_{21}	$R_{22} \ldots\ldots$	$R_{2j} \ldots\ldots$	R_{2m}
•	•	•	•	•
β_i	R_{i1}	$R_{i2} \ldots\ldots$	$R_{ij} \ldots\ldots$	R_{im}
•	•	•	•	•
β_n	R_{n1}	$R_{n2} \ldots\ldots$	$R_{nj} \ldots\ldots$	R_{nm}

If it is intended to use a graphical solution, the following approach is used. The costs are resolved into two parts:

—the costs in the watersupply system,

$$R_s = f_s\,(\beta, P)$$

—and the costs at the consumers,

$$R_N = f_N\,(\beta, P)$$

and the total costs are found separately as before. These values are plotted in a (P, β) system of coordinates and the iso-lines $R_{N_{\text{const}}}$ and $R_{s_{\text{const}}}$ are obtained (fig. 4).

The optimal (P, β) values are found with the help of the iso-lines

$$R_{\text{const}} = R_{N_{\text{const}}} + R_{s_{\text{const}}} \qquad /24/$$

under the condition

$$\text{opt}\,(P, \beta) = f\,(R_{\min}).$$

Kalatshev has used a different approach to the problem [7]. In his considerations he reduced the task to finding the optimal realiability pertaining to a particular degree of development. The substance of the method is that the equation

$$R = \ddot{U} + aB + V \qquad /25/$$

is regarded as a function of reliability P and the cost minimum is determined under the condition

$$\frac{\partial R}{\partial P} = \frac{\partial \ddot{U}}{\partial P} + a\,\frac{\partial B}{\partial P} + \frac{\partial V}{\partial P} \qquad /26/$$

For solving this optimization problem a graphical method proved most effective as before.

The optimal reliability, i.e., that pertaining to the minimal cost, is determined in two steps:

1. Considering the relation $\ddot{U} + aB = f\,(P)$ a curve rising with increasing reliability (curve a in fig. 5) is obtained.

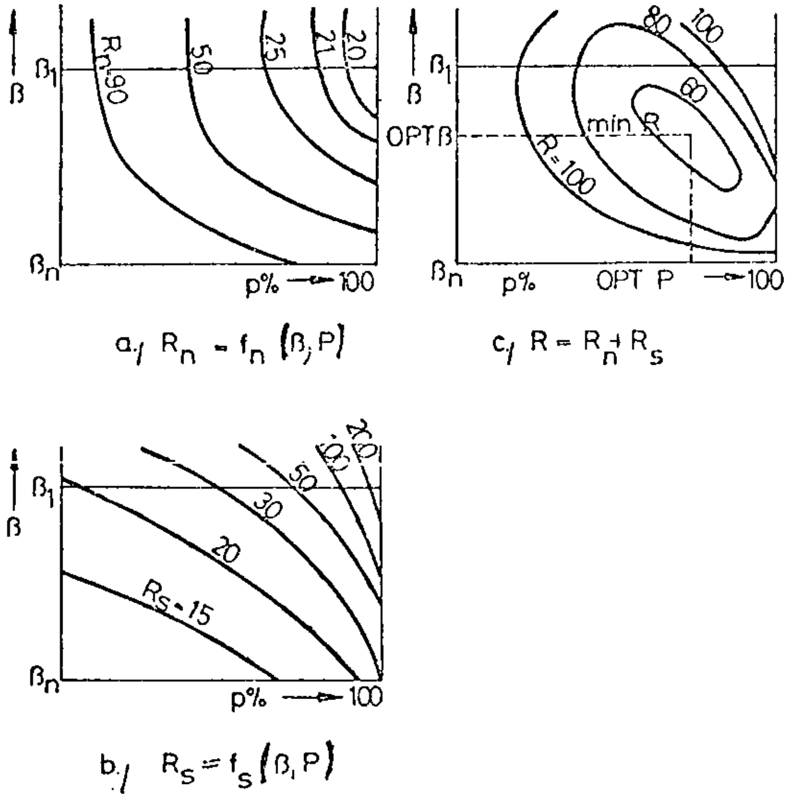

Figure 4.—Graphical analysis of optimal storage capacity in reservoirs and of optimal watersupply reliability.

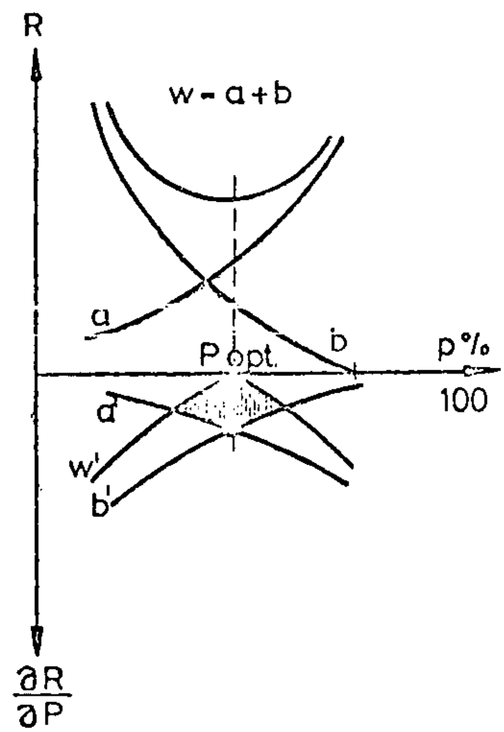

Figure 5.—Graphical analysis of reliability at minimal cost.

2. A curve dropping with increasing reliabilities describes the relation $V = f(P)$ and attains the value $R = O$ at $p = 100$ percent (curve b in fig. 5).

In figure 5 the partial derivatives of the cost components with respect to P have also been entered. The relation

$\frac{\partial \ddot{U}}{\partial P}$ is described by the curve a', while the relation

$\frac{\partial V}{\partial P}$ by curve b'. The minimum total cost pertains to the reliability P, for which the condition

$$\frac{\partial \ddot{U}}{\partial P} + a \frac{\partial B}{\partial P} = \frac{\partial V}{\partial P} \qquad /27/$$

is satisfied (the intersection of curves a' and b'), i.e., at the value of P, where the ordinate of the partial derivative of the cumulative curve $w' = a' + b'$ becomes O.

3.4 *Determination of the optimum capacity of development of a watersupply system*

For delivering water to the consumers in a particular area (for meeting the irrigation, drinking, industrial, etc. demands) a watersupply system is contemplated.

The magnitude of the water demand to be met and thus the design capacity of the watersupply system is, however, not a value fixed in advance, but must be found by economic analysis. In view of the fact that the unsatisfied water demands pertaining to different capacities and the unreliability of supply are sources of economic losses, the aim of the economic analysis is to find the design capacity, which can be realized at the lowest outlay from the national economy, taking the losses into consideration. The solution of the problem is facilitated by applying the production and cost functions.

The annual costs of watersupply systems of different capacity and reliability are controlled on the level of national economy by

- the amortization and operating costs of the watersupply system,
- the amortization and operating costs of the storage and transfer system permitting the reliable diversion of the volume specified for distribution,
- the annual losses incurred owing to demands which remain unsatisfied at the particular capacity and reliability.

The parameters of the water management system, the capacity ($\propto$) of the distribution and storage-transfer system and the reliability P of supply will subsequently be optimized in terms of the cost factors listed before.

The annual cost at the level of the national economy is expressed as

$$R(P, \propto) = aR_1(\propto) + R_2(\propto) + R_3(P, \propto) + a'R_4(P, \propto) + R_5(P, \propto) \qquad /28/$$

where

R_1 = the investment cost of the distribution system,

R_2 = the annual operating cost of the distribution system,

R_3 = the losses accruing annually to the national economy as a consequence of unsatisfied water demands,

R_4 = the investment cost of the storage-transfer system,

R_5 = the annual operating costs of the storage-transfer system,

a = mortization rate after fixed assests of the distribution system,

a' = amortization rate after the fixed assests of the storage-transfer system.

Of the factors of production R_1 and R_2 depend exclusively on capacity, whereas R_3, R_4 and R_5 are functions of capacity and reliability of supply.

The problem consists of finding the minimum of $R\ (P, \propto)$. Several approaches can be suggested to the solution.

3.41 *Continuous model*

In examining the extreme values of the relation /22/ the engineering or economic factors unaffected by optimization can be considered separately and thus the range of interpretation of the variables involved in the problem can be narrowed down. For the reliability level of supply an upper and a lower boundary, P_1 and P_2 respectively, can be specified, since it would be unjustified economically to specify either $P = O$, or $P = 1$ reliability levels. The capacity $\propto$ of the distribution and storage-transfer systems is also confined by engineering possibilities between rationally judged limits.

For the possible values of P the interval $P_1 \leq P \leq P_2$, for those of $\propto$ the interval $A \leq \propto \leq B$ should be specified (fig. 6). In solving the problem allowance must be made for the fact that the desired minimum of function $R\ (P, \propto)$ occurs either on the boundary or in the interior of the range of interpretation. Accordingly the minimum value must be sought at the edges, the corner points and within the range of interpretation. The solution of the problem involves the following steps:

a/ The local extreme values are determined for the $R\ (P_1, \propto)$, $R\ (P_2, \propto)$, $R\ (P, A)$, $R\ (P, B)$ now already single-variable functions (edges) by solving the equations

$$\frac{\partial}{\partial \propto} R\ (P_1, \propto) = O$$

$$\frac{\partial}{\partial \propto} R\ (P_2, \propto) = O$$

$$\frac{\partial}{\partial P} R\ (P, A) = O$$

$$\frac{\partial}{\partial P} R\ (P, B) = O$$

and selecting those of the solutions for which the value of $R\ (P, \propto)$ is lowest.

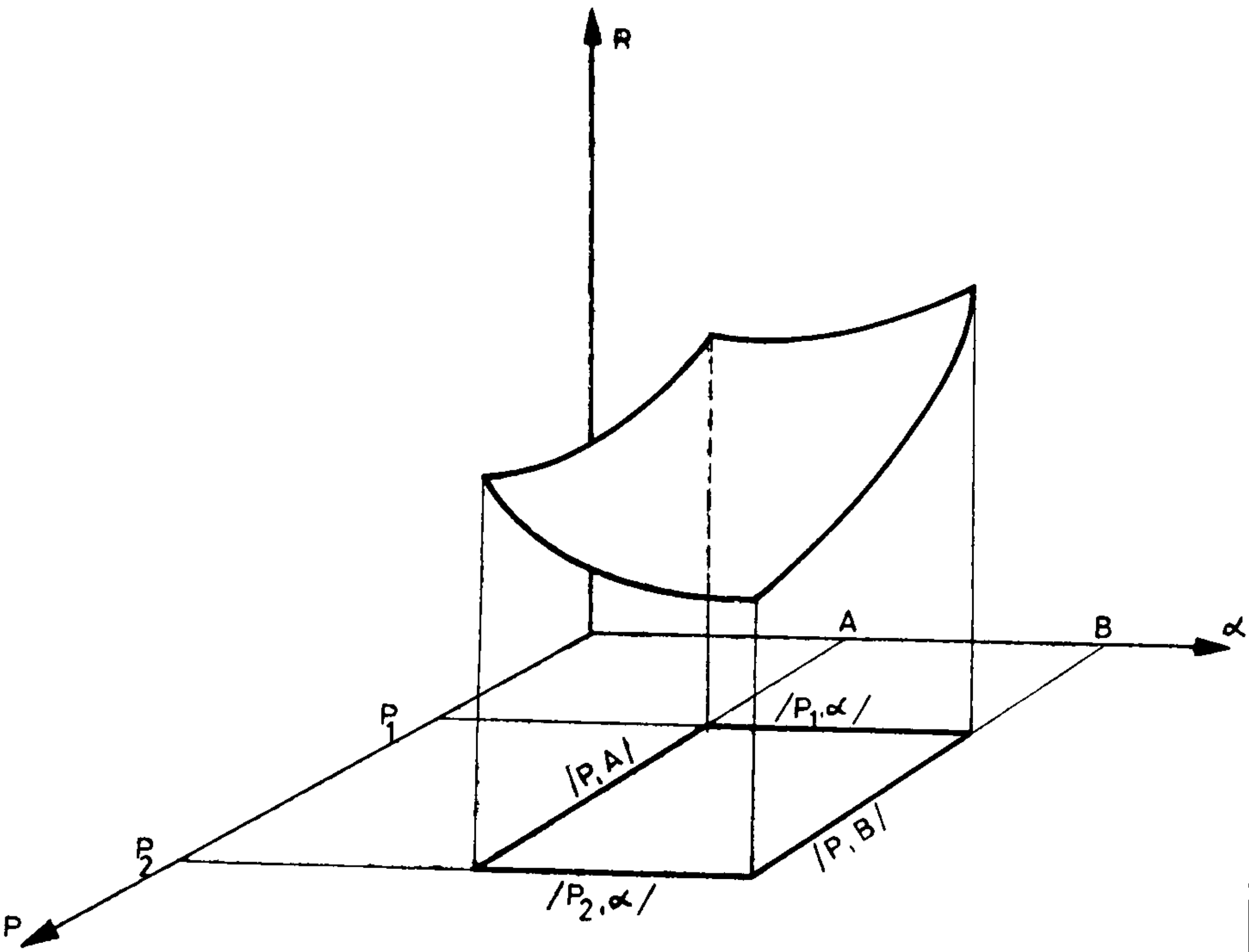

Figure 6.—–Range of interpretation of the cost function $R\ (P, \propto)$

b/ The lowest of the values $R(P_1, A)$, $R\ (P_1, B)$, $R\ (P_2, A)$, $R\ (P_2, B)$ (corner points) is selected.

c/ The local extreme value problem of the function $R\ (P, \propto)$ is solved, i.e., if the function can be differentiated, the set of equations

$$\frac{\partial}{\partial P} R\ (P, \propto) = O$$

$$\frac{\partial}{\partial \propto} R\ (P, \propto) = O \qquad /30/$$

is solved. Those yielding minimum value for $R\ (P, \propto)$ are then selected from among the solutions of the set of equations.

d/ From among the solutions under a/, b/ and c/ select the one for which $R\ (P, \propto)$ is lowest. The parameters pertaining to this value will yield the optimal parameter values.

3.42 *Discrete model*

For the parameter values alternatives are assumed and the optimum is selected from these discrete values.

The alternative values of the parameters α and P should be denoted by $\alpha_1, \alpha_2, \ldots\ldots, \alpha_n$ and $P_1, P_2, \ldots\ldots, P_m$, respectively. In view of the circumstance that five variables have been entered into the present problem (R_1, R_2, R_3, R_4, R_5) let us introduce the following notations: Concerning the distribution system:

$$R_k^i = R_k(\alpha_i) \qquad (k = 1, 2;\ 1 \leqq i \leqq n) \qquad /31/$$

since we have two variables which depend on α. Concerning the storage-transfer system

$$R_k^{i,j} = R_k(P_j, \alpha_i) \qquad (k = 3, 4, 5;\ 1 \leqq i \leqq n;\ 1 \leqq j \leqq m) \qquad /32/$$

since in Eq. /30/ three variables are involved which depend on both P and α.

The functions under consideration will be specified in the following tabular form:

For function /31/:

	α_1	α_2	..... α_n	
R_k	R_k^1	R_k^2	R_k^n	$k = 1, 2$

For function /32/

	α_1	α_2		α_n	
P_1	R_k^{11}	R_k^{21}	......	R_k^{n1}	
P_2	R_k^{12}	R_k^{22}	......	R_k^{n2}	$k = 3, 4, 5$
....	....	....	......	....	
P_m	R_k^{1m}	R_k^{2m}	......	R_k^{nm}	

With the above notations the discrete optimization problem is written into the form

$$R_{opt} = \min_{1 \leqq j \leqq m} \min_{1 \leqq i \leqq n} \left\{ aR_1^i + R_2^i + R_3^{i,j} + a' R_4^{i,j} + R_5^{i,j} \right\} \qquad /33/$$

i.e., the value of $R\ (P_j\ \alpha_i)$ is examined for every potential value of i and, j, in other words all alternatives $1 \leqq i \leqq n$, and $1 \leqq j \leqq m$ are considered and the minimum is selected from among these (from among a finite number of values).

For determining the optimal parameters the algorithm related to the discrete model given in the block diagram in figure 7 can be used.

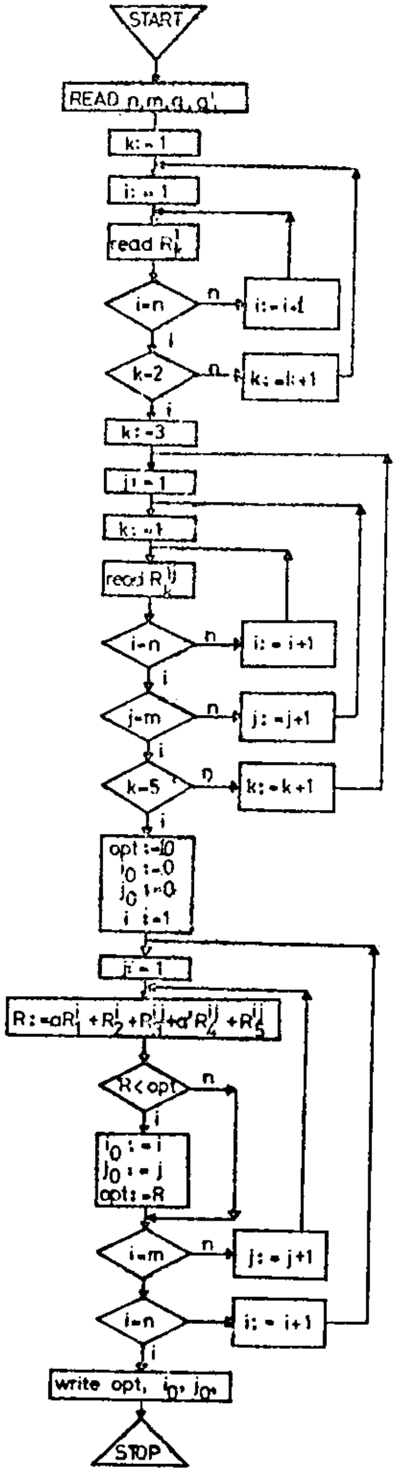

Figure 7.—Block diagram for determining the optimal development capacity of watersupply system.

3.43 *Numerical example*

Consider a distribution system, the size and operation of which are characterized by the following parameters:

Values of α (m^3/sec)	10	20	30	40	50	n = 5
Values of R_1 (mil. Ft)	10	15	19	22	24	m = 6
Values of R_2 (mil. Ft)	1.1	1.6	2.0	2.3	2.5	

Values of R_3:

α \ P	50	60	70	80	90	95
10	1.60	1.55	1.45	1.30	1.10	0.85
20	1.50	1.45	1.30	1.10	.85	.70
30	1.35	1.30	1.10	.85	.70	.50
40	1.10	1.00	.85	.70	.50	.30
50	.65	.60	.50	.35	.20	.05

/The values of P are given in percentages hereafter/Values of R:

α \ P	50	60	70	80	90	95
10	25	26	28	32	36	41
20	30	31	33	37	41	46
30	34	35	37	41	45	50
40	37	38	40	44	48	53
50	39	40	42	46	50	55

Values of R_5:

P	50	60	70	80	90	95
10	0.50	0.52	0.56	0.64	0.72	0.82
20	.60	.62	.66	.74	.82	.92
30	.68	.70	.74	.82	.90	1.00
40	.74	.76	.80	.88	.96	1.06
50	.78	.80	.84	.92	1.00	1.10

Assume further

$$a = 0.05 \qquad \text{and } a' = 0.02$$

A programme for the problem has been written in ICL FORTRAN language for an ODRA 1304 computer. The optimum values were obtained as

$$\alpha = 10 \text{ m}^3/\text{sec}$$
$$P = 95 \text{ /=/}$$

so that in the present example the smallest development size, together with highest reliability will yield the minimum annual outlay for the national economy. The minimum annual outlay is 3.96 million Ft.

CONCLUSIONS

The examples quoted from the domain of water management illustrate well the wide field of potential applications for models of the production function type. The advantages of using them in practical water management activities may also be appreciated. The functional relation of economics to production, the method of marginal analysis, is readily applicable to determining the optimum size of engineering projects, such as the determination of the economically optimum diameter of water conveying pipelines, or the selection of the optimal project parameters (capacity, reliability, extent of runoff control) of water management systems and the overall economic effect of watersupply and utilization systems.

The determination of the economically justified share and size of water management activities coupled with other economic activities, with due allowance to the economic benefits expected, yields in many instances useful information for decision making in water management development issues. Thus, for instance, the production function affords the possibility of determining the economically justified magnitude of outlay for drainage on the basis of the production value of drainage. The contribution of drainage, as one of the outlays of social production, to the total value produced can be determined by partial differentiation and the economic evaluation at the level of national economy of drainage outlays is made possible.

In the decision making problems of water management the application of mathematical-economic models offers several advantages, such as the exact formulation of assumptions serving as the bases of the theoretical models whereby the theories themselves are made more precise and conclusions from the basic assumptions more specific. Moreover it becomes possible to develop relations which can be checked against actual data and which can be interpreted quantitatively. Mathematical economics consequently plays an important role in analytical, forecasting and planning work. Its general introduction makes the guidance of economy more specific both in the determination of objectives and in the realization thereof.

In the course of application it must be borne in mind that several simplifying assumptions had to be introduced in the formulation of the mathematical models. Models of the production function type involve abstractions which are not related to the problem analysed, to the specific form of economy, or to the production relations, but are due to their bourgeois origin.

The primary source of abstractions of general validity is that in determining the empirical production functions the unknown parameters of the dependent and independent variables are estimated from statistical records. As a consequence, owing to the imperfections of statistical surveys the unknown parameters can be determined with a bias only. Moreover, a biased estimate of the unknown parameters results also from the fact that in quantifying the influence of the individual factors of production on the output the necessary condition related to the constancy and independence of the other factors is impossible to realize in the domains of research and practice of economy. The mutual interdependence of the relevant factors implies that there is no possibility for the unbiased identification of the effects of various outlays, which would be required for exact mathematical formulation.

Beyond the estimation of parameters the computation method of the economic optimum involves also certain assumptions. Thus, in determining the optimal input ratio of the factors of production, the mutual substitution and large number of potential combinations of the factors of production is assumed. The ratio of the factors of production (e.g. the fixed assets to the labour force operating them) is fixed technologically.

The ratio between the factors of production represents a specific combination of a particular factor of production and of labour. In this way the product increment consequent upon a change in the ratio of the factors of production is not the result of a change in the quantity of specific work of the same kind, but rather of the changed form of the specific type of work and together therewith of the means of production. The problem presented by this circumstance is less severe in prospective planning, where the funds to be assigned to fixed assets controlling the ratio of potential outlays to these and to the related technology is not yet determined.

The source of abstraction related to the bourgeois origin is the assumption that labour and capital are equivalent and cooperating partners in creating the output. Actually this partnership is not an equivalent one. The effectiveness of the resources of production can be interpreted only as a consequence of, and in relation with, the human labour mobilizing them. The resources of production involved in the production function are thus understood as a measure of the change in the productivity of labour. The change in the productivity of labour is a consequence of advances in technology. These advances are on the one hand quantitative in character, as represented by the technical equipment of labour, on the other hand qualitative, related to the changes in the conditions of production, the growth of technological knowledge and to the improvement of technical organization.

Within the limits of application, models of the production function type are suited to the determination of water management objectives in an exact and tangible manner and to the analysis of the fundamental factors affecting the realization thereof. Such applications are encouraged by examples of the use of the functional relations of economics in water management practice.

REFERENCES

1. Andorka, R.: Mikromodellek/Micro-models, in Hungarian/. Közgazdasági és Jogi Könyvkiadó, Budapest, 1970.
2. Degen, I.: Vizgazdalkodas I. A vizgazdálkodás közgazdasági alapja/Water Management I, The economic foundations of water management, in Hurgarian/. Tankönyvkiadó, Budapest, 1972.
3. Karpe, H.J.: Zur Dokumentation des Entscheidungsprozesses in der Siedlungswasserwirtschaft/ in German/. Gwf. Wasser, Abwasser, Vol. 110, No. 6, 1969.
4. VITUKI: A parcialis elaszticitás módszerének használata az uzemi vizrendezés gazdasági hatékonyságának meghatározására/ The method of partial elasticity for estimating the economic efficiency of farm drainage, in Hungarian/. VITUKI Report, Dept. II, 1970. Manuscript.
5. Lange, O.: Optimális döntések /Optimal decisions, in Hungarian/. Közgazdasági és Jogi Könyvkiadó, Budapest, 1966.
6. Klemens, V.: Pestimmung der wirtschaftlich optimalen Parameter der wasserwirtschaftlichen Anlagen /in German/. Paper subm. Conference on Water Management Planning. Budapest, 1962.
7. Kalatshev, N.S.: Ustanowlen' ie slesobraznyh predelov regulirovania stoka /in Russian/. Probl. gidroenerg. i vodnogo hoziaystva. AN KSSR, Alma Ata.
8. Kaufmann, A.: Methodes et modeles de la recherche operationnelle, Dunod Paris 1962.
9. Douglas, J.: Economics of Water Resources Planning. McGraw-Hill Company New York 1971.
10. de Neufville-Safford: System analysis for engineers and managers McGraw-Hill Company New York 1971.
11. Baumol, W.: Economics Theory and Operation Analyses, 1961, Englewood Cliffs Prentice Hall, London.

THE KARST ARTESIAN WATER SYSTEM OF THE SOUTHEASTERN STATES

By

V.T. Stringfield, PhD. and H.E. LeGrand, B.A.
U.S. Geological Survey, Washington, D.C. and Raleigh, N.C.

INTRODUCTION

The Atlantic and Gulf Coastal Plain of the United States is underlain by an immense hydrologic system that has more immediate potential for development of ground-water resources than any other province of comparable size in the Western Hemisphere. The Coastal Plain forms a broad belt that extends from Long Island southward along the Atlantic Coast and westward along the Gulf Coast to the Rio Grande.

Discussion in this paper is restricted to that part of the Coastal Plain in the southeastern States where carbonate rocks represent a special part of the overall artesian system (see fig. 1). The carbonate rocks have been altered by circulating water and solution of the rock to form cavernous openings. The German term "karst", of Slavic origin, is now applied almost universally to carbonate rocks that have been modified by removal of minerals in solution.

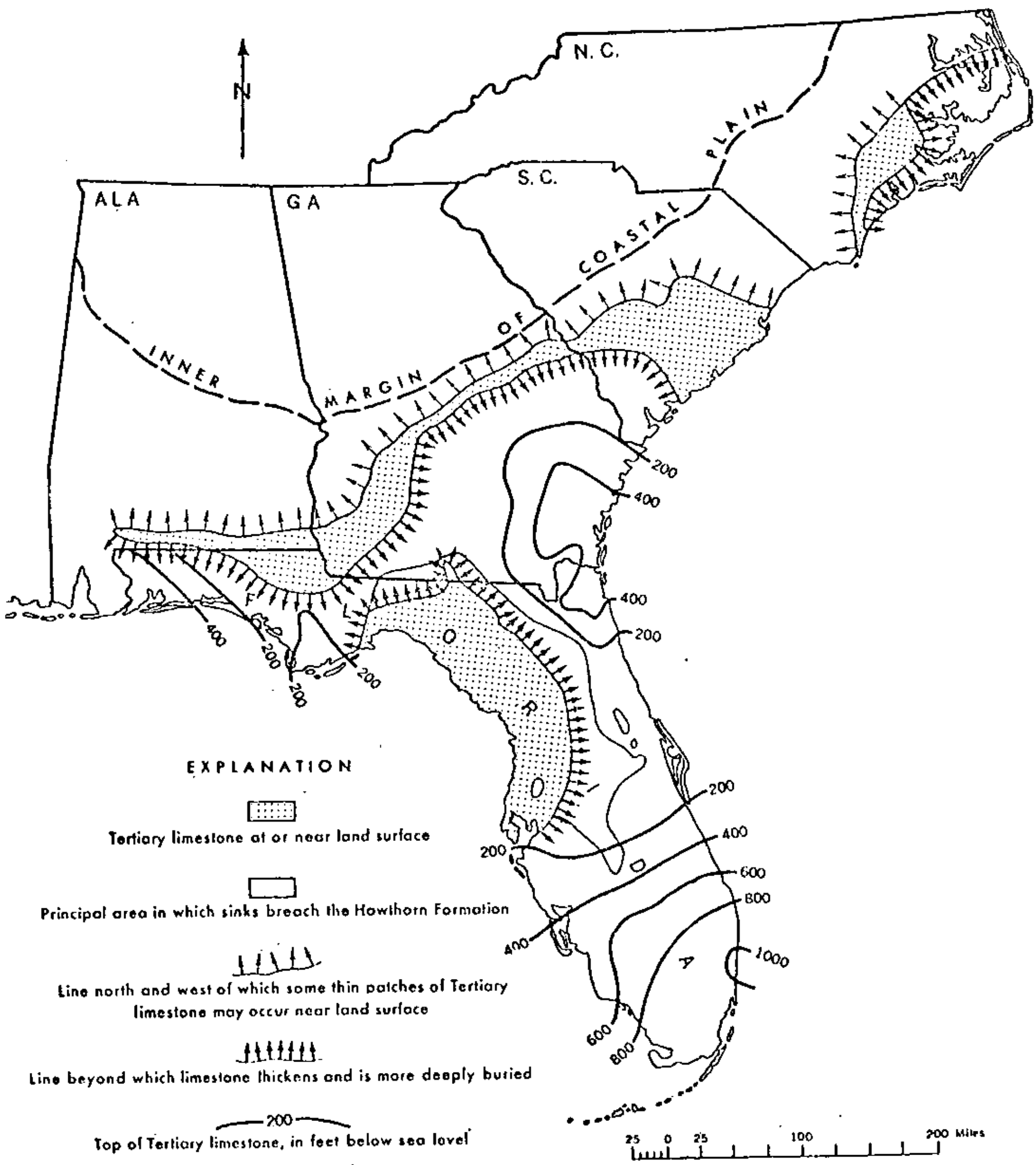

Figure 1.—Map showing distribution of the karst aquifer at the land surface and beneath it.

The authors have drawn on their own experience in the region and on many publications on the geology and hydrology of specific parts of the region. The senior author compiled and synthesized available information on the hydrologic system in Florida and Georgia (Stringfield, 1966), and listed many references of specific studies. Results of investigations since that time by many authors have been published by the U.S. Geological Survey and State Geological Surveys of Georgia and Florida.

The hydrologic system is described as both karst and artesian. It seems appropriate, therefore, to discuss in the paper briefly some pertinent characteristics of karst regions and of artesian conditions and to relate their characteristic to the system described here.

The authors are indebted to George D. DeBuchananne and John Rapp, U.S. Geological Survey for their constructive review of the manuscript.

GEOLOGIC SETTING

The Coastal Plain slopes gently to the sea, extending beyond the coastline as the Continental Shelf. Beneath the plain, beds of sand, clay, and limestone of Cretaceous, Tertiary, and Quaternary age dip seaward. In gross terms, the beds dip seaward at a rate only slightly greater than the slope of the land surface. Also, beds tend to thicken seaward. Many beds occurring at depth near the coast tend to wedge out before reaching the land surface at inland places. The most striking gross structural features of the Coastal Plain are (1) the seaward dip of the beds, (2) an increase in the thickness of individual beds toward the coast, (3) an increase in the number of beds toward the coast, and (4) alternation of beds of different degrees of permeability. The beds commonly dip only a fraction of one degree. There are many departures from the gentle homoclinal dip, some beds exhibiting depressed, or negative, features and other beds exhibiting uplifted, or positive, features.

The limestone formations are of Tertiary age and underlie all of Florida and parts of adjacent areas in Alabama and Georgia. These formations extend northward through Georgia and South Carolina and into North Carolina. They are at or near land surface through much of the Coastal Plain province in these latter States. The Tertiary limestone sequence is more than 1,000 feet thick in central Florida and is much thicker to the south, east, and west. The Tertiary limestone formations are commonly covered by sands and clays, which range in thickness from a few feet near the inner margin of the Coastal Plain to several tens of feet along the coast. A broad general arch in the overall monoclinal structure occurs in central Florida, at which place the limestone is at the land surface and around which very gentle radial dips occur.

The Tertiary limestone system in Florida includes as many as seven geologic formations ranging in age from middle Eocene to middle Miocene, but farther northward and inland as the aggregate system becomes thinner only one or two formations are present. Some beds of the Tertiary limestone are rather hard and consolidated locally, whereas other parts are semiconsolidated and marly. The lithology, texture, and general character of the limestone range greatly. Unconformities separate several of the limestone formations as the sea advanced and withdrew several times during the depositional period.

The modern climate is temperate and humid. Annual rainfall ranges from about 38 inches at the southern tip of Florida to 50 or 60 inches in other places; the rainfall is fairly evenly distributed during each year.

SOME GENERAL FEATURES OF KARST HYDROLOGY

Carbonate rocks exhibiting karst features are widespread at or near land surface in the Northern Hemisphere, and are common in many European countries especially in the Mediterranean region; they are also common in the Carribean Islands and in many regions of the United States. They vary considerably in the degree to which they have been karstified, or altered by circulating water.

Where carbonate rocks have some degree of permeability, commonly through fractures, moving water carrying carbon dioxide tends to dissolve the rock and to enlarge the openings. Cave systems are advanced stages in karstification, and, of course, continued solution causes sinkhole development and extensive subsidence of the land surface. Common karst features include: sinkhole topography, bare rock (because of little insoluble residue to regenerate soils), caverns, a deep water table, scarcity of surface streams, a few large springs, and a complex groundwater circulation system through part of which water moves rapidly.

Most karst features originally develop in the ground-water circulation system, which is generally a water-table, rather than an artesian, system. Many carbonate rocks are deeply buried beneath other sedimentary rocks and as such have never been karstified. Others now buried were at an earlier time exposed to circulating water and still retain some earlier solution openings.

A distinction of karst regions is the progressive development of permeability as some openings in the path of circulating water become larger. This permeability is unevenly distributed, commonly having characteristics of arteries and veins rather than of the conventional ground-water system in sandy deposits, where the movement is more even, diffused, and massive. Moreover, in most karst regions the permeability decreases with increased depth below the water table.

SOME GENERAL FEATURES OF ARTESIAN CONDITIONS

The geologic structure of the Coastal Plain is ideally suited for the presence of artesian water. The idea that artesian water is deep water is not altogether accurate, and a better distinction between water-table and artesian conditions is necessary. The water table is the top of the zone of saturation, and it separates air-filled pore space above from water-filled pore space below. At some place below the water table a relatively impermeable bed occurs, which retards the further downward movement of water. This impermeable bed, commonly clay in this region, confines water under pressure that lies beneath it. The water enters the ground, reaches the water table, and flows . . .

> "down with the slope of the water table to a point where the zone of saturation is interrupted by an impermeable bed. Part of the water may pass above the bed and continue to flow under water-table conditions, and part of it flows beneath the bed. Now it is confined, pressing upward against the impermeable bed with a head equivalent to the difference in elevation between that point and the elevation of the water table in the area of recharge, less the loss of head resulting from friction in movement. This is confined, or artesian, water; it will rise in a tightly cased well to a height above the bottom of the confining bed equivalent to the pressure head at that point. If the bed happens to be above the land surface, as it commonly is in the valleys, or along the coast . . . the well will flow." (McGuinness, 1951, p. 12–13)

The Coastal Plain is composed of many beds, of different permeabilities, some of which allow water to pass through them readily, while others prevent or retard the movement of water. The more permeable ones, commonly medium to coarse sand or limestone, are referred to as aquifers. The poorly permeable or impermeable beds, commonly clay or shale, are called aquicludes. The interlayered sands, clays, and limestone form a composite artesian system composed of a number of separate artesian aquifers and aquicludes. Since most geologic formations contain more than one type of material, they rarely coincide precisely with either aquifers or aquicludes. The tendency for most of the beds to have a coastward homoclinal slope slightly greater than that of the land surface results in an increase in depth to a specific artesian bed toward the coast; the number of artesian zones below a specific place also increases toward the coast.

SOURCE AND MOVEMENT OF WATER IN THE KARST ARTESIAN SYSTEM

The principal aquifer of Tertiary age in the southeastern States is the most widespread prolific karst artesian aquifer known. It is unusual in its karst characteristics. Most karst terrains have extremely high permeability, at least locally, because of the removal of some soluble materials in the path of moving water. This extremely high permeability is not necessarily an aquifer asset under water-table conditions because water infiltrates the cavernous system quickly and discharges quickly; thus much of the zone of high permeability above the water table is, unfortunately, not available for storage of aquifer water in most mature karst regions.

The karst region in the southeast has had an unusual geologic and hydrologic history, and it can be shown that paleohydrology is an important consideration in evaluating the aquifer. Much of the permeability within the buried artesian part of the aquifer developed at an early time, when part of the limestone was exposed and in a water-table circulation system. Unconformities occur in the limestone sequence, and karst features were developed during the time represented by these unconformities and were partly preserved as the sea encroached and as overlying formations were deposited. Although the distribution of permeability is not even throughout the system, it is much more even than that of most karst regions. Much of the solution occurred when sea level was lower, and the present high position of sea level results in ground-water levels near the top or above the top of the aquifer. In fact, unlike many karst regions where air-filled caverns are common, the karst system of the Southeastern States is saturated with water in most places.

The piezometric surface, or the height (with reference to sea level) to which water in an artesian aquifer would rise in wells, shows the chief areas of recharge and discharge and direction of lateral movement of the artesian water (see fig. 2). In general, the high areas of the piezometric surface indicate recharge, and the low areas indicate discharge. Recharge may, however, occur in some of the areas of relatively low pressure. The piezometric surface ranges from sea level near some coastal areas to more than 120 feet above sea level in the lake region of central Florida and in the Jackson County area in western Florida. The piezometric surface is as much as 250 feet above sea level in an outcrop area of the aquifer, extending from southeastern Alabama northeastward across Georgia where it is at or near the land surface, but also where the overlying beds have been penetrated by sinkholes. In general the piezometric surface slopes to the east, southeast, and south from the high area in Georgia. In the Valdosta area in Lowndes and Brooks Counties, where there is local recharge through sinkholes and drainage wells, the piezometric surface is as much as 100 feet above sea level.

The lateral movement of water is generally away from the recharge areas. Although the lateral movement may be controlled over considerable distances by geologic structure and the movement may be parallel to the dip of the formations, the relative positions of the recharge and discharge areas are more important than the geologic structure in controlling the direction of the movement of the water in the area of this report. For example, the lateral movement of the water in the Polk

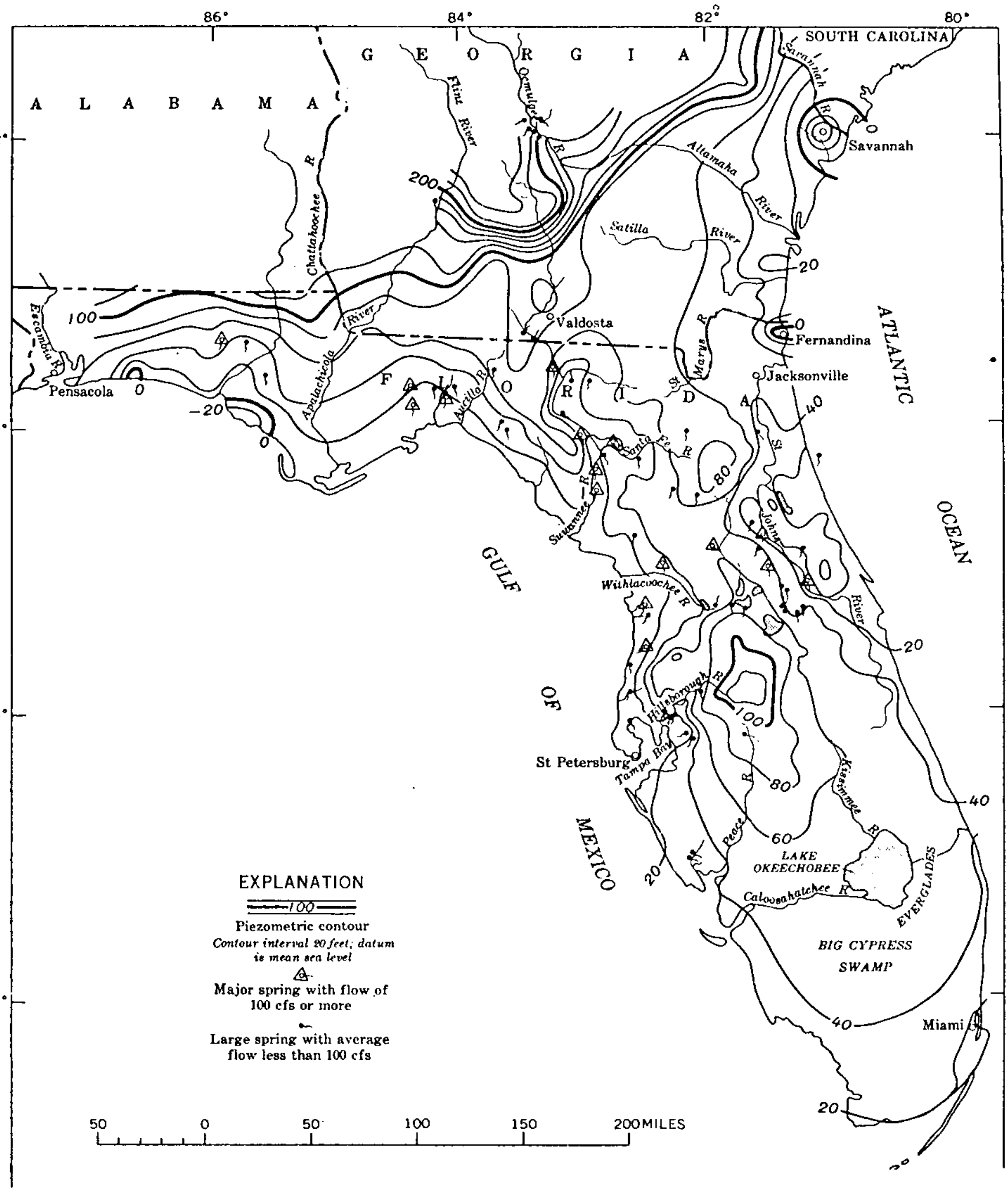

Figure 2.—Piezometric map of water in the karst artesian aquifer.

County area, Florida, is in all directions from the recharge area, even though it is on the flank of the Ocala uplift.

Prior to the mapping of the piezometric surface it was thought that the aquifer in the Florida peninsula was recharged only where it is at or near the surface in the north central part of the peninsula. However, the piezometric surface revealed that the aquifer is recharged in several large areas in the Lake Region of the Florida Peninsula and in Georgia, even though the aquifer is overlain by as much as several hundred feet of the Hawthorn Formation of Miocene age which contains relatively impervious beds. The hydrogeologic studies of the ground water show that the numerous lakes in the recharge area occupy sinkholes with permeable sands that extend to the aquifer.

The piezometric map indicates that the intake, movement, and discharge of the artesian aquifer are independent of the major structural features of the area. For example, in south-central Florida, where the aquifer dips southward on the flank of the Ocala uplift, the artesian water moves radially from the recharge area without being affected by the geologic structure.

The piezometric surface of artesian water in the coastal area of Georgia and northeastern Florida when the first artesian wells were drilled shows that the direction of lateral movement of the artesian water was towards the northeast, east, and southeast, indicating submarine discharge in the Atlantic Ocean northeast of Savannah and southeast of St. Augustine.

The effect of large withdrawals of water from artesian wells at Brunswick and Savannah, Georgia, and Fernandina and Jacksonville, Florida is shown by the lowering of the piezometric surface in these areas. With the same rate of withdrawals it has been lowered more at Savannah and Fernandina than at Brunswick and Jacksonville, indicating that the aquifer is more productive at Brunswick and Jacksonville than at the other two areas. That difference is caused in part by differences in the permeability and the thickness of the aquifer.

The piezometric surface of artesian water is fluctuating almost continuously, and a study of the fluctuations is essential in determining the characteristics of an aquifer and quantity of water that can be obtained from it.

Pumping a well or permitting a well to overflow at the surface lowers the piezometric surface at the well and in an area adjacent to the well. The rate at which such lowering is transmitted from the well is much more rapid under artesian conditions than is the rate under water-table conditions, because the artesian aquifer behaves as a conduit and pressure system, but under water-table conditions the aquifer behaves as a storage reservoir with relatively large quantities of water being moved from storage as the water level (water table) declines. The largest fluctuations of water levels generally are caused by changes in rate of withdrawal of water. Such fluctuations in the Coastal Plain may be 100 feet or more at the point of withdrawal, with the measurable effects on the water levels extending as much as 15 miles or more from the place of withdrawal under artesian conditions. Natural fluctuations of the piezometric surface may be caused by changes in rates of natural recharge and discharge, changes in atmospheric pressure, changes in wind velocity, earth tides, ocean tides, earthquakes, and loading and unloading of aquifers as shown when railroad trains pass near an artesian well. Fluctuations caused by ocean tides occur on or near the coast, where the loading effect of high tide on the aquifer compresses the aquifer and causes an increase in artesian pressure. The unloading permits an expansion of the aquifer and causes a decrease in pressure; also, where the aquifer is exposed to tide water near the coast, tide fluctuations in the aquifer may be caused by actual transfer of water.

WATER-BEARING CHARACTERISTICS OF THE AQUIFER

The karst artesian aquifer is the principal source of water for industrial, municipal, domestic, and irrigation supply in Florida and southeastern Georgia. It is the source of water for most of the public supplies, including some of the largest supplies such as those for Savannah, Jacksonville, and St. Petersburg. Water from thousands of artesian wells is used for irrigation and domestic supplies. Millions of gallons of water from artesian wells is used daily in industrial plants. The artesian wells range from about 50 to 1,000 feet in depth, depending on the local conditions within the area in which they are constructed, and from about 2 to 12 inches in diameter. Some of them are as much as 24 inches in diameter. Except in western Florida, where part of the karst artesian aquifer includes unconsolidated formations, few of the wells are entirely cased. The casing generally ends at the top of the first limestone penetrated. Some wells, as much as 1,000 feet deep, may have only 100 feet of casing.

Wells in the areas of artesian flow are commonly finished with valves to shut off the flow when the water is not needed.

It is notable for its water-bearing capacity in Florida and Georgia, as indicated by the fact that it is the source of the largest limestone springs in this country. The yield of the largest of these springs, Silver Springs, near Ocala, Florida has ranged from 526 to 1,240 second cubic feet (cfs), or about 340 million to 800 million gallons a day. The minimum yield is sufficient to supply a city of 3,400,000 people with 100 gallons of water a day per capita.

Although the karst artesian aquifer is tapped by wells throughout its extent, wells are most numerous within areas in which the wells flow. The greatest concentration are in irrigation districts as in Indian River, Seminole, Manatee, and Sarasota Counties, Florida. In Seminole County, several thousand wells have been drilled for irrigation of celery and other truck crops. Artesian wells are also numerous in Jacksonville, Savannah, and other large cities and industrial areas. Some nonflowing wells are used to drain surface water into the aquifer. The largest concentration of these is in the Orlando area of Orange County. In southern Florida, the karst artesian aquifer is as much as 1,000 feet deep and yields water with a relatively high chloride content. Wells that tap the deep aquifer will overflow at the surface.

A few wells used for drainage of surface water in the Miami area, Florida, are in the very productive shallow limestone aquifer, the chief source of ground water in southeastern Florida.

The yield of the artesian wells depends on the hydrologic conditions and the construction of the wells. In general, the wells having the smallest capacities are in the southern part of Florida. The yield of flowing artesian wells ranges from a few to thousands of gallons per minute.

For many years, an artesian well with a reported yield of 8.5 mgd by natural flow from carbonate rocks in the Roswell Basin, New Mexico was considered the largest in the United States until it was exceeded by a flowing well 24 inches in diameter drilled in San Antonio, Texas, into the Edwards and associated limestones. The reported yield by natural flow of the San Antonio well was 19,300 gpm in October 1941 and 16,800 gpm on June 16, 1942. Since then, the increased withdrawal of water in that area has caused the artesian pressure and yield by flow to decline. An artesian well drilled in 1964 into the karst artesian aquifer near Palatka, Florida, now apparently has the largest natural flow of any well in carbonate aquifers in the United States (M.L. Brashears, written communication, 1964). When the well was completed in 1964 it had an estimated natural flow of more than 16,000 gpm and is presently flowing at 11,200 gpm, (G.W. Leve, written communication, 1970).

After the construction of the early artesian wells in South Carolina, Alabama, and Mississippi in the first half of the 19th century, there was no discovery of artesian areas in other States until the latter part of the century, when jetting and cable tool drilling methods were introduced in the southeast. In 1854, before discovery wells were drilled in the other southeastern States, it was estimated that there were about 100 flowing wells in Mississippi and more than 500 in Alabama. The first flowing well in Florida was drilled at St. Augustine between 1880 and 1882 by a driller from the Pennsylvania Oil Fields with a standard cable tool drilling rig used in drilling salt wells in West Virginia, Ohio, and Pennsylvania. The "discovery" well for artesian water supply in Jacksonville, Florida, was completed about 1885.

For many years Jacksonville had the largest municipal supply derived entirely from natural flow of artesian wells. A flowing well was drilled in Savannah about 1885. Artesian wells were drilled for the public supply of Savannah in 1887. In 1888 artesian wells completely replaced the city supply from the Savannah River. About the same time, artesian wells were drilled for the public supply of Memphis, Tennessee. Among the other large public supplies from artesian wells is Baton Rouge, Louisiana. Thousands of artesian wells, many of them with sufficient head to continue to overflow at the present time were drilled along the coastal belt of Mississippi and in the Mississippi Valley, (the Mississippi Delta). The artesian aquifers in that region west of Florida consist chiefly of sand, sandstones and gravel. The yields of the individual wells are not as great as those in the karst artesian aquifer in Florida and the quality of water is different.

Much of the early drilling for artesian water, like the early drilling for oil, was without adequate geologic advice. There are few notable exceptions in which geologic information was used; at Jacksonville, Florida, after the first flowing well was drilled at St. Augustine, R.N. Ellis, City Engineer at Jacksonville, without an understanding of the geologic structure, assumed that artesian water could be reached at about the same depth at Jacksonville as at St. Augustine. The test well at Jacksonville was unsuccessful because it was not deep enough to tap the artesian aquifer, the top of which is about 500 feet below sea level at Jacksonville, although it is only about 200 feet below sea level at St. Augustine. The hope of obtaining flowing wells in Jacksonville was, therefore, abandoned until L.C. Johnson, a geologist of the U.S. Geological Survey, on a ground-water reconnaissance in Florida, was informed of the effort to obtain water. From his information on the geologic structure of Florida, Johnson estimated correctly that the flow of artesian water could be reached at a depth of about 500 feet. This discovery started the development of the large artesian system in the northeastern part of Florida. Thousands of artesian wells are now in use in the Coastal Plain of the southeastern States.

Most, if not all, of the springs with a discharge of 100 second cubic feet (cfs) or more and some of the smaller springs from the karst artesian aquifer are artesian and rise from considerable depth through vertical solution channels, some of which are sinkholes or natural wells. Some of the springs, such as Silver Springs, emerge below the water surface from a series of outlets which may be along a large solution channel. Wakulla Springs south of Tallahassee is one of a series of outlets for a large underground stream system.

The remarkable depth of some of the springs is illustrated by Bugg Spring, 176 feet deep, about half a mile northwest of Okahumpka, in Lake County, Florida. Seventeen of the largest springs of the karst artesian aquifer in Florida have an average discharge of 100 cfs or more, (one cfs equals

646,317 gallons a day). The maximum discharge of the springs from the karst artesian aquifer ranges from a few gallons a minute to more than 1,000 cfs. Two of the largest springs are Silver Springs near Ocala and Rainbow Springs near Dunnellon in Marion County, Florida with a combined maximum flow of 2,310 cfs. The combined average discharge of the springs has been estimated to be 3,700 mgd.

The flow of the springs vary with artesian head in the artesian aquifer, as is shown by the comparison of the discharge of Silver Springs in Marion County with the head of an artesian well about 4 miles southeast of the spring. The flow of artesian springs also varies with the relation of artesian head to the altitude of the outlet of the spring. For example, Bugg Spring yields water from the karst artesian aquifer but the yield was only about 17 cfs. Although the artesian head is much higher at Bugg Spring in Lake County than at Silver Springs, the outlet for Bugg Spring is approximately as high as the artesian head in the area.

One of the deepest pools of the springs with a discharge of more than 100 cfs is that of Weekiwachee Spring near Brooksville in Hernando County, which, according to measurements made by a sounding line, has a depth of about 145 feet.

Warm Mineral Springs and Little Salt Springs near Murdock in Sarasota County appear to be circular sinkholes about 250 feet in diameter. These sinks, along with many other sinkholes in the karst artesian aquifer were formed during a low stand of the Pleistocene sea when the zone of saturation in the cavernous limestone was much lower than at present time. Divers have explored these sinks and found cave systems below sea level. There is evidence that some of these caves now below sea level were occupied by early cave man during a low stand of the Pleistocene sea, when the water in the artesian aquifer stood below the level of the caves.

In general, water from the limestone aquifers is typically of the calcium bicarbonate type and relatively hard, the hardness increasing with distance from the intake area. In some of the deeper formations of the aquifer system on the flanks of the Ocala uplift in southern Florida and eastern Florida, the water is relatively high in sulfate where the limestone contains anhydrite and gypsum. Most of the artesian water from the limestone aquifers has a hydrogen sulfide odor before it is aerated, and therefore aeration is a common practice in water works plants. Only one part per million of hydrogen sulfide will give a slight odor before aeration of the water.

In cavernous limestone where water from the ground surface may move freely into the limestone without filtering action, such as that received by ground water moving through sandy aquifers, the same care should be used in treatment of ground water for human consumption as is for surface water. Generally there is less chance of pollution in the karst artesian aquifer in the southeast than in most other limestone aquifers, because many of the sinkholes and solution cavities in the aquifer are filled with relatively permeable sand and other unconsolidated materials which serve as a filter for the water moving through it.

A large area of the karst aquifer is under artesian conditions, with a thick cover of relatively impervious material, many miles from the area of recharge through sinkholes and caverns. Under these conditions, there is little or no chance for pollution of the artesian water under natural conditions.

Salt water in fresh-water aquifers may be from (1) encroachment of sea water in the coastal areas where there is an overdraft from wells, (2) originally entrapped sea water or sea water that entered the aquifer during a high stand of the sea in Pleistocene time, or (3) thin salt beds and sea water concentrated in tidal lagoons or other enclosed areas. Water having a relatively high chloride content is present in the artesian aquifer in coastal areas of Florida south of St. Augustine in southern Florida, and also in St. Johns River valley where the aquifer is near sea level.

REFERENCES

McGuinness, C.L., 1951, The water situation in the United States with special reference to ground water: U.S. Geol. Survey Circ. 114, 127 p.

Stringfield, V.T., 1966, Artesian water in Tertiary limestone in the southeastern States: U.S. Geol. Survey Prof. Paper 517, 226 p.

———, 1953, Artesian water in the southeastern States; Kentucky Geol. Survey, Spec. Pub. No. 1, p. 24–39. (Includes maps showing the piezometric surface of artesian water in Tertiary limestone and the areas in which artesian wells overflow at the land surface.)

TOXIC WATER POLLUTANTS

by

John Fabianek, Ph.D., Sc.D., J.D., Professor of Chemistry and
Vera Sajenko, M.S., Asst. Professor of Chemistry
New York Institute of Technology

INTRODUCTION

It is estimated that with our present trend of water pollution there will be no clean and safe drinking water in this country by the year 1980. One hundred million Americans live in areas where water is not safe to drink. Fifty million Americans drink health-defective water. The situation is even worse in other countries. Water in many cities is unsafe to drink; filtration and chlorination do not make it entirely safe.

Industry and agriculture pour a vast array of toxic contaminants into our water supplies. These are:

(1) Crude organic matter – a good nutritive medium for pathogenic bacteria and viruses.
(2) Oil, coal residues and natural gases.
(3) Various types of pesticides – discharged into water supplies.
(4) Non-metals and their ions – chlorine, fluorine, phosphorus, arsenic, nitrates, and nitrites.
(5) Heavy metals – lead, mercury, copper – discharged into sea and fresh waters by industrial plants.
(6) Radioactive products and hot water – released by industrial and power plants.

CRUDE ORGANIC MATTER

Usually, the sea contains from 0.1 to 2 parts per billion of soluble organic matter. The concentration of organic matter might, in some cases, be as high as one to twenty parts per billion.

A number of bacteria and viruses rely on organic matter found in both sea and freshwater. A high concentration of organic matter can protect some viruses and bacteria from the effects of water chlorination. On the other hand, an excessive chlorination of the fresh water may result in a formation of chloro-organic compounds with mutagenic effects.

Oxygen acts as a primary factor in the destruction of organic matter in water. The low oxygen concentration in water might not decompose these organic compounds completely, although it may liberate such substances as organic phosphates, acetic acid, fatty acids, glycerol, etc.

The content of organic matter in water is determined by the amount of potassium permanganate consumed by the water when it is boiled for ten minutes with this chemical, in an acid medium. In hygienically irreproachable drinking water, this value of potassium permanganate should not exceed 3 milligrams per liter of water. We found that tap water in New York City contained, in some cases, two of three times more organic matter than is hygienically allowed.

OIL, COAL RESIDUES AND NATURAL GASES

Ocean pollution by oil results from accidental spills of oil-carrying tankers into the sea water. Petrochemical plants, oil refineries, submarine oil wells and the disposal of used lubricants also introduce oil products into the sea water.

Airborne hydrocarbons from motor vehicles and industrial plants also contribute to the contamination of the oceans.

Some oils may contain heavy metals such as mercury, lead, nickel or copper; others may contain accumulated pesticides.

At the beginning of 1969, a drilling operation performed by the Union Oil Company in Santa Barbara, Calif. destroyed thousands of fish and birds in the adjacent sea and coastal areas. We know that oil has a deleterious effect on marine animals. There are, however, no conclusive research results available indicating why, in some cases, oil spills do cause severe damage to the marine animals, while in others there is no marked degree of damage observable.

Burning of coal, oil and natural gases in industrial plants and oil wells, which is accompanied by the release of carbon dioxide, and oxides of sulfur, nitrogen and mercury, also contribute to the pollution of water.

PESTICIDES*

In the recent years, the concentration of DDT and other pesticides in rivers and estuaries increased considerably. The oceans are the ultimate site of accumulation for pesticides and their residues. The intoxication with pesticides results in a decline of productivity of marine phytoplankton and consequently in the reduction of fish.

Phytoplankton is very important from the nutritional point of view. It has been estimated that 90 percent of the photosynthesis on earth is carried out by the aquatic plants, primarily sea algae. Phytoplankton is also of extreme importance for the solution of the world's nutrition problems. Half of the mankind today, goes to bed hungry. There are serious plans under consideration as how to use sea food more extensively. One expects that, within the next fifteen to twenty years, about 20 percent of food will come from the sea, especially as far as needs in protein are concerned.

Laboratory experiments have shown that, indeed, the concentration of 5 parts per million of DDT reduces the photosynthesis of marine phytoplankton by approximately 20 percent.

A reduced production of marine phytoplankton would result in the decline of marine life. On the other hand, phytoplankton, being at the bottom of the biological food ladder, are at the same time the primary concentrators of DDT and other pesticides. Crustaceans feed on phytoplankton, and fish again feed on crustaceans, thus substantially building up the concentration of DDT. Then a gull which feeds on fish accumulates even a higher dosis of DDT in the body. DDT and other pesticides concentrate mainly in the adipose tissue. The same process is involved when man relies mainly on fish as food. This also explains why birds like ospreys, peregrine falcons and bald eagles are today at the verge of extinction.

All pesticides are highly toxic in even such minute quantities as 10^{-12} to 10^{-9} grams. Their toxicity and extent of capacity to damage is best demonstrated by the following event. In June 1969, an estimated count forty million dead fish were found in the lower reaches of the Rhine River in West Germany. The Dutch Institute for Social Health identified endosulfane, a pesticide sold under the trade name of Thiodan, as the poison. It was found that only about 200 pounds of the compound seeped out of the lead plated metal canisters. Endosulfane appeared to be two to three times more toxic to aquatic life than DDT. One to two parts per million of endosulfane can kill half the fish exposed to it.

---

*A pesticide is any poisonous chemical intended to destroy, repel or exterminate insects, rodents, weeds and any other form of living organisms declared as pests. Pesticides used for killing of insects are called insecticides, those used for destroying undesirable plants are called herbicides.

NON-METALS AND THEIR IONS

On all the major nutrients for plants (nitrogen, phosphorus, potassium and calcium), phosphorus is the most toxic to animals and man. Like nitrogen, it is used in fertilizers and accumulates, therefore, in estuaries and lakes as a nutrient run-off from agricultural land. The eutrophication (overnurishment) of lakes and estuaries, particularly with phosphorus, presents a very serious problem in all developed countries. Domestic refuse, human excrements and farm manure, all rich in phosphorus, are also a source of pollution of the water supplies.

Eutrophication of lakes, rivers and estuaries must be reduced to a minimum, especially in the proximity of urban developments, since it results in a deficiency of oxygen. In both the developed and the underdeveloped countries, most of the large cities are located on estuaries and shores, where their wastes can be discharged.

A considerable decline in or a complete disappearance of animal life in estuaries results from contamination with toxic compounds. Eutrophication of waters through over-fertilization, mainly with nitrogen and phosphorus, produces an excess of organic matter which kills the fish.

In 1969, a power plant located on the Newfoundland's coast in Canada was forced to suspend the discharge of phosphorus into the coastal waters, because a substantial number of d ad, discolored fish, poisoned by it, was found floating around this area.

Phosphates used in detergents are another culprit in addition is nutrients to lakes, rivers and sea waters. Lake Erie is being daily charged with 150,000 pounds of phosphates, a by-product of man's indulgence in cleanliness.

Fluorine, in the form of fluorides, presents another serious problem in pollution. Compounds of fluorine are very toxic. This pollution originates in steel, aluminum, phosphates, glass, and brick works, all of which discharge their waste in fluorides into the atmosphere.

Arsenic, also from detergents, is one more source of serious water pollution. It is cumulative poison which builds up slowly in the body. Filtration treatment of water with charcoal appears to be the best method for removal of arsenic from the polluted water.

River and rain waters contain nitrogen in form of nitrates. Nitrates, as such, are not toxic, but they are easily converted to the very toxic nitrites, usually by the denitrification bacteria which can be found in the digestive tract of domestic animals and human infants until the age of three. Reaching the blood stream, nitrites react with hemoglobin from the red blood cells to form the methemoglobin, which, then, blocks the oxygen transport capabilities of free hemoglobin. Methemoglobinemia is characterized by labored breathing, any may result in suffocation.

Water pollution by nitrates is a severe hazard to public health in the Midwest and in Southern California, where physicians are recommending the use of bottled drinking water in case of infants.

Pollution of water with nitrates is also caused by the use of fertilizers containing nitrogen. The situation is alarming, since use of this type of fertilizers is expected, according to the United States Department of Agriculture, to increase some ten times within the next thirty years. Consequently, an increase in posioning of infants and animals with nitrites would result.

HEAVY METALS

Copper and, especially, lead are the two main heavy metals which may still endanger our drinking water. Marine animals accumulate in their tissues from several hundred up to several thousand times the concentration of heavy metals, found in the surrounding water. Lead, copper and mercury are extremely toxic to marine animals, especially the shellfish.

It is known that the sea water has a killing effect on the fresh water bacteria. According to some recent views, these deleterious effects appear to be due to the presence of small amounts of lead, nickel, zinc or copper in the sea water, rather than to the salinity effect or to the presence of some kind of bacteriophage, a type of bacteria virus.

Interestingly enough, if a chelating agent for the binding of heavy metal is introduced into the sea water, its toxic effect disappears completely.

The intake of lead by the average American in his food, water and air, has been estimated to reach approximately 0.4 mg per day. This lead is mainly coming from the tetraethyl-lead, used to increase the anti-knock properties of gasoline when used as an automobile fuel.

The average concentration of lead found in human blood has doubled in the last twenty years in the United States. It is presently found to be 0.25 p.p.m. which is just below the limit concentration allowed in case of lead industry's workers. Garage mechanics and parking lot attendants were found to have as high as 0.35 to 0.45 p.p.m. of lead in their blood.

Chronic lead poisoning symptons are: a loss of appetite, apathy, miscarriage, lesions of neuromuscular, brain and circulatory systems. It was recently advanced that an over-exposure to lead and copper was probably the cause of decline of the Greek and Roman civilizations. The chronic poisoning with lead and copper, which were used for coating of their cooking, eating and wine storage vessels, killed the elite of the ancient world. The lower classes of these ancient civilizations used less lead for coatings, drank less wine and were therefore less exposed to poisoning than the wealthier ones.

Although the Romans were using lead pipes to carry water, which might have been dangerous, there was little poisoning observed, since water is slightly alkaline and does not dissolve either lead or copper.

Mercury when taken in with food is also very poisonous. It may cause a permanent damage to the alimentary tract and the kidneys. According to an information by the World's Health Organization, the maximum permissible concentration of mercury present in human food is 0.5 p.p.m. Elemental mercury and most of its organic compounds are extremely toxic, since they are causing a permanent damage to the nervous system. In case of lower concentrations of mercury a chronic poisoning of the nervous system may occur, even though some patients do not develop the well defined symptoms.

The most harmful of all mercury compounds is the methyl-mercury. Some years ago more than a hundred people in Japan died or were afflicted with severe disabilities after having eaten mercury-contaminated fish. Although the only source of mercury in the afflicted area was a plastics factory, which claimed to be discharging only harmless inorganic mercury into the bay waters, the fish showed the presence of almost pure organic methyl-mercury. The dispute was cut short after the chemists found about 1 percent of the methyl-mercury in the factory discharge. This, of course, did not exclude completely the possibility that some of the discharged inorganic mercury could also have been converted, in the fish organism, into the deadly methyl-mercury.

It was found that twenty-two of the children born to Japanese women who did eat the contaminated fish were severely mentally retarded. This served as a proof for the damaging effect of mercury to human fetus, even though the poison was not consumed in sufficiently large quantities to affect the pregnant mother. It also suggested that the genetic changes in offspring did occur by mutation of chromosomes.

According to some studies performed by a number of Swedish investigators, both fish and mammals can convert small quantities of inorganic mercury into the methyl-mercury, in the liver.

In anaerobic (oxygen-free) ecosystems such as the mud on the bottom of a lake, some microorganisms can also convert inorganic mercury to the methyl-mercury. Since the same results were obtained recently in the United States, dumping of wastes of inorganic mercury into the lakes and streams appears to be the cause of one of the most dangerous poisonings ever known.

The statistical data from 1966 show that in the United States farmers used over 400 tons of mercury-containing pesticides on a total area of 300 million acres, while at the same time farmers in Sweden did use only 2 tons on a total of 7.5 million acres. In the United States the amount of mercury used per acre exceeded forty times that used in Sweden.

Approximately a year ago, (1971) the Canadian Wildlife Service officials reported that fish caught in Lake St. Clair did contain mercury levels as high as 7 p.p.m. which is about four times higher than those allowed by the Food and Drug Administration–(F.D.A.)–regulations.

An amount of 25,000 vitamin pills containing mercury were on sale in health and food stores in this country in September 1970. They were prepared from freeze-dried liver of seals caught in the waters near Alaska. Mercury level in the pills was found to be as high as 30 p.p.m. by weight.

According to a report by the F.D.A., 90 percent of swordfish sold on the Christmas Eve 1970 in the United States contained mercury in concentrations reaching the permissible limit level of 0.5 p.p.m.

RADIOACTIVE PRODUCTS AND HOT WATER

Traditional and nuclear power plants are polluting our lakes, rivers and coastal areas with "hot" water and radioactive wastes. Waters may, in the future, become so hot that any form of aquatic life would be impossible. With the exception of a few species of bacteria and algae which can live in springs as hot as 60°C no other aquatic life is expected at temperatures above 35°C. Fish of any kind are rare in water above 30°C. Largemouth bass can survive and grow at 32°C, but does not reproduce at a temperature higher than 24°C. Atlantic salmon and the lake trout require for reproduction temperatures even lower than 10°C.

Oxygen concentration is water is, besides temperature, another important factor affecting the aquatic life. The amount of oxygen dissolved in water decreases as the temperature is increasing. When the water temperature rises from 20°C to 30°C, the solubility of oxygen decreases by approximately 20 percent. At the same the requirement of aerobic organisms for oxygen increases. Since the salt water has a lower solubility for oxygen, the addition of heat to estuaries becomes even more critical. Decrease of oxygen in water results in a reduction of aquatic animal life. On the other hand, as the temperature rises toxic compounds, parasites and pathogenic bacteria are more likely to spread out, especially in waters rich in autotrophic plants, and in nutrients such as phosphorus, calcium, potassium and nitrogen compounds.

Nuclear power plants release also harmful radioactive isotopes to our waters. Nuclear tests are another source of radioactive products found to pollute our rivers, lakes and sea water.

Clouds from atmospheric nuclear explosions some times rise to the stratosphere. Higher altitudes and stronger winds contain usually a larger fraction of radioactive products. Thus, the radioactive compounds can easily be transported to large distances and deposited in places far away from the original site of the nuclear explosion.

REFERENCES

1. John Fabianek, Environmental Sciences. Lecture notes used for the course taught at New York Institute of Technology
2. Paul K. Anderson. Omega Murder of the Exosystem and Suicide of man, 1971. WM.C. Brown Company, Publishers. Dubuque. Iowa.
3. Eugene P. Odum. Fundamentals of Ecology, 1971. W.B. Saunders Company. Philadelphia.
4. Various articles published in Science, issues 1969–72. American Association for the Advancement of Science. Washington, D.C. 20005.
5. Man's Impact on the Global Environment. Assessment and Recommendations for Action, 1971. Report of the Study of Critical Environmental Problems.
6. Paul R. Ehrlich and Anne H. Ehrlich, Population, Resources and Environment. Issues in Human Ecology, 1970. W.H. Freeman and Company. San Francisco.
7. R. Revelle, A. Khosba and M. Vinovskis, The Survival Equation: Man, Resources and His Environment. Houghton Mifflin Company. Boston.
8. Jack Bresler–Environments of Man, 1968. Addison–Wesley, Publishing Company. Reading, Mass.
9. Chemical and Engineering News, issues 1970–72. American Chemical Society. Washington, D.C.
10. Biological Abstracts, years 1967–71.
11. Scientific Research, years, 1969–71.
12. Wes Jackson, Mann and the Environment. 1971. Wm. C. Brown Company Publishers, Dubuque, Iowa.

SOME PROBLEMS OF THE PAPALOAPAN RIVER BASIN

by

Ing. Gerardo Cruickshank, Under Secretary
Department of Water Resources,
Government of Mexico

Before the discovery of America and upon the arrival of the Spaniards, the Mesoamerican portion of Mexico was populated by numerous communities and linguistic and ethnic groups together having a population of several million inhabitants. Great civilizations were successively evolved by Olmecs, Mayas, Zapotecs and finally Aztecs, who controlled a large portion of this area at the arrival of the Spanish conquerors.

I will now discuss one of the hydrological regions of the country, presently inhabited by more than 25 ethnic groups, some of which go back more than 2,000 years in history.

GEOGRAPHICAL LOCATION

The Papaloapan River, one of the most important in Mexico, is located on the slopes of the Gulf of Mexico. Its geographical location is between 17° and 19° latitude north and between 95° and 97°40′ longitude west of Greenwich.

The center of the Basin is only 450 kilometers from the capital of the Republic and is adjacent to the Isthmus of Tehuantepec, the shortest distance between the Atlantic and Pacific oceans. This allows easy, low-cost communication with the most important centers in the country, as well as with national and foreign ports.

PHYSIOGRAPHY

The Basin is formed by three main orographic units: A Continental Mass, the Oaxacan Peninsula is underlain principally by gneiss and schist. A great marine deposit which surrounds the Continental Mass is formed mainly by folded and faulted limestones and lutites of the Eastern Sierra Madre and the Upper Oaxaca Mixteca. The last unit is a more recent sediment deposit underlying the Coastal Gulf Plains, a farming region with important deposits of gas, oil, salt and sulphur.

In the mountainous region there are a number of granitic intrusions associated with important gold, silver, copper, lead and zinc deposits. There are also valuable deposits of manganese, graphite, feldspar, asbestos, mica and other minerals.

Lastly, it is of interest to mention zones of recent volcanic activity. The Peak of Orizaba, 5,600 meters above sea level, is Mexico's highest mountain. The smaller Sierra of the Tuxtlas is adjacent to the Gulf coast on the northeast margin of the Basin.

These orographic units define the physiography of the Basin, consisting of two zones: the Coastal Plain, which is not a plain according to the common definition. There are hills up to 100 meters. Topography is interrupted by river-beds, swamps and low-lands near the coast. The mountainous area of the basin is formed by the Eastern Sierra Madre. It is an extremely uneven and furrowed area with many ravines and canyons.

There are two important sub-basins; one at the foot of the mountain, between the Coastal Plain and the upper portion of the sierras, the second a great depression called Cañada Poblano-Oaxaqueña, located between the Sierra Madre and the Mixteca Mountain System.

Of the 46,500 km^2 which constitute the Basin, approximately 21,000 are plains and 25,000 km^2 are mountainous. The Cañada Poblano-Oaxaqueña, covering one percent of the area, is included with the mountainous area.

EDAPHOLOGY

In this area there are two dominant soil groups: 1) fluvogenic or hydromorphic soils, and 2) yellow and red lateritic or incipient lateritic soils.

Fluviogenic soils are found along river courses and former beds of meandering streams.

In almost all areas they include terraces composed of light, sandy textured sediments.

The hydromorphological soils are fresh water swamp soils, generally without any saline-sodium problems. The sediments which form this soil are fine, clay-like and heavy, with a low-capacity for ionic exchange. The formation process takes place in an anaerobic environment or else there is reduction leading to the formation of "gley".

Red and yellow soils predominate at the foot of the mountains. These have high oxide and aluminum contents and may be considered laterites or incipient laterites. Gravel beds are present. Lack of soluble phosphates reduce the usefulness of these soils.

ECOLOGY

One of the most important factors in this area is undoubtedly man. Agriculture, forestry, and various uses of streamflow have had important ecologic effects.

The effect of man on forests has not been limited to exploitation for forest products. In addition, with the growth of the population there has been an increase in the intensity of migratory agriculture in large areas of the mountain zone, causing soil and vegetation disruption.

The population groups which work areas where there is limited land have evolved cultures based on the conservation of soil, as is the case with the Mixteca people. When this culture breaks down or is destroyed,– as happened during the Spanish conquest–there is an alarming destruction of resources. In the case of the Cañada Poblano-Oaxaqueña, deforestation and accelerated soil erosion, have increased the sediment load of the Santa Domingo River to the greatest value in the Basin.

When the natural balance between flora and man is maintained, the soil is able to maintain productive physical, chemical and biological characteristics. But when it is subjected to the burning and clearing every 4 or 5 years, its fertility is greatly diminished and there is a loss of physico-chemical characteristics to such a degree that the growth of secondary vegetation necessary for the conservation of the soil can no longer be maintained.

The tropical low-lands of the southeast of Mexico, and especially the Lower Papaloapan was an area with low population density during the time of the Aztecs. It was settled mainly by Totonacas and Olmec groups which were only partially subject to the Aztec Empire. The Mayas of Yucatan and Guatemala did not penetrate this area.

In 1518 the first Spanish expedition left from Cuba for this area under the direction of Juan de Grijalva. The following year Hernán Cortés organized a second expedition, subduing the Totonacas and thus beginning the conquest of the Aztec Empire.

In 1873 a railroad from Mexico City to Veracruz was completed and towards the end of the 19th century English and American companies began to extract oil along the whole coast of the Gulf in spite of the fact that the Basin was infested with malaria and yellow fever.

Surface areas are as follows:

Lagoons, rivers and swamps	2,300 km^2
Areas with a slope of less than 10 percent (Coastal Plains)	18,300 km^2
Areas with a slope between 10 and 25 percent	10,600 km^2
Areas with a slope greater than 25 percent	15,300 km^2

HYDROLOGY

Physiography and climate make this Basin one of the most important hydrographic systems of the country. The main rivers are as follows:

– The Blanco River rises from the Zongolica Sierra and the lower slopes of the Peak of Orizaba. Its outlet is the Alvarado Lagoon.

– The Tonto River rises from the spurs of the Sierra Mazateca. It is the most important tributary of the Papaloapan on its left border. Because its basin is located in the zone of highest precipitation and in spite of its small area, the Tonto produces almost 20 percent of the annual average discharge of the Papaloapan River. Its water contains the lowest percentage of sediment of any river in the basin due to the fact that the majority of the basin is in a Karstic zone and is covered by vegetation. The President Miguel Alemán Dam, with a capacity of 9,000 million m^3 is located on this river.

– The Salado River empties the Cañada Poblano-Oaxaqueña and the High Mixteca. It is the most arid and deforested sub-basin of the system and carries more than 60 percent of the sediment reaching the Papaloapan River. In the mountainous area the Salado River joins the Grande River to form the Santo Domingo River, the most important tributary of the Papaloapan.

– Other important tributaries to the upper portion of the Papaloapan include the Usila or Santa Rosa, Valle Nacional and Obispo Rivers.

– Near the outlet lie the Tesechoacán River, whose basin covers 5,695 km^2 and the San Juan Evangelista River with a course of 410 km.

The average annual discharge of the Papaloapan into the Alvarado Lagoon, thence to the sea is 43,000 million m^3.

CLIMATOLOGY

The Coastal Plain has a humid or semi-humid tropical jungle or savanna climate, very hot with moderate shortage of rainfall.

In the upper portions of the mountainous area the climate is sub-humid, temperate and has low winter rainfall.

In the Cañada Poblano-Oaxaqueña and the Upper Mixteca the climate is arid or semi-arid, hot with year-round lack of rainfall.

Cyclones have been a major cause of floods of the Papaloapan River and large parts of the lower portion of the Basin. In 1944 two cyclones caused the greatest flood in the last 100 years inundating a number of towns and covering several hundred thousand hectares.

The coastal area was colonized and divided into large estates.

Since then a number of ways of using the land have been recorded, some successful, some failures. The growth of sugar cane, bananas and tobacco has been successful due to appropriate soil and climate and to promoting action.

Later, cattle-raising appeared as a more or less stable and productive enterprise.

In other areas of the Basin, soil exhaustion and poor growing practices have placed the farmer in a very precarious position and have frequently caused the abandonment of land. In comparison to the low-lands, the mountainous portion of the Basin has always been densely populated by different ethnic groups. Perhaps the insolation which they maintained, and still maintain, has been the determining factor in the survival of Mazatecos, Chochos, Ixcatecos, Mixtecos, Cuicatecos, Zapotecos, Chinantecos, Nahuas, Mixes, Totonacas and Olmecs.

The social organization of the Indian population is different in each area, as is the relationship between Indians and "mestizos". Whenever we evaluate socio-economic development programs, it is necessary to consider integration and progress of each group to assure harmonious and just participation.

It is also necessary to take into account languages and dialects when programs for the integration of cultural groups into the socioeconomic life of the country are elaborated.

The groups of this area have maintained contact with settlers since the Spanish conquest. Since the establishment of the Papaloapan Commission in 1947 they have been subject to more active communication among themselves as well as with a number of newly-arrived settlers. In spite of this increase in communication, the Indian groups have maintained their social structure. Their technological level has gone little beyond the limits of the original culture. To a large degree the persistence of this marginalism has been due to the fact that important aspects of the native culture have not been amenable to socio economic changes based on policies of understanding and social justice. In addition, the practices of middlemen, tradesmen and small businessmen, most of whom are "mestizos", has also led to insulation for self-protection.

PROBLEMS OF THE PAPALOAPAN BASIN

FLOODING

Since this is a Coastal Plain, it is only natural that there is frequent flooding. This tendency is enhanced by the location of this area within the cyclone zone of the Gulf of Mexico. Unexpected floods cause considerable damage, not only affecting the economy of the area, but frequently leading to the loss of life. The most extensive of these floods covering 470,000 hectares, took place in September of 1944 and caused great losses of life and property.

In 1958 and 1969 there were further disastrous floods, both taking place after the President Miguel Alemán Dam had been built on the Tonto River. The 1958 flood covered 195,000 hectares and the one occurring in 1969, 340,000.

The losses caused by these floods are hard to quantify, but in 1944 were estimated 30 million pesos and 100 lives. The economic losses in 1958 reached 40 million because agricultural production had increased considerably. In 1969 losses were estimated at 443 million because infrastructural development as well as industrial and agricultural investments were greater than before.

The flood situation has become more dangerous in spite of the President Miguel Aleman Dam. The Papaloapan River capacity has been reduced from 5,000 to 3,500 m^3/sec as a consequence of the deposition of sediment carried by the Santo Domingo River. The probable maximum flood is about 14,000 m^3/sec and would occur with simultaneous flooding in the Tonto, Santo Domingo and Valle Nacional Rivers.

The persistence of this dangerous situation has impeded development of the basic infrastructure and in consequence, isolation of large sectors of the population persists especially in the mountainous zone where the construction of roads is difficult and costly.

Most of the marginal groups work in extensive agriculture and cattle raising systems that have not transformed the productivity to satisfy the demand that would result from economic improvement of the population. These land use practices have increased deforestation and erosion of scarce flat areas.

Technological change in this area cannot be simple modification of the farming system, but must be carried on within the framework of an integral development. The integration of cultural groups is a challenge for the technicians and planners, because of the great internal cohesivness of the groups present. The change from their subsistence economy and town market system to a commerical economy will not be easy. Not only will technological change be necessary, but also an economic and social infrastructure which will improve productive organization without damaging their culture must be developed.

Another major problem in the basin is water pollution, especially of the Blanco River, which has several factories along its course.

Sugar mill effluents entering other streams increase the B.O.D. of the water and damage fisheries of the Alvarado Lagoon and the shore close to river outlets.

SOLUTIONS

The Papaloapan River Commission was established largely because flood control measures require planned solutions affecting the entire Basin. Up to 1947 only a few isolated studies had been made for the construction of flood control works. During the same year, the Commission was officially established for the purpose of planning and executing a program of integrated development for the region. The wide range of activities of this body include anti-malaria campaigns, flood prevention, education, construction of over 2,000 km of roads, irrigation, settlement and farm credits.

Essential to flood control and the generation of electric power, the primary responsibilities of the commission, were the construction of the Temascal and Cerro de Oro dams. The Temascal Dam on the Tonto River was built between 1949 and 1955. Construction of the Cerro de Oro Dam on the Santo Domingo River was planned for the mid-1950's. Flood control works along the edges of the Papaloapan River have been and are being constructed.

In spite of what has been done, the development of the region requires several projects that were not completed because of the lack of financial resources. Among these are the multiple-purpose Cerro de Oro Dam, with which the risk of flooding will be reduced to the capacity for which flood control measures were built on the Lower Papalóapan.

The Cerro de Oro and President Miguel Aleman Dams would impound a single reservoir with a maximum capacity of 13,300 million m^3. Because a single reservoir would be formed, power generation at the existing plant at Temascal would be increased.

At the same time it will be possible to increase the area under irrigation for the production of meat, sugar, fruits and oil crops. With controlled water use it is possible to integrate water resources with groundwater, so as to facilitate irrigation and drainage of 180,000 ha of the Lower Papaloapan.

Concurrent with these projects there have been studies on conservation and management of basins and on development of areas which may increase their production without irrigation. Integrated programs for soil and water conservation, technical assistance, road networks in undeveloped areas, forest utilization and farm industry have been developed.

Fishing is being encouraged to improve diets and to increase tourist use of reservoirs.

The impact of the Commission's works in increasing harvested areas is evident if we observe the increase from 223,000 to 800,000 ha between 1947 and 1970. The total value of production increased from 569 million pesos to over 6,500 million, at current (1973) prices.

Income from public and private investment calculated by means of a multiplier, is greater than double the initial investment.

One social problem of great importance related to the construction of the Cerro de Oro Dam is the flooding of 20,000 ha, of farmland now belonging to 19,029 people in 52 communities.

90 percent of this surface is held by "ejidos" and the remaining 10 percent is privately owned.

Most of the inhabitants belong to the Chinanteco linguistic group. They have long been permanently settled and their culture is well developed. Around 1,300 A.D. they had established a significant number of villages which were divided into two "señoríos" (dominions).

Even today the villages of Chinantla (lower area of the Oaxacan part of the coast) maintain strong economic, cultural and political ties. Their social structure is strong and maintains their customs and traditions, above all a courageous attitude in defense of the group.

57 percent of the people are monolingual and the Spanish of the bilingual group is rudimentary.

The economy is based on subsistence farming. A co-operative work system is maintained for farm labor and work of a social nature such as road and school repairs and the construction of houses.

Techniques and tools are basically the traditional Indian type, and are frequently manufactured in the home. While the Indians are not ignorant of farm machinery, its use is limited to the privileged land owners or wealthy mestizos called "ladinos". Cattle raising is not an important aspect of the economy. Chicken and hogs are raised for local consumption. Means of trade are traditional like the people themselves. Street vendors and commerical establishments form a small portion of the economy, but are exploitative, absorbing the small surplus available.

Housing, constructed entirely of local material, is insubstantial and easily infested. There are variants in the construction of houses which indicate the social strata among the traditional Indian as well as the "mestizo" or aculturated Indian.

Dress (the huipil) can be divided into three classes, according to the type of thread used and the amount of labor involved in its production.

Ceremonies at transitions are changes in life show the individual's relationship to the society. Behavior during pregnancy, the practice of couvade, measures taken in cases of sterility, the cermony followed by the couple and the midwife during birth, the burial of the umbilical cord symbolizing the link between the child and his environment; the transition to puberty, marriage and death, and acts of regeneration of life (before the presence of death) through sex, impress an unusually strong sense of indentity upon the Chinanteco.

Social organization is based on five different age groups, each with a different language, which evolve through life in an ascending hierarchical order. At each stage there are well-defined socio-political-religious responsibilities. At the highest stage is found the Council of Elders, influenced by political leaders or groups which strive for political as well as economic control.

This whole structure, ornamented with ritual "fiestas" and "protected" by an extraordinarily rich magical-religious sensitivity, cannot be easily eliminated by the mere proposal of constructing a dam.

Facing this problem, with a sincere desire to help, causing the least damage possible, is not an easy task or quickly resolved. It was necessary to undertake studies in social anthropology, power structure, attitudes towards change and other cultural aspects at the same time that the geology of the dam was being studied and tests on soil mechanics were performed.

Physically, the problem does not present major complications. The relocation of 3,000 families would require an investment of less than 5 percent of the total cost of the project. However, land is scarce in the area of irrigation. Relocation would require fragmentation of social groups, an alternative accepted only by "mestizos" and tradesmen. The Indians require that their social system not be disrupted and that they not move too far from their place of origin.

Progress itself comes to our aid. A desire to satisfy the land requirements of children and relatives increases weakening the ecological cohesion of the group. A majority accept the decision to move to a different, but single, area.

It took singlemindedness to overcome the opposition of large land holders and tradesmen who were against the construction of the dam, wishing to maintain their privileges.

When it was felt that all would be satisfied; some with land, municipal works and services, schools, workshops, social and technical assistance, etc.; others with fair payment for their belongings, a new conflict appeared between traditional Chinantecos and greedy livestock-raisers. Then there arose a miracle: "The Virgin appears and orders a peasant that the dam must not be constructed". This last card played by internal colonialism, begins a Messianic movement whose magnitude, although limited, is not to be scorned. So we are now waiting for another miracle to arise and for the dam to be built for those who do not want it as well as for all those who do, because all need it.

MEMBERS OF THE SEMINAR, 1971–72

Chairman of the Seminar:
George J. Halasi-Kun
Hydrologist
Columbia University

Steering Committee:

Charles H. Behre, Jr.
Professor Emeritus of Geology
Columbia University

Courtney C. Brown
Dean, Graduate School of Business
Columbia University

Laszlo Czirjak
International Financial Research
633 W. 115th St., New York, 10025

Jewell M. Garrelts
Associate Dean of School of Engineering & Applied Science
Columbia University

Wesley J. Hennessy
Dean of School of Engineering & Applied Science
Columbia University

Kemble Widmer
State Geologist of New Jersey
Trenton, New Jersey

Members:

Enrique Gregorio Aisiks
Consulting Engineer
Buenos Aires, Argentina

Thad P. Alton
International Financial Research, Inc.
633 West 115th Street
New York, N.Y. 10025

Charles G. Amato
Nuclear Engineer, Department of Environmental Protection
State of New Jersey
Trenton, New Jersey

Conrad M. Arensberg
Professor of Anthropology
Columbia University

Armando Balloffet
Civil Engineer, Lecturer of Columbia University
c/o Tippetts Abbett-McCarthy-Stratton, Engineers & Architects
New York

Joseph Barnea
Director, Department of Economic & Social Affairs
Resources & Transportation Division
United Nations, New York

Samuel S. Baxter
Water Commissioner
Water Department
City of Philadelphia

Byron Beattie
Expert on Forest & Watershed Management
United Nations
Manila, Philippines

Chaba Benedek
Chief Engineer
Swindell-Dressler Pan American Co.
Inez, Kentucky 41224

Paul Bock
Professor of Hydrology
University of Connecticut

L. Joseph Bollyky
Pollution Control Industries, Inc.
Stamford, Conn. 06902

Stephen K. Breslauer
NUS Corp. Environmental Safeguards Division
Rockville, Md. 20850

Wallace S. Broecker
Professor of Geology
Columbia University

Joseph H. Butler
Professor of Geography
State University of New York at Binghamton

George Claus
University of Vienna, Austria
Faculty of Medicine

Leonard B. Dworsky
Professor of Civil Engineering
Cornell University

Augustine O. Esogbue
Professor of Industrial & Systems Engineering
Georgia Institute of Technology

John Fabianek
Professor of Life Siences
New York Institute of Technology

Rhodes W. Fairbridge
Professor of Geology
Columbia University

James J. Geraghty
Groundwater Geologist
Port Washington, New York

Robert D. Gerard
Research Associate in Physical Oceanography
Columbia University

Samuel Gofseyeff
Civil Engineer
White Stone, New York

Alvin S. Goodman
Professor of Civil Engineering
New York University

Harry P. Gregor
Professor of Chemical Engineering
Columbia University

Guy R. Gresford
Director, Section of Science & Technology
United Nations, New York

M. Grant Gross
Professor of Oceanography
State University of New York at
Stony Brook

Isadore S. Grossman
Board of Water Supply of
New York City

William A. Hance
Professor of Geography
Columbia University

Ernest LeRoy Hendricks
Chief Hydrologist
U.S. Department of the Interior
Geological Survey, Washington, D.C.

John E. Harrison
Director, Environmental Quality
New York State, Department of Health

Allan Hirsch
U.S. Department of the Interior
Federal Water Pollution Control
Washington, D.C.

Robert Hordon
Professor of Geography
Rutgers University

Raphael Hurwitz
Board of Water Supply of
New York City

John A. Jones
Professor of Earth Sciences
Miami-Dade Junior College

William C. Kennard
Director, Institute of Water Resources
Research
University of Connecticut

Walter Kiechel, Jr.
Deputy Asst. Attorney General
Land & Natural Resources Division
U.S. Department of Justice
Washington, D.C.

Adolfo Korn
Mining & Mechanical Engineer
Section of Science & Technology
United Nations, New York

Martin Lang
Commissioner of Water Resources of
New York City

Gregory Lazarcik
Professor of Economy
State University of New York at
Geneseo

Cyrus Levinthal
Professor of Biology
Columbia University

Robert A. Lewis
Associate Professor of Geography
Columbia University

Daniel P. Loucks
Associate Professor of Water Resources
Engineering
Cornell University

Everett L. McLeman
U.S. HEW, Public Health Service
New York, New York

Francis M. McGowan
North Atlantic Division
Department of the Army Corps of Engineers
New York

Ulrich Maniak
Professor of Hydrology
Technical University
Braunschweig, F.R. Germany

David C. Major
Asst. Professor of Economy
Massachusetts Institute of Technology

David Miller
Groundwater Geologist
Port Washington, New York

Mahboob Mohammad
Sr. Lecturer of Chemistry
University Islamabad, Pakistan

Francis W. Montanari
Parsons, Brinckerhoff, Quade & Douglas
Engineers
Denver, Colo.

Nathaniel M. Perlmutter
Hydrologist
U.S.G.S. Water Resources Division
Mineola, New York

Charles M. Pike
Director, Water Resources Division
Environmental Protection Department
Trenton, New Jersey

Habib S. Rahme
Nassau College
Long Island, New York

George Redey
Civil Engineer
Englewood, New Jersey

Peter P. Remec
Professor of Political Sciences
Fordham University

Roland R. Renne
Associate Dean
University of Illinois

Hugh B. Ripman
Director of Administration
International Bank for Reconstruction and Development
Washington, D.C.

Oswald A. Roels
Sr. Researcher in Marine Biology
Columbia University

Harold R. Shipman
Head of Water Supply Division
International Bank for Reconstruction and Development
Washington, D.C.

Richard Skalak
Professor of Civil Engineering
Columbia University

Lawrence Slote
Grumman Aerospace Corp.
Bethpage, New York

Zdenek Slouka
Associate Professor of Political Sciences
Lehigh University

Nicolay P. Timofeeff
Professor of Geography
State University of New York at Binghamton

Michael A. Tirabassi
Asst. Professor of Operations Research
Stevens Institute of Technology

John Volkert
Associate in Geography
Barnard College

Grant F. Walton
Associate Professor of Environmental Sciences
Rutgers University

Leon W. Weinberger
Vice President
Environmental Control Management
Zurn Industries, Inc.
Washington, D.C.

William Whipple, Jr.
Director
Water Resources Research Institute
Rutgers University

Gordon R. Williams
Professor Emeritus of Civil Engineering
Massachusetts Institute of Technology
c/o Tippetts-Abbett-McCarthy-Stratton, Engineers & Architects
New York

John Winsser
Associate Professor of Biology
Long Island University

Lamar J. Worzel
Professor of Geology
Columbia University

Christopher Wright
Director
Institute for the Study of Science in Human Affairs
Columbia University

Akhtar Yaseen
Chief of Laboratories
New York Medical College

Warren E. Yasso
Associate Professor of Natural Sciences
Columbia University, Teachers College

Leonard B. Zobler
Professor of Geology & Geography
Columbia University

JUNIOR MEMBERS:

Lawrence A. Buck
Northport, New York

Kathy Hartman
Brooklyn, New York

Steve Hartman
Roslyn Heights, New York

William Jamieson
Amityville, New York

Peter P. Madri
Seacliff, New York

Yeshwant K. Purandare
East Farmingdale, New York

Frank Pecenka
New York, New York

Gerald W. Robin
Hicksville, New York

☆ U.S. GOVERNMENT PRINTING OFFICE: 1980 O— 311-344/97