SIMULATION OF RAINFALL, RUNOFF, PEAKFLOW AND SOIL LOSS IN THE UPPER GAMBIA RIVER BASIN.

by

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ABSTRACT

A number of West African river basins are under study for management and development of major projects such as irrigated agriculture supported by dams and reservoirs. For many of them the dams exist or are being built, on the Senegal river basin for example.

The Gambia river basin management process is one of the latest and need major basic studies especially in hydrology and watershed management. This study is a contribution for the hydrologic analysis and modeling of the Gambia river upper basin.

The study assesses the distributions and the statistics of recorded rainfall data and simulates long term sequences of data. Correlations between rainfall depth and rainfall duration then others between rainfall duration and rainfall excess duration are defined for time to peak and peakflow computation. It assesses as a first step towards further studies runoff and soil loss. One of the major problems that threatten the dams and reservoirs in that West African region is the erosion and sediment transport.

1. INTRODUCTION

The weather patterns in the SAHEL region, especially in West Africa these last 15 years, are characterized by severe droughts. Several river basin development projects have been implemented as the result. The major objectives of these projects are to prevent food shortage and increase energy production. Most of the major West African rivers are under active management, and usually riparian countries cooperate with the help of international funding agencies such as FAO and AID to carry out the development activities. (see figure 1)

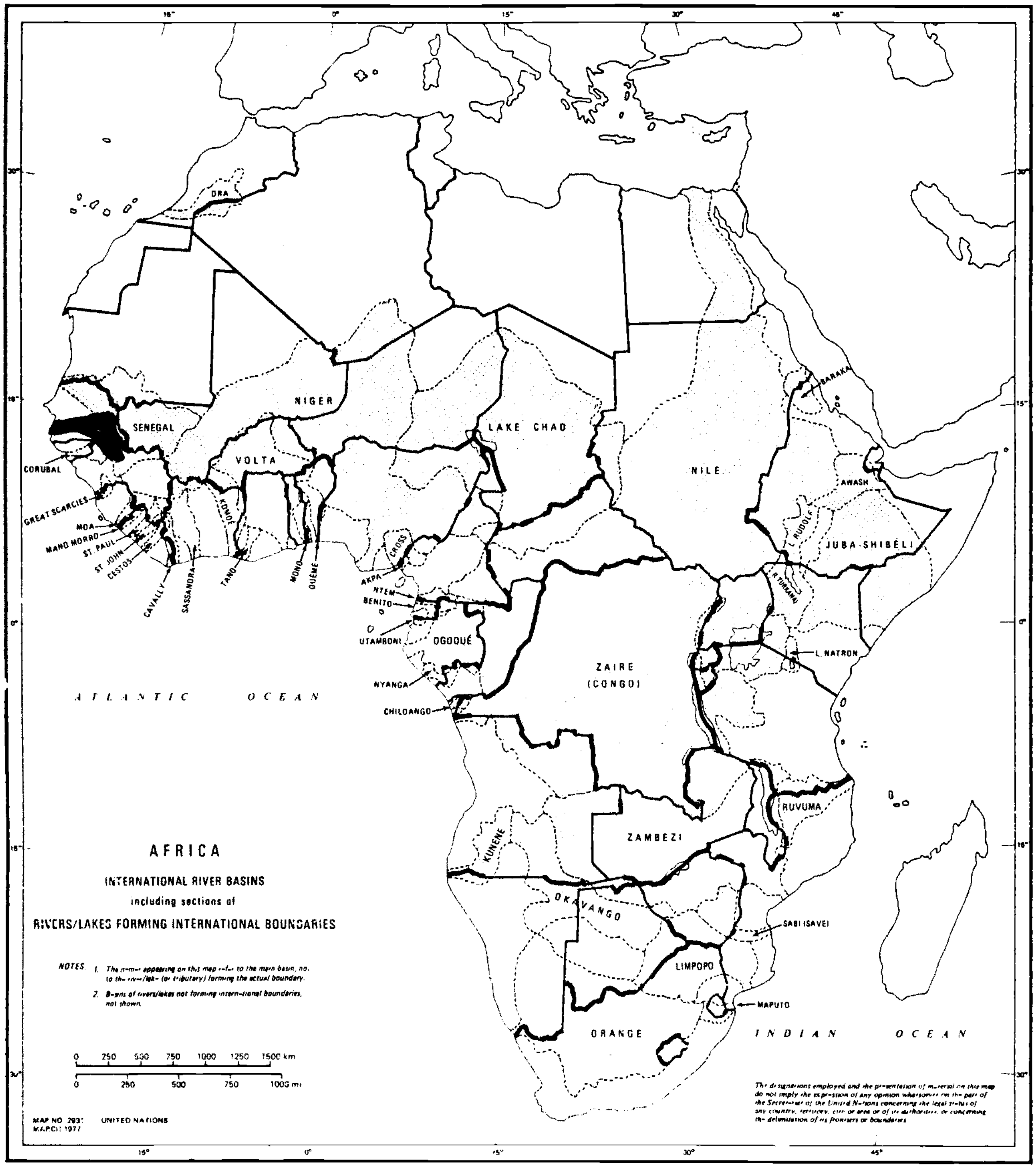
The countries involved in the Gambia River Basin development are: the Gambia, Guinea, Guinea Bissau, and Senegal. Their common institution is the Gambia River Basin Commission, (OMVG: organization pour la Mise en Valeur du fleuve Gambie), headquartered at Dakar, Senegal. The role of OMVG is to coordinate development activities and promote development projects, primarily for river control and irrigation.

The major development projects under study are:

a) A series of high dams:

- Balingo, in the lower basin in the GAMBIA;
- Kekreti, in the basin mid-section in SENEGAL;
- Kouya, Kogoufoulbe and Kankakoure in GUINEA.

Fig. : 1 : African International River Basins.



b) Irrigated areas in the Gambia and in Senegal.

c) Energy production at Kekreti and eventually at Kouya.

d) Possible construction of small earth dams in the upper basin in Guinea for local development of flood plains.

With the implementation of the projects, the activities of OMVG will include monitoring studies such as: water quality and quantity assessment, water rights, protection and conservation of natural resources, agriculture extension, etc..., in relation with the institutions of the member States.

Developing simulated sets of data that are as close as possible to the observed data allows for long sequences of information that can be used for planning purposesses, structural projects, irrigation water supply for industry, energy production and drinking water.

The main problem that has to be solved in the Gambia river upper basin is the highly degraded conditions of the vegetation cover. Shifting cultivation and clearing of the vegetation expose the soils to wind and water erosion, especially during the dry season and at the beginning of the the rainy season. The subsequent sediment load carried into the river and its tributaries is a major threat for the dams that are projected for construction in the Gambia river basin. The phenomenon has to be assessed and the characteristics defined for mitigation measures to be taken on a rational basis.

The Kouya dam planned for future construction is one of the major projects in the Gambia river basin even though it does not have a high priority. The reservoir behind the dam could be important for irrigation and energy production. However, the conditions of erosion in the upper basin are a major factor in limiting its lifespan.

Using observed rainfall data (1963 - 1982) from the meteorological station of Labe-Aero (12' 16" W, 11' 19" N) near the Kouya watershed in the Gambia river upper basin in Guinea, the objectives of this study were to:

* Determine the distributions and the statistics of the historical data for interarrival time, and rainfall amounts per day.
* Simulate a longterm sequence (100 years)of synthetic rainfall data based on the statistics of the historical data.
* Estimate runoff from the watershed using the SCS method;
* Estimate sediment delivery to the river using the Modified Soil Loss Equation (MUSLE).

2. APPROACH

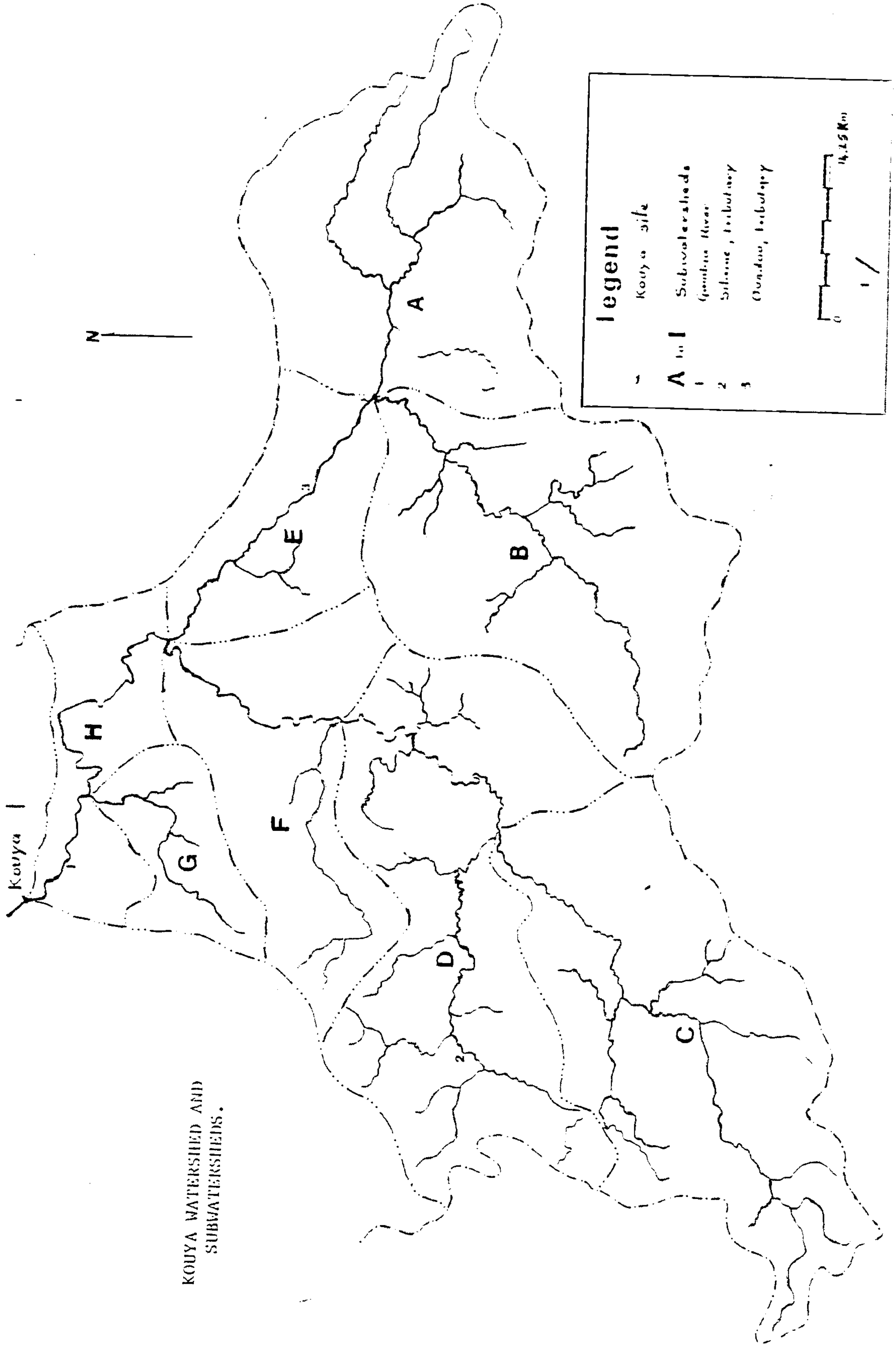
This study was made as a first step towards assessing the potential sediment load delivered into the Gambia River channel. The transport of sediment in the channel and the subsequent effects on reservoir capacity were not included in the study, but should be the subject of future research. The first step in this study was to develop a stochastic model for simulating long sequences of rainfall data for the meteorologic station of Labe-Aero. The Labe-Aero station is located just outside the upper basin boundaries, however, it was the only station available for the watershed. A new station installed within the river basin at Balaki is not yet fully operational.

The study assessed the distributions and statistics (Variance, mean, lambda and k) of the historical data which were used as parameters for modeling and synthesizing. This technique provides artificial data similar to the historical records. The technique is basically an approximation, and can be used where the records are not of sufficient length for planning and management purposes. The use of historical data is recommended if the record has been taken over a period sufficiently long to include the extreme events that might occur.

The second step in the study, after rainfall simulation, was to estimate the runoff in the Kouya dam site subwatershed using the SCS (Soil Conservation Service of U.S.A.) method, and then to assess the soil loss potential using vegetation and soils maps of the subwatershed and the Modified Soil Loss Equation. The Kouya watershed is larger than recommended for application of the SCS method. Therefore, the watershed was divided into eight smaller subwatershed areas, labelled A to H in figure 2.

The volume of runoff, peak flow and soil loss prediction was computed for each subwatershed and added to give totals.

Fig. : 2 : Kouya Watershed and Subwatersheds.



3 - THE GAMBIA RIVER BASIN

The Gambia River originates from the Fouta Djallon mountains (highest peak: 5046 feet), and flows through three States: Guinea, Senegal, and Gambia. The three states, joined by Guinea Bissau (which includes a tiny portion of the basin) are planning the development and management of the river. Some characteristics of the basin are given in table 1. The northern section of the basin (above the 13th parallel) is in the Sahel subclimatic region. The southern portion is mostly in Savanna grassland with a higher density of tree cover and with gallery forests along the river and tributaries. The topography along the river is relatively flat except in the south where the river makes its way through the Fouta Djallon Mountains.

Field surveys have identified several potential dam sites and also rich flood plains that can be converted into irrigated agriculture areas. Several dam projects are under study for implementation in the near future: They can be listed by priority as:

a) The Balingo dam, located at 130 km from the Atlantic Ocean. The major objectives are:

- stop the salt water intrusion up-river,
- fresh water storage for agriculture,
- regulation of the river flow,
- bridge and navigation lock for road and river transportation.

b) The Kekreti dam, located at 800 km from the sea

Table 1: Some characteristics of the Gambia River Basin:

	Basin sub-section area; km^2	River sub-section length; km	Annual mean precip; mm	mean discharge m^3/s
GUINEA	7100	150	1600	83
SENEGAL	42250	450	1200	168
GAMBIA	28500	500	800	270
Total	77850	1100		

has a proposed reservoir of $5,2.10^8$ m^3 ($1.8364*10^{11}$ ft^3). It has a subwatershed of 13,400 km^2 (5,173.77 mi^2). The proposed objectives of the dam require a mean release of water of 45 m^3/s (1,589 ft^3/s). This includes:

- 7,000 ha of irrigated areas,
- electric energy production,
- hold back the salt water intrusion downstream at the Balingo dam site in case the Baigo dam is not constructed.

c) The Kouya dam is located in the upper basin in GUINEA with a proposed storage capacity of 4,300 * 10^6 m^3 (1.518 * 10^{11} ft^3), and a subwatershed of 3,800 km^2-1,467.19 mi^2-(4,250 km^2 was measured in this study).

d) Two other dam projects are being studied also in the GUINEA upper basin: Kankakoure and Kogoufoulbe.

4 - RAINFALL ANALYSIS

A 30-year record (1953-1982) of daily precipitation was available from the meteorologic station of LABE-AERO in Guinea. All rainfall events recorded that were greater than 2.5 mm were entered into the computer by year, month and day for the 30 year period. The data were separated into the following periods for future analysis:

- 1953 to 1982 = 30 years;
- 1953 to 1961 = 15 years;
- 1968 to 1982 = 15 years;
- 1963 to 1982 = 20 years.

The data were analyzed to develop distribution functions that would allow long term stochastic simulation.

The simulation required distribution functions for the amount of rainfall per day and for interarrival time between days on which rainfall occurred. Two programs were used for the analysis: one for interarrival time and another for rainfall amount per day. These programs were developed by Jones (1981) and modified since then to characterize summer precipitation in South Western United States.

Interarrival times are defined as the number of days between rainy days plus one day. (e.g.: two consecutive rainy days are separated by one interarrival day; rainy days that are two days apart are separated by 3 interarrival days).

After computing the interarrival times, the parameters for a PDF (probablity distribution function) and a CDF (cumulative distribution function) were generated. The distributions obtained were then compared with theoretical exponential, geometric and gamma distributions provided also by the program. The K-S test was made to select the theoretical distribution that best fit the actual distribution of interarrival times.

The Student's T-test was also used to determine the consecutive months that were similar in the distribution of interarrival days.

Rainfall amounts were sorted into intervals of 2.5 mm by month for the historical period of record. The PDF and CDF were then computed and compared with theoretical distributions described above.

5 - RESULTS OF THE PRELIMINARY ANALYSIS

The rainfall events that occur in December, January and February are very small both in depth and number. No rain was recorded for March during the 30 year period of record. Consequently, the data for those months did not fit any of the common theoretical distributions. The decision was made to ignore the rare rainfall events that occurred during these four months and to define the dry season as starting in November and ending in April.

The wet period, it was therefore assumed, extends from the end of April through October. About 94 percent of the annual precipitation occurs during this period.

The results of fitting the distributions are given in table 2. The following characteristics of interarrival time were adopted:

- November to April: dry season,the interarrival time is assumed to be equal to the length of the month.
- May through October: The Geometric distribution was adopted.
- November,December and April: considered to be in the dry season, even though it rains occasionnally during those months.

No single theoretical distribution was found to fit rainfall amount per event for all of the months. The results of fitting were best for the exponential distribution, shifted and not shifted, but were unsatisfactory for June, July and August (Table 2).

STUDENT'S T-TEST.

Student's T-test was used to assess similarity in the amount of rainfall per event and the interarrival time between events for the purpose of grouping similar consecutive months. The entire 30 year period was used in the analysis. Degrees of freedom and T-values were calculated by the same program that computed the distribution parameters for precipitation. The computed values were then compaired with T-table values.

The differences for interarrival time were highly significant for all the months. Differences in precipitation amount per event were not significant for months within either the wet season or the dry season. However there were large differences between seasons. The differences between April and May in the beginning of the wet season and between October and November at the end of the wet season were highly significant.

Because of the non-similarity in interarrival times between any of the months it was decided not to group months, but to treat each month separately on a daily basis.

ANALYSIS OF THE SUBSEQUENCES OF THE RECORDED DATA:

A further analysis of the 30 year historical record was made to test for homogeneity by breaking the record into subsequences of 15 and 20 years. The distribution parameters were determined for each subsequence

Table 2: Fitted distributions for each month of the period 1953-82.

MONTHS	INTERARRIVAL TIME DISTRIBUTION	RAINFALL AMOUNTS DISTRIBUTION
April	GAMMA	EXPON. not shifted
May	GEOMETRIC	EXPON. shifted
June	GEOMETRIC	EXPON. close to
July	GEOMETRIC	EXPON. close to
August	GEOMETRIC	EXPON. close to
September	GEOMETRIC	EXPON. shifted
October	GEOMETRIC	EXPON. shifted
November	GAMMA	EXPON. not shifted

Table 3: Mean number of events and mean rainfall amounts per month over the period of 30 years (1953-1982).

MONTHS	TOTAL PPT mm	MEAN PPT mm	TOTAL EVENTS	MEAN EVENTS
January	67.1		5	
February	77.1		9	
March	249.9	8.33	23	0.77
April	1210.3	40.34	95	3.17
May	4356.5	145.17	288	9.6
June	7232.2	241.00	453	15.1
July	9709.51	323.65	562	18.73
August	10431.8	347.73	595	19.83
September	9318.31	310.31	572	19.
October	4463.9	148.8	351	11.7
November	1158.3	38.61	76	2.53
December	218.2	7.27	11	

years. The distribution parameters were determined for each subsequence and the K-S test applied. The subsequences tested were:

- 15-year subsequence, 1953 - 1967;
- 15-year subsequence, 1968 - 1982;
- 20-year subsequence, 1963 - 1982.

Results of the analysis for precipitation per event were:

- The data for 1953-1967 were found to fit a gamma distribution for April, May, June, July and November. The data for August, September and October approached a gamma distribution but did not pass the K-S test (table 4)
- The data for the months of April to November for 1968-1982 fit the gamma distribution (table 4).
- The data for the months from April to November fit a gamma distribution and that for August was close to GAMMA (table 4) for the sequence 1963-1982.
- The distribution analysis of the entire sequence of 30 years of data (1953 to 1982) showed distributions close to exponential for May through October but only April and November showed a significant fit (table 4).

Because the 20 year sequence (1963-1982) was consistent in fitting the gamma distribution, this period was selected for developing the simulation.

Table 4: Comparison of different subsequences of the historical data.

PERIOD 1953 - 1982

MONTHS	OCCURRENCES	PRECIP/OCC.	VARI.	DISTRI.
April	3	12.74	94.876	EXPOnot sh.
May	9	15.127	165.635	EXPO sh.
June	15	15.965	172.64	EXPO cl.
July	19	17.267	200.15	EXPO cl.
August	20	17.532	250.714	EXPO cl.
September	19	16.290	176.923	EXPO sh.
October	11	12.718	114.728	EXPO sh.
November	2	15.241	300.414	EXPO not sh.

PERIOD 1968 TO 1982

MONTHS	OCCURRENCES	PRECIP/OCC.	VARI.	DISTRI.
April	3	13.705	97.528	GAMMA
MAY	9	15.002	151.403	GAMMA
JUNE	14	16.385	170.228	GAMMA
JULY	17	16.694	162.423	GAMMA
AUGUST	19	16.675	209.556	GAMMA
SEPTEMBER	18	16.131	146.053	GAMMA
OCTOBER	10	12.036	88.973	GAMMA
NOVEMBER	2	11.91	127.4.5	GAMMA

cl.GAMMA = close to GAMMA.

PERIOD 1953 - 1967

MONTHS	OCCURRENCES	PRECIP/OCC.	VARI.	DISTRI.
April	3	11.908	93.2	GAMMA
May	10	15.241	179.805	GAMMA
June	16	15.579	175.278	GAMMA
July	20	17.793	233.663	GAMMA
August	21	18.316	287.809	cl.GAMMA
September	20	16.432	204.871	cl.GAMMA
October	13	13.221	133.663	cl.GAMMA
November	3	17.296	400.948	GAMMA

PERIOD 1963 TO 1982

MONTHS	OCCURRENCES	PRECIP/OCC	VARI.	DISTRI.
April	2	12.986	119.749	GAMMA
May	9	15.038	162.781	GAMMA
June	14	16.483	180.256	GAMMA
July	18	16.932	178.084	GAMMA
August	19	16.561	207.493	cl.GAMMA
September	19	16.437	183.334	GAMMA
October	11	12.560	102.716	GAMMA
November	2	13.146	188.294	GAMMA

Over 94 percent of the annual rainfall in the study area occurs during the wet period of May to October. The rare events that do occur occasionnally just prior to and immediately after the rainy season seldom produce runoff. Therefore, the assumption was made that no rainfall occurs in the dry season. Precipitation was simulated according to the following:

1) A 100 year synthesis was made for precipitation falling only in the wet season between April and October.

2) A 20 year period (1963-1982) of historic data was analysed to develop the following distributions:

- geometric for interarrival time;
- gamma for rainfall amounts.

3) The process of generating synthetic rainfall data was made on a daily basis for every month. The synthesis employed the parameters derived for each month.

6 - RAINFALL DATA SYNTHESIS

The program that synthesizes rainfall data generates first a gamma distribution using the parameters defined for each month. That distribution is the basis for the synthesis of rainfall amount per event.

The interarrival time parameters are used to generate geometric distributions for each month. A uniform random number (0,1) is generated and compared with the CDF of a one day interarrival time to determine if the interarrival time to be generated will be one day or more. Interarrival time is then computed. A CDF is selected from the gamma distribution to generate the rainfall amount.

The distribution of the amount of rainfall over the year is a major concern in areas with long dry seasons and relatively short wet seasons.

Particular care was taken in this study to make sure that the program synthesized long-term daily precipitation in the manner which occurs naturally. The tables 5 and 6 are given in generation parameters. An equation in the program allows the synthesized data to be adjusted. The equation is:

$$X = j / A + (i-1) / B \qquad (1)$$

where:

X = rainfall amounts in mm;

i-j = counters;

A-B = adjustment parameters.

Table 5: Gamma parameters of precip/event for each month.

MONTH	MEAN	VARIANCE	LAMBDA	K	DIST.
May	15.038	162.781	0.0923836	1.3892868	GAMMA
June	16.483	180.296	0.0914399	1.5071669	GAMMA
July	16.932	178.084	0.0950778	1.6098447	GAMMA
August	16.561	207.493	0.0798168	1.3218811	GAMMA
September	16.437	183.334	0.089655	1.4736474	GAMMA
October	12.56	102.716	0.1222768	1.5357749	GAMMA

Table 6: Geometric parameters of interarrival time for each month.

MONTH	MEAN	P = 1./MEAN	DISTRIBUTION
May	2.663	1.375516	GEOMETRIC
June	1.963	0.909424	GEOMETRIC
July	1.666	0.600240	GEOMETRIC
August	1.509	0.662691	GEOMETRIC
September	1.522	0.657030	GEOMETRIC
October	2.523	0.396394	GEOMETRIC

The equation was adjusted by trial and error until a curve of the adjusted means and a curve of the generated means matched satisfactorily (table 7 and figure 3).

The algorithm of equation (1) is :

```
X = float(j) / 1000.0  +  float(i-1) /1.7
```

where:

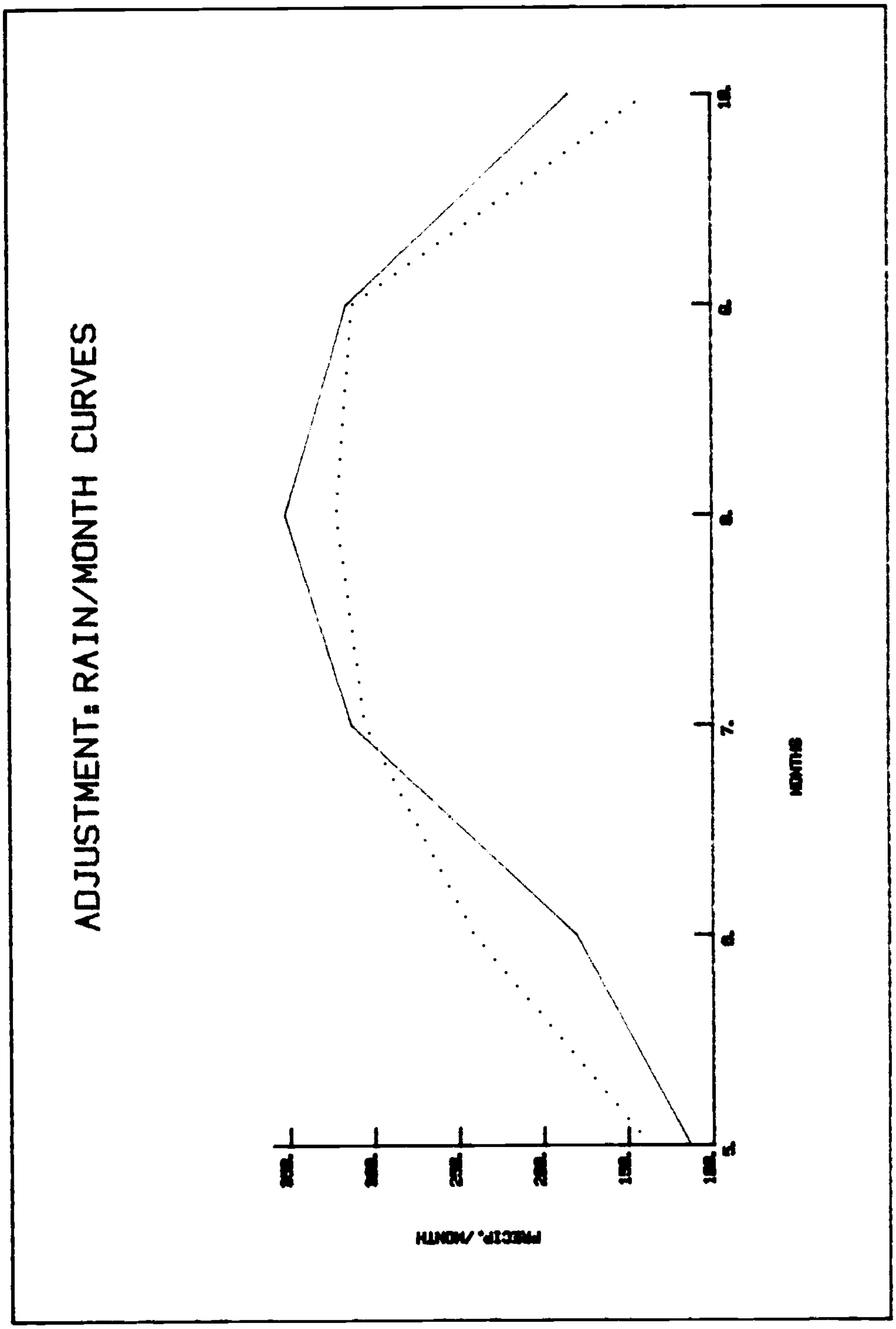
i = 1 to 120;

j = 1 to 100.

Table 7: Monthly mean number of events and mean rainfall amounts over the period 1963-1982.

MONTHS	TOTAL PPT mm	MEAN PPT mm	TOTAL EVENTS	MEAN EVENTS
March	206.7	10.34	16	1
April	766.2	38.31	59	3
May	2752.	137.6	183	9
June	4829.	241.45	293	15
July	6112.41	305.62	361	18
August	6442.4	322.12	389	19
September	6246.01	312.30	380	19
October	2750.6	137.53	219	11
November	460.1	23.	35	2

Fig. : 3 : Adjustment of RainfallAmount per Month Curve.



7 - RUNOFF VOLUMES AND PEAK FLOWS ESTIMATES

A number of ralationships have been developed for estimating runoff from rainfall. The SCS method is one of the simplest and most widely used. The method was used in the present study to estimate runoff volumes and peak flows.

Map Analysis:

Because of the large size of the watershed and the large number of 1/200,000 orthophotomaps used it was decided use a sampling method to estimate slope length, slope inclination and vegetation cover.

Runoff Volume Estimates

The SCS equation for runoff volume is:

Q = (P - 0.2 * S) ** 2 / (P + 0.8 ** S) (2)

Where :

Q = the runoff depth in mm

P = the potential runoff (precipitation) in mm

S= the potential maximum retention of the watershed that includes infiltration, interception and surface water storage.

The component 0.2 * S of the equation represents the initial abstraction resulting from early infiltration, and surface storage volume.

The parameter S lumps into one number the hydrologic characteristics of the watershed. The term is derived from an estimate of the curve number (CN) by the following relationships:

$$S = (1000/CN) - 10 \quad ; \quad \text{in english units}$$

$$S = (25400/CN) - 254 \quad ; \quad \text{in metric units}$$

where CN is estimated from field observations that include:

- slope of the watershed
- vegetation cover
- soil type
- land use
- antecedent moisture
- hydrologic condition of the basin.

For this study, maps available at the Gambia River Basin commission (OMVG-DAKAR) were used to evaluate the slopes, the vegetation cover, land use, and soil types of the subwatersheds. An average soil antecedent moisture condition (AMC) was assumed. The hydrologic condition was estimated from assumptions. Analysis of the maps, reports and personal observations gave allowed classification and grouping of the watershed areas used in order to select appropriate curve numbers. Tables of curve numbers are available in publications such as R.H. McCuen's "Guide to hydrologic analysis using the SCS methods" (1982).

<u>Runoff Computation Procedure:</u>

The SCS equation was programed for the computer. Given the curve, the initial retention (S) is calculated. The current rainfall to be converted into runoff is taken and compared with the initial abstraction. If the rainfall is less than or equal to the initital abstraction no runoff is produced. If rainfall is greater than the initial abstraction, the runoff is computed. The algorithm is:

```
IF ( RAIN . LE . ( 0.2 * S )) RUN = 0.0                (3)
RUN = ( RAIN - (0.2 * S )) ** 2/( RAIN + (0.8 * S ))
```

Since the vegetation cover changes over the year, especially during the rainy season, the parameters related to that factor must be changed accordingly. For the computation of the S factor, the curve number CN was arbitrarily set to change every month according to seasonal changes in vegetation cover. The variation of CN could have been set for shorter periods but precise phenological data were not available.

Peak-Flow Estimates:

Peak flow was estimated for each rainfall event, and the hightest peak flow of the year determined. The SCS peak flow equation was used:

$$Qp = KAQ/TP \qquad (4)$$

where: Qp = is the peak flow rate, in m3/s

K = 16.7, is a constant for the metric system.

A = watershed area, in km2.

Q = total runoff, in millimeters.

Tp = time to peak for hydrograph, in minutes.

Peak-Flow computation Procedure:

Peak flow computations require estimates of the time of concetration . Several formulas using the length of channel reach, slope parameters and watershed parameters have been developed for estimating time of concentration. In this study the lag time method was used :

$$L=((l*1000/0.3048)**0.8*(S+1)**0.7)/(1900*Y**0.5)*60 \quad (5)$$

where:

L = lag time, in minutes;

l=length of watershed along stream channel, converted into feet;

S= maximum watershed retention parameters computed from the curve number;

Y = slope in percent.

Time of concentration was computed as :

$$Tc = 5/3 * L \quad , \quad \text{in minutes} \quad (6)$$

The time to peak was computed using the time of concentration and the duration of rainfall excess according to the following equation :

$$Tp = 0.5 * DURAT + 0.6 * Tc \quad (7)$$

where:

Tp = time to peak , in minutes;

DURAT = rainfall excess duration , in minutes;

Tc= time of concentration , in minutes;

The algorithm for peak flow also computes the hydrograph base time (Tb) in minutes with :

Tb = 2.67 * Tp (8)

where :

Tb = time to peak

Peak flow is computed by :

Qp = 16.7 * A * Run/TP (9)

where:

Qp = peak flow, in m3/s

A = watershed area, in km2

RUN = runoff amounts, in mm

TP = time to peak, in mn

8 - PARAMETERS ESTIMATES

A - RAINFALL AND RUNOFF DURATIONS

Rainfall duration:

Previous studies, expecially that by Humphrey and Sons (1974) analyzed the rainfall depth-duration-frequency relationship for the major stations of the Gambia river basin using rainfall data for 24, 48, 72 and 120 hours. The probable maximum precipitation for a given period of time was derived by a first order Markov type of equation, using the method of Hershfield (1961; 1965); The equation is :

$$Xt = Xn + K\ Sn \qquad (10)$$

where:

- Xt: is the rainfall depth for a given return period;
- Xn: is the mean of annual precip. maxima for n years;
- K : is the variable related to the frequency distribution;
- Sn: is the standard deviation of the series of annual maxima for the n years.

From analysis of the graphs presented by Humprey and Sons (1974) for the Labe area, an equation relating rainfall to the rainfall duration was developed for Labe :

The equation is :

$$\log y = \log a + b \log x \qquad (11)$$

where:

y = rainfall depth
a = constant

b = slope of the curve

x = rainfall duration

The equation to compute rainfall duration is :

$$X = 10 ** ((\log y - \log a)/b) \quad (12)$$

And the algorythm is :

```
RDURAT = ( 10 ** ((ALOG (RAIN) - ALOG(A))/B ) * 60
```

with: RDURAT = rainfall duration in minutes;

RAIN = depth of a given precipitation event;

A = Intercept;

B = Slope.

Examination of the curves given in Humphrey and Sons (1974) study indicated that the range covered by the lower curve was within the range of the recorded events (see appendix 3 for Humphrey and Sons study). The values of A and B were calculated from this curve as :

A = 18.5

B = 0.454414

Runoff Duration Computation:

Most of the stream gaging stations in West Africa are non-recording, and there are very few meteorological stations equipped with recording raingages. Therefore, measurements or calculations of the duration of rainfall excess are not available and it is necessary to develop a method of estimating the duration of rainfall excess using calculations of rainfall duration.

It was assumed that the duration of rainfall excess was related to the curve number (CN). It was also assumed that when the curve number is equal to 100 the duration of rainfall excess was equal to the duration of runoff and that the relationship D/PD=f(CN) can be described as an exponential function of the form:

$$D/PD = c * e ** (K.CN) \qquad (13)$$

where:

PD = rainfall duration , in hours;

D = runoff duration , in hours;

CN = curve numbers;

k and c = coefficients.

The boundary conditions of the equation are:

when: D/PD = 1, CN = 100 , (upper boundary) (14)

when: D/PD ---> 0, CN ---> 20 , (lower boundary) (15)

let D/PD = 0.0001 when CN = 20

then:

$$0.0001 = c * e ** (20 * k) \qquad (16)$$

Substituting equation (14) into equation (13)

$$1 = c * e ** 100 \qquad (17)$$

and

$$c = e ** (- 100 * k) \qquad (18)$$

Combining equation (18) and equation (16)

$$0.0001 = e ** (- 100 * k) * e ** (20 * k) \qquad (19)$$

Simplifying:

$$0.0001 = e ** (- 80 * k)$$

Taking the natural log:

$$-9.21034 = - 80 * k$$

Therefore :

$$k = 0.115129 \qquad (20)$$

Solving equation (18) for c

$$c = e ** ((- 100) * (0.115129)) = 0.00001$$

Substituting values of c and k in equation (13)

$$D / PD = 0.00001 * e ** (0.115129 * CN) \qquad (21)$$

Therefore the equation for the duration of rainfall excess is:

$$D = PD * 0.00001 * e ** (0.1151129 * CN) \qquad (22)$$

Its Fortran computational form is:

```
DURAT = RDURAT * 0.00001 * EXP (0.115129 * CN)
```

where:

DURAT = rainfall excess duration, in minutes;

RDURAT = rainfall duration, in minutes;

CN = curve number.

<u>Watershed parameters</u>:

The watershed parameters were estimated by analyzing several sets of maps of the upper Gambia river basin. The maps used were:

- Contour- orthophotomaps made by the company Mark Hurd, Minnesota, USA, 1982-1983 for USAID-OMVG;
- Soils maps made in 1983 by FAO-OMVG;
- Soil potential maps in 1983 by FAO-OMVG;
- Land use and vegetation made in 1984 by the University of Michigan-Harza-USAID-OMVG.

For each of the 8 subwatersheds of the Kouya watershed the following information was obtained (tables 8 and 9):

- subwatershed area;
- total area of each land-use or vegetation type and proportion compared to the total watershed;
- total area of each soil type;

- mean slope in percent;
- mean slope length;
- length of channel reach within the subwatershed;

The parameters given in tables 8 and 9 were used to estimate:

- Runoff and Peak flow estimate
  - .CN (curve number) and S parameters
  - .The time to peak (Tp)
- Soil loss equation parameters.

Curve Number And S Parameters Estimate :

Estimating of the curve number requires information on:

- soil type;
- land use;
- agricultural land treatment class;
- hydrologic condition of the cover;
- antecedent soil moisture.

The cycle of a very dry season alternating with wet seasons causes dramatic changes in the vegetation cover throughout the year. Except for the gallery forests which occupy a very small portion of the watersheds, all the other vegetation types are greatly reduced in the dry season. The grasslands are mostly covered by annuals are which are heavily grazed by cattle and are burned almost every year by wild fires. The land progresses back to maximum vegetation cover at about the middle of the

TABLES 8 = CHANNEL AND TOPOGRAPHIC CHARACTERISTICS OF THE SUB WATERSHEDS

Watershed Characteristics	SUB WATERSHEDS							
	A	B	C	D	E	F	G	H
Mean hight change over mean distance (M)	30.78	33.89	36.62	36.57	43.8	36.95	30.12	37.16
Mean distance (M)	271.06	261.7	237.22	244.64	266.55	254.56	253.869	252.62
Mean Slope Length (M)	272.8	263.885	240.03	247.36	270.125	257.23	255.65	255.34
Mean % Slope	11.355	12.95	15.44	14.95	16.43	14.52	11.86	14.71
Channel Length (KM)	42.180	62.145	77.520	86.640*	36.765	29.925	26.22	44.745
Routing Channel Reach Kouya Site(KM)	81.510	81.510	109.135	74.650	44.745	44.745	13.395	0

*Gambia river: 34485
Silame river: 52155

TABLE 9 = AREA (km^2) AND PROPORTION OF LAND USE, VEGETATION AND SOIL TYPES

Watershed Characteristics	A		B		C		D	
	Area	%	Area	%	Area	%	Area	%
Total area	983.63	100%	748.90	100%	809.69	100%	780.409	100%
Land-use/Vegetation								
Barelands-Rocks	11.45	1.16	28.023	3.74	3.168	0.39	12.427	1.59
Grasslands	40.53	4.12	19.088	2.55	71.559	8.84	208.261	26.67
Galery forest	4.39	0.45	8.123	1.08	21.119	2.61	13.402	1.72
Open forest	14.54	1.48	111.359	14.87	436.584	53.92	163.831	20.99
Closed forest	911.75	92.69	573.367	76.96	257.402	31.79	380.864	48.80
Rainged Agriculture	0.97	0.1	8.953	1.19	19.900	2.46	1.624	0.21
Soil types*								
1	983.63	100%	703.733	93.97	724.77	89.51	652.074	83.56
7	0	0	45.161	6.03	84.96	10.49	128.335	16.44

*1 = Lithic - Ustorthents
7 = Lithic - Ustorthents
Topic - Ustorthents
Ultic - Haplustox = with clay B Lorizon and low base status

Cont.

Cont.

TABLE 9 = AREA (km^2) AND PROPORTION OF LAND USE, VEGETATION AND SOIL TYPES

Watershed Characteristics	E		F		G		H	
	Area	%	Area	%	Area	%	Area	%
Total area	87.276	100%	436.84	100%	157.82	100%	244.162	100%
Land-use/Vegetation								
Barelands-Rocks	6.254	7.16	38.619	8.79	0	0	21.281	8.72
Grasslands	2.924	3.35	14.702	3.37	0	0	0	0
Galery forest	0	0	0.975	0.22	0	0	0	0
Open forest	51.822	59.38	144.012	32.97	33.140	20.99	4.711	1.93
Closed forest	21.809	24.99	234.740	53.74	119.969	76.02	217.358	89.02
Rainged Agriculture	4.467	5.12	3.980	0.91	4.711	2.99	0.812	0.33
Soil types*								
1	172.197	60.73	362.02	82.87	148.154	93.88	185.437	75.95
7	111.359	39.27	74.808	17.13	9.666	6.12	58.726	24.05

*1 = Lithic - Ustorthents
7 = Lithic - Ustorthents
Topic - Ustorthents
Ultic - Haplustox = with clay B Lorizon and low base status

rainy season. The rainfed agriculture areas are subjected to the same dry and wet cycle of bare land alternating with vegetative cover. The open forests and the closed forests also follow this cycle. The understory vegetation of grass and shrubs is cleared and most of the trees lose their leaves. Recovery during the rainy season is also slow. The increase in vegetation cover in the wet season modifies runoff in several ways:

a) increases interception losses;

b) increases evapotranspiration that draws directly on soil moisture ;

c) improves infiltration rates by preventing sealing of the soil surface ;

d) creates surface roughness to retard surface runoff and increase the water retained by the vegetation.

The cyclical nature of changes in the vegetation cover during the rainy season made it necessary to use a different curve number for each period of the rainy season. For the needs of this study, the curve number was calibrated for each month on the basis of estimates of the development of the vegetation cover as soil water increased.

In the Gambia river head waters, the group 'A' soil: (deep sand, deep loess, aggregated silt) and the group 'D': (soils that swell significantly when wet, with heavy plastic clays, and certain saline soils), do not exist or are negligible in extent. The group 'C': (clay-loams, shallow sandy-loams, soils low in organic content, and soils usually high in clay) occupies large areas of the watershed. Group 'B' soils (shallow loess, sandy loam) are located in the low foothills and valleys and do not cover large areas. The head waters of the Gambia River Basin is characterized by a hilly-mountainous topography and steep slopes.

Soil group 'C' was used in determining the curve numbers for the subwatersheds because of the lateritic nature of soils on the watershed. Large areas of lateritic shields appear in the watershed, and often times the laterite is present just below the first soil layer (20 to 40 cm) and limits considerably the infiltration potential. There are also calcarous or metamorphic rocks that form the hills which have a relatively thin layer of top soil. Appendix 2 gives a brief description of the soils of the Kouya watershed.

The curve number is also a function of the type of land-use and/or vegetation cover on a given soil type. Tables for estimating curve numbers were available and were used for the estimates. The curve number values were adjusted for each month according to the evolution of the vegetation cover, and also adjusted for the proportion of the different areas of land use and plant cover on the subwatersheds.

The final curve number for a subwatershed for a given month was calculated as the sums of the products of the basic curve numbers and the proportion of the different areas on the watershed (Table 10 and 11):

CN = BLR*CN1 + GF*CN2 + GLRA*CN3 + OF*CN4 + CF*CN5

With:

BLR = barelands and CN1 its curve number,

GF = galery forest and CN2 its curve number,

GLRA = grasslands, rainfed agriculture and their curve number CN3,

OF = open forest and the curve number CN4,

CF = closed forest and CN5 the curve number.

Table 10: Basic monthly values per soil-vegetation type of curve numbers. Reference: wsm 462 course.

Months	Bare lands	Galery forests	Grass-lands + rainfed agricul.	Open forest	closed forest
MAY	90	75	86	82	77
JUNE	90	75	86	83	77
JULY	90	75	87	86	78
AUG	90	75	88	86	79
SEPT	90	75	87	85	79
OCT	90	75	86	84	78

Table 11: Monthly CN for the eight subwatersheds.

	A	B	C	D	E	F	G	H
MAY	78	79	81	81	82	80	78	78
JUNE	78	79	81	81	82	81	79	78
JULY	79	80	83	82	84	82	80	79
AUG	80	81	84	83	85	83	81	80
SEPT	80	81	83	83	84	82	80	80
OCT	79	77	82	82	83	81	79	79

9 - EVALIATION OF EROSION FROM RAINFALL-RUNOFF EVENTS

The high level of solar input and the wind patterns in West Africa create serious problems of wind erosion. In some areas, especially agricultural lands, it is far more important than water erosion during the long dry season. In addition, the depositions made by wind erosion favor water erosion by accumulating fine soil particles that can be easilly carried away by surface runoff. The particles also increase the abrasive power of surface runoff. Interelationships between wind and land water erosion was not investigated in this study but it is an important phenomenon in West Africa and deserves future study.

For this study the Modified Soil Loss Equation (MUSLE) was used. G.R.Foster (in Hann,1982) has given a brief description of the MUSLE: The model is a modification of the Universal Soil where the 'R' factor has been replaced with a runoff erosivity factor. It allows estimates of sediment yield from watersheds for individual storm events.

The model is simple to apply. Haan (1982) points out that the model provides no information on time distribution of sediment yield during a runoff event. It is strictly a sediment yield equation and should not be used where detachment controls sediment yield.

The transport capacity, which is a function of slope, discharge rate, soil transportabilty and roughness effect, is one of the major factors that mobilize already detached particles. The more important factors of particle detachment are raindrop impact, rapid shifts in temperature and the biological action of plants and animals.

It should also be pointed out that MUSLE provides a lumped sediment yield for the total watershed. It does not provide sediment yields from different areas of the watershed.

The Modified Universal Soil Loss Equation (Musle)

The MUSCLE equation is:

A = RW * K * SL * C * P (23)

where: A= is the sediment yield expressed in megagrams for the total watershed area when K is expressed in megagrams-per-newton-time/hour-hectare (Mg.h/ha.N)

RW= replaces the combined rainfall-runoff erosivity factor 'R' of the USLE. It is estimated as follow, with :

V = runoff/1000 * watershed area * 10**6, in m3

RW = 9.05 * (v * Qp) ** 0.56

in newton/hour (N/h) in english units; multiplied by 1.702 it changes in metric units.

K =soil loss erodibility factor measured from a unit plot (22.1 m long on a 9% slope maintained in continuous fallow and tilled up and downhill periodically. It is expressed in Mg.h/ha.N.

The combination-cancellation of the units of 'R' and those of 'K' gives the units of 'A' in Mg/ha since the other parameters are dimensionless.

L = slope length factor, equal to the slope length of interest over the length of unit plot (22.1 m) and the ratio raised to the power of 'n' (usually 0.5):

$$L = (l / lu) ** n \quad (24)$$

S= steepness factor, with 's' equals the sine of the slope angle:

$$S = 65.4 * s ** 2 + 4.56 * s + 0.065 \quad (25)$$

The equation:

$$SL = SQRT (L)/100 \times (0.76 + 0.53 s + 0.076 s**2) \quad (26)$$

is used for computation. It has been used with success in West Africa by Orst OM (Roose, 1977).

C = cover management factor: soil loss for a given management practice over soil loss from the unit plot.

P=supporting practices factor: soil loss with contouring and supporting practices over soil loss from the unit plot.

MUSLE was developed for estimation long term soil losses from upland areas in the agricultural humid regions of the United States. However it is an empirical equation that can be applied anywhere if the variables are adjusted to the specific characteristics of the area of interest. Its modified version, MUSLE, is applicable on an entire watershed instead of the uplands only.

The climatic and ecologic conditions in the western Africa are different from those of the area for which the equation was designed this implies. That factors in the equation must be adjusted specifically to:

- long dry periods,
- nigh wind erosion potential,
- frequent and extensive wild fires,
- the chemical behavior of the laterite soils rich in Fe and Al.

Estimate of the MUSLE Parameters

The Kouya dam watershed was divided into eight (8) subwatersheds for parameter estimate and computation in order to satisfy constraints of watershed size. (figure 2).

For each of the subwatersheds the following computations were made for the S and CN parameters:

- Total area,
- Different land-use-vegetation areas,
- soil types areas,
- slopes estimate from photo-topographic survey.

For this study field measurements were not available for estimating MUSLE parameters. However, information was used from previous studies such as those made by research centers, especially ORSTOM (French Government). ORSTOM conducted a 20 year research program of calibrating the USLE for West African conditions. Their work was the major reference used in this study. ORSTOM points out that the serious damages observed locally in West Africa are caused mostly by the high intensities of the tropical rainfalls ('R' index = 200 to 2000). The fragility of tropical soils ('K' = 0.02 to 0.18 for ferrallitic and 0.20 to 0.30 for ferruginous tropical soils) is less a factor than the energy available for erosion. The protection afforded by the vegetation cover is the most important factor ('C' = 1 to 0.001), implying that soil conservation practices should have a high priority in this region. When the vegetation cover is damaged, the effect of slope inclination becomes more important ('SL'= 0.1 to 2.5), and the soil erodibility factor is increased ('K' = 0.02 to 0.30). The agricultural techniques ('C' = 1 to 0.1) and antierosion practices ('P' = 1 to 0.1) become highly important in this erosive environment.

Computation of the MUSLE Parameters:

The algorithm for MUSLE is :

$$A = RW * K * SL * C * P \qquad (27)$$

The R Factor :

The R factor is calculated as :

$$R = 9.05 * (VOL * Qp) ** 0.56 \qquad (28)$$

Where :

VOL = runoff volume in m3

Qp = peak discharge in m3/s

The K Factor:

Most of the studies carried out on tropical ferruginous soils, with or without concrete like surfaces, give a 'K' of about 0.25 (CTFT at Gampala, 1973 ; Roose et al. at Saria in Upper Volta, 1974; Charreau at Sefa in Senegal, 1969).

The SL Factor :

The formula adapted from Wishmeier and Smith (1960) for West Africa was used in this study and was calculated as :

$$SL = SQRT(L/0.3048)/100 * (0.76 + 0.53*s + 0.0076 * s ** 2) \quad (29)$$

Were:

L = slope length in meters divided by 0.3048 to convert it into feet.

s = slope in percent

The C Factor :

Evaluation of the C factors were based on the work of Roose et al (1977) (table 11) different types of land uses/vegetation on the Kouya watershed. Evaluations were made as follow :

- Bare lands = 1;

- Galery and closed forests = 0.001;
- Open forests and savanna grasslands = 0.01;
- Rainfed agriculture = 0.3 to 0.8.

These values were weighed according to the percent of soil type in the subwatersheds. The values were computed and tabulated with the following formula :

$$C = BL*1 + GCF*0.001 + OFSG*0.01 + RA*0.5 \quad (30)$$

Were :

C = 'C' factor for a subwatershed;

BL = percent of barelands on the watershed;

GCF = percent of gallery and closed forest;

OFSG = percent of open forest and savana grasslands;

RA = percent of rainfed agriculture.

Previous studies have shown that a good vegetation cover is enough to insure good soil and water conservation despite slope inclination and raindrop effect. The slope becomes the major factor when the vegetation cover is in poor conditions.

THE P FACTOR

The topograghy of the Gambia river upper basin makes it difficult to find levelled fields for cropping. Most of the crop fields are located on steep slopes except narrow pieces of land along the river and its tributaries. To protect the soils from potential erosion, contour shaped belts of rocks are piled across the fields. In addition to protecting the fields from erosion, they prevent land slide and clear rocks from the fields. These types of structures are very common in the study area and have been the subject of studies including the evaluation of the USLE antierosive practice factor 'P'.

The 'P' factor observed for these types of structures in West Africa is 0.10 which was used in this study for the the subwatersheds.

Only agricultural areas on steep lands are treated with the contour levees. All the other lands especially the natural lands are exploited as they are. The P factor of the non treated lands was assumed to be 1. The weighed P factor for the subwatersheds including the agricultural areas (P = 0.1) was calculated as follows:

$$P = BL*1 + GL*1 + GF*1 + OF*1 + CF*1 + RA*0.1 \qquad (31)$$

Where :

BL = barelands;

GL = grasslands;

GF = galery forest;

OF = open forest;

CF = closed forest;

RA = rainfed agriculture.

TABLE (12) = MUSLE 'C' AND 'P' FACTORS OF THE 8 SUB WATERSHEDS

	A	B	C	D	E	F	G	H
Bareland (1)	0.0116	0.0374	0.0039	0.0159	0.0716	0.0879	0	0.0872
Galery forest and Closed forest (0.001)	0.000931	0.0007764	0.000344	0.000505	0.000249	0.00054	0.00076	0.00089
Open forest and Savana Grassland (0.01)	0.00056	0.001742	0.006276	0.004746	0.00627	0.003634	0.002099	0.000193
Rain agriculture (0.5)	0.0005	0.00595	0.0123	0.00105	0.0255	0.00455	0.01495	0.00165
C Factor	0.013591	0.045868	0.02282	0.022201	0.103619	0.096624	0.017809	0.08993
P Factor	0.999	0.989	0.977	0.998	0.954	0.992	0.973	0.997

10 - RESULTS AND DISCUSSION

Simulation of rainfall, runoff, peak flow and soil loss is one of the planning tools that developing countries can use to overcome problems related to lack of data. The importance of computers, especially personal computers, in the future development and use of simulation technique in Africa and other developing countries cannot be overemphasized.

Rainfall Simulation

Historical records of a length sufficient to determine the distribution and statistics of interarrival time and precipitation amounts are required for simulation. In West Africa, the rainfall records are of daily amounts. Recording rain gage stations that provide information on duration, intensity, and depth, of rainfall are rare. This makes it difficult to simulate, for example runoff rates, peak flow and soil loss resulting from precipitation patterns. Accurate and detailed data collection is necessary even if only for short periods. Furthermore, the use of stochastic simulation technique are not well known in West Africa. In the French system, stochastic modeling is mostly limited to specialists and has not reached the same level in education as it has in the U.S.

Runoff Simulation

Stream gaging stations in most of the developing nations are not sufficient in number, often are not in suitable locations and commonly receive poor maintenance. Continuous records of good quality are available most of the time in stations provided with resident agents.

The problems related to measurements of rainfall and runoff do not allow the development of reliable rainfall-runoff relationships for areas where data are insufficient or are of poor quality. Methods developed by the SCS (U.S.) or derived from the SCS methods (ORSTOM, France) are usually used for runoff estimates. However, records exist that could be exploited statistically.

Rainfall and Runoff Duration

There is little information about rainfall and runoff durations. The analysis and use of existing data require that a correlation be developed to evaluate rainfall and runoff duration. The rainfall duration and runoff duration relationships developed in this study should be calibrated with actual depth and duration data when it becomes available for use in further analysis of the existing data.

Peak Flow

Information was not available for routing the peak flows from the eight subwatersheds down to the Kouya outlet. For this study, continuity of flow was assumed to accomplish rooting. The peak flow computed for Kouya is the sum of the peak flows derived for the different subwatersheds.

Soil Loss Evaluation

The major objective of this study was to take a first step towards the assessment of sediment yield in the Gambia river basin especially in relation with the proposed dam projects at Kouya. It is necessary eventually to determine the total amount of sediment yield, sediment transport patterns and sediment resettlement in the reservoir. Future studies are needed to assess the relation between sediment yield and vegetation cover, the major source areas of sediment, and to implement subsequent reclamation.

The sediment model, MUSLE, used in this study does not provide information on the differences in sediment yield between different types of vegetation or crop cover within a complex watershed. Indirect methods could be developed to assess sediment yield from a given vegetation type if the vegetation cover of interest totally occupies a watershed. Runoff plots established on approporate soil cover types are sometimes suitable. Small natural catchments of uniform soil and cover are more suitable if they can be instrumented.

Wild fires are another important factor ecologically in West Africa. Comparison of consecutive annual LANDSAT image (OMVG,1985) confirms the observation that large portions of the Gambia River Basin are subjected to wild fires every year. The burnings clear the vegetation cover built up during the previous rainy season and expose the soils to solar radiation, and wind erosion, and to water erosion at the beginning of the rainy season when the vegetation cover has not yet recovered sufficiently to protect the soil. In addition, wild fires modify the top soil structure and exposes the soil surface to rain drop impact.

Several development projects have suffered seriously from the tremendous amount of sediment produced in the Gambia Upper River Basin. For example during the 50's a reservoir was created to provide Labe with electricity . It is now completely filled with sediment and is useless. At the time of construction the vegetative cover on the watershed was in much better condition than at present.

The sediment problem is one of the greatest threats to the proposed management activities in the Gambia River Basin. The proposed reservoirs of Kouya and Koyoufoulbe, and even that of Kekreti in Senegal, are vulnerable to sedimentation for several reasons:

- the steep sloped, montaneous nature of the upper basin;
- the degraded conditions of the vegetation cover;
- the cycle of long dry seasons and short rainy seasons which triggers erosion processes.

However, accurate studies of sediment yeilds and sediment dynamics in the river and its tributaries have not been made.

As a result of this study a correlation between total monthly rainfall depth and total monthly soil loss for the Kouya Watershed was developed. The graph was developed from 50 years of simulation, the 300 data points are plotted in figure 4.

Even though the soil is highly vulnerable to erosion at the beginning of the rainy season when vegetation cover is sparce, soil loss is low because of the lower frequency and the generally lower intensity of rainfall. In the other hand, despite the maximum development of the vegetation during the months of July, August and September, the soil loss is high because of the frequency and intensity of rainfall. This emphasizes more the necessity of protective agricultural techniques and protection and regeneration of the natural vegetation cover.

Few soil loss studies of the upper Gambia River basin exist, and a long time is required to collect and record data that can be used for land management. In order to provide a working tool that allows for predicting soil loss from the rainfall depth, 50 years of data were synthesized for rainfall depth and amount of soil loss per month and plotted. A quadratic form curve was fitted to the points according to the following equation obtained by regression analysis:

$$Y = 0.0045 * X ** 2 - 0.0676 * X - 43.0873 \qquad (32)$$

With:

Y = soil loss in thousands of megagrams;

X = precipitation depth in millimeters.

The curve will allow an approximation of the soil loss in Kouya watershed and can be used and improved by managers for agricultural purposes or land protection and reclamation. (Figure 4). The confidence interval of the curve is determined with different levels of confidence. The monthly predicted soil loss computed by the main program for 50 years is used for the estimation of the confidence interval. The characteristics of the predicted soil loss output are:

- Mean monthly soil loss : 221.286 Thousands Megagrams;
- Standard deviation : 235.789

The confidence interval equation with a level of of confidence of 100(1-a) percent for large samples is:

$$X_i \text{ + or - } z_{a/2} * s * SQRT(n)$$

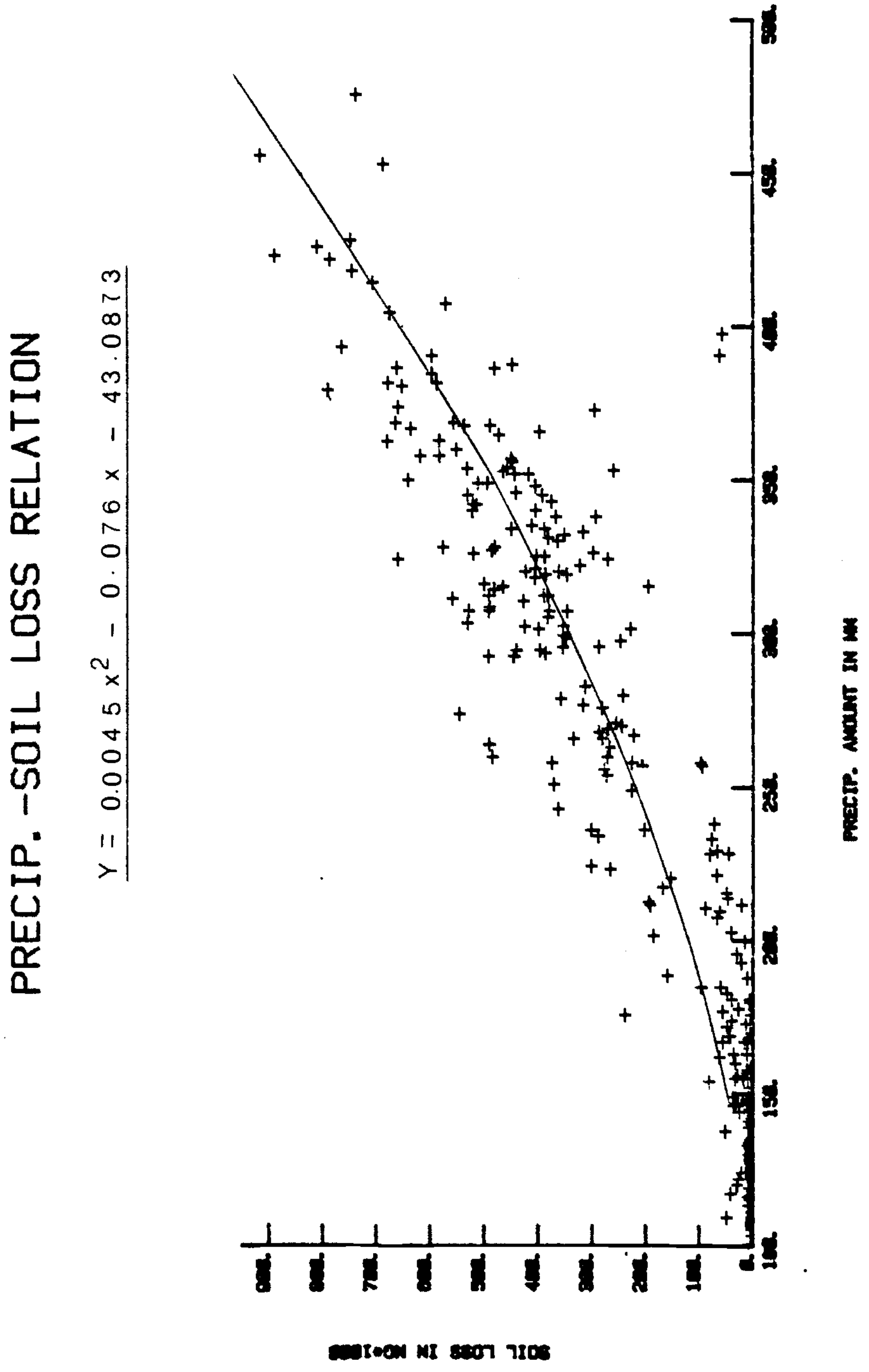
With:

- x_i = the i_{th} element of the soil loss per month population.
- z = coefficient.
- s = standard deviation of the soil loss population.
- n = the size of the population.

The values obtained are:

- For a 90 percent confidence interval:
  x_i+ or - 1.6449 * s / SQRT(n) = X_i + or - 22.39
- For a 95 percent confidence interval:

Fig. : 4 : Precipitation / Soil Loss Relation.



X_i + or - 1.9000 * s / SQRT(n) = X_i + or - 26.68

- For a 99 percent confidence interval:

  X_i + or - 2.5758 * s / SQRT(n) = X_i + or - 35.07

The final equation for the soil loss prediction after regression analysis and estimation of the confidence interval is:

Y = 0.0045 * X ** 2 - 0.0676 * X - 43.0873 + or - C (34)

with:

- C = 22.39 for a 90 percent confidence;
- C = 26.68 for a 95 percent confidence;
- C = 35.07 for a 99 percent confidence.

11 - CONCLUSION

All along this study, the SCS methods were mostly used especially for runoff, peak flow and soil loss. Rainfall simulation, rainfall and runoff durations were computed based on personal program (appendix 4), literature research and personal communication.

The use of the SCS methods in West Africa needs further research for parameters evaluation:

a) For the SCS runoff equation:

$$Q = (P - 0.2*s)**2/P + 0.8s$$

the investigations have to be carried out for determining the curve number (CN) that is the main factor for evaluating the S value. The multiplying factor (0.2) of the expression (0.2*2) has to be tested for reliability of adjusting the initial abstraction.

b) For determining time of concentration:

$$Tc = 5/3 * 1**0.8\ (5+1)**0.7/(1900*y**0.5)$$

it might be necessary to check out the applicability of the factors (0.8), (0.7) and (1900) on West African conditions of vegetation, soil and channel roughness for better estimate of peak flows.

c) The Soil Loss Equation has been extensively studied for adjustment and application in West Africa but especially for different types of agricultural areas mostly, located on relatively flat areas. Adjustments have to be carried out for natural areas and for areas with mild and steep slope. Furthur more, the MUSLE equation that uses Runoff and Peakflow as parameters needs even more adjustments for West African conditions.

This study leads to a number of conclusions that point out some of the needs of West African river basin development.

- Develop the use of personal computers for analysis and modeling;
- Improve data collection, storage and management;
- Improve rain gaging stations, increase the number of automatic recorders.
- Analyze the existing statistics and develop correlations between:

  1 = rainfall/rainfall duration;

  2 = rainfall/runoff

  3 = rainfall soil loss

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APPENDIX 1

ANALYSIS OF THE KOUYA WATERSHED MAPS

1 - Land Use-Vegetation-Soils :

The first step to work with the Land-use-vegetation maps was to complete them by the soils maps. Since there are only 2 major soil types in the watershed, that way is more convenient. Some other soil types like alluvial soils cannot be mapped accurately, they occupy too small areas. Then the area and percentage of each soil type, land use type and vegetation type have been calulated.

2 - Orthophoto Maps

For slope and slope length measurement

Each map sheet has been divided into 36 squares of 5 km2 and numbered from 1 to 36.

Then a sample size of the squares determined for each soil, vegetation and land use type. The highest number of 5 km2 squares determined was selected for each watershed to be the sample size. The squares were drawn in random for measurement and calculations.

APPENDIX 2

BRIEF DESCRIPTION OF THE SOILS OF THE WATERSHED

1.Laterite Soils : intrazonal soils.

PROFILE: Red-brown surface soil; red-deep B horizon; red or reticulatedly mottled parent material. Very deeply weathered.

NATIVE VEGETATION: Tropical selva and savannah vegetation.

CLIMATE: Tropical alternate wet/dry; High to moderate rainfall.

NATURAL DRAINAGE: Good externally, favorable to runoff. Good or excessive internally.

SOIL DEVELOPMENT PROCESSES: Laterization and a little podzolization.

PRODUCTIVITY CROP-PLANTS: Low-medium to high with heavy irrigation and fertilization.

PRESENT USE: Small farm units with wide variety of subsistence crops. Some specialization on plantations large areas of vaste land and forest-mined for iron and aluminum in places.

2. Lithosols : azonal soils.

PROFILE: Thin, stony surface soils; little or no alluvion; stony parent material.

VEGETATION: Depends on climate.

CLIMATE: All climates; most characteristic of deserts; least so of humid tropics.

DRAINAGE: A wide range, mostly good to excessive.

SOIL DEVELOPMENT PROCESSES: Those characteristics of the region of interest. Little effect has been made.

PRODUCTIVITY AND PRESENT USE: Forestry, grazing, barren. Some agriculture on limited areas, low productivity support cereals, corn and fonio (digitaria oxilis).

3. Alluvial Soils : azonal soils.

PROFILE: Little profile development. Some organic matter accumulated-stratified.

VEGETATION: Galery forests are mostly supported by alluvial soils. They exist in small areas in the Gambia river basin.

CLIMATE: All climates except exetremely rigid ones.

DRAINAGE: Wide range, mostly poor to good.

SOURCE: Charles W. FINKL, 1982

SOIL DEVELOPMENT PROCESSES:Can undergo some evolution.

PRODUCTIVITY AND PRESENT USE: Practically all crops of The world represented. Yields vary from very high to very low. Large proportion of the world's population supported by production from alluvial soils. Both subsistence farms and large plantations on these soils. In the Gambia river upper basin, the alluvial soils support most of the agriculture production, fruit-trees and cereals, eliminating significantly the galery forest.

USDA hydrograph developed specifically for the damsite, using the following parameters:

$L = 393,000$ m

$H = 1,075$ m

$A = 13,890$ km^2

$Tc = 64$ hours

$Tr = 3$ hrs

$P = 1$ mm.

The triangular 1 mm 3 hr unit graph is presented in Figure C1.5. The synthetic unit hydrographs upstream at Mako and downstream at Simenti are also shown in this Figure, for comparative purposes.

C1.5 Storm Rainfall Analysis

C1.5.1 General

Storm rainfall profiles representing a Probable Maximum Precipitation event and storms of more frequent recurrence interval are required for convolution with the Kekreti unit hydrograph in order to produce flood inflow hydrographs for design purposes.

Rainfall data suitable for this analysis were available from Kedougou in Senegal and Labe in Guinea (the latter from the Report : "Plan General d'Amenagement Hydraulique de la Moyenne Guinee; Polytechnia - Prague - Checoslovaquie, 1981)

C1.5.2 Rainfall Depth - Duration - Frequency Analysis

Autographic rainfall charts from the Kedougou Meteorological Station were available from 1968 to 1980. Details of every storm event over this period were extracted from the charts, and analysed to provide the depth - duration - frequency curves shown in Figure C1.6. Very few recorded storms had a duration greater than 12 hours, and consequently no curve could be prepared for single storms having a duration greater than this value.

Rainfall data for durations of 24, 48, 72 and 120 hours, however, were available for Labe for the period 1939 to 1977. These data have been analysed to provide the depth - duration - frequency curves given in Figure C1.7. The Probable Maximum Precipitation shown on this figure has been derived by the method of Hershfield (1961; 1965). This procedure is based on the general frequency equation:

$$x_t = x_n + KS_n$$

when : x_t = rainfall for return period t years (mm)

x_n = mean of a series of annual maxima for n years (mm)

S_n = standard deviation of the series of n years (mm)

K = a statistical variable related to the frequency distribution.

From an analysis of 2600 stations, Hershfield found that, using the series without the observed maximum event, the largest value of Km needed to give the correct value of x_m was 15. Consequently the probable maximum rainfall for the Kekreti catchment has been computed for different durations using the frequency factor value of 15. Further verification of this estimate of the probable maximum rainfall could only be provided by a detailed storm maximisation analysis, which is beyond the scope of this study.

C1.5.3 Storm Profile and Duration

For the purposes of combining the storm rainfall with the unit hydrograph to produce design floods at selected return periods, it is necessary to arrange the storm rainfalls in increments of 3 hours, with profiles and durations such as to provide flood hydrographs of shapes corresponding to the maximum observed events. A number of profiles and durations have been tested during the course of the study. It was found that a bell-shaped storm profile of duration 48 hours gave the worst case and it has therefore been adopted for convolution to produce the design hydrographs. The storm profiles for the 50 year, 1000 year and P.M.P. events are reproduced in Table C1.4.

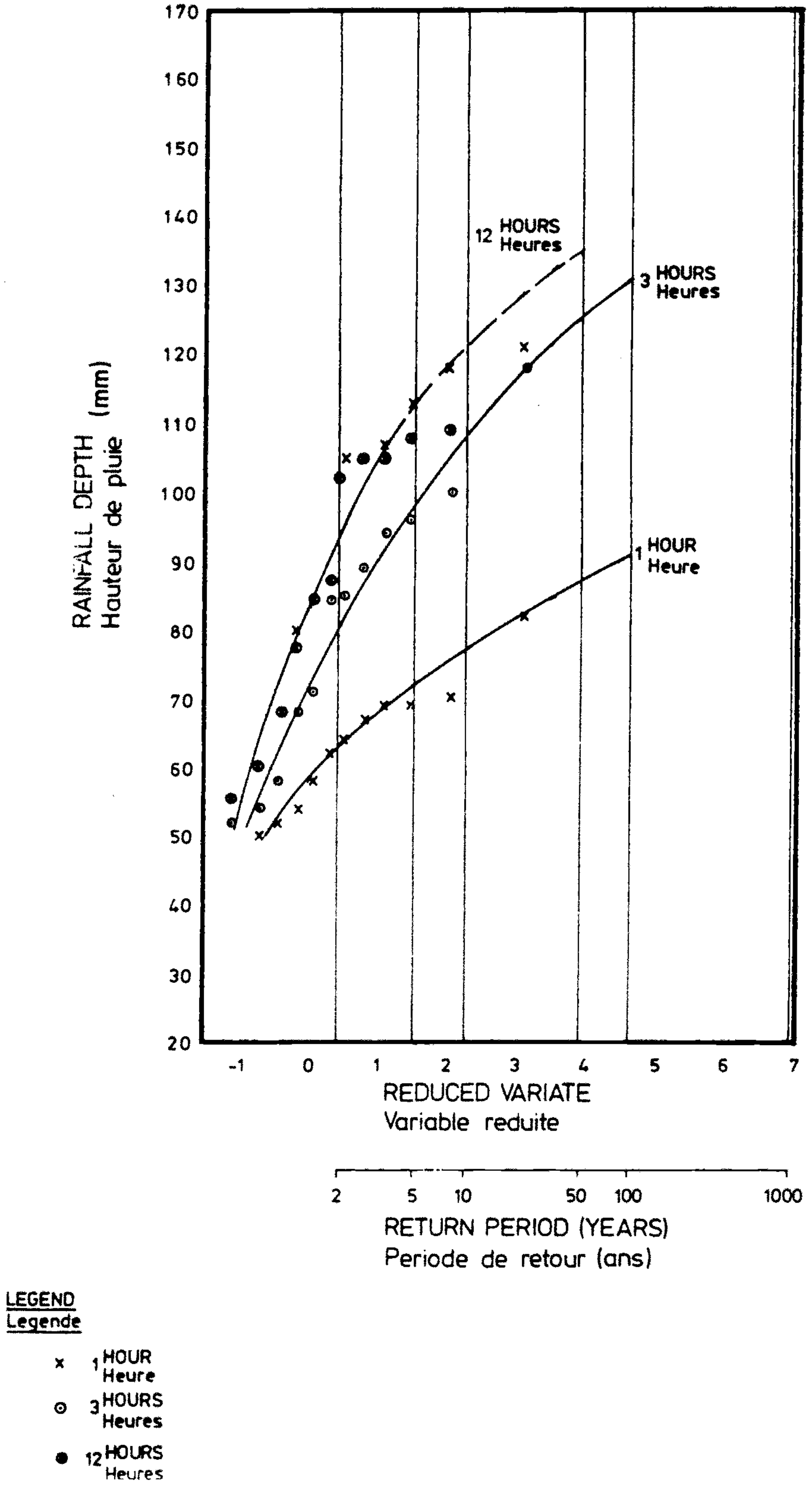
ANNEX C

Table C1.4 Rainfall Profiles for 50 year, 1000 year and PMF Convolution (mm)

50 years	Hours	3	6	9	12	15	18	21	24	
	mm	4	4	4	5	6	8	13	65	
	Hours	27	30	33	36	39	42	45	48	Total (mm)
	mm	18	9	7	6	5	5	4	4	167
1000 years	Hours	3	6	9	12	15	18	21	24	
	mm	4	6	7	7	9	14	24	90	
	Hours	27	30	33	36	39	42	45	48	Total (mm)
	mm	16	12	8	7	7	7	6	4	228
P.M.P.	Hours	3	6	9	12	15	18	21	24	
	mm	10	10	15	15	20	30	50	230	
	Hours	27	30	33	36	39	42	45	48	Total (mm)
	mm	30	20	13	10	10	10	8	7	490

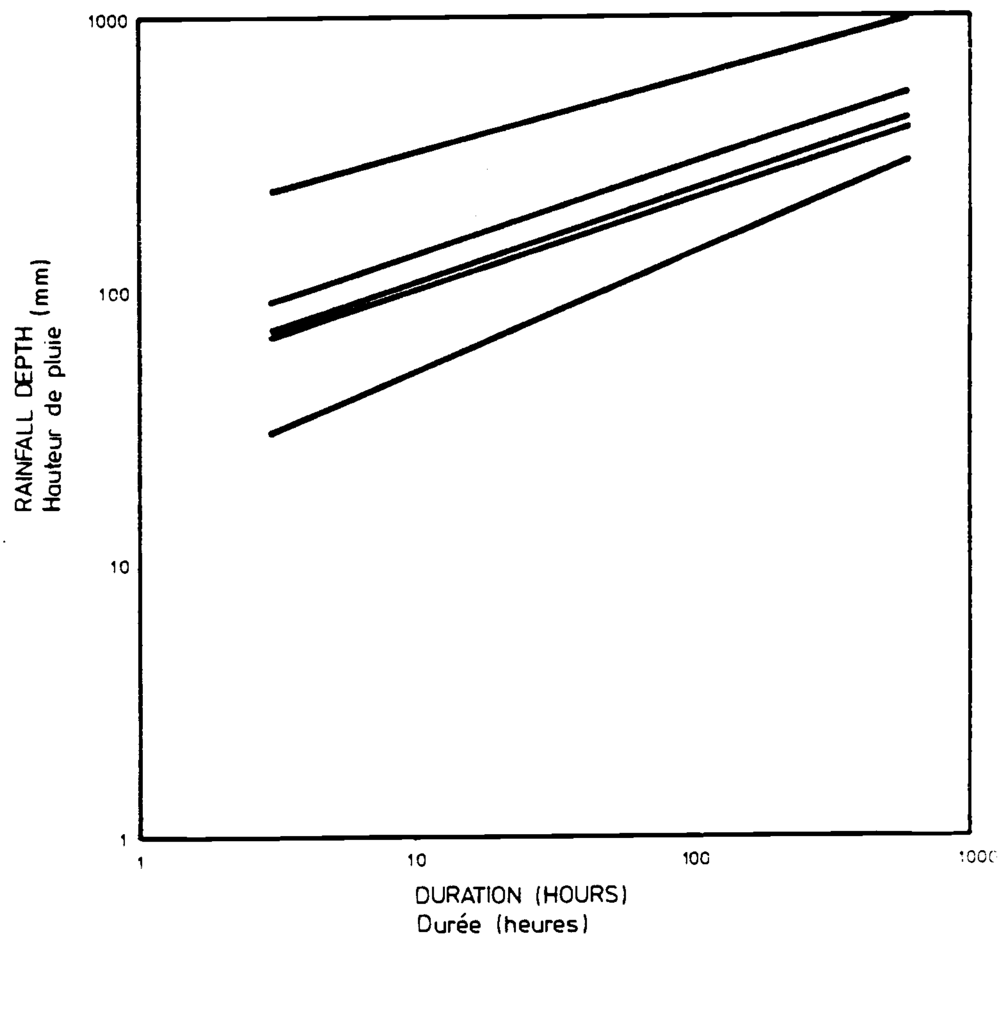
HEIGHT-DURATION-FREQUENCY RELATIONSHIP KEDOUGOU RAINFALLS

Relation Hauteur-Durée-Frequence Kedougou Pluviomètrie



RAINFALL DEPTH-DURATION-FREQUENCY ANALYSIS LABE, GUINEE

Relation Hauteur-Durée-Frequence de la Pluviometre à Labe/Guinee



APPENDIX 4

PROGRAM LISTING

```
&DIMMA T=00004 IS ON CR00015 USING 00075 BLKS R=0000

FTN7X,L
$FILES 1,1


      PROGRAM DIMMA


************************************************************************
*                                                                      *
*   PROGRAM THAT GENERATES RAINFALL SYNTHETIC DATA  FROM PREVIOUSLY    *
*   DETERMINED  DISTRIBUTIONS. THE DATA SIMULATED  ARE BASED ON THE    *
*   DISTRIBUTIONS  AND STATISTICS OF DATA  RECORDED FROM THE METEO-    *
*   ROLOGIC STATION OF LABE-AERO IN THE REPUBLIC OF GUINEA, IN WEST    *
*   AFRICA. THEN FOR EACH RAINFALL EVENT THE PROGRAM COMPUTES :        *
*             - RAINFALL AND RUNOFF DURATIONS                          *
*             - THE RAINFALL EXCESS (RUNOFF) AMOUNTS                   *
*             - THE PEAK FLOWS                                         *
*             - THE SOIL LOSS AMOUNTS                                  *
*                                                                      *
************************************************************************
*                                                                      *
*                       G L O S S A R Y                                *
*                                                                      *
*   GAMMA PARAMETERS :                                                 *
*         M1          :   MEAN PRECIP. PER EVENT                       *
*         VAR1        :   VARIANCE OF PRECIP. PER EVENT                *
*         LAMBDA      :   LAMBDA OF PRECIP. PER EVENT                  *
*         K           .   FACTOR OF PRECIP. PER EVENT                  *
*         GAMMA       :   GAMMA FUNCTION                               *
*         R1 AND R2   :   PARAMETERS                                   *
*   GEOMETRIC PARAMETERS :                                             *
*         M2          :   MEAN INTERARRIVAL TIME                       *
*         PITP        :   INTERARRIVAL TIME PARAMETER                  *
*   OTHER PARAMETERS :                                                 *
*         F           :PDF OF 1 INTERARRIVAL DAY OF HISTORICAL DATA    *
*                                                                      *
*         IC          :   INTERARRIVAL DAYS BETWEEN 2 EVENTS           *
*         NDAY        .   NUMBER OF DAYS FOR A GIVEN MONTH             *
*         DAY         :   RANK OF A GIVEN DAY OF A MONTH               *
*         RAIN        :   RAINFALL AMOUNT FOR A GIVEN RAINY DAY        *
*         TOTRAIN     .   TOTAL RAINFALL FOR A MONTH                   *
*         TOTRAIN     :   CUMMULATED RAINFALL AMOUNT                   *
*         ARA,ARB,....:   AREA OF WATERSHED A, B, ...                  *
*         CNA,CNB,....:   CURVE NUMBER OF WATERSHED A, B, ...          *
```

```
*          LA,LB......:   CHANNEL LENGTH OF WATERSHED A, B, ...        *
*          RCLA,RCLB,..:  ROUTING CHANNEL TO KOUYA DAM SITE            *
*          RDURAT      :  RAINFALL DURATION                            *
*          DURAT       :  RAINFALL EXCESS DURATION                     *
*          SPA,SPB....:   MEAN SLOPE OF WATERSHED A, B, ...            *
*          SPLA,SPLB,..:  MEAN SLOPE LENGTH OF WATERSHED A, B, ...     *
*          RUNA,RUNB...:  RUNOFF OF WATERSHED A, B, ...                *
*          QPA,QPB,...:   PEAK FLOW WATERSHED A, B, ...                *
*          AA,AB,AC,...:  SOIL LOSS OF WATERSHED A, B, C, ...          *
*          RW,KE,SL    :  MUSLE FACTORS (KE=K FACTOR)                  *
*          C,P         :  MUSLE FACTORS                                *
*          TC          :  TIME OF CONCENTRATION                        *
*          TP          :  TIME TO PEAK                                 *
*          TB          :  TIME BASE                                    *
*          SLS         :  TOTAL SOIL LOSS IN KOUYA WATERSHED           *
*          TSLS        :  TOTAL SOIL LOSS FOR A MONTH                  *
*                                                                      *
************************************************************************

      REAL P(120),LA,LB,LC,LD,LE,LF,LG,LH
      REAL M1,LAMBDA,K,M2
      REAL AA,AB,AC,AD,AE,AF,AG,AH
      INTEGER  IG,YEAR,DAY

      LU=1
      FD=1
      WRITE(FD,*) 'ENTER THE OUTPUT DEVICE NUMBER : '
      READ(FD,*)LU

************************************************************************

*   MEAN SLOPE OF THE 8 SUBWATERSHED :
      DATA SPA,SPB,SPC,SPD,SPE,SPF,SPG,SPH/11.86,12.95,15.44,14.95,
     C 16.43,14.52,11.86,14.71/

*   MEAN SLOPE LENGTH OF THE SUBWATERSHEDS :
      DATA SPLA,SPLB,SPLC,SPLD,SPLE,SPLF,SPLG,SPLH/272.80,263.89,
     C 240.03,247.36,270.13,257.23,255.65,255.34/

*   CHANNEL LENGTH OF THE SUBWATERSHEDS :
      DATA LA,LB,LC,LD,LE,LF,LG,LH/42.18,62.42,77.52,86.64,36.77,
     C 29.93,26.22,44.75/

*   LENGTH OF ROUTING CHANNELS OF THE SUBWATERSHEDS .
      DATA RCLA,RCLB,RCLC,RCLD,RCLE,RCLF,RCLG,RCLH/81.51,81.51,
     C 109.14,74.65,44.75,44.75,13.40,0.0/

```

```
*   SUBWATERSHED AREAS:
      DATA ARA,ARB,ARC,ARD,ARE,ARF,ARG,ARH/983.63,748.90,809.69,
     C 780.41,87.28,436.84,157.82,244.16/

*   MUSLE " C " FACTORS OF SUBWATERSHEDS :
      DATA CA,CB,CC,CD,CE,CF,CG,CH/0.014,0.046,0.023,0.022,
     C 0.104,0.097,0.018,0.090/

*   MUSLE " P " FACTORS OF SUBWATERSHEDS :
      DATA PA,PB,PC,PD,PE,PF,PG,PH/0.999,0.989,0.977,0.998,0.954,
     C 0.992,0.973,0.997/

*********************************************************************

                NDAY=0
                IG=0
                YEAR=1
                MONTH=1

       DO Y=1,100
           DO M=1,12

*   CHECK LEAP YEAR, MONTH, LENGTH OF MONTH

       LEAPY=MOD(YEAR,4)

       IF(MONTH.EQ.1.OR.MONTH.EQ.3.OR.MONTH.EQ.5.OR.MONTH.EQ.7.
      1OR.MONTH.EQ.8.OR.MONTH.EQ.10.OR.MONTH.EQ.12) NDAY=31
       IF(MONTH.EQ.4.OR.MONTH.EQ.6.OR.MONTH.EQ.9.OR.MONTH.EQ.11)
      1                                                NDAY=30
       IF(MONTH.EQ.2.AND.LEAPY.EQ.0)                   NDAY=29
       IF(MONTH.EQ.2)                                  NDAY=28

*   CHECK THE PARAMETERS FOR SYNTHETIC DATA GENERATION ACCORDING
*    TO THE CURRENT MONTH.

       IF(MONTH.EQ.5) THEN
*               GAMMA PARAMETERS. MAY
       WRITE(LU,900)
       WRITE (LU,*) '----------------------------------    MAY   -----'
            M1=15.058
            VAR1=162.781
            LAMBDA=0.0923836
            K=1.3892868
            GAMMA=0.887679
            R1=LAMBDA/GAMMA
            R2=K-1.0
```

```
*               GEOMETRIC PARAMETERS: MAY
              M2=2.663
              PITP=1./M2
*               OTHER PARAMETERS: MAY
              F=0.39877
              CNA=78
              CNB=79
              CNC=81
              CND=81
              CNE=82
              CNF=80
              CNG=78
              CNH=78


        ELSE IF(MONTH.EQ.6) THEN
*               GAMMA PARAMETERS: JUNE
        WRITE(LU,900)
        WRITE (LU,*) '------------------------------  JUNE   -----'
              M1=16.483
              VAR1=180.256
              LAMBDA=0.0914399
              K=1.5071669
              GAMMA=0.886488
              R1=LAMBDA/GAMMA
              R2=K-1.0
*               GEOMETRIC PARAMETERS: JUNE
              M2=1.963
              PITP=1./M2
*               OTHER PARAMETERS: JUNE
              F=0.48352
              CNA=78
              CNB=79
              CNC=81
              CND=81
              CNE=82
              CNF=81
              CNG=79
              CNH=78

        ELSE IF(MONTH.EQ.7) THEN
*               GAMMA PARAMETERS: JULY
        WRITE(LU,900)
        WRITE(LU,*) '------------------------------  JULY   -----'
              M1=16.932
              VAR1=178.084
              LAMBDA=0.0950778
              K=1.6098443
```

```
          GAMMA=0.894662
          R1=LAMBDA/GAMMA
          R2=K-1.0
*            GEOMETRIC PARAMETERS: JULY
          M2=1.666
          PITP=1./M2
*            OTHER PARAMETERS: JULY
          F=0.6217
          CNA=79
          CNB=80
          CNC=83
          CND=82
          CNE=84
          CNF=82
          CNG=80
          CNH=79

      ELSE IF(MONTH.EQ.8) THEN
*            GAMMA PARAMETERS: AUGHUST
      WRITE(LU,900)
      WRITE(LU,*) '-------------------------------   AUGHUST   ------'
          M1=16.561
          VAR1=207.493
          LAMBDA=0.0798168
          K=1.3218811
          GAMMA=0.894403
          R1=LAMBDA/GAMMA
          R2=K-1.0
*            GEOMETRIC PARAMETERS: AUGHUST
          M2=1.509
          PITP=1./M2
*            OTHER PARAMETERS: AUGHUST
          F=0.67751
          CNA=80
          CNB=81
          CNC=84
          CND=83
          CNE=85
          CNF=83
          CNG=81
          CNH=80

      ELSE IF(MONTH.EQ.9) THEN
*            GAMMA PARAMETERS: SEPTEMBER
      WRITE(LU,900)
      WRITE(LU,*) '----------------------------   SEPTEMBER   -----'
          M1=16.437
          VAR1=183.334
```

```
            LAMBDA=0.089655
            K=1.4736474
            GAMMA=0.885674
            R1=LAMBDA/GAMMA
            R2=K-1.0
*              GEOMETRIC PARAMETERS: SEPTEMBER
            M2=1.522
            PITP=1./M2
*              OTHER PARAMETERS: SEPTEMBER
            F=0.65000
            CNA=80
            CNB=81
            CNC=83
            CND=83
            CNE=84
            CNF=82
            CNG=80
            CNH=80

      ELSE IF(MONTH.EQ.10) THEN
*               GAMMA PARAMETERS: OCTOBER
      WRITE(LU,900)
      WRITE(LU,*) '----------------------------   OCTOBER   ------'
            M1=12.56
            VAR1=102.716
            LAMBDA=0.1222768
            K=1.5357749
            GAMMA=0.887922
            R1=LAMBDA/GAMMA
            R2=K-1.0
*              GEOMETRIC PARAMETERS: OCTOBER
            M2=2.523
            PITP=1./M2
*              OTHER PARAMETERS: OCTOBER
            F=0.46734
            CNA=79
            CNB=77
            CNC=82
            CND=82
            CNE=83
            CNF=81
            CNG=79
            CNH=79

      ELSE IF(MONTH.EQ.11.OR.MONTH.EQ.12.OR.MONTH.EQ.1.
     1OR.MONTH.EQ.2.OR.MONTH.EQ.3.OR.MONTH.EQ.4) THEN
*           WRITE(LU,900)
*           WRITE(LU,*) '----- JAN,FEB,MAR,APR - NOV,DEC  ------'
```

```
                DAY=0
               DO N=1,NDAY
                   DAY=DAY+1
                   RAIN=0.0
*          WRITE(LU,1000) YEAR,MONTH,DAY,RAIN
                IF(DAY.EQ.NDAY) GO TO 500
                END DO
           END IF

*     PRECIPITATION PER EVENT IS GAMMA DISTRIBUTED
*     INTERARRIVAL TIME IS (SHIFTED) GEOMETRIC DISTRIBUTED

*     A GAMMA DISTRIBUTION: PDF PRECIPITATION PER EVENT
                Z=0.0
                DO I=1,120
                    DO J=1,100
                        X=FLOAT(J)/1000.+FLOAT(I-1)/1.7
                        Z=Z+R1*((LAMBDA*X)**R2*EXP(-LAMBDA*X))
                    END DO
                        P(I)=Z
                END DO

                DO J=1,120
                    P(J)=P(J)/Z
                END DO

*     GENERATE A GEOMETRIC DISTRIBUTION: PDF OF INTERARRIVAL TIME

                    STVOL=0.0
                    STSL=0.0
                    TOTRAIN=0.0
                    TOTOP=0.0
                    TOTRUN=0.0
                    DAY=0

             DO C=1,NDAY

*    RUNOFF, PEAKFLOW AND SOIL LOSS INITIALIZATION.

                  TVOL=0.0
                  TSL=0.0
                  TDRUN=0.0
                  TDOP=0.0

*    RAINFALL AMOUNTS COMPUTATION.
                  DAY=DAY+1
   10             X=URAN()
                  IF(X.LT.F) THEN
```

```
                 DO L=1,120
                    N1=L
                    IF(P(L).GE.X) GO TO 11
                 END DO
              ELSE
                 RAIN=0.0
                 RDURAT=0.0
                 DURAT=0.0
                 GO TO 12
              END IF
 11          RAIN=FLOAT(N1-1)/1.01+1.
             IF(N1.LE.2) GO TO 10


*   COMPUTATION OF RAINFALL DURATION, IN MINUTES.
             RDURAT=(10**((ALOG(RAIN)-ALOG(18.5))/0.454414))*60

 12   CONTINUE

      WRITE(LU,*) '------------------------------------------------------'
      WRITE(LU,*) 'DATE : ',MONTH,'-',DAY,'-',YEAR,':'
      WRITE(LU,*) '                        ','RAINFALL DEPTH = ',RAIN
      WRITE(LU,*) '                        ','RAINFALL DURATION = ',RDURAT
      IF(RAIN.EQ.0.0) GO TO 13

      WRITE(LU,900)
      WRITE(LU,1100)
      WRITE(LU,900)
*   CALL STATEMENTS FOR RUNOFFS, PEAKFLOWS, ROUTINGS AND SOIL
*   LOSSES COMPUTATION.
* ------------- SUBWATERSHED  A  ---------------------------------------

      CALL RPFSL(CNA,CA,PA,RAIN,ARA,LA,SPA,SPLA,RUNA,VOLA,RDURAT,
     cDURAT,QPA,AA)
      WRITE(LU,1000) 'SUBWATERSHED A ',RUNA,DURAT,VOLA,QPA,AA
           TVOL=TVOL+VOLA
           TSL=TSL+AA
           TDQP=TDQP+QPA
           TDRUN=TDRUN+RUNA

* ------------- SUBWATERSHED  B  ---------------------------------------

      CALL RPFSL(CNB,CB,PB,RAIN,ARB,LB,SPB,SPLB,RUNB,VOLB,RDURAT,
     cDURAT,QPB,AB)
      WRITE(LU,1000) 'SUBWATERSHED B ',RUNB,DURAT,VOLB,QPB,AB
           TVOL=TVOL+VOLB
           TSL=TSL+AB
           TDQP=TDQP+QPB
```

```
            TDRUN=TDRUN+RUNB

*  ------------  SUBWATERSHED  C  ------------------------------------

      CALL RPFSL(CNC,CC,PC,RAIN,ARC,LC,SPC,SPLC,RUNC,VOLC,RDURAT,
     cDURAT,QPC,AC)
      WRITE(LU,1000) 'SUBWATERSHED C ',RUNC,DURAT,VOLC,QPC,AC
            TVOL=TVOL+VOLC
            TSL=TSL+AC
            TDQP=TDQP+QPC
            TDRUN=TDRUN+RUNC

*  ------------  SUBWATERSHED  D  ------------------------------------

      CALL RPFSL(CND,CD,PD,RAIN,ARD,LD,SPD,SPLD,RUND,VOLD,RDURAT,
     cDURAT,QPD,AD)
      WRITE(LU,1000) 'SUBWATERSHED D ',RUND,DURAT,VOLD,QPD,AD
            TVOL=TVOL+VOLD
            TSL=TSL+AD
            TDQP=TDQP+QPD
            TDRUN=TDRUN+RUND

*  ------------  SUBWATERSHED  E  ------------------------------------

      CALL RPFSL(CNE,CE,PE,RAIN,ARE,LE,SPE,SPLE,RUNE,VOLE,RDURAT,
     cDURAT,QPE,AE)
      WRITE(LU,1000) 'SUBWATERSHED E ',RUNE,DURAT,VOLE,QPE,AE
            TVOL=TVOL+VOLE
            TSL=TSL+AE
            TDQP=TDQP+QPE
            TDRUN=TDRUN+RUNE

*  ------------  SUBWATERSHED  F  ------------------------------------

      CALL RPFSL(CNF,CF,PF,RAIN,ARF,LF,SPF,SPLF,RUNF,VOLF,RDURAT,
     cDURAT,QPF,AF)
      WRITE(LU,1000) 'SUBWATERSHED F ',RUNF,DURAT,VOLF,QPF,AF
            TVOL=TVOL+VOLF
            TSL=TSL+AF
            TDQP=TDQP+QPF
            TDRUN=TDRUN+RUNF

*  ------------  SUBWATERSHED G  ------------------------------------

      CALL RPFSL(CNG,CG,PG,RAIN,ARG,LG,SPG,SPLG,RUNG,VOLG,RDURAT,
     cDURAT,QPG,AG)
      WRITE(LU,1000) 'SUBWATERSHED G ',RUNG,DURAT,VOLG,QPG,AG
            TVOL=TVOL+VOLG
```

```
              TSL=TSL+AC
              TDQP=TDQP+QPG
              TDRUN=TDRUN+RUNG

*  ------------  SUBWATERSHED  H  ----------------------------------------

         CALL RPFSL(CNH,CH,PH,RAIN,ARH,LH,SPH,SPLH,RUNH,VOLH,RDURAT,
        cDURAT,QPH,AH)
         WRITE(LU,1000) 'SUBWATERSHED H ',RUNH,DURAT,VOLH,QPH,AH
              TVOL=TVOL+VOLH
              TSL=TSL+AH
              TDQP=TDQP+QPH
              TDRUN=TDRUN+RUNH

*  ------------------------------------------------------------------------

*    TOTAL RUNOFF AND TOTAL SOIL LOSS PER MONTH

*  ------------------------------------------------------------------------
*          WRITE(LU,1000) YEAR,MONTH,DAY,RAIN,RDURAT,RUN,DURAT,QP,SLS

 13         CONTINUE

                TOTRAIN=TOTRAIN+RAIN
                STVOL=STVOL+TVOL
                STSL=STSL+TSL
                TOTQP=TOTQP+TDQP
                TOTRUN=TOTRUN+TDRUN/8.    ! MEAN RUNOFF ON WATERSHED

                END DO

 500  CONTINUE

         WRITE(LU,*) '-----------------------------------------------------'
         WRITE(LU,900)
         WRITE(LU,*) '                ','YEAR-MONTH : ',YEAR,'-',MONTH
         WRITE(LU,*) '                ','TOTAL RAINFALL  = ',TOTRAIN
         WRITE(LU,*) '                ','MEAN RUNOFF DEPTH  = ',TOTRUN
         WRITE(LU,*) '                ','TOTAL RUNOFF VOLUME  = ',STVOL
         WRITE(LU,*) '                ','TOTAL PEAKFLOW   = ',TOTQP
         WRITE(LU,*) '                ','TOTAL SOIL LOSS  = ',STSL

                MONTH=MONTH+1
                IF(MONTH.EQ.13) MONTH=1
                TOTRAIN=0.0
                STVOL=0.0
                STSL=0.0

```

```
              END DO

   900          FORMAT(/)

   1000          FORMAT(A15,4X,F6.2,4X,F6.2,4X,F7.2,4X,F6.2,4X,F6.2)
   1100          FORMAT(20X,'RUNOFF',2X,'RUN.DURAT.',3X,'RUN.VOL.',
       c2X,'PEAKFLOW',1X,'SOIL LOSS')
                 YEAR=YEAR+1

              END DO

            STOP
            END


*   SUBROUTINE THAT COMPUTES RUNOFF, RUNOFF DURATION, PEAK FLOW, AND
*   SOIL LOSS FOR EACH RAINFALL EVENT.

       SUBROUTINE RPFSL(CN,C,P,RAIN,AR,L,SP,SPL,RUN,VOL,RDURAT,DURAT,
      COP,A)
        REAL KE,L,A

*   S FACTOR AND RUNOFF COMPUTATION.
        S=25400/CN-254
        IF(RAIN.LE.(0.2*S)) THEN
             RUN=0.0
             DURAT=0.0
             VOL=0.0
        ELSE
             RUN=(RAIN-0.2*S)**2/(RAIN+0.8*S)       ! RUNOFF
             VOL=RUN*AR*1000 ! RUNOFF VOLUME IN M3 (1000=10**6m2/1000m)

             DURAT=RDURAT*0.00001*EXP(0.115129*CN)  ! RUNOFF DURATION
        END IF

*  PEAK FLOW COMPUTATION, QP, IN M3/S. TC, TP, TB IN MN. L DIVIDED BY
*  0.3048 TO CONVERT IT FEET.

        TC=((L*1000/0.3048)**0.8*(S+1)**0.7)/(1900*SP**0.5)*60*5/3
        TP=0.5*DURAT+0.6*TC
        TB=2.67*TP
        QP=16.7*AR*RUN/TP

```

```
*   SOIL LOSS COMPUTATION USING THE MUSLE EQUATION.


        RW=9.05*(VOL*QP)**0.56

        SL=SQRT(SPL/0.3048)*(0.76+0.53*SP+0.076*SP**2)/100.

        KE=0.25

        A=RW*KE*SL*C*P

        RETURN

        END
```

APPENDIX 5

PROGRAM OUTPUT SAMPLES

1 - Dry months outputs

```
------------------------------------------------

YEAR-MONTH :  1- 1
TOTAL RAINFALL  =  0.
MEAN RUNOFF DEPTH  =  0.
TOTAL RUNOFF VOLUME  =  0.
TOTAL PEAKFLOW  =  0.
TOTAL SOIL LOSS  =  0.
------------------------------------------------

YEAR-MONTH :  1- 2
TOTAL RAINFALL  =  0.
MEAN RUNOFF DEPTH  =  0.
TOTAL RUNOFF VOLUME  =  0.
TOTAL PEAKFLOW  =  0.
TOTAL SOIL LOSS  =  0.
------------------------------------------------

YEAR-MONTH :  1- 3
TOTAL RAINFALL  =  0.
MEAN RUNOFF DEPTH  =  0.
TOTAL RUNOFF VOLUME  =  0.
TOTAL PEAKFLOW  =  0.
TOTAL SOIL LOSS  =  0.
------------------------------------------------

YEAR-MONTH :  1- 4
TOTAL RAINFALL  =  0.
MEAN RUNOFF DEPTH  =  0.
TOTAL RUNOFF VOLUME  =  0.
TOTAL PEAKFLOW  =  0.
TOTAL SOIL LOSS  =  0.
```

2 - five dry days follwed by a rainy day with a rainfall depth not large enough to give runoff.

```
-----------------------------------------------
DATE :  5- 23- 1:
                    RAINFALL DEPTH =  0.
                    RAINFALL DURATION =  0.
-----------------------------------------------
DATE :  5- 24- 1:
                    RAINFALL DEPTH =  0.
                    RAINFALL DURATION =  0.
-----------------------------------------------
DATE :  5- 25- 1:
                    RAINFALL DEPTH =  0.
                    RAINFALL DURATION =  0.
-----------------------------------------------
DATE :  5- 26- 1:
                    RAINFALL DEPTH =  0.
                    RAINFALL DURATION =  0.
-----------------------------------------------
DATE :  5- 27- 1:
                    RAINFALL DEPTH =  0.
                    RAINFALL DURATION =  0.
-----------------------------------------------
DATE :  5- 28- 1:
                    RAINFALL DEPTH =  2.9802
                    RAINFALL DURATION =  5.75801E-3
```

	RUNOFF	RUN.DURAT.	RUN.VOL.	PEAKFLOW	SOIL LOSS
SUBWATERSHED A	0.00	0.00	0.00	0.00	0.00
SUBWATERSHED B	0.00	0.00	0.00	0.00	0.00
SUBWATERSHED C	0.00	0.00	0.00	0.00	0.00
SUBWATERSHED D	0.00	0.00	0.00	0.00	0.00
SUBWATERSHED E	0.00	0.00	0.00	0.00	0.00
SUBWATERSHED F	0.00	0.00	0.00	0.00	0.00
SUBWATERSHED G	0.00	0.00	0.00	0.00	0.00
SUBWATERSHED H	0.00	0.00	0.00	0.00	0.00

4 - Rainy day with rainfall depth large enough to give runoff in some subwatersheds.

DATE : 5- 3- 1:

RAINFALL DEPTH = 13.871
RAINFALL DURATION = 13.947

	RUNOFF	RUN.DURAT.	RUN.VOL.	PEAKFLOW	SOIL LOSS
SUBWATERSHED A	0.00	0.00	0.00	0.00	0.00
SUBWATERSHED B	.00	1.24	1489.82	.01	2.52
SUBWATERSHED C	.06	1.56	50302.6	.28	81.28
SUBWATERSHED D	.06	1.56	48483.6	.24	69.19
SUBWATERSHED E	.13	1.76	11043.2	.12	112.54
SUBWATERSHED F	.02	1.39	9266.97	.10	71.99
SUBWATERSHED G	0.00	0.00	0.00	0.00	0.00
SUBWATERSHED H	0.00	0.00	0.00	0.00	0.00

5 - Rainfall depth large enough to give runoff and soil loss in all the subwatersheds.

DATE : 6- 3- 1:

RAINFALL DEPTH = 18.822
RAINFALL DURATION = 65.478

	RUNOFF	RUN.DURAT.	RUN.VOL.	PEAKFLOW	SOIL LOSS
SUBWATERSHED A	.27	5.20	260875.	1.78	234.38
SUBWATERSHED B	.39	5.84	290781.	1.62	925.89
SUBWATERSHED C	.72	7.35	580775.	3.23	1257.9
SUBWATERSHED D	.72	7.35	559773.	2.80	1070.9
SUBWATERSHED E	.93	8.24	80965.0	.88	1046.7
SUBWATERSHED F	.72	7.35	313337.	3.61	3802.0
SUBWATERSHED G	.39	5.84	61278.0	.65	76.81
SUBWATERSHED H	.27	5.20	64755.4	.48	482.04

6 - End of month data output;

MAY.

```
YEAR-MONTH :  1- 5
TOTAL RAINFALL  =  145.72
MEAN RUNOFF DEPTH  =  .13363
TOTAL RUNOFF VOLUME  =  4.77293E+5
TOTAL PEAKFLOW   =  3.01
TOTAL SOIL LOSS  =  1416.1
```

JUNE.

```
YEAR-MONTH :  1- 6
TOTAL RAINFALL  =  202.17
MEAN RUNOFF DEPTH  =  2.4396
TOTAL RUNOFF VOLUME  =  9.80436E+6
TOTAL PEAKFLOW   =  66.761
TOTAL SOIL LOSS  =  39571.
```