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ANALYSIS AND SIMULATION OF WEATHER
VARIABLES-PART 1:
RAIN AND WIND IN WAGENINGEN

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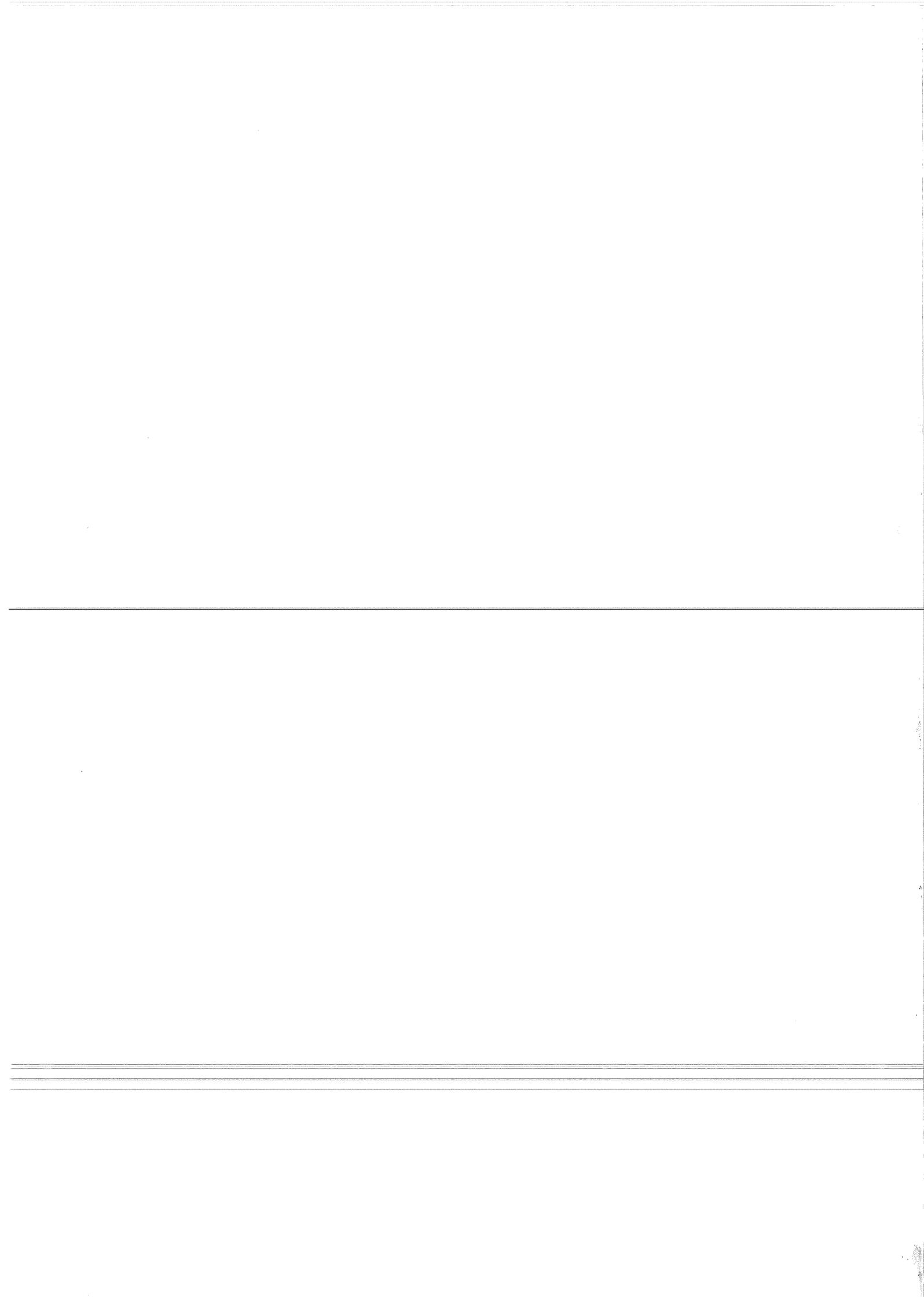
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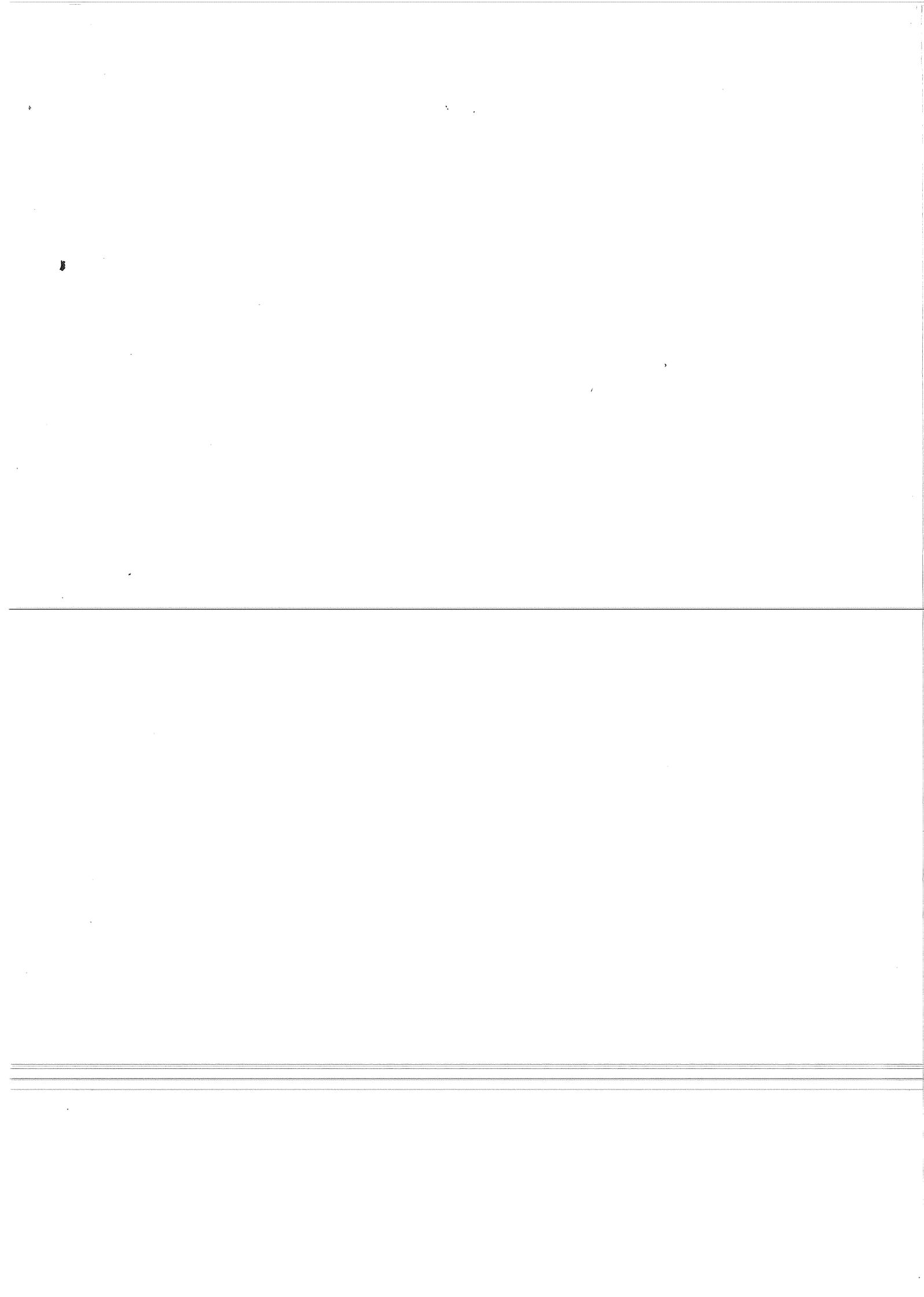
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CONTENTS	PAGE
Acknowledgment	4
Abstract	5
1. Occurrence and Amount of Precipitation	7
1.1 Introduction	7
1.2 Occurrence of Precipitation	7
1.3 Estimation and Simulation of the Occurrence of Precipitation	9
1.4 The Amount of Precipitation	10
1.5 Estimation and Simulation of the Amount of Precipitation	13
1.6 Simulation: Results and Discussion	14
1.7 Literature Cited	20
2. Wind Speed	22
2.1 Introduction	22
2.2 Models of Wind Speed	24
2.3 Simulation: Results and Discussion	26
2.4 Literature Cited	29
3. Program Listing: RAWIN	30
Appendix A Listings of parameters of rain and wind models	40
Appendix B Summaries of the Wageningen data	47
Appendix C Summaries of the simulation printouts	52

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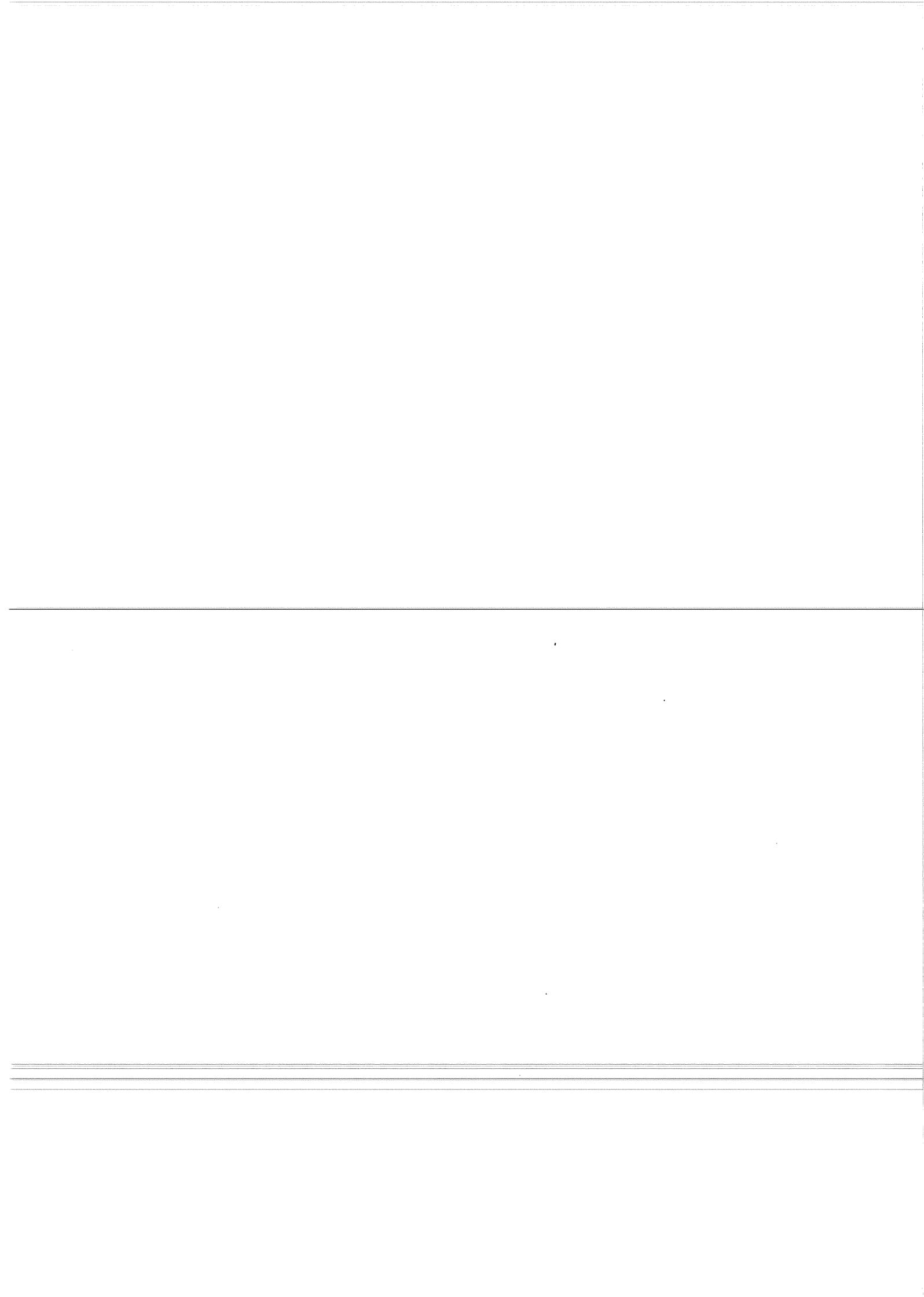
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ABSTRACT

A first order, two-states, Markov chain has been used by many authors to describe the probabilities of whether a day would be dry or wet based on the given condition of whether yesterday was dry or wet. Estimates of these probabilities can be obtained from an analysis of the historical weather data. The simulation of the occurrence of rainfall for a day is accomplished by comparing the computer generated random uniform deviates with the estimated transitional probabilities. Further more it has been shown that the amount of rainfall in a wet day can be adequately described by a two-parameter Gamma distribution function. Thus with a Markov chain-gamma function model, simulation programs can be constructed to simulate the amount of rainfall for a location. In addition Gamma function was also found to fit the wind speed data satisfactorily for a number of locations. A Fortran computer program, RAWIN, has been developed to estimate model parameters based on available historical data, and to generate rainfall and wind speed data for that location. Results showed that the simulation resembles the observation rather closely for Wageningen conditions.



1. OCCURRENCE AND AMOUNT OF PRECIPITATION

1.1 Introduction

The pattern and amount of rainfall are among the most important weather factors that affect profoundly the lives of human beings. They influence our decisions in construction of buildings, hydrological systems and the design of transportation systems, in addition to agricultural systems. Research in understanding and modification of the rainfall patterns has been a concern in every branch of science. In particular, modelling and simulation of rainfall for various purposes of applications have been found popular as is evident from the large number of publications in the last twenty years or so. Some examples of the application of rainfall simulation models can be found in papers by Murphy and Knoerr (1975), Berndt and White (1976), Ahme et al (1976) and Shriner (1977). Models of generating hourly rainfall data under storm conditions were attempted by Franz (1974) and Witter (1984).

Our primary concern of the rainfall lies in its impact on agricultural systems; the growth and development of crops, pests and diseases, and on the other agro-ecologically related issues. In this chapter, we shall document our experience in modelling and simulation of the occurrence and the amount of rainfall based on the last ten years' rainfall data of Wageningen.

We would like to point out that, in this report, 'weather simulation' refers to 'imitating' or 'mimicking' the weather patterns in a rather realistic manner but without involving simulation of the physical and meteorological processes. Thus 'weather simulation' and 'crop simulation' have different implications.

1.2. Occurrence of Precipitation

Several stochastic models have been proposed to describe the occurrence of rainfall. Gabriel and Neumann (1962), Caskey (1963) were among the first to demonstrate that the first order Markov Chain was a simple but effective model to describe the occurrence of precipitation. This model assumes that the probability of the occurrence of rainfall at a given day depends on the status of rainfall of the previous day. Since then this model has gained much

popularity and has been applied to analyze rainfall data of many locations. Lowry and Guthrie (1968) pointed out, however, that not all rainfall data can be adequately fitted by the first order Markov Chain. Chin (1977) classified a day into several possible status according to the degree of dryness and wetness. Thus a multiple-states Markov Chain should be used in contrast to a two-states model that was used by previous authors. Illustrations and examples of the application of Markov Chains to analyze rainfall data were also shown in papers of Leaf and Brink (1975), Deulleur et al. (1978) and Coe and Stern (1982). An alternative approach of fitting the rainfall data by a negative binomial model was suggested by Cole and Sherriff (1972). Through an extensive analysis of the data from a large number of weather stations and years in The Netherlands, Buishand (1977, 1978) concluded that certain variations of the negative binomial distribution function such as the truncated negative binomial, fitted the lengths of weather spells very well. In general, it compared favorably to the Markov Chain procedures.

Obviously, there is no one model that could fit the rainfall data well for all conditions and locations. For Markov Chain like polynomial models, the higher order of the model would fit the data better, but also would require more parameters to specify the model. In case of Markov Chain, the number of parameters required is 2 with $(k+1)$ power where k is the order of the model. This implies that a large data base of long historical information is required to adequately estimate the parameters. In reality, it is more than often that such long historical data are not in existence or not available for analysis. Even if such long series of data are available, it could be still questionable whether the homogeneity condition over the years is warranted to permit an indiscriminant analysis of the data. In fact, evidences of the changes in rainfall patterns during a long course of history were shown in Neyman et al (1969) and Witter (1984).

Since our interest in rainfall is not so much the rainfall itself but its effects on biological identities, any reasonable approximation is satisfactory. Buishand (1977) also pointed out that estimates of parameter for a Markov Chain can be obtained more easily than for an alternating renewal process. Besides this, the generation of synthetic sequences is simpler for a Markov Chain.

For various reasons stated above, we decided to use the first order Markov Chain for modelling the rainfall occurrence. Subsequently, the amount of the rainfall will be determined for wet days.

1.3 Estimation and Simulation of the Occurrence of Precipitation

A first order, two-states, Markov Chain assumes that a day can either be classified as dry or wet, and that the probability of the status of a given day, whether it is dry or wet, depends only on the status of the day before. A second order Markov Chain would require a dependence on the previous two days and so on. Below, the first order Markov Chain is described in detail.

Suppose P_{10} represents the probability that today is dry given that yesterday was wet, and P_{00} is the probability of today being dry given that yesterday was dry. Let i and j represent the status of yesterday and today which can be either 0 or 1. Then for given status of the t th and the $(t-1)$ th day, a variable f_{ij} is defined as,

$f_{ij}(t)$	$i = 0$		$i = 1$	
	$j=0$	$j=1$	$j=0$	$j=1$
$f_{00}(t)$	1	0	0	0
$f_{01}(t)$	0	1	0	0
$f_{10}(t)$	0	0	1	0
$f_{11}(t)$	0	0	0	1

and

$$P_{ij} = \sum f_{ij}(t) / n_i ; \text{ for } i = 0, 1 \text{ and } j = 0, 1.$$

The summation (\sum) runs over a period of time while the probabilities are estimated. And n_0 is the total number of dry days, n_1 is the total number of wet days in that period. It is clear that $P_{11} = 1 - P_{10}$ and $P_{01} = 1 - P_{00}$.

Thus for a given period of time, the proportions that today is dry or wet by given that yesterday was dry or wet are estimates of the conditional probabilities, P_{ij} 's. They are also referred to as transitional probabilities.

Since it is well known that the rainfall pattern depends on the seasonality in a year, the Markov Chain can best be applied for each month separately. The reliability of the estimates of the transitional probabilities depends on the homogeneity condition of the rainfall and the number of years of the available data.

After the estimates are obtained for a location, the simulation of the occurrence of precipitation can be accomplished by comparing the computer generated random uniform deviates with the transitional probabilities. That is, a uniform random deviate u , on the interval $[0, 1]$ is generated, and if u is less or equal to P_i then today is classified as a dry day, otherwise today is defined as a wet day. In the present report, we did not consider the occurrence of trace amount rainfall as a separate category. A wet day is defined as having at least 0.05 mm rain.

1.4 The Amount of Precipitation

Early studies of the amount of rainfall indicated that the frequency distribution of the amount tends to be reversely J-shaped (Neyman et al., 1969).

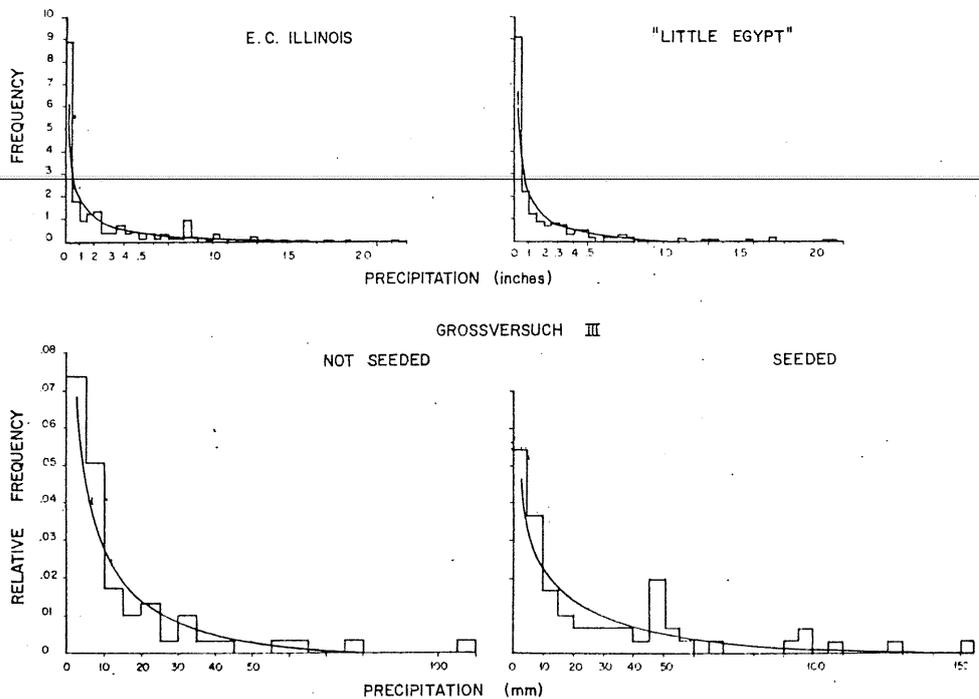


Figure 1.1 Rainfall distribution (after Neyman et al, 1969)

That is, the small amount rainfalls have higher probabilities to occur than the large amount rainfalls. This type distribution falls in the family of Gamma distributions. The probability density function of a Gamma variable, X , is of the following form,

$$P(X) = \frac{(X - r)^{a-1} \exp[-(X - r) / b]}{b^a T(a)}$$

$a > 0, \quad b > 0 \quad \text{and} \quad X > r$

Where $T(a)$ is the conventional, mathematical Gamma function. This distribution is also known as a type III of Pearson's system with three parameters; a , b , and r . In case all X values are greater than zero which is the case for amount rainfall at wet days, r can be set equal to zero and reduce the distribution to only a two-parameter Gamma distribution function which is,

$$P(x) = \frac{x^{a-1} \exp(-x / b)}{b^a T(a)}$$

$a > 0, \quad b > 0 \quad \text{and} \quad X > 0$

A Gamma distribution can also represent many special distributions. For instance, when $b = 2$, it is a Chi-square distribution, and if $a = b = 1$, it becomes the standard exponential function. If a random variable X , after a power transformation becomes exponentially distributed, then X is said to be a Weibull random variable which is related to extreme values. Some typical Gamma distribution curves are shown in Figure 1.2 (after Johnson and Kotz, 1970).

It is evident that a Gamma distribution with " a " less than 1 normally describes the rainfall amount very well. The Gamma distribution has been used almost universally for analyzing the rainfall data. (Das, 1955; Neyman et al., 1969; Stern, 1980; Larsen and Pense, 1982). Buishand(1977) suggested the use of a shifted Gamma function when " r " is small but non-zero. That is, all rainfall data should subtract the lower limit value before the fitting of a two parameter Gamma probability function.

The mean and variance for a three parameter Gamma variable are $ab + r$ and abb respectively and they are ab and abb respectively for a two parameter Gamma variable. The corresponding mode is $(a - 1) b + r$ and $(a - 1) b$ for three and two parameter cases. This information is useful in characterizing the Gamma distribution.

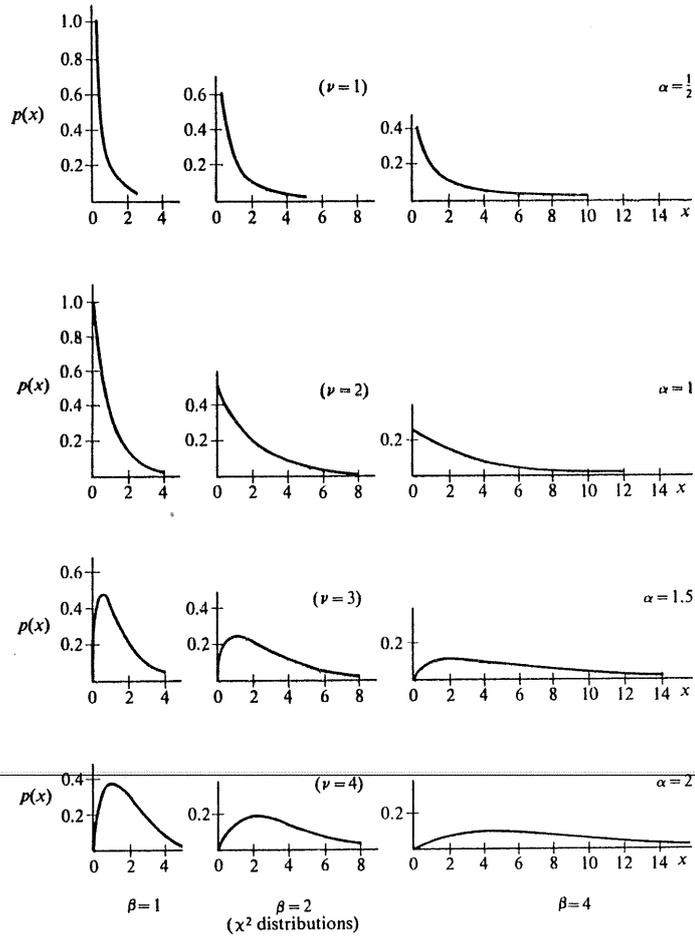


Figure 1.2 Some Gamma distribution functions (after Johnson and Kotz, 1970)

Figure 1.3 shows three different Gamma distributions each having the same expected value (zero) and standard deviation (unity) (after Johnson and Kotz, 1970). Note that the b values are 1, 1/2 and 1/3 for distributions with $a = 1, 4$ and 9 respectively.

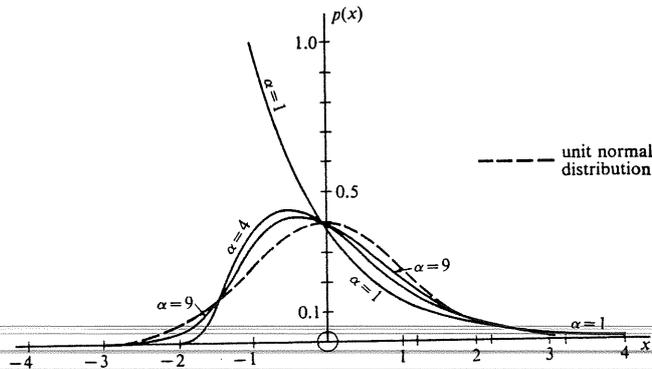


Figure 1.3 Some Gamma distributions with zero mean and unit variance (after Johnson and Kotz, 1970).

One nice property about the Gamma distribution is the reproductivity. If X1 and X2 are independent Gamma random deviates, possibly with different values of "a" but with common values of "b" and "r", then the sum of these variables also has a Gamma distribution with same parameters "b" and "r" but the third parameter is the sum of the "a" s'. This property implies that if the daily rainfall data follows a two parameter Gamma distribution, then the sum of them over a number of days is also Gamma distributed provided that the "b" parameters do not change significantly. Thus Gamma function can then be used to describe daily, weekly, monthly or yearly rainfall data.

1.5 Estimation and Simulation of the Amount of Precipitation

The estimation of the parameters "a" and "b", can be difficult when "a" is small which is the case for fitting the rainfall data. Estimates obtained from the ordinary maximal likelihood and method of moments are not stable when "a" is less than one. Approximate maximal likelihood solutions were suggested by Das(1955), Greenwood and Durand (1960), and Buishand (1977). In this report, we will use the approximate method by Greenwood and Durand, which is described in Johnson and Kotz (1970) and used by Larsen and Pense (1982).

$$a = (0.5000876 + 0.1648852 Y - 0.0544274 Y^2) / Y$$

$$\text{for } (0 < Y < 0.5772)$$

or

$$= (8.898919 + 9.059950 Y + 0.9775373 Y^2) /$$

$$Y (17.79728 + 11.968477 Y + Y^2)$$

$$\text{for } (0.5772 < Y < 17)$$

where $Y = \ln (\bar{X} / G)$; \bar{X} = the arithmetic mean and G = geometric mean.

$$b = \bar{X} / a$$

This estimation method is appropriate for $0 < a < 1$. After "a" and "b" estimates were obtained from the historical rainfall data, Gamma random deviates are generated by a method suggested by Berman (1971), which was also used by Larsen and Pense(1982).

When many years data are available for estimation, however, there are several possible procedures to obtain the estimates. Larsen and Pense (1982) estimated "a" and "b" by further dividing the wet days according to the status of the rainfall of the previous day. Richardson and Wright (1984) pooled data over years to yield one set of estimates for each month. We will estimate "a" and "b" for each month and each year, and the average estimates over the years will be used for simulation. The difference of Richardson and Wright's estimates and ours is that their's are weighted averages while ours are unweighted over the years. Also we can compute the variability between years easier than by using their procedure.

1.6 Simulation: Results and Discussion

Weather data of Wageningen between 1975 - 1984 were used to fit the above described models. A Fortran computer program, RAWIN, which has been developed to estimate the parameters and to simulate daily rainfall is listed in section 3. The program will generate daily rainfall status, amount of precipitation and also wind speed (see section 2) based on the estimated monthly parameters. If more than one years data are available, the program will also yield a summary table of the averages and a table of standard deviations among the yearly estimated parameters. RAWIN contains a main program which controls the input / output files and the following three subroutines;

ESTRW: estimate parameters of rain and wind speed models
GENRA: simulation of rainfall
GENWIN: simulation of wind speed
and a Gamma function to generate Gamma deviates.

The estimated parameters of the rainfall model for Wageningen are listed in appendix A. Some simulated results are shown in Appendix B. The actual observed minimum and maximum number of wet days and amounts of precipitation of the last ten years at Wageningen are summarized for each month in the following table.

Table 1.1 Monthly average and extreme values of the number of wet days and the amounts of precipitation at Wageningen between years 1975 - 1984.

Month	wet days			amount (mm)		
	ave	min	max	ave	min	max
1	20	13	27	69.1	35.5	99.4
2	11	6	20	43.5	16.5	84.9
3	18	10	25	68.3	29.6	132.4
4	15	3	24	36.8	7.0	80.4
5	16	6	25	55.8	9.3	132.1
6	15	4	21	69.5	34.6	148.4
7	12	5	18	53.8	11.7	145.7
8	14	8	24	48.7	11.7	134.4
9	14	7	24	57.5	6.1	159.4
10	16	8	26	58.3	14.5	137.2
11	18	11	25	70.0	21.5	170.3
12	18	12	24	58.7	22.5	98.9

Obviously there exist tremendous variations in raining days and amounts of precipitation among years. It is difficult to conclude which months are drier or wetter than the other months. But from the minimum and average values, it may be said that January, November and December appear to have more raining days than the other months. Summer and fall, June to October, may have fewer raining days but the amount of precipitation per wet day can be greater than the other seasons.

Another point worth noting is that, roughly speaking, the monthly mean number of wet days ± 7 days would approach the extreme situations of wet or dry months at Wageningen.

The amount of precipitation in a month is partly dictated by the number of wet days and partly determined by the rainfall pattern for that month. That is, the total amount of precipitation depends on transitional probabilities as well as the parameters for the Gamma function. The estimates of these parameters for Wageningen are shown in Appendix A. Note that the averages of the monthly parameters fell in narrow ranges. The transitional probabilities from a dry day to a wet day ranged from 0.22 to 0.45, and from a wet day to a wet day ranged between 0.55 to 0.77. Most "a" values were between 0.77 to 0.87, and most "b" values fell between 4.0 to 5.0. The standard deviations of these parameters over the years were about the same magnitude as the parameters themselves. The standard errors which can be obtained by dividing the standard

deviations by the square root of 10 are about 30% of the size of the parameters. These numbers suggest that the rainfall patterns between months in Wageningen are not significantly different in the statistical sense, considering the variations between years.

In order to gain some understanding about the influences of these parameters on the simulated monthly rainfall, we have generated some rainfall data from certain hypothesized parameters. The values of the hypothesized parameters were chosen in such way that they could be real for Wageningen conditions. Also the theoretically expected rainfalls were calculated so that the performance of the random number generators (Uniform and Gamma deviates) could be evaluated. All data were generated for a month with assumed 31 days.

The theoretically expected number of wet days, $E(W)$, is calculated by the following formula

$$E(W) = [P_{01} \times P_0 + P_{11} \times P_1] \times 31$$

Where P_0 is the marginal probability of dry days, and P_1 is the marginal probability of wet days. P_{01} and P_{11} are transitional probabilities. The expected amount of monthly precipitation, $E(A)$, on wet days is

$$E(A) = E(W) \times a \times b$$

Since the Gamma distribution with $a < 1$ is skewed to the right and the probability tends to infinite as A tends to zero, the expected value (mean) is usually much greater than the median. From the last ten years data, P_0 is estimated as 0.48 and P_1 is 0.52.

Table 1.2 shows the calculated number of wet days and the simulated number of wet days for various combinations of P_{01} and P_{11} and fixed values of a ($= 0.8$) and b ($= 5.0$). Due to the similarity of the marginal probabilities, the difference in effect of P_{01} and P_{11} on resulting expected number of wet days is negligible. Theoretically, every 10% increase of P_{01} or P_{11} corresponds to an increase of 1.5 wet days in a month. Furthermore the effect of the two parameters on the number of wet days is additive, i.e. a 20% increase of one parameter is about the same as 10% increase on both parameters. The simulated results are in close approximation to the expected values as shown in Table 2.

Table 1.2 Simulated and Expected Wet Days for $a = 0.8$ and $b = 5.0$. The expected days are presented in the parentheses.

$P01 \setminus P11$.5	.6	.7	.8
.2	10 (11.0)	10 (12.6)	14 (14.3)	15 (15.9)
.3	10 (12.5)	10 (14.1)	14 (15.7)	15 (17.4)
.4	12 (14.0)	12 (15.6)	15 (17.2)	16 (18.8)
.5	18 (15.5)	18 (17.1)	21 (18.7)	22 (20.3)

For fixed a and b , the effects of the transitional probabilities on amount of rainfall is shown in Table 1.3.

Table 1.3 Simulated and Expected Rainfall Amount(mm) for $a = 0.8$ and $b = 5.0$. The expected amounts are presented in the parentheses.

$P01 \setminus P11$.5	.6	.7	.8	mean
.2	27.8 (44.0)	43.4 (50.4)	42.0 (56.8)	47.5 (63.2)	40.2 (53.6)
.3	46.1 (50.0)	56.6 (56.4)	60.1 (62.8)	49.4 (69.2)	53.1 (59.6)
.4	41.4 (56.0)	39.0 (62.4)	42.3 (68.8)	103.7 (75.2)	56.6 (65.6)
.5	71.4 (62.0)	46.0 (68.4)	98.9 (74.8)	91.6 (81.2)	76.9 (71.6)
mean	46.7 (53.0)	46.2 (59.4)	60.8 (65.8)	73.1 (72.2)	

In theory, a 10% increase of $P01$ will produce 6 mm rainfall and a 10% increase of $P11$ will produce 6.4 mm rainfall for $a = 0.8$ and $b = 5.0$. It turns out that the simulated results change more drastically than expected. The

average increase of rainfall is about 10 mm for every 10% increase of the transitional probability. However, in this particular case the expected CV ($= 1/a = 1.1$) is greater than 1, and the observed deviations of results of one simulation from the expected values are well within the normally acceptable limits. As we have mentioned earlier, because of the skewness of the rainfall distribution, the mean is always greater than the median which in turn is greater than the mode. Thus, it is not unusual that the expected values are greater than the simulated amounts of rainfall. Indeed, this is the case (11 of 16 theoretical means are greater than the simulated numbers). Thus we may conclude that the random number generators (uniform and Gamma function in the computer program) work satisfactorily as programmed.

The possible impact of "a" and "b" parameters on rainfall amount are shown in Table 1.4. Again, "a" and "b" are chosen to cover most likely cases for Wageningen. Unlike the case of the transitional probabilities, the effects of "a" and "b" on rainfall are not additive but multiplicative. The synergistic effect of "a" and "b" however can not be seen too clearly from Table 1.4 due to the small ranges of "a" and "b" values used. Again 11 of 16 simulated values are smaller than the expected mean values because of the positive skewness of the distributions.

Table 1.4 Simulated and expected amount of precipitation (mm) for $P_{01} = 0.4$ and $P_{11} = 0.7$. The expected values are presented in parentheses.

a \ b	4.0	4.5	5.0	5.5	mean
0.75	51.6 (51.6)	44.7 (58.1)	43.1 (64.5)	59.2 (70.9)	49.7 (61.3)
0.80	53.8 (55.0)	81.0 (61.9)	69.1 (68.8)	62.0 (75.7)	66.5 (65.4)
0.85	39.4 (58.5)	53.6 (65.8)	53.6 (73.1)	106.4 (80.4)	63.3 (69.5)
0.90	51.3 (61.9)	46.6 (69.7)	94.0 (77.4)	114.1 (85.1)	76.5 (73.5)
mean	49.0 (56.8)	56.5 (63.9)	65.0 (71.0)	85.4 (78.0)	

Results presented in Table 1.3 and Table 1.4, suggest that within the range of values of the four parameters that are most probable in Wageningen, transitional probabilities

appear having greater impact on rainfall than the Gamma parameters in terms of the total monthly precipitation. However the pattern of rainfall is characterized by "a" and "b". A combination of small "a" toward zero and small "b" would give uniform amount of rainfalls, while large "a" and large "b" would be likely to produce heavy rainfall on wet days.

In viewing Table 1.2, 1.3, and 1.4, one must be aware of the following limitations on possible interpretations.

--. The parameters are chosen in certain ranges which are relevant only to Wageningen conditions. The effects of these parameters on rainfalls at other range values may be different.

--. The simulation results are generated from one run and therefore only give some rough ideas of the performance of the procedure. A large number of runs are necessary to obtain a rigorous conclusion.

Rainfall pattern and amount were simulated based on parameters estimated for each year and the averages of the ten years. The computer print outs of the simulation are presented in Appendix B. It is clear that the simulations resemble the reality quite closely. The following table summarizes the percent errors of the simulation on basis of yearly totals

Table 1.5 Percentage of Errors in Simulation of Yearly Totals.

year	wet days	amount(mm)
75	6.3	1.8
76	-2.7	0.1
77	0.9	1.0
78	-6.1	-3.1
79	-2.1	-6.4
80	2.1	-5.1
81	6.8	6.4
82	1.6	6.4
83	-2.1	-3.4
84	4.2	-1.9
Average	7.5	2.8

In all cases, the errors are less than 8%. Compared with the yearly variations, these errors are small and are

within an acceptable level for our purpose. Much of the errors in the amount of rainfall could be inherited from the errors in simulating the number of wet days.

On the yearly basis, 1976 was the driest year of the last ten years. It had 148 wet days and produced 449.5 mm of rain, 1977 was the wettest year, with 226 days of raining and 806.8 mm rainfall. The simulated results of these two years are 144 wet days with 450.1 mm of rain for 1976 and 228 wet days with 849.7 mm of rain for 1977. The close resemblance of the simulation to the observations at these two years indicates the method used in the simulation is capable of reproducing normal and extreme situations.

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2. WIND SPEED

2.1 Introduction

Differentials in heating of the ground and the unequal action of sunshine between areas affect the displacements of the air masses on our globe. The movement of air masses produces wind. The wind in the free atmosphere is predominantly influenced by the distribution of atmospheric pressure. The mechanism of surface wind as measured 10 m above the ground is much more complicated and of greater concern to most people than the wind in the free atmosphere. The rugosity and color of a surface, the topography or altitude of a land, the distance of an area to mountains or oceans are all capable of modifying the force and the direction of the air flows and forming surface winds with special features.

Before modern instruments were invented, estimation of wind-speed was made by observing the state of motion of trees and ocean waves. One such classic system was proposed by a British admiral, Beaufort. May it be not accurate, it provides a sensual judgement of the speed of wind.

The relationships of wind to other meteorological factors are extremely complex and intricate. Temperature, solar radiation and humidity help forming the wind and, in turn, the wind can modify or change the status of these variables. Thus, the wind is a very important factor in the determination of a climate.

The relationship of wind and vegetation is also a complicated one. Strong wind is deemed harmful to agriculture in which the production can be reduced or destroyed. The effects of a normal range of wind speeds on crops are of great interest to agricultural scientists.

Wind affects plant growth directly through its effect on ventilation of plant surface. Thus, fresh supplies of CO₂ are brought to the leaves, while water vapour and heat are dissipated. Wind also promotes the evaporation from the soil and effect the rate of water uptake by the plant. A knowledge of the profiles of wind-speed within the plant canopy can help scientists to determine the rate of photosynthesis within canopy layers. In all crops, the wind-speed declines as the Leaf Area Index (LAI) increases, and approaches zero in the lower part of the canopy. A quantitative relationship between wind speed and plant height was suggested by Thom (1971) and Landsberg and James (1971).

$$u(z) / u(h) = (1 + a (1 - z / h))$$

When $u(z)$ is the wind-speed at a height z from the ground, $u(h)$ is the wind-speed at the height of the vegetation h . "a" is an empirical coefficient, usually lying between 1.0 and 5.0, and within a given crop varying for position in the canopy and wind-speed (Grace, 1977). Landsberg and James (1971) also showed that a could be related to the mean drag coefficient C_d , the mean LAI and the transfer coefficient of momentum K_m .

$$a = h [c (d) (u_h) (LAI)]^{1/2} / 6 K_m$$

It is possible to estimate "a" and hence predict the velocity profiles from a knowledge of C_d , LAI and K_m .

The effects of wind speed on leaf temperature and transpiration rate of a leaf can be evaluated from the heat balance equation (Gates and Papian, 1971; Grace, 1977) which is briefly described below,

$$Q = \epsilon z (T_s)^4 + C + lE$$

Where Q is the radiation absorbed by the leaf, ϵ is the emissivity (often about 0.95), z is Stefan-Boltzmann constant,

$$5.67 \times 10^{-8} \text{ Wm}^{-2} \text{ K}^{-4}$$

and T_s is the leaf surface temperature. C is the heat flux by convection, or sensible heat, l is the latent heat of evaporation of water and E is the evaporation rate. The explicit forms of C and lE are,

$$C = d h (T_s - T_a) / R_{ha}$$

Where d is air density, h is specific heat, T_a is air temperature and R_{ha} is the boundary layer resistance to heat. And

$$lE = d h (V_s - V_a) / k (R_{ws} + R_{wa})$$

Where V_s and V_a are respectively saturated and actual air vapour pressures, R_{ws} and R_{wa} are resistances for the diffusion of water vapour through the stomata and boundary layer respectively, and k is the psychrometric constant (0.66 mbar/c).

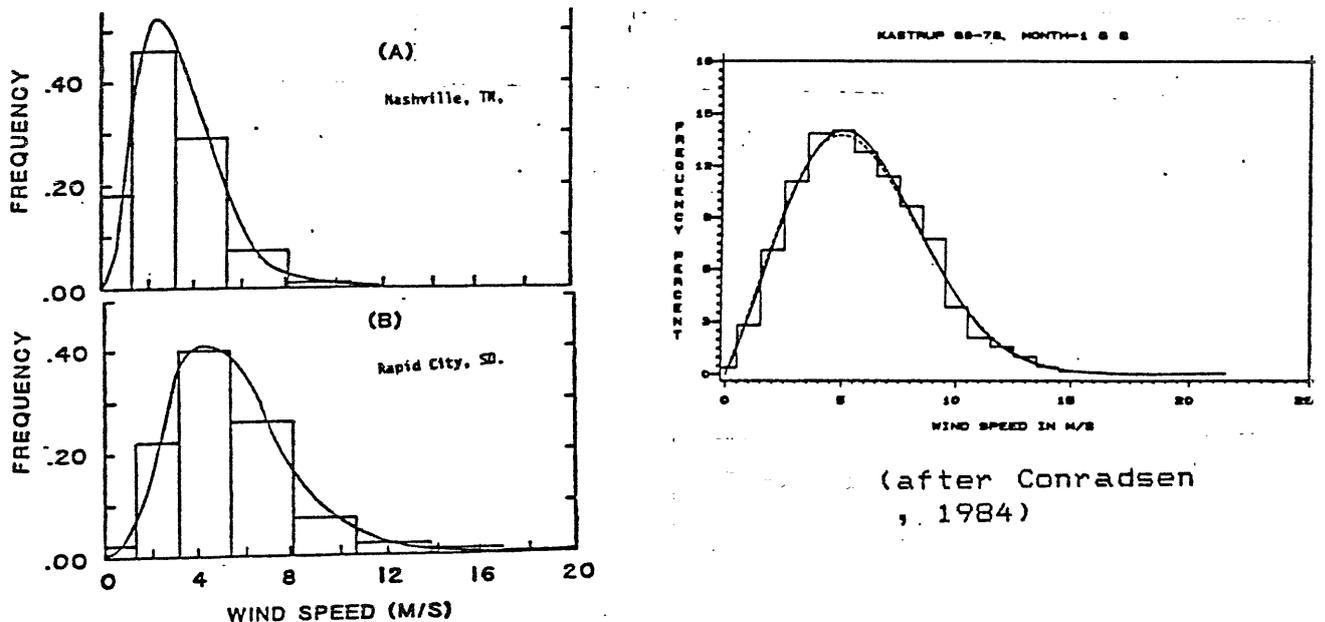
The leaf temperature can be determined at the point when the leaf is in thermal equilibrium with its environment or when the heat balance equation is satisfied. Wind modifies boundary layer resistance (R_{ha} , R_{wa}), thus changes leaf temperature. Under conditions of high energy absorption

and large leaf dimension, wind speed determines the leaf temperature to a large extent, the leaf temperature being in excess of air temperatures often by 10 or 20 C. When leaves are small, absorbed energy low or air temperature high, the influence of wind is relatively small. Always, the greatest effect is over the lower range of wind speed from 0 to 1 m/s.

The relationship between wind speed and transpiration rate will depend on the ratio $1E / C$. If the value of this ratio is large at a constant available energy ($C + 1E$), then an increase in wind speed will increase $1E$ or evaporation rate. On the other hand, at lower values of this ratio, increase in wind speed will increase C and decrease the transpiration rate. The effects of wind speed on photosynthesis and growth rate of the whole plant can also be found in Grace (1977).

2.2 Models of Wind Speed

Empirical wind speed distributions were plotted by Richardson (1982) and Conradson et al. (1984) and they are shown in Figures 2.1. The common feature of the distributions is that they are positively skewed.



(after Richardson, 1982)

(after Conradson
, 1984)

Fig.2.1 Empirical wind speed distributions

Several recent papers advocated the application of the Weibull distribution to analyze wind speed data (Justus et al., 1978; Takle and Brown, 1978; Conradsen et al., 1984). The Weibull distribution has been shown to fit positively skewed data well and is used as a tolerance distribution in the analysis of quantal response data. It also relates to some extreme value distributions with a logarithmic transformation. One advantage of using a Weibull distribution lies in its property of power transformation. That is when total wind speed is fitted by a two parameter (b, c) Weibull distribution, the wind energy proportional to the cubic power of the speed is also Weibull distributed with parameters (b, c /3). A good description of the Weibull distribution is given in Johnson and Kotz(1970). A random variable X has a Weibull distribution if there are values of the parameters $b > 0$, $c > 0$ such that

$$Y = [(X - r) / b]^c$$

has the exponential distribution with probability density function

$$P (Y) = e^{-y} , \quad Y > 0$$

Thus a power transformation of a Weibull random variable is a special case of a Gamma variable.

The probability density function of X is,

$$P (X) = (c / b) [(X - r) / b]^{c - 1} \exp (- [(X - r) / b]^c) , \quad X > r$$

If $r = 0$ and $b = 1$, the distribution is referred to as standard Weibull distribution. The most commonly used Weibull distribution is a two parameter Weibull (b, c) with $r = 0$. The methods of estimating the Weibull parameters were discussed in Johnson and Kotz (1970) and Conradsen et al. (1984).

Richardson (1984) suggested to use a two-parameter Gamma distribution to approximate the distribution of daily wind speed. As shown in Figure 1.3, for $a > 1$ and $r > 0$, the Gamma distribution can also fit positively skewed data. For locations where wind speed is extremely variable and strong winds (greater than 10 m/s) often occur, the Weibull distribution is expected to fit such data better than the Gamma distribution. For locations where strong winds are

rare, a Gamma distribution probably would fit the data as well as a Weibull.

Since the Gamma function has already been programmed for simulating rainfall, it is easier for us to adapt the same program for wind speed generation. Also it is generally believed that the speed of the wind does not depend on the condition of the precipitation. Thus in simulation, the wind speed of a day is generated independently from the rainfall.

2.3 Simulation: Results and Discussion

Generally speaking, the distribution of wind speeds in Wageningen follows a seasonal pattern with stronger winds in winter and spring months. The monthly averages of the last ten years showed that the wind speeds from November to February were greater than 2.9 m/s, but were less than 2.5 m/s from May to October. A simple empirical representation of the monthly average wind speed in relation to the month in a year is,

$$W = 2.4 - 0.04 (m - 6) (m - 8), \quad R^2 = 0.74$$

Where W is the predicted monthly average wind speed and m is the month number in a year. Therefore, monthly averages of wind speed in Wageningen can easily be calculated from the above equation.

The parameters "a" and "b" of the Gamma distribution function were estimated for each month of the last ten years based on Wageningen wind speed data between 1975 to 1984 (see Appendix A). The yearly variations of these parameters were calculated and the standard deviations were about 1.1 times the sizes of their corresponding means. The percent coefficient of variation of the mean parameters (based on standard errors) was about 35%. There definitely exists a general seasonal trend in the values of these parameters. The "a" values increase from January to summer and then progressively decrease until December. On the contrary, the "b" values tend to be greater at the beginning and the end of the year while minimum values usually occur in June or July. The average "a" and "b" values over the years are plotted in the following figure.

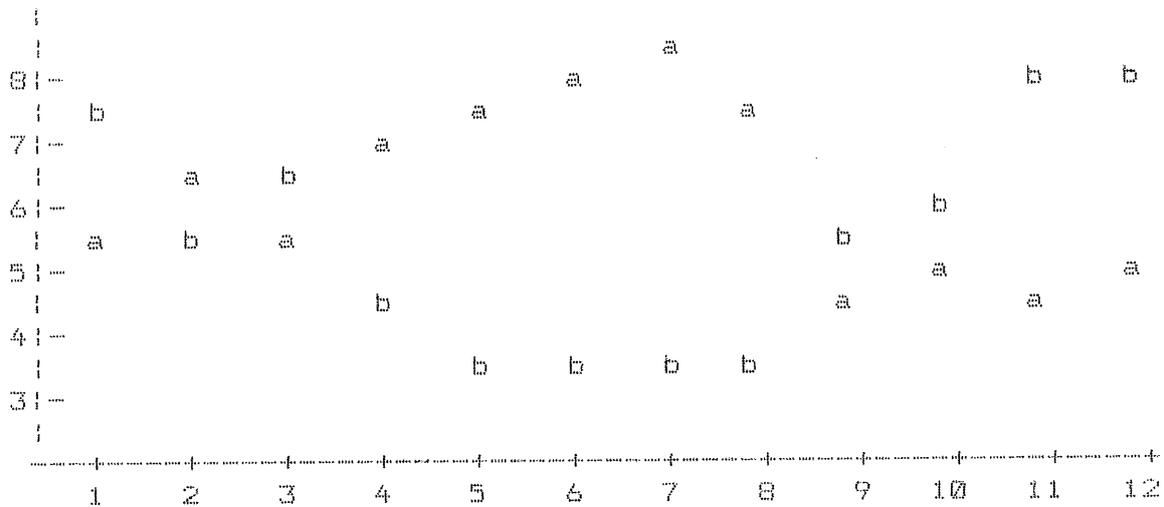


Figure 2.2 Average monthly a and b (X10) values (1975 - 84) of Wageningen

Again quadratic curves were found to fit the seasonal trends very well for both parameters. The R²'s are 0.62 and 0.83 respectively for the fitted a and b curves which are

$$\hat{a} = 7.1 - 0.008 (m - 6) (m - 5)$$

$$\hat{b} = 0.37 + 0.014 (m - 6) (m - 6.3)$$

Where m is the month number in a year. Thus considerable reduction of required parameters to simulate wind speed at Wageningen is achieved, since they can be regenerated from the above equations.

Results of simulation of wind speed are in close approximation to observations. On the yearly averages, only for two of ten years the simulated averages are different from the historical means. And then the differences are only 0.1 m/s.

In 1983, the wind speed in January is the highest among the ten years. The observed and simulated monthly averages of that year are plotted in Figure 2.3.

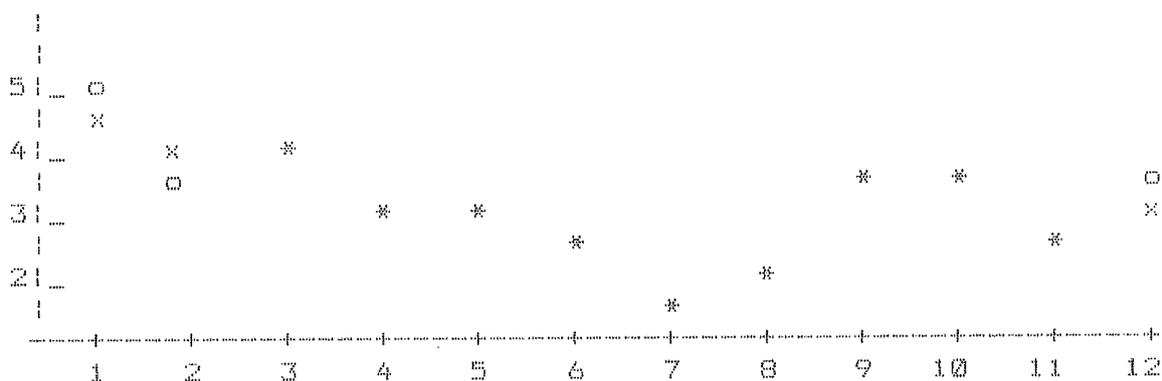


Figure 2.3 Simulated (x) and Observed (o) monthly average wind speeds in 1983 at Wageningen. * means the two points are not separable in this scale.

The fitted quadratic equation for 1983 data is,

$$\hat{W} = 2.5 + 0.06 (m - 6)^2, \quad R = 0.7$$

At this extreme situation, a Gamma function still provides good simulation. Thus no further improvement on methods of simulating wind speed is necessary for climatic conditions such as in Wageningen.

Perhaps a few remarks should be made about simulation models of wind direction. Usually, wind direction is reported in coordinates of the polar system. To define the azimuth, the direction can be given either following the cardinal points and the intermediate points or in degrees following the nonagesimal scale (Primault, 1979). Statistically, the proportions of the wind directions for a given period of time can be assumed to follow a multinomial distribution. Each direction can be represented as a segment or an interval between [0, 1]. The length of the segment corresponds to the magnitude of the proportion. The simulation can easily be accomplished by generating uniform random deviates on the interval [0, 1]. Thus, depending on the segment which this random number falls in, a direction can be defined accordingly.

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PROGRAM LISTING: RAWIN

```

C*****
C   THIS PROGRAM STOCHASTICALLY SIMULATES DAILY PRECIPITATION
C   AND WIND SPEED VALUES. THE REQUIRED INPUT DATA ARE HISTORICAL
C   DAILY RAINFALL AND WIND SPEED MEASUREMENTS WHICH ARE USED TO
C   ESTIMATE THE MODEL PARAMETERS.
C   THIS PROGRAM WILL ALSO CALCULATE VARIABILITY ESTIMATES (SD)
C   FOR MODEL PARAMETERS, IF MORE THAN ONE YEAR DATA ARE AVAILABLE.
C
C   PROGRAMMED BY SHU GENG AND IWAN SUPIT
C                   MARCH, 1985

```

```

C*****
C
C   VARIABLES USED:
C   IPAR           AN INDEX VALUE. 1 FOR RAINFALL DATA, 2 FOR WIND
C                   SPEED.
C   RAIN           INPUT RAINFALL DATA MATRIX, DIMENSIONED 20,365.
C   WINDA          INPUT WIND SPEED DATA MATRIX, DIMENSIONED 20,365.
C   XDATA          A DATA MATRIX USEDE TO STORE RAIN OR WIND FOR
C                   PARAMETER ESTIMATION
C
C   YDATA          OUTPUT PARAMETER MATRIX ESTIMATED FROM DATA
C   SYDATA         OUTPUT SUM OR MEAN PARAMETER MATRIX OVER YEARS
C   VYDATA         OUTPUT STANDERD DEVIATION OF PARAMETERS FOR YEAR
C   ASUM           HISTORICAL MONTHLY TOTAL AMOUNT
C   NNW           " " " WET DAYS
C
C   NTRAIN         SIMULATED DAILY RAIN STATUS FOR A MONTH
C   PRECIP         " " " AMOUNT " " "
C   NTRA           " " " STATUS " " YEAR
C   PREC           " " " AMOUNT " " "
C   TORAIN         " MONTHLY TOTAL RAINFALL
C   NTT           " NUMBER WET DAYS IN MONTH
C   WIND           " DAILY WIND SPEED FOR A MONTH
C   WINDS         " " " " " YEAR
C
C   NY(MONTH)     COUNTER OF YEARS THAT ESTIMATION ARE MADE
C   NNY(MONTH)    THE TOTAL NUMBER YEARS ARE USED FOR ESTIMATION
C
C   ALPH           ALPHA VALUE IN FUNCTION GAMMAD
C   BET           BETA VALUE " " "
C
C   NMONTH         COUNTER OF THE NUMBER OF MONTH.
C
C   NM            COUNTER NUMBER OF MONTH
C   NCOR          SCREEN TEST IF CORRECT DATA ARE USED
C   I1            SEED FOR THE RANDOMGENERATOR
C   I2            SEED FOR THE RANDOM GENERATEOR
C   U             RESULT OF THE RANDOMGENERATOR
C   NTEST         TEST WHETHER YOU START THE SIMULATION PROCES OR
C                   ALREADY IN IT
C   TP1           TEST TRANSITIONAL PROBABILITY
C   AA            DAILY AVERAGE RAINFALL
C
C   P10           TRANSITIONAL PROBABILITY YESTEDAY
C   P00           " " " WET TODAY DRY
C   P01           " " " DRY " DRT
C   P11           " " " DRY " WET
C   P11           " " " WET " WET
C   ALPHA         ALPHA VALUES
C   BETA          BETA VALUES

```

```
C      NDAYS          NUMBER OF DAYS IN A MONTH
C *****
C      MAIN PROGRAM
C *****
      CHARACTER*15 INPNAM
      COMMON IX,ALPA,BET
      INTEGER*2 I1,I2
      COMMON NTRA(365),PREC(365),P00(12),P10(12),P01(12),P11(12)
      COMMON ALPHA(12),BETA(12),NY(12),NNY(12),WINDS(365),WIND(31)
      DIMENSION SYDATA(4,12),VYDATA(4,12),RAIN(25,365),WINDA(25,365)
      COMMON YDATA(4,12),XDATA(25,365),NDAYS(12)
      COMMON NNW(12),NW(12),SUM(12),ASUM(12),ADUM(12),NTT(12)
      COMMON TORAIN(12),DATE(12)
      DATA DATE/ 'JAN.', 'FEB.', 'MAR.', 'APR.', 'MAY ', 'JUNE',
      $           'JULY', 'AUG.', 'SEP.', 'OCT.', 'NOV.', 'DEC.' /
      DATA NDAYS/31,28,31,30,31,30,31,31,30,31,30,31/

C *****
C      READ IN DATA
C *****

      TYPE 30
      READ(-3,35)INPNAM
      TYPE 31
      READ(-3,217)NYR
30      FORMAT(' WHICH FILE HAS TO BE READ?', $)
35      FORMAT(A15)
31      FORMAT(' HOW MANY YEARS DATA ARE USED FOR ESTIMATION?', $)
217     FORMAT(I5)

      OPEN(UNIT=11,STATUS='OLD',FILE=INPNAM)
      DO 215 J=1,NYR
          READ(11,216) (RAIN(J,K),K=1,365)
          READ(11,216) (WINDA(J,K),K=1,365)
215     CONTINUE
216     FORMAT(/,37(10(F22.0),/))
      CLOSE(11)

C *****
C      CALL SUBROUTINES FOR PARAMETER ESTIMATIONS
C *****

      DO 51 IPAR=1,2
      DO 81 J=1,NYR
      DO 81 K=1,365
          XDATA(J,K)=0.0
81      CONTINUE
      DO 82 I=1,12
          NY(I)=0
          NNY(I)=0
          ADUM(I)=0.0
          ASUM(I)=0.0
          NNW(I)=0
      DO 82 K=1,4
          YDATA(K,I)=0.0
          SYDATA(K,I)=0.0
          VYDATA(K,I)=0.0

82      CONTINUE
      DO 41 J=1,NYR
          IF(IPAR.EQ.2) GOTO 42
      DO 43 K=1,365
          XDATA(J,K)=RAIN(J,K)
43      CONTINUE
```

```
GOTO 44
42 DO 45 K=1,365
    XDATA(J,K)=WINDA(J,K)
45 CONTINUE
44 CONTINUE
```

```
C*****
C CALL SUBROUTINE ESTRW(IPAR,XDATA,J,YDATA,NY)
C ASUM IS THE SUM OF OBSERVED AMOUNT OVER YEARS
C NNW IS THE OBSERVED RAINING DAYS IN A MONTH
C OVER YEARS
C*****
```

```
CALL ESTRW(IPAR,XDATA,J,YDATA,NY,SUM,NW)
DO 46 K=1,12
ASUM(K)=ASUM(K)+SUM(K)
NNW(K)=NNW(K)+NW(K)
NNY(K)=NNY(K)+NY(K)
DO 47 I=1,4
    SYDATA(I,K)=SYDATA(I,K)+YDATA(I,K)
    VYDATA(I,K)=VYDATA(I,K)+YDATA(I,K)*YDATA(I,K)
47 CONTINUE
46 CONTINUE
41 CONTINUE
DO 410 L=1,12
ASUM(L)=ASUM(L)/FLOAT(NNY(L))
NNW(L)=FLOAT(NNW(L))/FLOAT(NNY(L))
410 CONTINUE
```

```
C*****
C CALCULATE MEANS AND VARIABILITY OF YEARLY ESTIMATED
C PARAMETERS, IF MORE THAN ONE YEAR DATA ARE USED.
C*****
```

```
DO 48 K=1,12
DO 49 I=1,4
    SYDATA(I,K)=SYDATA(I,K)/FLOAT(NNY(K))
    IF(NYR.EQ.1) THEN
        VYDATA(I,K)=0.0
    ELSE
        VYDATA(I,K)=VYDATA(I,K)-SYDATA(I,K)**2/FLOAT(NNY(K))
        VYDATA(I,K)=SQRT(VYDATA(I,K)/(FLOAT(NNY(K))-1.))
    END IF
49 CONTINUE
IF(IPAR.EQ.2) GOTO 48
P11(K)=SYDATA(1,K)
P01(K)=SYDATA(2,K)
P00(K)=1. - P01(K)
P10(K)=1. - P11(K)
ALPHA(K)=SYDATA(3,K)
BETA(K)=SYDATA(4,K)
48 CONTINUE
IF (IPAR.EQ.2) GOTO 62
```

```
C*****
C PRINT RAINFALL PARAMETERS
C*****
```

```
WRITE(20,63)
WRITE(20,64)
63 FORMAT(/2X,' MEAN PARAMETERS OVER THE YEARS')
64 FORMAT(/2X,' MONTH',5X,' P(W/W)',5X,' P(W/D)',7X,' ALPHA',
$ 10X,' BETA')
DO 65 I=1,12
WRITE(20,66)I,(SYDATA(K,I),K=1,4)
```

```
66     FORMAT(2X,I3,3X,F10.4,1X,F10.4,2X,F10.6,4X,F10.6)
65     CONTINUE
      IF(NYR.EQ.1) GOTO 32
      WRITE(20,67)
67     FORMAT(/2X,'STANDARD DEVIATIONS OF THE PARAMETERS OVER YEARS')
      WRITE(20,64)
      DO 68 I=1,12
      WRITE(20,66)I,(VYDATA(K,I),K=1,4)
68     CONTINUE
32     CONTINUE
C
C     RAINFALL SIMULATION.
C*****
C     CALL SUBROUTINE GENRA(NDAYS,P11,P01,ALPHA,BETA,NTRA,PREC)
C*****
      CALL GENRA(NDAYS,P11,P01,ALPHA,BETA,NTT,TORAIN)
C*****
C     PRINT THE OBSERVED AVERAGES AND THE SIMULATED RESULTS
C     FOR RAINFALL
C *****
      WRITE (20,413)
413    FORMAT(///,5X,'SUMMARY OF THE MONTHLY RAINFALL(MM)
      $ INFORMATION'/5X,'MONTH RAINDAYS--AMOUNT'
      $ 2X, ' RAINDAYS--AMOUNT'/12X,' (SIMULATED) '6X,
      $ ' (OBSERVED)')
      NT1=0
      T2=0.0
      NT3=0
      T4=0.0
      DO 411 L=1,12
      WRITE(20,412)DATE(L),NTT(L),TORAIN(L),NNW(L),ASUM(L)
      NT1=NT1+NTT(L)
      T2=T2+TORAIN(L)
      NT3=NT3+NNW(L)
      T4=T4+ASUM(L)
411    CONTINUE
412    FORMAT(5X,A4,5X,I3,4X,F6.1,5X,I3,F10.1)
      WRITE(20,421) NT1,T2,NT3,T4
421    FORMAT(/5X,'TOTAL',I7,F10.1,2X,I5,F10.1)
      GOTO 51
C*****
C     PRINT WIND SPEED PARAMETERS
C*****
62     WRITE(20,70) NYR
      WRITE(20,71)
70     FORMAT(/2X,'WIND SPEED PARAMETERS OVER',I3,' YEARS'/2X,
      $ 'STANDARD DEVIATIONS ARE ZEROS IF ONLY ONE YEAR DATA USED')
71     FORMAT(2X,'MONTH',7X,'ALPHA',7X,'S.D.',7X,'BETA',7X,'S.D. ')
      DO 72 I=1,12
      WRITE(20,73)I,SYDATA(3,I),VYDATA(3,I),SYDATA(4,I),VYDATA(4,I)
73     FORMAT(2X,I3,4X,F10.6,1X,F10.4,1X,F10.6,1X,F10.4)
      ALPHA(I)=SYDATA(3,I)
      BETA(I)=SYDATA(4,I)
72     CONTINUE
C*****
C     SIMULATE DAILY WIND SPEED. OUTPUT DATA STORED IN WINDS.
C*****
```

```
NCD=0
DO 74 L=1,12
  CALL GENWIN(L,NDAYS,ALPHA,BETA,WIND)
  NDAY=NDAYS(L)
DO 75 I=1,NDAY
  DUM=WIND(I)
  NCD=NCD+1
  WINDS(NCD)=DUM
  ADUM(L)=ADUM(L)+DUM
75  CONTINUE
  WRITE(20,76) L,(WIND(I),I=1,NDAY)
76  FORMAT(// ' GENERATED WIND SPEED FOR MONTH',I3,/10F8.1/
  $ 10F8.1/10F8.1/10F8.1)
74  CONTINUE
  WRITE(20,418)
418  FORMAT(//5X,'AVERAGE MONTHLY WIND SPEED(M/SEC) '//5X,
  $ 'MONTH      SIMULATED      OBSERVED')
  YAV1=0.
  YAV2=0.
  DO 416 L=1,12
  ADUM(L)=ADUM(L)/FLOAT(NDAYS(L))
  ASUM(L)=ASUM(L)/FLOAT(NDAYS(L))
  YAV1=YAV1+ADUM(L)
  YAV2=YAV2+ASUM(L)
417  WRITE(20,417)DATE(L), ADUM(L),ASUM(L)
  FORMAT(5X,A4,2X,F10.1,2X,F10.1)
416  CONTINUE
  YAV1=YAV1/12.
  YAV2=YAV2/12.
  WRITE(20,419) YAV1,YAV2
419  FORMAT(/5X,'AVE ',2F12.1)
51  CONTINUE
  END
```

```
C*****
C
C   GENWIN IS WIND SPEED GENERATOR: TRUNCATED GAMMA FUNCTION
C   WMIN IS THE LOWER LIMIT; WMAX IS THE UPPER LIMIT
C   THESE VALUES ARE GIVEN VALUES FOR A LOCATION
C
C*****
C   SUBROUTINE GENWIN(L,NDAYS,ALPHA,BETA,WIND)
C   DIMENSION WIND(31)
C   DIMENSION NDAYS(12),ALPHA(12),BETA(12)
C   NDAY=NDAYS(L)
C
C   THE FOLLOWING LIMITS ARE FOR WAGENINGEN
C
C   WMIN=0.2
C   WMAX=9.5
C   DO 211 I=1,NDAY
C   WIND(I)=0.0
211  CONTINUE
  ALPH=ALPHA(L)
  BET=BETA(L)
  DO 212 I=1,NDAY
213  WIND(I)=(AINT((GAMMAD(ALPH,BET)+0.005)*100.))/100.
  IF(WIND(I).LT.WMIN) GOTO 213
  IF(WIND(I).GT.WMAX) GOTO 213
C
C   A 10% CORRECTION IS USED FOR WAGENINGEN
C
C   WIND(I)=0.9*WIND(I)
```

212 CONTINUE
RETURN
END

C*****
C THE FOLLOWING SUBROUTINE, ESTRW, WILL TAKE RAW DATA TO
C ESTIMATE THE PARAMETERS FOR RAINFALL OR FOR WIND
C SPEED GENERATION
C*****

SUBROUTINE ESTRW(IPAR,XDATA,J,YDATA,NY,SUM,NW)
DIMENSION NWD(12),NDD(12),NDW(12),NWW(12)
DIMENSION SUM(12),SUM2(12),SUM3(12),SL(12)
DIMENSION RBAR(12),NW(12),P11(12),P01(12),ALPHA(12),BETA(12)
DIMENSION IC(12),SUML(12),RLBAR(12),AL2(12),BE2(12)
DIMENSION DATE(12),PPPW(12),ND(12)
DIMENSION YDATA(4,12),NY(12),XDATA(25,365)
CHARACTER *36 A(2)

DATA DATE/'JAN.', 'FEB.', 'MAR.', 'APR.', 'MAY', 'JUNE',
\$ 'JULY', 'AUG.', 'SEP.', 'OCT.', 'NOV.', 'DEC.'/'

DATA A(1)/' '/
DATA A(2)/'NOT ENOUGH DATA '/

DO 10 I=1,12

ND(I)=0

PPPW(I)=0.

NWD(I)=0

NWW(I)=0

NDD(I)=0

NDW(I)=0

NW(I)=0

SL(I)=0.

SUML(I)=0.

SUM(I)=0.

SUM2(I)=0.

SUM3(I)=0.

RBAR(I)=0.

RLBAR(I)=0.

P11(I)=0.

P01(I)=0.

ALPHA(I)=0.

BETA(I)=0.

10 CONTINUE

RIM1=0.

DO 30 K=1,365

IF(K.GE.001 .AND. K.LE.031)MO=1

IF(K.GE.032 .AND. K.LE.059)MO=2

IF(K.GE.060 .AND. K.LE.090)MO=3

IF(K.GE.091 .AND. K.LE.120)MO=4

IF(K.GE.121 .AND. K.LE.151)MO=5

IF(K.GE.152 .AND. K.LE.181)MO=6

IF(K.GE.182 .AND. K.LE.212)MO=7

IF(K.GE.213 .AND. K.LE.243)MO=8

IF(K.GE.244 .AND. K.LE.273)MO=9

IF(K.GE.274 .AND. K.LE.304)MO=10

IF(K.GE.305 .AND. K.LE.334)MO=11

IF(K.GE.335 .AND. K.LE.365)MO=12

RWIN=XDATA(J,K)

IF(RWIN.GT.0.0) NW(MO)=NW(MO)+1

IF(IPAR.EQ.2) GOTO 11

ND(MO)=ND(MO)+1

IF(RWIN)5,5,3

3 IF(RIM1)2,2,4

2 NWD(MO)=NWD(MO)+1

```
GOTO 6
4   NWW(MO)=NWW(MO)+1
6   CONTINUE
11  IF(RWIN.LE.0.01)RWIN=0.01
    SUML(MO)=SUML(MO)+ALOG(RWIN)
    SUM(MO)=SUM(MO)+RWIN
    SUM2(MO)=SUM2(MO)+RWIN*RWIN
    SUM3(MO)=SUM3(MO)+RWIN*RWIN*RWIN
    SL(MO)=SL(MO)+ALOG(RWIN)
    GOTO 9
5   IF(RIM1)7,7,8
7   NDD(MO)=NDD(MO)+1
    GO TO 9
8   NDW(MO)=NDW(MO)+1
9   RIM1=RWIN
30  CONTINUE
    DO 120 I=1,12
    NY(I)=0
    IF(IPAR.EQ.2)GOTO 12
    XXND=ND(I)
    YYNW=NW(I)
    PFPW(I)=YYNW/XXND
    III=1
    IF(NW(I) .LT. 3)III=2
    IC(I)=III
    IF(NW(I).LT.3) GOTO 120
    XNWW=NWW(I)
    XNWD=NWD(I)
    XXNW=NWW(I)+NWD(I)
    XND=NDD(I)+NWD(I)
    P11(I)=XNWW/XXNW
    P01(I)=XNWD/XND
C*****
C   A CORRECTION FACTOR IS USED TO REDUCE OVERESTIMATION
C   OF P01 AND P11. THESE FACTORS CAN BE DERIVED FROM A
C   PRILIMINARY RUN AND FROM THE PRINTOUTS OF MEAN VALUES
C   AND SD VALUES
C*****
    IF(P11(I).GT. 0.88) P11(I)=0.88
    IF( P01(I).GT.0.65) P01(I)=0.65
12  XNW=NW(I)
    NY(I)=1
    RBAR(I)=SUM(I)/XNW
    RLBAR(I)=SUML(I)/XNW
    Y=ALOG(RBAR(I))-RLBAR(I)
    ANUM=8.898919+9.05995*Y+0.9775373*Y*Y
    ADOM=Y*(17.79728+11.968477*Y+Y*Y)
    ALPHA2=ANUM/ADOM
    IF(IPAR.EQ.1. AND. ALPHA2 .GE. 1.) ALPHA2=0.998
    BETA2=RBAR(I)/ALPHA2
    ALPHA(I)=ALPHA2
    BETA(I)=BETA2
C   TYPE 808,I,SUM(I),SUML(I)
C   TYPE 808,I,RBAR(I),RLBAR(I),Y,ALPHA2,BETA2
C 808  FORMAT(/2X,15,5F10.2)
120 CONTINUE
    IF(IPAR.EQ.2) GOTO 13
    WRITE(20,203) J
203  FORMAT(/5X,'RAINFALL PARAMETER ESTIMATION FOR YEAR',I3)
    WRITE(20,201)
201  FORMAT(/' MONTH',7X,'P(W/W)',7X,'P(W/D)',7X,
$     'ALPHA', 7X,'BETA')
    DO 130 I=1,12
```

```
WRITE(20,202)DATE(I),P11(I),P01(I),ALPHA(I),BETA(I),A(IC(I))
202 FORMAT(2X,A4,5X,F10.4,3X,F10.4,2X,F10.4,2X,F10.4,A30)
130 CONTINUE
GO TO 17
13 WRITE(20,14)
14 FORMAT(///2X,'WIND SPEED PARAMETERS FOR YEAR',/
$ 2X,'MONTH',7X,'ALPHA',10X,'BETA')
DO 15 I=1,12
WRITE(20,16) DATE(I),ALPHA(I),BETA(I),A(IC(I))
16 FORMAT(2X,A4,4X,F10.6,4X,F10.6,A36)
15 CONTINUE
17 CONTINUE
DO 18 I=1,12
IF(IPAR.EQ.2) THEN
YDATA(1,I)=0.
YDATA(2,I)=0.
ELSE
YDATA(1,I)=P11(I)
YDATA(2,I)=P01(I)
END IF
YDATA(3,I)=ALPHA(I)
YDATA(4,I)=BETA(I)
18 CONTINUE
RETURN
END
```

```
C*****
C
C SUBROUTINE GENRA FOR RAINFALL SIMULATION
C RMIN AND RMAX ARE LIMITS GIVEN BY RESEARCHER
C THEY ARE LOCATION SPECIFIC.
C
C*****
```

```
SUBROUTINE GENRA(NDAYS,P11,P01,ALPHA,BETA,NTT,TORAIN)
DIMENSION NTT(12),NTRAIN(31),NTRA(365),P10(12),P00(12)
DIMENSION TORAIN(12),PRECIP(31),PREC(365)
DIMENSION ALPHA(12),BETA(12),NDAYS(12),P11(12),P01(12)
NCD=0
NM=1
```

```
C
C THE FOLLOWING LIMITS ARE FOR WAGENINGEN
C
```

```
RMIN=0.05
RMAX=40.0
NMONTH=12
NTEST=555
DO 53 L=1,NMONTH
NTT(L)=0
P10(L)=1.-P11(L)
P00(L)=1.-P01(L)
53 CONTINUE
DO 120 L=NM,NMONTH
I1=6351*L*0.2527
I2=3753*L*0.15
NDAY = NDAYS(L)
IF(NTEST.EQ. 555) THEN
TP1=P10(L)
ELSE IF(NTEST.EQ. 1) THEN
TP1=P10(L-1)
ELSE
TP1=P00(L-1)
END IF
```

```
C*****  
C      TEST IF TODAY IS DRY OR NOT  
C      (TWO STATE MARKOV CHAIN)  
C*****
```

```
      DO 50 I=1,NDAY  
          CALL RANDU (I1,I2,U)  
          IF(U.LT.TP1) THEN  
              NTRAIN(I)=0  
              TP1=P00(L)  
              NTEST=0  
          ELSE  
              NTRAIN(I)=1  
              TP1=P10(L)  
              NTEST=1  
          END IF  
      NTT(L)=NTT(L)+NTRAIN(I)  
50      CONTINUE
```

```
      TORAIN(L)=0.0
```

```
      DO 55 I=1,NDAY  
          PRECIP(I)=0.0  
55      CONTINUE
```

```
C*****  
C      SIMULATE AMOUNT OF RAINFALL BY GAMMA FUNCTION  
C*****
```

```
      ALPH=ALPHA(L)  
      BET=BETA(L)  
      DO 90 I=1,NDAY  
          IF(NTRAIN(I).EQ. 1) THEN  
60          PRECIP(I)=(AINT((GAMMAD(ALPH,BET)+.005)*100.))/100  
              IF (PRECIP(I).LT.RMIN) GOTO 60  
              IF( PRECIP(I).GT.RMAX) GOTO 60  
              TORAIN(L)=TORAIN(L)+PRECIP(I)  
          END IF  
90      CONTINUE
```

```
      DO 105 I=1,NDAY  
          NCD=NCD+1  
          PREC(NCD)=PRECIP(I)  
          NTRA(NCD)=NTRAIN(I)  
105     CONTINUE  
      WRITE(20,100) L,(PRECIP(I),I=1,NDAY)  
100     FORMAT(/2X,'SIMULATED RAINFALL FOR MONTH',I3,/  
$      10F8.1/10F8.1/10F8.1/10F8.1)  
120     CONTINUE  
      RETURN  
555     END
```

```
C*****  
C*      FUNCTION  GAMMAD                                *  
C*      (METHOD OF JOHNS)                              *  
C*****
```

```
      FUNCTION  GAMMAD(ALPH,BET)  
      Z=0.0  
      K=ALPH
```

```
F=K
IF (K) 303,303,301
301  PROD=1.0
      DO 302 L=1,K
          CALL RANDU (I1,I2,U)
302  PROD=PROD*U
      Z=-ALOG(PROD)
303  D=ALPH-F
      IF (D) 308,308,304
304  A=1.0/D
      B=1.0/(1.0-D)
      L=1

305  CALL RANDU (I1,I2,U)
      UA=-50/ALOG10(U)
      X=0.
      IF (A.LT.UA) X=U**A
      CALL RANDU (I1,I2,U)
      UB=-50/ALOG10(U)
      Y=X
      IF (B.LT.UB) Y=U**B+X
      IF (Y-1.0) 307,307,306
306  L=L+2
      GOTO 305
307  W=X/Y
      CALL RANDU (I1,I2,U)
      Y=-ALOG(U)
      GAMMAD=(Z+W*Y)*BET
      RETURN
308  GAMMAD=Z*BET
      RETURN
      END
```

APPENDIX A

APPENDIX A; LISTINGS OF PARAMETERS OF RAIN AND WIND MODELS
(RAIN AND WIND PARAMETERS OF WAGENINGEN, 1975-1984)

RAINFALL PARAMETER ESTIMATION FROM YEAR 1975

MONTH	P(W/W)	P(W/D)	ALPHA	BETA
JAN.	0.8696	0.5000	0.6967	5.0534
FEB.	0.5714	0.0952	0.9980	4.7595
MAR.	0.8400	0.6500	0.9980	3.0942
APR.	0.8636	0.5000	0.9393	2.6337
MAY	0.6154	0.2222	0.9980	3.4152
JUNE	0.6923	0.2941	0.6359	9.6820
JULY	0.6000	0.3125	0.5299	12.4552
AUG.	0.4545	0.3000	0.5401	8.9541
SEP.	0.5882	0.6154	0.6526	6.1720
OCT.	0.4667	0.5000	0.7326	1.3195
NOV.	0.7778	0.3333	0.8528	5.6087
DEC.	0.4167	0.3684	0.7273	2.5779

RAINFALL PARAMETER ESTIMATION FROM YEAR 1976

MONTH	P(W/W)	P(W/D)	ALPHA	BETA
JAN.	0.8182	0.4444	0.9980	4.5272
FEB.	0.7143	0.0952	0.9980	2.5766
MAR.	0.5000	0.2381	0.8397	3.5250
APR.	0.0000	0.1111	0.9980	2.3380
MAY	0.6429	0.3529	0.9604	2.3878
JUNE	0.2000	0.1200	0.9980	8.6673
JULY	0.5556	0.2273	0.9980	2.8657
AUG.	0.7778	0.0909	0.9980	2.2823
SEP.	0.5882	0.5385	0.9980	2.4814
OCT.	0.6429	0.2353	0.9980	2.7902
NOV.	0.7222	0.5000	0.8334	3.1261
DEC.	0.7000	0.4545	0.9980	2.6158

RAINFALL PARAMETER ESTIMATION FROM YEAR 1977

MONTH	P(W/W)	P(W/D)	ALPHA	BETA
JAN.	0.8400	0.6500	0.9980	2.1884
FEB.	0.8500	0.3750	0.9980	4.2535
MAR.	0.5333	0.4375	0.9197	2.8560
APR.	0.8696	0.5714	0.9563	2.1959
MAY	0.8125	0.1333	0.9980	3.6874
JUNE	0.6471	0.5385	0.6120	5.8368
JULY	0.6429	0.2353	0.5889	8.8825
AUG.	0.8750	0.4286	0.6130	9.1356
SEP.	0.2857	0.2174	0.8243	1.0572
OCT.	0.7222	0.3846	0.6630	3.0918
NOV.	0.8750	0.6500	0.9378	7.2637
DEC.	0.7727	0.5556	0.7038	2.7321

RAINFALL PARAMETER ESTIMATION FROM YEAR 1978

MONTH	P(W/W)	P(W/D)	ALPHA	BETA
JAN.	0.7143	0.6500	0.7003	4.0112
FEB.	0.6000	0.4615	0.6412	5.3549
MAR.	0.8000	0.6500	0.9980	3.2986
APR.	0.7333	0.2667	0.8580	2.7039
MAY	0.5333	0.3750	0.5554	4.2569
JUNE	0.7778	0.4167	0.8774	3.6952
JULY	0.6667	0.2500	0.6038	6.7074
AUG.	0.7059	0.4286	0.7301	2.3588
SEP.	0.6250	0.4286	0.8007	5.3702
OCT.	0.3636	0.3000	0.9980	1.6132
NOV.	0.6364	0.2105	0.9980	1.9585
DEC.	0.7857	0.2353	0.8702	7.5770

RAINFALL PARAMETER ESTIMATION FROM YEAR 1979

MONTH	P(W/W)	P(W/D)	ALPHA	BETA
JAN.	0.6471	0.4286	0.8024	2.6024
FEB.	0.5833	0.3125	0.6959	5.2209
MAR.	0.6316	0.6500	0.8668	4.7009
APR.	0.7895	0.3636	0.9442	2.8262
MAY	0.7895	0.3333	0.9382	4.2467
JUNE	0.5333	0.4667	0.4164	23.7598
JULY	0.6429	0.2941	0.5091	4.4057
AUG.	0.5000	0.4667	0.6481	8.7231
SEP.	0.3750	0.2273	0.9980	2.2295
OCT.	0.2857	0.2500	0.6545	6.9902
NOV.	0.7368	0.4545	0.6850	4.6023
DEC.	0.7917	0.6500	0.8348	4.6970

RAINFALL PARAMETER ESTIMATION FROM YEAR 1980

MONTH	P(W/W)	P(W/D)	ALPHA	BETA
JAN.	0.8000	0.2500	0.6914	4.2398
FEB.	0.6923	0.2000	0.6494	5.9673
MAR.	0.5000	0.4706	0.5952	6.1496
APR.	0.6429	0.2500	0.7216	4.3279
MAY	0.2000	0.1923	0.9804	1.5809
JUNE	0.8571	0.3333	0.9003	3.5014
JULY	0.6842	0.4167	0.6988	11.5838
AUG.	0.5625	0.5333	0.6511	4.1923
SEP.	0.5000	0.4375	0.6937	2.8212
OCT.	0.7391	0.6250	0.5943	5.1549
NOV.	0.8421	0.2727	0.7259	3.8138
DEC.	0.6842	0.5833	0.9980	2.8156

RAINFALL PARAMETER ESTIMATION FROM YEAR 1981

MONTH	P(W/W)	P(W/D)	ALPHA	BETA
JAN.	0.6000	0.3750	0.9379	5.8571
FEB.	0.6667	0.3125	0.5209	6.9851
MAR.	0.8400	0.5000	0.5758	9.5801
APR.	0.3750	0.2727	0.7606	2.1182
MAY	0.6957	0.6500	0.7772	3.6025
JUNE	0.6111	0.5833	0.4529	7.8994
JULY	0.5000	0.4118	0.4859	7.2624
AUG.	0.5556	0.1364	0.4954	5.0208
SEP.	0.6429	0.3125	0.7979	5.1834
OCT.	0.8800	0.6500	0.7416	7.1159
NOV.	0.8333	0.6500	0.7823	3.7655
DEC.	0.7222	0.3846	0.7897	4.1084

RAINFALL PARAMETER ESTIMATION FROM YEAR 1982

MONTH	P(W/W)	P(W/D)	ALPHA	BETA
JAN.	0.7500	0.2105	0.9980	4.1699
FEB.	0.6667	0.1579	0.9980	1.8370
MAR.	0.7222	0.3077	0.5966	7.3757
APR.	0.6923	0.2941	0.9517	1.3659
MAY	0.6875	0.2667	0.8822	2.5618
JUNE	0.6316	0.6364	0.7969	4.0484
JULY	0.5000	0.2857	0.4642	3.2707
AUG.	0.6111	0.5385	0.8101	3.5659
SEP.	0.5455	0.2632	0.9980	2.8785
OCT.	0.7368	0.3333	0.6456	7.1418
NOV.	0.7500	0.5000	0.6175	5.3279
DEC.	0.8333	0.2308	0.9980	3.3010

RAINFALL PARAMETER ESTIMATION FROM YEAR 1983

MONTH	P(W/W)	P(W/D)	ALPHA	BETA
JAN.	0.8571	0.4000	0.6587	5.6382
FEB.	0.8333	0.1250	0.7870	3.9921
MAR.	0.8800	0.1667	0.9980	3.5281
APR.	0.5714	0.6500	0.8288	4.8504
MAY	0.7917	0.6500	0.9236	5.7213
JUNE	0.6000	0.4000	0.6130	5.6984
JULY	0.3333	0.1200	0.9980	2.3447
AUG.	0.3333	0.3182	0.6396	5.1128
SEP.	0.6842	0.4545	0.6568	7.7305
OCT.	0.7059	0.3571	0.8661	2.4246
NOV.	0.7273	0.2105	0.4360	14.1426
DEC.	0.7059	0.2857	0.7035	6.5919

RAINFALL PARAMETER ESTIMATION FROM YEAR 1984

MONTH	P(W/W)	P(W/D)	ALPHA	BETA
JAN.	0.8800	0.6000	0.8388	3.9916
FEB.	0.7500	0.1250	0.6893	7.9922
MAR.	0.8333	0.1579	0.9570	3.4966
APR.	0.7692	0.1765	0.7472	1.5340
MAY	0.6842	0.4167	0.8653	5.0658
JUNE	0.5455	0.3158	0.9980	4.6176
JULY	0.4000	0.2381	0.7076	5.8417
AUG.	0.7000	0.1905	0.7417	1.4340
SEP.	0.7917	0.6500	0.5638	11.7808
OCT.	0.7500	0.3636	0.7979	7.8760
NOV.	0.6875	0.3571	0.9296	3.3079
DEC.	0.7059	0.4286	0.8554	2.0719

MEAN PARAMETERS OVER THE YEARS

MONTH	P(W/W)	P(W/D)	ALPHA	BETA
1	0.7776	0.4509	0.832018	4.227922
2	0.6928	0.2260	0.797563	4.893907
3	0.7080	0.4228	0.834480	4.760486
4	0.6307	0.3456	0.870575	2.689418
5	0.6453	0.3592	0.887871	3.652638
6	0.6096	0.4105	0.730091	7.740648
7	0.5525	0.2791	0.658406	6.561965
8	0.6076	0.3432	0.686728	5.077973
9	0.5626	0.4145	0.798382	4.770473
10	0.6293	0.3999	0.769168	4.551808
11	0.7588	0.4139	0.779842	5.291692
12	0.7118	0.4177	0.847865	3.908844

STANDARD DEVIATIONS OF THE PARAMETERS OVER YEARS

MONTH	P(W/W)	P(W/D)	ALPHA	BETA
1	0.8213	0.4970	0.884030	4.586071
2	0.7331	0.2704	0.856562	5.462075
3	0.7583	0.4849	0.893077	5.472569
4	0.7130	0.4024	0.918632	3.032467
5	0.7000	0.4160	0.941013	4.030714
6	0.6629	0.4572	0.794947	10.110328
7	0.5915	0.3058	0.718057	7.742959
8	0.6573	0.3947	0.734419	6.070137
9	0.6082	0.4621	0.852310	5.949453
10	0.6873	0.4439	0.819507	5.422202
11	0.7993	0.4638	0.835354	6.534299
12	0.7553	0.4617	0.897200	4.501169

WIND SPEED PARAMETERS FROM YEAR 1975

MONTH	ALPHA	BETA
JAN.	8.094646	0.504914
FEB.	6.164051	0.387037
MAR.	5.732491	0.476064
APR.	5.933573	0.438185
MAY	6.023070	0.431138
JUNE	13.483269	0.165143
JULY	3.934908	0.547621
AUG.	9.942267	0.203757
SEP.	2.811130	0.826477
OCT.	7.162688	0.292285
NOV.	4.060557	0.582843
DEC.	2.055740	1.201985

WIND SPEED PARAMETERS FROM YEAR 1976

MONTH	ALPHA	BETA
JAN.	5.180591	0.917818
FEB.	8.160401	0.341807
MAR.	4.601714	0.656838
APR.	3.891873	0.620952
MAY	6.852160	0.368615
JUNE	4.735429	0.453320
JULY	11.404892	0.171404

AUG.	10.327596	0.196155
SEP.	4.422133	0.438702
OCT.	5.291277	0.453577
NOV.	3.242450	0.800835
DEC.	4.232962	0.679003

WIND SPEED PARAMETERS FROM YEAR 1977

MONTH	ALPHA	BETA
JAN.	2.389540	1.150174
FEB.	3.692410	0.833757
MAR.	7.205658	0.428427
APR.	4.266280	0.784446
MAY	8.873117	0.303926
JUNE	9.309717	0.226287
JULY	8.229543	0.295944
AUG.	4.394923	0.358185
SEP.	2.306855	0.851086
OCT.	3.467254	0.648463
NOV.	2.884872	1.359968
DEC.	3.341326	0.961565

WIND SPEED PARAMETERS FROM YEAR 1978

MONTH	ALPHA	BETA
JAN.	4.751363	0.688427
FEB.	5.577946	0.466121
MAR.	3.734396	0.965739
APR.	6.595176	0.348740
MAY	5.597667	0.333664
JUNE	5.374447	0.452760
JULY	3.548995	0.613531
AUG.	5.687952	0.364664
SEP.	6.044247	0.522811
OCT.	4.941686	0.407984
NOV.	2.801594	1.027986
DEC.	5.999963	0.540864

WIND SPEED PARAMETERS FROM YEAR 1979

MONTH	ALPHA	BETA
JAN.	3.859359	0.723837
FEB.	4.874014	0.579605
MAR.	8.552196	0.476392
APR.	8.565685	0.349846
MAY	6.479383	0.413221
JUNE	8.990582	0.259902
JULY	5.780568	0.435832
AUG.	6.392419	0.361315
SEP.	4.878148	0.459874
OCT.	4.376555	0.553536
NOV.	5.272319	0.569010
DEC.	5.157028	0.811921

WIND SPEED PARAMETERS FROM YEAR 1980

MONTH	ALPHA	BETA
JAN.	7.737987	0.364352
FEB.	8.957526	0.320959
MAR.	6.830513	0.498239
APR.	5.959288	0.511806
MAY	6.772991	0.449127
JUNE	8.169826	0.328036
JULY	9.496943	0.293133
AUG.	4.427401	0.594538
SEP.	4.009488	0.552024
OCT.	4.197262	0.739345
NOV.	5.395637	0.669677
DEC.	5.476402	0.663256

WIND SPEED PARAMETERS FROM YEAR 1981

MONTH	ALPHA	BETA
JAN.	3.390822	0.878082
FEB.	2.996092	0.932167
MAR.	4.018390	0.854940
APR.	9.456658	0.259782
MAY	6.290559	0.326142
JUNE	3.606812	0.619199
JULY	8.893339	0.244837
AUG.	2.499484	0.583346
SEP.	4.113156	0.470037
OCT.	3.731483	0.808292
NOV.	4.505286	0.741351
DEC.	6.986847	0.361047

WIND SPEED PARAMETERS FROM YEAR 1982

MONTH	ALPHA	BETA
JAN.	4.375153	0.631867
FEB.	15.074591	0.177451
MAR.	2.827323	1.147786
APR.	7.851989	0.379522
MAY	8.516328	0.310978
JUNE	6.413820	0.399658
JULY	9.928978	0.235219
AUG.	5.772645	0.457665
SEP.	5.253565	0.440970
OCT.	6.943791	0.380939
NOV.	5.286236	0.723893
DEC.	2.916134	1.258847

WIND SPEED PARAMETERS FROM YEAR 1983

MONTH	ALPHA	BETA
JAN.	10.379431	0.499748
FEB.	5.533151	0.613187
MAR.	6.444809	0.568099
APR.	10.943540	0.281140
MAY	9.004904	0.313449
JUNE	12.459380	0.207608
JULY	12.252221	0.149018
AUG.	12.554542	0.164444
SEP.	5.791130	0.607826
OCT.	3.633236	0.909169

NOV.	3.470468	0.729969
DEC.	5.023979	0.700511

WIND SPEED PARAMETERS FROM YEAR 1984

MONTH	ALPHA	BETA
JAN.	5.280506	0.923054
FEB.	4.610762	0.747475
MAR.	7.176214	0.398269
APR.	6.072853	0.380381
MAY	7.556542	0.344073
JUNE	6.464450	0.416122
JULY	8.769535	0.280664
AUG.	6.733387	0.283613
SEP.	5.573074	0.470716
OCT.	5.482330	0.558392
NOV.	6.263474	0.551345
DEC.	6.486539	0.444593

WIND SPEED PARAMETERS OVER 10 YEARS

STANDARD DEVIATIONS ARE ZEROS IF ONLY ONE YEAR DATA USED

MONTH	ALPHA	S.D.	BETA	S.D.
1	5.543940	6.3123	0.728227	0.8007
2	6.564095	7.7252	0.539957	0.6168
3	5.712371	6.2682	0.647079	0.7255
4	6.953692	7.6291	0.435480	0.4848
5	7.196672	7.6468	0.359433	0.3807
6	7.900773	8.8962	0.352803	0.3960
7	8.223993	9.1130	0.326720	0.3763
8	6.873262	7.8559	0.356768	0.4041
9	4.520293	4.9019	0.564052	0.6114
10	4.922756	5.3280	0.575198	0.6355
11	4.318289	4.6873	0.775688	0.8505
12	4.767692	5.2521	0.762359	0.8542

APPENDIX B

APPENDIX B: SUMMARIES OF THE WAGENINGEN DATA
(ACTUAL RAINFALL AND WINDSPEED DATA
OF WAGENINGEN IN 1975 TO 1984)

SUMMARY OF YEAR 1975

MONTH	WET DAYS	AMOUNT (MM)	WINDSPEED (M/S)
JAN.	24	84.5	4.1
FEB.	6	28.5	2.4
MAR.	25	77.2	2.7
APR.	23	56.9	2.6
MAY	12	40.9	2.6
JUNE	14	86.2	2.2
JULY	14	92.4	2.2
AUG.	11	53.2	2.0
SEP.	18	72.5	2.3
OCT.	15	14.5	2.1
NOV.	18	86.1	2.4
DEC.	12	22.5	2.5
TOT.	192	715.4	
MEAN	16.0	59.6	2.5
VAR.	33.5	759.8	0.3

SUMMARY OF YEAR 1976

MONTH	WET DAYS	AMOUNT (MM)	WINDSPEED (M/S)
JAN.	22	99.4	4.8
FEB.	7	18.0	2.8
MAR.	10	29.6	3.0
APR.	3	7.0	2.4
MAY	15	34.4	2.5
JUNE	4	34.6	2.1
JULY	10	28.6	2.0
AUG.	9	20.5	2.0
SEP.	17	42.1	1.9
OCT.	13	36.2	2.4
NOV.	19	49.5	2.6
DEC.	19	49.6	2.9
TOT.	148	449.5	
MEAN	12.3	37.5	2.6
VAR.	38.1	536.7	0.6

SUMMARY OF YEAR 1977

MONTH	WET DAYS	AMOUNT (MM)	WINDSPEED (M/S)
JAN.	25	54.6	2.7
FEB.	20	84.9	3.1
MAR.	15	39.4	3.1
APR.	24	50.4	3.3
MAY	15	55.2	2.7
JUNE	18	64.3	2.1
JULY	13	68.0	2.4
AUG.	24	134.4	1.6
SEP.	7	6.1	2.0
OCT.	18	36.9	2.2
NOV.	25	170.3	3.9
DEC.	22	42.3	3.2
TOT.	226	806.8	
MEAN	18.8	67.2	2.7
VAR.	31.4	2008.8	0.4

SUMMARY OF YEAR 1978

MONTH	WET DAYS	AMOUNT (MM)	WINDSPEED (M/S)
JAN.	22	61.8	3.3
FEB.	15	51.5	2.6
MAR.	25	82.3	3.6
APR.	15	34.8	2.3
MAY	14	33.1	1.9
JUNE	19	61.6	2.4
JULY	14	56.7	2.2
AUG.	18	31.0	2.1
SEP.	16	68.8	3.2
OCT.	10	16.1	2.0
NOV.	11	21.5	2.9
DEC.	15	98.9	3.2
TOT.	194	618.1	
MEAN	16.2	51.5	2.6
VAR.	18.3	629.2	0.3

SUMMARY OF YEAR 1979

MONTH	WET DAYS	AMOUNT (MM)	WINDSPEED (M/S)
JAN.	17	35.5	2.8
FEB.	12	43.6	2.8
MAR.	20	81.5	4.1
APR.	19	50.7	3.0
MAY	19	75.7	2.7
JUNE	15	148.4	2.3
JULY	14	31.4	2.5
AUG.	15	84.8	2.3
SEP.	8	17.8	2.2
OCT.	8	36.6	2.4
NOV.	19	59.9	3.0
DEC.	24	94.1	4.2
TOT.	190	760.0	
MEAN	15.8	63.3	2.9
VAR.	23.4	1297.3	0.4

SUMMARY OF YEAR 1980

MONTH	WET DAYS	AMOUNT (MM)	WINDSPEED (M/S)
JAN.	16	46.9	2.8
FEB.	12	46.5	2.9
MAR.	15	54.9	3.4
APR.	13	40.6	3.0
MAY	6	9.3	3.0
JUNE	21	66.2	2.7
JULY	18	145.7	2.8
AUG.	17	46.4	2.6
SEP.	14	27.4	2.2
OCT.	22	67.4	3.1
NOV.	19	52.6	3.6
DEC.	20	56.2	3.6
TOT.	193	660.1	
MEAN	16.1	55.0	3.0
VAR.	20.1	1071.1	0.2

SUMMARY OF YEAR 1981

MONTH	WET DAYS	AMOUNT (MM)	WINDSPEED (M/S)
JAN.	15	82.4	3.0
FEB.	13	47.3	2.8
MAR.	24	132.4	3.4
APR.	9	14.5	2.5
MAY	23	64.4	2.1
JUNE	18	64.4	2.2
JULY	14	49.4	2.2
AUG.	8	19.9	1.5
SEP.	14	57.9	1.9
OCT.	26	137.2	3.0
NOV.	24	70.7	3.3
DEC.	18	58.4	2.5
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TOT.	206	798.9	
MEAN	17.2	66.6	2.5
VAR.	36.3	1390.6	0.4

SUMMARY OF YEAR 1982

MONTH	WET DAYS	AMOUNT (MM)	WINDSPEED (M/S)
JAN.	13	54.1	2.8
FEB.	9	16.5	2.7
MAR.	17	74.8	3.2
APR.	14	18.2	3.0
MAY	15	33.9	2.6
JUNE	19	61.3	2.6
JULY	11	16.7	2.3
AUG.	18	52.0	2.6
SEP.	11	31.6	2.3
OCT.	18	83.0	2.6
NOV.	20	65.8	3.8
DEC.	18	59.3	3.7
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TOT.	183	567.2	
MEAN	15.3	47.3	2.9
VAR.	13.1	539.9	0.2

SUMMARY OF YEAR 1983

MONTH	WET DAYS	AMOUNT (MM)	WINDSPEED (M/S)
JAN.	22	81.7	5.2
FEB.	12	37.7	3.4
MAR.	19	66.9	3.7
APR.	20	80.4	3.1
MAY	25	132.1	2.8
JUNE	15	52.4	2.6
JULY	5	11.7	1.8
AUG.	10	32.7	2.1
SEP.	18	91.4	3.5
OCT.	17	35.7	3.3
NOV.	12	74.0	2.5
DEC.	16	74.2	3.5
TOT.	191	770.9	
MEAN	15.9	64.2	3.1
VAR.	30.6	1047.7	0.8

SUMMARY OF YEAR 1984

MONTH	WET DAYS	AMOUNT (MM)	WINDSPEED (M/S)
JAN.	27	90.4	4.9
FEB.	11	60.6	3.4
MAR.	13	43.5	2.9
APR.	13	14.9	2.3
MAY	18	78.9	2.6
JUNE	12	55.3	2.7
JULY	9	37.2	2.5
AUG.	11	11.7	1.9
SEP.	24	159.4	2.6
OCT.	19	119.4	3.1
NOV.	16	49.2	3.5
DEC.	18	31.9	2.9
TOT.	191	752.4	
MEAN	15.9	62.7	2.9
VAR.	30.4	1880.9	0.6
PQD			

SIMULATED RAINFALL FOR MONTH 9

0.0	3.2	0.0	0.0	1.7	0.2	4.8	0.4	0.0	0.0
0.0	3.3	0.0	5.1	0.7	0.2	5.9	0.0	0.0	0.0
0.0	0.0	5.4	0.0	0.0	10.0	5.1	0.0	0.0	7.8

SIMULATED RAINFALL FOR MONTH 10

12.5	5.8	0.4	0.0	0.0	0.0	0.6	4.4	0.0	0.0
0.0	3.0	0.8	0.0	0.0	27.1	0.0	0.0	0.9	0.0
4.2	0.2	6.1	0.0	0.0	0.5	2.0	0.0	2.7	2.2
3.7									

SIMULATED RAINFALL FOR MONTH 11

1.2	1.8	1.3	0.0	0.0	0.0	0.0	1.0	0.0	0.0
0.0	2.8	1.9	1.9	0.0	0.0	0.0	0.2	0.0	1.8
1.0	0.0	0.0	14.1	1.4	13.0	4.1	4.1	0.0	0.0

SIMULATED RAINFALL FOR MONTH 12

5.4	5.1	0.2	0.3	9.3	0.0	0.0	1.3	4.2	15.9
0.0	7.2	1.7	1.8	1.1	1.5	0.8	0.8	0.2	0.0
0.0	0.3	2.6	0.0	0.0	0.0	0.0	0.0	5.3	0.0
0.0									

SUMMARY OF THE MONTHLY RAINFALL(MM) INFORMATION

MONTH	RAINDAYS--AMOUNT (SIMULATED)		RAINDAYS--AMOUNT (OBSERVED)	
	RAINDAYS	AMOUNT	RAINDAYS	AMOUNT
JAN.	24	96.3	20	69.1
FEB.	15	41.4	11	43.5
MAR.	20	75.7	18	68.3
APR.	12	30.7	15	36.8
MAY	20	58.5	16	55.8
JUNE	13	61.3	15	69.5
JULY	16	60.0	12	53.8
AUG.	16	38.5	14	48.7
SEP.	14	53.3	14	57.5
OCT.	17	77.1	16	58.3
NOV.	15	51.5	18	70.0
DEC.	19	65.0	18	58.7
TOTAL	201	709.3	187	689.9

GENERATED WIND SPEED FOR MONTH 9

2.6	3.2	1.6	0.9	2.6	1.4	3.2	2.4	3.0	1.9
3.8	3.7	2.4	3.6	2.1	2.5	2.1	4.5	1.8	1.3
3.5	3.1	4.0	2.2	3.3	2.1	1.9	3.5	2.7	1.9

GENERATED WIND SPEED FOR MONTH 10

3.6	4.3	4.9	1.8	1.5	2.5	3.5	2.2	3.3	2.1
3.7	1.7	4.3	1.9	2.5	1.9	3.7	3.3	3.5	4.9
2.5	2.5	2.9	3.1	5.0	1.0	2.5	2.9	3.0	1.4
3.1									

GENERATED WIND SPEED FOR MONTH 11

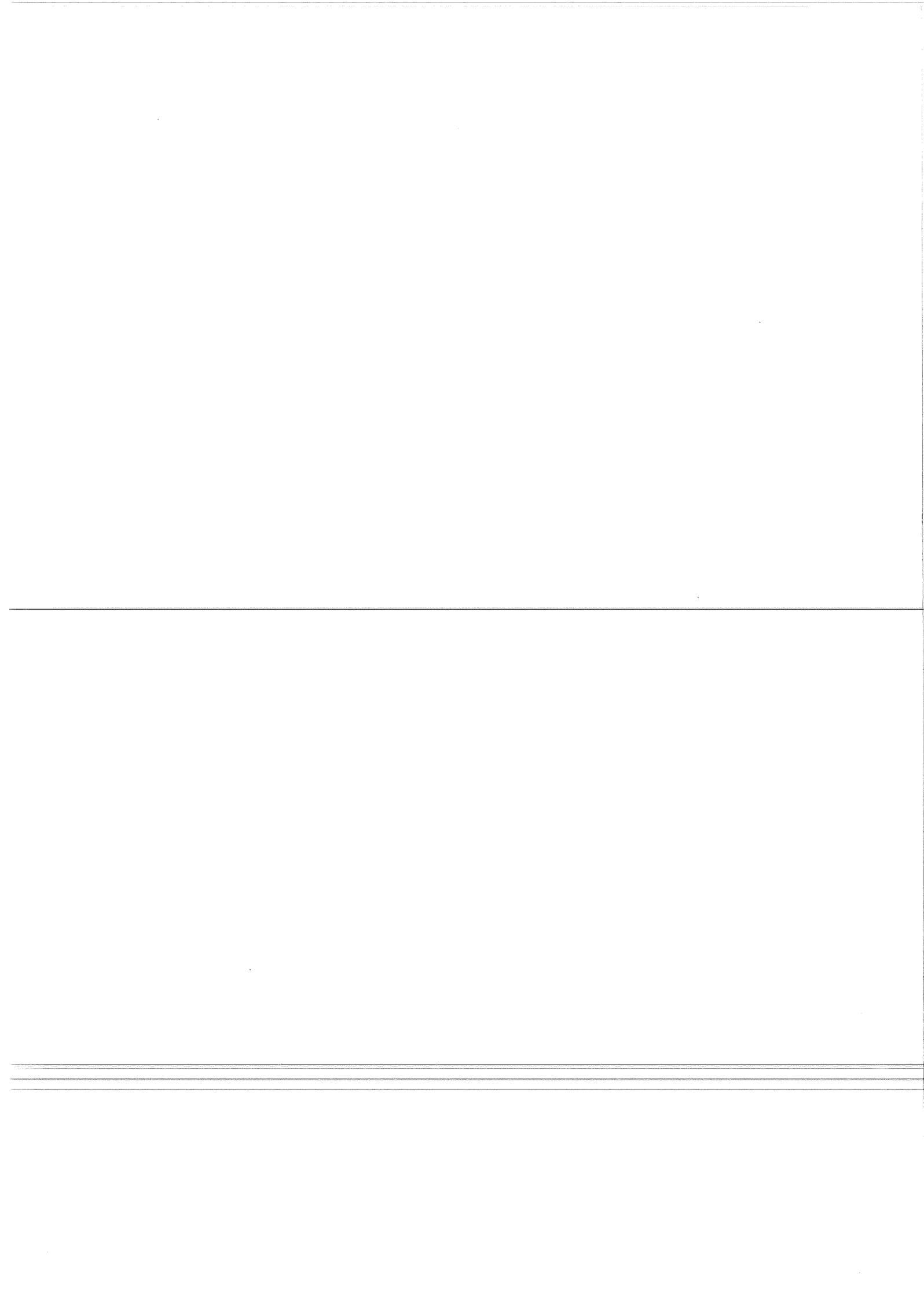
1.4	2.6	2.8	2.1	5.1	0.8	4.0	4.5	4.0	6.1
2.6	3.4	1.0	4.6	6.3	2.3	4.4	3.5	4.3	3.2
2.8	3.2	2.9	3.3	2.5	3.8	3.7	4.4	2.3	1.7

GENERATED WIND SPEED FOR MONTH 12

5.3	3.5	2.0	4.3	3.9	4.2	4.3	2.5	2.2	2.6
3.1	3.0	1.6	2.6	5.3	1.9	2.8	0.2	1.4	4.2
5.0	4.7	3.5	5.1	1.7	5.9	1.7	1.1	4.5	2.4
4.7									

AVERAGE MONTHLY WIND SPEED(M/SEC)

MONTH	SIMULATED	OBSERVED
JAN.	3.9	3.6
FEB.	3.7	2.9
MAR.	3.7	3.3
APR.	3.2	2.8
MAY	2.9	2.6
JUNE	2.8	2.4
JULY	2.6	2.3
AUG.	2.4	2.1
SEP.	2.6	2.4
OCT.	2.9	2.6
NOV.	3.3	3.2
DEC.	3.3	3.2
AVE	3.1	2.8



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