Technical Memorandum 27

Annual rainfall statistics for stations in the Top End of Australia: normal and log-normal distribution analysis

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ANNUAL RAINFALL STATISTICS FOR STATIONS IN THE TOP END OF AUSTRALIA

NORMAL AND LOG-NORMAL DISTRIBUTION ANALYSIS

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ABSTRACT

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A simple procedure is presented for the statistical analysis of measurement data where the primary concern is the determination of the value corresponding to a specified average exceedance probability. The analysis employs the normal and log-normal frequency distributions together with a χ^2-test and an error analysis. The error analysis introduces the concept of a counting error criterion, or ς-test, to test whether the data are sufficient to make the χ^2-test reliable. The procedure is applied to the analysis of annual rainfall data recorded at stations in the tropical Top End of Australia.

1 INTRODUCTION

Release of water from Retention Pond 2 of Ranger Uranium Mine into the adjacent Magela Creek is presently based on a one-in-ten year rule (Carter 1990). Ranger must have sufficient storage capacity to retain runoff from the Restricted Release Zone every nine years out of ten (on average) and only when the rainfall equals or exceeds that expected every ten years is release to be approved. For this release rule to be functional it is necessary to predict the 10-year rainfall and know the reliability of this prediction.

Predictions of the frequency of recurrence of hydrologic events is highly dependent on the assumed distribution of events (rainfall in the case of Ranger). An inappropriate frequency distribution may grossly over- or under-estimate the predicted value. For Ranger Uranium Mine an overestimate of the 10-year rainfall would impose an unnecessary cost. On the other hand, an underestimate of the 10-year rainfall would result in releases being more frequent than once in every 10 years (on average), with resultant administrative and regulatory difficulties. Thus, it is important to have a method for assessing the 'goodness-of-fit' of a particular distribution that also gives an estimate of the error of the prediction.

This paper presents a method for assessing the reliability of an assumed distribution which is based on the χ^2-test and a counting error criterion. The method is applied to a time series of annual rainfall for five stations in the Northern Territory, Australia. The theoretical basis of the method is developed for the normal and log-normal distributions and presented with examples drawn from the five rainfall stations. A computer program and sample data set are provided.

Environmental and physical data are often found to follow normal or log-normal frequency distributions (Yevjevich 1972). It has been a common practice to assume these distributions in order to evaluate the mean and the standard deviation of a data set. Alternatively, these frequency distributions can be thought of as stochastic models with three parameters: the mean, $\bar{x}$, the standard deviation, s, and N, the total number of observations.

What is often missing is an analysis to determine whether the observed distribution is consistent with the assumed theoretical distribution or stochastic model. The χ^2-test has been used to test how well a model matches the observations (Vardavas 1988, 1989) and is a standard technique for testing the agreement between expected theoretical and observed frequency distributions of data (Taylor 1982). However, the χ^2-test itself is only valid if the number of data is sufficiently large for the sampling process to be statistically significant.

In this work a simple procedure is given for the statistical analysis of independent random variables using the normal and log-normal frequency distributions employing a χ^2-test with a counting error criterion to establish its validity. The error criterion is based on the idea that the average number of observations counted within a given interval of values has an uncertainty which increases as the number of counts decreases. A point is thus reached when the total number of counts becomes insufficient to draw any conclusions about the data.

The present statistical procedure was applied to the analysis of annual rainfall data recorded at five stations in the Top End of Australia. These five stations are Darwin (014015), Jabiru (014198), Oenpelli (014042), Katherine (014902) and Pine Creek (014933). All stations except Jabiru have sufficiently long annual rainfall records to determine the mean, standard deviation and the annual rainfall corresponding to various exceedance probabilities based on normal and log-normal frequency distributions. Comparisons of the data with expected frequency distributions show that the data are better described by a normal distribution than by a log-normal distribution.

2 AVERAGE EXCEEDANCE PROBABILITY

If a given annual rainfall x is exceeded, on average, once every ten years then the average exceedance probability P has the value 1/10 or 0.10 and this rainfall shall be denoted by x_{10}. If the probability distribution is symmetrical then the annual rainfall that is exceeded on average five times every ten years corresponds to the mean annual rainfall, i.e. x_2, with P = 0.50. The normal distribution is symmetrical about the mean (mean = median) and so is the log-normal distribution plotted in terms of ln x.

2.1 The normal distribution

Figure 1 shows the symmetrical normal distribution about the mean $\bar{x}$; the shaded area corresponds to the probability that the mean annual rainfall $\bar{x}$ is exceeded by ns, where s is one standard deviation. This probability can be written for a normal distribution as:

$$P\ (x \geq \bar{x} + ns) = \frac{1}{s\sqrt{2\pi}} \int_{\bar{x}+ns}^{\infty} \exp(-(x - \bar{x})^2/2s^2)dx \qquad (1)$$

If we let $u = (x - \bar{x})/s\sqrt{2}$ then

$$P\ (x \geq \bar{x} + ns) = \frac{1}{\sqrt{\pi}} \int_{n/\sqrt{2}}^{\infty} \exp(-u^2)du \qquad (2)$$

This probability can now be written in terms of the error function erf(x) given by:

$$\text{erf}(x) = 1 - \frac{2}{\sqrt{\pi}} \int_{x}^{\infty} \exp(-t^2)dt \qquad (3)$$

and so $P(x \geq \bar{x} + ns) = {}^1/_2 - {}^1/_2\ \text{erf}(n/\sqrt{2})$ (4)

If we denote the annual rainfall that has an exceedance probability of one in T years by x_T then:

$$x_T = \bar{x} + n(T)s \qquad (5)$$

where

$$\text{erf}\ (n/\sqrt{2}) = 1 - 2P = 1 - 2/T \qquad (6)$$

Equation (6) can be solved iteratively, by the Newton-Raphson method, for n given T or P. The error function can be generated by the following expression given in Abramowitz & Stegun (1965):

$$\text{erf}(x) = 1 - (a_1t + a_2t^2 + a_3t^3 + a_4t^4 + a_5t^5)\exp(-x^2) + \varepsilon(x) \qquad (7)$$

where $t = 1/(1 + px)$ $\qquad p = 0.3275911$

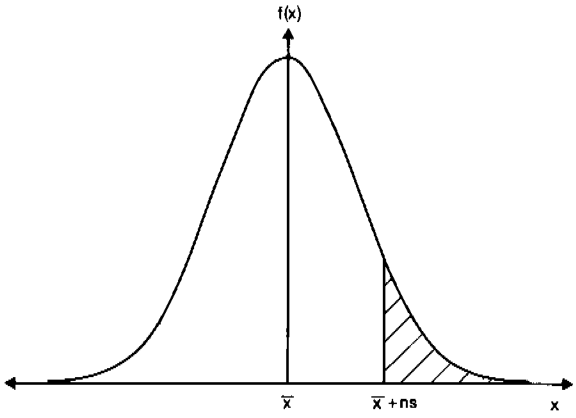

Figure 1. The normal distribution with shaded area corresponding to the probability of x exceeding $\bar{x}$+ns

and

a_1 = 0.254829592 a_2 = -0.284496736
a_3 = 1.421413741 a_4 = -1.453152027
a_5 = 1.061405429   with $|\varepsilon(x)| \le 1.5.10^{-7}$

Table 1 gives the values of n(T) for various return intervals T.

Table 1. The number of standard deviations n(T) as a function of return interval T(yr) for a normal distribution

T	2	5	10	20	50	100
n(T)	0.0	0.842	1.282	1.645	2.054	2.326

2.2 The log-normal distribution

For a log-normal distribution we can evaluate x_T from:

$$\ln x_T = \mu + n(T)\,\sigma \tag{8}$$

where the mean, μ, and the standard deviation, σ, are now evaluated for lnx and n(T) is, again, given by equation (6). Note that the mean, $\overline{x}$, of a continuous log-normal distribution evaluated for x is given by:

$$\overline{x} = E(x) = \int_0^{\infty} x f(x)\,dx \tag{9}$$

where E(x) is the first moment of the distribution and the integral of f(x) is normalised to unity:

$$f(x) = (1/x\sigma\sqrt{2\pi})\exp[-(\ln x - \mu)^2/2\sigma^2] \tag{10}$$

assuming that f(x) = 0 at x = 0, so that $\overline{x}$ is given by:

$$\overline{x} = (1/\sigma\sqrt{2\pi})\exp(-\mu^2/2\sigma^2)\int_{-\infty}^{\infty} \exp(-y^2/2\sigma^2)\exp(y(1 + \mu/\sigma^2))\,dy \tag{11}$$

Now $\overline{x}$ can be obtained, for example, from the general integral (Gradshteyn & Ryzhik 1980, p. 337):

$$\int_{-\infty}^{\infty} y^m \exp(-py^2)\exp(2qy)\,dy = m!\ \exp(q^2/p)(q/p)^m S\sqrt{\pi/p} \tag{12}$$

with $S = \sum_{k=0}^{\epsilon(m/2)} (p/4q^2)^k[1/(m-2k)!k!]$

where $\varepsilon(m/2)$ denotes the integral part of the fraction m/2, by setting $p = 1/2\sigma^2$, $q = (1 + \mu/\sigma^2)/2$ and m = 0 so that:

$$\bar{x} = \exp(\mu + \sigma^2/2) \quad (13)$$

The standard deviation s based on x is then given by:

$$\begin{aligned} s^2 &= E[(x - \bar{x})^2] \\ &= E(x^2) - 2\bar{x}\,E(x) + \bar{x}^2 \\ &= E(x^2) - \bar{x}^2 \end{aligned}$$

Now since $E(x^2) = \exp(2\mu + 2\sigma^2)$ then:

$$s = \bar{x}\,[\exp(\sigma^2) - 1]^{\frac{1}{2}} \quad (14)$$

The skewness, g, or measure of asymmetry about the mean $\bar{x}$ can be evaluated from:

$$g = E[(x - \bar{x})^3]/s^3 \quad (15)$$

with

$$E[(x - \bar{x})^3] = \exp(6\mu + 9\sigma^2/2) - 3\bar{x}^2 s^2 - \bar{x}^3$$

Note that the skewness of a log-normal distribution is zero in terms of ln x.

2.3 Standard error of estimate

In order to evaluate the error in x_T we need to evaluate the standard error in $\bar{x}$ and s for the normal distribution and in μ and σ for the log-normal distribution.

The error ε_{xT} for a normal distribution is given by:

$$\varepsilon_{xT} = [\varepsilon_{\bar{x}}^2 + n^2(T)\,\varepsilon_s{}^2]^{\frac{1}{2}} \quad (16)$$

with $\epsilon_{\bar{x}} = s/\sqrt{N}$ and $\epsilon_S = s/\sqrt{2N}$ for N years of rainfall data.

Thus the annual rainfall corresponding to a return period of T years can be estimated from $x_T \pm \varepsilon_{xT}$. For a log-normal distribution $\varepsilon_{\bar{x}}$ and ε_s are replaced by ε_μ and ε_σ and the error $\varepsilon_{xT} = \exp[(\varepsilon_\mu^2 + n^2(T)\varepsilon_\sigma^2)^{\frac{1}{2}}]$ with $x_T = \exp(\mu + n(T)\sigma)$.

3 EXPECTED AND OBSERVED DISTRIBUTIONS

3.1 The χ^2-test for distributions

According to the Poisson distribution (Taylor 1982) which describes the results of experiments where one counts events that occur at random, but at a definite average rate, the average number, N, of expected counts has an average error of $\sqrt{N}$, if the experiment is repeated many times. As N increases the Poisson distribution approaches the normal or Gaussian distribution.

Generally, in order to decide whether an observed distribution is consistent with an expected theoretical distribution one can use the χ^2-test. If the expected theoretical distribution is sub-divided into K sampling intervals or bins (see Fig. 2) then the observed number of counts O_k in bin k should have an average value of E_k with an error $\sqrt{E_k}$. In the

χ^2-test we compare the magnitude of the differences $O_k - E_k$ with the error $\sqrt{E_k}$ for each bin by evaluating the sum:

$$\chi^2 = \sum_k \chi_k^2 = \sum_k (O_k - E_k)^2/E_k \quad (17)$$

which we expect to be of order K since each χ_k^2 should be of order 1, i.e. the difference $O_k - E_k \simeq \sqrt{E_k}$. Thus we can define a $\bar{\chi}^2 = \chi^2/K$ which represents the bin average value of χ^2 for the K independent bin observations. In particular, if we wish to compare the observed distribution with a normal distribution, which can be thought of as a stochastic Gaussian model involving the three parameters $\bar{x}$, s and N, then we have only K - 3 independent bin observations since the normalisation of the distribution is achieved by evaluating the above three parameters from the observations themselves. Hence, our average $\bar{\chi}^2$, or χ^2 per degree of freedom, is now $\bar{\chi}^2 = \chi^2/(K - 3)$.

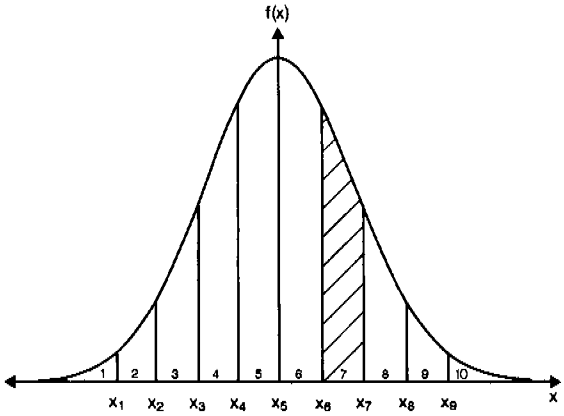

Figure 2. Subdivision of distribution into 10 bins with the probability that a counting event falls in bin 7 given by the shaded area

Thus if $\bar{\chi}^2 \le 1$ then the observed and expected theoretical distributions agree as well as can be expected. Note that if the distribution is sub-divided into K bins but n bins have no counts then the number of degrees of freedom should be modified to K - 3 - n.

We can evaluate the expected theoretical number of counts E_k within the sampling interval $x_{k+1} - x_k$ from:

$$E_k = N\, P_k(x_k < x < x_{k+1}) \quad (18)$$

where $P_k(x_k < x < x_{k+1})$ is the probability that a measurement x falls within the sampling interval and is given by:

$$P_k\ (x_k < x < x_{k+1}) = \frac{1}{\sigma\sqrt{2\pi}} \int_{x_k}^{x_{k+1}} \exp[-(x-\bar{x})^2/2s]\,dx \quad (19)$$

If we now transform to sampling intervals Δu_k defined by:

$$\Delta u_k = (x_{k+1} - x_k)/s\sqrt{2}$$

$$\text{then } P_k(u_k < u < u_{k+1}) = \frac{1}{\sqrt{\pi}} \int_{u_k}^{u_{k+1}} \exp(-u^2)\,du \quad (20)$$

$$= \tfrac{1}{2}[\mathrm{erf}(u_{k+1}) - \mathrm{erf}(u_k)]$$

Thus, the expected number of counts in bin k is:

$$E_k = \frac{N}{2} [\mathrm{erf}(u_{k+1}) - \mathrm{erf}(u_k)] \tag{21}$$

with an error $\pm \sqrt{E_k}$ and a normalisation condition:

$$N = \Sigma_k E_k \tag{22}$$

The E_k can be similarly evaluated for a log-normal distribution but with x, $\bar{x}$ and s replaced by ln x, μ and σ.

3.2 The ς-test for data record

According to the Poisson distribution the average error in the bin count E_k is $\sqrt{E_k}$ so that E_k has an error bar of width $2\sqrt{E_k}$. From this we see that when $E_k = 2\sqrt{E_k}$ then the uncertainty in the count is as large as the count itself. This point is reached when $E_k = 4$. Below this point the number of counts becomes too low to draw any conclusions about the data in bin k so generally we need $E_k > 4$ (see Taylor 1982, p. 224). If the distribution is sub-divided into K bins then we need N > 4K. However, the normal distribution peaks at $\bar{x}$ and bins in the far wings of the distribution, where P_k is very low, may have insufficient counts although the bins nearer $\bar{x}$ have a significant number of counts.

It is thus important to weight the number of counts in each bin by the probability of a count occurring in that bin. This has the effect of reducing the importance of the wing bins on the total count condition.

If we define f_k as the expected average relative frequency of bin k then for trapezoidal integration this corresponds to the mid-point, $\bar{u}_k$, of the sampling interval $\Delta u_k = u_{k+1} - u_k$.

Thus:

$$\sum_k \Delta u_k \, f_k(\bar{u}_k) = E_k \tag{23}$$

where $\bar{u}_k = \frac{1}{2}(u_{k+1} + u_k)$ and so we can define the expected average relative probability $\Delta u_k \bar{f}_k$ for an event occuring in bin k by:

$$\Delta u_k \bar{f}_k = E_k/N \tag{24}$$

with

$$\sum_k \Delta u_k \, \bar{f}_k = 1 \tag{25}$$

from equation (22).

The error, δ_k, in $\bar{f}_k$ is then given by:

$$\delta_k = \sqrt{E_k}/(N\Delta u_k) \tag{26}$$

and we can define an error envelope determined by the two curves corresponding to:

$$\bar{f}_k^{+} = \bar{f}_k + \delta_k \tag{27}$$

and

$$\bar{f}_k^- = \bar{f}_k - \delta_k$$

with a total expected error probability given by:

$$\begin{aligned}\zeta &= \sum_k (\bar{f}_k^+ - \bar{f}_k^-)\Delta u_k \\ &= 2 \sum_k \Delta u_k \delta_k \\ &= (2/N) \sum_k \sqrt{E_k} \qquad (28)\end{aligned}$$

which must obey the condition $\zeta \leq 1$. If $\zeta > 1$ then the number of data points is insufficient to allow any statistically significant conclusions to be made. As N increases ζ decreases and the error envelope becomes progressively narrower. If the observed average relative frequency points $\bar{o}_k = O_k/(N\Delta u_k)$ lie within the error envelope such that $\bar{\chi}^2 \leq 1$ and the envelope has $\zeta < 1$ then the agreement between the expected and observed frequency distributions is statistically significant. If $\zeta > 1$ then the χ^2-test is unreliable.

Generally ζ will depend on the record length and on the profile of the chosen frequency distribution. Thus for the normal and log-normal Gaussian distributions we expect ζ to be the same for a given record length N.

For example, if we approximate the Gaussian distribution with a Step Function of equal area then

$$\sum_k E_k = N = K\bar{E}$$

and hence from the general expression for ζ given by equation (28) we have the approximation ζ_a given by:

$$\zeta_a = 2\sqrt{K/N} \qquad (29)$$

The condition $\zeta_a < 1$ then corresponds to the condition $N > 4K$ discussed earlier which is strictly valid for a Step Function distribution. However, it can be shown that in the present case $\zeta_a \simeq 1.1\zeta$ so that the simple condition $N > 4K$ ensures that $\zeta < 1$. For more complex frequency distributions ζ will need to be evaluated from equation (28). As discussed in Taylor (1982), the minimum value of K will be 4 to ensure that the bin width on either side of the mean is equal to about one standard deviation.

4 ANNUAL RAINFALL ANALYSES

In the present work, the sampling bins were selected on a grid $v_k = \sqrt{2u_k}$ where u_k is a fixed grid with intervals measured in units of standard deviations from the mean, i.e. $v_k = (x_k - \bar{x})/s$. The v_k grid is given in Table 2 and was chosen so that the bin width is s/2 near the mean ($k = 6$, $v_k = 0$) and ~ 2s far from the mean (in the wings of the distribution).

Table 2. The grid v_k defining the choice of sampling bins in units of standard deviations from the mean

k	1	2	3	4	5	6	7	8	9	10	11
v_k	-5.	-3.	-1.5	-1.0	-0.5	0.0	0.5	1.0	1.5	3.0	5.0

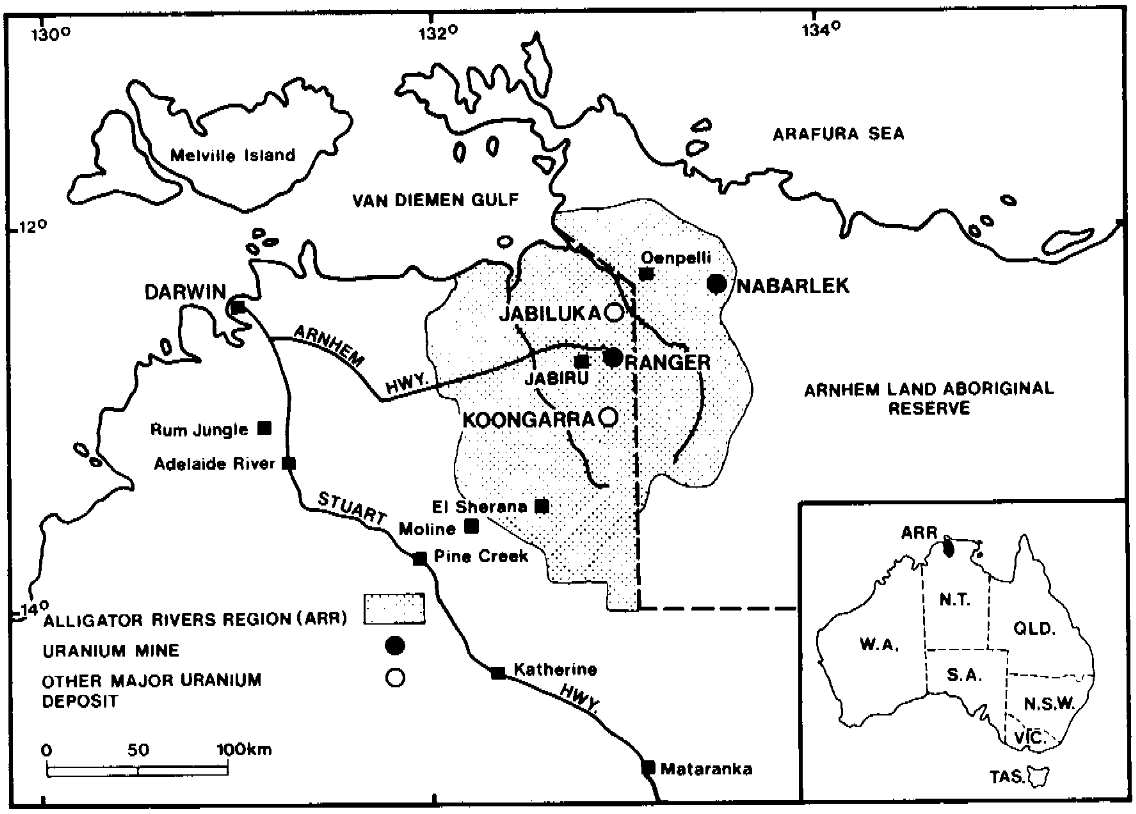

Figure 3. The Top End of Australia showing the location of the five rainfall recording stations used in the present work, Darwin, Oenpelli, Jabiru, Pine Creek and Katherine

The statistical analysis of the annual rainfall record for each station in the Top End (see Fig. 3) is presented in the form of two tables and one graph for each station. The first table in the set gives the record length in years, mean, standard deviation, skewness, $\overline{\chi}^2$ and ς. The second set of tables give the annual rainfall x_T corresponding to a given return period, T, (or exceedance probability P = 1/T) for normal and log-normal distributions. The graph for each station gives a plot of the expected average relative frequency $\overline{f}_k$ for an event occuring in bin k plus the error envelope bounded by the curves $\overline{f}_k^+$ and $\overline{f}_k^-$ versus v_k (in standard deviations from the mean). The observed average relative frequencies $\overline{o}_k$ in each bin k, plotted as points, should lie within the error envelope and closely follow the $\overline{f}_k$ curve if the agreement between the expected and observed frequency distributions is statistically significant. Further, if the area, ς, within the envelope is smaller than the area under the curve $\overline{f}_k$ (i.e. $\varsigma < 1$), then the data record length is sufficiently long for the statistical analysis to be reliable.

4.1 Darwin

The annual rainfall distribution for Darwin follows closely a normal distribution as can be seen in Fig. 4. In Table 3a $\overline{\chi}^2 = 0.27$ for the normal distribution compared with $\overline{\chi}^2 = 1.78$ for the log-normal distribution. The value of $\varsigma = 0.52$ confirms that the record length of 120 years is sufficiently long for the χ^2-test to be reliable. Table 3b gives the annual rainfall for various return periods for both distributions. Based on the normal distribution the one-in-ten years annual rainfall for Darwin is 1971 ± 37 mm while the mean (one-in-two years) is 1583 ± 28 mm.

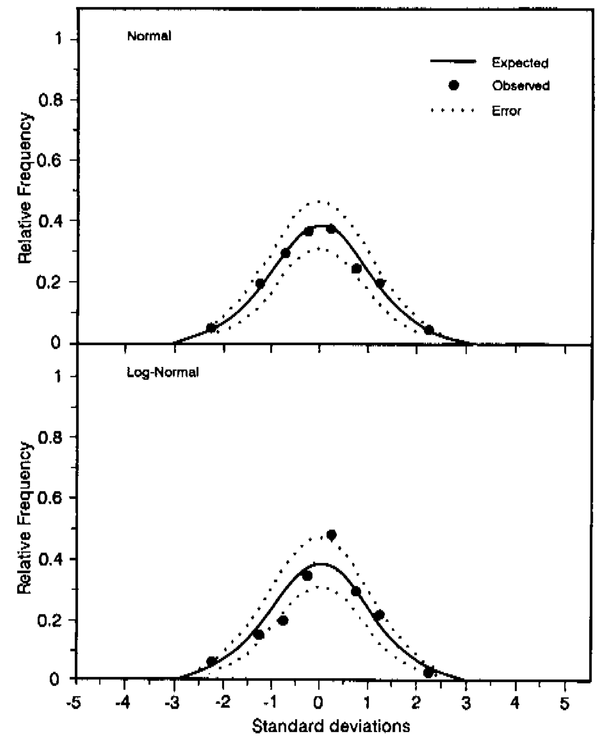

Figure 4. Expected and observed annual rainfall distributions for Darwin

Table 3a. Statistical parameters for Darwin annual rainfall (mm) record

Statistical parameter	Normal	Log-normal
Years of record	120	120
Mean	1583 ± 28	1584 ± 29
Standard deviation	303 ± 20	321 ± 21
Skewness	0.01	-0.61
$\overline{\chi}^2$	0.27	1.78
ζ	0.52	0.52

Table 3b. Darwin annual rainfall (mm) for a given return period

Return period (years)	Normal	Log-normal
2	1583 ± 28	1584 ± 29
5	1838 ± 32	1838 ± 40
10	1971 ± 37	2007 ± 50
20	2081 ± 42	2159 ± 62
50	2205 ± 49	2343 ± 77
100	2287 ± 53	2475 ± 89

4.2 Oenpelli

The statistical parameters for Oenpelli are given in Table 4a and annual rainfall for return periods in Table 4b. As for Darwin, the χ^2-test indicates that the annual rainfall follows more the normal than the log-normal distribution as can be also seen from Fig. 5. The ζ-test also indicates that the 59-year record is adequately long. The mean rainfall at Oenpelli, based on the normal distribution, is 1383 ± 35 mm while the one-in-ten years annual rainfall is 1724 ± 47 mm.

4.3 Jabiru

The rainfall analysis for Jabiru is important because of its possible use as a trigger quantity to control water release into Magela Creek from the Ranger uranium mine site. The trigger mechanism (Carter 1990) is based on a government decision to allow such releases on average once-in-ten years. The statistical parameters for Jabiru are given in Table 5a. Although the χ^2-test indicates that the annual rainfall is more log-normally than normally distributed, the ζ-test clearly indicates that the record length is too short for the χ^2-test to be reliable. As can be seen in Fig. 6 the error envelope for both distributions is large (ζ = 1.4).

In view of the short record one may assume the simpler normal distribution to perform a preliminary analysis for Jabiru. Certainly, the evidence at Darwin and Oenpelli indicates that the annual rainfall distribution for coastal regions in the Top End is probably normal.

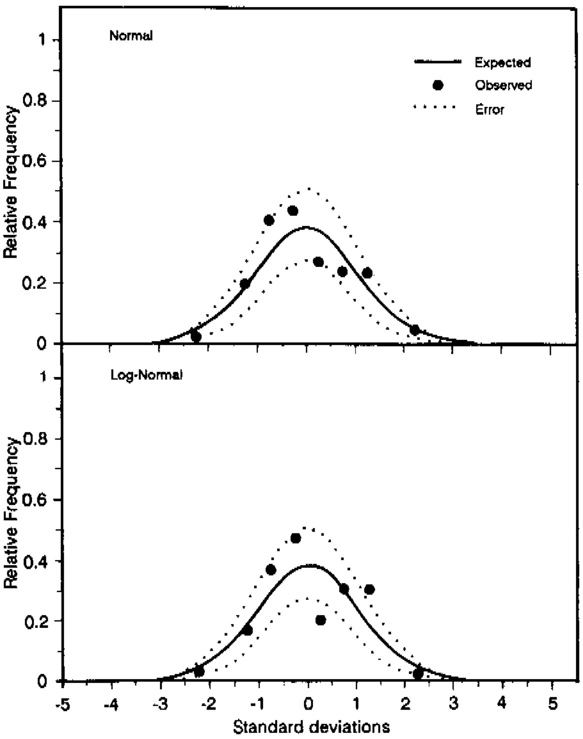

Figure 5. Expected and observed annual rainfall distributions for Oenpelli

Table 4a. Statistical parameters for Oenpelli annual rainfall (mm) record

Statistical parameter	Normal	Log-normal
Years of record	59	59
Mean	1383 ± 35	1384 ± 36
Standard deviation	266 ± 24	273 ± 25
Skewness	0.22	-0.26
$\overline{\chi}^2$	0.86	1.46
ζ	0.74	0.74

Table 4b. Oenpelli annual rainfall (mm) for a given retur n period

Return period (years)	Normal	Log-normal
2	1383 ± 35	1384 ± 36
5	1607 ± 40	1601 ± 48
10	1724 ± 47	1745 ± 61
20	1820 ± 53	1873 ± 75
50	1929 ± 61	2029 ± 93
100	2001 ± 67	2141 ± 108

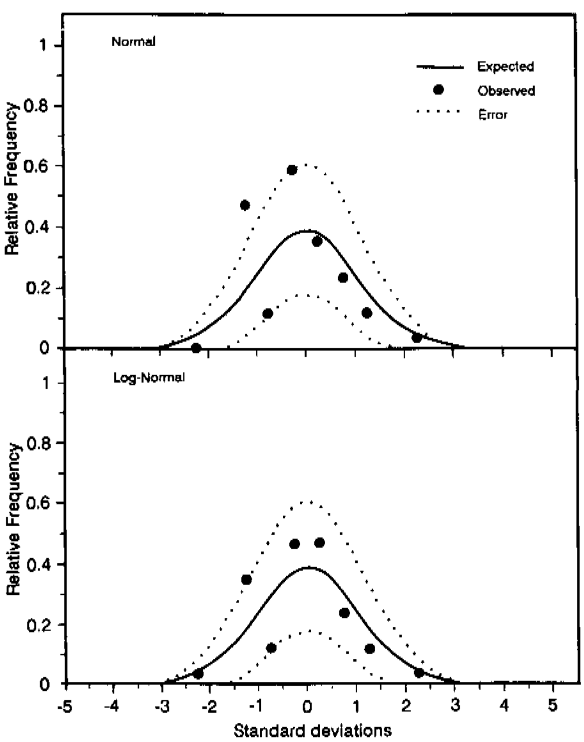

Figure 6. Expected and observed annual rainfall distributions for Jabiru.

Table 5a. Statistical parameters for Jabiru annual rainfall (mm) record

Statistical parameter	Normal	Log-normal
Years of record	17	17
Mean	1513 ± 69	1514 ± 68
Standard deviation	286 ± 49	279 ± 48
Skewness	0.85	0.39
$\overline{\chi}^2$	1.8	0.6
ζ	1.4	1.4

Table 5b. Jabiru annual rainfall (mm) for a given return period

Return period (years)	Normal	Log-normal
2	1513 ± 69	1514 ± 68
5	1754 ± 81	1736 ± 92
10	1879 ± 94	1881 ± 116
20	1983 ± 106	2010 ± 141
50	2100 ± 122	2166 ± 176
100	2178 ± 133	2277 ± 202

Based on the normal distribution the mean annual rainfall at Jabiru is 1513 ± 69 mm while from Table 5b the one-in-ten years annual rainfall is 1879 ± 94 mm.
Note that the log-normal values for the annual rainfall of different return periods are not too different from those based on the normal distribution. It is interesting to compare the mean annual rainfall at Oenpelli based on the last 17 years with the Jabiru record. The 17-year mean at Oenpelli is 1480 ± 75 mm compared with 1513 ± 69 mm at Jabiru and 1383 ± 35 mm based on the 59-year record at Oenpelli. It appears then that in the last 17 years the annual rainfall has been higher than during the preceding 42 years at Oenpelli.

It is interesting to note that a similar trend is observed (see Hanson et al. 1989) in the mean annual precipitation of the contiguous U.S. (averaged using 6,000 stations) with 767 ± 14 mm for the 17-year period 1971-1987 compared with 734 ± 6 mm for the 93-year record period 1895-1987.

4.4 Pine Creek

Pine Creek is located inland and south of Darwin (see Fig. 3). Despite the long record length of 90 years ($\varsigma = 0.6$) the χ^2-test (see Table 6a) indicates that the normal and log-normal distributions are not good representations of the annual rainfall distribution. From Fig. 7 it appears that the distribution might be bimodal. The 90-year average rainfall at Pine Creek is 1135 ± 26 mm, based on the normal distribution, while the one-in-ten years rainfall is 1449 ± 35 mm (Table 6b).

Table 6a. Statistical parameters for Pine Creek annual rainfall (mm) record

Statistical parameter	Normal	Log-normal
Years of record	90	90
Mean	1135 ± 26	1137 ± 28
Standard deviation	245 ± 18	262 ± 20
Skewness	0.04	-0.56
$\bar{\chi}^2$	2.2	3.0
ς	0.6	0.6

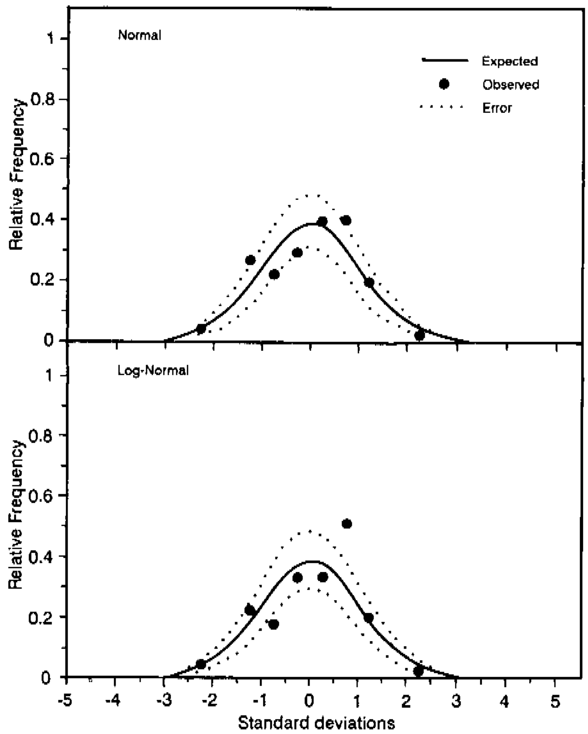

Figure 7. Expected and observed annual rainfall distributions for Pine Creek

Table 6b. Pine Creek annual rainfall (mm) for a given return period

Return period (years)	Normal	Log-normal
2	1135 ± 26	1137 ± 28
5	1341 ± 30	1341 ± 38
10	1449 ± 35	1483 ± 49
20	1538 ± 40	1610 ± 60
50	1638 ± 46	1767 ± 76
100	1705 ± 50	1880 ± 89

4.5 Katherine

Katherine is the most inland of the five stations studied in this work. From Table 7a and Fig. 8 we see that the record length is adequate ($\varsigma = 0.53$) and the χ^2-test should thus be reliable. According to the χ^2-test the annual rainfall tends to be more log-normally than normally distributed. Based on the log-normal distribution the mean annual rainfall is 975 ± 26 mm while the one-in-ten years rainfall is 1339 ± 47 mm (Table 7b) which is significantly below that of Darwin.

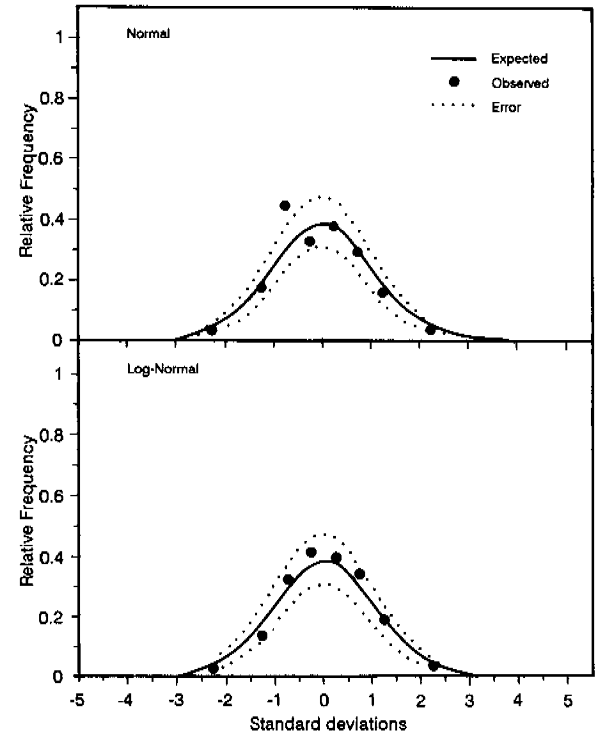

Figure 8. Expected and observed annual rainfall distributions for Katherine

Table 7a. Statistical parameters for Katherine annual rainfall (mm) record

Statistical parameter	Normal	Log-normal
Years of record	116	116
Mean	974 ± 24	975 ± 26
Standard deviation	260 ± 17	275 ± 18
Skewness	0.52	-0.50
$\bar{\chi}^2$	1.8	1.3
ς	0.53	0.53

Table 7b. Katherine annual rainfall (mm) for a given return period

Return period (years)	Normal	Log-normal
2	974 ± 24	975 ± 26
5	1192 ± 28	1185 ± 36
10	1307 ± 33	1339 ± 47
20	1401 ± 37	1480 ± 60
50	1507 ± 43	1658 ± 77
100	1578 ± 46	1787 ± 91

5 COMPUTER PROGRAMME

The computer programme has been designed to read an input data file, which in this work is called LTRAIN, and to produce a statistical analysis on an output file called SAMPLE. The program also writes distribution profile data on FREHIST.DAT which then can be used to generate graphs of the expected and observed distributions plus the associated error envelope.

5.1 Input data

The input data file, LTRAIN, has a specific format as shown below. The first number specifies the number of stations, here it is equal to 5. The names of the stations are then listed with their corresponding number. The total number of data points is then listed, here 120. Column 1 corresponds to the year, while columns 2 to 6 correspond to the annual rainfall (mm) for each of the five stations. Zeros signify no record for that year. In the present study the period covers the years 1870-1988.

Input data file: LTRAIN

```
5
  1 DARWIN
  2 OENPELLI
  3 JABIRU
  4 PINE CREEK
  5 KATHERINE
120
1870   1581  0     0     0     0
1871   1570  0     0     0     0
1872   1985  0     0     0     0
1873   1593  0     0     0     1058
1874   1464  0     0     0     1143
1875   1419  0     0     1068  1240
1875   1419  0     0     1068  1240
1876   1600  0     0     1168  1155
1877   1712  0     0     1206  966
1878   1209  0     0     1030  1090
1879   1934  0     0     1427  1298
1880   1581  0     0     1119  900
1881   1436  0     0      839  728
1882   1504  0     0     0     1022
1883   1605  0     0     0     712
1884   1656  0     0     1455  848
1885   1727  0     0     0     893
1886   1553  0     0     0     825
1887   1614  0     0     0     925
1888   1744  0     0     0     926
1889   1261  0     0     0     1003
1890   1693  0     0     1276  1152
1891   1883  0     0     1077  831
1892   1110  0     0     761   424
1893   1588  0     0     872   802
1894   1549  0     0     1468  1055
1895   1809  0     0     1137  1076
1896   2002  0     0     1340  1136
1897   1441  0     0     1306  932
1898   1900  0     0     1871  1923
1899   1519  0     0     1626  1621
1900   1205  0     0     686   725
1901   1418  0     0     1081  1388
1902   1326  0     0     923   498
1903   1143  0     0     876   807
1904   1953  0     0     1576  1512
1905   1576  0     0     853   751
1906    700  0     0     544   623
1907   1471  0     0     1295  1293
1908   1683  0     0     1339  1245
1909   1318  0     0     764   679
1910   2143  0     0     1459  1202
1911   1639  0     0     0     747
1912   1457  1630  0     1275  974
1913   1398  1813  0     1278  856
1914   1337  1318  0     910   827
1915   1326  833   0     1017  750
1916   1579  1669  0     1373  1063
```

1917	2211	1812	0	0	1137
1918	1871	1515	0	0	1219
1919	1431	1675	0	1140	624
1920	1366	1110	0	948	665
1921	1705	1408	0	1336	1114
1922	1837	1626	0	0	842
1923	1796	0	0	1255	1020
1924	1187	0	0	0	1073
1925	1753	1468	0	1258	857
1926	1196	818	0	1165	600
1927	1148	1207	0	952	674
1928	1095	1358	0	975	781
1929	1850	1166	0	782	506
1930	1102	1772	0	1248	1055
1931	1494	1247	0	1399	1146
1932	1545	1573	0	808	704
1933	1753	1181	0	0	734
1934	1687	1516	0	1100	969
1935	1403	0	0	840	1136
1936	1331	1064	0	718	764
1937	1115	1205	0	1044	1180
1938	1132	1297	0	1054	723
1939	1822	1170	0	1056	1027
1940	1607	1438	0	1079	1430
1941	1523	1314	0	1204	876
1942	1110	0	0	865	842
1943	1735	1603	0	1441	1078
1944	1350	1283	0	1266	1179
1945	1836	1442	0	825	805
1946	1221	0	0	0	916
1947	1430	1060	0	1007	813
1948	1384	1280	0	937	851
1949	1711	1342	0	886	816
1950	1590	0	0	0	969
1951	1418	1262	0	1264	1199
1952	1078	0	0	788	364
1953	1649	1143	0	989	823
1954	1526	1338	0	1432	1108
1955	2089	1192	0	1387	1004
1956	1891	0	0	1440	832
1957	1963	0	0	1373	1354
1958	1173	1344	0	1207	763
1959	1319	1469	0	1218	861
1960	1923	1324	0	1183	1006
1961	1090	993	0	904	807
1962	1536	0	0	805	502
1963	1379	1174	0	0	1050
1964	1254	0	0	1173	702
1965	1666	0	0	1144	861
1966	1544	1191	0	1348	728
1967	1934	0	0	1246	1158
1968	2085	1540	0	1255	1343
1969	1825	1894	0	1209	1010
1970	1100	1020	0	660	649
1971	1890	1399	0	1517	1103
1972	1716	1602	1129	1377	1078
1973	1604	1269	1482	1176	868

1974	2109	1751	1754	0	1364
1975	2288	0	1538	0	1056
1976	2048	2011	2223	0	1413
1977	2243	1755	1395	0	1268
1978	1207	1170	1448	996	1128
1979	1698	0	1504	0	819
1980	1610	1703	1895	0	1237
1981	2115	1781	1627	0	1067
1982	1763	0	1485	0	1026
1983	1684	1266	1195	1023	752
1984	2013	1554	1608	1348	1619
1985	1434	0	1758	1261	920
1986	1566	0	1222	0	0
1987	1977	1220	1271	1302	1209
1988	1851	1044	1190	1174	896

5.2 Flow diagram

The flow diagram of the computer program is given in Fig. 9. The main program FREQAN reads the input file LTRAIN then calls FREQDIS which computes, for a given station, the statistical parameters: mean, standard deviation, skewness and annual rainfall corresponding to a specified recurrence interval T. To do this FREQDIS calls AKT which computes n(T) (see equation 5). Some of the statistical parameters are transferred to DIST which is called by FREQAN after FREQDIS is called. The subroutine DIST computes the $\overline{\chi}^2$ for the matching of expected and observed distributions. This is achieved by a call to BINS which sets up the bin or sampling interval subdivisions, u_k, of the expected distribution. Using ERF, which computes the error function for some value y, it computes the expected probability of a counting event falling within each bin (see Fig. 2) and compares this with the observed value o_k. It also uses the expected probability in each bin to compute the total area, ς, of the associated error envelope.

Subroutine FREQDIS writes the statistical parameters and the input data for the specified station onto the file SAMPLE where DIST also writes the values of $\overline{\chi}^2$ and ς. DIST also writes the distribution profile data for each bin onto file FREHIST.DAT.

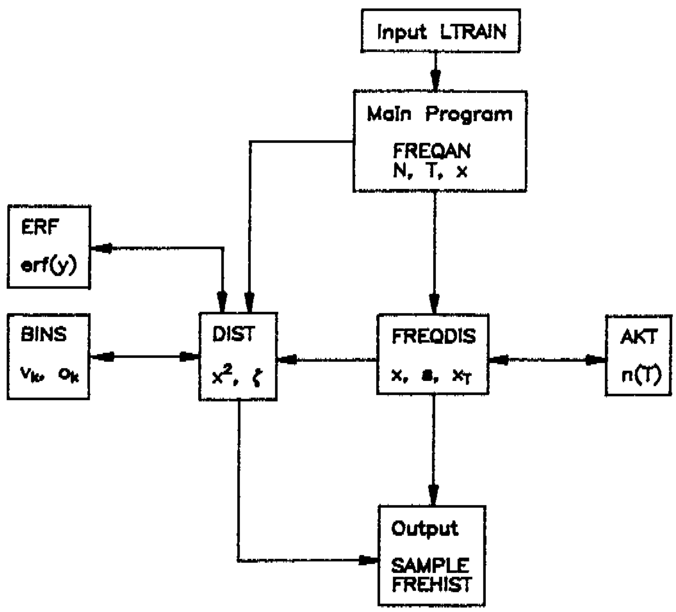

Figure 9. Computer programme flow diagram

5.3 Main programme and subroutines

Main programme FREQAN

The main programme FREQAN first requests, interactively, the name of the input data file. This name must be typed in by the user via the terminal. The programme then reads the input file and extracts the number of stations, NST, and the names of the stations, STAS. The programme then requests the station number, NS, corresponding to the station for which a statistical analysis is required. It then requests the recurrence interval, T, for which the annual rainfall is desired, and the expected type of frequency distribution. The programme then reads the annual rainfall, y, for each year, YEAR, then calls FREQDIS and DIST.

Main programme parameters

Computer name	Name
DATAF	Input dummy filename
NST	Number of stations
STAS(N)	Station N name
NS	Specified station
T	Recurrence interval
IFR	Distribution flag: 0-normal, 1-log-normal
NYR	Number of years
YEAR	Year of record
Y(J)	Annual rainfall for station J

Subroutine FREQDIS

Subroutine FREQDIS evaluates the mean, XMEAN, the standard deviation, S either for a normal or log-normal distribution and the skewness of the distribution, G, and the error in each, EXM, ES and EG. For a log-normal distribution it distinguishes between the mean, XM, and standard deviation, SM, based on the logarithms of the annual rainfall and the actual mean, XMEAN, and standard deviation, S.

Subroutine FREQDIST parameters

Text symbol	Computer name	Name
x	X(I)	Annual rainfall for year I
$\bar{x}$	XMEAN	Mean based on x and equal to XM for normal distribution
μ	XM	Mean based on ln x for log-normal distribution
s	S	Standard deviation of x for normal distribution
σ	SM	Standard deviation of ln x for log-normal distribution
g	G	Skewness based on x for normal and ln x for log-normal
$\varepsilon_{\bar{x}}$	EXM	Standard error in $\bar{x}$
ε_s	ES	Standard error in S
x_T	XT	Annual rainfall exceeded once in T years
ε_{xT}	EXT	Error in x_T
n(T)	AKT	See equation 5

Subroutine DIST

Subroutine DIST uses XM and SM assuming a Gaussian distribution for x (normal) or ln x (log-normal). It then computes the expected count E(K) for each bin K and the associated error EREK. Computes the area, ζ, of the error envelope and $\bar{\chi}^2$. If $\zeta > 1$ it issues a warning.

Subroutine DIST parameters

Text symbol	Computer name	Name
N	IMAX	Length of record
$\bar{x}$	XM	Mean of x for normal distribution
μ	XM	Mean of ln x for log-normal distribution
E_k	E(K)	Expected count in bin K
$\surd E_k$	EREK	Error in E_k
O_k	O(K)	Observed count in bin K
s	S	Standard deviation based on x
σ	S	Standard deviation based on ln x
x_k	X(K)	Grid of sampling interval
erf	ERF	Error function
u_k	A	Bin grid
Δu_k	DIF	
$N\Delta v_k$	SDIF	$N\Delta v_k = N\Delta u_k \surd 2$
$\bar{f}_k/\surd 2$	EKA	$\bar{f}_k$ on v_k grid
$\bar{f}_k^+/\surd 2$	EKAP	$\bar{f}_k^+$ on v_k grid
$\bar{f}_k^-/\surd 2$	EKAM	$\bar{f}_k^-$ on v_k grid
$\bar{O}_k/\surd 2$	OKA	$\bar{O}_k$ on v_k grid
$\bar{v}_k$	XMIP	$\frac{1}{2}(v_k + v_{k+1})$
$\bar{\chi}^2$	CHI	Average χ^2
K	NB	Number of bins
n	NC	Number of empty bins
ζ	SUM	Error probability

Function ERF

The error function is evaluated via a call to Function ERF. Function ERF follows the notation given in equation 7.

Subroutine BINS

Subroutine BINS subdivides the Gaussian distribution (assumed for normal or log-normal) into 10 bins. Each bin is defined by the bounds v_k and v_{k+1} which area measured in standard deviations from the mean. The observed number of counts O_k are evaluated for each bin.

Subroutine BINS parameters

Text symbol	Computer name	Name
$\bar{x}$ or μ	XM	Mean of distribution
s or σ	SM	Standard deviation
v_k	X(K)	
x or ln x	Y(I)	
O_k	O(K)	Observed counts in bin k

Subroutine AKT

Subroutine AKT evaluates n(T) (equation 5) by using Newton-Raphson interation to solve for the n(T). It seeks the zero of the function G = erf(x) - 1 + 2/T where x + n/√2 and uses the derivative $\partial G/\partial x$ to correct an initial guess.

Subroutine AKT parameters

Text symbol	Computer name	Name
n(T)	AKT	See equation 5
erf	ERF	Error function
n/√2	X	
π	PI	$\pi = 3.14159$

5.4 Computer code

PROGRAM FREQAN

```
      DIMENSION Y(200),Z(200)
      COMMON /STATS/XM,SM,NSUM,X(200)
      CHARACTER STAS(10)*40,DATAF*40
      INTEGER YR1,YEAR
      OPEN(3,FILE='SAMPLE',STATUS='UNKNOWN')
      OPEN(7,FILE='FREHIST.DAT',STATUS='UNKNOWN')
      WRITE(1,*) ' Enter DATA FILENAME'
      READ(1,'(A20)') DATAF
      OPEN(2,FILE=DATAF,STATUS='UNKNOWN')
      READ(2,*) NST
      DO 1 N=1,NST
      READ(2,20) N,STAS(N)
      WRITE(1,20) N,STAS(N)
   20 FORMAT(1X,I2,1X,A20)
    1 CONTINUE
      WRITE(1,*) ' Enter STATION NUMBER'
      READ(1,*) NS
      WRITE(1,*) ' Enter RECURRENCE INTERVAL'
      READ(1,*) T
```

```
      WRITE(1,*) ' Enter frequency distribution code'
      WRITE(1,*) ' 0 for NORMAL, 1 for LOGNORMAL'
      READ(1,*) IFR
      READ(2,*) NYR
      NSUM=0
      DO 2 N=1,NYR
      READ(2,*) YEAR,(Y(J),J=1,NST)
C     WRITE(1,*) YEAR,(Y(J),J=1,NST)
      IF(Y(NS).EQ.0.) GO TO 2
      NSUM=NSUM+1
      X(NSUM)=Y(NS)
      Z(NSUM)=YEAR
    2 CONTINUE
    3 CONTINUE
      WRITE(1,'(A40)') STAS(NS)
      WRITE(3,'(A40)') STAS(NS)
      WRITE(3,20) NS,STAS(NS)
      DO 4 I=1,NSUM
      WRITE(3,*) Z(I),X(I)
    4 CONTINUE
      CALL FREQDIS(T,IFR)
      CALL DIST
      STOP
      END
```

SUBROUTINE FREQDIS(T,IFR)

```
      COMMON /STATS/XM,SM,IMAX,X(200)
      SUM1=0
      SUM2=0
      SUM3=0
      IF(IFR.EQ.0) GO TO 10
      DO 1 I=1,IMAX
      X(I)=ALOG(X(I))
    1 CONTINUE
   10 CONTINUE
      DO 2 I=1,IMAX
      SUM1=SUM1+X(I)
    2 CONTINUE
      XMEAN=SUM1/IMAX
      DO 3 I=1,IMAX
      DIF=X(I)-XMEAN
      SUM2=SUM2+DIF*DIF
      SUM3=SUM3+DIF*DIF*DIF
    3 CONTINUE
      AN=IMAX
      S=SQRT(SUM2/(AN-1))
      S2=S*S
      S3=S2*S
      XM=XMEAN
      SM=S
      IF(IFR.EQ.0) GO TO 20
      XMLOG=XMEAN
      SLOG=S
      SLOG2=SLOG*SLOG
      XMEAN=EXP(XMLOG+.5*SLOG2)
```

```
      S=XMEAN*SQRT(EXP(SLOG2)-1)
 20   G=AN*SUM3/((AN-1)*(AN-2)*S3)
      EXM=S/SQRT(AN)
      EXMS=EXM*EXM
      ES=S/SQRT(2*AN)
      ESS=ES*ES
      EG=SQRT(6*AN*(AN-1)/((AN-2)*(AN+1)*(AN+3)))
      CALL AKT(T,AK)
      WRITE(1,*) 'T =',T,' AK =',AK
      WRITE(3,*) 'T =',T,' AK =',AK
      AKS=AK*AK
      IF(IFR.NE.0) GO TO 5
      XT=XMEAN+AK*S
      EXT=SQRT(EXMS+AKS*ESS)
      GO TO 6
  5   CONTINUE
      AXT=XMLOG+AK*SLOG
      XT=EXP(AXT)
      EXML=SLOG/SQRT(AN)
      EXMLS=EXML*EXML
      ESL=SLOG/SQRT(2*AN)
      ESLS=ESL*ESL
      EAXT=SQRT(EXMLS+AKS*ESLS)
      EXT=XT*(EXP(EAXT)-1)
  6   CONTINUE
      WRITE(1,*) ' Number of years    ',IMAX
      WRITE(3,*) ' Number of years    ',IMAX
      WRITE(1,*) ' Mean               ',XMEAN,'  Error = ',EXM
      WRITE(3,*) ' Mean               ',XMEAN,'  Error = ',EXM
      WRITE(1,*) ' Standard deviation ',S,'  Error = ',ES
      WRITE(3,*) ' Standard deviation ',S,'  Error = ',ES
      WRITE(1,*) ' Skewness           ',G,'  Error = ',EG
      WRITE(3,*) ' Skewness           ',G,'  Error = ',EG
      WRITE(1,*)
      WRITE(3,*)
      WRITE(1,*) ' Recurrence interval',T,' years'
      WRITE(3,*) ' Recurrence interval',T,' years'
      WRITE(1,*) ' Rainfall for RI    ',XT,' Error = ',EXT
      WRITE(3,*) ' Rainfall for RI    ',XT,' Error = ',EXT
      IF(IFR.EQ.0) WRITE(1,*) ' Normal distribution'
      IF(IFR.EQ.0) WRITE(3,*) ' Normal distribution'
      IF(IFR.EQ.1) WRITE(1,*) ' Log-normal distribution'
      IF(IFR.EQ.1) WRITE(3,*) ' Log-normal distribution'
      RETURN
      END
```

SUBROUTINE AKT(T,AK)

```
      DATA PI/3.14159/
      X=0
      DO 1 N=1,20
      XS=X*X
      G=ERF(X)-1+2/T
      G1=2*EXP(-XS)/SQRT(PI)
      DX=-G/G1
      X=X+DX
```

```
      ER=ABS(DX/X)
      IF(ER.LT.0.001) GO TO 2
    1 CONTINUE
      IF(N.GE.20) WRITE(1,*) ' No convergence in AKT'
      IF(N.GE.20) WRITE(3,*) ' No convergence in AKT'
      IF(N.GE.20) STOP
    2 CONTINUE
      AK=SQRT(2.)*X
      RETURN
      END
```

SUBROUTINE DIST

```
      COMMON /STATS/XM,SM,IMAX,Y(200)
      COMMON /BIN/NB,X(11),O(10)
      DIMENSION E(10)
      CALL BINS
      S=SM
      S2=S*S
      SQRT2=SQRT(2.)
      DEN=S*SQRT2
      SUM=0
      CHI=0
      NC=0
      DO 1 K=1,NB
      A=(X(K)-XM)/DEN
      B=(X(K+1)-XM)/DEN
      DIF=B-A
      ERFA=ERF(A)
      ERFB=ERF(B)
      E(K)=0.5*IMAX*(ERFB-ERFA)
      EREK=SQRT(E(K))
      SDIF=IMAX*DIF*SQRT2
      EKA=E(K)/SDIF
      EREKA=EREK/SDIF
      EKAP=EKA+EREKA
      EKAM=EKA-EREKA
      OKA=O(K)/SDIF
      DFE=(E(K)-O(K))/EREK
      CHI=CHI+DFE*DFE
      XMIP=.5*(A+B)*SQRT2
      SUM=SUM+2*EREK
      write(1,*) xm,den,a,b,erfa,erfb,erek,sum
      IF(O(K).LT.1.) NC=NC+1
      WRITE(7,*) K,XMIP,EKAP,EKAM,EKA,OKA
    1 CONTINUE
      CHI=CHI/(NB-3-NC)
      SUM=SUM/IMAX
      WRITE(1,*) ' Chi-squared per degree of freedom =',CHI
      WRITE(3,*) ' Chi-squared per degree of freedom =',CHI
      WRITE(1,*) ' Error probability =',SUM
      WRITE(3,*) ' Error probability =',SUM
      IF(SUM.LE.1.) RETURN
      WRITE(1,*) ' WARNING !  Insufficient data for reliable statistics'
      WRITE(3,*) ' WARNING !  Insufficient data for reliable statistics'
      RETURN
```

```
      END
```

FUNCTION ERF(Y)

```
      DATA P/.3275911/,A1/.254829592/,A2/-.284496736/
      DATA A3/1.421413741/,A4/-1.453152027/,A5/1.061405429/
      X=ABS(Y)
      DEN=1+P*X
      T=1/DEN
      T2=T*T
      T3=T2*T
      T4=T3*T
      T5=T4*T
      X2=X*X
      EX=EXP(-X2)
      SUM=A1*T+A2*T2+A3*T3+A4*T4+A5*T5
      ERF=1-SUM*EX
      IF(Y.LT.0.) ERF=SUM*EX-1
      RETURN
      END
```

SUBROUTINE BINS

```
      COMMON /STATS/XM,SM,IMAX,Y(200)
      COMMON /BIN/NB,X(11),O(10)
      DIMENSION S(11)
      DATA S/-5.,-3.,-1.5,-1.,-.5,0.,.5,1.,1.5,3.,5./
      NB=10
      X(1)=SM*S(1)+XM
      DO 1 K=1,NB
      O(K)=0
      X(K+1)=SM*S(K+1)+XM
      DO 2 I=1,IMAX
      YP=Y(I)
      IF(YP.GT.X(K+1)) GO TO 2
      IF(K.GT.1.AND.YP.LE.X(K)) GO TO 2
      O(K)=O(K)+1
    2 CONTINUE
    1 CONTINUE
      RETURN
      END
```

5.5 Sample output

Output data file: SAMPLE

```
KATHERINE
  5 KATHERINE
  1873. 1058.
  1874. 1143.
  1875. 1240.
  1875. 1240.
  1876. 1155.
  1877. 966.
```

1878.	1090.
1879.	1298.
1880.	900.
1881.	728.
1882.	1022.
1883.	712.
1884.	848.
1885.	893.
1886.	825.
1887.	925.
1888.	926.
1889.	1003.
1890.	1152.
1891.	831.
1892.	424.
1893.	802.
1894.	1055.
1895.	1076.
1896.	1136.
1897.	932.
1898.	1923.
1899.	1621.
1900.	725.
1901.	1388.
1902.	498.
1903.	807.
1904.	1512.
1905.	751.
1906.	623.
1907.	1293.
1908.	1245.
1909.	679.
1910.	1202.
1911.	747.
1912.	974.
1913.	856.
1914.	827.
1915.	750.
1916.	1063.
1917.	1137.
1918.	1219.
1919.	624.
1920.	665.
1921.	1114.
1922.	842.
1923.	1020.
1924.	1073.
1925.	857.
1926.	600.
1927.	674.
1928.	781.
1929.	506.
1930.	1055.
1931.	1146.
1932.	704.
1933.	734.
1934.	969.

1935. 1136.
1936. 764.
1937. 1180.
1938. 723.
1939. 1027.
1940. 1430.
1941. 876.
1942. 842.
1943. 1078.
1944. 1179.
1945. 805.
1946. 916.
1947. 813.
1948. 851.
1949. 816.
1950. 969.
1951. 1199.
1952. 364.
1953. 823.
1954. 1108.
1955. 1004.
1956. 832.
1957. 1354.
1958. 763.
1959. 861.
1960. 1006.
1961. 807.
1962. 502.
1963. 1050.
1964. 702.
1965. 861.
1966. 728.
1967. 1158.
1968. 1343.
1969. 1010.
1970. 649.
1971. 1103.
1972. 1078.
1973. 868.
1974. 1364.
1975. 1056.
1976. 1413.
1977. 1268.
1978. 1128.
1979. 819.
1980. 1237.
1981. 1067.
1982. 1026.
1983. 752.
1984. 1619.
1985. 920.
1987. 1209.
1988. 896.

T = 10. AK = 1.2816

Number of years	116		
Mean	973.59	Error =	24.119
Standard deviation	259.77	Error =	17.055

```
Skewness                 .52456  Error =  .22456

Recurrence interval 10. years
Rainfall for RI     1306.5 Error =  32.549
Normal distribution
Chi-squared per degree of freedom = 1.7785
Error probability = .52751
```

Output data file: FREHIST.DAT

k	$\bar{u}_k$	$\bar{f}^{+}_k/\sqrt{2}$	$\bar{f}^{-}_k/\sqrt{2}$	$\bar{f}_k/\sqrt{2}$	$\bar{o}_k/\sqrt{2}$
1	-4.00	0.00238	-0.00103	0.00067	0.00000
2	-2.25	0.05947	0.02780	0.04364	0.02874
3	-1.25	0.23997	0.12742	0.18370	0.17241
4	-0.75	0.37166	0.22787	0.29976	0.44828
5	-0.25	0.46418	0.30167	0.38292	0.32759
6	0.25	0.46418	0.30167	0.38292	0.37931
7	0.75	0.37166	0.22787	0.29976	0.29310
8	1.25	0.23997	0.12742	0.18370	0.15517
9	2.25	0.05947	0.02780	0.04364	0.04023
10	4.00	0.00238	-0.00103	0.00067	0.00431

Note: Column headings have been added for clarity

The Office of the Supervising Scientist can provide the computer programme as an ASCII file on IBM compatible format disks.

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