ANALYSIS OF HYDROLOGICAL DATA FOR SUBSURFACE DRAINAGE DESIGN FOR AN ARID AREA IN INDIA

by

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ABSTRACT

In the semi-arid to arid State of Rajasthan, 90% of the annual rainfall occurs as convective storms during the monsoon season.

The suitability of a Markov chain analysis to model rainfall in this region was evaluated. A 5 day transition probability matrix accurately predicts sequences of wet and dry days based solely on the state of the preceding day.

Both a daily model and an event-based model were used to describe rainfall pattern and distribution. Although the daily model is a traditional choice, the event-based model produced superior results. The event-based model describes the distribution of rainfall during a storm, the length of dry periods between rainfall events, and rainfall depths.

The drainage coefficient derived from the normal value analysis, is 32.26 mm using the daily model, compared with 10.69 and 21.77 mm for the event-based models. The most cost-effective drainage coefficient is 10.69 mm derived from the 0.1 mm threshold event model.

The Penman (1963) method best estimated ET_c over both seasons as well as within each season. The Jensen-Haise method, when adjusted by a correction factor of 1.15 for $ET_{alfalfa}$, produced comparable estimates of ET_c. The minimal climatic data required for the Jensen-Haise method makes it the most suitable evapotranspiration method for this area.

A set of coefficients, ranging from 0.73 to 1.40, was developed to convert pan evaporation measurements to ET_{JH}*. General crop coefficients for each development stage were determined from the generalized cropping pattern of the Chambal Command area.

A water balance using effective wet year rainfall and evapotranspiration for the Kharif season was used to calculate the drainage requirement. The drainage requirement for the 178 ha Daglawada test plot is 749.2 and 1165.3 ($x10^3$) m^3, for return periods of 5 and 10 years, respectively.

The leaching requirement of 0.0309, can be met with the Kharif season rainfall expected in wet years with return periods of 5 or more years, and normal years with return periods of 10 or more years.

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1.0 Introduction

In humid areas agricultural drainage, particularly subsurface drainage systems, are designed to remove excess soil water to prevent waterlogging conditions for crop production. In monsoonal, irrigated areas, such as the State of Rajasthan, India, the system has to be designed for waterlogging control during the monsoon season, as well as salinity control for the irrigation period.

Prior to the introduction of subsurface drainage in 1974, both waterlogging and soil salinity were problems affecting many hectares of agricultural land. However, even with the installation of drains, salt accumulation has continued, and high water table levels have remained a problem.

During the irrigated Rabi (dry) season in Rajasthan, there is often barely enough water to meet the requirements of the growing crop. Without the application of adequate water to leach salts from the soil, the productivity of the soil is negatively affected, even where subsurface drains have been installed.

Rather than applying excess water throughout the irrigated season, this thesis evaluates whether there is adequate precipitation during the monsoon season to leach salts from the soil prior to the start of the Rabi season. In order to achieve a soil salinity of 2 dSm^{-1}, 1.16 mmd^{-1} of excess water over the Kharif season is necessary (Chieng, personal communication). The level of soil salinity is based on the salt tolerance of the most sensitive crops grown in the area.

1.1 Objectives

The objectives of this thesis research are:

1. To examine each of the two seasons, Rabi and Kharif, independently in the analysis of weather data and in the determination of a water balance. The results of these analyses are combined to determine the most cost-effective subsurface drainage design.

2. Current subsurface drain spacings have been based on various drainage coefficients obtained from both published and unpublished reports. A drainage coefficient based on a water balance using the historical climatic records of the Kota station within the Chambal Command area, will be examined to improve the design of the subsurface drainage system.

3. To study the rainfall pattern and analysis of its distribution and occurrence. The intensity of the monsoon rains results in significant surface runoff, therefore, effective rainfall will be considered as well as actual rainfall.

4. To determine the most appropriate method of estimating evapotranspiration for a monsoonal, irrigated area. A coefficient correlating actual pan-evaporation and calculated evapotranspiration will also be investigated. A simple method of estimating evapotranspiration from pan evaporation measurements is desirable as data other than rainfall and pan evaporation, are not routinely collected at weather stations in the Chambal Command area.

2.0 Background

2.1 Salinity and Waterlogging Problems in India

The population of India is supported primarily by agricultural activities, particularly irrigated agriculture. The number of hectares of agricultural land under irrigation in India more than tripled from 1947 to 1990, increasing from 22 million ha to more than 70 million ha. Approximately 60% of the Chambal Command area, representing 229,000 ha, is under irrigation (Chieng, 1993).

Initially, irrigation was developed to allow for the expansion of agricultural activity during the dry, Rabi season. Surface drains were utilized to remove excess irrigation water. However, with the expansion of irrigation into the monsoon season, the surface drainage system was unable to cope with the combined runoff from the monsoon rain and irrigation water. Where once the heavy monsoon rainfall was solely responsible for waterlogged soils, now irrigation water has compounded the problem.

Irrigation practices contributed to increased salinity and waterlogging. Many inadequately planned irrigation projects were developed in areas with soils unsuited to excessive irrigation. Other projects, such as railway and highway development, often had a negative impact on the surface drains and canals. In addition, the local people found that by blocking the surface drains, pools of water suitable for fish harvesting or irrigation water supplies, were created.

As a result, almost 7 million ha of land in India is affected by salinity, and approximately 6 million ha experiences waterlogging (Table 1).

Table 1 **Saline and Alkali affected areas**

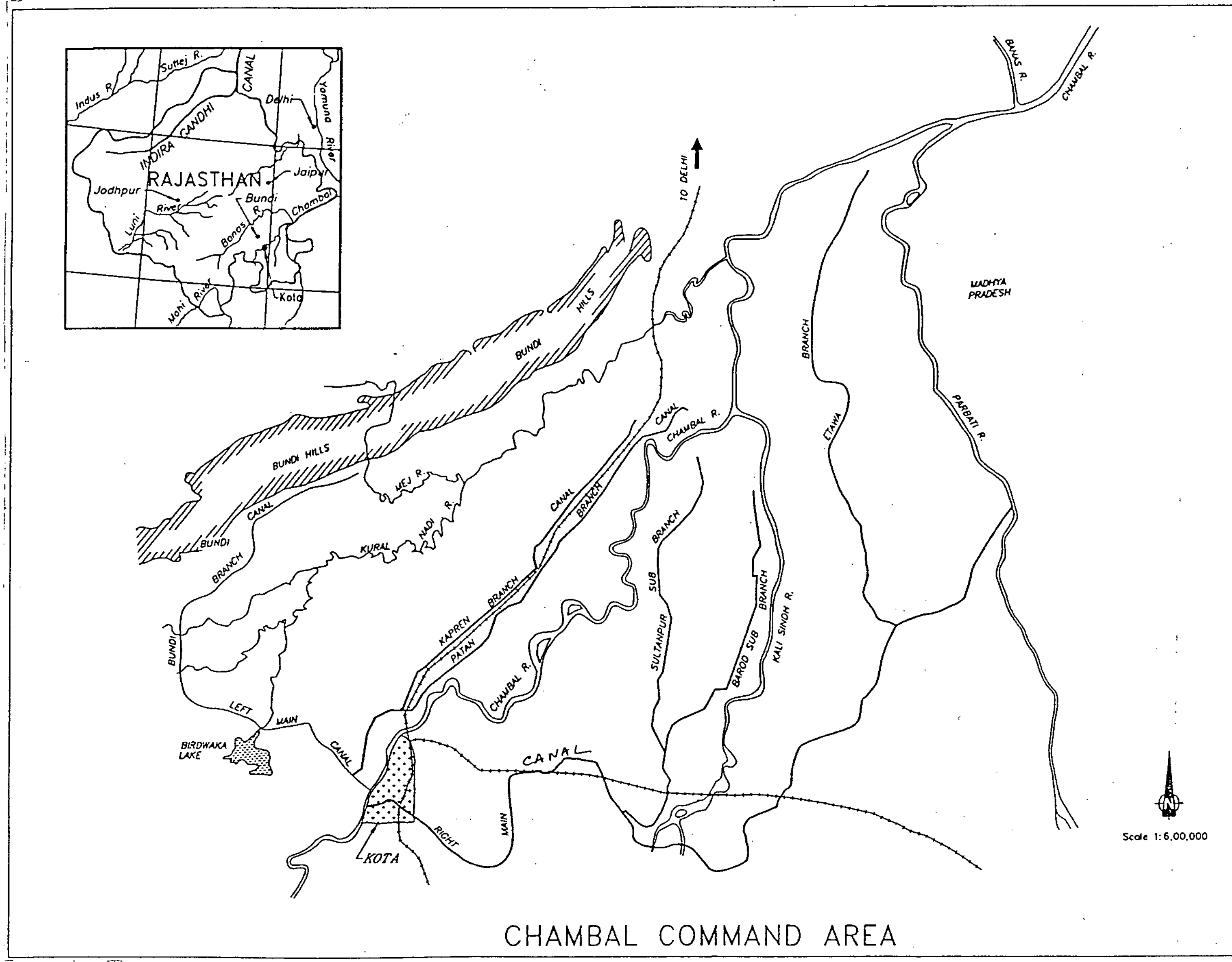
State	Saline/Alkali (millions of ha)	Waterlogged (millions of ha)
Uttar Pradesh	1.295	0.810
Gujarat	1.214	0.484
West Bengal	0.850	1.850
Rajasthan	0.728	0.348
Punjab	0.688	1.090
Haryana	0.526	0.620
Maharashtra	0.534	0.111
Orissa	0.404	0.060
Karnataka	0.404	0.010
Madhya Pradesh	0.224	0.057
Andhra Pradesh	0.042	0.339
Bihar	*	0.117
Kerala	*	0.061
Tamil Nadu	*	0.018
Jammu and Kashmir	*	0.010
Delhi	*	0.001
Other	0.040	

Source: Maheshwari, 1993; CSSRI, 1991 (cited in Chieng, 1993)
* Included under Other

2.2 Chambal Command Area

The lower Chambal Valley lies between 24° 45' - 26 °45' North and 75° 20' -79° 20', encompassing an area of 12,050 sq. km. Within the state of Rajasthan, the districts of Bundi, Kota, Sawai, Madhopur and Bharatpur lie within the valley. The Bundi-Karauli hills form the north-western boundary of the valley from Kota to Dhaulpur. The Chambal Command area represents 385,000 ha of the lower Chambal Valley, and encompasses approximately 60 distinct watersheds. It lies in the south-eastern part of Rajasthan between 25 ° and 26 ° north latitude and 75° 30' and 76° 6' east longitude (Figure 1). The primary water source for the Command Area is the Chambal river, one of the tributaries of the Yamuna river. The Kali-Sindh and Parbati streams enter the Valley from the south-eastern plateau, joining the Chambal River within the Valley to form an alluvial plain. This triangular plain, known as the Chambal Plain, lies within the Kota district of Rajasthan. As the Chambal river continues through the valley in a north-eastern direction, it forms several tributaries including the Kalisindh, Parwatim, Mej and Banas rivers.

Figure 1 **Chambal Command area, Rajasthan, India**



Source: Chieng, 1993

The elevation of the Chambal Plain ranges from 240 to 270 meters elevation, representing a drop of 600 meters from the south-western plateau. The elevation of the Valley diminishes further, to 150 meters above mean sea level, where the Chambal River meets the Yamuna in the north-east. The Bundi-Karauli hills, reaching a maximum height of 650 meters are the highest landforms in the Valley (Sharma, 1979). The elevation of the Chambal Command area ranges from 170 and 260 meters above mean sea level, with a slope of approximately 0.8% (Chieng, 1993).

The city of Kota, at 250 to 270 meters above mean sea level within the Chambal Plain, is of major importance in the state of Rajasthan. The development of hydro, thermal and nuclear power in Kota has allowed it to become a major industrial centre. In the rural district surrounding Kota, 1140 villages with an estimated combined population of 500,000 lie within the Chambal Command area (1985 census, Chieng, 1993).

2.2.1 Daglawada Test Site

A large scale research project has identified 25,000 ha of land with salinity and waterlogging problems in the Chambal Command area. Within this problem area, several test sites, each consisting of a number of test plots, have been established. The test plots are intended to investigate the performance of the subsurface drainage system and to aid in the determination of optimal drain spacing, drain depth and filter materials, for large-scale subsurface drainage system installation.

The Daglawada test site encompasses approximately 178 ha, and it is located approximately 20 km east of Kota. It is representative of the Chambal Command area in terms of soil type and condition, cropping pattern and irrigation practice. The site includes 20 test plots, evaluating a combination of drain depths (1.0 and 1.3 m) and drain spacings (15, 30, 40 and 60 m) with and without fabric envelope (filter).

2.3 Climate

The sub-tropical climate of the Chambal Command area is generally classified as arid to semi-arid. The region experiences three distinct seasons, the Kharif (monsoon), Rabi (dry winter) and Zaid (hot dry summer). The Zaid season begins in March and ends with the sudden onset of monsoon rain in the month of June. The monsoon (Kharif) season tapers off in October followed by the dry Rabi season.

During the Zaid season, the average temperature climbs from approximately 23 °C to a high of almost 34 °C in May, the warmest month of the year. It is not uncommon for temperatures in May to reach 49 °C , with an average maximum day time temperature of 41.83 °C (Table 2). By the end of April, hot, dry winds from the south-west begin, with average daily wind speeds in excess of 6 ms^{-1}. Average daily humidity lies below 30 % throughout the Zaid season.

In contrast, winter (Rabi season) temperatures may reach a low of 4 °C. The average minimum day time temperature for the month of January, the coldest month of the year is 6.38 °C. On average, the mean day time temperature for the Rabi season is 17.17°C, with humidity of 40 to 55% (Table 2). Winds are generally from the north-west and north with an average speed of less than 3 ms^{-1} during the Rabi season, although wind direction during this period is variable.

During the Kharif season, winds are predominantly from the south-west and west, with an average wind speed of approximately 8 ms^{-1} during July, tapering off to approximately 4 ms^{-1} in August. Mean day time temperature during the height of the monsoon in July and August, is 28.5 °C (Table 2). Humidity reaches almost 90% during August and September.

2.3.1 Rainfall

In temperate climates, the rainfall pattern tends to follow a normal distribution. Such a distribution allows the use of univariate statistics such as the mean, median and mode to characterize the rainfall. However, in arid and semi-arid areas, such statistics are not representative of actual rainfall.

Table 2 Average climatic conditions, Kota Station 1970-1993

Month	Min. temp. (°C)	Max. temp. (°C)	Mean daily temp. (°C)	Min. humidity (%)	Max. humidity (%)	Mean daily humidity (%)	Daily wind speed (ms^{-1})	Daily sun hrs. (hrs.)	Daily pan evaporation (mmd^{-1})	Daily rainfall (mmd^{-1})
Jan.	6.38	23.61	15.01	32.36	77.94	55.15	2.29	8.71	3.09	0.07
Feb.	8.39	25.84	17.12	20.29	61.14	40.71	2.71	9.64	4.38	0.19
Mar.	14.02	32.46	23.24	10.90	44.39	27.65	3.19	9.22	7.41	0.06
Apr.	20.92	38.42	29.67	12.05	30.54	21.30	4.38	10.06	11.80	0.07
May	25.68	41.83	33.75	18.31	39.11	28.71	6.39	9.80	15.25	0.30
Jun.	26.93	39.41	33.15	46.10	67.87	56.98	8.22	8.74	13.02	2.63
Jul.	25.20	33.48	29.34	52.39	76.03	64.21	7.31	7.71	7.45	8.39
Aug.	24.08	31.42	27.75	79.06	89.55	84.31	4.53	4.35	4.90	8.57
Sept.	22.36	32.65	27.50	65.00	87.97	76.48	3.68	7.06	5.41	3.44
Oct.	17.37	33.70	25.53	26.87	71.65	49.26	2.40	9.78	5.20	1.01
Nov.	11.28	29.60	20.44	16.30	71.52	42.95	1.61	9.86	3.91	0.39
Dec.	7.09	25.08	16.09	23.77	73.45	48.61	1.69	9.08	2.96	0.14

Annual rainfall varies considerably in the Chambal Command, from 309.10 mm to a high of 1506.80 mm (Appendix B). The mean is a poor indicator of annual rainfall, as the rainfall ranges from 40 to 194 % of the mean value of 777.67 mm (Figure 2). The annual distribution, strongly influenced by the extreme values, has the characteristics of an arid or semi-arid area as described by Jones (1981). It is positively skewed; the mode is less than the median value; both the mode and the median values are less than the mean; and the majority (59%) of the annual values fall below the mean rainfall.

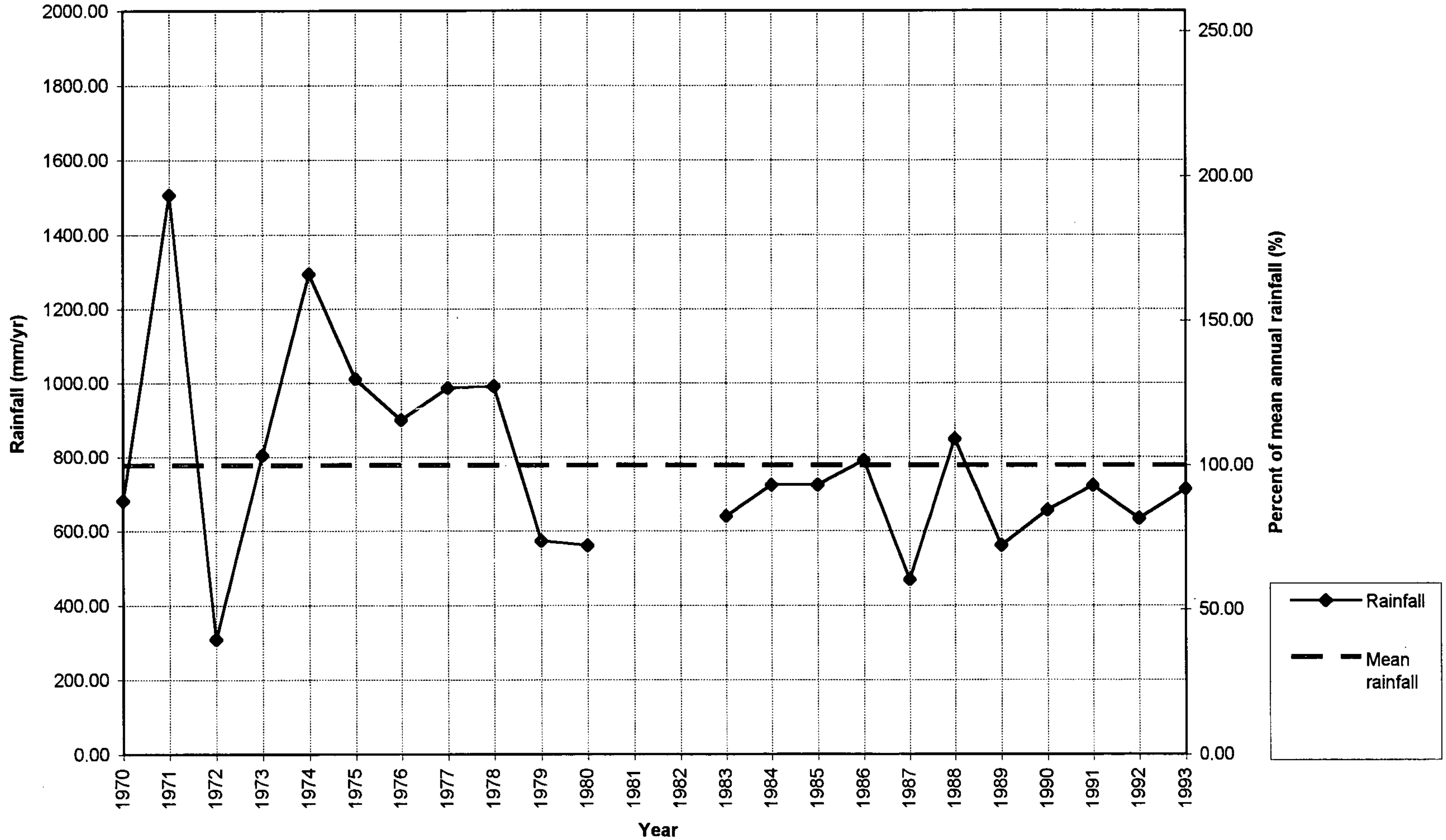
The distribution of rainfall throughout the year is also very different from that experienced in temperate climates. From the sudden onset of the summer monsoon rain in the month of June until its departure in late September or early October, the Chambal Command area receives approximately 90% of the total annual rainfall. During the Zaid season, little or no rain is recorded. From 1970 - 1993 the maximum rainfall for this season was 40 mm, with less than 11 mm of rain recorded in 64% of the years (Appendix B). Most of the rainfall outside of the Kharif season falls in November, although there may be some small contribution from December to February.

The seasonal, monthly and daily rainfall depths for June through September, exhibit more variability than the annual rainfall (Figure 3). Monsoonal storms are typically of short duration with intense rainfall, although many of the storms are of much lower intensity. The storms are interspersed with dry periods of 1 or more days. As a result, daily rainfall depths ranging from 0 mm to 174 mm have been recorded during the Kharif season (Appendix B).

2.3.2 Evaporation

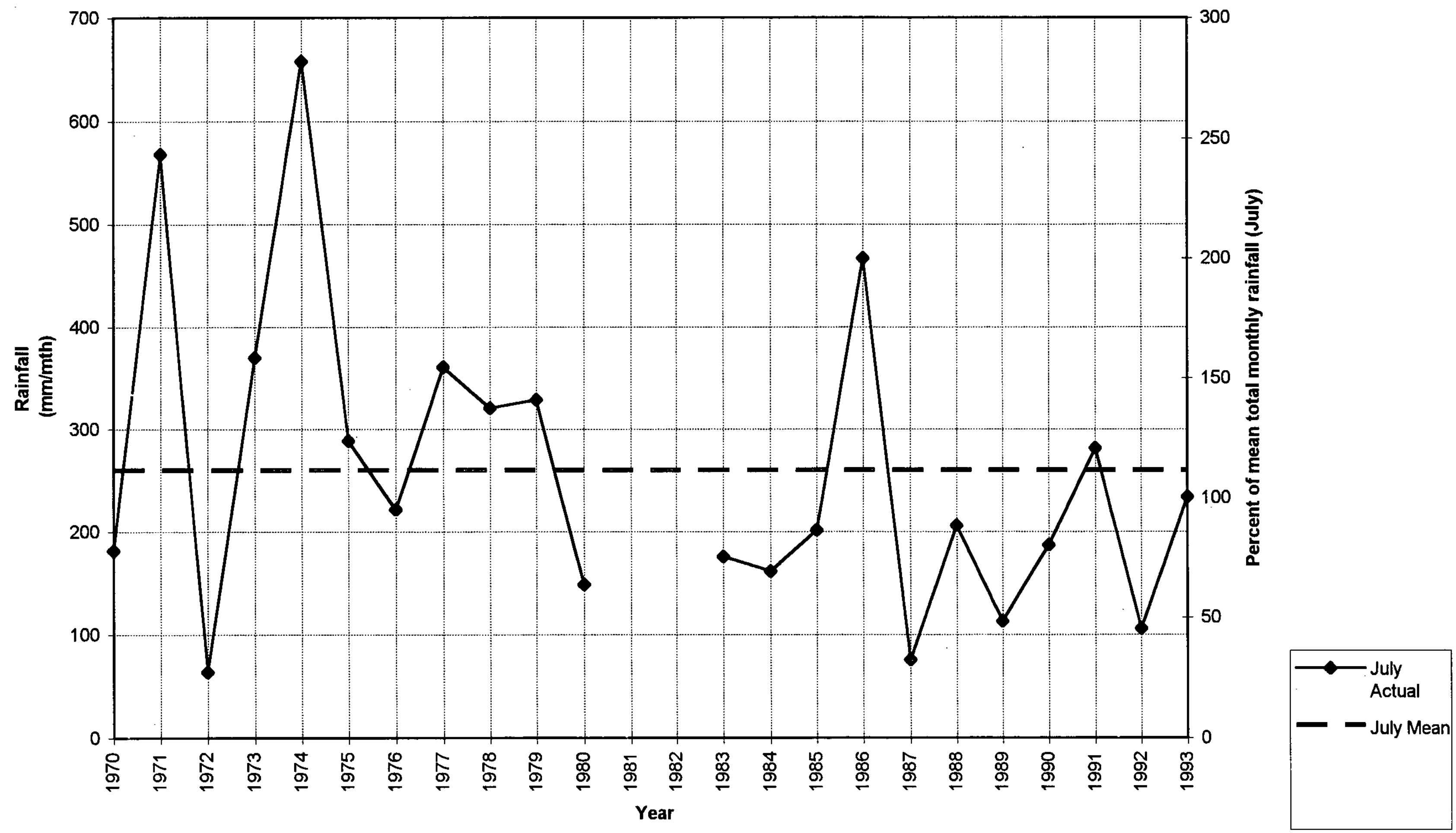
The annual potential evaporation has an estimated mean value of 2486 mm, with actual evaporation values varying from 64 to 133% of the mean (Appendix B and Figure 4). The distribution of annual evaporation values more closely follows a normal distribution than rainfall. However, as with the rainfall distribution, the extreme values have a strong influence. Potential evaporation is highest during the months of April and May during the hot, dry Zaid season. Maximum evaporation occurs

Figure 2 Annual rainfall distribution, Kota station



Note: mean rainfall = 777.67 mm

Figure 3 Monthly rainfall distribution for July, Kota station



Note: mean rainfall = 260 mm

during May, the warmest month of the Zaid season, with mean daily evaporation rates reaching a high of 15.25 mmd^{-1} (Table 2). During all months of the year, except for the height of the monsoon season, mean daily evaporation rates exceed mean daily rainfall rates (Table 2).

2.4 Soil

The soils of the Chambal Command area were first classified by Mehta (1958, cited by Sharma, 1979) into two broad categories based on colour. The categories were further subdivided into 3 groups relating to the presence and depth of a kankar layer (Table 3). The soil survey was conducted in 1951-1957, prior to the development of irrigation and drainage in the area.

Table 3 Soil Survey, Mehta (1958)

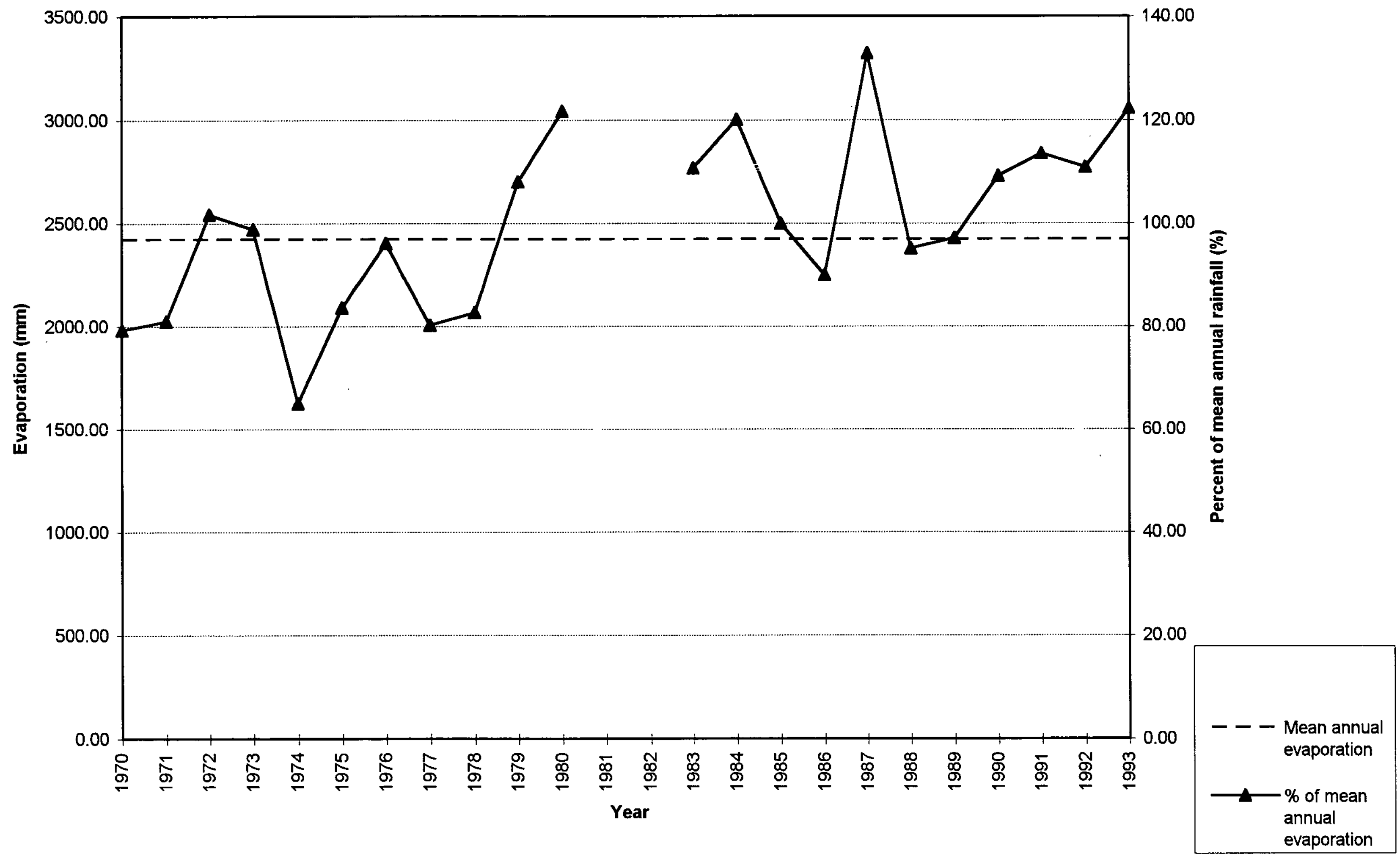
Soil Type	% of Area
Grey, without kankar layer	67.4
Grey, with kankar layer below 1.2 m	2.1
Grey, with kankar layer above 1.2 m	2.4
Brown, without kankar layer	24.7
Brown, with kankar layer below 1.2 m	2.5
Brown, with kankar layer above 1.2m	0.9

Source: Chieng, 1993

The high evaporation, low humidity and low rainfall of the region result in high evaporation rates from the upper layers of the soil, causing calcium carbonate concretions to accumulate, forming the restrictive kankar layer. Silicate particles (30%) are bound tightly together with magnesium carbonate (35%), a combination of aluminum, iron, sodium, potassium and trace elements (10%) and water (20%) to form the concretions (Bhatnagar, 1990).

Soil surveys conducted since 1958 indicate that calcium carbonate concretions (kankar grits) may be found at depths other than 1.2 m, and do not lead to a restrictive layer. However, all of the hard-pan layers in the Chambal Command area, regardless of depth, contain kankar grits (Chieng, 1993).

Figure 4 Annual Potential evaporation, Kota Station



Note: mean evaporation = 2486 mm

2.4.1 Soil Classification

A detailed soil survey was conducted from 1968 to 1981, resulting in the definition of eight soil series based on soil colour, texture, and presence and depth of a kankar layer (Table 4). A more recent survey was completed in 1993 for ten drainage blocks selected from within the Chambal Command area. The Chambal, and Kota soil series and their variations, were found to be the most common. Although the Sultanpur and Bundi soils occur in small amounts, they are often important on a local level.

Table 4 Soil Classification Series

Soil Series	% of Chambal Command area (approx.)
Chambal	63.0
Chambal Variant	5.0
Kota	23.0
Kota Variant	5.5
Sultanpur	1.0
Bundi	1.5
Guda	1.0
Alod	1.0

Source: Chieng, 1993

2.4.1.1 Chambal Soil Series

The most common soil in the Chambal Command area is the Chambal soil series (63%). These level to gently sloping soils (0-2% slope) are primarily comprised of fine textured montmorillonite clay. This deep, hard, mostly calcareous soil exhibits a slow permeability down to 120 cm. Below this point, the soils are non-saline to saline and non-sodic to sodic. A detailed description of the soil profile characteristics is given in Table 5.

The Chambal variant is similar to the Chambal soil series, although it is far less common (5%). The physical and chemical characteristics of the two soils is very similar except for the absence of calcium carbonate in the Chambal variant.

2.4.1.2 Kota Soil Series

The second most common soil in the Chambal Command area is the Kota soil series (23%). Like the Chambal soil series, these soils exhibit a level to gentle slope of 0-2%. The soil profile is deep to very deep and is comprised mainly of non-calcareous clay loam to clay soils. Permeability throughout the profile is slow to moderately slow. A detailed description of the soil profile characteristics is given in Table 5. The Kota variant is similar in character to the Kota soil series, except for the presence of calcium carbonate in the Kota variant. It is less common than the Kota series, encompassing less than 6% of the Chambal Command area.

2.4.2 Salinity

With the introduction of irrigation to the Chambal Command area in the 1960's, soil salinity became problematic. The World Bank (1974, cited in Chieng, 1993) reported that by 1972, soil salinity in varying degrees, was a problem over approximately 20,000 ha, or 5% of the command area.

Irrigation water applied in the Chambal Command area has an average electrical conductivity (EC_i) of 0.3 dSm^{-1} and total dissolved solids of 200-250 ppm (Chieng, 1993). This water is of excellent quality with low salinity, however it is of some concern with respect to soil sodicity according to the FAO irrigation water quality criteria (Ayers and Westcot, 1985).

Salinization in the Chambal Command area is primarily due to low salt efflux from the root zone and salinization from groundwater. During the irrigated season, there is little or no rainfall and evaporation rates are high. As there is often barely enough water to irrigate, the application of water in excess of plant needs is not practised. Irrigation has led to increased groundwater recharge

Table 5 **Soil Profile Characteristics**

Characteristics	Chambal Series				Kota Series			
	Depth in Soil Profile (cm)				Depth in Soil Profile (cm)			
	00-10	**10-56**	**56-115**	**115-146**	**00-10**	**10-56**	**56-115**	**115-146**
Physical Characteristics:								
CaCO3 (%)	7.0	6.0	6.0	6.0	0.5	1.5	1.5	2.5
Sand (%)	20.5	22.2	22.0	21.5	36.4	29.8	29.8	23.3
Silt (%)	20.2	24.3	23.5	25.2	20.2	25.3	23.5	27.2
Clay (%)	52.3	47.5	48.5	47.3	42.9	43.4	45.2	47.0
Bulk density (g/cc)	1.45	1.51	1.50	1.50	1.45	1.54	1.62	1.62
Specific gravity (g/cc)	2.27	2.34	2.13	2.11	2.57	2.59	2.57	2.59
Porosity (%)	51.6	58.0	51.2	52.0	57.05	57.51	61.30	54.70
H.C. (m/day)[1]	0.067	0.417	0.245	0.192	0.091	0.156	0.161	0.050
Chemical Characteristics:								
pH	8.2	7.9	8.0	7.8	8.1	8.1	8.1	8.1
EC_e (mS/cm)[2]	1.85	1.20	0.83	1.34	1.28	1.44	0.72	1.11
Organic carbon	0.78	0.51	0.42	0.45	0.85	0.66	0.69	0.51
C.E.C. (meq/100g)[3]	30.0	32.5	34.9	30.0	29.6	21.1	32.4	37.8
Exch. cations (meq/100g)[4]:								
Calcium	20.1	18.8	20.4	22.0	21.4	20.0	17.9	26.8
Magnesium	4.6	8.8	12.4	14.4	2.8	4.6	8.8	6.6
Sodium	2.8	2.4	2.0	2.4	3.3	3.5	4.0	2.4
Potassium	1.1	0.8	0.6	0.8	1.2	0.9	0.9	1.0

[1] Hydraulic conductivity
[2] Electrical conductivity of soil solution at saturation point
[3] Cation Exchange capacity
[4] Exchangeable cations

Source: Chieng, 1993

resulting in a significant rise in the water table depth. As the saline groundwater evaporates, salts accumulate in the root zone.

Salts also rise upward into the root zone by capillary action. Potential capillary rise investigated under laboratory conditions of the clay loam was found to range from 91 to 132 cm (Joshi, 1993). Field investigations are being undertaken.

2.5 Water Table

A good supply of groundwater is located in the deeper alluvial deposits of the soil profile. As the clay content of the soil increases toward the south-west of the Chambal Command area, the aquifer diminishes. The overall gradient of the groundwater for the region is sloped towards the Chambal River (Darra, 1993, cited in Chieng, 1993).

Water table monitoring wells were established in each of the test plots in the Chambal Command area. Data for June 1993 to January 1994 collected from wells in drainage zone B near Kota, indicate a median water table height of 650 mm below the surface. The water table height during this 6 month period fluctuated from a depth of more than 1300 mm to 0 mm from the ground surface.

2.5.1 Waterlogging

Waterlogging had affected approximately 161,000 ha of land in the Chambal Command area by the 1970's. Potential and actual waterlogged areas increased from 79,000 ha in 1964 to 161,000 ha in 1971 (Chambal Drainage Master Plan, 1978, cited in Chieng, 1993).

In this thesis, waterlogged areas are defined as those in which the water table is within 1.5 metres of the surface. In potential waterlogged areas, the water table lies between 2-3 metres from the surface. All areas with a water table below 3 metres from the surface by the end of March, are considered to be safe from waterlogging.

2.6 Crops

The development of irrigation in India has had a dramatic effect on the timing and type of crops grown. Gradually the shift has been made from dry farming to irrigation dependent agriculture in both the Kharif and Rabi seasons.

Prior to the introduction of irrigation, approximately 70 and 35 % of the land was left fallow during the Kharif and Rabi seasons, respectively (Darra, 1993). The percent of fallow land has steadily decreased to the present level of approximately 50 % during the Kharif season, and 5 % during the Rabi season (Chieng, 1993).

2.6.1 Kharif season crops

Prior to irrigation development, sorghum, maize and some pulses were the primary crops. The main Kharif crops at present are soybean, paddy rice, sorghum, maize, sesame, pigeon pea and sugarcane (Haroon, 1993, cited in Chieng, 1993).

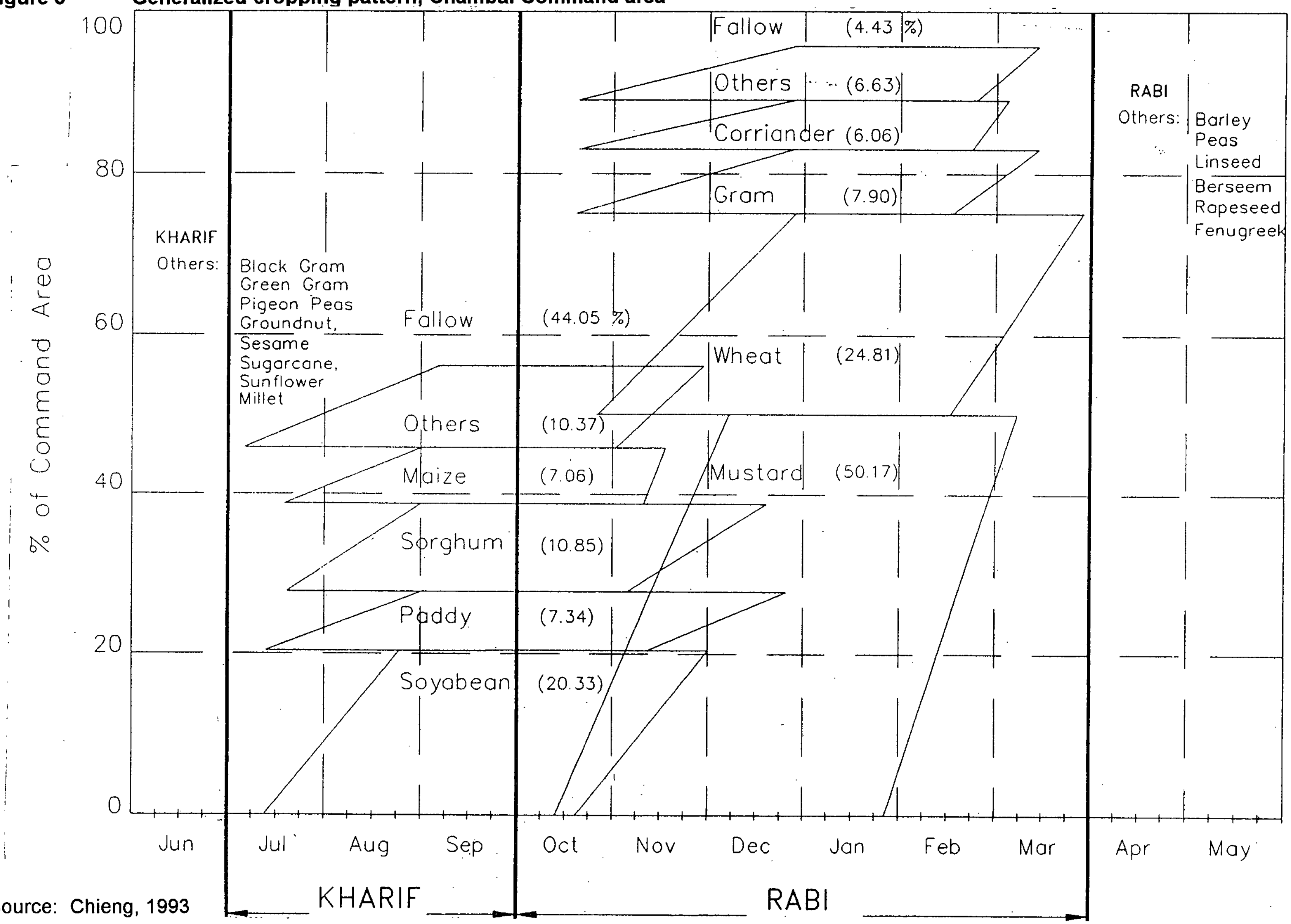
Crops are generally sown between the start of the monsoon season and the middle of July (Figure 5). Harvesting begins toward the end of October, continuing through to early December.

2.6.2 Rabi season crops

The main Rabi crops are mustard, wheat, barley, gram and berseem. Prior to the development of irrigation, the main Rabi season crops were wheat, linseed, gram, and a combination of other crops. Mustard has increased dramatically from less than 1 % of the area, to approximately 50 %, making it the predominant Rabi crop.

Rabi crops are sown from the middle of October through to the end of November. Harvesting generally takes place from late February through to the end March or early April.

Figure 5 **Generalized cropping pattern, Chambal Command area**



Source: Chieng, 1993

3.0 Literature review

3.1 Subsurface drainage

Extensive literature exists on the use of subsurface drainage to control the water table for salinity control in arid areas, and waterlogging control in humid areas. In monsoonal irrigated areas it is necessary for both salinity control and the prevention of waterlogged soils.

The drainage coefficient, or amount of water which a system must remove from an area over a 24 hour period, differs with the purpose of subsurface drainage.

A drainage system for salinity control must be able to remove excess water applied to meet the leaching requirement. It must also be able to maintain the water table at a minimum depth, in order to prevent upward movement of soluble salts.

To prevent waterlogged soils, the drainage system must have the capacity to remove precipitation in excess of the crop evapotranspiration demand.

3.1.1 Salinity control

All irrigation water carries small, but significant amounts of dissolved salts into the soil profile. The concentration of soluble salts increases as pure water is removed from the root zone by the evapotranspiration process.

Salt accumulation in the root zone reduces crop yield at concentrations above the tolerance level of the crop. High salt concentrations make it more difficult for plants to take-up water, due to the increased osmotic pressure exerted by the soil solution. Over time, the crop becomes water stressed, and its growth rate diminishes.

3.1.1.1 Source of soluble salts

Soil salinization is the result of excessive concentrations of soluble salts, such as chloride (Cl^-), sodium (Na^+) and calcium (Ca^{++}), that are easily transported by water. Soluble salts are introduced into the soil profile primarily through the application of irrigation water, the dissolution of salt deposits in the soil, agricultural drainage from higher areas and shallow water tables. Other sources include fertilizers, agricultural amendments, weathering soil minerals, and rain (Smedema and Rycroft, 1983).

Crops deplete water first from the upper portions of the root zone. The salts left behind are leached into deeper levels of the root zone, with each subsequent irrigation water application. As a result, soil water salinity increases with depth, with salinity near that of the irrigation water, at the top of the root zone (FAO/Unesco, 1973).

3.1.1.2 Crop sensitivity to salinity

Agricultural crops exhibit a wide range of salt tolerances. Many of the crops commonly grown in the Chambal Command area are sensitive, or moderately sensitive to soil salinity (EC_e) (Table 6). During the Kharif season, approximately 25% of the crops (gram, maize, paddy rice, groundnut and sugarcane) will suffer a significant yield reduction when cultivated under saline soil conditions. The majority of crops grown during the Rabi season are moderately tolerant of soil salinity.

3.1.1.3 Leaching requirement

The removal of accumulated salts in the root zone is accomplished through the application of irrigation water in excess of crop water requirements. The water removes accumulated salt as it percolates through the root zone, and is removed from the soil profile through subsurface drains.

Table 6 Selected Crop Salt Tolerance

Crop	Yield potential as influenced by soil salinity (EC_e) [1]				Sensitivity[2]
	100%	90%	75%	50%	
Rabi crops:					
Wheat	<6.0	7.5	9.5	13.0	moderately tolerant
Mustard (Safflower)	<5.5	6.0	7.5	10.0	moderately tolerant
Gram (field beans)	1.0	1.5	2.3	3.6	sensitive
Barley	<8.0	10.0	13.0	18.0	moderately tolerant
Kharif crops:					
Soybean	<5.0	5.5	6.0	7.5	moderately tolerant
Paddy rice	<3.0	4.0	5.0	7.0	moderately sensitive
Sorghum	<4.0	5.0	7.0	11.0	moderately tolerant
Maize	<1.5	2.5	4.0	6.0	moderately sensitive
Gram, black and green	1.0	1.5	2.3	3.6	sensitive
Groundnut	<3.0	3.5	4.0	5.0	moderately sensitive
Sugarcane		3.0	5.0	8.5	moderately sensitive

1 Ayers and Westcot, 1985 (EC_e values in mmhos.cm^{-1})
2 Doorenbos and Kassam, 1979

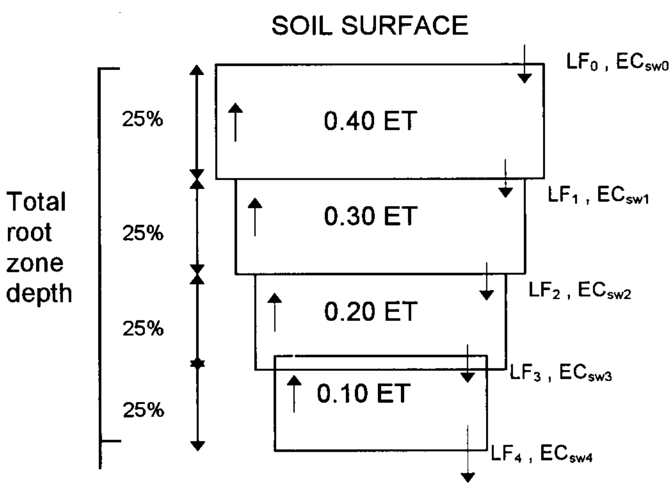
Leaching effectiveness is related to the soil type and its drainage properties (Bouwer, 1969). In sandy soils, leaching efficiency can be as high as 100%. With swelling heavy clays, it can be as low as 30% (Doorenbos and Pruitt, 1977).

The drainage coefficient for salinity control is determined from the leaching requirement and the evapotranspiration demand. The leaching requirement is dependent on the irrigation water salinity, and the salt tolerance of the crops. The leaching fraction is that portion of irrigation water percolating through the entire root zone, removing salts to the region below the root zone.

The conventional method of calculating the leaching requirement is based on the input water quality and the output drainage water quality. This method assumes soil water depletion occurs evenly throughout the root zone (FAO/Unesco, 1973). In addition, soil salinity is assumed to remain constant, reflecting steady state conditions. Therefore within the root zone, the contribution of salts from precipitation and dissolution processes and the removal of salts by crops are considered negligible (ASCE, 1990).

An alternative method is based on the soil water salinity as it relates to the 40-30-20-10 pattern of crop water use in the root zone (Figure 6). Crops are assumed to take 40% of their water requirement from the top quarter of the root zone. In each of the subsequent quarters moving downward in the root zone, 10% less water is depleted. Field measurements support this pattern, under normal irrigation conditions (Burman and Pochop, 1994; Ayers and Westcot, 1985).

Figure 6 Average root zone salinity, 40-30-20-10 method



ET = evapotranspiration
$LF_{1\text{-}4}$ = leaching fraction at the bottom of each quarter; LF_0 = leaching fraction at surface
$EC_{sw1\text{-}4}$ = soil water salinity at bottom of each quarter; EC_{sw0} = soil water salinity at surface

Source: Ayers and Westcot, 1985

3.1.1.4 Salt leaching in the monsoon season

In semi-arid and arid areas there is often a shortage of water in the irrigated season. As a result, insufficient irrigation water is applied to meet the leaching requirement. Therefore, leaching of accumulated salts from the root zone must occur in the monsoon season.

The monsoon season is characterized by low evapotranspiration rates and high rainfall amounts. Under these conditions, rainfall that infiltrates into the root zone can be used to leach the salts. This will result in low soil salinity at the start of the irrigated season, when crops are most sensitive to salinity. Salt accumulation would not reach critical levels until the later part of the growing season, when crops are not as sensitive to soil water salinity (Ayers and Westcot, 1985).

3.1.2 Water table control

In arid and semi-arid areas, shallow water table conditions exist during the monsoon season. As the water table rises, the air content of the soil diminishes as the pore spaces are filled with water. A reduction of 5 - 10% in the volume of air-filled pore space results in anaerobic conditions (Smedema and Rycroft, 1983).

Anaerobic conditions impair crop respiration and results in the accumulation of toxic levels of carbon dioxide. Toxic concentrations of reduced iron and manganese compounds, sulphides and organic gases are also possible. As a result, root growth is stunted and the roots are less able to absorb nutrients from soil water. The early stages of crop growth are more sensitive to waterlogging conditions, event those of short duration, than later well-developed stages.

High intensity rainfall during the monsoon season, results in a rise of the water table. High water table conditions over a short period of time will have less of an effect on crops than persistent waterlogging. Therefore, the rate at which the water table drops is important.

Early stages of crop development are more sensitive to waterlogging conditions, even those of short duration, than later well-developed stages. Throughout the crop development stages, higher temperatures serve to intensify the reaction to a high water table, as the crops require higher amounts of oxygen under such conditions.

3.1.2.1 Water table and salinity

High water table conditions increase soil water salinity, and reduce the effectiveness of leaching. With a rise in the water table, dissolved salts in the groundwater are introduced into the root zone. In low lying areas, with insufficient natural drainage, the salt concentration of groundwater may be 1.5 to 2 times that of the root zone soil water (FAO/Unesco, 1973).

A water table at a depth of 3 m or more from the surface will contribute salts to the root zone (FAO/Unesco, 1973). With the depletion of soil water from the unsaturated zone, groundwater moves upward through capillary flow, depositing salts in the root zone. Upward capillary flow increases as the distance from the root zone to the water table decreases.

Talsma (1963, cited in van Schilfgaarde, 1974) recommends water table depths of 120 cm to 190 cm, for light-textured soils and medium-textured soils respectively, based on a review of available information. The physical properties of the soil affect the rate of capillary flow, and the critical water table depth The highest capillary flow occurs in loam soil, with the most flow resistance in clay soils. The critical water table depth also varies with groundwater salinity, crop tolerance and the climate of the region.

3.1.2.2 Crop sensitivity to high water table conditions

Many crops grown in the Chambal Command area are sensitive to a high water table. Peas and pulses are very sensitive to waterlogging conditions, whereas rice exhibits a high tolerance. Maize is sensitive to a groundwater table at 50 cm below the soil surface, while wheat, barley and peas moderately tolerate these conditions, and sugarcane has a high tolerance (FAO/Unesco, 1973).

3.1.2.3 Water balance

Subsurface drainage in monsoonal areas, is used to prevent fluctuating water table conditions. A water balance is necessary to determine the amount of excess water which must be drained. The water balance calculation method using precipitation and evapotranspiration, developed by Thornthwaite and Mather (1955), has been used extensively throughout the world.

The water balance over a period of 3 to 5 days is normally the most critical in the drainage coefficient determination. A drainage system may be capable of removing excess water resulting from a single high intensity storm, but fail if the rainfall event occurs over several days. Intermediate periods of 1.5 to 2 days are important for shallow subsurface drainage systems and storms of less than 6 hours duration (Smedema and Rycroft, 1983).

3.3 Rainfall modelling

Rainfall models are important in semi-arid and arid zones where records of adequate length necessary to determine the true characteristics of the monsoon season rainfall are often lacking. As rainfall is the limiting factor in crop development, rainfall modelling is an important tool in agricultural planning and drainage design.

Most rainfall models are based on the assumption that daily, monthly and annual rainfall follow a normal distribution. In semi-arid and arid monsoonal areas however, the distribution is seldom normal. Rainfall is a highly variable, intermittent process during the monsoon season, and rainfall occurrences tend to be persistent. This introduces a complexity to the modelling of rainfall events in such areas, but also makes modelling that much more important.

3.3.1 Daily rainfall

The determination of available water during the monsoon season is dependent on the amount of rainfall and the pattern of rainfall occurrence. In many arid and semi-arid zones, a pattern emerges in the daily rainfall probability within the monsoon season when records of adequate length are examined. An analysis of 73 years of rainfall data in Tucson, Arizona showed that the daily rainfall probability exhibited a distinct pattern within the four month rainy season (Smith and Schreiber, 1973; Lane and Osborn, 1972).

3.3.1 Markov Chain Model

Gabriel and Neumann (1962) were the first to model the sequence of wet and dry days recorded over 27 years in Tel Aviv, Israel with a simple first-order, two state Markov chain. Since that time, Markov chain models have been used extensively in work in arid and semi-arid regions as they provide a reasonable fit to the observed monsoonal rainfall pattern.

A Markov chain is a two stage, discrete model which provides the probability of rain on a given day and the probable rainfall depth. Markov chains base the probability of a wet day on the occurrence or non-occurrence of rain on one or more previous days. A wet or rain day may be described as a day on which any rain is recorded; or alternatively, a day on which rainfall above a threshold value is recorded.

The expected amount of rain is obtained from a probability distribution of rainfall depth. Under most conditions, a gamma distribution provides an adequate fit to rainfall depth on wet days (Maidment, 1993). An exponential distribution, which requires less complex calculations may be used as an alternative to the gamma distribution (Todorovic and Woolhiser, 1975).

Markov chain models are often selected over other models due to their flexibility and ease of use. Different orders and number of states can be selected depending on the specific needs of the location. Rainfall modelling generally requires only a simple, two-state Markov chain:

$$X(t) = 0 \qquad \text{if day } t \text{ is dry,} \quad t = t_1 \ldots t_n \qquad \textbf{[Eq. 1]}$$
$$\text{and, } X(t) = 1 \qquad \text{if day } t \text{ has rain,} \quad t = t_1 \ldots t_n$$

where $X(t)$ is a discrete-value process representing two states, wet and dry, for each day within the period t_1 to t_n..

A first-order Markov chain assumes the probability of occurrence of a wet or dry state on day t is dependent only on the state of the preceding day:

$$P\,[X(t) = x_t \mid X(t\text{-}1)], \quad t = t_1 \ldots tn \qquad \textbf{[Eq. 2]}$$

where P is the probability of occurrence, x_t is the value of the state (0 or 1) on day *t* in the *n* day process X(*t*).

If the probability is dependent on the previous 2 days, then a second-order Markov chain model is assumed. Higher orders of Markov chains are possible for those rainfall patterns dependent on more than two preceding days.

In practice, first and second order chains are used as they provide an adequate fit to the data, and are preferred due to their ease of use (Coe and Stern, 1982). In arid and semi-arid areas, first-order, two-state Markov chains have been found to provide a reasonable fit to the seasonal analysis of rainfall distribution patterns (Smith and Schreiber, 1973; Osborn and Lane, 1972; Gabriel and Neumann, 1962).

3.3.1.1 Transition probability matrix

A two-state Markov chain analysis is based on a matrix containing the probability of occurrence of combinations or transitions of wet and dry states on successive days over a fixed time interval. The resulting transition probability matrix contains the following probabilities:

$$\begin{bmatrix} P_{00} & P_{01} \\ P_{10} & P_{11} \end{bmatrix}$$

where P is the probability of occurrence of a wet or dry state on a given day conditional on the state of the preceding day. The matrix elements represent the probabilities of dry-dry (P_{00}), dry-wet (P_{01}), wet-dry (P_{10}) and wet-wet (P_{11}) 2 day sequences over the interval.

In semi-arid regions, the dry season is generally excluded from the analysis and a single transition probability matrix is calculated for the entire rainy season or a portion of the season. The transition probabilities are assumed to be consistent or stationary within the selected interval. A further assumption is that the probabilities exhibit stationarity from one year to the next. Gabriel and Neumann (1962) assuming stationarity over the entire rainy season, reported a reasonable fit to the data collected at Tel Aviv, Israel.

However, the assumption of stationarity over an entire season has been challenged by the results of studies from various parts of the world. Significant variation in rainfall probability within a given month of the rainy season has been reported. Several transition probabilities, corresponding to smaller stationary portions of the season such as 5 and 10 day periods, have been successfully applied to regions exhibiting non-stationarity (Jackson, 1981; Heermann et al, 1968). This is similar to using a different Markov chain to model each of the time periods.

Stern and Coe (1984) report however, that in regions dominated by convective storm precipitation, the rainfall process may not exhibit stationarity even over a period as short as 5 days. Transition probabilities which change smoothly over time often provide better results in arid and semi-arid regions (Coe and Stern, 1982; Smith and Schreiber, 1973). A fourier series may be used to model the transition probabilities as a continuous function of time (Feyerherm and Bark, 1965).

The complex calculations required to model transition probabilities which vary over small time intervals are not practical for field use. A simple model using constant probabilities over a number of days, a month or a season is preferable. In assessing whether Markov chain analysis is appropriate to a given area, a model based on a single seasonal transition probability matrix may predict the fit of a more realistic, variable probability model (Gabriel and Neumann, 1962).

3.3.2 Rainfall events

The predominant form of precipitation in semi-arid zones are convective storms, which occur intermittently, often clustered in groups. Many of the stations in these zones record a single 24 hour rainfall depth only. This aggregated rainfall information does not provide the detail necessary to determine the characteristics of individual rainstorms.

The intermittent nature of precipitation in semi-arid and arid regions does not fit well in traditional rainfall models based on equally spaced time intervals such as days or months. An alternative approach is the modelling of rainfall events. An event is defined as successive rainy days, which occur between dry intervals. Convective storms generally produce rainfall events consisting of one or more rainy days, randomly distributed throughout the season. Dry intervals of 1 to more than 30 days in duration exist between rainfall events.

Models based on events, have been found to provide satisfactory results in semi-arid and arid zones especially when rainfall depth is limited to daily measurements. These stochastic models focus on rainfall event duration, rainfall depth per event and the distribution of events throughout the monsoon season. Event based models have the advantage of being easily extended to other stations in the region, as they do not depend on spatial uniformity. An event based probabilistic approach, however, is more complex than the analysis routinely carried out in temperate regions.

Rainfall depths on successive rainy days within an event are an important factor in drainage design. Drainage systems are designed to remove a specific magnitude of water, up to a maximum amount. Several days of rainfall below this maximum amount may strain the system and produce failure. A pattern of rainfall depths over the duration of an event often emerge.

3.3.2.1 Event Based Model

Early work on event based models was directed at the determination of runoff, rather than the characterization of monsoonal rainfall (Todorovic and Yevjevich, 1969; Fogel and Duckstein, 1969) Duckstein et al (1972) defined event based models as those models that describe two or more random variables, such as the number of events per monsoon season and the rainfall magnitude for each event, and their distribution functions.

Bogárdi et al (1988) presented a practical procedure to analyze rainfall events under semi-arid climatic conditions in central Tanzania. Probability distribution functions were fitted to four random variables: events per rainy season, duration of rainfall events, rainfall depth per event, and the interarrival time between rainfall events. They reported satisfactory results assuming an independent random process, although convective storm series are generally not purely random sequences (Fogel and Duckstein, 1982). Application of such an assumption reduces the computational complexity of the model, while retaining the accuracy required in practice.

A Poisson probability density function (pdf) has been found to adequately describe the number of events per rainy season under a number of semi-arid and arid conditions (Bogárdi et al, 1988; Duckstein et al, 1972). Geometric pdf's adequately describe the duration of rainfall events (Bogárdi et al, 1988; Fogel and Duckstein, 1969). A negative binomial distribution provides a reasonable fit to the interarrival time between events (Bogárdi et al, 1988).

Bogàrdi et al, (1988) found it was necessary to separate rainfall depths into various duration classes, as rainfall depth and duration were directly related. Their study indicated that rainfall depths for events of more than 5 days were best described by a log Pearson type III distribution, while depths for events of 1 day were fit to a negative binomial distribution.

3.3.3 Frequency analysis of extreme events

Extreme events such as intense storms, floods and droughts are important considerations in drainage design. An event, for this purpose, may be defined as a single rain storm, 24 hour rainfall, or a sequence of dry or rainy days. In semi-arid and arid monsoonal areas where mean climatic values are often meaningless, information regarding extreme events is important to agricultural planning.

The objective of frequency analysis of hydrologic data is to relate the magnitude of extreme events to their frequency of occurrence through the use of probability distributions. These distributions are based on the inverse relationship between the magnitude of an extreme event and its frequency of occurrence. Estimates of the risk of extreme drought or flood conditions can be determined using long rainfall records, although the true probability of such extreme events cannot be predicted.

Most project areas however, do not have rainfall records of adequate length. A probability distribution that reasonably accounts for the recorded rainfall information must be used to extrapolate beyond the available data. From the distribution, the average recurrence interval or return period for events equalling or exceeding a given rainfall amount can be determined. The maximum return period which can be calculated from rainfall data at a single station is limited by the length of the record. Generally a minimum of 30 years of data from a single station is necessary to estimate rainfall with a return period of 100 years (National Research Council Canada, 1989).

3.3.3.1 Assumptions in frequency analysis

Several assumptions are inherent in extreme value analysis. Annual maxima and minima for consecutive years are assumed to be independent and identically distributed. A lack of independence introduces a random error with respect to the estimated exceedence probability. In practice annual, rather than daily precipitation most closely meets the independence requirement (Mockus, 1960). However, persistent trends of above- or below-average annual rainfall exhibit a degree of dependence which may increase the variance in the frequency analysis (Zhang, 1982).

A further assumption is that the hydrologic system is stochastic. In addition, the system must be comprised of random precipitation depths, independent with respect to both time and space (Maidment, 1993).

3.3.3.2 Hydrologic data series

A complete, partial or extreme value data series is commonly used in frequency analysis. A complete data series includes all rainfall values and provides an estimate of probability. A partial duration data series includes only those values exceeding a threshold value. The resulting data series is known as an exceedence series.

Extreme event analysis is generally applied to either an extreme value or partial duration data series. An extreme data series is comprised of a single maximum or minimum value for each equally spaced time period. This series is known as an annual series if one value is selected for each year of the record. A partial duration series, includes only those events above a threshold value. Thus, a single year may contribute more than one value, with values from other years excluded from the series.

A partial duration series may be preferable in semi-arid and arid areas where the maximum value for a given year may be less than the second largest value of another year. In such a series, the maximum rainfall in drought years which may be exceptionally low compared to maximum values in average years, is excluded. The use of a partial duration series requires a more complex analysis method. In addition, a successful analysis requires the use of an appropriate threshold limit, which is not always easy to determine.

In practice, analyses utilizing either type of data series provide comparable results, if more than 15 years of rainfall data is available. The National Environment Research Council (1975) reports that an annual maximum series may provide more efficient results as both magnitude and a time interval are indicated, whereas annual exceedence values indicate magnitude only.

3.3.3.3 Extraordinary values

Extraordinarily high and low values, common in semi-arid and arid monsoonal areas often have a recurrence interval which greatly exceeds the one calculated by flood frequency analysis. Some engineers use their personal judgement to determine whether such values should be excluded from the analysis or shifted to a position closer to the probability curve. The U.S. Water Resources Council (1982) suggest that high outliers, defined by a skewness-based test, be removed from the analysis if they are considered to be extraordinary values based on historical information. If such information is unavailable, the outliers are retained. Extraordinarily low values are eliminated from the frequency analysis.

Since the true probability of such extraordinary events is unknown, deleting these values or shifting their position may adversely affect the analysis. Zhang (1982) reports that the inclusion of extraordinary events decreases the random error in frequency analyses. A graphical curve-fitting technique rather than a computed best-fit curve may provide better results when outliers are present in the frequency analysis. This allows the curve to be adjusted so that it is not excessively influenced by extraordinary values (Dunne and Leopold, 1988).

3.3.3.4 Probability distributions

Several families of probability distributions are in common use in hydrology. These include the normal/lognormal family, the extreme value family and the exponential/Pearson/log-Pearson type 3 family. The choice of distribution is generally based on a judgement as to which curve provides the best fit to the rainfall data, unless a specific recommendation for the region exists. Countries such as the United Kingdom and the United States have adopted as standard, the Extreme value type II and log Pearson type III methods, respectively (NERC, 1975; Benson, 1968).

The normal distribution is not well-suited to semi-arid or arid areas as the annual and daily rainfall is generally positively skewed. Instead, the data may follow a log-normal distribution, with two or three parameters. Hazen (1914) first introduced the two parameter log-normal distribution to hydrological applications. The incorporation of a third, lower bound parameter, which is subtracted from each value before the logarithm is calculated, improves the flexibility of the log-normal distribution.

Extreme value distributions are based on the probability distribution of the largest or smallest values of a random variable, such as rainfall depth. First introduced by Fisher and Tippett (1928), the extreme value distribution was developed into the Type I, II and III forms by Gumbel (1941), Frechet

(1927), and Weibull (1939), respectively. The Type I and Type II distributions have been used extensively in flood frequency studies, while the Type III distribution is commonly applied to drought analysis. The equation for the extreme value type I or Gumbel distribution is contained in Appendix D. A General Extreme Value distribution, developed by Jenkinson (1955) has become more popular in recent years. It is a single extreme value distribution in which each of the Type I, II and III forms is a special case.

The Pearson Type III and the log Pearson Type III distributions, derived by Pearson (1902) assume a number of different shapes depending on the parameters used. Their flexibility makes them well-suited to hydrological analysis of random rainfall events. However, the Pearson distributions are limited to the prediction of shorter return periods when extraordinarily high values are present (Reich, 1973). The equation for the log Pearson Type III distribution is contained in Appendix D.

3.3.3.5 Plotting position

Foster (1934) introduced the term plotting position to indicate the exceedence probability or recurrence interval of extreme events. When extreme values are plotted using one of the available plotting position formulae which depend on rank and sample size, the return period of an extreme event of a given magnitude can be determined graphically. The return period is defined as the reciprocal value of the plotting position.

Hazen (1914) first introduced a formula to calculate the plotting position, which has since been modified by a number of authors:

$$P(X \geq x_m) = \frac{m - 0.5}{n} \qquad \textbf{[Eq. 3]}$$

where P is the exceedence probability or plotting position of the value, m is the rank of the value in descending order and n is the total number of values.

Each of the formulae show similar results within the middle range of values, but may differ considerably in the plotting position of the largest and smallest values.

The plotting position formula developed by Weibull (1939) is the most practical and widely accepted. The formula generates probability-unbiased plotting positions such that each position is equal to the average exceedence probability of the ranked observations:

$$P(X \geq x_m) = \frac{m}{n+1} \qquad \text{[Eq. 4]}$$

where P is the exceedence probability or plotting position of the value, m is the rank of the value in descending order and n is the total number of values.

Cunnane (1978) argues that a quantile-unbiased method with minimum variance is preferable. A quantile-unbiased method, applied to a sufficiently large number of equally sized samples, results in a distribution line through the average value of the plotting positions. Cunnane recommended a formula which provides better results than the Weibull formula, when the largest values of a sample are important:

$$P(X \geq x_m) = \frac{m - 0.40}{n + 0.2} \qquad \text{[Eq. 5]}$$

For the Gumbel extreme value distribution the plotting position formula developed by Gringorten (1963) provides optimal results for the largest values:

$$P(X \geq x_m) = \frac{m - 0.44}{n + 0.12} \qquad \text{[Eq. 6]}$$

3.3.4 Drought

The extreme lack of rainfall, or drought, is a common occurrence in semi-arid and arid regions. Agricultural drought is based on the depletion of soil moisture in the root zone such that crop yield is adversely affected.

A number of states in India have attempted to establish criteria for drought conditions for various climatic conditions. Seasonal rainfall below set limits, rainfall deficit levels and variable rainfall within a season have all been used to define drought (Sikka, 1973).

In semi-arid and arid regions, the characterization of drought is often related to the total monsoon rainfall. As a very dry season preceding the monsoon depletes all soil moisture, there is always a water deficit prior to the onset of the monsoon. Without adequate replenishment from rainfall, crop failure during the monsoon season is certain. Irrigated crops grown during the dry season are also affected as the supply of irrigation water is dependent on the monsoon rains stored in the reservoirs.

3.3.4.1 Drought analysis

The pattern and distribution of rainfall throughout the season is often more important than the total rainfall to the determination of drought conditions. Prolonged dry periods randomly distributed between rainfall events can result in drought conditions. In arid and semi-arid regions, studies indicate that the length of dry day sequences may provide an indication of drought conditions (Gupta and Duckstein, 1975).

Hershfield et al (1973) used the frequency distribution of dry day sequences between rainfall events as an indicator of reliable precipitation in the mid-latitude eastern region of the United States. The authors cautioned that other information must be considered to determine the occurrence and severity of drought conditions. The soil moisture capacity, soil moisture content, and the water-use pattern of the crops, are all important factors in addition to the length of dry day sequences.

Gupta and Duckstein (1975) applied extreme value analysis to the maximum dry day sequences. Extreme frequency analysis of dry day sequences and the minimum annual rainfall provides information on the recurrence interval of extreme drought.

3.4 Effective rainfall

Dastane (1974) presents a overview of effective rainfall definitions, which differ with the hydrological application. In conventional hydrology, effective rainfall is considered to be that portion of total rainfall that contributes to runoff. Conversely, effective rainfall for agricultural purposes is considered to be that portion of total rainfall which satisfies evapotranspiration (ET) requirements (Burman 1980, 1983; ASCE, 1990; Burman and Pochop, 1994).

Surface runoff and deep percolation losses do not contribute to crop water requirements, nor do they serve to reduce ET. Although deep percolation is excluded from effective rainfall, it may be beneficial to crops. The percolation of water through the root zone may remove excess salt, thereby reducing the leaching requirement. Water temporarily stored in surface depressions and plant-intercepted rainfall are generally included as part of effective rainfall. The water may infiltrate the soil over time, or evaporate into the atmosphere so that ET is reduced.

Intercepted water which evaporates directly into the atmosphere from plant surfaces is excluded from effective rainfall by some authors (Burman and Pochop,1994). Effective rainfall is restricted to that portion of total rainfall which infiltrates into the soil profile at a point in a field, without contributing to deep percolation. Although water evaporating into the atmosphere from plant surfaces reduces ET, it occurs downwind from the interception point (Burman et al, 1975).

3.4.1 Factors affecting effective rainfall

3.4.1.1 Rainfall pattern and distribution

In arid and semi-arid regions of India, there is little or no moisture stored in the soil root zone prior to the onset of the monsoon season. The monsoon rains are the only source of plant-available soil water; however, much of the rainfall is not effective.

The intensity, depth and duration of rainfall events are related to the magnitude of effective rainfall. The high intensity, short duration rainfall events of substantial depth characteristic of convective storms in semi-arid and arid regions result in large surface runoff.

Of equal importance is the distribution of rainfall events throughout the monsoon season. If the soil moisture in the root zone is depleted between rainfall events, the surface runoff and deep percolation losses are reduced. However, large magnitude rainfall events with short dry periods between events do not allow adequate time for plants to take-up available soil water.

The timing of rainfall events with respect to crop growth stage is also important. Rainfall just before harvesting is for most crops a waste, and is considered ineffective.

3.4.1.2 Soil characteristics

Soils have a limited water intake rate and moisture holding capacity. The amount of water held by the soil between its field capacity and the wilting point, is the portion available for uptake by plant roots.

Soils with high infiltration rates and permeability are able to intake more water and reduce surface-runoff. Both infiltration and permeability are related to the texture, structure and compactness of the soil.

The plant-available soil water stored in the soil profile depends upon its depth, texture, structure and organic matter content. Values range from 200 mm/m for heavy textured soils, to 60 mm/m for coarse textured soils. Fine textured soils with deep soil profile have more storage capacity, thereby increasing effective rainfall.

3.4.1.3 Crop factors

Under conditions of high crop water requirements or evapotranspiration (ET), the moisture in the soil root zone is depleted rapidly. This allows more rainfall to infiltrate the soil profile, increasing effective rainfall.

The type of crop and its growing stage, together with climatic conditions, are directly related to evapotranspiration rates. As the rooting depth increases and the crop matures, more water is required, increasing evapotranspiration. Deep-rooted crops take-up soil moisture from deeper levels of the root zone, further increasing the proportion of effective rainfall.

3.4.1.4 Other factors

Management practices which influence runoff, infiltration, permeability and soil water holding capacity also influence the amount of effective rainfall. Surface ruts and channels, or soil compaction resulting from poor field management, increase surface runoff rates.

The topography also impacts surface runoff. In areas with little or no gradient, water that has an opportunity to pond at the surface, may infiltrate into the soil over time. As the gradient increases, more rainfall is lost to surface runoff.

3.4.2 Effective rainfall estimations

Several methods of effective rainfall estimation, based on direct measurement, empirical formulae and the soil water balance, have been developed. Dastane (1974) provides an comprehensive overview of all of the methods, including the relative merits of each.

Although direct measurement techniques often provide the best information with regard to effective rainfall, historical data is seldom available. In the absence of direct field measurements, empirical methods and soil water balance methods are commonly used to estimate effective rainfall.

3.4.2.1 Soil water balance models

Soil water balance models (SWBM) are considered to provide the best estimates of effective rainfall for a specific location. They incorporate all of the processes of the hydrologic cycle which contribute to soil water storage in the soil profile. These models are therefore, easily adapted to the climate and soil conditions of any location. However, many are complex and difficult to apply, especially if there is a lack of data.

Several models have been developed which simulate the soil moisture balance, which consider rainfall and irrigation as inputs to soil water. Interception, runoff and deep percolation in excess of actual field capacity represent losses to the balance. An estimation of evapotranspiration is used to determine the soil water depletion. Often the models use methods to estimate the various components that were developed for other purposes.

One of the more common soil water balance models, known as the SPAW model was developed by Saxton et al (1974). The model simulates the soil water balance using rainfall, actual evapotranspiration, infiltration and the redistribution of soil moisture. Each of the components is considered separately on a daily basis, together with the previous day's soil water balance, to determine the effective rainfall.

Both interception and evaporation from water stored in surface depressions are taken into account in the SPAW model. Interception losses up to a maximum value, are subtracted from actual evapotranspiration regardless of the stage of crop growth. In the early crop growth stages, the interception loss is assumed to account for evaporation from water stored in surface depressions.

3.4.2.2 Empirical methods

3.4.2.2.1 U.S. Bureau of Reclamation method

Stamm (1967) developed a method of effective rainfall estimation for the arid and semi-arid areas of the Western United States. Monthly effective rainfall is calculated as a percentage of incremental rainfall amounts, for the 5 driest consecutive years only.

The simplicity of this method has resulted in widespread use throughout the world. Dastane (1974) reports that the U.S. Bureau of Reclamation method is not appropriate for most areas. The method does not incorporate soil and crop information, rainfall frequency and distribution, or the degree of aridity, raising questions as to its accuracy.

3.4.2.2.2 USDA-SCS method

The USDA-SCS (1970) presented an effective rainfall estimation method which relates average monthly effective rainfall to average monthly evapotranspiration and the normal depth of depletion prior to irrigation:

$$R_e = f(D)[1.25\ R_t^{\ 0.824} - 2.93][10^{\ 0.000955\ ET_c}] \qquad \textbf{[Eq. 7]}$$

where R_e = effective rainfall, R_t = mean monthly rainfall, ET_c = ET for the crop, D = normal depth of depletion prior to rainfall/irrigation.

The relationship is based on measurements of daily soil water storage, rainfall and evapotranspiration over a 50 year period. A total of 22 stations located in arid to humid climates in the United States contributed to the results.

This method is often recommended in areas where a daily water balance simulation is not practical (ASCE, 1990). However, as it does not take into account either soil infiltration rates nor rainfall intensity, it is only applicable in areas with high soil infiltration rates relative to the intensity of rainfall (Patwardhan et al, 1990; Dastane, 1974).

Patwardhan et al (1990) compared the results of the USDA-SCS method with a soil water balance model. The USDA-SCS method produced effective rainfall estimates comparable to the SWBM for well-drained soils, but did not perform as well with poorly drained soils. The method produced less accurate estimates under both soil conditions, when rainfall exceeded the mean annual event.

The discrepancy between the effective rainfall estimated by each method was considered to be related to several weaknesses in the USDA-SCS method. The USDA-SCS method is not sensitive to soil type and does not account for carry-over soil water. In addition, event frequencies and local climatic characteristics are not explicitly incorporated into the method.

3.4.2.2.3 Local methods

Dastane (1974) discusses several methods, based on practical experience, developed locally in India. The effective rainfall for rice is generally considered separately from other crops. Dastane (1974) provides an overview of the methods. The estimates vary in accuracy, with some appropriate for preliminary planning only.

Many of the methods are based on a set percentage of rainfall or an amount above or below a threshold rainfall value. Fifty to 80% of the total rainfall is considered effective for rice, with 70% of average seasonal rainfall used as effective rainfall for other crops (Dastane, 1974). Smith (1991) estimates effective rainfall as 70 to 90% of mean monthly rainfall of 120 mm or less for use with the FAO computer program developed for irrigation and planning purposes (CROPWAT).

3.5 Evapotranspiration

The term evapotranspiration (ET) is commonly used to describe the water requirement of crops. It refers to the transpiration component, as well as the evaporation of water from soil, water surface and plant canopy.

An accurate measure of evapotranspiration is essential to the planning and design of both irrigation and drainage systems. Evapotranspiration determined directly through tanks, lysimeters, water balance or other methods provide the best prediction of crop water requirements. However, such data is seldom available over a long enough time period to be useful. Estimations obtained from empirical formulae, based on climatic data and calibrated to the local area, are often relied upon in the planning of water resource projects.

3.5.1 Climatic Factors

Evapotranspiration is affected by several climatic factors, including precipitation, temperature, wind speed, and sunlight hours and intensity.

3.5.1.1 Temperature

Temperature is considered to be the major factor influencing ET in crops. Temperature has a direct influence on transpiration, but it also indirectly affects transpiration through its effect on plant growth. Under conditions of lower or higher than average temperatures, crop growth is retarded or stopped completely (USDA, 1970).

3.5.1.2 Wind

Evaporation from land and plant surfaces is accelerated by wind, therefore it is an important factor in the determination of ET. Most wind measurements represent average wind speeds over a 24 hour period. As day and night wind speeds differ significantly, the use of daily average wind speeds in empirical ET formulae often results in a poor estimate of ET. Under conditions of stronger daytime wind, often experienced during the Rabi season, ET estimates tend to be underestimated.

In the absence of actual day to night wind ratios, an approximation of 2.0 is often recommended. Based on this approximation, a correction factor of 1.33 is used to obtain day time wind speeds from mean 24 hour wind speed measurements (Doorenbos and Pruitt ,1977).

Rao et al (1981) however, found that the day-night ratio differed dramatically between the monsoon and dry periods. The study, conducted over a two year period in the state of Maharashtra, suggests that the day-night ratio during the monsoon season varied between 1.0 and 1.4. During the hot, dry season, the ratio increased to between 1.8 and 3.8.

3.5.1.2 Other Climatic Factors

In areas with low relative humidity, higher crop water requirements can be expected. Dry air promotes both evaporation and transpiration, while they are suppressed under conditions of high humidity.

ET processes require energy in the form of sunshine. Thus, crop ET requirements are directly proportional to the number of daily sunshine hours. As areas of higher latitude receive much more sunshine during summer months than those closer to the equator, latitude is also an important factor.

3.5.2 Crop Factors

Seasonal crop ET is affected by the length of the growing season. Also of importance, is the length of each crop development stage. Crops require more water in their mid-season development stage, between the time they reach effective ground cover until they begin to mature.

The length of the mid-season development stage and the growing season vary depending on the time of year. Generally, those crops planted in warm summer months will have shorter growing seasons.

3.5.2.1 Advection

In arid irrigated areas, sensible heat advection becomes an additional source of energy for ET processes. Sensible heat is transferred from drier areas into the irrigated areas, where it is converted into latent heat. The aerodynamic roughness of the crop affects the amount of sensible heat advection that occurs.

3.5.3 Reference Evapotranspiration

Empirical formulae are designed to calculate reference ET or potential ET. The relationship between reference ET (ET_r) and crop ET (ET_c) is defined as:

$$ET_c = k_c \, ET_r \qquad \textbf{[Eq. 8]}$$

Reference ET estimates are generally based either on grass, 8 to 15 cm tall (Doorenbos and Pruitt, 1977) or alfalfa, 30 to 50 cm tall (ASCE, 1990). In each case the crop is assumed to be well-watered and actively growing.

3.5.3.1 Comparison of Grass and Alfalfa Reference Evapotranspiration

The ET requirement of alfalfa is 13 to 20% more than that of grass (ASCE, 1990). Factors such as the canopy density, leaf resistance, aerodynamic roughness and root system account for the difference between grass and alfalfa ET rates.

The dense ground cover provided by alfalfa leaves absorbs more incoming solar radiation than grass, preventing excessive drying of the soil. In addition, alfalfa leaves have a lower leaf resistance to water vapour diffusion than blades of grass. In areas where sensible heat advection is a factor, alfalfa may provide better crop ET estimates as the aerodynamic roughness of its leaves is more similar to other agricultural crops than grass.

Under conditions of unlimited soil water supply, ET reaches maximum or potential rates. As the soil water is depleted, the ET rate decreases. The extensive root system of alfalfa occupies a greater volume of soil than that of grass roots, minimizing ET rate changes due to soil water depletion (Wright and Jensen 1972; ASCE, 1990).

The main disadvantage of alfalfa as a reference crop is its change in height throughout the growing season. Grass provides a more consistent reference as it can be clipped to a constant height (Burman and Pochop, 1994).

3.5.3.2 Conversion between reference ET estimates

In order to compare grass and alfalfa ET estimations, it is necessary to convert from one to the other. The conversion of alfalfa based estimates to grass and vice versa can produce questionable results due to lack of local calibration. The differences in cultivation practices and climate make conversion factors determined for one area not easily applied to other regions (Burman and Pochop, 1994).

Doorenbos and Pruitt (1977) recommend a factor of 1.15 to convert grass ET estimates to alfalfa in arid and semi-arid regions, under conditions of predominately light to moderate wind. Studies in semi-arid regions have found alfalfa ET is reasonably estimated as 1.15 the ET of grass (Allen and Pruitt, 1986; Hussein and El Daw, 1989). Saeed (1986) reported a conversion factor of 1.2 produced better results under the arid conditions of central Saudi Arabia.

3.5.4 Empirical formulae for ET estimation

Extensive research on empirical formulae has been conducted since 1948, when Penman introduced the first ET formula relating various climatic factors.

Empirical formulae are classified into combination, radiation, temperature and pan evaporation methods based on the required climatic factors. Combination methods require the greatest number of climatic parameters, while temperature methods require the least.

ET formulae are recommended for specific climatic regimes depending on the location and climatic conditions under which the equation was developed. Some combination methods however, can be applied to any area (Allen, 1986). The equations for those methods suitable for estimating ET in semi-arid and arid climates are contained in Appendix E.

3.5.4.1 Combination methods

The Penman equation, developed in 1948, was based on aerodynamic and energy components. It has undergone several modifications to the present. Allen (1986), provides a comprehensive overview of the variations in the Penman equation.

Wright and Jensen (1972) modified the original Penman equation to estimate alfalfa reference ET, based on work in Kimberly, Idaho. The Kimberly-Penman method introduced new wind function coefficients and a revised saturation deficit method.

Wright (1982) refined the Kimberly-Penman 1972 equation, introducing varying coefficients for the wind function. Sensible heat advection, which exhibits seasonal variation, is better estimated with a varying wind function. A set of crop coefficients were compiled for use with alfalfa reference ET based on the studies at Kimberly Idaho.

Monteith (1965) incorporated aerodynamic and canopy resistance factors into the original Penman equation to create a new alfalfa reference method. Thom and Oliver (1977) further refined the Penman-Monteith equation to account for varying surface roughness. It is unclear as to how the Monteith equation was adapted from a forest canopy to agricultural crop ET. However, the use of the Penman-Monteith method for agricultural application has gained widespread acceptance.

Doorenbos and Pruitt (1977) developed the grass reference FAO Penman, and the FAO Corrected Penman. The corrected version, uses solar radiation, wind and humidity to refine the ET estimate.

3.5.4.2 Temperature methods

Thornwaite (1948) correlated mean monthly air temperature with ET. The correlation, based on water balance studies in valleys of east-central USA, allows for the estimation of ET with temperature and latitude data only. The conditions under which this correlation is valid do not occur in arid or semi-arid areas except during short post-rainfall periods. The Thornwaite equation only applies to areas where a standard albedo can be applied to the evaporating surface, and advection is not a factor.

USDA-SCS (1970) introduced the Blaney-Criddle method, which is based solely on temperature and daylight hours. Rather than a grass or alfalfa based set of crop coefficients, the SCS Blaney-Criddle relies on a coefficient combining climatic and crop factors, to convert reference ET to crop ET.

Doorenbos and Pruitt (1977), modified the original SCS Blaney-Criddle equation to create a grass reference method, known as the FAO Blaney-Criddle. This method uses standard grass coefficients rather than the original SCS coefficients. It can be adjusted to various climatic zones through correction factors.

Hargreaves and Samani (1982;1985) revised an earlier radiation method (Hargreaves, 1974) to eliminate the need for radiation information. The new method, based on research in Arizona, is a minimal data method requiring temperature alone.

3.5.4.3 Radiation Methods

Turc (1961) developed a radiation method which estimates potential rather than reference ET. The equation was based on research in western Europe and is best suited for areas with similar climates.

Jensen-Haise (1963) and the modified Jensen-Haise (Jensen et al, 1971) provide estimates of alfalfa reference ET. It provides reasonable estimates for arid and semi-arid regions.

The Priestly-Taylor (1972) method was designed primarily for humid regions, and does not give adequate ET estimations for arid or semi-arid areas. A reference crop for this method was not indicated.

Hargreaves (1974) introduced a method of estimating ET using radiation and temperature information, based on 15 years of research conducted in Cochocton, Ohio. Grass was used as the reference in the estimation of crop ET in this humid area.

The FAO Radiation method (Doorenbos and Pruitt, 1977) is a modification of the Makkinik (1957) radiation method. This method was designed to provide grass reference ET estimates for a wide range of climatic regimes, through the use of correction factors.

3.5.4.4 Pan Evaporation Methods

Christiansen (1968) and Christiansen and Hargreaves (1969) developed a method of estimating ET from Class A pan evaporation and climatic data. The pan coefficients, relating evaporation to ET, are based on regression equations.

The FAO Pan evaporation method (Doorenbos and Pruitt, 1977) estimates ET from both Class A pan and Colorado sunken pan evaporation measurements. Pan coefficients, dependent on wind, fetch and humidity, are presented in tabular form.

3.5.4.5 Correction coefficients

Correction coefficients are used in the FAO radiation, Blaney-Criddle, Corrected Penman and Pan methods to account for different climatic conditions. Doorenbos and Pruitt (1977) presented a number of "look-up" tables in the FAO-24 document which provide these coefficients. A number of mathematical representations of these "look-up" tables have been developed which allow for computerized calculation of ET using the FAO methods.

Frevert et al (1983) developed correction coefficient regression equations for each of the 4 methods. These correction coefficients agree closely with values in the original FAO-24 tables.

Allen and Pruitt (1991) found that the results of Frevert et al (1983) for all methods but the FAO Radiation method deviated from the FAO-24 tables by up to 10%. The accuracy of the correction factor equations for the FAO Penman, Blaney-Criddle and Pan methods was improved through the introduction of additional parameters. The resulting equations provide an accurate representation of the original FAO-24 tables.

Snyder (1992) derived a Class A pan coefficient for use with the FAO Pan method, based on the regression equation developed by Cuenca (1989). The number of terms in the regressions equation were minimized to create a simpler equation.

3.5.5 Studies

Studies comparing various ET methods from areas with climates similar to the Rajasthan area were examined. In general, the ET studies tend to be focused on the irrigated dry season rather than the monsoon season. Studies comparing methods which could be used over both a humid and a semi-arid or arid area were not common.

3.5.5.1 Arid Regions

A comparison of ET methods under extremely arid conditions was conducted by Salih and Sendil (1984) in central Saudi Arabia. Lysimeter measurements for alfalfa were compared to ET estimates calculated with Jensen-Haise, Modified Penman, Class A Pan, Hargreaves, Penman, SCS Blaney-Criddle, FAO Blaney-Criddle and a local version of the Blaney-Criddle equation. The Jensen-Haise and Class A Pan methods were ranked first and second, respectively, although the authors were not confident of the validity of the pan evaporation measurements. The Hargreaves method was ranked third, while the Modified Penman method was ranked fourth[1]. The Blaney-Criddle methods were ranked lowest, with the local version of the Blaney-Criddle equation resulting in the least accurate estimate.

Although the Jensen-Haise method produced the most accurate estimates, ET_{JH} underestimated $ET_{alfalfa}$ by as much as 20%. The authors recommended adjusting ET_{JH}, based on the results of their work and earlier work in the same area as follows:

$$ET_{alfalfa} = 1.16\ ET_{JH} - 0.37 \qquad \textbf{[Eq. 9]}$$

Saeed (1986) conducted a similar study in the same region of central Saudi Arabia from 1981-1983. In this study, the SCS Blaney-Criddle, FAO Blaney-Criddle, Jensen-Haise, Turc, Hargreaves (1974) and Pan Evaporation methods were investigated. The Jensen-Haise method provided a good estimate of ET during the October to March (winter) period, but underestimated ET during the summer months by as much as 33%. The Turc and Hargreaves methods resulted in fair estimates

[1] The version of the Penman equation was not indicated.

during the winter months, but also underestimated ET during the summer period. Both versions of the Blaney-Criddle method underestimated ET throughout the year.

An evaluation of minimal data ET methods in Arizona was reported by Samani and Pessarakli (1986). The Jensen-Haise, Modified Jensen-Haise, Hargreaves (1974), Hargreaves-Samani (1982; 1985), Modified Penman (Hansen et al, 1980) and SCS Blaney-Criddle, Class A Pan were compared. The authors ranked the methods in descending order as follows: Hargreaves, Pan, Hargreaves-Samani, Penman, Jensen-Haise and Modified Jensen-Haise, and SCS Blaney-Criddle. While the Hargreaves, Pan and Hargreaves-Samani methods were within 1% of the actual ET, the SCS Blaney-Criddle method underestimated ET values by 21%.

The ET comparison study conducted by Al-Sha'lan and Salih (1987) in central Saudi Arabia is the most comprehensive report on the estimation of ET in an arid area. Twenty-three empirical methods were compared, over two 12 month periods, using 5 different rating criteria. The Jensen-Haise, class A pan, Ivanov, adjusted class A pan, Behnke-Maxey and Stephens-Stewart methods were ranked one to six respectively using a combined rating criteria. The Makkink, local Blaney-Criddle (described by Salih and Sendil, 1984), SCS Blaney-Criddle, Turc, and Ostromecki and Oliver methods resulted in the least accurate estimates, respectively.

3.5.5.2 Semi-Arid Regions

A comparison of ET estimation methods in the flat central plains of the Sudan was reported by Hussein and El Daw (1989). The Jensen-Haise, Hargreaves, FAO-Penman and FAO-Class A evaporation pan methods were selected for comparison against actual evapotranspiration data. . The Hargreaves method produced reasonable estimates. The Jensen-Haise and FAO-Class A pan methods overestimated ET; the FAO Penman method, uncorrected and corrected versions, resulted in an underestimation of ET. Use of the original Penman (1948) wind function in the FAO-Penman equation resulted in a more accurate estimate of ET. The application of the correction factor developed by Frevert et al. (1983), further improved the estimate.

3.5.5.3 Combination studies - Arid and Humid Climates

Allen (1986) reported on the variations of the Penman combination equation and evaluated the performance of each form over a 3 year period. The evaluation included arid (Kimberly, Idaho) and humid (Coshocton, Ohio) locations, as well as a Mediterranean climate (Davis, California). The 1982 Kimberly Penman performed well in the arid area for which it was developed, with good results from the FAO corrected Penman and Penman-Monteith methods. The Penman-Monteith, 1963 Penman and Priestly-Taylor methods all produced reasonable estimates at the humid site. The Penman-Monteith, and FAO Corrected Penman performed well at all 3 locations; the Penman-Monteith produced the most consistent results between the 3 locations. The 1982 Kimberly-Penman produced good results in both the arid and humid areas when ET estimates were adjusted downward to convert from alfalfa to grass.

4.0 Methods and Materials

4.1 Data

Climatic data for the Chambal Command area is collected at several weather stations throughout the watershed. Data collected at the Kota station was used for this study as it is the closest station to the Daglawada test plot. The method of data collection was determined by the weather station in Kota, based solely on the local need for weather information. The author had no input into the method of collection or the level of detail recorded.

4.1.1 Data assumptions

The data obtained from the Kota station in Rajasthan, India posed some problems. Within the climatic data, there is no distinction between true zero values and zero as a missing value. It is not known whether this lack of distinction is due to faulty record-keeping at the station, or if the problem was introduced when the paper records were entered into database/spreadsheet software at the station. As access to the original paper records was not possible, assumptions as to when a zero value was reasonable were necessary in order to analyze the data (Appendix C).

In addition, some of the measures were entered in error. All climatic values were subjected to a reasonableness test, and obvious errors were corrected (Appendix C).

4.1.2 Analysis Limitations

Measurements of such climatic data as minimum and maximum humidity, sunshine hours and wind speed were routinely taken only in some years. In addition, measurements for an entire month or more within those years were neglected. As a result, many calculations are based on a single month's data, even though 24 years of data were collected.

Rainfall data for 1981 and 1982 have been excluded from all rainfall modelling, effective rainfall and water balance calculations. The rainfall data for the Kharif season months of these years is incomplete. The data has been included in evapotranspiration calculations, and general climatic information where possible.

The analysis is further limited by the lack of detailed data. Rainfall was recorded once every 24 hours, without detail as to the pattern of rain throughout the day. It is therefore impossible to determine whether the rain fell continuously over 24 hours, or whether there were one or more short duration rain storms. Throughout this thesis, daily recorded rainfall is assumed to have occurred as one continuous storm over a 24 hour period.

4.2 Programming and calculations

All necessary programs were written in the SAS programming and procedural language contained in BASE SAS for Windows, version 6.10. Statistical analyses were completed using both BASE and STAT SAS, version 6.10. Some data was summarized in Microsoft Excel for Windows, version 6.0. A complete set of programs is available from the Bio-Resource Engineering Program, Department of Chemical and Bio-Resource Engineering, the University of British Columbia.

The programs require a minimum of a 386 DX personal computer with 8 mb of ram, with Windows 3.1 or higher, BASE and STAT SAS for Windows, version 6.08 or higher. A 486 computer with 16 mb of ram provides better processing times. With minor modifications, the programs can be run in a main frame environment.

4.3 Rainfall Modelling

Rainfall modelling was conducted over the monsoon season months only. The emphasis is on 1-4 day rainfall depths due to its significance in subsurface drainage design.

4.3.1 Characteristics of the monsoon season

The monsoon season was characterized through a number of measures. All measures were based on a portion of the Kharif season between a defined start and end date, referred to as the model monsoon season.

The start of the season was defined as the first June rainfall of at least 0.1 mmd^{-1}. The first rainfall in June of 5.0 mmd^{-1} or more was also determined for comparison purposes.

The annual monsoon cycle was defined as the time between the start of two subsequent model monsoon seasons.

The end of the season was defined as the date on which total rainfall from the start of the season reached 90% of the yearly total. The 90% cut-off was a consistent measure that allowed for comparison between years. It was based on the average percentage of annual rainfall recorded during June through September for the Chambal Command area (Appendix B).

The length of the monsoon season was defined as the period between the start and end of the model monsoon season.

Days within the model monsoon season, with at least 0.1 mm of recorded rain were considered rain days.

Persistence was evaluated using a cumulative departure from the mean model monsoon season rainfall. This allowed for the determination of independence between successive monsoon seasons, or alternatively, the recognition of trends.

4.3.2 Markov chain analysis

The suitability of a first-order, two state Markov chain analysis to predict the daily probability of rainfall over the Kharif season months of June to September was examined. The model monsoon season period was not considered suitable for this analysis, as it is biased toward wet day sequences due to the definition of the start and end dates.

The probability of rainfall on a given day was based solely on the occurrence or non-occurrence of rain on the previous day. Wet days were defined as those which recorded a minimum of 0.1 mm of rain, and were assigned a value of 1. All other days were considered dry days, and were assigned a value of 0.

Fixed intervals of 5 and 10 days and 1 month were selected for evaluation. A transition probability matrix for each month of the Kharif season, and for 10 and 5 day fixed intervals within each month was calculated. Intervals ending on the 31st day of July and August were included in the preceding 5 and 10 day interval periods. The number of wet-wet, wet-dry, dry-dry and dry-wet sequences for each interval were summed over all years of data, providing corresponding P_{11}, P_{10}, P_{00} and P_{01} matrix values for the interval:

$$P_{11} = \frac{\text{number of occurrences of } X(t) = 1 \text{ and } X(t\text{-}1) = 1}{\text{total number of occurrences of } X(t) = 1} \quad \textbf{[Eq. 10]}$$

$$P_{10} = \frac{\text{number of occurrences of } X(t) = 1 \text{ and } X(t\text{-}1) = 0}{\text{total number of occurrences of } X(t) = 1} \quad \textbf{[Eq. 11]}$$

$$P_{00} = \frac{\text{number of occurrences of } X(t) = 0 \text{ and } X(t\text{-}1) = 0}{\text{total number of occurrences of } X(t) = 0} \quad \textbf{[Eq. 12]}$$

$$P_{01} = \frac{\text{number of occurrences of } X(t) = 0 \text{ and } X(t\text{-}1) = 1}{\text{total number of occurrences of } X(t) = 0} \quad \textbf{[Eq. 13]}$$

where $X(t)$ is the represents the state (wet = 1, dry = 0) of day t in the interval.

Stationarity over each interval and between years was evaluated. Variation in the values of P_{00}, P_{01}, P_{11} and P_{10} within the interval, was used as an indication of stationarity over the interval. For each of the years (1970 - 1980, 1983-1993) the probability values over 5 day intervals were calculated and compared.

The occurrence of each combination of wet and dry days, over 3 and 4 days within the interval, was predicted from the transition probability matrix. More than 1 day preceding the last day of the sequence was assumed not to influence the outcome. For example:

Predicted (wet-dry-dry-wet) = Actual (wet-dry-dry) P_{01} **[Eq. 14]**

and Predicted (dry-wet-dry-wet) = Actual (dry-wet-dry) P_{01} **[Eq. 15]**

where Predicted is the number of occurrences of the bracketed combination of wet and dry states over a 4 day period within the interval, recorded over all years; Actual is the observed number of occurrences of the bracketed combination of wet and dry states over a 3 day period within the interval, recorded over all years; and P_{01} is the probability of occurrence of a wet state preceded by a dry state, calculated over all years for the interval.

A chi-square test of independence was used to verify the assumption that the probability of rain was not dependent on more than 1 preceding day. Two levels of significance, 5 and 10% were used to evaluate independence. The interval with the best fit of actual to predicted 3 and 4 day wet and dry state combinations was selected as the most appropriate for Markov chain analysis in this region of India.

The results of the Markov chain analysis were verified against each of the years of available rainfall data (1970-1980, 1983-1993). For each year, the predicted and actual 3 and 4 wet and dry state combinations for the selected interval were compared. The transition probability matrix generated from all years of data for the selected interval was applied to each year. A chi-square test of independence with 5 and 10% levels of significance was used to evaluate the results.

4.3.3 Daily rainfall modelling

The rainfall depth distribution over 1-4 day periods from June to September were determined. Moving totals of daily recorded rainfall were used to determine the 2-4 day rainfall depths.

Missing rainfall data within a 1-4 day period resulted in the exclusion of that period from the analysis. All periods were recorded in the month in which in the period ended.

4.3.4 Rainfall event modelling

An event-based model for rainfall pattern and distribution was developed from rainfall event depth and duration, and interarrival times. The model was applied to the model monsoon season rather than to the months of June through September. The inclusion of 90% of the monsoon season rainfall within the model monsoon season, ensures that all relevant events are included in the model. It also eliminates the introduction of extraordinary interarrival times resulting from the departure of the monsoon rains prior to September.

4.2.4.1 Model definition

Rainfall events were defined as consecutive days of rainfall, while interarrival times were defined as the consecutive dry days between rainfall events. Missing values in the data collected at the Kota station were treated as the end of a rainfall event or dry day sequence. Events were reported on the date in which they ended.

Events were characterized by rainfall depth and event duration. In addition, the rainfall depth of each day over the event was examined for pattern.

Probability distribution functions were fitted to sample data wherever possible.

4.2.4.2 Threshold rainfall values

Two event-based models were developed with different rainfall threshold values. The first model included all successive days with at least 0.1 mm of rain as part of a rainfall event. The second model defined a rainfall event as successive days with 5.0 mm or more recorded rain.

The selection of 5.0 mm of rain was considered the threshold for significant rainfall, given that evaporation rates meet or exceed 5.0 mmd^{-1} throughout the Kharif season. The start of the model monsoon season for the 5.0 mm threshold model was set to the first day in June with 5.0 mm or more recorded rainfall.

4.2.4.3 Model assumptions

Event-based modelling assumes the rainfall events in the monsoon season are part of a random process. The parameters describing the monsoon season, and the rainfall events throughout the season are therefore assumed to be independent.

The assumption of independence was tested using a correlation analysis. Relationships between the monsoon season measures and between the event-related measures were examined.

Successive rainfall events and interarrival times were each subjected to a pairwise correlation to ensure independence.

4.4 Frequency analysis

For each analysis, the sample data were ranked and exceedence and non-exceedence values determined from the Weibull formula (Appendix D). The Weibull formula was selected as it is suitable to both the Gumbel and Log Pearson Type III distributions.

The Gumbel and Log Pearson type III probability distributions were selected as they are the most commonly used distributions for hydrologic data. The equations for both distributions are contained in Appendix D. The Gumbel probability distribution curve was constructed from the sample moments for the data series. The frequency factor method was used to determine the Log Pearson Type III probability distribution curve. Values with return periods of 2, 3, 4, 5, 10, 15, 25 and 50 years were determined from the equation for each curve.

The standard normal variable (z) and reduced variate were used to linearize the graph for the Log Pearson Type III and Gumbel distributions, respectively. The logarithms of the data were plotted against the Log Pearson Type III probability distribution.

The fit of the distribution to the sample data was judged graphically to ensure that extraordinary values did not bias the distribution. More weight was given to the fit of the curve against data values with non-exceedence values of 0.900 or less, representing a return period of 10 years. Values for each return period were selected from the curve providing the best fit to the data.

4.4.1 Normal rainfall

A complete duration data series was generated for each month of the Kharif season for total rainfall depth, and number of rain days. An annual rainfall series was also generated from the available data.

A data series for each of the daily, 0.1 and 5.0 event models was generated for rainfall depths over 1-4 days for the Kharif season.

4.4.2 Extreme rainfall

The maximum daily rainfall for each year was compared to the total annual rainfall to determine if an annual exceedence series was more appropriate than an annual maximum series. With the exception of 2 years with less than 500 mm of rain, each of the years had maximum rainfall depths in excess of 75 mmd^{-1} (Appendix B). An exceedence series would draw heavily from the years with more than 1000 mm of rain if a threshold value of 75 mmd^{-1} were applied. An extreme value series was therefore considered to be more representative of the years of available data.

A single maximum and minimum rainfall depth over 1-4 days from the daily model, and the 0.1 and 5.0 mm threshold event-based models, were selected for each year. For the daily model, minimum values were selected from rainfall depths of greater than 0.0 mm.

4.4.3 Design storm

Depth-duration-frequency curves and intensity-duration-frequency curves were constructed from the results of the extreme value analysis for 1-4 day rainfall from the daily and event-based models. A set of curves for return periods of 2, 5 10, 15 and 25 years were generated from the Gumbel probability distribution. Straight lines were drawn through the values to allow for extrapolation and.

4.4.4 Wet and dry year rainfall

Wet and dry year rainfall was calculated from maximum and minimum daily rainfall over the Kharif season. The rainfall contribution from months outside the Kharif season was not considered.

The pattern of rainfall throughout the Kharif season indicates that rainfall does not occur on every day. The number of rain (wet) days for the season was determined from the results of the Markov chain analysis. The interval for which the wet and dry day sequences predicted by the Markov chain most closely fit the actual sequences was selected. For each interval the number of rain days was calculated as follows:

$$\text{\# of rain days} = P(X(t) = 1)\ (\text{\# of days in interval}) \qquad \textbf{[Eq. 16]}$$

where $P(X(t) = 1)$ is the probability of occurrence of a wet day within the interval calculated over all available years of data.

Daily rainfall depths from the extreme value analysis for the 0.1 mm threshold event model were assumed to have occurred on each rain day. The rainfall depths with return periods of 5 and 10 years were selected from the best-fit probability distribution.

Wet year rainfall was calculated using the maximum daily rainfall depth with return periods of 5 and 10 years. Dry year rainfall was calculated from the minimum daily rainfall depth. In each case, the total rainfall depth for each month of the monsoon season was calculated as follows:

$$\text{Monthly rainfall} = \sum [(\text{rainfall depth})\ (\#\ \text{of rain days})] \qquad \textbf{[Eq. 17]}$$

where the monthly rainfall is the sum of total rainfall for each interval within the month; rainfall depth is the maximum or minimum daily rainfall value generated from the extreme value analysis; and the # of rain days is calculated from the probability of rain within a given interval.

4.5 Evapotranspiration calculation method

Based on the results of other studies in semi-arid and arid environments, several ET estimation methods were selected (Table 7). The ET formula for each method is contained in Appendix E. In addition, an adjusted version of the Modified Jensen-Haise method (1.15 adjustment factor) was evaluated.

Table 7 Selected Evapotranspiration Estimation Methods

Type of method	Method	Reference crop	Time period[1]
Combination	Penman (1963)	Grass	Daily
	Kimberly-Penman (1972)	Alfalfa	Daily
	Kimberly-Penman (1982)	Alfalfa	Daily
	FAO-24 Penman (c=1)	Grass	Daily
	FAO-24 Corrected Penman	Grass	Daily
	Penman-Monteith	Alfalfa	Daily
Radiation	FAO-24 Radiation Method	Grass	5 days
	Modified Jensen-Haise	Alfalfa	5 days
Temperature	FAO Blaney-Criddle	Grass	5 days
	Hargreaves, 1985	Grass	10 days
Pan Evaporation	Christiansen	Grass	Monthly
	FAO Pan	Grass	5 days

[1] Minimum recommended time period (ASCE, 1990)

4.5.1 Time period

Although the combination methods were designed to estimate ET on a daily basis, the radiation, temperature and pan evaporation methods are limited in their ability to estimate ET over short periods of time. For each of these methods, ET estimates were calculated over the minimum recommended time periods (Table 7).

Moving averages based on 5 and 10 day periods were calculated wherever 5 or 10 days of consecutive climatic values were recorded. Monthly averages were based on all climatic data for each month over the 1970-1993 time period.

4.5.2 10 day moving and fixed averages

In the field, both farmers and researchers find it easier to calculate 10 day fixed, rather than moving average values for ET calculations.

Ten day averages of temperature, humidity, wind speed, sunshine hours, and solar radiation were calculated using each of the two methods. Fixed 10 day averages were calculated on the 10^{th}, 20^{th} and 30^{th} of each month. Moving averages were generated over each consecutive 10 day period with recorded climatic data. A correlation analysis of the monthly average of each measure using fixed and moving average values was completed on the irrigated months of November to February, inclusive.

4.5.3 Crop coefficients

Grass reference crop coefficients were selected for the typical crops grown in the Chambal Command Area (Appendix L). They were selected over alfalfa reference coefficients owing to the availability of coefficients for the crops grown in the Chambal Command area. A conversion factor of 0.85 for alfalfa to grass reference ET was applied.

4.5.3.1 Crop Development Stages

Initial, development, mid-season and late season crop development stages, as defined by Doorenbos and Pruitt (1977), were determined. The length of some crop stages were adjusted, based on the actual growing season length reported by Chieng (1993). Stage lengths were also compared against those reported by Subramaniam (1989) for Maharastra, India, wherever possible.

4.5.3.2 Crop Coefficients for each development stage

For each crop development stage, an appropriate grass reference crop coefficient (k_c) was selected. Coefficients for the initial crop stage were based on the curves relating initial k_c to the interval between significant rainfall or irrigation and grass reference ET published by Doorenbos and Pruitt (1977). The k factors for fallow land were determined from the same curves.

Reference ET from the selected methods were averaged to give a single ET_{grass} for each month. Significant rainfall was assumed to be 5.0 mmd^{-1} for the Kharif season. Interarrival times from the 5.0 mm threshold event model with a probability of occurrence of 70% were selected for each month (Table 15). The interval between irrigation water applications in the Rabi season is 20 days (Chieng, 1993).

Crop coefficients for the mid-season and last season (end) stages were taken from published tables (Doorenbos and Pruitt, 1977). Development stage and late season stage coefficients were calculated as follows, based on the procedure for the development of a crop coefficient curve described by Doorenbos and Pruitt (1977):

$$k_c \text{ development stage} = k_c \text{ mid-season} - k_c \text{ initial} \quad \textbf{[Eq. 18]}$$

$$k_c \text{ late season stage} = k_c \text{ mid-season} - k_c \text{ late season (end)} \quad \textbf{[Eq. 19]}$$

4.5.4 Seasonal ET requirements for selected crops

For each of the crops for which lysimeter data was available, a seasonal ET value was calculated. Soybean, sorghum and groundnut, grown in the Kharif season represent 74.26% of the sown area[2]. Wheat, mustard and gram, grown in the Rabi season represent 86.72% of the sown area.

The actual sowing date for each crop as reported by Chieng (1993) was used as the start of the initial stage. The length of each development stage was converted into a number of days per month, and the grass reference ET for that month was multiplied by the appropriate coefficient. The seasonal ET value for each crop was then summed over the 4 development stages.

4.5.5 Comparison of estimated seasonal ET with lysimeter data

Seasonal ET_c measurements were calculated over all years of available data. For some of the methods, the necessary information was present only in 1 year. $ET_{lysimeter}$, for crops other than wheat and sorghum, was based on 2 - 3 years of lysimeter measurements. Comparisons were not necessarily made between the same years.

The variation reported in ET_c between 2 different periods for wheat and sorghum indicates that 2 - 3 years of data may not accurately reflect average ET_c requirements. Lysimeter measured ET_c for sorghum was 717.90 mm for 1982-83, whereas the 1978-1983 average was 548.70 mm. Lysimeter measurements for wheat varied between 414.30 and 527.10 mm for the same two periods (Chieng, 1993).

Estimated seasonal ET_c for the selected crops were compared with actual seasonal $ET_{lysimeter}$ to determine the most appropriate ET estimation method. The results were ranked according to the ratio of estimated ET_c to $ET_{lysimeter}$ for each crop, the crops of each season, and all of the crops.

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[2] The sown area excludes fallow land of 44.06% and 4.43% in the Kharif and Rabi seasons respectively.

Both a weighted and unweighted ratio was calculated to rank the ET methods over all of the crops within each season. The methods were also ranked using unweighted and weighted ratios of ET_c totalled over the crops of both seasons. The weighting factor was based on the percentage of crop grown, assuming 100% of the area was sown (Figure 5).

4.5.6 Pan evaporation coefficient

Reference ET was calculated from available data using the most appropriate ET estimation method. A comparison of pan evaporation rates and $ET_{r,}$ was used to determined a suitable coefficient to convert evaporation to $ET_{r,}$ for each month.

Coefficients were based on the ratio of pan evaporation to ET_r adjusted to eliminate the effect of extraordinary values.

4.5.7 Crop water requirements for the Daglawada test plot

4.5.7.1 Generalized crop coefficient

A set of generalized crop coefficients for each season was determined for the calculation of ET_c for the Daglawada test plot. Based on the generalized cropping pattern of the Chambal Command area (Figure 5), and crop information (Appendix L), an average weighted coefficient and length for each development stage was determined (Table 10). A set of coefficients was also determined for various proportions of dry crop to rice.

A general sowing date was selected for each season, based on the date by which at least 60% of the crops are sown. July 8th and November 1st were selected as the start of the growing season for the Kharif and Rabi seasons, respectively. The general sowing date for the Rabi season was moved from October 12th, at which point the majority of the crops were sown, to November 1st to eliminate overlap between Kharif and Rabi crops.

4.5.7.2 Seasonal ET_c

Some farmers in this area are planting rice during the monsoon season (Chieng, personal communication). As the k_c values for rice are much higher than those for other Kharif crops except during the mid-season development stage, this practice can dramatically increase the crop ET requirement. Therefore, a number of values of seasonal ET_c based on 0 - 100% rice were estimated for the Daglawada test plot.

4.6 Effective rainfall

Effective rainfall was calculated for normal Kharif season rainfall, and for the 1 in 5 and 1 in 10 wet years. All rainfall during a dry year is assumed to be effective.

The USDA-SCS formula was used in the calculation of effective rainfall (Section 3.4.2.2.2). Normal depth of depletion prior to rainfall was assumed to be 75 mm. Soils were assumed to be well-drained, assisted by sub-surface drainage system. ET_c was calculated using ET_{pan} values and the generalized crop information for the Daglawada test site.

A comparison of the USDA-SCS effective rainfall with the 70% method for India (Section 3.4.2.2.2) was completed to determine if such a method would be suitable for broad planning purposes.

4.7 Water balance

A simple water balance over the monsoon period was completed to determine the drainage coefficient. Rainfall amounts in excess of ET_c or ET_{soil} were assumed to recharge the groundwater. The soil profile was assumed to be dry at the start of the Kharif season.

A water balance was completed over the interval used in the calculation of the 1 in 5 and 1 in 10 wet and dry years, using effective rainfall. Normal effective rainfall depths were also examined. ET_c was calculated from ET_{pan} values and the generalized crop information for each interval.

4.7.1 Leaching requirement

The leaching requirement for average soil salinity conditions was determined for the irrigated season using the conventional method:

$$LR = EC_w / (5 (EC_e) - EC_w) \quad \textbf{[Eq. 20]}$$

where LR is the minimum leaching requirement with surface irrigation, EC_w is the salinity of the applied irrigation water in dSm^{-1}, and EC_e is the average soil salinity tolerated by the cop.

The depth of water necessary to meet both ETc and the leaching requirement on an annual basis was determined using the following equation:

$$AW = (ET_c - rain)/ (1 - LR) \quad \textbf{[Eq. 21]}$$

where AW is the depth of applied water (mm/year), ET_c is the total annual crop water requirement (mm/year), rain is the amount of rainfall (mm) and LR is the leaching fraction.

The electrical conductivity of the Irrigation water (E_C) is 0.3 dSm^{-1}. Average salinity tolerance was based on the most sensitive crops, giving an EC_e of 2.0 dSm^{-1} at a 90% yield potential.

5.0 Discussion of results

5.1 Rainfall modelling

5.1.1 Characteristics of the monsoon season

The monsoon season begins suddenly in June and tapers off in October. In 55 % of the years of recorded monsoon rainfall, the first rainfall was between the 1st and the 9th day of June. With the exception of 1 year, the start of the monsoon occurred prior to the 15th of June. In many years (36.36%), the first rainfall event was of less than 5 mm, with a subsequent event of 5 mm or more within 1 to 6 days (Appendix F).

The annual cycle, the time between the onset of successive monsoon seasons, ranges from 354 to 383 days In 70% of the recorded years, the length of the annual monsoon cycle is between 360 and 370 days, inclusive (Appendix F).

The end of the model monsoon season was defined as the date on which accumulated monsoon rainfall reached 90% of annual rainfall. In 68.1% of the years, the model monsoon season ended on or before the 23rd of September. By October 20th, a further 22.7% of the years had reached 90% of the monsoon rainfall (Appendix F).

The length of the model monsoon season, measured as the number of days between the start and end of the model monsoon season, varied from 58 to 169 days. A length of 80 and 100 days, was recorded in 50 % of the years from 1970 - 1993 (Appendix F).

Significant variation was evident in the number of days with more than 0.1 mm of recorded rainfall. Between 24 and 57 days of rainfall were recorded within the model monsoon season. In 55% of the years, less than 40 days of rainfall occurred, with more than 50 rain days recorded in 9% of the years examined between 1970 - 1993(Appendix F).

A degree of persistence is evident in the monsoon rainfall. The cumulative departure from the mean rainfall indicates that the monsoon rainfall from year to year is not independent (Appendix F). Trends of greater and less than average rainfall over 5 - 6 years, for the model monsoon season, appear throughout the period of 1970 to 1993. The length of record is insufficient to indicate a long-term pattern. In addition, the lack of rainfall information in 1981 and 1982 makes it difficult to be certain of the length of trend between 1978 and 1986.

5.1.2 Markov chain analysis

5.1.2.1 Transition probability matrix

The number of wet and dry days within each month varies over the Kharif season, resulting in significantly different monthly transition probabilities. The probability of a wet-wet sequence (P_{11}) varies from 0.426 in June to 0.687 in August (Table 8).

The transition probabilities calculated over 5 and 10 day periods varied significantly within each month (Table 8). This variation indicates non-stationarity over monthly intervals, making a single

Table 8 Wet and dry day classification and transitional probability, by preceding day, by month

Period	Interval	Transitional Probability	
		P_{11}[a] (Range)	P_{01}[b] (Range)
June	month	0.426	0.147
	10 day	0.267- 0.515	0.079 - 0.240
	5 day	0.176 - 0.600	0.043 - 0.241
July	month	0.663	0.260
	10 day	0.560 - 0.750	0.208 - 0.303
	5 day	0.550 - 0.830	0.178 - 0.310
August	month	0.687	0.303
	10 day	0.654 - 0.743	0.256 - 0.356
	5 day	0.647 - 0.797	0.208 - 0.380
September	month	0.571	0.123
	10 day	0.429 - 0.634	0.063 - 0.254
	5 day	0.273 - 0.700	0.040 - 0.371

[a] P_{11} = probability of wet - wet sequence occurrence
[b] P_{01} = probability of dry - wet sequence occurrence

transition probability matrix for each month unsuitable. The wide range of values in the 5 day interval transition probability matrix indicates non-stationarity over 10 day periods.

5.1.2.2 Stationarity over 5 day intervals

The transition probabilities for some successive 5 day intervals, most notably P_{11} over the period from July 25 to August 25, exhibit a near stationary trend (Figure 7). In the month of June, the probabilities vary significantly, becoming more consistent toward the end of the month. The trend is consistent with the onset of the monsoon rains in early June. Similarly, the non-stationary transition probability trend over the month of September is consistent with diminishing monsoon rains.

Varying degrees of stationarity is evident in the transition probabilities within 5 day intervals. The trend is similar to that exhibited by successive 5 day periods. However, during the months of June and September probabilities are more consistent, especially with respect to dry-wet and dry-dry sequences.

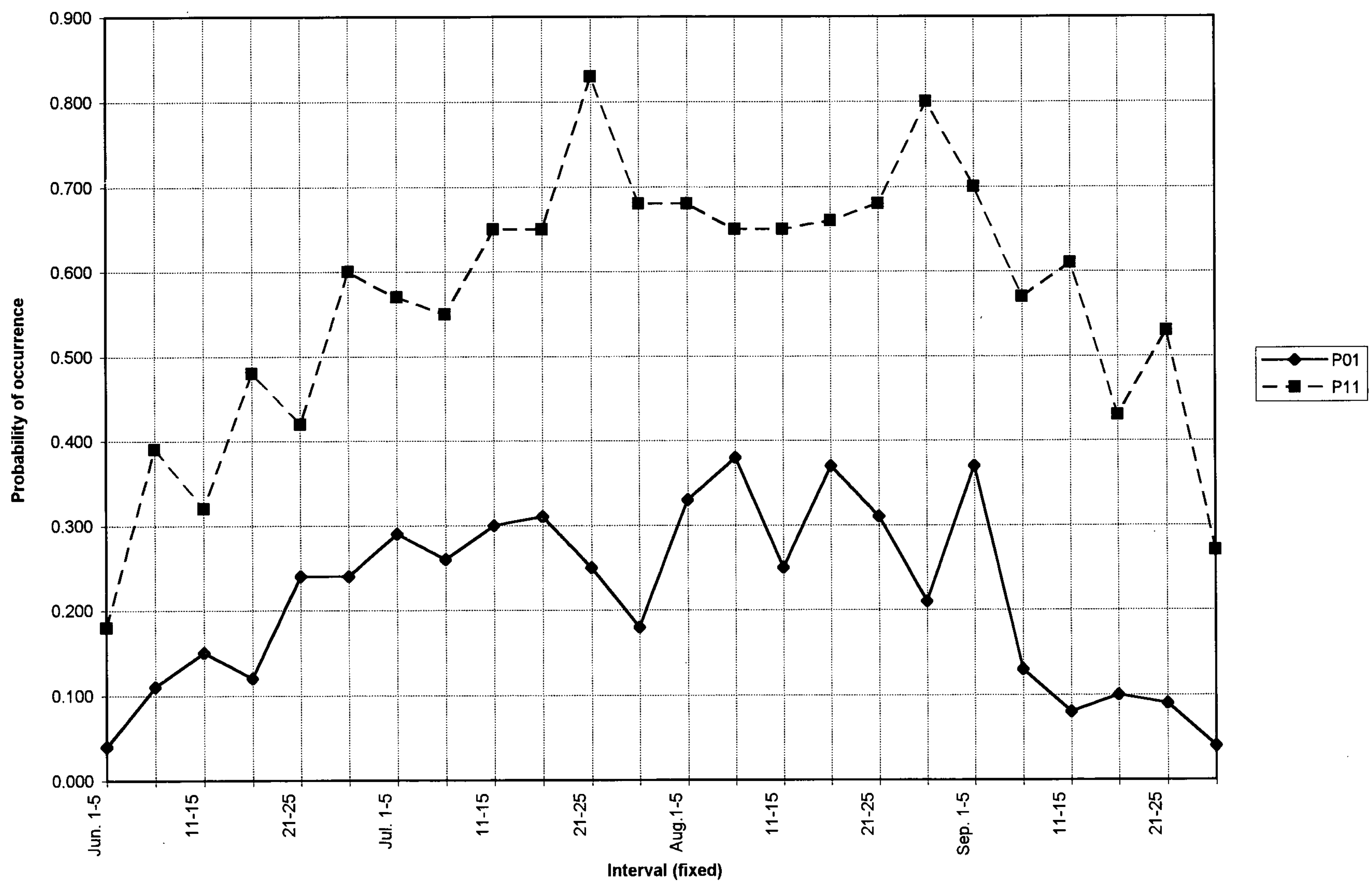
The 5 day transition probability matrix for each year does not exhibit stationarity. The probability values range from 0.0 to 1.0 in each interval throughout the season, regardless of the month (Appendix G). This result is consistent with the pattern of drought and flood conditions from year to year experienced in semi-arid and arid monsoonal areas.

5.1.2.3 Actual vs. predicted 3 and 4 day wet-dry sequences

5.1.2.3.1 Results over all years

Use of the monthly transition probability matrix in the calculation of 3 and 4 day wet-dry sequences resulted in poor prediction of actual wet and dry day sequences. The chi-square test of independence of rain on the second preceding day was not significant at the 5 and 10% level. Rain was independent of the second and third preceding days, at 5% significance for only September (Table 9).

Figure 7   5 day interval transition probability



A reasonable prediction of actual wet and dry day sequences resulted from the application of a separate transition probability matrix to each 10 day interval. The chi-square test of independence of rain on the second preceding day was significant at the 5 and 10% levels in 75 and 58.3% of the intervals, respectively . At the 5 and 10% significance levels, the probability of rain was independent of the second and third preceding days, in 66.7 and 75% of the intervals.(Table 9).

The 5 day interval transition probability matrix provided the best predictions of actual wet and dry day sequences. The percentage of intervals found to be independent of the second preceding day at both the 5 and 10% significance level, was 83.3 and 75 %, respectively. The percentage increased slightly to 87.5 and 79.2% in the test of independence on the second and third preceding days. In all months but September, the 5 day interval transition probability matrix met or exceeded the results of the 10 day interval analysis (Table 9).

Table 9 Independence of rainfall probability on more than 1 preceding day, by month

Month	Interval[1]	Percentage of the interval for which Chi-squares were significant			
		Independent of second preceding day[2] (%)		Independent of second and third preceding days[3] (%)	
		P=5%[4]	P=10%[5]	P=5%	P=10%
June	month	0.0	0.0	0.0	0.0
	10 day	66.7	66.7	66.7	66.7
	5 day	83.3	66.7	83.3	83.3
July	month	0.0	0.0	0.0	0.0
	10 day	66.7	0.0	66.7	66.7
	5 day	66.7	66.7	83.3	66.7
August	month	0.0	0.0	0.0	0.0
	10 day	66.7	66.7	100.0	66.7
	5 day	100.0	100	100.0	83.3
September	month	0.0	0	100.0	0.0
	10 day	100.0	100.0	100.0	100.0
	5 day	83.3	66.7	83.3	83.3
Total	month	0.0	0.0	75.0	0.0
	10 day	75.0	58.3	66.7	75.0
	5 day	83.3	75.0	87.5	79.2

[1] Fixed intervals

[2] $H_o = P(x_t|x_{t-1},x_{t-2}) = P(x_t|x_{t-1})$; χ^2 with 2 d.f.

[3] $H_o = P(x_t|x_{t-1}, x_{t-2}, x_{t-3}) = P(x_t|x_{t-1})$; χ^2 with 6 d.f.

[4] χ^2 at 5% significance

[5] χ^2 at 10% significance

5.1.2.3.2 Results of yearly analysis

The 5 day interval transition probability generated from rainfall occurrences recorded in all years provided reasonable predictions of actual wet and dry day sequences in the Kharif season for each year. Dependence on the annual rainfall was not evident. The percentage of intervals independent of the second preceding day ranged from 50.0 to 87.5% at the 10% significance level. The percentage increased slightly to 70.8 to 100.0% at the 10% significance level in the test of independence on the second and third preceding days (Table 10).

Table 10 Independence of rainfall probability on more than 1 preceding day, by year

Annual rainfall, sorted (mm)	Year	Percentage of the 5 day intervals for which Chi-squares were significant			
		Independent of second preceding day[1] (%)		Independent of second and third preceding days[2] (%)	
		P=5%[3]	P=10%[4]	P=5%	P=10%
309.10	1972	87.5	70.8	100.0	95.8
469.10	1987	84.5	75.0	100.0	91.7
561.10	1980	87.5	79.2	100.0	100.0
562.10	1989	83.3	79.2	95.8	87.5
574.00	1979	91.7	83.3	100.0	100.0
634.00	1992	75.0	75.0	91.7	79.2
640.50	1983	62.5	54.2	91.7	83.3
656.10	1990	66.7	58.3	79.2	70.8
681.80	1970	79.2	75.0	91.7	87.5
713.82	1993	75.0	62.5	87.5	87.5
722.70	1991	95.8	87.5	95.8	95.8
724.30	1984	83.3	75.0	95.8	91.7
725.40	1985	83.3	66.7	95.8	91.7
791.30	1986	83.3	75.0	100.0	100.0
804.50	1973	75.0	54.2	87.5	87.5
848.80	1988	70.8	58.3	83.3	79.2
900.10	1976	70.8	70.8	95.8	83.3
986.70	1977	79.2	70.8	87.5	83.3
991.60	1978	75.0	58.3	91.7	87.5
1011.00	1975	79.2	66.7	83.3	83.3
1294.00	1974	91.7	79.2	91.7	91.7
1506.80	1971	54.2	50.0	79.2	70.8

[1] $H_o = P(x_t|x_{t-1},x_{t-2}) = P(x_t|x_{t-1})$; χ^2 with 2 d.f.
[2] $H_o = P(x_t|x_{t-1}, x_{t-2}, x_{t-3}) = P(x_t|x_{t-1})$; χ^2 with 6 d.f.
[3] χ^2 at 5% significance
[4] χ^2 at 10% significance

5.1.3 Daily rainfall modelling

5.1.3.1 1 day rainfall depths

Over a 24 hour period, rainfall depths in excess of 100 mm are recorded during the months of June through October (Table 2). The maximum 24 hour rainfall depth recorded at the Kota station is 174.00 mm occurring in July, 1970 (Appendix B). In both July and September, 3% of the daily rainfall depths exceeded 100 mm, with 1% of the 1 day rainfall in June in excess of this magnitude (Table 11).

Daily rainfall depths of less than 10 mm are the most common throughout the Kharif season. At the start of the active monsoon period, 86% of the daily rainfall is less than 20 mm, with a further 7% of the rainfall depths between 20 and 50 mm. During July and August, daily rainfall of more than 20 mm becomes more common, with 20% of the depths recorded at 20 to 50 mm. This trend continues into September, with rainfall depths of between 20 and 50 mm occurring over 14% of the month (Table 11 and Appendix H).

5.1.3.2 2 day rainfall depths

The distribution of precipitation over 2 day intervals in June, is very similar to the 1 day rainfall depths for that month. The majority of the 2 day rainfall depths (80%) are less than 20 mm, with 91% of the month recording rainfall depths of 40 mm or less (Table 11).

September also shows a similar pattern in its 1 and 2 day rainfall depths. Depths of less than 20 mm account for 66% of the 2 day rainfall totals with 50 mm or less rainfall over 89% of the month (Table 11).

During the months of July and August, the number of 2 day rainfall depths of 20 mm or less falls to 55%. Two day rainfall depths of less than 70 mm and 60 mm account for 90% of July and August, respectively. In each of these two months, 10% or more of the 2 day rainfall depths are greater than 60 mm, with 4% of the depths exceeding 100 mm (Table 11 and Appendix H).

5.1.3.3 3 day rainfall depths

The majority of 3 day rainfall depths in June were less than 30 mm (85%), with only 9% of the depths totalling more than 50 mm. Similarly, 3 day depths in September were predominantly less than 30 mm (75%), with 12% of the total depths in excess of 50 mm (Table 11).

At the height of the monsoon, approximately 24% of the 3 day rainfall depths exceed 50 mm. Rainfall depths in excess of 100 mm over a 3 day interval occur over 8 and 6% of July and August, respectively (Table 11).

5.1.3.4 4 day rainfall depths

During the month of June, 70% of the 4 day rainfall depths are less than 20 mm in magnitude. As with 3 day intervals for this month, 90% of the 4 day rainfall depths are less than 50 mm (Table 11).

The distribution of rainfall over four day intervals in September, also shows a trend similar to that exhibited over 3 day intervals. The majority of the 4 day rainfall depths (75%) fall below 30 mm, with 26% of the depths recorded between 30 and 70 mm (Table 11).

During the months of July and August, 4 day rainfall depths of less than 20 mm decrease by approximately 50% as compared to June. In July, 90% of the depths are less than 110 mm, with 29% of those exceeding 50 mm. Similarly, 90% of the 4 day depths in August are less than 100 mm, with 35% of those exceeding 50 mm (Table 11, and Appendix H).

Table 11 **1 - 4 day rainfall depth, Kharif season (1970-1993)**

Month	1-4 day rainfall frequency, categorized by depth (mm)																# of intervals [2]
	<10[1]	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120-130	130-140	140-150	>150	
1 day depth																	
Jun.	0.58	0.28	0.04	0.02	0.01	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	136
Jul.	0.50	0.18	0.12	0.07	0.04	0.01	0.01	0.01	0.01	0.02	0.01	0.00	0.01	0.00	0.00	0.01	297
Aug.	0.52	0.19	0.10	0.07	0.04	0.02	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	335
Sept.	0.55	0.22	0.08	0.03	0.03	0.03	0.02	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	147
2 day depth																	
June	0.51	0.29	0.07	0.04	0.01	0.01	0.03	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	214
July	0.38	0.17	0.14	0.10	0.06	0.02	0.03	0.02	0.02	0.02	0.01	0.00	0.01	0.00	0.00	0.02	397
Aug.	0.37	0.18	0.13	0.09	0.07	0.06	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.01	440
Sept.	0.45	0.21	0.13	0.07	0.03	0.03	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	210
3 day depth																	
Jun.	0.45	0.29	0.11	0.04	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	271
Jul.	0.29	0.16	0.14	0.11	0.07	0.04	0.03	0.02	0.03	0.02	0.02	0.01	0.00	0.01	0.00	0.04	457
Aug.	0.28	0.15	0.14	0.11	0.08	0.08	0.04	0.04	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	501
Sept.	0.39	0.21	0.13	0.10	0.05	0.03	0.02	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.03	259
4 day depth																	
Jun.	0.40	0.30	0.09	0.07	0.03	0.03	0.02	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.01	318
Jul.	0.23	0.15	0.13	0.12	0.08	0.05	0.03	0.03	0.03	0.02	0.03	0.01	0.00	0.01	0.01	0.06	498
Aug.	0.23	0.11	0.14	0.10	0.07	0.09	0.06	0.05	0.02	0.03	0.02	0.01	0.01	0.01	0.01	0.03	549
Sept.	0.34	0.21	0.13	0.09	0.07	0.03	0.03	0.04	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.03	299

[1] rainfall depths of 0.1 mm or more

[2] total number of 1-4 day moving intervals with more than 0.1 mm of total rain, totalled from 1970 - 1993 for each month; 2-4 day intervals starting in 1 month and ending in another, are reported in the month of last day of the interval

5.1.4 Rainfall event analysis

5.1.4.1 Randomness of events

The number of rainfall events is independent of all other parameters in the model, with the degree of independence varying with the definition of a rain day. Pairwise relationships between current and preceding rainfall event duration, rainfall depth and interarrival times were not evident (Table 12).

A weak relationship between total monsoon rainfall depth and the number of rain days exists for rainfall 0.1 mm or more. The number of rainfall events and the length of the monsoon season also exhibits a weak relationship. A significant correlation is apparent between the total number of dry days and the maximum interarrival time (Table 12).

Rain days defined by a threshold value of 5.0 mm show a weak relationship with the total monsoon rainfall. The length of the monsoon season and the maximum interarrival time is also characterized by a weak relationship. A significant correlation is evident between the total number of dry days and the maximum interarrival time (Table 12).

The results indicate the assumption of randomness with respect to the events of the monsoon season is valid.

The correlation between the length of the monsoon season and the number of rain days is consistent with the definition of the monsoon season used in this model. A relationship between the duration of rainfall events and the total rainfall depth of that event is expected (Table 13). As the maximum interarrival time is expected to occur under drought conditions, a relationship between the number of dry days and the maximum interarrival time is expected.

Table 12 Correlation of model monsoon season characteristics, by threshold rainfall[1]

Characteristic	Number of rain days		Number of rainfall events		Maximum interarrival time		Length of annual cycle	
	≥0.1 mm	≥ 5.0 mm	≥0.1 mm	≥ 5.0 mm	≥0.1 mm	≥ 5.0 mm	≥0.1 mm	≥ 5.0 mm
Total monsoon rainfall depth (mm)	0.47	0.63	0.21	0.25	-0.15	-0.19	-0.07	-0.07
Length of the monsoon season (days)	0.37	0.27	0.47	0.09	0.65	0.52	-0.43	-0.42
Length of the annual cycle (days)	-0.08	-0.10	-0.36	-0.19	0.03	0.13	ni	ni
Total number of dry days (days)	0.15	0.33	0.31	0.23	0.89	0.93	-0.22	-0.05

Note: correlation measured by Pearson correlation coefficients
ni = not investigated

[1] threshold rainfall values of 0.1 and 5.0 mm as defined in the 2 event-based models

Table 13 Correlation of event-related characteristics, by threshold rainfall[1]

Characteristic	Rainfall depth of event (mm)		Duration of rainfall event (days)		Interarrival time (days)	
	≥ 0.1 mm	≥ 5.0 mm	≥ 0.1 mm	≥ 5.0 mm	≥ 0.1 mm	≥ 5.0 mm
Duration of rainfall event (days)	0.79	0.78	ni	ni	-0.10	-0.05
Interarrival time (days)	-0.06	-0.07	-0.10	-0.05	ni	ni
Duration of preceding rainfall event (days)	0.00	0.03	-0.01	0.03	-0.06	-0.07
Rainfall depth of preceding event (mm)	-0.02	0.09	0.00	0.03	ni	ni
Preceding interarrival time (days)	ni	ni	ni	ni	-0.03	-0.06

Note: correlation measured by Pearson correlation coefficients
ni = not investigated

[1] threshold rainfall values of 0.1 and 5.0 mm as defined in the 2 event-based models

5.1.4.2 Number of rainfall events

The distribution of the number of rainfall events per season is similar for both the 0.1 mm and 5 mm threshold models. In each case, between 10 and 16 rainfall events were recorded in approximately 55% of the model monsoon seasons. The distribution is described by a Poisson probability density function, with reasonable accuracy for both models (Appendix I, J). The Poisson density function is given by:

$$f_N(n) = (e - \lambda^n)/ n! \qquad \textbf{[Eq. 22]}$$

where λ is estimated by the mean number of rainfall events, e is the natural logarithm base and n is the total number of events.

5.1.4.2.1 Distribution of events within the season

Most of the events within the season occur at the height of the monsoon season, during the months of July and August. Approximately 63 - 65% of all events, regardless of duration or threshold rainfall definition, occur during this period. A further 20 - 23% of the events occur during the month of June (Table 14).

5.1.4.3 Duration of rainfall events

Rainfall events of 1 day in length are the most common, in both the 0.1 mm and 5.0 mm rainfall threshold models. This result is consistent with the general character of convective storms. However, longer periods of consecutive rain days occur throughout the season. The maximum rainfall event is 16 days, and 11 days for the 0.1 and 5.0 mm threshold models respectively (Appendix I, J).

The definition of a rain day using a 0.1 mm threshold results in approximately 82% of the events occurring over 4 days or less. The 5.0 mm threshold model results in 95.3% of the events occurring over 4 days or less. The probability of rainfall events of more than 2 days decreases significantly as the duration increases.

The duration of rainfall events was fitted to a geometric probability distribution function (pdf) given by:

$$f(j) = pq^{j-1} \quad \text{[Eq. 23]}$$

where *j* is the duration of the event in days, *p* is the probability of occurrence, and $q = 1-p$.

5.1.4.3.1 Event duration distribution

Events of more than 7 days occur only during the months of July and August, in both the 0.1 mm and 5.0 mm threshold models. One day events are the most common throughout the season, especially in June when they comprise 70 and 82% of all events in the 0.1 and 5.0 mm models, respectively. In July and August, 1-3 day events are commonly encountered. In September, 4-6 day events are common in the 0.1 mm threshold model (Table 14).

5.1.4.4 Rainfall depth

5.1.4.4.1 0.1 mm threshold model

5.1.4.4.1.1 1 day events

One day rainfall event depths of 5.0 mm or less, are common. More than 70% of all of the 1 day events in this model, are of less than 15 mm in depth (Appendix I).

5.1.4.4.1.2 2 day events

The most common total depths recorded for a 2 day event range between 0.1-10.0 mm and 20.0 - 25.0 mm (Appendix I).

Table 14 **Event duration distribution, by month**

Month	Event probability, categorized by event duration (days)								Total # of events[1]
	1	2	3	4	5	6	7	≥8	
0.1 mm threshold									
June	0.70	0.17	0.06	0.03	0.03	0.00	0.01	0.00	71
July	0.41	0.21	0.11	0.04	0.07	0.04	0.01	0.10	97
August	0.33	0.18	0.22	0.07	0.05	0.05	0.03	0.06	95
September	0.32	0.24	0.08	0.11	0.13	0.11	0.03	0.00	38
5.0 mm threshold									
June	0.82	0.02	0.07	0.00	0.00	0.00	0.00	0.00	60
July	0.53	0.28	0.09	0.01	0.04	0.02	0.01	0.02	102
August	0.52	0.23	0.14	0.08	0.02	0.00	0.01	0.00	96
September	0.54	0.32	0.03	0.05	0.05	0.00	0.00	0.00	37

[1] total number of events from 1970-1993 recorded for each month; events are reported in the month in which the event ends

Rainfall depths of less than 10.0 mm are recorded on each day of the event in approximately 50% of the events. Rainfall depths are not significantly different between the first and second day of the event (Appendix I).

5.1.4.4.1.3 3 day events

The total rainfall depths recorded over 3 day events exhibit significant variation. Approximately 28% of the events are in the range of 15.0 - 25.0 mm, however a substantial number of events have depths of 45.0 - 50.0 mm and 60.0 - 65.0 mm (Appendix I).

The rainfall depth is similar on the first 2 days of the event, tapering off slightly on the third day. Approximately 50% of the events have rainfall depths of less than 10 mm on each of the 3 days. The highest depths are commonly recorded on the second day of the event (Appendix I).

5.1.4.4.1.4 4 day events

Approximately 33% of the 4 day event depths occur within the ranges of 75.0 - 80.0 mm and 120.0 mm or more, using the 0.1 mm threshold. The distribution of rainfall depths varies between 5.0 mm to more than 120.0 mm (Appendix I).

The first 2 days of the event commonly receive less than 10.0 mm of rain. The rainfall depth increases over the third and fourth days, with more than 45% of the events recording rainfall depths of greater than 20 mm. Rainfall depths in excess of 50 mm occur in approximately 25% of the events on the last 2 days of the event (Appendix I).

5.1.4.4.2 5.0 mm threshold model

5.1.4.4.2.1 1 day events

Approximately 53% of all 1 day events have rainfall depths of 5.0 - 15.0 mm. Rainfall depths of 15.0 - 30.0 mm are recorded in a further 26% of these events (Appendix J).

5.1.4.4.2.2 2 day events

Approximately 39% 2 day event depths range between 20.0 - 35.0 mm, with a variable distribution over other depths. Depths of 85.0 mm to more than 120.0 mm are recorded in a significant number of events (Appendix J).

The rainfall depth over each of the 2 days is consistent, with depths of less than 20.0 mm commonly recorded (Appendix J).

5.1.4.4.2.3 3 day events

The 5.0 mm threshold model results in 3 day event depths which are more variable than the 0.1 mm model. A high proportion of events occur within various depth ranges from 35.0 - 65.0 mm to more than 120.0 mm (Appendix J)

Rainfall depths vary significantly over the 3 days of the event in the 5.0 mm threshold model. Rainfall depths of less than 15.0 mm are recorded on the first day in more than 60% of the events. On the second day of the event, rainfall depths of 20.0 - 40.0 mm are recorded in 30% of the events. The rainfall depth decreases slightly on the third day of the event, with approximately half of the days receiving less than 20.0 mm of rain (Appendix J).

5.1.4.4.2.4 4 day events

The most common rainfall depth, occurring in approximately 46% of the 5.0 mm threshold events, is 120.0 mm or more. The remaining events are included in equal proportions in a number of depth ranges (Appendix J).

The rainfall distribution over 4 day events in the 5.0 mm model, differs from that of the 0.1 mm model. The first and last days of the event commonly receive less than 15.0 mm of rainfall. During the second day of the event, rainfall depths of more than 30.0 mm are recorded in approximately 50% of the events. The highest daily rainfall depths are recorded on the second day of the event. On the third day, the rainfall depth tapers slightly, with approximately 50% of the events receiving between 10.0 and 25.0 mm of rain on that day (Appendix J).

5.1.4.4.3 Probability distribution function

A geometric probability distribution function (pdf) provides a general fit to the 1 day event depths. It does not however, account for the variable number of events with depths in excess of 40 mm.

The variable probability of 2 day event rainfall depths over a large range of values cannot be defined by a distribution function.

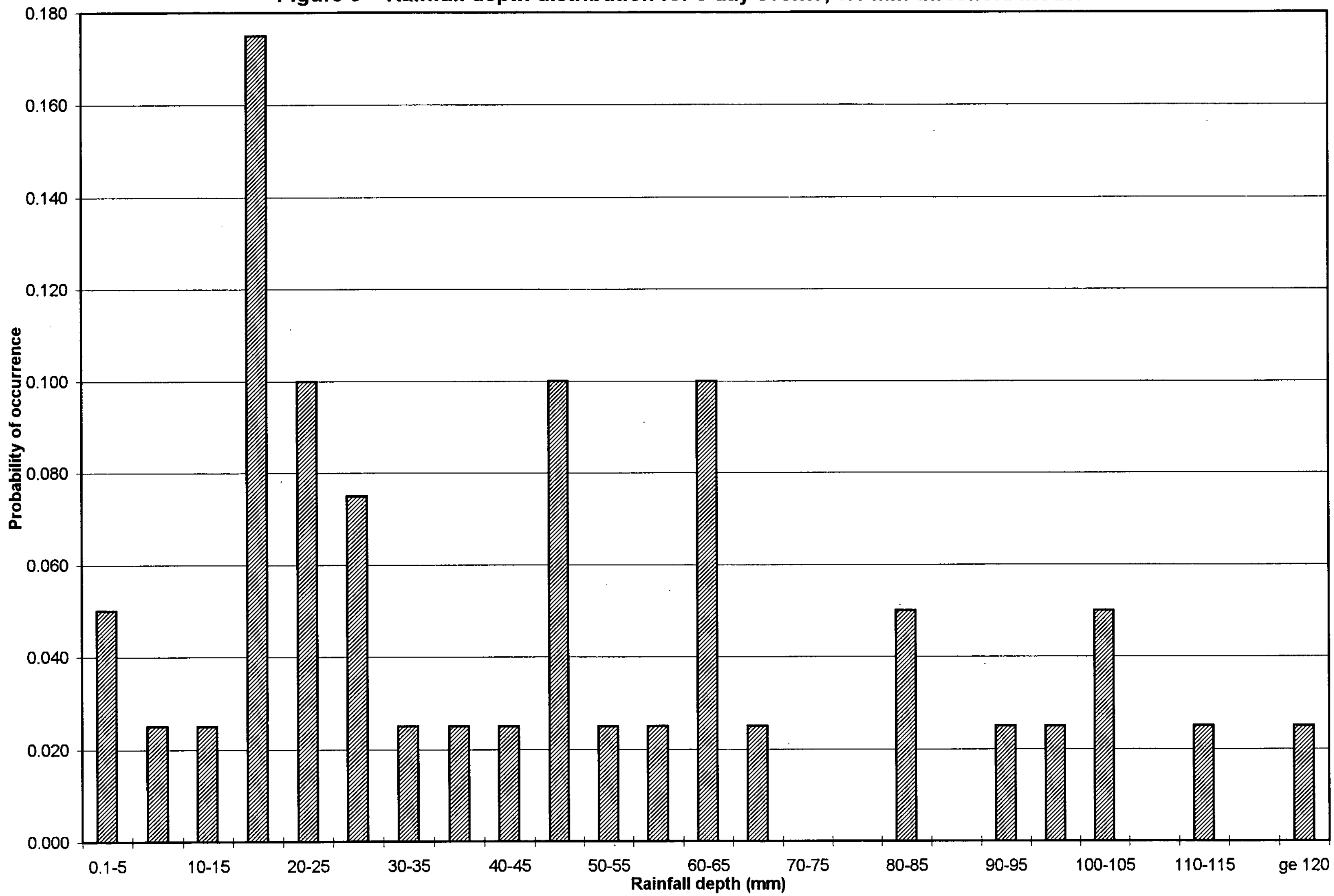
The 3 and 4 day events are also not adequately described by a pdf. The total rainfall depth is highly variable and near random in nature (Figure 8).

5.1.4.5 Rainfall event depth-duration probability

The relationship between rainfall depth and duration requires the consideration of the rainfall event duration probability in the determination of the most probable rainfall depth.

The conditional probability of rainfall event depth, indicates rainfall events of 1 day with a rainfall depth of less than 10.0 mm are the most common, using the 0.1 mm threshold. Similar results are obtained in the 5.0 mm threshold model (Appendix J).

Figure 8 Rainfall depth distribution for 3 day events, 0.1 mm threshold model



5.1.4.6 Rainfall Distribution

Throughout the Kharif season, rainfall events are interspersed with dry intervals, or interarrival time periods. Interarrival times of 1 - 2 days in length are common, although dry intervals of 15 days or more also occur within the model monsoon season (Appendix J). Interarrival times of more than 30 days may occur as the monsoon rains taper in September and October. Generally, interarrival times of this magnitude are reported as a result of the definition applied to the end of the model monsoon season.

The distribution of interarrival times between significant rainfall events does not vary significantly over the model monsoon season. Interarrival times during July are of 1 - 2 days in length more than half of the time. During June, August and September 3 day interarrival times are also common. Throughout the model monsoon season, approximately 70% or more of all interarrival times are of 5 days or less (Table 15).

5.1.4.7 Drought conditions

When the year is examined on a continuous basis, rather than by individual months, drought conditions over the 1970 - 1993 period emerge (Figure 9). The maximum sequence of dry days reached in a single year was 283 days which began in September of 1972. This 9 month interval without rain followed a model monsoon season in which only approximately 282 mm of rain was recorded (Appendix F).

5.2 Frequency analysis

5.2.1 Annual and monthly rainfall

The monthly rainfall data is more accurately modelled with the Log-Pearson Type III probability distribution. Although both methods provide similar rainfall values for return periods of less than 10 years, the Log Pearson Type III distribution gives a better estimate of rainfall amounts for higher return periods.

Table 15 **Interarrival time between significant rainfall events[1], within selected months**

Interarrival time (days)	June		July		August		September	
	#[2]	Cum. P.[3]	#	Cum. P.	#	Cum. P.	#	Cum. P.
1	10	0.26	32	0.32	25	0.26	14	0.38
2	8	0.46	21	0.52	17	0.44	3	0.46
3	7	0.64	9	0.61	14	0.58	2	0.51
4	0	0.64	5	0.66	6	0.65	4	0.62
5	0	0.64	9	0.75	8	0.73	3	0.70
6	3	0.72	2	0.77	5	0.78	1	0.73
7	1	0.74	3	0.80	4	0.82	1	0.76
8	1	0.77	4	0.84	1	0.83	0	0.76
9	2	0.82	2	0.86	4	0.88	2	0.81
10	2	0.87	0	0.86	1	0.89	2	0.86
11	1	0.90	2	0.88	0	0.89	1	0.89
12	0	0.90	1	0.89	3	0.92	1	0.92
13	1	0.92	2	0.91	2	0.94	1	0.95
14	1	0.95	1	0.92	0	0.94	0	0.95
15	2	1.00	0	0.92	1	0.95	0	0.95
> 15	0	1.00	8	1.00	5	1.00	2	1.00
Total	**39**		**101**		**96**		**37**	

[1] Significant rainfall events are defined as successive days of 5.0 mm or more rainfall

[2] Number of interarrival time periods (dry periods between rainfall events) recorded from 1970 - 1993 for each month

[3] Cumulative probability of occurrence of the specified interarrival time length

Figure 9 Maximum dry day sequences, by year

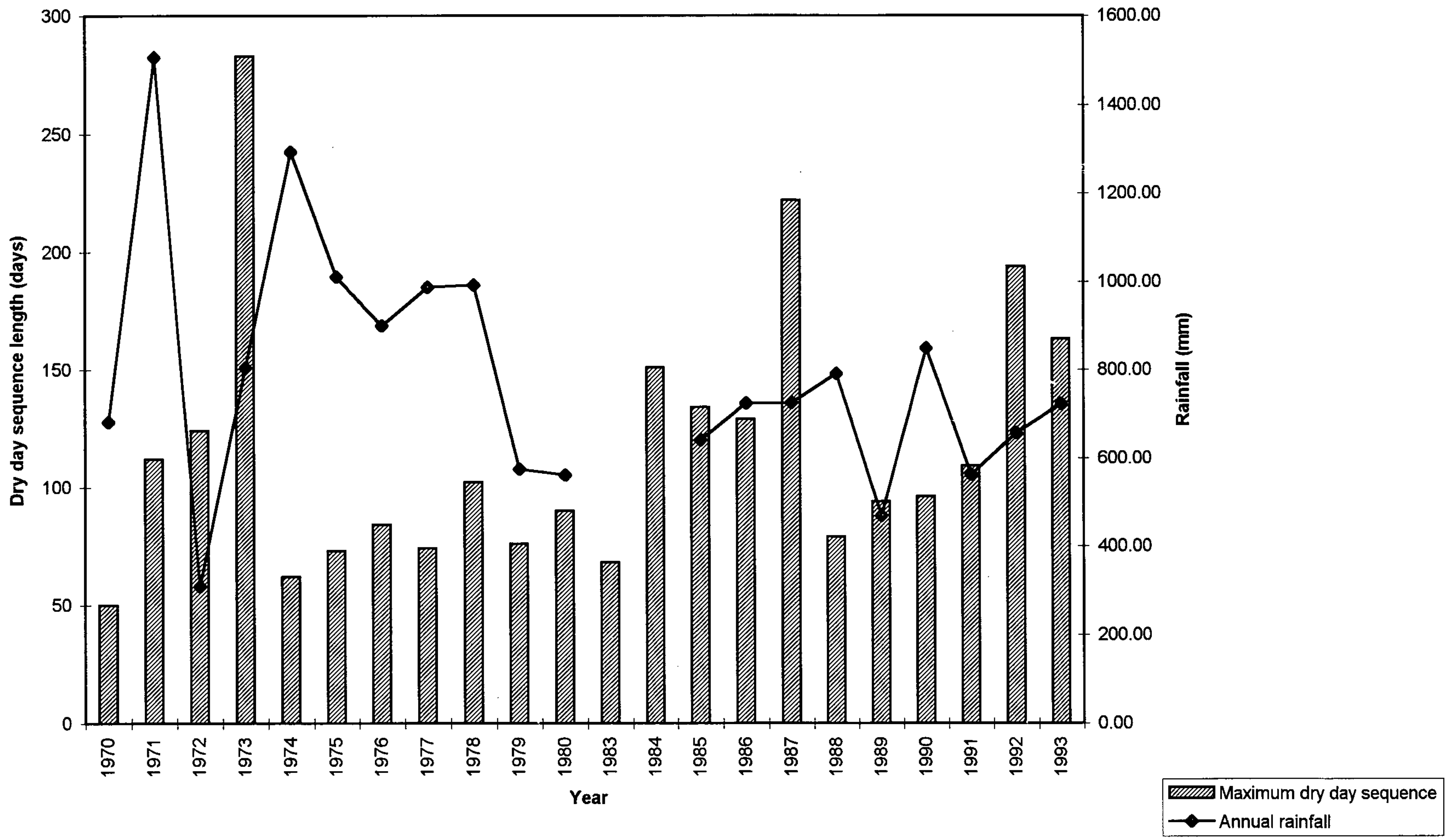


Table 16 Normal monthly rainfall and number of rain days

Return period (years)	Jun.[1]		Jul.[1]		Aug.[1]		Sept.[1]		Kharif season[2]	
	Total rainfall (mm)	# of rain days[4]	Total rainfall (mm)	# of rain days[4]	Total rainfall (mm)	# of rain days[4]	Total rainfall (mm)	# of rain days[4]	Total rainfall (mm)	# of rain days[4]
2	55.04	5.65	225.62	13.40	276.14	15.01	88.46	6.03	645.25	40.09
3	87.39	7.66	291.03	15.74	316.02	16.75	138.85	8.13	833.28	48.30
4	111.49	8.90	334.98	17.06	335.78	17.78	171.27	9.53	953.52	53.27
5	130.78	9.77	368.34	17.96	347.96	18.49	194.33	10.57	1041.41	56.79
10	193.51	12.09	470.17	20.22	374.33	20.42	254.64	13.63	1292.64	66.36
15	231.83	13.22	529.41	21.29	384.37	21.41	282.64	15.32	1428.25	71.24
25	281.42	14.45	604.36	22.43	393.40	22.54	311.37	17.38	1590.55	76.80
50	350.44	15.83	707.25	23.71	401.25	23.94	340.64	20.05	1799.58	83.52

[1] Frequency analysis of complete duration series of monthly rainfall and rain days;
[2] Monthly rainfall values from Log Pearson Type III distribution
[3] Kharif season = sum of Jun.-Sept. rainfall for given return period
[4] Monthly rain days (defined as days on which at least 0.1 mm of rain is recorded); values from Log Pearson Type III distribution

Table 17 Normal annual rainfall and number of rain days

Return period (years)	Annual[1]	
	Total rainfall (mm)[2]	# of rain days[3]
2	733.93	40.50
3	845.25	45.15
4	916.50	48.00
5	969.24	50.03
10	1125.03	55.76
15	1212.93	58.83
25	1321.88	62.49
50	1467.91	67.19

[1] Frequency analysis results of complete duration series of annual rainfall and rain days
[2] Annual rainfall; Values from Gumbel distribution
[3] Annual rain days (defined as days on which at least 0.1 mm of rain is recorded); Values from Log Pearson Type III distribution

Both the Gumbel and Log-Pearson Type III probability distributions provide a reasonable fit to the annual data series. However, for return periods of less than 10 years the Gumbel distribution provides a better estimate. Annual rainfall depths for return periods of more than 5 years are underestimated by both methods. As a result the total Kharif season rainfall calculated from monthly rainfall is higher than the annual rainfall for return periods of more than 5 years (Table 16, and Table 17).

5.2.2 Number of rain days

The Log Pearson Type III distribution provides the most reasonable fit to the number of rain days for both the monthly and annual data series. The number of rain days per month summed over the Kharif season results in higher values than the annual total number of rain days (Table 16 and Table 17).

5.2.2 Maximum and minimum 1-4 day rainfall depths

Maximum and minimum rainfall depths for each return period were selected from the Gumbel and Log Pearson Type III probability distribution curves, respectively. The fit of the curves was based primarily on 1 to 2 day rainfall depths as the sample data was the most reliable over this period for all three models.

Maximum and minimum rainfall depths for various return periods were significantly higher for the daily model than for the event-based models (Table 18 and Appendix K). The high daily rainfall depths result from 6 extraordinary values of more than 110.00 mmd^{-1}. Each of these rainfall depths occur within periods of 3 or more successive days of rain.

Results for 3 and 4 day rainfall depths for the 5.0 mm model are not reliable, due to a lack of data. In many years, 3 and 4 day rainfall events did not occur.

5.2.2.1 Normal 1-4 day rainfall depths

Normal rainfall depths for each return period were selected from the Gumbel probability distribution

Table 18 Comparison of maximum 1-4 day rainfall depths, various return periods

Return period (years)	Maximum rainfall depths (mm) categorized by event duration and model											
	1 day			2 day			3 day			4 day		
	Daily[i]	≥0.1 mm[ii]	≥5.0 mm[iii]	Daily	≥0.1 mm	≥5.0 mm	Daily	≥0.1 mm	≥5.0 mm	Daily	≥0.1 mm	≥5.0 mm
2	96.01	27.86	48.38	128.06	35.07	76.89	147.64	59.75	88.66	167.26	65.85	114.94
3	112.73	35.61	59.18	151.71	46.20	98.43	170.91	75.27	103.17	197.17	83.91	144.19
4	123.43	40.56	66.09	166.27	53.33	112.22	185.80	85.20	112.46	216.32	95.47	162.92
5	131.35	44.23	71.20	177.05	58.60	122.43	196.82	92.55	119.34	230.49	104.02	176.78
10	154.75	55.07	86.31	208.90	74.18	152.57	229.38	114.27	139.65	272.35	129.29	217.72
15	167.95	61.18	94:84	226.86	82.97	169.58	247.75	126.53	151.11	295.97	143.55	240.82
25	184.31	68.76	105.40	249.13	93.86	190.66	270.51	141.71	165.32	325.24	161.22	269.45
50	206.24	78.91	119.56	278.98	108.46	218.92	301.03	162.07	184.36	364.48	184.91	307.82

Note: all values from Gumbel extreme value probability distribution

Table 19 Comparison of normal 1-4 day rainfall depths, various return periods

Return period (years)	Normal rainfall depths (mm) categorized by event duration and model											
	1 day			2 day			3 day			4 day		
	Daily[i]	≥0.1 mm[ii]	≥5.0 mm[iii]	Daily	≥0.1 mm	≥5.0 mm	Daily	≥0.1 mm	≥5.0 mm	Daily	≥0.1 mm	≥5.0 mm
2	12.20	2.18	7.52	17.52	10.51	22.36	21.88	16.54	30.11	25.70	22.88	36.38
3	21.69	6.21	14.26	30.42	17.54	33.26	37.50	28.71	44.48	43.70	38.14	54.14
4	27.76	8.78	18.58	38.68	22.04	40.24	47.49	36.50	53.67	55.23	47.91	65.50
5	32.26	10.69	21.77	44.80	25.37	45.40	54.89	42.27	60.48	63.76	55.14	73.92
10	45.54	16.33	31.21	62.86	35.21	60.66	76.75	59.31	80.58	88.95	76.49	98.77
15	53.03	19.51	36.53	73.05	40.76	69.26	89.08	68.92	91.93	103.17	88.54	112.79
25	62.32	23.45	43.13	85.68	47.64	79.93	104.36	80.83	105.98	120.79	103.48	130.17
50	74.77	28.73	51.98	102.61	56.86	94.23	124.85	96.80	124.83	144.40	123.50	153.47

Note: all values from Gumbel probability distribution
[i] Daily rainfall model
[ii] 0.1 mm threshold event model
[iii] 5.0 mm threshold event model

curves, respectively. The fit of the curve was based primarily on 1 to 2 day rainfall depths as the sample data was the most reliable over this period for all three models.

Normal 1 day rainfall depths for various return periods calculated from the daily model were higher than from the event-based models (Table 19). The rainfall depths in the daily model are lower than the 5.0 mm event model over 2-4 days due to the inclusion of dry days in moving 2-4 day rainfall depths. In contrast, the 5.0 event-based model includes only those days on which rainfall in excess of the threshold value is recorded.

5.2.3 Design storm

Rainfall depth-duration-frequency curves for each of the models exhibit significantly different storm profiles (Appendix K).

The rainfall intensity for a return period of 5 years ranges from approximately 40 mm/hr from the daily model, to 10 mm/hr from the 0.1 mm model (Figure 10, Figure 11 ,Figure 12). Rainfall intensity of this magnitude would results in significant runoff given the slow to moderately slow permeability, characteristic of the soils in the Chambal command area (Table 5).

5.2.4 Wet and dry year rainfall

5.2.4.1 Probability of occurrence

The probability of occurrence of either the 1 in 5 or 1 in 10 year maximum daily rainfall depth (44.23 and 55.07mm, respectively) is less than 6.0%. The conditional probability of a 1 day event with rainfall depth of this magnitude is less than 2.0% (Appendix I).

The probability of occurrence of daily rainfall depths of 0.71 mm and 0.35 mm used in the 1 in 5 and 1 in 10 dry year calculations, is based on the probability of rainfall depths of less than 5.0 mm. The probability of occurrence of a 1 day event of this magnitude is 42.6%, with a conditional probability of 19.0% (Appendix I).

Figure 10 Rainfall intensity curves, daily model

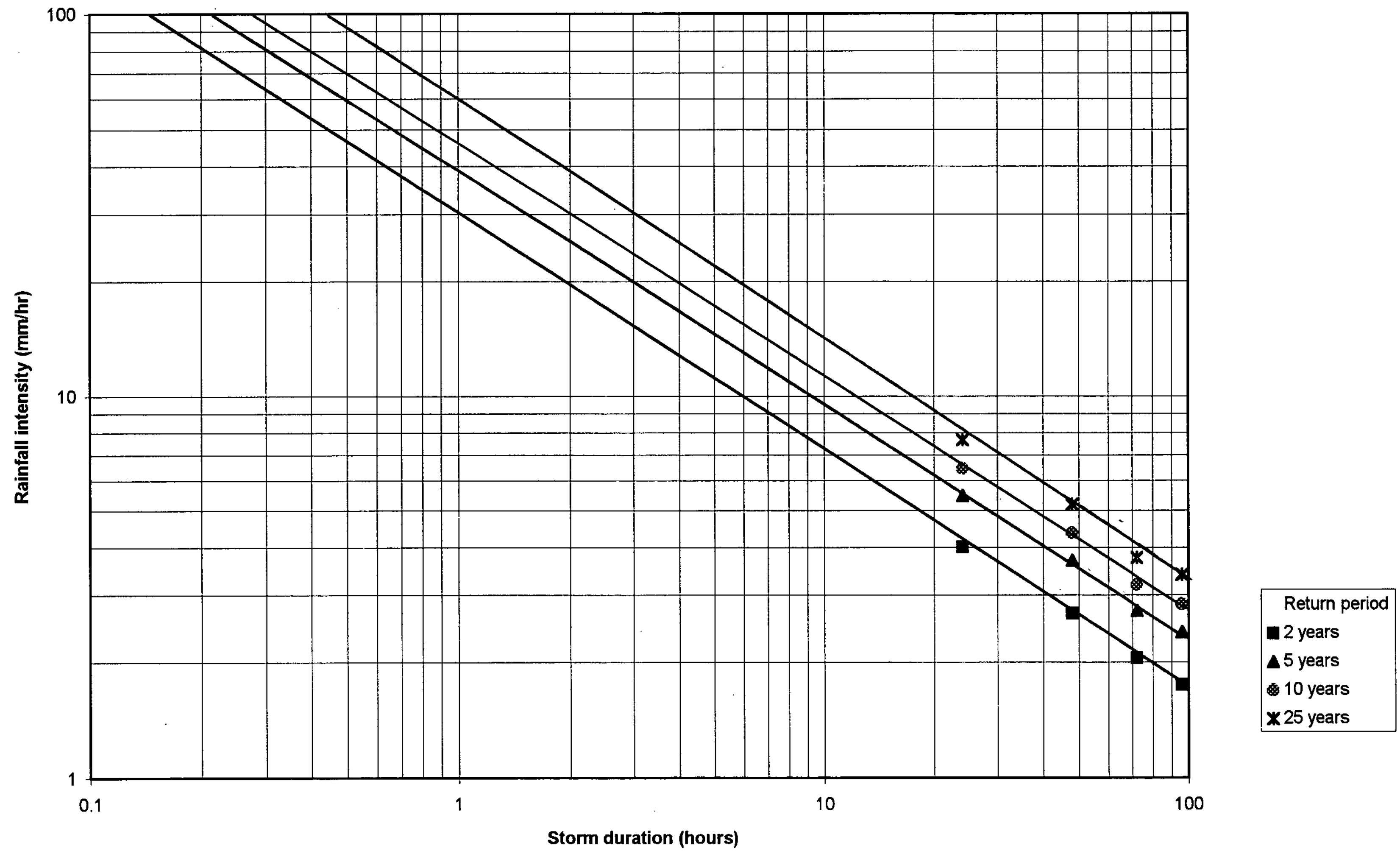


Figure 11 Rainfall intensity curves, 0.1 mm threshold model

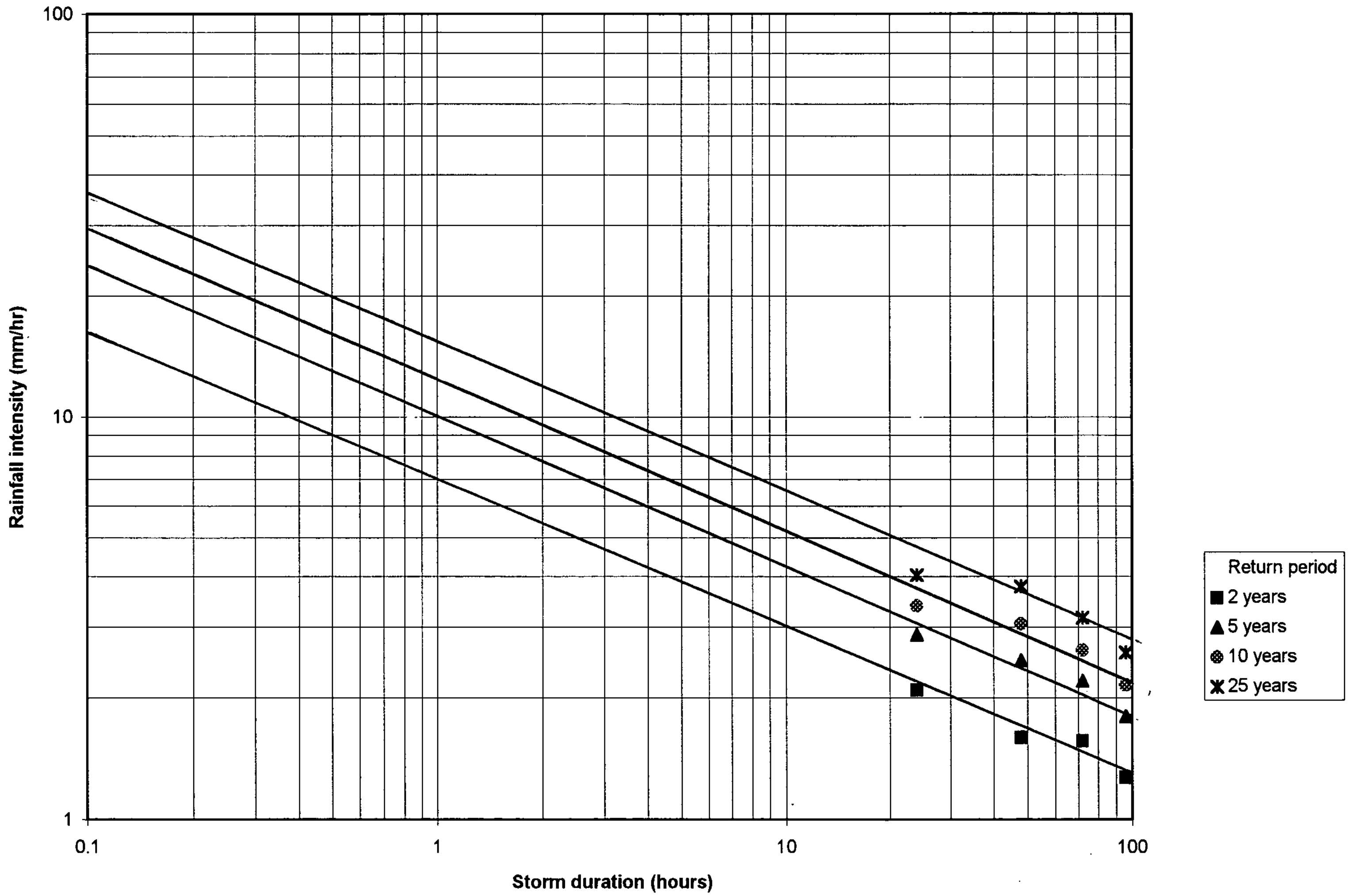
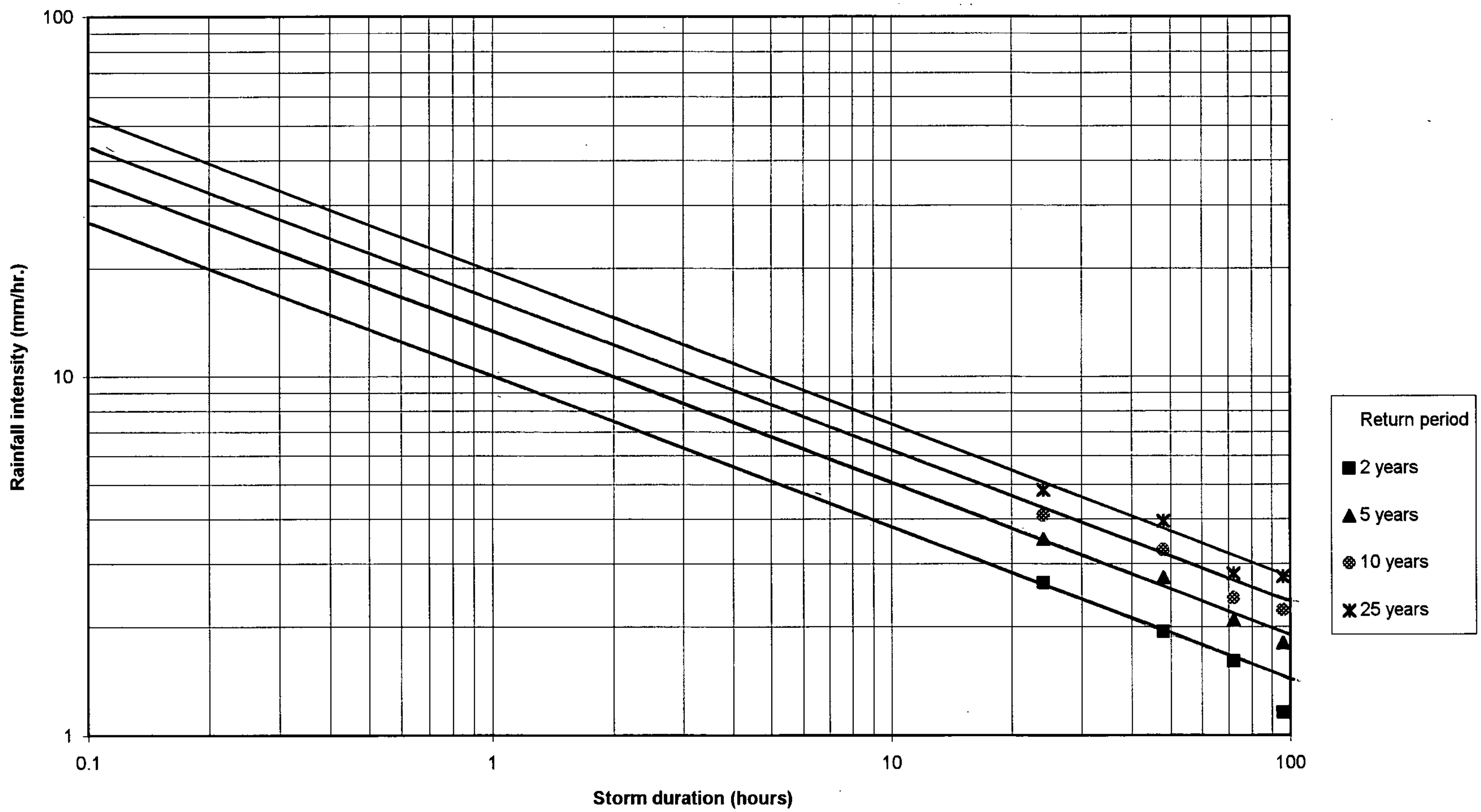


Figure 12 Rainfall intensity curves, 5.0 mm threshold model



A total of 44 days of rain for the Kharif season is generated from the probability of a wet day within 5 day intervals. This total is slightly higher than the 1 in 2 normal number of rain days (40.09) for the season (Table 16). The occurrence of 44 rain days during the Kharif season is therefore, very likely.

5.2.4.2 1 in 5 wet and dry year rainfall

The daily maximum rainfall depth based on the 0.1 mm threshold event model is 44.23 mm for a 5 year return period (Table 18). The daily minimum rainfall depth from the same model is 0.71 mm for a 10 year return period (Appendix K).

The 1 in 5 wet year seasonal rainfall of 1946.12 mm is more than 300% of the 1 in 2 normal seasonal rainfall (645.25 mm) (Figure 13 and Appendix K). It exceeds the highest recorded annual rainfall (1506.80 mm) by approximately 30%.

The 1 in 5 dry year Kharif season rainfall of 31.24 represents approximately 5% of the normal rainfall (Figure 13 and Appendix K). It represents approximately 10% of the lowest annual recorded rainfall of 309.10 mm.

5.2.4.3 1 in 10 wet and dry year rainfall

The daily maximum rainfall depth based on the 0.1 mm threshold event model is 55.07 mm for a 10 year return period (Table 18). The daily minimum rainfall depth from the same model is 0.35 mm for a 10 year return period (Appendix K).

The 1 in 10 wet year seasonal rainfall of 2423.08 mm is approximately 375% of the 1 in 2 normal seasonal rainfall (645.25 mm) (Figure 14 and Appendix K). It exceeds the highest recorded annual rainfall (1506.80 mm) by approximately 60%.

The 1 in 10 dry year seasonal rainfall of 15.40 is insignificant compared to normal rainfall (Figure 14 and Appendix K). It represents approximately 5% of the lowest annual recorded rainfall of 309.10 mm.

Figure 13 1 in 5 year rainfall, kharif season

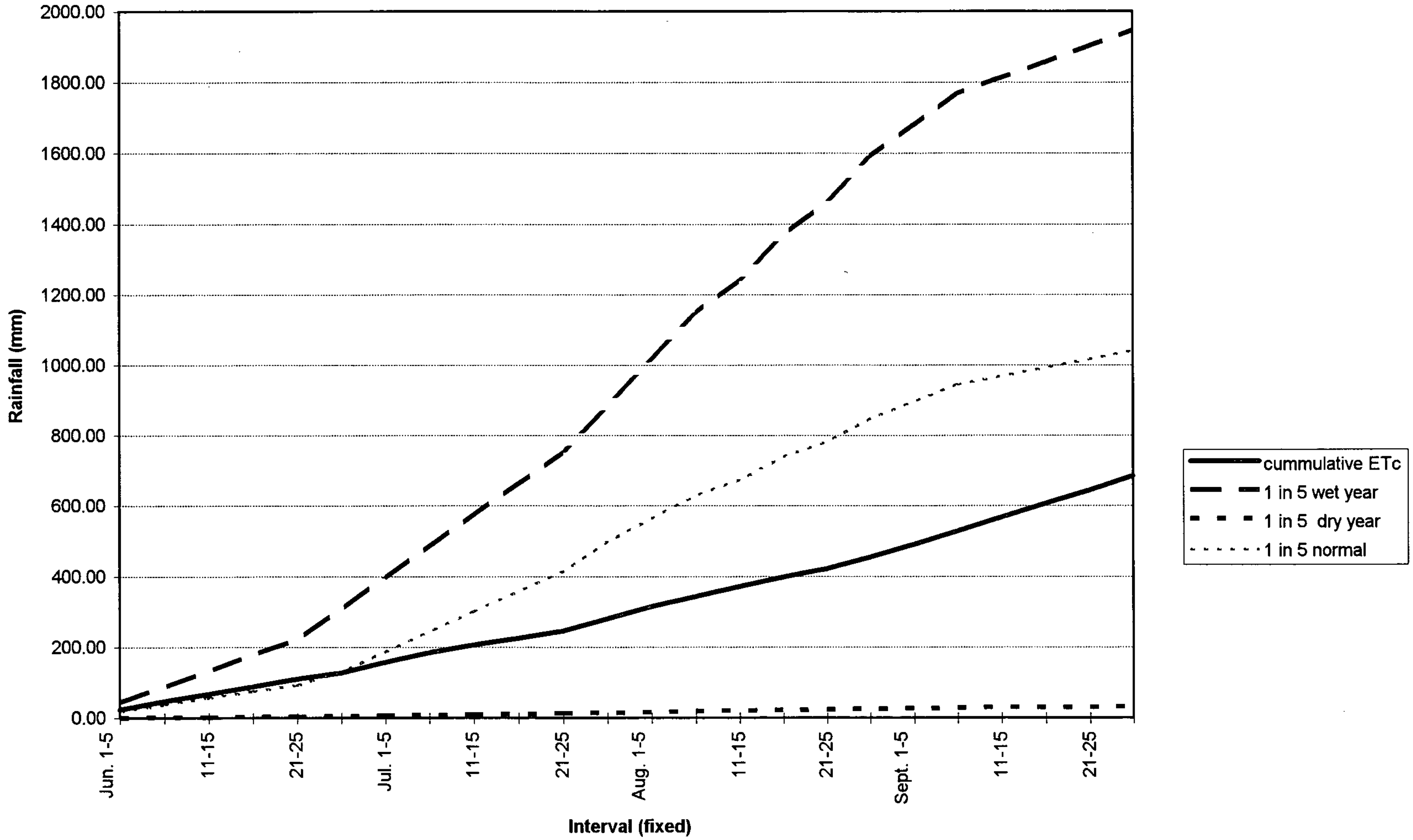
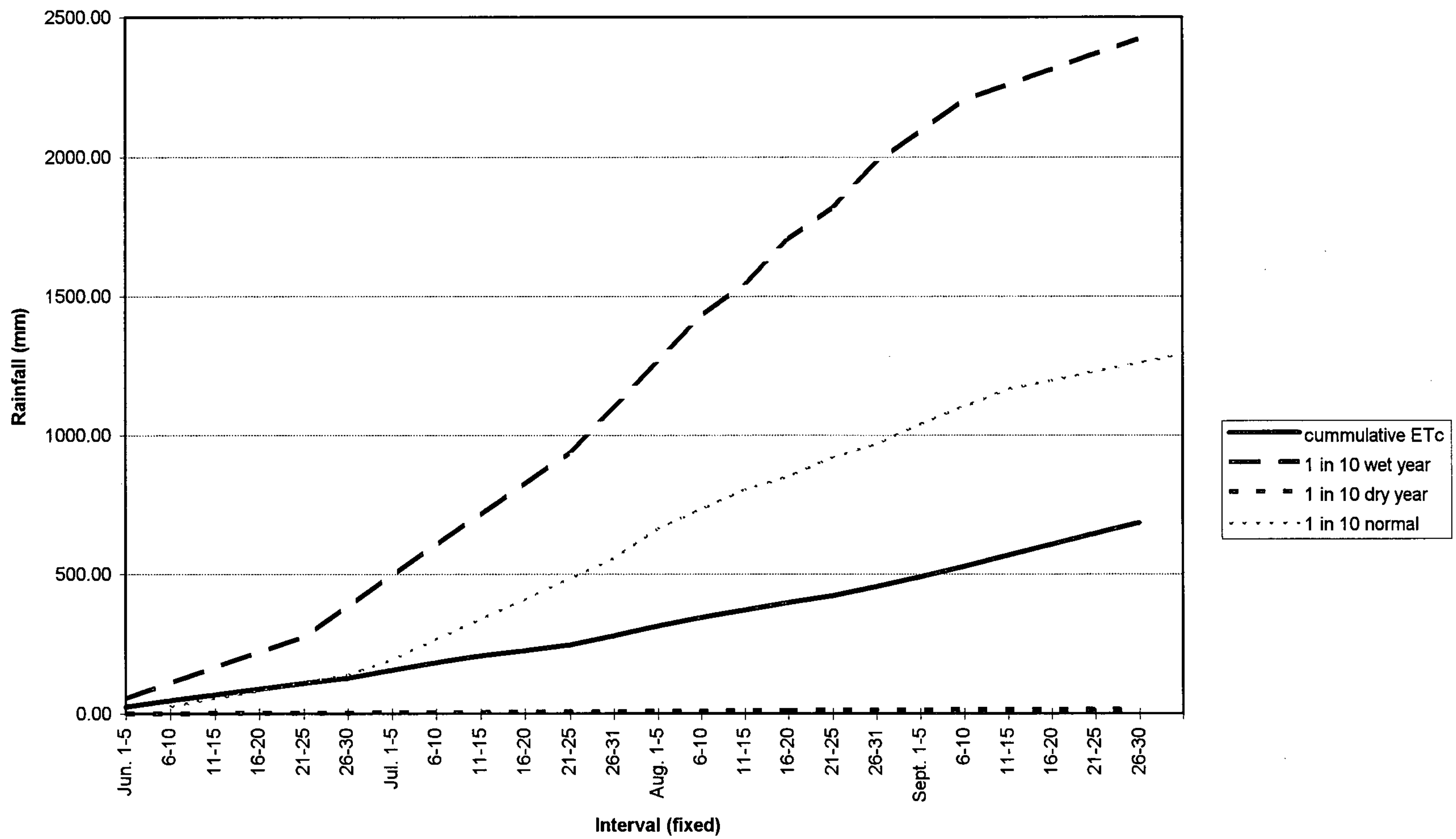


Figure 14 1 in 10 year rainfall, Kharif season



5.3 Evapotranspiration

5.3.1 Reference ET

The mean alfalfa reference ET ($ET_{alfalfa}$) rates exceed mean grass reference ET (ET_{grass}) rates throughout the year, by an average of approximately 29%. During April and May, the warmest months of the year, $ET_{alfalfa}$ is more than 36% higher than ET_{grass}. (Table 20).

ET_r rates for both alfalfa and grass reference vary significantly between the methods, particularly during the months of May - July inclusive. ET_r rates for May range from 7.02 -18.20 mmd^{-1} for grass reference and 10.29 - 23.03 mmd^{-1} for alfalfa reference (Appendix L).

Table 20 Alfalfa vs. grass reference evapotranspiration

Month	ET_r, averaged by reference crop (mmd^{-1})			Mean ET_{grass} all methods[2]
	Alfalfa reference	Grass reference	% Difference[1]	
Jan.	4.35	3.14	27.89	3.42
Feb.	6.64	4.65	29.95	5.15
Mar.	8.90	6.34	28.68	6.95
Apr.	14.29	9.05	36.69	10.60
May	17.85	11.22	37.14	13.20
Jun.	15.00	10.33	31.09	11.54
Jul.	12.21	8.49	30.46	9.44
Aug.	6.05	4.52	25.22	4.83
Sept.	6.60	4.68	29.20	5.14
Oct.	7.91	6.44	18.69	6.58
Nov.	5.37	4.09	23.77	4.33
Dec.	4.33	3.25	25.05	3.46

[1] % difference = ET alfalfa/ETgrass
[2] Adjustment factor for alfalfa to grass of 0.85

5.3.2 Comparison of 10 day moving and fixed average measurements

Analysis of 10 day moving and fixed average measurements (Appendix L) indicates the two methods produce similar results. Overall differences are within ± 2% for the irrigated months of November through March, although the variation within individual months lies between 0.008% and 17.55%.

A fixed average calculation method provides an adequate estimate for preliminary planning purposes.

5.3.3 Actual vs. Estimated Seasonal Crop ET

Many of the methods estimate seasonal ET_c more accurately for some crops than for others. The estimated crop coefficients, necessary due to lack of local information, may account for some of the variation.

5.3.3.1 Kharif season

For Kharif crops the top 5 ranked methods estimated ET_c to within 10% of seasonal $ET_{lysimeter}$ measures. Weighted and unweighted ranking results were similar. The Penman-Monteith, original Penman and Kimberly-Penman (1982) and the adjusted Jensen-Haise methods provided the most accurate estimates over weighted Kharif season crops (Table 21).

The top 5 weighted ranked methods were predominantly comprised of combination methods. All but 2 of the top ranked methods were based on alfalfa reference. The pan evaporation methods and the temperature methods significantly underestimated ET_c for each crop (Appendix L).

The accuracy of the ET_c estimates from each method varied with the crop. Estimates of seasonal groundnut ET_c were overestimated by the combination methods by as much as 18%. However, these same methods produced estimates of within 7% of $ET_{lysimeter}$ for soybean and sorghum (Appendix L).

5.3.3.2 Rabi Season

Seasonal ET_c was estimated to within 7% of $ET_{lysimeter}$ by the top 5 weighted ranked results. Weighted and unweighted rankings produced similar results. The most accurate estimates were produced from the FAO radiation, Penman and FAO corrected Penman methods and the adjusted Jensen-Haise method (Table 21).

The top 5 ranked methods included combination, radiation and temperature methods, the majority of which were grass reference. The pan evaporation methods consistently underestimated seasonal ET_c.

The seasonal ET_c was overestimated for both gram and mustard by most of the combination methods. The Penman-Monteith method estimate was 39% greater than the $ET_{lysimeter}$ measure for gram, and 21% higher for mustard. The seasonal ET_c estimates for wheat were underestimated by all methods except Penman-Monteith.

Table 21 Comparison of top ranked ET_c estimation methods for each season

Kharif season ET_c estimates			Rabi Season ET_c estimates		
Top 5 methods	**Rank**	$\frac{ET_c}{ET_{lysimeter}}$ [1]	**Top 5 Methods**	**Rank**	$\frac{ET_c}{ET_{lysimeter}}$ [1]
Penman (1963)	1	0.99	FAO Radiation	1	1.02
Penman-Monteith	1	1.01	FAO Corrected Penman	2	1.03
Adjusted Jensen-Haise[2]	1	0.99	Penman (1963)	3	1.05
Kimberly-Penman (1982)	2	0.97	FAO Blaney-Criddle	4	0.94
Kimberly-Penman (1972)	3	1.04	Adjusted Jensen-Haise[2]	4	0.94
FAO Corrected Penman	4	1.06	FAO Penman (c=1)	5	1.07

[1] average ratio weighted over all selected crops for the season
[2] Modified Jensen-Haise * 1.15

5.3.4 ET estimate summary over both seasons

Alfalfa reference ET methods performed well in both seasons. Although only 4 alfalfa reference ET methods were included in the analysis, they were within the top 5 methods in the Kharif and Rabi seasons.

The Kimberly-Penman (1972), Kimberly-Penman (1982) and FAO Radiation methods were ranked among the top 5 methods over both seasons. However none of these methods consistently ranked in the top 5 for both the Rabi and Kharif season crops.

The Penman ET_c estimates were within 2% of $ET_{lysimeter}$ in the weighted average over all crops (Table 22). The estimates were within 1% and 5% of $ET_{lysimeter}$ for Kharif and Rabi season crops, respectively (Table 21).

The FAO Corrected Penman estimates were within 5% of $ET_{lysimeter}$ in the weighted average over all crops (Table 22). The estimates were within 6% and 3% of $ET_{lysimeter}$ for Kharif and Rabi season crops, respectively (Table 21).

The adjusted Jensen-Haise ET_c estimates were within 3% of $ET_{lysimeter}$ in the weighted average over all crops (Table 22). The estimates were within 1% and 6% of $ET_{lysimeter}$ for Kharif and Rabi season crops, respectively (Table 21).

5.3.5 Selection of most appropriate method of estimating ET

The selection of an ET method for the Chambal Command area requires consideration of both the accuracy of the method and the amount of climatic data required. Although both the Penman and FAO Corrected Penman methods performed well over both season, these combination methods require a number of climatic parameters.

Of the minimal data methods, the FAO Radiation and FAO Blaney-Criddle estimates are inconsistent over both seasons. The modified Jensen-Haise estimates of ET_c adjusted upward by 15%, performed consistently over both seasons.

The Penman (1963) and adjusted Jensen-Haise methods are the most suitable methods of estimating ET for this region. The Penman (1963) method is the preferred choice if the required data is available. The modified Jensen-Haise method adjusted upward by 15% provides a reasonable estimate of $ET_{lysimeter}$ for both Kharif and Rabi season crops. It is the most suitable method for this region when only minimal climatic data is available as this method requires only temperature data.

Table 22 Top ranked ET_c estimation methods, both seasons

Top 5 Methods	Rank	$\frac{ET_c}{ET_{lysimeter}}$[1]
Penman (1963)	1	1.02
Adjusted Jensen-Haise[2]	2	0.97
FAO corrected Penman	3	1.05
Kimberly-Penman (1972)	4	1.07
FAO Radiation	4	0.93
Kimberly-Penman (1982)	5	0.92

[1] average ratio weighted over all selected crops
[2] modified Jensen-Haise * 1.15

5.3.5 Crop water requirements for the Daglawada Test Plot

ET_c for the sown area of the test plot is 53% higher for the Kharif season crops than for the Rabi season crops (Table 24). Seasonal ET_c was calculated from the general crop mix of 87% mixed dry crop and 13% rice (Figure 5, using the general crop coefficients (Table 23). With different proportions of rice to mixed dry crop the seasonal ET_c changes significantly. The seasonal ET_c increases from 600.60 mm to 892.86 mm as the proportion of rice increases from 0 to 100% (Table 25).

Seasonal ET_c weighted by the proportion of mixed crops to fallow land (general cropping pattern) is 29% higher during the Kharif season than the Rabi season (Table 24).

Rabi season ET_c is reasonably estimated by the crop water requirements as only approximately 4% of the land is left fallow. However, ET_c for the Kharif season is 21% higher than the weighted seasonal ET_c including evaporation from fallow land.

Table 23 **Generalized crop Information for the Daglawada test site**

Season	Crop mix		Development Stages							
			Initial[ii]		Devl.		Mid-Season		Late	
	Dry crop (%)	Rice (%)	Coeff.	Length (days)	Coeff.	Length (days)	Coeff.	Length (days)	Coeff.	Length (days)
Kharif Season	100.0	0.0	0.53	18	0.77	33	0.99	41	0.76	18
	90.0	10.0	0.59	18	0.80	33	1.00	42	0.78	18
	87.0[i]	13.0[i]	0.61	18	0.81	34	1.01	42	0.79	18
	80.0	20.0	0.65	18	0.84	34	1.00	43	0.80	19
	70.0	30.0	0.72	19	0.87	34	1.01	44	0.82	19
	60.0	40.0	0.78	19	0.90	34	1.01	45	0.84	19
	50.0	50.0	0.84	19	0.94	34	1.02	46	0.86	19
	40.0	60.0	0.90	19	0.97	34	1.03	47	0.87	19
	30.0	70.0	0.96	19	1.00	34	1.03	47	0.89	19
	20.0	80.0	1.03	20	1.03	35	1.04	48	0.91	20
	10.0	90.0	1.09	20	1.07	35	1.04	49	0.93	20
	0.0	100.0	1.15	20	1.10	35	1.05	50	0.95	20
Rabi Season	100.0	n/a	0.24	19	0.67	35	1.10	48	0.69	26

[i] crop mix from general cropping pattern (Figure 5)
[ii] sowing date for Kharif season is July 8th for 0 - 90% rice and July 7th for 100% rice; sowing date for Rabi season is November 1st

Table 24 Crop water requirements for the Daglawada test site

Month	Mean ET_{grass} (mmd^{-1})[1]	ET_c (100% mixed crops)[2]	E_{soil} (100% fallow)[3]	ET_c + ET_{soil} (weighted)[4]	ET_{rice} 100% rice	ET_{rice} + ET_{soil} (weighted)[5]
Kharif season						
Jul.	8.28	117.29	115.63	116.35	236.08	183.01
Aug.	6.18	151.52	86.31	122.79	210.33	155.69
Sept.	6.44	191.26	87.04	145.34	202.85	151.82
Oct.[6]	6.75	152.54	35.57	94.46	211.69	134.09
Total[7]		**612.61**	**324.55**	**478.93**	**860.95**	**624.61**
Rabi season						
Nov.	4.94	59.49	28.97	58.14		
Dec.	3.75	90.31	27.67	87.53		
Jan.	3.67	126.31	27.08	121.91		
Feb.	4.90	116.12	30.32	112.32		
Mar.[8]	6.44	36.05	33.94	34.46		
Total		**428.28**	**147.98**	**414.37**		

Note: all ET values in mm unless otherwise indicated
[1] $ET_{grass} = ET_{JH}$*
[2] assumes 0% fallow; generalized crop k_c and growing stage lengths for 87% dry crop and 13% rice
[3] k factor for each month contained in Appendix L
[4] weighted ET for mixed crops and fallow (Figure 5)
[5] weighted ET for 100% rice on sown portion, and fallow land (Figure 5)
[6] portion of October for crops is 28 days; 31 days are used for fallow
[7] ET for November of 31.91 mm was excluded to prevent overlap with Rabi season
[8] portion of March for crops is 3 days; 31 days are used for fallow

Table 25 Monthly and seasonal ET_c for various crop mix proportions

Crop mix		ET_c by month (mm)					Seasonal ET_c (mm)
Dry crop[1] (%)	Rice (%)	Jul.	Aug.	Sept.	Oct.	Nov.	
100.0	0.0	117.29	152.88	191.26	139.17		600.60
90.0	10.0	127.73	158.13	193.19	148.83		627.88
87.0	13.0	131.21	158.81	195.13	157.40		642.55
80.0	20.0	138.66	164.80	193.19	163.41		660.07
70.0	30.0	149.35	168.32	195.13	187.05		699.84
60.0	40.0	160.04	173.70	195.13	190.76	4.15	723.77
50.0	50.0	171.14	180.98	197.06	195.15	8.50	752.82
40.0	60.0	181.82	186.48	198.99	198.32	12.90	778.51
30.0	70.0	192.51	191.86	198.99	200.48	13.19	797.03
20.0	80.0	204.77	197.23	200.92	206.29	31.48	840.68
10.0	90.0	216.03	204.89	200.92	208.79	36.77	867.39
0.0	100.0	236.08	210.33	202.85	211.69	31.91	892.86

Note: ET_c calculated from adjusted Jensen-Haise method
[1] mixture of dry crops as indicated in Figure 5

5.3.6 Coefficient to convert Class A Pan Evaporation measurements to ET

The coefficient relating pan evaporation rates and ET_r calculated from the adjusted Jensen-Haise method was difficult to define. Very little data was available for some months, especially July, August and October. Although evaporation were averaged over 5 day periods in order to correspond with the adjusted Jensen-Haise method (ET_{JH}*), significant variation in evaporation rates was evident (Table 26)..

Manual adjustment of the ratio of daily pan evaporation rates to ET_r resulted in some improvement of the coefficient. The selected monthly coefficients produce reasonable estimates of ET_r over the normal range of evaporation rates for each month. ET_r is over- or underestimated for extraordinary values of evaporation.

Table 26 Comparison of ET pan evaporation and adjusted Jensen-Haise

Month	Coeff.[1]	# of days[2]	Pan evaporation		Mean ET_{JH}*[4] (mmd^{-1})	Mean ET_{pan}[5] (mmd^{-1})	Mean difference[6] (mmd^{-1})	Paired t test[7] (p values)
			mean[3]	r^2				
Jan.	1.08	82	3.40	0.32	3.66	3.67	0.02	0.79
Feb.	1.02	81	4.78	1.10	4.91	4.97	-0.62	0.50
Mar.	0.89	93	7.30	3.16	6.44	6.80	0.36	0.02
Apr.	0.79	85	11.58	3.17	9.11	9.10	-0.01	0.93
May	0.73	83	14.10	6.61	10.28	10.53	0.25	0.16
Jun.	0.75	64	13.78	6.98	10.01	10.34	0.21	0.22
Jul.	0.95	30	9.61	11.25	8.29	9.17	0.88	0.14
Aug.	1.30	12	5.87	4.07	6.18	7.63	1.45	0.12
Sept.	1.40	50	4.64	0.47	6.33	6.50	0.17	0.21
Oct.	1.34	23	4.78	0.53	6.79	6.40	-0.06	0.62
Nov.	1.20	47	3.97	0.22	4.95	4.77	-0.04	0.51
Dec.	1.16	62	3.75	0.25	3.75	3.71	-0.38	0.63

[1] coefficient to convert pan evaporation to ET
[2] number of days in the month with both pan evaporation and ET_{JH}* values
[3] pan evaporation values averaged over 5 day periods
[4] adjusted Jensen-Haise ET, calculated over 5 day periods
[5] ET_{pan} = pan evaporation * coefficient
[6] $ET_{pan} - ET_{JH}$*
[7] H0: $\mu_1 - \mu_2 = 0$; μ_1 = mean ET_{JH}*, μ_2 = mean ET_{pan}

The mean values for ET_r estimated from pan evaporation rates is significantly different from ET_{JH}* for the months of July and August (Table 26). Without additional data, the coefficients for these months cannot be improved. However, the coefficients are suitable for planning and modelling purposes.

5.4 Effective rainfall

5.4.1 Comparison of USDA and 70% effective rainfall

The effective rainfall resulting from the USDA method for the 1 in 5 and 1 in 10 wet years, is approximately 55 - 57% of the total rainfall (Figure 15). The 70% effective rainfall method represents a 13 - 15% increase over the USDA estimated rainfall (Appendix M).

USDA estimates of effective rainfall for normal Kharif season rainfall with return periods of 5 and 10 years, is approximately 60 - 66% of the total rainfall (Figure 15).

The USDA method is more suitable to this region than the 70% method commonly applied. Daily rainfall depths are commonly less than 5.0 mm, most of which would be effective. The 70% method underestimates the effective portion of these rainfall depths, while overestimating the effective portion of higher rainfall depths (Appendix M).

5.5 Water balance

The water balance was calculated for 5 day fixed intervals from evapotranspiration and total and effective rainfall for the Kharif season. The adjusted Jensen-Haise method and the general crop coefficients (general cropping pattern) were used to determine ET_c for each 5 day interval. Effective rainfall was calculated from total rainfall depth for each interval using the USDA method.

The use of effective rather than total rainfall significantly reduces the amount of rainfall in excess of evapotranspiration requirements. As expected, groundwater recharge is highest during the months

Figure 15 Effective rainfall, 5 and 10 year return periods

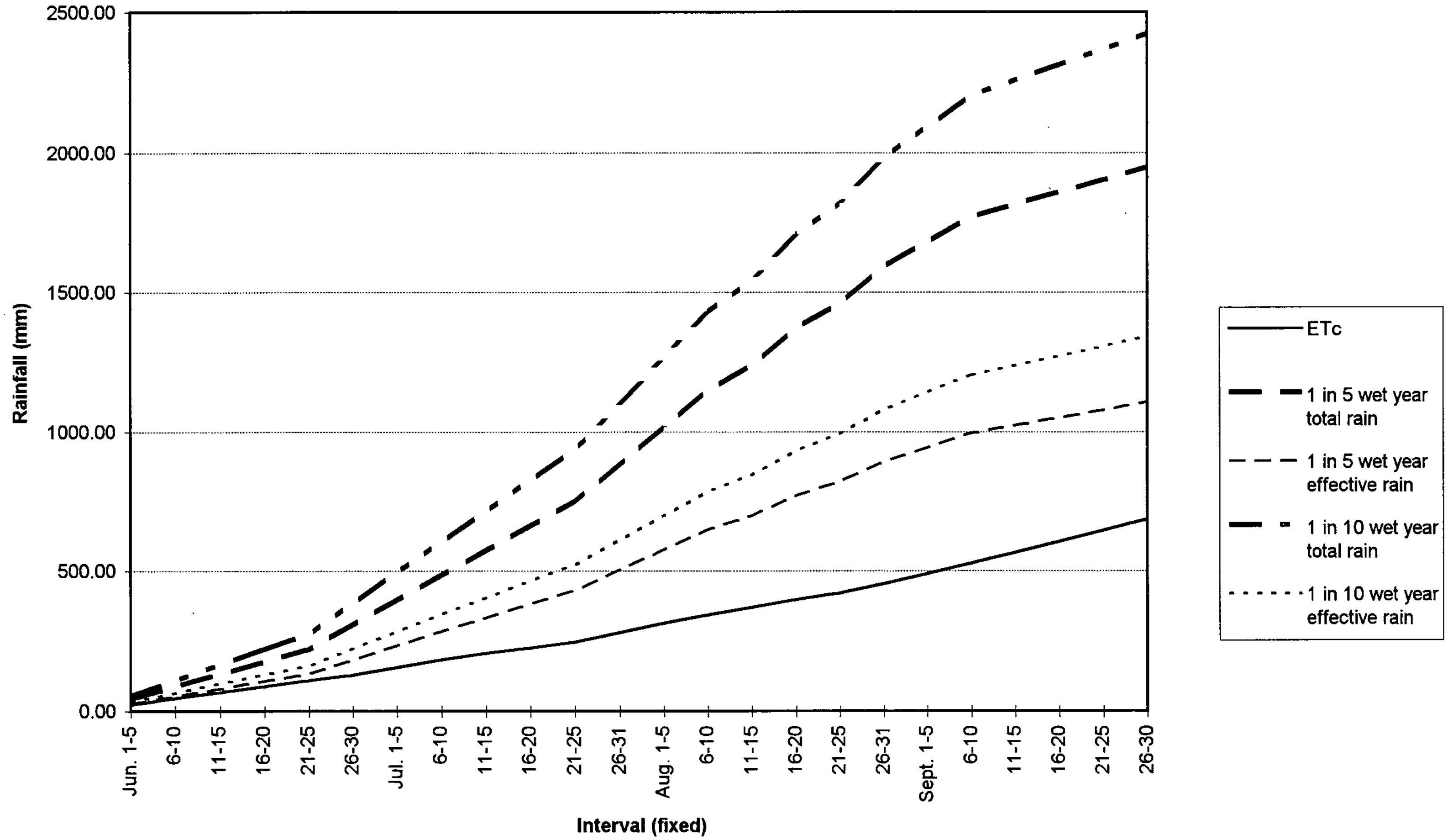


Table 27 Water balance for wet and normal rainfall, Kharif season

Month	Interval[1]	ET_c (mm)	Total rainfall[2] (mm)				Effective rainfall[3] (mm)				Groundwater recharge[4] (mm)			
			Normal year		Wet year		Normal year		Wet year		Normal year		Wet year	
			1 in 5	1 in 10	1 in 5	1 in 10	1 in 5	1 in 10	1 in 5	1 in 10	1 in 5	1 in 10	1 in 5	1 in 10
June	1-5	24.09	18.68	27.64	44.23	55.07	11.62	17.22	26.83	32.76	-12.47	-6.86	2.75	8.67
	6-10	23.08	18.68	27.64	44.23	55.07	11.59	17.19	26.77	32.68	-11.49	-5.89	3.69	9.60
	11-15	20.71	18.68	27.64	44.23	55.07	11.53	17.10	26.63	32.51	-9.17	-3.61	5.93	11.81
	16-20	20.85	18.68	27.64	44.23	55.07	11.54	17.10	26.64	32.52	-9.32	-3.75	5.79	11.67
	21-25	20.71	18.68	27.64	44.23	55.07	11.53	17.10	26.63	32.51	-9.17	-3.61	5.93	11.81
	26-30	18.19	37.37	55.29	88.46	110.14	22.65	32.45	49.24	59.59	4.47	14.26	31.05	41.40
July	1-5	29.12	56.67	72.33	88.46	110.14	33.98	42.25	50.44	61.04	4.86	13.13	21.31	31.92
	6-10	26.47	56.67	72.33	88.46	110.14	33.79	42.01	50.14	60.68	7.31	15.53	23.67	34.21
	11-15	23.18	56.67	72.33	88.46	110.14	33.54	41.70	49.78	60.25	10.36	18.52	26.60	37.07
	16-20	19.09	56.67	72.33	88.46	110.14	33.24	41.33	49.34	59.71	14.15	22.24	30.24	40.61
	21-25	19.70	56.67	72.33	88.46	110.14	33.29	41.39	49.40	59.79	13.58	21.68	29.70	40.08
	26-31	34.21	85.00	108.50	132.69	165.21	49.25	60.93	72.49	87.47	15.04	26.72	38.28	53.25
August	1-5	34.79	65.24	70.19	132.69	165.21	39.04	41.65	72.58	87.58	4.25	6.87	37.79	52.79
	6-10	29.32	65.24	70.19	132.69	165.21	38.57	41.16	71.71	86.53	9.25	11.83	42.39	57.21
	11-15	26.85	43.50	46.79	88.46	110.14	26.58	28.43	50.19	60.74	-0.27	1.57	23.33	33.88
	16-20	27.30	65.24	70.19	132.69	165.21	38.40	40.97	71.40	86.15	11.10	13.68	44.10	58.85
	21-25	23.69	43.50	46.79	88.46	110.14	26.40	28.23	49.84	60.31	2.71	4.54	26.15	36.62
	26-31	33.47	65.24	70.19	132.69	165.21	38.92	41.53	72.37	87.32	5.45	8.06	38.90	53.85
Sept.	1-5	35.25	48.58	63.66	88.46	110.14	29.96	38.23	51.12	61.87	-5.28	2.98	15.87	26.62
	6-10	37.47	48.58	63.66	88.46	110.14	30.11	38.42	51.37	62.17	-7.36	0.95	13.90	24.70
	11-15	39.29	24.29	31.83	44.23	55.07	15.69	20.40	27.74	33.87	-23.60	-18.89	-11.54	-5.42
	16-20	39.34	24.29	31.83	44.23	55.07	15.69	20.40	27.75	33.87	-23.65	-18.94	-11.59	-5.47
	21-25	39.24	24.29	31.83	44.23	55.07	15.69	20.40	27.74	33.87	-23.55	-18.84	-11.50	-5.37
	26-30	39.59	24.29	31.83	44.23	55.07	15.70	20.41	27.76	33.89	-23.89	-19.18	-11.83	-5.70
Total		**685.00**	**1041.41**	**1292.65**	**1946.12**	**2423.08**	**628.32**	**767.99**	**1105.91**	**1339.67**	**-56.69**	**82.98**	**420.91**	**654.66**

[1] Fixed intervals
[2] total rainfall = (1 day rainfall depth, normal or wet year model) (# of rain days in the interval)
where # of rain days = [(total # of rain days/total number of days)*days] for each interval
[3] USDA-SCS method
[4] Effective rainfall - ET_c

of July and August, tapering off in September. In September, the effective rainfall is less than ET_c for most of the month.

The water balance calculated from effective wet year rainfall and ET_c does not significantly change between the 1 in 5 and 1 in 10 wet years. However, groundwater recharge for a 1 in 10 normal year is approximately 20% of the 1 in 5 wet year rainfall (Table 27).

5.5.1 Drainage requirement

Over the Kharif season, excess effective rainfall of 420.91 and 654.66 mm is estimated for the 1 in 5 and 1 in 10 wet years, respectively (Table 27). For the 178 ha Daglawada test plot, a total of 749.2 and 1165.3 ($x10^3$) m^3 of excess water must be drained, for return periods of 5 and 10 years, respectively.

The drainage requirement for a 1 in 10 normal year rainfall is 82.98 mm, or 147.7 ($x10^3$) m^3 (Table 27). The 1 in 5 normal year rainfall results in a groundwater deficit over the Kharif season.

A drainage coefficient of 10.69 mmd^{-1} based on the 0.1 mm threshold event model would adequately remove excess water over 5 day intervals for each of the rainfall conditions (1 in 5 and 1 in 10 normal and wet years).

5.5.2 Leaching requirement

The leaching requirement is 0.0309, expressed as a fraction. To meet the leaching requirement within the main monsoon period (July to September), a value of 0.49 mmd^{-1}, or 164.45 mm of water is required, based on ET_c and rainfall for the Rabi and Kharif seasons. In each of the 1 in 5 and 1 in 10 wet years, the leaching requirement can be met during the monsoon season.

6.0 Summary of Main Results

Markov chain analysis

The actual wet and dry day sequences were accurately predicted by the Markov chain analysis, using a 5 day transition probability matrix. Transition probabilities over 5 day fixed intervals demonstrate a reasonable stationarity, although stationarity between years is not evident.

The results from the 10 day transition probability matrix were reasonable for some months of the Kharif season. Stationarity over 10 day fixed intervals is evident only over portions of July and August.

A monthly or seasonal transition probability matrix is not suitable to this region.

Daily and event-based rainfall models

Event-based modelling is well suited to semi-arid and arid regions, where storms often occur in clusters. The event-based model provides information regarding rainfall pattern and distribution that is not evident from the daily rainfall model. In addition, the model is not limited by daily rainfall records.

The random nature of the rainfall pattern and distribution within the monsoon season was confirmed through correlation analysis. Dependence between rainfall depth and duration and between maximum interarrival times and total dry days was evident. Such dependence is expected and not inconsistent with an assumption of randomness with respect to rainfall events.

The event-based model provides information regarding storm behaviour over 2 or more successive days. Although the daily model gives total rainfall over 2-4 day periods, information regarding rainfall during that period is not available.

Interarrival times give an indication of the amount of time available for drainage of excess water from the soil profile. The interarrival times between significant rainfall events provides valuable information for irrigation planning. In addition, maximum dry day sequences may be a useful measurement of drought conditions.

Design storm

The depth-duration-frequency curves for the daily and event-based rainfall models produced significantly different results. The hourly rainfall intensity values ranged from 10.0 - 40.0 mm/hr from the 0.1 threshold event and the daily model, respectively.

Wet and Dry year models

The probability of rain over 5 day fixed intervals and the maximum and minimum 1 day rainfall from the 0.1 threshold event model were used to construct wet and dry year models. The probability of occurrence of the annual rainfall modelled in these scenarios is very small. The annual wet and dry year rainfall with a return period of 5 years is 1946.12 and 31.24 mm, respectively. The wet year rainfall is approximately 30% greater than the highest annual rainfall recorded from 1970-1993. The dry year rainfall is approximately 10% of the lowest annual rainfall for the same period.

Evapotranspiration

The estimation of ET_c was very successful, despite limited available data. The top 5 ranked methods over both seasons, Penman (1963), FAO Corrected Penman, adjusted Jensen-Haise, FAO Radiation and Kimberly Penman (1972 and 1982), were within 8% of seasonal $ET_{lysimeter}$. The best estimation methods for each season were very different with only 3 methods, Penman (1963), FAO Corrected Penman and adjusted Jensen-Haise ranking in the top 5 of each season. In addition, the results for many of the methods were inconsistent within a season.

The Penman (1963) method results in the most accurate estimation of ET and is the appropriate choice when adequate data is available. The Modified Jensen-Haise method, provides reasonable estimates of ET, when adjusted upward by 15%. This method is the most appropriate choice when only minimal climatic data is available.

Crop water requirements are accurately estimated from the general crop coefficients for the Daglawada test plot. ET_c values increase significantly as the proportion of rice to dry mixed crops increases.

The monthly coefficient relating pan evaporation to ET produces reasonable results. The lack of data, and extraordinary values resulted in poor correlation between pan evaporation and Jensen-Haise calculated ET rates in some months.

Effective rainfall

The rainfall intensity determined from the design storm analysis indicates much of the rainfall is lost to surface runoff. The effective wet year rainfall as calculated from the USDA-SCS method, is approximately 55 - 57% of the actual rainfall. The effective normal year rainfall is approximately 60 - 66% of actual rainfall, using the same method. The 70% method commonly used in India overestimates effective rainfall, and is not well-suited to this region.

Water balance

The water balance calculated from effective rainfall indicates that groundwater recharge is highest at the height of the monsoon season. Excess rainfall of 82.98 mm is produced during the Kharif season of a 1 in 10 normal year, which is approximately 20% of the excess rainfall produced during a 1 in 5 wet year.

Drainage coefficient

The drainage coefficient for the Daglawada test plot is 10.69 mmd^{-1} based on the 1 in 5 normal daily rainfall from the 0.1 mm threshold event model. The coefficient increases to 16.33 mmd^{-1} for a 10 year return period.

Leaching requirement

The leaching requirement, based on the average EC_e (2.0 dSm^{-1}) of the most sensitive crops, is 0.0309. To meet the leaching requirement, 164.45 mm of leaching water is required.

7.0 Conclusion

Rainfall modelling in semi-arid and arid areas is necessary as the average values are not representative of actual conditions.

The design of a sub-surface drainage system requires accurate information regarding rainfall over 1 or more days. Traditionally, daily rainfall modelling has been used. However, such models do not adequately characterize the monsoon season rainfall. They do not provide information as to the pattern and distribution of rainfall over the season; Nor do they provide details concerning the distribution of rainfall over 2 or more days.

Event-based modelling is a flexible alternative to daily modelling. Events are defined as successive days of rainfall over a specified threshold value, with dry days or interarrival times between them. Although the event-based model described by Bogàrdi et al (1988) cannot be rigidly applied to this region, an adaptation of the model makes it a valuable tool in sub-surface drainage design and irrigation planning.

Event-based modelling helps to overcome the difficulty in characterizing storms from daily rainfall measurements. A rain storm may be a few hours in length, but a single daily reading means the storm is assumed to have occurred over 24 hours. The problem is exaggerated when the storm straddles the daily recording time. In this case, the storm is actually recorded on each of 2 days, and is then assumed to have occurred over 48 hours.

It is probable that a portion of rainfall depths of 5.0 mmd^{-1} or less, commonly recorded, are due to the problem of a single daily measure. Rainfall depths of this magnitude may be part of a rain storm occurring before or after the daily recording time.

Event-based modelling characterizes the event, rather than individual storms. It is well suited to sub-surface drainage design where the rainfall over 1-4 days is more important than the rainfall of a single storm. A waterlogged root zone resulting from a single storm will drain before the crops are affected. However, several days of storms of significant rainfall depth will result in a failure of the sub-surface drainage system, and damage to the crops.

Significant rainfall events are separated by dry day intervals of 5 or less days 70% of the time. Most of the dry-day intervals are of 1 - 2 days in length. Such dry intervals allow for system recovery after rain storms.

The use of a daily model measuring rainfall depths over 1-4 day periods is difficult to defend. A 4 day period does not represent a 4 day rainfall event. One or more of the days within the period may not have recorded rainfall. This is a highly probable occurrence given that approximately 45% of events (0.1 mm threshold) are 1 day in duration, and dry intervals of 1 - 2 days are common. Additionally, events of 3 days or less account for almost 80% of all events.

The modelling of design storms is also better achieved through event-based models. Daily rainfall modelling results in an poor estimates of rainfall intensity, depth and duration. The measured period may lie in the middle of a storm of significant length, when rainfall depths are at their highest. The hourly rainfall intensity determined from the daily rainfall model is 4 times higher than the results of the event-based model (0.1 mm threshold).

The overestimation of maximum rainfall depths results in the overdesign of sub-surface drainage systems. The daily maximum rainfall depth used to construct the 1 in 5 wet year model is approximately 34% of the 1 day maximum calculated from the daily model.

Effective, rather than actual rainfall is an important consideration in the determination of a drainage coefficient. Much of the rainfall occurring during storms of significant magnitude is lost to surface runoff. The use of actual rainfall would result in an overestimation of the drainage coefficient by as much as 47%.

The drainage coefficient was determined from a water balance using effective rainfall and crop water requirements. The crop water requirements were estimated from a set of general crop coefficients and a coefficient to convert pan evaporation rates to evapotranspiration. As pan evaporation rates are commonly measured in the Chambal Command area, while other climatic data is not, evapotranspiration from pan evaporation provides the most information. A set of general crop coefficients allows for consistent modelling over any interval length, based on the general cropping pattern.

The resulting drainage coefficients, for 5 and 10 year return periods did not differ significantly. Since the probability of occurrence of the 1 in 5 and 1 in 10 wet year rainfall is extremely low, basing the sub-surface drainage design on this scenario is not necessary. The most appropriate and cost-effective drainage coefficient of 10.69 mmd^{-1}, based on the 1 in 10 effective normal rainfall. As 1 day rainfall events followed by 1-2 dry days are common, this drainage coefficient is adequate to meet the 1 in 5 maximum daily rainfall of 44.23 mm.

The leaching requirement of 0.0309 can be easily met with the Kharif season rainfall occurring in wet years with return periods of 5 and 10 years. However, the 164.45 mm of necessary excess water is not available in normal rainfall years with return periods of 2, 5 and 10 years, considered here to approximate average conditions.

The persistence evident in the Kharif season rainfall from 1970-1993, indicates that over 5 year periods drier than average conditions exist. During such periods, soil salinity would increase to levels which would adversely affect crops. The dry year models based on minimum daily rainfall depths are not adequate to describe drought conditions nor the recurrence interval of same.

The failure of the Kharif season rainfall to meet leaching requirements would occur in years in which seasonal effective rainfall is less than approximately 700 mm. Of the 22 years with recorded Kharif season rainfall, 41% are below 700 mm in total rainfall. Consideration of effective rainfall only would result in a higher failure rate.

8.0 Recommendations

- Comparison of the event-based model results on data from other stations in the Chambal Command area. A model that accurately represents the region rather than a single station is highly desirable.
- A study of rainfall depths of 10.0 mm or less to determine if such events are part of larger storms. A comparison of daily rainfall depths of 10.0 mm or less with hourly data would aid in the determination of an appropriate threshold value for event-based modelling.
- Comparison of the rainfall intensity values with hourly data to determine if the event-based design storm based on the 0.1 mm threshold value is accurate.
- Comparison of estimates of ET from pan evaporation using the monthly coefficient with actual ET for a variety of crops grown in the Chambal command area.
- Determination of effective rainfall using soil water balance to determine if effective rainfall calculated by the USDA-SCS method is appropriate to this region of India.
- Analysis of drought conditions based on the maximum dry-day intervals to determine appropriate dry year rainfall for various return periods.

LITERATURE CITED

Al-Sha'lan, S.A. and A.M. Salih. 1987. Evapotranspiration estimates in extremely arid areas. J. Irrig. Drain. Eng. 113(4): 565-574.

Allen, R.G. 1986. A Penman for all seasons. J. Irrig. Drain. Eng. 112(4): 348-368.

Allen, R.G. and W.O. Pruitt. 1986. Rational use of the FAO Blaney-Criddle formula. J. Irrig. Drain. Eng. 112(2): 139-155.

Allen, R.G. and W.O. Pruitt. 1991 FAO-24 reference evapotranspiration factors. J. Irrig. Drain. Eng. 117(5): 758-773.

Allen, R.G. et al. 1989. Operational estimates of evapotranspiration. Agron. J. 81: 650-662.

ASCE (Am. Soc. of Civil Engineers). 1990. Evapotranspiration and Irrigation Water Requirements. No. 70. M.E. Jensen, R.D. Burman and R.G. Allen (eds.).

Ayers, R.S. and Westcot, D.W. 1985. Water Quality for Agriculture. FAO. Irrigation and Drainage Paper 29, 1976, revised 1985. FAO, Rome.

Benson, M.A. 1968. Uniform flood frequency estimating methods for federal agencies. Water Resour. Res. 4(5): 891-908.

Bhatnagar, D.K. 1990. Saline and Alkaline Soils of India. Directorate of Extension, Ministry of Agriculture, Government of India. *cited in* S.T. Chieng, Analysis of subsurface drainage design criteria, Chambal Command, Rajasthan, India, Unpublished, 1993.

Bogárdi, J.J., L. Duckstein, O.H. Rumamba. 1988. Practical generation of synthetic rainfall event time series in a semi-arid climatic zone. J. Hydrol. 103(1988): 357-373.

Bouwer, H. 1969. Salt balance, irrigation efficiency, and drainage design. ASCE, Proc. 95(IR1):153-170.

Brunt, D. 1932. Notes on radiation in the atmosphere. Quart. J. Roy. Meteor. Soc. 58:389-418.

Budyko, M.I. 1956. The heat balance of the earth's surface (translated by N.A. Stepanova, 1958). U.S. Dep. Com. Weather Bur. PB131692.

Burman, R.D., J.L. Wright and M.E. Jensen. 1975. Changes in climate and estimated evaporation across a large irrigated area in Idaho. Trans. of the ASAE 18(6): 1089-1091, 1093.

Burman, R.D. et al. 1980. Design and Operation of Farm Irrigation Systems. ASAE. pp. 189-232.

Burman, R.D. and L.O. Pochop. 1994. Evaporation, evapotranspiration and climatic data. Developments in Atmospheric Science, 22, Elsevier Science.

Chambal Drainage Master Plan. 1978. *cited in* S.T. Chieng Analysis of subsurface drainage design criteria, Chambal Command, Rajasthan, India, Unpublished. 1993.

Chieng, S.T. 1993. Analysis of subsurface drainage design criteria, Chambal Command, Rajasthan, India. Unpublished.

Christiansen J.E. and G.H. Hargreaves. 1969. Irrigation requirements from evaporation. Trans. Int. Comm. on Irrig. and Drain., 4: 23.569-23.596.

Christiansen, J.E. 1968. Pan evaporation and evapotranspiration from climatic data. J. Irrig. and Drain. Div. (now J. Irrig. Drain. Eng.), ASCE 94: 243-265

Coe, R. and R. D. Stern. 1982. Fitting Models to Daily Rainfall Data. J. of Appl. Meteor. 21: 1024-1031.

CSSRI. 1991. Drainage for reclamation of waterlogged saline lands in irrigation commands. Report # 3; CSSRI, Karnal-132 001, India *cited in* S.T. Chieng Analysis of subsurface drainage design criteria, Chambal Command, Rajasthan, India, Unpublished. 1993.

Cuenca, R.H. 1989. Irrigation system design. An engineering approach. Prentice Hall, Englewood Cliffs, N.J.

Cunnane, C. 1978. Unbiased Plotting Positions - A Review. J. Hydrol. 37: 205-222.

Darra, B.L. 1993. Resource Inventory of Chambal Command Area. Extracts From Technical Bulletin No. 6. RAJAD Project, Kota. *cited in* S.T. Chieng, Analysis of subsurface drainage design criteria, Chambal Command, Rajasthan, India, Unpublished, 1993.

Dastane, N.G. 1974. Effective Rainfall. FAO Irrigation and Drainage Paper 25. FAO, Rome.

Doorenbos, J. and A.H. Kassam. 1979. Yield Response to Water. FAO Irrigation and Drainage Paper 33. FAO, Rome.

Doorenbos, J. and W.O. Pruitt. 1977. Guidelines for predicting crop water requirements. FAO Irrigation and Drainage Paper 24, 2nd ed., FAO, Rome.

Drainage Master Plan of Chambal Command C.A.D. Kota. 1978. General report of the project and abstract cost estimate - Volume-1. Superintendent Engineer, Circle-II (Drainage) C.A.D. Kota, Rajasthan, India. *cited in* S.T. Chieng, Analysis of subsurface drainage design criteria, Chambal Command, Rajasthan, India, Unpublished, 1993.

Duckstein L., M.M. Fogel and C.C. Kisiel. 1972. A stochastic model of runoff-producing rainfall for summer type storms. Water Resour. Res. 8(2):410-421.

Duffie, J.A. and W.A. Beckman. 1980. Solar engineering of thermal processes. John Wiley and Sons. New York.

Dunne, T. and L.B. Leopold. 1978. Water in Environmental Planning. W.H. Freeman and Company, New York.

FAO/Unesco. 1973. Irrigation, Drainage and Salinity: An International Source Book. (Paris/Unesco) Hutchinson & Co. Ltd., London. 1973.

Feyerherm, A.M. and L.D. Bark. 1965. Statistical methods for persistent precipitation patterns. J. Appl. Meteor. 4: 320-328.

Fisher, R. A., and L.H.C. Tippett. 1928. Limiting forms of the frequency distribution of the largest or smallest member of a sample. Proc. Cambridge Phil. Soc. 24(II): 180-191.

Fogel, M.M. and L. Duckstein. 1969. Point rainfall frequencies in convective storms. Water Resour. Res. 5(6) 1229-1237.

Foster, H.A. 1934. Duration Curves. Trans. Am. Soc. Civil Eng. 99: 1213-1235.

Frechet, M. 1927. Sur la loi de probabilite de l'ecart maximum ("On the probability law of maximum values"). Annales de la societe Polonaise de Mathematique, 6: 93-116.

Frevert, D.K., R.W. Hill, and B.C. Braaten. 1983. Estimation of FAO evapotranspiration coefficients. J. Irrig. Drain. Eng. 109(2): 265-270.

Gabriel, K.R. and J. Neumann. 1962. A Markov chain model for daily rainfall occurrence at Tel Aviv. Quart. J. Roy. Meteor. Soc. 88: 90-95.

Gringorten, I.I. 1963. A Plotting Rule for Extreme Probability Paper. J. of Geophys. Res. 68: 813-814.

Gumbel, E.J. 1941. The return period of flood flows. The Annals of Mathematical Statistics 12(2): 163-190.

Gumbel, E. J. 1954. Statistics Theory of Extreme Values and Some Practical Applications. National Bureau of Standards, Applied Mathematics Series #33.

Gupta, V. K. and L. Duckstein. 1975. A Stochastic Analysis of Extreme Droughts. Water Resour. Res. 11(2): 221-228.

Hansen, V.E., O.W. Israelsen and G.E. Stringham. 1980. Irrigation Principles and Practices., 4th.Ed., John Wiley and Sons Inc., NY, NY. pp. 112-144.

Hargreaves, G. H. 1974. Estimation of potential and crop evapotranspiration. J. Irrig. Drain. Eng. 17: 701-704.

Hargreaves, G. H. and Z.A. Samani. 1982. Estimating potential evapotranspiration. J. Irrig. Drain. Eng. 108(3): 225-230.

Hargreaves, G. H. and Z.A. Samani. 1985. Reference crop evapotranspiration from temperature. Appl. Eng. Agr. 1(2): 96-99.

Haroon, M. 1993. Why Farmers Plant What They Do. Support documentation for the RAJAD Project. RAJAD, Kota. *cited in* S.T. Chieng, Analysis of subsurface drainage design criteria, Chambal Command, Rajasthan, India, Unpublished, 1993.

Hazen, A. 1914. Storage to be provided in impounding reservoirs for municipal water supply. Trans. Am. Soc. Civ. Eng. 77: 1547-1550.

Heerman, D.F. et al. 1968. Probability of sequences of wet and dry days for eleven western states and Texas. Texas Colorado Agric. Exp. Station Tech. Bull. 117. *cited in* R.D. Stern and R. Coe, A model fitting analysis of daily rainfall data, J. Roy. Statist. Soc. A 147(I): 1-34.

Hershfield, D.M. et al. 1973. Some Measures of Agricultural Drought. Floods and Droughts, Proc. of 2nd International Symposium in Hydrology. Water Resources Publications. pp. 491-502.

Hussein, A.S., and A.K. El Daw. 1989. Evapotranspiration in Sudan Gezira irrigation scheme. J. Irrig. Drain. Eng. 115(6): 1018-1033.

Jackson, I.J. 1981. Dependence of wet and dry days in the tropics. Arch. Met. Geoph. and Biokl. Ser B., 29: 167-179. *cited in* R.D. Stern and R. Coe, A model fitting analysis of daily rainfall data, J. Roy. Statist. Soc. A 147(I): 1-34.

Jenkinson, A.F. 1955. The frequency distribution of the annual maximum (or minimum) values of meteorological elements. Quart. J. Roy. Meteor. Soc. 81: 158-171.

Jensen, M.E. and H.R. Haise. 1963. Estimating evapotranspiration from solar radiation. J. Irrig. Drain. Eng., 89: 15-41.

Jensen, M.E., J.L. Wright and B.J. Pratt. 1971. Estimating soil moisture depletion from climate, crop and soil data. Trans. ASAE. 14: 954-959.

Jensen, M.E. 1974. Consumptive use of water and irrigation water requirements. Rep. Tech. Com. on Irrig. Water Requirements. Irrig. and Drain. Div. ASCE. Revised: ASCE, Evapotranspiration and Irrigation Water Requirements, M.E. Jensen, R.D. Burman, R.G. Allen (eds.), 1990.

Jones, K.R. 1981. Arid zone hydrology. FAO Irrigation and Drainage Paper 37. FAO, Rome.

Joshi, A. 1993. Water capillary rise in clay loam soil of the Chambal Command Area (in preparation), RAJAD, Kota. *cited in* S.T. Chieng, Analysis of subsurface drainage design criteria, Chambal Command, Rajasthan, India, Unpublished, 1993.

Kite, G.W. 1977. Frequency and Risk analysis in Hydrology. Water Resources Publications, Fort Collins Colo.

Lane, L.J. and H.B. Osborn. 1972. Hypotheses on the seasonal distribution of thunderstorm rainfall in south-eastern Arizona. Floods and Droughts, Proc. of 2nd International Symposium in Hydrology. Water Resources Publications. pp. 83-94.

London, J.C. and C. Fröhlich (eds.). 1982. Extended abstracts presented at the symposium on the solar constant and the spectral distribution of solar irradiance. IAMAP Third Scientific Assembly, Aug. 17-28, 1981, Hamburg, Federal Republic of Germany.

Luthin, J.N. 1978. Drainage Engineering. Krieger Publishing, Huntington, New York.

Maheshwari. 1993. Indian drainage experience. Report to the RAJAD Project for Inclusion into the drainage criteria report. Unpublished. *cited in* S.T. Chieng, Analysis of subsurface drainage design criteria, Chambal Command, Rajasthan, India, Unpublished, 1993.

Maidment, David R. 1993. Handbook of Hydrology. McGraw-Hill, Inc., New York.

Makkink, G.F. 1957. Testing the Penman formula by means of lysimeters. J. Inst. Water Eng., 11(3): 277-288.

Mehta, K.M.. 1958. Report of Soil and Crop Investigation Survey, Chambal Commanded Area, Rajasthan. Udaipur, Department of Agricultural Chemistry. *cited in* H.S. Sharma, The Physiography of the Lower Chambal Valley and Its Agricultural Development: A Study in Applied Geomorphology, Concept Publishing Company, New Delhi. 1979.

Mockus, V. 1960. Selecting a Flood Frequency Method. Trans. of the ASAE 3(1): 48-54.

Monteith, J.L. 1965. Evaporation and the environment. *In* The state and movement of water in living organisms, XIXth Symposium. Soc. for Exp. Biol., Swansea, Cambridge University Press, pp. 205-234.

Murray, F.W. 1967 On the computation of saturation vapour pressure. J. of Appl. Meteor. 6:203-204.

National Environment Research Council. 1975. Flood studies report: Vol. I, Hydrological Studies. National Environment Research Council, London. *cited in* H.W. Shen (ed.), Stochastic Approaches to Water Resources: Vol. II, Fort Collins, Colorado, 1976.

National Research Council Canada. 1989. Hydrology of Floods in Canada: A Guide to Planning and Design. Ottawa, Ont.

Patwardhan, A. S., J.L. Nieber and E.L. Johns. 1990. Effective Rainfall Estimation Methods. J. Irrig. Drain. Eng. 116(2): 182-193.

Pearson, K. 1902. On the systematic fitting of curves to observations and measurements. Biometrika, 1(3): 265-303.

Penman, H.L. 1948. Natural evaporation from open water, bare soil and grass. Proc. Roy. Soc. London, A193:120-146.

Priestly, C.H.B., and R.J. Taylor 1972. On the assessment of surface heat flux and evaporation using large scale parameters. Mon. Weath. Rev., 100: 81-92.

Rao, G.R., S.L. Tate and S.B. Varade. 1981. A prediction equation for day night wind ratio correction on reference crop evapotranspiration. Annals of Arid Zone, 20(3), 199-201.

Reich, Brian M. 1973. Log-Pearson Type III and Gumbel Analysis of Floods. Floods and Droughts, Proc. of 2nd International Symposium in Hydrology. Water Resources Publications. pp. 291-303.

Saeed, M. 1986. The estimation of evapotranspiration by some equations under hot and arid conditions. Trans. of the ASCE, 29: 434-8.

Salih, A.M. and U. Sendil. 1984. Evapotranspiration under extremely arid climates. J. Irrig. Drain. Eng. 110(3): 289-303.

Samani, Z.A. and M. Pessarakli. 1986. Estimating potential crop evapotranspiration with minimum data in Arizona. Trans. of the ASAE., 29(2): 522-524.

Saxton, K.E. et al. 1974. Modelling Evapotranspiration and Soil Moisture. Trans. of the ASAE. 17(4): 618-621.

Sharma, H. S. 1979. The Physiography of the Lower Chambal Valley and Its Agricultural Development: A Study in Applied Geomorphology. Concept Publishing Company, New Delhi.

Sikka, D.R. 1973. Integrated Hydrologic and Societal Interactions to Floods and Droughts in India. Floods and Droughts, Proc. of 2nd International Symposium in Hydrology. Water Resource Publications. pp. 237-245

Smedema, L. K. and D.W. Rycroft. 1983. Land Drainage: Planning and Design of Agricultural Drainage Systems. Batsford Academic and Educational, London.

Smith, M. 1991. CROPWAT, a computer program for irrigation planning and management. FAO Irrigation and Drainage Paper 46. FAO, Rome.

Smith, R.E. and H.A. Schreiber. 1973. Point Processes of Seasonal Thunderstorm Rainfall. Part 1. Distribution of Rainfall Events. Water Resour. Res. 9(4): 871-884.

Snyder, R.L. 1992. Equation for evaporation pan to evapotranspiration conversions. J. Irrig. Drain. Eng. 118(6): 977-980.

Stamm, G.G. 1967. Problems and procedures in determining water supply requirements for irrigation projects. *In* Irrigation of Agricultural Lands by Hagan et al Amer. Soc. of Agron II, Madison, WI. Chapter 40.

Stern, R.D. and R. Coe. 1984. A model fitting analysis of daily rainfall data. J. Roy. Statist. Soc. A 147(I):1-34.

Subramaniam, A.R. 1989. Comparison of estimated and observed evapotranspiration of some crops in Maharashtra. *In* Estimation of Areal Evapotranspiration: Proceedings of an International Workshop, Vancouver, B.C., 9-22 August, 1987. T.A. Black, D.L. Spittlehouse, M.D. Novak and D.T. Price (eds.). International Association of Hydrological Sciences, Publication No. 177, Oxfordshire. pp. 229-234.

Talsma, T. 1963. The control of saline groundwater. Meded. Landbovwhogeschool. Wagebghyningen, The Netherlands. 63: 1-68. *cited in* J. van Schilfgaarde, Drainage for Agriculture, #17 in series Agronomy, Am. Soc. of Agron. Inc., Madison, Wisconsin, U.S.A, 1974.

Tetens, O. 1930. Uber einige meteorologische Begriffe. Z. Geophys. 6:297-309.

Thom, A.S. and H.R. Oliver. 1977. On Penman's equation for estimating regional evaporation. Quart. J. Roy. Meteorol. Soc. 103: 345-357.

Thornthwaite, C.W. 1948. An approach toward a rational classification of climate, Geograph. Rev., 38(1): 55-94.

Thornthwaite, C.W, and J.R. Mather. 1955. The Water Balance. Publications in Climatology, Laboratory of Climatology 8(1).

Todorovic, P. and D.A. Woolhiser. 1975. A stochastic model of n-day precipitation. J. Appl. Meteor. 14(1): 17-24.

Todorovic, P. and Yevjevich. 1969. Stochastic Processes of Precipitation. Hydrology Paper 35, Colorado State University, Fort Collins, Colorado. *cited in* J.J. Bogárdi, L. Duckstein, O.H. Rumamba, Practical generation of synthetic rainfall event time series in a semi-arid climatic zone, J. Hydrol., 103: 357-373, 1988.

Turc, L. 1961. Estimation of irrigation water requirements, potential evapotranspiration: A simple climatic formula evolved up to date. Ann. Agron., 12: 13-49.

U.S. Dept. of Agric., Soil Conservation Service. 1970. Irrigation Water Requirements. Tech Release #21. U.S. Department of Agriculture, Soil Conservation Service, Engineering Division, Apr. 1967. Revised Sept. 1970.

U.S. Water Resour. Council. 1982. Guidelines for determining flood flow frequency. Bulletin 17 C., Washington D.C.

van Schilfgaarde, J. 1974. Drainage for Agriculture. #17 in series Agronomy. Am. Society of Agronomy Inc., Madison, Wisconsin, U.S.A.

Weibull, W. 1939. The Phenomenon of Rupture in Solids. Ingeniors Vetenskaps Akademien Handlinga 153: 17. *cited in* D.R. Maidment, Handbook of Hydrology, McGraw-Hill, Inc., New York, 1993.

World Bank. 1974. Appraisal of the Chambal Command Area Development Project (Rajasthan) in India: Report No. 430-N, Asia Projects Department, Washington, D.C. *cited in* S.T. Chieng, Analysis of subsurface drainage design criteria, Chambal Command, Rajasthan, India, Unpublished, 1993.

Wright, J.L. 1982. New evapotranspiration crop coefficients. J. Irrig. Drain. Eng.. 108(1) 57-74.

Wright, J.L. and M.E. Jensen. 1972. Peak Water Requirements of Crops in Southern Idaho. J. Irrig. Drain. Eng. 98(IR2): 193-201.

Zhang, Y. 1982. Plotting Positions of Annual Flood Extremes Considering Extraordinary Values. Water Resour. Res. 18(4): 859-864.

APPENDIX A
Frequently used abbreviations and symbols

Appendix A Frequently used abbreviations and symbols

Abbreviation	Definition	
Cum.	cumulative	
d.f.	degrees of freedom	
evap	Class A pan evaporation	(mmd^{-1})
ET	evapotranspiration	
$ET_{alfalfa}$	alfalfa reference evapotranspiration	(mmd^{-1})
ET_c	crop evapotranspiration	(mmd^{-1})
ET_{JH}	reference evapotranspiration, Jensen-Haise method	(mmd^{-1})
$ET_{JH}*$	reference evapotranspiration, adjusted Jensen-Haise (1.15 ET_{JH})	(mmd^{-1})
$ET_{lysimeter}$	lysimeter measured crop evapotranspiration	(mmd^{-1})
ET_{pan}	evapotranspiration calculated from pan evaporation measurements	(mmd^{-1})
ET_r	reference crop evapotranspiration	(mmd^{-1})
ET_{soil}	evaporation from fallow land	(mmd^{-1})
hmax	maximum relative humidity in percent	
hmean	mean relative humidity in percent	
hmin	minimum relative humidity in percent	
k_c	crop coefficient	
P.	probability	
pdf	probability distribution function	
R_e	effective rainfall	(mm)
R_t	total rainfall	(mm)
sunhr	sunshine hours	(hrs.)
Tmax	maximum daily air temperature	(°C)
Tmean	mean daily air temperature	(°C)
Tmin	minimum daily air temperature	(°C)

wind	wind speed at 2 meters over 24 hrs	(ms^{-1})

Glossary of Hindi Words

Kharif	Monsoon season, June -October
Rabi	Irrigated season, October - March
Zaid	Dry season, March - mid-June

APPENDIX B
SUMMARY OF CLIMATIC DATA, KOTA STATION, 1970-1993

Appendix B Summary of climatic data, Kota station, 1970 - 1993

Table B-1 Temperature summary

Month	Year	Minimum daily temperature (°C)				Maximum daily temperature (°C)			
		Mean	Maximum	Minimum	Std. dev.	Mean	Maximum	Minimum	Std. dev.
Jan.	1971	3.91	9.20	0.40	1.99	22.62	25.80	15.50	2.42
	1972	4.89	9.50	0.00	2.91	24.36	28.80	21.50	1.64
	1973	4.96	14.00	-0.50	3.93	23.65	29.50	19.00	2.63
	1974	5.22	12.40	1.00	3.06	24.03	32.00	18.50	2.70
	1975	5.26	10.50	1.70	2.57	21.96	26.90	19.00	2.07
	1976	8.37	13.30	4.00	2.56	24.65	27.00	19.50	2.22
	1977	6.78	14.40	0.00	3.98	23.90	32.50	17.00	3.70
	1978	6.61	12.80	2.50	2.77	23.64	28.20	20.30	1.95
	1979	8.99	14.20	4.20	3.06	24.09	29.50	18.60	2.78
	1992	7.10	15.00	3.00	3.70	23.26	27.00	19.00	2.34
	1993	8.05	12.00	5.00	2.15	23.55	29.00	18.00	2.77
Feb.	1971	7.49	13.00	1.00	3.38	27.79	33.30	20.70	3.34
	1972	6.19	14.40	0.90	3.85	24.16	32.30	17.00	3.72
	1973	8.31	15.60	2.40	3.45	28.12	36.50	21.50	3.96
	1974	6.69	12.30	0.50	3.60	25.31	32.60	18.00	4.12
	1975	7.45	14.50	1.10	3.45	24.85	31.00	20.30	2.85
	1976	10.09	15.60	5.70	2.56	26.52	32.60	19.00	3.34
	1977	9.31	15.90	4.00	3.46	27.40	38.30	22.00	3.45
	1978	9.21	16.50	2.40	3.99	23.69	32.00	13.70	4.23
	1979	8.57	14.50	1.00	3.36	25.04	31.00	20.50	2.96
	1992	8.43	14.00	5.00	2.25	23.97	33.00	20.00	2.97
	1993	10.57	18.00	4.00	3.49	27.54	35.00	22.00	3.82
Mar.	1971	12.23	19.50	5.40	4.58	33.18	40.30	24.40	5.01
	1972	13.18	20.40	4.20	4.31	33.77	39.50	25.50	4.06
	1973	14.01	25.70	6.50	4.44	32.91	40.30	25.00	4.11
	1974	15.75	24.00	10.20	3.73	34.50	39.00	25.20	3.35
	1975	12.18	17.50	6.50	3.23	31.68	36.10	26.20	2.79
	1976	15.11	22.20	10.70	2.98	32.19	37.00	27.00	2.43
	1977	15.08	20.80	9.50	3.42	34.68	40.50	28.60	3.52
	1978	13.38	18.70	8.90	2.69	31.02	35.40	25.30	2.58
	1979	13.82	23.00	5.20	4.15	31.01	36.70	21.00	3.88
	1992	16.26	25.00	11.00	3.65	32.28	37.00	28.00	2.49
	1993	13.27	26.00	9.00	3.62	29.87	35.00	23.00	3.11
Apr.	1970	21.87	41.80	12.20	5.06	38.80	45.60	1.80	7.61
	1971	20.83	26.00	16.50	2.29	40.23	43.50	34.00	2.58
	1972	18.42	25.00	13.80	3.07	37.23	39.80	31.60	1.73
	1973	23.30	30.00	13.50	2.99	40.67	44.40	36.00	2.63
	1975	19.05	26.50	12.70	3.50	38.40	42.00	32.50	2.25
	1976	21.04	25.50	14.60	3.35	37.37	41.10	31.30	2.89
	1977	22.24	28.30	13.30	3.29	37.45	40.60	32.70	2.29
	1978	21.44	27.00	15.50	3.26	37.66	42.00	14.00	5.15
	1979	21.72	29.50	16.20	3.43	39.10	44.20	32.00	3.07
	1992	20.38	25.00	17.50	1.98	37.07	43.50	31.00	2.92
	1993	19.87	30.00	12.00	4.26	37.80	44.00	32.00	3.86

Table B-1 **Continued**

Month	Year	Minimum daily temperature (°C)				Maximum daily temperature (°C)			
		Mean	Maximum	Minimum	Std. dev.	Mean	Maximum	Minimum	Std. dev.
May	1970	26.77	32.50	21.50	3.01	43.24	46.00	39.00	1.50
	1971	23.44	28.00	17.50	2.77	40.73	43.40	37.00	1.71
	1972	23.42	28.00	18.20	2.75	42.09	45.50	36.00	2.09
	1973	28.32	33.80	21.90	2.60	43.09	46.00	35.80	2.38
	1975	26.26	30.50	20.50	2.44	41.90	44.50	38.50	1.30
	1976	26.16	29.50	21.50	2.25	40.76	43.30	37.20	1.51
	1977	25.22	31.70	19.00	3.63	39.69	43.40	36.50	2.02
	1978	28.34	31.40	22.70	2.49	43.38	45.30	40.70	1.29
	1979	24.06	30.00	19.70	2.97	39.80	43.50	34.20	2.46
	1992	22.91	32.00	18.00	3.05	41.59	44.50	33.00	2.18
	1993	27.55	34.00	18.00	3.41	43.84	47.00	41.00	1.62
Jun.	1970	25.73	29.50	21.00	2.24	39.19	42.50	32.70	2.25
	1971	24.43	28.80	19.50	2.01	36.31	42.40	27.00	3.17
	1972	25.21	29.50	19.50	2.84	41.07	45.00	34.50	2.49
	1973	28.83	34.00	24.80	1.99	39.74	45.70	32.00	2.92
	1974	27.44	31.20	21.20	2.59	39.67	44.00	34.00	2.23
	1975	25.51	30.50	20.00	2.56	38.62	43.50	31.50	2.85
	1976	25.94	31.00	22.00	2.72	36.96	43.10	26.50	4.08
	1977	27.26	30.90	22.00	2.63	38.42	44.50	30.00	4.45
	1978	27.61	32.00	22.70	2.66	39.15	44.50	29.70	4.35
	1979	27.74	32.80	23.60	2.75	40.86	46.00	32.90	3.13
	1992	29.03	35.00	23.00	2.80	43.00	47.00	38.00	2.38
	1993	28.56	35.40	23.40	3.94	40.00	47.10	31.20	4.46
Jul.	1970	24.42	26.50	22.50	1.06	34.39	37.00	30.50	1.81
	1971	22.52	25.00	20.80	1.13	30.68	36.00	24.70	2.91
	1972	23.65	26.40	20.50	1.30	35.22	38.50	27.60	1.88
	1973	25.72	30.00	23.30	1.55	33.28	42.40	29.00	3.51
	1974	25.56	31.00	22.30	2.19	33.90	42.10	27.00	4.34
	1975	24.17	26.00	21.60	1.17	32.64	36.50	28.00	2.57
	1976	26.11	29.50	22.50	1.74	34.95	41.30	31.00	3.03
	1977	25.49	27.30	24.00	0.83	31.47	35.20	26.80	2.13
	1978	25.34	26.70	23.50	0.85	31.68	35.00	28.40	1.50
	1979	26.27	30.30	22.00	1.93	34.75	41.00	26.50	3.87
	1992	27.31	31.00	24.00	2.42	35.66	41.00	26.00	4.42
	1993	25.82	28.00	22.80	1.33	33.18	39.00	26.00	2.90
Aug.	1970	23.25	24.70	22.00	0.71	31.60	34.50	21.50	2.29
	1971	22.21	24.00	19.80	0.96	31.11	34.20	26.50	1.58
	1972	22.49	25.80	20.00	1.38	31.94	40.60	27.50	3.37
	1973	24.76	26.70	22.70	1.02	31.18	34.70	26.00	1.87
	1974	24.65	27.00	21.50	1.34	31.86	35.10	25.50	2.14
	1975	23.57	26.10	21.50	1.02	31.57	36.50	26.20	2.18
	1976	24.23	26.00	23.00	0.67	31.03	34.20	25.20	1.90
	1977	24.45	26.60	22.20	0.89	31.06	33.50	25.70	2.06
	1978	24.48	26.50	22.40	1.07	30.65	33.00	28.00	1.41
	1979	24.40	27.10	22.00	1.36	32.23	36.60	28.00	2.02
	1992	25.05	27.00	24.00	0.91	30.71	38.00	26.00	2.36
	1993	25.39	27.50	23.50	1.21	32.16	36.00	24.00	3.00

Table B-1 **Continued**

Month	Year	Minimum daily temperature (°C)				Maximum daily temperature (°C)			
		Mean	Maximum	Minimum	Std. dev.	Mean	Maximum	Minimum	Std. dev.
Sept.	1970	22.16	23.50	20.60	0.71	30.83	34.30	0.50	5.94
	1971	20.90	23.70	19.10	1.27	32.32	36.20	23.60	2.91
	1972	18.39	23.50	11.50	4.38	34.22	42.00	30.50	2.36
	1973	23.87	25.50	21.70	0.83	31.22	34.50	27.50	1.84
	1974	23.18	25.00	20.00	1.29	35.31	39.00	32.00	2.05
	1975	22.98	28.80	20.10	1.52	31.47	34.00	28.00	1.60
	1976	22.93	35.00	19.00	2.79	32.62	38.80	28.00	2.38
	1977	22.97	25.40	20.00	1.58	31.60	35.50	26.50	2.04
	1978	22.77	24.60	21.00	0.79	32.61	36.00	25.60	2.61
	1979	23.03	26.90	18.90	2.29	35.49	37.70	33.00	1.37
	1992	22.03	27.00	17.00	2.89	31.80	37.00	28.00	2.11
	1993	23.14	24.00	21.50	0.87	32.27	35.00	28.00	1.87
Oct.	1970	16.65	21.00	12.50	2.56	35.00	37.00	33.00	0.95
	1971	15.68	21.20	9.00	3.69	32.75	36.00	27.80	1.98
	1972	13.67	17.50	9.20	2.14	34.82	38.50	26.00	3.28
	1973	16.97	24.00	11.70	3.60	32.22	35.20	20.50	2.93
	1974	19.38	24.30	13.40	3.89	32.65	36.60	24.00	3.10
	1975	18.15	22.60	10.50	3.86	32.15	35.00	24.00	2.51
	1976	17.60	21.50	12.00	2.37	34.76	38.80	32.20	1.47
	1977	18.19	22.80	14.50	2.46	35.22	36.90	30.50	1.30
	1978	16.87	25.40	12.20	3.91	34.39	36.00	30.50	1.20
	1979	20.04	23.50	17.00	1.69	34.86	37.10	27.90	2.02
	1992	17.84	22.00	13.00	2.46	31.16	35.00	22.00	2.85
	1993	17.37	22.40	12.00	2.47	34.45	36.80	27.80	1.98
Nov.	1970	7.25	11.00	2.10	2.50	30.00	37.50	24.90	2.84
	1971	8.01	15.00	5.30	2.12	30.07	32.50	28.50	1.09
	1972	8.61	13.40	5.70	1.57	30.97	33.10	24.40	2.79
	1973	8.49	11.00	4.00	1.95	29.82	32.80	27.20	1.42
	1974	9.89	15.80	5.00	3.30	29.34	32.50	25.50	2.31
	1975	8.20	13.50	4.30	2.21	28.52	31.70	23.50	2.51
	1976	16.48	20.00	11.00	2.55	28.63	33.50	18.00	4.61
	1977	14.76	19.00	10.90	2.01	30.79	36.10	22.50	3.57
	1978	13.90	20.30	5.10	3.52	30.47	35.00	24.00	3.08
	1979	16.70	20.20	13.00	2.13	28.56	34.40	20.00	5.14
	1992	11.42	19.00	7.00	3.06	27.63	31.00	22.00	2.43
	1993	11.63	17.00	0.00	3.64	30.39	35.00	27.20	2.22
Dec.	1970	5.14	9.00	2.30	1.73	26.02	28.50	22.00	1.59
	1971	3.85	7.50	0.00	1.82	25.29	28.00	23.00	1.40
	1972	5.37	10.20	2.00	2.30	25.53	30.50	20.70	2.15
	1973	6.34	12.00	0.50	3.12	23.74	28.00	20.00	2.42
	1974	6.47	13.70	2.00	3.09	23.97	28.80	18.60	2.78
	1975	6.15	11.10	4.00	1.45	26.20	29.00	24.00	1.25
	1976	8.55	15.40	4.50	3.12	24.23	28.90	22.00	1.75
	1977	9.16	14.60	3.90	2.47	26.34	30.00	19.70	2.67
	1978	8.29	16.50	3.00	3.12	24.62	27.60	18.50	2.17
	1979	10.81	15.80	7.50	2.07	24.39	27.70	21.00	1.60
	1992	8.03	11.00	5.00	1.81	24.74	26.00	22.00	1.21
	1993	7.05	10.50	4.00	2.19	25.92	31.00	21.80	2.31

Table B-2 Humidity summary

Month	Year	Minimum daily humidity (%)				Maximum daily humidity (%)			
		Mean	Maximum	Minimum	Std. Dev.	Mean	Maximum	Minimum	Std. dev.
Jan.	1971	33.19	64.00	13.00	13.11	80.39	97.00	61.00	10.55
	1993	6.50	6.50	6.50	0.00	2.00	2.00	2.00	0.00
Feb.	1971	20.29	38.00	4.00	9.97	61.14	90.00	32.00	15.04
Mar.	1971	10.90	23.00	4.00	4.47	44.39	74.00	16.00	15.11
Apr.	1970	8.86	18.00	2.00	3.80	26.93	59.00	15.00	8.99
	1971	15.13	40.00	8.00	7.42	34.03	71.00	21.00	12.66
May	1970	17.97	39.00	7.00	7.40	36.39	64.00	17.00	10.73
	1971	18.65	37.00	5.00	8.53	41.84	78.00	10.00	17.75
Jun.	1970	41.17	91.00	17.00	17.64	62.93	85.00	37.00	12.67
	1971	51.03	98.00	32.00	20.66	72.80	93.00	53.00	12.23
Jul.	1970	52.39	95.00	29.00	14.92	76.03	92.00	59.00	8.16
Aug.	1970	79.06	95.00	60.00	9.67	89.55	97.00	80.00	4.33
Sept.	1970	65.00	96.00	47.00	12.80	87.97	96.00	66.00	5.71
Oct.	1970	26.87	70.00	14.00	12.05	71.65	92.00	47.00	12.62
Nov.	1970	16.30	28.00	10.00	5.13	71.52	89.00	43.00	12.15
Dec.	1970	23.77	44.00	9.00	10.87	73.45	91.00	39.00	15.28

Table B-3 Wind speed summary

Month	Year	Daily wind speed (ms^{-1})			
		Mean	Maximum	Minimum	Std. dev
Jan.	1971	2.80	8.90	1.40	1.40
	1992	2.06	4.30	1.10	0.82
	1993	2.01	4.10	1.00	0.65
Feb.	1971	2.96	6.10	0.60	1.20
	1992	2.60	5.10	1.60	0.77
	1993	2.57	5.00	1.10	1.19
Mar.	1971	3.06	6.30	1.90	1.00
	1992	3.24	5.70	0.90	1.29
	1993	3.27	6.30	1.10	1.21
Apr.	1970	4.91	10.80	3.20	1.48
	1971	5.05	10.80	2.30	2.02
	1992	3.20	5.90	1.20	1.15
May	1970	7.68	13.40	4.00	2.63
	1971	6.90	11.30	3.10	2.29
	1992	4.59	9.30	2.50	1.68
Jun.	1970	9.48	16.80	4.80	2.80
	1971	9.39	16.30	2.30	3.16
	1992	5.79	10.20	2.50	2.37
Jul.	1970	9.24	13.80	3.10	3.00
	1992	5.38	8.70	2.40	1.54
Aug.	1970	5.45	10.30	2.60	1.99
	1992	3.61	8.00	1.50	1.22
Sept.	1970	4.75	9.50	1.60	1.91
	1992	2.61	6.20	0.90	1.05
Oct.	1970	2.85	5.10	1.80	0.91
	1992	1.95	5.30	0.70	1.16
Nov.	1970	1.71	2.90	1.10	0.39
	1992	1.51	2.90	0.90	0.55
Dec.	1970	1.85	2.90	1.10	0.60
	1992	1.53	6.60	0.30	1.07

Table B-4 Sunshine summary

Month	Year	Daily sunshine hours			
		Mean	Maximum	Minimum	Std. dev.
Jan.	1971	8.85	10.00	2.70	1.82
	1992	8.34	9.50	2.00	1.59
	1993	8.96	10.00	6.50	0.90
Feb.	1971	10.38	10.80	9.00	0.42
	1992	9.39	10.50	4.50	1.34
	1993	9.16	10.50	4.00	1.65
Mar.	1971	9.87	10.60	8.70	0.41
	1992	8.60	10.00	6.00	1.09
	1993	9.19	10.30	1.50	1.81
Apr.	1970	9.72	16.60	2.90	2.52
	1971	10.28	11.90	8.60	0.92
	1992	10.17	11.00	6.00	1.04
May	1970	9.48	12.20	4.00	2.27
	1971	10.10	12.10	5.50	1.69
	1992	9.80	11.00	6.00	1.19
Jun.	1970	8.27	12.40	0.20	3.60
	1971	7.78	11.70	0.50	3.46
	1992	10.24	11.70	6.50	1.28
Jul.	1970	7.71	12.00	0.40	3.68
Aug.	1970	4.35	11.70	0.90	2.97
Sept.	1970	6.09	10.10	1.00	3.30
	1992	8.10	10.40	2.80	2.20
Oct.	1970	10.18	11.00	7.60	0.76
	1992	9.33	10.50	4.30	1.59
Nov.	1970	10.26	10.70	9.70	0.27
	1992	9.46	12.00	7.50	0.73
Dec.	1970	9.76	10.20	9.00	0.36
	1992	8.40	9.40	4.30	0.94

Table B-5 Pan evaporation summary

		Daily pan evaporation (mmd^{-1})				Monthly pan evaporation (mm)		
Month	Year	Mean	Maximum	Minimum	Std. dev	Total	Mean	% of mean
Jan.	1971	2.79	3.85	0.72	0.66	86.38	93.51	92.38
	1972	2.52	3.80	0.90	0.53	78.10	93.51	83.52
	1973	3.49	6.90	2.60	0.84	108.30	93.51	115.82
	1974	3.14	6.80	1.80	1.10	97.40	93.51	104.16
	1975	2.61	3.00	2.00	0.25	80.80	93.51	86.41
	1976	2.72	5.80	1.30	0.95	84.40	93.51	90.26
	1977	2.82	4.90	0.00	1.05	87.40	93.51	93.47
	1978	2.80	4.00	1.60	0.55	86.84	93.51	92.87
	1979	3.16	6.00	1.60	0.93	97.90	93.51	104.69
	1980	2.93	4.50	1.50	0.59	84.90	93.51	90.79
	1981	4.14	6.20	1.10	1.22	128.30	93.51	137.20
	1984	3.33	5.70	1.70	0.97	103.10	93.51	110.26
	1985	2.69	3.60	1.60	0.54	83.40	93.51	89.19
	1986	2.28	3.70	0.70	0.67	70.70	93.51	75.61
	1987	2.87	4.00	1.50	0.54	89.00	93.51	95.18
	1988	2.19	4.00	1.30	0.68	67.90	93.51	72.61
	1989	2.72	3.90	1.70	0.47	84.30	93.51	90.15
	1990	4.28	7.30	2.00	1.33	132.60	93.51	141.80
	1991	3.98	5.20	1.90	0.73	123.50	93.51	132.07
	1992	3.50	5.30	1.40	0.90	108.40	93.51	115.92
	1993	3.71	5.50	1.80	0.81	114.90	93.51	122.87
Feb.	1971	4.62	8.68	2.55	1.27	129.33	121.30	106.62
	1972	3.84	7.10	0.80	1.38	111.40	121.30	91.84
	1973	4.91	12.80	3.30	1.85	137.50	121.30	113.36
	1974	4.04	5.40	2.50	0.80	113.00	121.30	93.16
	1975	3.83	6.00	2.50	0.83	107.20	121.30	88.38
	1976	4.01	6.40	1.70	1.31	116.20	121.30	95.80
	1977	3.76	6.20	1.40	0.89	105.40	121.30	86.89
	1978	3.71	6.70	1.50	1.07	104.00	121.30	85.74
	1979	3.76	5.40	2.00	0.93	105.30	121.30	86.81
	1980	4.50	7.80	2.70	1.38	130.40	121.30	107.50
	1981	5.63	8.10	3.80	1.27	157.60	121.30	129.93
	1983	5.24	8.30	2.60	1.52	125.70	121.30	103.63
	1984	4.48	9.80	2.40	1.41	129.90	121.30	107.09
	1985	4.95	9.50	2.50	1.91	138.70	121.30	114.34
	1986	3.54	6.30	1.00	1.21	99.10	121.30	81.70
	1987	4.19	9.10	2.20	1.36	117.40	121.30	96.78
	1988	4.50	7.20	2.20	1.30	130.40	121.30	107.50
	1989	4.41	5.50	2.70	0.72	123.50	121.30	101.81
	1990	4.43	6.00	1.70	1.07	123.90	121.30	102.14
	1991	4.17	5.60	2.40	0.75	116.70	121.30	96.21
	1992	4.57	8.80	2.10	1.35	132.60	121.30	109.32
	1993	5.34	8.00	2.40	1.68	149.60	121.30	123.33

Table B-5 **Continued**

Month	Year	Daily pan evaporation (mmd^{-1})				Monthly pan evaporation (mm)		
		Mean	Maximum	Minimum	Std. dev	Total	Mean	% of mean
Mar.	1971	7.74	11.81	4.63	1.77	239.97	220.41	108.87
	1972	7.08	11.50	4.80	1.76	219.50	220.41	99.59
	1973	7.49	13.70	3.80	2.24	232.20	220.41	105.35
	1974	7.08	12.20	3.40	1.96	219.49	220.41	99.58
	1975	6.23	8.80	4.10	1.25	193.00	220.41	87.56
	1976	6.61	9.70	3.90	1.32	205.00	220.41	93.01
	1977	6.58	10.30	3.80	1.58	203.90	220.41	92.51
	1978	0.64	6.40	0.00	1.75	19.93	220.41	9.04
	1979	6.92	11.20	3.60	1.75	214.50	220.41	97.32
	1980	10.73	24.40	3.30	5.60	332.50	220.41	150.86
	1981	7.49	11.20	3.90	1.52	232.30	220.41	105.39
	1983	9.16	16.50	4.80	2.67	283.90	220.41	128.81
	1984	8.84	14.80	3.20	2.83	274.10	220.41	124.36
	1985	7.55	11.90	3.30	2.18	233.90	220.41	106.12
	1986	5.91	9.50	2.60	1.41	183.30	220.41	83.16
	1987	7.03	12.00	3.50	2.22	217.90	220.41	98.86
	1988	7.84	12.70	1.90	2.30	243.10	220.41	110.29
	1989	5.65	6.90	3.70	0.77	175.10	220.41	79.44
	1990	6.22	9.20	3.80	1.42	192.80	220.41	87.47
	1991	8.04	12.60	4.10	2.24	249.30	220.41	113.11
	1992	7.07	9.30	4.00	1.20	219.10	220.41	99.41
	1993	8.91	13.40	4.80	2.46	276.11	220.41	125.27
Apr.	1970	10.97	18.57	7.08	2.96	318.14	348.25	91.35
	1971	12.12	18.16	8.91	2.50	363.53	348.25	104.39
	1972	9.71	15.30	3.10	2.29	291.20	348.25	83.62
	1973	11.92	16.60	9.20	2.10	357.50	348.25	102.66
	1975	8.72	11.90	7.50	1.12	261.50	348.25	75.09
	1976	10.16	16.60	3.70	2.79	304.70	348.25	87.49
	1977	8.93	13.20	4.90	1.99	268.00	348.25	76.96
	1978	10.05	17.60	0.00	2.93	301.60	348.25	86.60
	1979	12.35	19.61	7.10	3.19	370.61	348.25	106.42
	1980	13.91	28.90	7.70	4.45	417.20	348.25	119.80
	1981	14.74	21.10	8.90	3.76	427.60	348.25	122.79
	1983	10.79	17.30	2.30	3.92	323.60	348.25	92.92
	1984	16.61	32.30	8.80	5.41	498.30	348.25	143.09
	1985	11.05	16.70	5.40	2.80	331.60	348.25	95.22
	1986	9.86	16.10	6.80	2.40	295.70	348.25	84.91
	1987	15.67	26.00	7.80	4.75	454.35	348.25	130.47
	1988	11.42	17.50	7.50	2.07	342.60	348.25	98.38
	1989	9.74	14.30	5.00	2.39	292.10	348.25	83.88
	1990	12.52	18.50	7.30	3.22	375.70	348.25	107.88
	1991	11.18	15.10	4.80	2.53	335.40	348.25	96.31
	1992	12.19	17.90	8.30	2.19	365.80	348.25	105.04
	1993	14.80	25.20	6.60	4.17	444.10	348.25	127.52

Table B-5 Continued

Month	Year	Daily pan evaporation (mmd^{-1})				Monthly pan evaporation (mm)		
		Mean	Maximum	Minimum	Std. dev	Total	Mean	% of mean
May	1970	15.41	43.41	6.19	6.22	477.70	467.35	102.21
	1971	13.21	20.72	8.84	3.19	409.41	467.35	87.60
	1972	13.29	21.70	7.30	3.73	411.90	467.35	88.14
	1973	15.58	23.90	4.90	3.84	482.90	467.35	103.33
	1975	13.58	22.60	8.30	3.16	420.90	467.35	90.06
	1976	13.76	20.70	7.50	2.73	426.50	467.35	91.26
	1977	10.40	16.10	6.80	2.42	322.42	467.35	68.99
	1978	15.63	19.10	11.10	2.26	484.50	467.35	103.67
	1979	12.37	18.00	7.30	2.57	383.41	467.35	82.04
	1980	17.54	29.20	9.60	3.93	543.60	467.35	116.32
	1981	19.00	23.10	8.10	3.11	589.00	467.35	126.03
	1983	16.54	29.40	7.90	4.74	512.80	467.35	109.73
	1984	17.14	34.50	9.20	4.69	531.20	467.35	113.66
	1985	13.85	19.50	9.40	2.54	429.40	467.35	91.88
	1986	11.81	17.80	5.90	2.98	366.10	467.35	78.34
	1987	19.49	26.40	14.00	2.97	604.20	467.35	129.28
	1988	16.75	21.30	10.10	3.09	519.20	467.35	111.09
	1989	13.16	16.20	8.10	1.82	407.90	467.35	87.28
	1990	15.14	19.40	8.10	2.91	469.20	467.35	100.40
	1991	15.66	19.50	12.30	1.89	485.40	467.35	103.86
	1992	13.94	21.00	8.60	2.84	432.20	467.35	92.48
	1993	22.37	28.70	6.30	3.35	693.41	467.35	148.37
Jun.	1970	12.79	42.14	3.91	6.53	383.63	377.57	101.61
	1971	10.24	17.63	0.00	4.74	307.07	377.57	81.33
	1972	12.41	17.10	5.00	3.53	372.20	377.57	98.58
	1973	13.27	19.70	1.20	3.72	398.20	377.57	105.46
	1974	12.75	24.50	7.80	3.26	382.60	377.57	101.33
	1975	10.68	17.90	0.00	3.81	320.30	377.57	84.83
	1976	10.46	15.23	0.00	3.66	313.84	377.57	83.12
	1977	10.00	17.90	0.00	4.35	300.10	377.57	79.48
	1978	10.95	18.50	0.00	5.18	328.60	377.57	87.03
	1979	13.74	26.40	5.90	4.63	412.11	377.57	109.15
	1980	13.86	31.90	0.00	7.61	415.70	377.57	110.10
	1981	21.91	27.40	16.10	3.69	153.40	377.57	40.63
	1983	17.41	24.60	5.70	5.26	522.40	377.57	138.36
	1984	14.29	24.60	1.50	5.28	428.80	377.57	113.57
	1985	13.89	19.30	5.80	3.22	416.60	377.57	110.34
	1986	12.44	20.20	4.60	4.65	373.10	377.57	98.82
	1987	13.56	19.70	3.80	4.91	406.70	377.57	107.72
	1988	10.86	18.30	0.00	5.86	325.70	377.57	86.26
	1989	11.45	17.10	7.90	2.47	343.40	377.57	90.95
	1990	13.16	18.40	2.50	3.52	394.80	377.57	104.56
	1991	14.94	21.80	5.70	3.50	448.30	377.57	118.73
	1992	16.41	20.20	3.70	3.11	492.40	377.57	130.41
	1993	7.34	23.50	0.00	6.40	220.10	377.57	58.29

Table B-5 **Continued**

Month	Year	Daily pan evaporation (mmd^{-1})				Monthly pan evaporation (mm)		
		Mean	Maximum	Minimum	Std. dev	Total	Mean	% of mean
Jul.	1970	8.72	23.64	1.62	4.00	270.30	221.60	121.98
	1971	3.59	13.31	0.00	3.28	111.19	221.60	50.18
	1972	9.61	15.60	3.00	2.87	297.90	221.60	134.43
	1973	5.31	12.80	0.30	3.11	164.60	221.60	74.28
	1974	4.83	13.30	0.00	4.46	149.70	221.60	67.55
	1975	3.80	7.90	0.00	2.59	117.90	221.60	53.20
	1976	7.05	14.25	0.00	3.74	218.51	221.60	98.61
	1977	3.57	12.60	0.00	3.00	110.70	221.60	49.95
	1978	3.35	7.90	0.00	2.34	103.90	221.60	46.89
	1979	7.75	22.70	0.00	6.32	240.40	221.60	108.48
	1980	6.49	12.90	0.00	3.33	201.20	221.60	90.79
	1983	6.45	14.10	0.10	3.75	200.10	221.60	90.30
	1984	8.43	18.50	0.50	3.51	261.20	221.60	117.87
	1985	8.51	17.00	0.90	4.33	263.80	221.60	119.04
	1986	4.90	13.30	0.00	4.00	152.00	221.60	68.59
	1987	13.52	20.50	5.80	4.15	419.20	221.60	189.17
	1988	4.65	10.30	0.00	2.54	144.30	221.60	65.12
	1989	7.14	10.50	0.00	2.43	221.20	221.60	99.82
	1990	5.42	10.00	0.00	2.91	168.10	221.60	75.86
	1991	9.25	23.40	0.00	6.08	286.90	221.60	129.47
	1992	10.51	19.50	0.00	5.91	325.70	221.60	146.98
	1993	7.31	17.10	0.00	4.82	226.50	221.60	102.21
Aug.	1970	4.67	25.12	0.69	4.21	144.71	142.16	101.79
	1971	4.69	9.83	0.00	2.09	145.46	142.16	102.32
	1972	4.88	12.70	0.00	3.51	151.20	142.16	106.36
	1973	3.39	7.70	0.00	2.02	105.10	142.16	73.93
	1974	3.77	8.80	0.00	2.48	116.80	142.16	82.16
	1975	3.21	7.70	0.00	2.28	99.50	142.16	69.99
	1976	4.12	7.95	0.00	1.59	127.64	142.16	89.79
	1977	3.26	6.70	0.00	2.04	101.20	142.16	71.19
	1978	2.37	5.60	0.00	1.89	73.40	142.16	51.63
	1979	5.45	13.60	0.00	2.57	168.90	142.16	118.81
	1980	4.67	10.60	0.00	2.64	144.90	142.16	101.93
	1983	5.29	24.00	0.10	4.64	164.10	142.16	115.43
	1984	5.90	16.80	0.50	4.33	182.80	142.16	128.59
	1985	3.86	7.80	0.20	1.85	119.80	142.16	84.27
	1986	3.39	6.80	0.80	1.58	105.00	142.16	73.86
	1987	12.45	21.90	0.00	5.81	385.90	142.16	271.45
	1988	3.44	5.40	0.30	1.44	106.60	142.16	74.99
	1989	4.04	8.40	0.00	2.25	125.30	142.16	88.14
	1990	4.08	7.30	0.00	1.98	126.40	142.16	88.91
	1991	3.83	8.20	0.00	2.64	118.80	142.16	83.57
	1992	3.42	9.70	0.00	2.42	106.10	142.16	74.63
	1993	6.71	14.10	0.00	3.62	208.00	142.16	146.31

Table B-5 Continued

Month	Year	Daily pan evaporation (mmd^{-1})				Monthly pan evaporation (mm)		
		Mean	Maximum	Minimum	Std. dev	Total	Mean	% of mean
Sept.	1970	4.65	11.25	0.35	1.99	139.56	151.83	91.92
	1971	0.23	3.98	0.00	0.88	6.85	151.83	4.51
	1972	5.35	11.90	1.50	1.86	160.60	151.83	105.78
	1973	3.41	7.80	0.10	1.82	102.44	151.83	67.47
	1974	6.24	8.50	3.00	1.27	187.30	151.83	123.36
	1975	3.58	7.60	0.00	1.63	107.40	151.83	70.74
	1976	5.05	9.17	0.00	2.03	151.46	151.83	99.76
	1977	3.70	6.70	0.00	1.81	111.05	151.83	73.14
	1978	4.44	7.50	0.00	1.70	133.20	151.83	87.73
	1979	8.47	26.90	5.70	3.84	254.06	151.83	167.33
	1980	7.14	12.70	0.00	2.65	214.20	151.83	141.08
	1983	5.91	16.20	1.10	2.70	177.40	151.83	116.84
	1984	5.32	15.00	1.30	2.83	159.50	151.83	105.05
	1985	4.56	6.50	1.60	1.36	136.90	151.83	90.17
	1986	5.67	9.00	3.70	1.18	170.20	151.83	112.10
	1987	8.08	13.20	1.00	2.80	242.40	151.83	159.65
	1988	4.76	6.80	0.00	1.44	142.80	151.83	94.05
	1989	5.79	8.10	2.90	1.20	173.60	151.83	114.34
	1990	5.10	9.10	0.00	2.12	152.90	151.83	100.70
	1991	4.94	6.80	0.00	1.79	148.10	151.83	97.54
	1992	4.72	7.60	1.00	1.37	141.70	151.83	93.33
	1993	4.22	9.90	0.60	2.56	126.70	151.83	83.45
Oct.	1970	0.00	0.00	0.00	0.00	0.00	159.49	0.00
	1971	0.00	0.00	0.00	0.00	0.00	159.49	0.00
	1972	5.24	8.30	2.90	1.05	162.30	159.49	101.76
	1973	4.19	6.70	1.10	1.61	129.80	159.49	81.38
	1974	4.20	7.10	0.00	1.94	130.30	159.49	81.70
	1975	4.06	6.00	0.00	1.15	125.80	159.49	78.88
	1976	5.82	8.36	2.90	1.51	180.32	159.49	113.06
	1977	4.68	7.00	2.20	0.86	145.10	159.49	90.98
	1978	5.21	6.80	3.00	0.96	161.40	159.49	101.20
	1979	6.65	9.00	3.70	1.29	206.30	159.49	129.35
	1980	6.51	10.10	3.20	1.70	201.70	159.49	126.47
	1982	5.97	7.70	2.90	1.35	101.50	159.49	63.64
	1983	4.35	6.80	0.10	1.68	135.00	159.49	84.64
	1984	4.86	8.60	0.50	1.71	150.80	159.49	94.55
	1985	3.05	6.00	0.10	1.45	94.50	159.49	59.25
	1986	5.50	8.80	3.80	1.31	170.50	159.49	106.90
	1987	4.94	10.70	1.10	2.10	153.10	159.49	95.99
	1988	3.83	4.90	0.20	0.93	118.70	159.49	74.42
	1989	6.04	7.60	3.70	1.02	187.30	159.49	117.44
	1990	7.10	9.30	4.90	1.27	220.10	159.49	138.00
	1991	5.57	7.60	3.50	0.97	172.80	159.49	108.35
	1992	4.24	5.80	0.00	1.50	131.50	159.49	82.45
	1993	6.85	11.50	3.70	1.98	212.40	159.49	133.17

Table B-5 **Continued**

Month	Year	Daily pan evaporation (mmd^{-1})				Monthly pan evaporation (mm)		
		Mean	Maximum	Minimum	Std. dev	Total	Mean	% of mean
Nov.	1970	3.25	5.59	0.00	1.46	97.55	114.33	85.32
	1971	2.83	4.20	0.00	1.22	84.80	114.33	74.17
	1972	4.17	8.10	2.20	1.04	125.00	114.33	109.33
	1973	3.42	5.60	0.60	1.19	102.50	114.33	89.65
	1974	3.53	4.60	2.50	0.51	105.80	114.33	92.54
	1975	3.45	5.70	2.40	0.65	103.50	114.33	90.53
	1976	3.11	5.46	0.00	1.39	93.35	114.33	81.65
	1977	3.71	4.90	1.00	0.93	111.30	114.33	97.35
	1978	4.21	6.40	1.90	0.97	126.20	114.33	110.38
	1979	3.02	7.30	0.00	2.23	90.70	114.33	79.33
	1980	4.95	8.40	3.00	1.33	148.60	114.33	129.97
	1983	4.25	9.20	1.30	1.83	127.50	114.33	111.52
	1984	3.71	5.10	0.80	0.97	111.30	114.33	97.35
	1985	3.19	5.90	1.80	0.80	95.80	114.33	83.79
	1986	3.71	5.70	2.20	0.83	111.20	114.33	97.26
	1987	2.54	5.30	0.50	1.09	76.30	114.33	66.74
	1988	3.12	4.10	1.80	0.64	93.70	114.33	81.96
	1989	4.11	6.70	1.90	1.02	123.30	114.33	107.85
	1990	5.11	6.80	2.30	0.95	153.20	114.33	134.00
	1991	4.70	7.80	1.00	1.47	141.00	114.33	123.33
	1992	4.05	5.50	2.30	0.75	121.60	114.33	106.36
	1993	5.70	10.10	2.10	1.84	171.00	114.33	149.57
Dec.	1970	2.92	4.48	1.98	0.58	90.54	91.45	99.00
	1971	2.54	3.50	1.80	0.49	78.60	91.45	85.95
	1972	2.68	4.30	1.60	0.59	83.20	91.45	90.98
	1973	2.36	3.80	0.70	0.71	73.30	91.45	80.15
	1974	2.32	3.10	1.60	0.39	72.00	91.45	78.73
	1975	2.88	5.40	0.50	0.93	89.30	91.45	97.65
	1976	3.48	30.01	1.50	4.98	107.99	91.45	118.09
	1977	2.54	3.80	1.10	0.73	78.60	91.45	85.95
	1978	2.56	3.50	0.60	0.64	79.40	91.45	86.82
	1979	2.46	4.70	0.00	0.93	73.80	91.45	80.70
	1980	3.69	5.60	1.60	1.03	114.30	91.45	124.99
	1982	2.94	5.70	0.30	1.39	85.20	91.45	93.17
	1983	3.54	6.10	2.20	0.79	109.60	91.45	119.85
	1984	2.62	4.60	1.30	0.83	81.10	91.45	88.68
	1985	2.59	7.90	1.20	1.18	80.30	91.45	87.81
	1986	2.70	5.40	1.40	0.74	83.70	91.45	91.53
	1987	1.79	3.30	0.30	0.73	55.50	91.45	60.69
	1988	2.25	3.10	1.50	0.40	69.60	91.45	76.11
	1989	3.16	4.10	2.10	0.51	98.10	91.45	107.27
	1990	4.39	8.70	2.20	1.41	136.20	91.45	148.93
	1991	4.02	7.30	1.00	1.35	124.60	91.45	136.25
	1992	3.58	6.80	1.10	1.23	111.00	91.45	121.38
	1993	3.91	14.10	0.40	2.96	121.20	91.45	132.53

Table B-6 Rainfall summary

Month	Year	Daily rainfall (mmd^{-1})				Monthly rainfall (mm)		
		Mean	Maximum	Minimum	Std. dev.	Total	Mean	% of mean
Jan.	1971	0.03	1.00	0.00	0.18	1.00	2.13	46.95
	1972	0.00	0.00	0.00	0.00	0.00	2.13	0.00
	1973	0.00	0.00	0.00	0.00	0.00	2.13	0.00
	1974	0.00	0.00	0.00	0.00	0.00	2.13	0.00
	1975	0.02	0.70	0.00	0.13	0.70	2.13	32.86
	1976	0.45	9.80	0.00	1.85	13.80	2.13	647.89
	1977	0.21	5.20	0.00	0.94	6.50	2.13	305.16
	1978	0.00	0.00	0.00	0.00	0.00	2.13	0.00
	1979	0.00	0.00	0.00	0.00	0.00	2.13	0.00
	1980	0.00	0.00	0.00	0.00	0.00	2.13	0.00
	1981	0.13	2.00	0.00	0.45	4.00	2.13	187.79
	1984	0.18	3.60	0.00	0.71	5.70	2.13	267.61
	1985	0.13	4.00	0.00	0.72	4.00	2.13	187.79
	1986	0.00	0.00	0.00	0.00	0.00	2.13	0.00
	1987	0.00	0.00	0.00	0.00	0.00	2.13	0.00
	1988	0.00	0.00	0.00	0.00	0.00	2.13	0.00
	1989	0.35	10.80	0.00	1.94	10.80	2.13	507.04
	1990	0.00	0.00	0.00	0.00	0.00	2.13	0.00
	1991	0.00	0.00	0.00	0.00	0.00	2.13	0.00
	1992	0.00	0.00	0.00	0.00	0.00	2.13	0.00
	1993	0.00	0.00	0.00	0.00	0.00	2.13	0.00
Feb.	1971	0.07	2.00	0.00	0.38	2.00	5.55	36.04
	1972	0.32	9.20	0.00	1.71	9.20	5.55	165.77
	1973	0.00	0.00	0.00	0.00	0.00	5.55	0.00
	1974	0.00	0.00	0.00	0.00	0.00	5.55	0.00
	1975	0.00	0.00	0.00	0.00	0.00	5.55	0.00
	1976	0.00	0.00	0.00	0.00	0.00	5.55	0.00
	1977	0.18	3.00	0.00	0.63	5.10	5.55	91.89
	1978	0.53	10.80	0.00	2.15	14.80	5.55	266.67
	1979	0.10	2.80	0.00	0.53	2.80	5.55	50.45
	1980	0.03	1.00	0.00	0.19	1.00	5.55	18.02
	1981	0.00	0.00	0.00	0.00	0.00	5.55	0.00
	1983	0.00	0.00	0.00	0.00	0.00	5.55	0.00
	1984	0.00	0.00	0.00	0.00	0.00	5.55	0.00
	1985	0.00	0.00	0.00	0.00	0.00	5.55	0.00
	1986	2.23	58.10	0.00	10.98	62.30	5.55	1122.52
	1987	0.00	0.00	0.00	0.00	0.00	5.55	0.00
	1988	0.00	0.00	0.00	0.00	0.00	5.55	0.00
	1989	0.00	0.00	0.00	0.00	0.00	5.55	0.00
	1990	0.69	6.60	0.00	1.66	19.30	5.55	347.75
	1991	0.00	0.00	0.00	0.00	0.00	5.55	0.00
	1992	0.00	0.00	0.00	0.00	0.00	5.55	0.00
	1993	0.00	0.00	0.00	0.00	0.00	5.55	0.00

Table B-6 **Continued**

Month	Year	Daily rainfall (mmd^{-1})				Monthly rainfall (mm)		
		Mean	Maximum	Minimum	Std. dev.	Total	Mean	% of mean
Mar.	1971	0.00	0.00	0.00	0.00	0.00	1.87	0.00
	1972	0.00	0.00	0.00	0.00	0.00	1.87	0.00
	1973	0.00	0.00	0.00	0.00	0.00	1.87	0.00
	1974	0.00	0.00	0.00	0.00	0.00	1.87	0.00
	1975	0.01	0.40	0.00	0.07	0.40	1.87	21.39
	1976	0.00	0.00	0.00	0.00	0.00	1.87	0.00
	1977	0.00	0.00	0.00	0.00	0.00	1.87	0.00
	1978	0.34	10.60	0.00	1.90	10.60	1.87	566.84
	1979	0.27	8.00	0.00	1.44	8.40	1.87	449.20
	1980	0.02	0.70	0.00	0.13	0.70	1.87	37.43
	1981	0.10	2.80	0.00	0.50	3.10	1.87	165.78
	1983	0.00	0.00	0.00	0.00	0.00	1.87	0.00
	1984	0.00	0.00	0.00	0.00	0.00	1.87	0.00
	1985	0.02	0.50	0.00	0.09	0.50	1.87	26.74
	1986	0.00	0.00	0.00	0.00	0.00	1.87	0.00
	1987	0.00	0.00	0.00	0.00	0.00	1.87	0.00
	1988	0.30	5.70	0.00	1.12	9.40	1.87	502.67
	1989	0.18	3.20	0.00	0.72	5.70	1.87	304.81
	1990	0.00	0.00	0.00	0.00	0.00	1.87	0.00
	1991	0.00	0.00	0.00	0.00	0.00	1.87	0.00
	1992	0.00	0.00	0.00	0.00	0.00	1.87	0.00
	1993	0.12	3.60	0.00	0.65	3.60	1.87	192.51
Apr.	1970	0.00	0.00	0.00	0.00	0.00	2.01	0.00
	1971	0.00	0.00	0.00	0.00	0.00	2.01	0.00
	1972	0.00	0.00	0.00	0.00	0.00	2.01	0.00
	1973	0.00	0.00	0.00	0.00	0.00	2.01	0.00
	1975	0.00	0.00	0.00	0.00	0.00	2.01	0.00
	1976	0.04	1.10	0.00	0.20	1.30	2.01	64.68
	1977	0.41	8.20	0.00	1.64	12.20	2.01	606.97
	1978	0.00	0.00	0.00	0.00	0.00	2.01	0.00
	1979	0.00	0.00	0.00	0.00	0.00	2.01	0.00
	1980	0.00	0.00	0.00	0.00	0.00	2.01	0.00
	1981	0.11	3.20	0.00	0.58	3.20	2.01	159.20
	1983	0.25	6.90	0.00	1.26	7.40	2.01	368.16
	1984	0.00	0.00	0.00	0.00	0.00	2.01	0.00
	1985	0.11	3.20	0.00	0.58	3.20	2.01	159.20
	1986	0.00	0.00	0.00	0.00	0.00	2.01	0.00
	1987	0.00	0.00	0.00	0.00	0.00	2.01	0.00
	1988	0.05	0.80	0.00	0.20	1.60	2.01	79.60
	1989	0.00	0.00	0.00	0.00	0.00	2.01	0.00
	1990	0.00	0.00	0.00	0.00	0.00	2.01	0.00
	1991	0.55	14.00	0.00	2.56	16.60	2.01	825.87
	1992	0.00	0.00	0.00	0.00	0.00	2.01	0.00
	1993	0.00	0.00	0.00	0.00	0.00	2.01	0.00

Table B-6 **Continued**

Month	Year	Daily rainfall (mmd^{-1})				Monthly rainfall (mm)		
		Mean	Maximum	Minimum	Std. dev.	Total	Mean	% of mean
May	1970	0.25	4.40	0.00	0.88	7.60	2.01	378.11
	1971	1.04	17.60	0.00	3.32	32.30	9.66	334.37
	1972	0.00	0.00	0.00	0.00	0.00	9.66	0.00
	1973	0.00	0.00	0.00	0.00	0.00	9.66	0.00
	1975	0.17	5.20	0.00	0.93	5.20	9.66	53.83
	1976	0.71	18.20	0.00	3.31	21.90	9.66	226.71
	1977	0.84	11.00	0.00	2.35	26.00	9.66	269.15
	1978	0.00	0.00	0.00	0.00	0.00	9.66	0.00
	1979	0.97	21.80	0.00	3.97	30.00	9.66	310.56
	1980	0.19	6.00	0.00	1.08	6.00	9.66	62.11
	1981	0.10	1.50	0.00	0.37	3.00	9.66	31.06
	1983	1.25	28.60	0.00	5.29	38.70	9.66	400.62
	1984	0.00	0.00	0.00	0.00	0.00	9.66	0.00
	1985	0.00	0.00	0.00	0.00	0.00	9.66	0.00
	1986	0.00	0.00	0.00	0.00	0.00	9.66	0.00
	1987	0.07	2.30	0.00	0.41	2.30	9.66	23.81
	1988	0.04	1.10	0.00	0.20	1.10	9.66	11.39
	1989	0.00	0.00	0.00	0.00	0.00	9.66	0.00
	1990	0.42	9.10	0.00	1.71	13.10	9.66	135.61
	1991	0.00	0.00	0.00	0.00	0.00	9.66	0.00
	1992	0.60	9.40	0.00	2.32	18.60	9.66	192.55
	1993	0.00	0.00	0.00	0.00	0.00	9.66	0.00
Jun.	1970	3.85	79.00	0.00	14.69	115.50	80.00	144.38
	1971	7.28	56.10	0.00	14.62	218.50	80.00	273.13
	1972	1.01	7.60	0.00	2.22	30.30	80.00	37.88
	1973	0.47	14.00	0.00	2.56	14.00	80.00	17.50
	1974	1.01	12.40	0.00	2.88	30.20	80.00	37.75
	1975	3.74	37.20	0.00	9.95	112.30	80.00	140.38
	1976	3.18	24.80	0.00	6.48	95.30	80.00	119.13
	1977	4.21	78.00	0.00	14.44	126.20	80.00	157.75
	1978	5.28	67.60	0.00	13.40	158.40	80.00	198.00
	1979	0.85	13.20	0.00	2.60	25.40	80.00	31.75
	1980	6.81	127.00	0.00	23.72	204.30	80.00	255.38
	1981	0.00	0.00	0.00	0.00	0.00	80.00	0.00
	1983	1.00	10.20	0.00	2.83	29.90	80.00	37.38
	1984	0.40	12.00	0.00	2.19	12.00	80.00	15.00
	1985	0.47	7.80	0.00	1.73	14.10	80.00	17.63
	1986	1.40	18.20	0.00	4.14	41.90	80.00	52.38
	1987	1.77	24.30	0.00	5.29	53.20	80.00	66.50
	1988	7.33	62.00	0.00	17.35	219.80	80.00	274.75
	1989	1.80	19.80	0.00	4.52	54.10	80.00	67.63
	1990	2.89	50.50	0.00	9.70	86.80	80.00	108.50
	1991	0.39	11.70	0.00	2.14	11.70	80.00	14.63
	1992	0.10	3.00	0.00	0.55	3.00	80.00	3.75
	1993	3.43	14.20	0.00	5.15	103.02	80.00	128.78

Table B-6 Continued

Month	Year	Daily rainfall (mmd^{-1})				Monthly rainfall (mm)		
		Mean	Maximum	Minimum	Std. dev.	Total	Mean	% of mean
Jul.	1970	5.86	76.00	0.00	16.50	181.60	260.13	69.81
	1971	18.32	174.00	0.00	36.34	568.00	260.13	218.35
	1972	2.07	21.40	0.00	5.74	64.20	260.13	24.68
	1973	11.93	100.60	0.00	26.22	369.90	260.13	142.20
	1974	21.21	171.20	0.00	36.87	657.60	260.13	252.80
	1975	9.31	92.20	0.00	19.26	288.70	260.13	110.98
	1976	7.16	86.50	0.00	19.55	222.00	260.13	85.34
	1977	11.66	53.60	0.00	15.05	361.40	260.13	138.93
	1978	10.36	94.60	0.00	22.71	321.30	260.13	123.52
	1979	10.60	122.50	0.00	28.77	328.70	260.13	126.36
	1980	4.80	32.00	0.00	8.34	148.80	260.13	57.20
	1983	5.68	25.70	0.00	7.97	176.20	260.13	67.74
	1984	5.21	67.00	0.00	14.08	161.60	260.13	62.12
	1985	6.52	49.30	0.00	13.37	202.20	260.13	77.73
	1986	15.07	96.10	0.00	23.23	467.30	260.13	179.64
	1987	2.44	34.30	0.00	7.09	75.50	260.13	29.02
	1988	6.64	40.70	0.00	10.67	205.70	260.13	79.08
	1989	3.65	42.70	0.00	10.03	113.30	260.13	43.56
	1990	6.03	66.60	0.00	13.64	186.80	260.13	71.81
	1991	9.08	123.60	0.00	24.49	281.60	260.13	108.25
	1992	3.42	46.40	0.00	9.48	105.90	260.13	40.71
	1993	7.56	51.00	0.00	13.29	234.40	260.13	90.11
Aug.	1970	7.33	43.00	0.00	11.94	227.30	265.76	85.53
	1971	8.00	87.20	0.00	17.57	247.90	265.76	93.28
	1972	6.04	37.20	0.00	10.12	187.20	265.76	70.44
	1973	9.50	71.70	0.00	16.96	294.60	265.76	110.85
	1974	12.06	93.60	0.00	23.53	373.80	265.76	140.65
	1975	12.56	80.40	0.00	19.78	389.30	265.76	146.49
	1976	9.79	88.30	0.00	16.81	303.40	265.76	114.16
	1977	8.60	72.20	0.00	17.27	266.60	265.76	100.32
	1978	13.23	167.40	0.00	30.80	410.10	265.76	154.31
	1979	2.12	24.60	0.00	5.12	65.60	265.76	24.68
	1980	3.90	35.00	0.00	8.98	120.90	265.76	45.49
	1983	7.31	65.70	0.00	15.56	226.70	265.76	85.30
	1984	10.45	85.50	0.00	19.71	324.00	265.76	121.91
	1985	9.33	68.80	0.00	15.91	289.10	265.76	108.78
	1986	7.03	87.00	0.00	17.90	217.80	265.76	81.95
	1987	5.86	38.30	0.00	9.50	181.80	265.76	68.41
	1988	9.51	75.90	0.00	18.81	294.70	265.76	110.89
	1989	11.68	115.50	0.00	25.10	362.00	265.76	136.21
	1990	7.78	91.50	0.00	17.75	241.20	265.76	90.76
	1991	9.22	63.80	0.00	18.02	285.80	265.76	107.54
	1992	11.51	101.00	0.00	22.43	356.70	265.76	134.22
	1993	5.82	69.90	0.00	14.36	180.30	265.76	67.84

Table B-6 **Continued**

Month	Year	Daily rainfall (mmd^{-1})				Monthly rainfall (mm)		
		Mean	Maximum	Minimum	Std. dev.	Total	Mean	% of mean
Sept.	1970	4.73	53.50	0.00	10.69	141.80	103.30	137.27
	1971	13.76	135.90	0.00	33.47	412.90	103.30	399.71
	1972	0.61	11.40	0.00	2.39	18.20	103.30	17.62
	1973	3.72	26.20	0.00	7.51	111.60	103.30	108.03
	1974	0.13	2.80	0.00	0.55	4.00	103.30	3.87
	1975	4.39	69.20	0.00	13.04	131.80	103.30	127.59
	1976	3.65	36.10	0.00	9.92	109.60	103.30	106.10
	1977	5.86	57.00	0.00	13.20	175.70	103.30	170.09
	1978	2.11	44.80	0.00	8.66	63.40	103.30	61.37
	1979	0.00	0.00	0.00	0.00	0.00	103.30	0.00
	1980	2.35	60.00	0.00	11.04	70.50	103.30	68.25
	1983	3.53	50.70	0.00	10.06	106.00	103.30	102.61
	1984	7.37	167.90	0.00	31.29	221.00	103.30	213.94
	1985	2.55	15.40	0.00	4.43	76.40	103.30	73.96
	1986	0.07	2.00	0.00	0.37	2.00	103.30	1.94
	1987	2.35	43.40	0.00	9.01	70.50	103.30	68.25
	1988	2.52	44.40	0.00	8.49	75.50	103.30	73.09
	1989	0.27	6.10	0.00	1.13	8.10	103.30	7.84
	1990	3.45	17.00	0.00	5.71	103.60	103.30	100.29
	1991	4.11	71.80	0.00	14.21	123.40	103.30	119.46
	1992	2.01	20.80	0.00	5.16	60.20	103.30	58.28
	1993	6.21	31.00	0.00	9.19	186.30	103.30	180.35
Oct.	1970	0.26	8.00	0.00	1.44	8.00	32.02	24.98
	1971	0.68	13.80	0.00	2.74	21.20	32.02	66.21
	1972	0.00	0.00	0.00	0.00	0.00	32.02	0.00
	1973	0.35	10.80	0.00	1.94	10.80	32.02	33.73
	1974	7.30	139.60	0.00	27.42	226.20	32.02	706.43
	1975	2.66	47.80	0.00	9.09	82.60	32.02	257.96
	1976	0.00	0.00	0.00	0.00	0.00	32.02	0.00
	1977	0.00	0.00	0.00	0.00	0.00	32.02	0.00
	1978	0.00	0.00	0.00	0.00	0.00	32.02	0.00
	1979	0.00	0.00	0.00	0.00	0.00	32.02	0.00
	1980	0.12	3.70	0.00	0.66	3.70	32.02	11.56
	1982	0.00	0.00	0.00	0.00	0.00	32.02	0.00
	1983	1.79	35.00	0.00	7.09	55.60	32.02	173.64
	1984	0.00	0.00	0.00	0.00	0.00	32.02	0.00
	1985	3.46	43.80	0.00	9.80	107.40	32.02	335.42
	1986	0.00	0.00	0.00	0.00	0.00	32.02	0.00
	1987	1.68	27.10	0.00	6.51	52.10	32.02	162.71
	1988	1.32	34.30	0.00	6.18	41.00	32.02	128.04
	1989	0.00	0.00	0.00	0.00	0.00	32.02	0.00
	1990	0.00	0.00	0.00	0.00	0.00	32.02	0.00
	1991	0.00	0.00	0.00	0.00	0.00	32.02	0.00
	1992	2.89	63.60	0.00	12.20	89.60	32.02	279.83
	1993	0.20	3.40	0.00	0.70	6.20	32.02	19.36

Table B-6 Continued

Month	Year	Daily rainfall (mmd⁻¹) Mean	Maximum	Minimum	Std. dev.	Monthly rainfall (mm) Total	Mean	% of mean
Nov.	1970	0.00	0.00	0.00	0.00	0.00	11.81	0.00
	1971	0.10	3.00	0.00	0.55	3.00	11.81	25.40
	1972	0.00	0.00	0.00	0.00	0.00	11.81	0.00
	1973	0.00	0.00	0.00	0.00	0.00	11.81	0.00
	1974	0.00	0.00	0.00	0.00	0.00	11.81	0.00
	1975	0.00	0.00	0.00	0.00	0.00	11.81	0.00
	1976	4.43	85.40	0.00	16.03	132.80	11.81	1124.47
	1977	0.23	7.00	0.00	1.28	7.00	11.81	59.27
	1978	0.09	2.60	0.00	0.47	2.60	11.81	22.02
	1979	3.69	32.90	0.00	8.61	110.80	11.81	938.19
	1980	0.00	0.00	0.00	0.00	0.00	11.81	0.00
	1983	0.00	0.00	0.00	0.00	0.00	11.81	0.00
	1984	0.00	0.00	0.00	0.00	0.00	11.81	0.00
	1985	0.00	0.00	0.00	0.00	0.00	11.81	0.00
	1986	0.00	0.00	0.00	0.00	0.00	11.81	0.00
	1987	0.00	0.00	0.00	0.00	0.00	11.81	0.00
	1988	0.00	0.00	0.00	0.00	0.00	11.81	0.00
	1989	0.00	0.00	0.00	0.00	0.00	11.81	0.00
	1990	0.00	0.00	0.00	0.00	0.00	11.81	0.00
	1991	0.12	3.60	0.00	0.66	3.60	11.81	30.48
	1992	0.00	0.00	0.00	0.00	0.00	11.81	0.00
	1993	0.00	0.00	0.00	0.00	0.00	11.81	0.00
Dec.	1970	0.00	0.00	0.00	0.00	0.00	4.51	0.00
	1971	0.00	0.00	0.00	0.00	0.00	4.51	0.00
	1972	0.00	0.00	0.00	0.00	0.00	4.51	0.00
	1973	0.12	3.60	0.00	0.65	3.60	4.51	79.82
	1974	0.07	2.20	0.00	0.40	2.20	4.51	48.78
	1975	0.00	0.00	0.00	0.00	0.00	4.51	0.00
	1976	0.00	0.00	0.00	0.00	0.00	4.51	0.00
	1977	0.00	0.00	0.00	0.00	0.00	4.51	0.00
	1978	0.34	8.80	0.00	1.60	10.40	4.51	230.60
	1979	0.08	1.50	0.00	0.31	2.30	4.51	51.00
	1980	0.17	4.20	0.00	0.77	5.20	4.51	115.30
	1982	0.00	0.00	0.00	0.00	0.00	4.51	0.00
	1983	0.00	0.00	0.00	0.00	0.00	4.51	0.00
	1984	0.00	0.00	0.00	0.00	0.00	4.51	0.00
	1985	0.92	28.50	0.00	5.12	28.50	4.51	631.93
	1986	0.00	0.00	0.00	0.00	0.00	4.51	0.00
	1987	1.09	33.70	0.00	6.05	33.70	4.51	747.23
	1988	0.00	0.00	0.00	0.00	0.00	4.51	0.00
	1989	0.26	8.00	0.00	1.44	8.00	4.51	177.38
	1990	0.17	5.30	0.00	0.95	5.30	4.51	117.52
	1991	0.00	0.00	0.00	0.00	0.00	4.51	0.00
	1992	0.00	0.00	0.00	0.00	0.00	4.51	0.00
	1993	0.00	0.00	0.00	0.00	0.00	4.51	0.00

Table B-7 Annual rainfall and evaporation summary

Year	Annual rainfall			Daily rainfall depths (mm)		Annual potential evaporation		
	Total	Mean	% of mean	75-100 (days)	≤ 100 (days)	Total	Mean	% of mean
1970	681.80	777.67	87.67	2	0	1922.13	2423.65	79.31
1971	1506.80	777.67	193.76	1	4	1962.59	2423.65	80.98
1972	309.10	777.67	39.75	0	0	2464.50	2423.65	101.69
1973	804.50	777.67	103.45	1	1	2394.34	2423.65	98.79
1974	1294.00	777.67	166.39	3	2	1574.39	2423.65	64.96
1975	1011.00	777.67	130.00	2	0	2027.10	2423.65	83.64
1976	900.10	777.67	115.74	3	0	2329.91	2423.65	96.13
1977	986.70	777.67	126.88	1	0	1945.17	2423.65	80.26
1978	991.60	777.67	127.51	2	1	2002.97	2423.65	82.64
1979	574.00	777.67	73.81	0	2	2617.99	2423.65	108.02
1980	561.10	777.67	72.15	0	1	2949.20	2423.65	121.68
1983	640.50	777.67	82.36	0	0	2682.10	2423.65	110.66
1984	724.30	777.67	93.14	1	1	2912.10	2423.65	120.15
1985	725.40	777.67	93.28	0	0	2424.70	2423.65	100.04
1986	791.30	777.67	101.75	2	0	2180.60	2423.65	89.97
1987	469.10	777.67	60.32	0	0	3221.95	2423.65	132.94
1988	848.80	777.67	109.15	1	0	2304.60	2423.65	95.09
1989	562.00	777.67	72.27	0	1	2355.10	2423.65	97.17
1990	656.10	777.67	84.37	1	0	2645.90	2423.65	109.17
1991	722.70	777.67	92.93	0	1	2750.80	2423.65	113.50
1992	634.00	777.67	81.53	0	1	2688.10	2423.65	110.91
1993	713.82	777.67	91.79	0	0	2964.02	2423.65	122.30

APPENDIX C
DATA CORRECTIONS AND ASSUMPTIONS

Appendix C Data corrections and assumptions

Table C-1 Assumptions applied to data collected at Kota station

Climatic Measure[i]	Assumption	Conditions
tmax	0 values missing	all months, all years
tmin	0 values missing	1980-1991 inclusive[a] May-Oct. incl., all years Apr. 1974[a]
hmax	0 values missing	all months, all years
hmin	0 values missing	all months, all years
wind	0 values missing	all months, all years
sunhr	0 values missing	all months, all years
evap	0 values missing	all months, all years
rain	0 values missing	Apr. - May incl., 1974[a] Nov. and Dec. 1-2 incl., 1982[a] Jan. and Feb. 1-4 incl., 1983[a]

[a] Parameter not measured during this period

Table C-2 Corrections applied to data collected at Kota station

Date (mm-dd-yy)	Climatic Measure[1]	Original value	Corrected value
04/13/70	tmin	1.8	41.8
07/03/70	evap	87.2	8.72
07/19/70	tmin	6.0	26.0
11/06/70	hmax	1.0	missing
12/18/70	tmax	2.4	24.0
02/25/72	tmax	7.0	27.0
10/28/73	tmax	0.5	30.5
03/24/76	tmin	115.3	11.5
04/23/76	tmax	410.3	41.0
10/07/76	evap	80.03	8.00
04/23/78	tmax	14.0	41.0
04/17/79	tmax	373.5	37.4
07/24/79	tmin	263.7	26.4
05/15/79	evap	133.1	13.31
09/25/79	evap	83.6	8.36
04/26/87	evap	187.5	18.75

[i] Refer to Appendix A for explanation of abbreviations and units of climatic measures

APPENDIX D
FREQUENCY ANALYSIS CALCULATION METHODS

Appendix D Frequency Analysis Calculation methods

1.0 Weibull plotting position (1939)

$$P(X \geq x) = m / (N + 1) \qquad \textbf{Equation D-1}$$

where

m	ranked (ascending) position, m = 1,2,3 ...N
N	total number of values

2.0 Reduced variate

$$y = -\ln[\ln(T/(T-1))] \qquad \textbf{Equation D-2}$$

where

T	return period; T = 1/P
P	probability; $P = P(X \geq x)$, for maxima $P = P(X < x)$, for minima

3.0 Gumbel probability distribution (Gumbel, 1954)

$$x_T = u + \alpha y_T, \text{ for maxima} \qquad \textbf{Equation D-3}$$

$$x_T = u - \alpha y_T, \text{ for minima} \qquad \textbf{Equation D-4}$$

where

x_T	magnitude of extreme event, with a return period T
u	mode of the distribution; $u = \bar{x} - 0.5772\alpha$, for maximum distributions $u = \bar{x} + 0.5772\alpha$, for maximum distributions
$\bar{x}$	mean value
α	slope of the distribution $\alpha = (\sqrt{6}/\pi)s_x$
s_x	standard deviation
y_T	reduced variate for return period T

4.0 Log Pearson Type III probability distribution

$$x_T = 10^{y_T}$$ **Equation D-5**

where

x_T	magnitude of the extreme event, with a return period T
y_T	log of the magnitude of extreme event, with a return period T; $y_T = \bar{y} + K_T s_y$, for maxima $y_T = \bar{y} - K_T s_y$, for minima
$\bar{y}$	mean value; $y = \log x$
K_T	frequency factor[ii]; $K_T = z + (z^2 - 1)\,k + 1/3\,(z^3 - 6\,z)\,k^2 - (z^2 - 1)\,k^3 + z\,k^4 + 1/3\,k^5$
w, z, k	intermediate variables; $z = w - \dfrac{2.515517 + 0.802853\,w + 0.010328\,w^2}{1 + 1.432788\,w + 0.189269\,w^2 + 0.001308\,w^3}$ $w = [\ln(1 / P^2)]^{1/2}$ $k = C_s/6$
C_s	coefficient of skewness
P	exceedence probability; $P = 1/T$ $(0 < P \leq 0.5)$ $P = 1/(1-T)$ $(P > 0.5)$

[ii] Kite (1977)

APPENDIX E
EVAPOTRANSPIRATION CALCULATION METHODS

Appendix E Evapotranspiration calculation methods

1.0 Combination Methods

1.1 General form of the Penman Equation (1963)

$$\lambda ET_o = [\Delta/(\Delta+\gamma)]\,(R_n - G) + [\gamma/(\Delta+\gamma)]\ 6.43\ W_f(e_z^\circ - e_z) \qquad \text{[Equation E-1]}$$

where

λET_o	evapotranspiration	($MJm^{-2}\,d^{-1}$)
Δ	slope of vapour pressure and temperature relationship	($kPa^\circ C^{-1}$)
R_n	net radiation	(($MJm^{-2}\,d^{-1}$)
G	soil heat flux	($MJm^{-2}\,d^{-1}$)
γ	psychrometric coefficient	($kPa^\circ C^{-1}$)
W_f	wind function	(ms^{-1})
$e_z^\circ - e_z$	vapour saturation deficit	(kPa)

The forms of the Penman Equation differ in the calculation of the wind function (W_f), net radiation (R_n) and vapour saturation deficit method (Table 1).

Table 1. Summary of parameters used in various forms of the Penman Equation

Method	Wind Function (W_f)	Net Radiation (R_n)	Vapour saturation deficit method ($e_z^\circ - e_z$)[1]
Penman (1963)	Jensen (1974)	Doorenbos and Pruitt (1977)	method 3
1972 Kimberly Penman	Wright and Jensen (1972)	Doorenbos and Pruitt (1977)	method 3
1982 Kimberly Penman	Wright (1982)	Wright (1982)	method 3
FAO-24 Penman	Doorenbos and Pruitt (1977)	Doorenbos and Pruitt (1977)	method 1
FAO-24 Penman, corrected[2]	Doorenbos and Pruitt (1977)	Doorenbos and Pruitt (1977)	method 1

[1] All vapour saturation deficit methods are taken from ASCE, 1990

[2] Correction factor taken from Allen and Pruitt, 1991

1.2 Penman - Monteith Combination Method (Monteith, 1981)

$$\lambda ET = [\Delta (R_n - G) + \rho c_p[e_z^\circ - e_z]/r_a] / \Delta + \gamma^*$$ **[Equation E-2]**

where

λET	evapotranspiration, alfalfa reference	$(MJm^{-2}\ d^{-1})$
Δ	slope of vapour pressure and temperature relationship	$(kPa^\circ C^{-1})$
R_n	net radiation	$((MJm^{-2}\ d^{-1})$
G	soil heat flux	$(MJm^{-2}\ d^{-1})$
ρ	air density	(kgm^{-3})
c_p	specific heat at constant pressure	$(kJkg^{-1}{}^\circ C^{-1})$
r_a	aerodynamic resistance; $r_a = \{\ln[(z_w - d)/z_{om}]\ \ln[(z_p - d)/z_{ov}]\}/[(0.41)^2 u_d]$	(sm^{-1})
z_w	height of wind speed measurement	(cm)
z_p	height of humidity and temperature measurements	(cm)
z_{om}	roughness length for momentum; $z_{om} = 0.123h_C$	(cm)
h_c	mean crop canopy[iii]	(cm)
z_{ov}	roughness length for vapour transfer; $z_{ov} = 0.1z_{om}$	(cm)
d	displacement height of crop; $d = 2/3h_c$	(cm)
γ^*	psychrometric constant modified by the ratio of resistance to atmospheric resistance; $\gamma^* = \gamma(1 + r_c/r_a)$	$(kPa^\circ C^{-1})$
r_c	canopy resistance; $r_c = 100/(0.5\ LAI)$	(sm^{-1})
LAI	leaf area index; $LAI = 1.5\ \ln(h_c) - 1.4$[iv]	(cm)
u_d	mean daytime wind speed at 2 meters	(ms^{-1})

[iii] mean crop canopy of 50 cm used for the Daglawada Test Plot

[iv] Equation for alfalfa with a mean canopy height of more than 3 cm, with periodic harvesting

2.0 Temperature methods

2.1 Blaney-Criddle, FAO-24 Method (Doorenbos and Pruitt, 1977)

$$ET_o = a + bf$$ [Equation E-3]

where

ET_o	evapotranspiration, grass reference	(mm d^{-1})
a, b	coefficients [v]; $a = 0.0043\ RH_{min} - n/N - 1.41$ $b = 0.908 + -0.483 \times 10^{-2}\ RH_{min} + 0.749\ (n/N) + 0.0768\ \log(U_d+1)^2 - 0.38 \times 10^{-2}\ RH_{min}(n/N) - 0.433 \times 10^{-3}\ RH_{min} U_d + 0.281\ \log(U_d + 1)\ \log(n/N + 1) - 0.00975\ \log(U_d+1)\ \log(RH_{min}+1)^2\ \log(n/N + 1)$	
f	Blaney-Criddle factor $f = p(.46T + 8.13)$	
p	mean monthly percent of yearly daytime hours	
T	mean temperature	(°C)
RH_{min}	minimum relative humidity in percent	
n/N	ratio of actual to maximum sunshine hours	
U_d	mean daytime wind speed at 2 meters	(ms^{-1})

2.2 Hargreaves (Hargreaves and Samani, 1982, 1985; Hargreaves et al., 1985)

$$\lambda ET_o = 0.0023\ R_a\ TD^{1/2}\ (T + 17.8)$$ [Equation E-4]

where

λET_o	evapotranspiration, grass reference	($MJm^{-2}\ d^{-1}$)
TD	difference between mean monthly maximum and minimum temperature	(°C)
R_a	extraterrestrial radiation	($MJm^{-2} d^{-1}$)
T	mean temperature	(°C)

[v] Allen and Pruitt, 1991

3.0 Radiation Methods

3.1 FAO-24 Radiation Method (Doorenbos and Pruitt, 1977)

$$ET_o = a + b\{[\Delta/(\Delta+\gamma)]R_s\}$$ **[Equation E-5]**

where

ET_o	evapotranspiration, grass reference	($mm\ d^{-1}$)
a,b	constants [vi]; $a = -0.3$ $b = 1.066 - 0.13 \times 10^{-2} RH_{mean} + 0.045 U_d - 0.20\times10^{-3} RH_{mean} U_d - 0.315\times10^{-4} RH_{mean} - 0.11 \times 10^{-2} U_d^2$	
RH_{mean}	mean relative humidity in percent	
R_s	solar radiation	(mmd^{-1})
Δ	slope of vapour pressure and temperature relationship	($kPa°C^{-1}$)
γ	psychrometric coefficient	($kPa°C^{-1}$)
U_d	mean daytime wind speed at 2 meters	(ms^{-1})

3.2 Modified Jensen-Haise (1971)

$$\lambda ET_r = C_T (T - T_x) R_s$$ **[Equation E-6]**

where

λET_r	evapotranspiration, alfalfa reference	($MJm^{-2}\ d^{-1}$)
C_T	temperature coefficient; $C_T = 1/(C_1 + C_2 C_H)$	
C_1, C_2, C_H	constants; $C_1 = 38 - (2\ Elev/305)$ $C_2 = 7.3$ $C_H = 5.0 / [e°(T_x) - e°(T_n)]$	 (m) (°C) (kPa)
T_x	intercept of the temperature axis; $T_x = \{-2.5 - 1.4[e°(T_x) - e°(T_n)\} - Elev/550$	(°C)
T	mean temperature	(°C)
R_s	solar radiation	($MJm^{-2}d^{-1}$)

[vi] Allen and Pruitt, 1991

$e°(T_x)$	saturation vapour pressure at mean maximum temperature for the warmest month[vii] of the year	(kPa)
$e°(T_n)$	saturation vapour pressure at mean minimum temperature for the warmest month of the year	(kPa)
Elev	elevation above sea level	(m)

[vii] Warmest month of the year for Kota station during the years 1970 - 1993 is May

4.0 Pan Evaporation Methods

4.1 FAO-24 Pan Evaporation Method

$$ET_o = k_p\, E_{pan}$$ [Equation E-7]

where

ET_o	evapotranspiration, grass reference	(mmd^{-1})
E_{pan}	pan evaporation	(mmd^{-1})

kp pan coefficient [viii];

$$k_p = 0.482 + 0.024 \log(Fetch) - 0.376 \times 10^{-3}\, U_d + 0.0045{*}RH_{mean}$$

Fetch	windward side distance of ground cover [ix]	(m)
U_d	mean daytime wind speed at 2 meters	(ms^{-1})
RH_{mean}	mean relative humidity in percent	

4.2 Christiansen-Hargreaves Pan Evaporation Method (1969)

$$ET_o = 0.755\, E_{pan}\, C_{T2}\, C_{W2}\, C_{H2}\, C_{S2}$$ [Equation E-8]

where

ET_o	evapotranspiration, grass reference	(mmd^{-1})
E_{pan}	pan evaporation	(mm)

C_{T2}, C_{W2}, C_{H2}, C_{S2} coefficients

$$C_{T2} = 0.862 + 0.179\,(T/T_{co}) - 0.041\,(T/T_{co})^2$$

$$C_{W2} = 1.189 - 0.240\,(U_d/W_o) - 0.051\,(U_d/W_o)^2$$

$$C_{S2} = 0.904 + 0.0080\,(S/S_o) + 0.088\,(S/S_o)^2$$

$$C_{H2} = 0.499 + 0.620\,(RH_{mean}/RH_{mo}) - 0.119\,(RH_{mean}/RH_{mo})^2$$

R_{mo}, S_o, T_{co}, W_o, constants

$RH_{mo} = 0.60$
$S_o = 0.80$
$T_{co} = 20$ °C

[viii] Snyder (1993)
[ix] Fetch of 100 m assumed for the Kota station

$W_o = 6.7\ kmh^{-1}$

U_d	mean daytime wind speed at 2 meters	(kmh^{-1})
RH_{mean}	mean relative humidity, in percent	
S	percentage of possible sunshine hours in a day, expressed decimally	

5.0 Common Parameters

5.1 Atmospheric and thermodynamic parameters

5.1.1 Latent heat of vaporization (ASCE, 1990)

$$\lambda = 2.501 - 0.002361\,T \qquad (MJkg^{-1})$$

where

T	mean temperature	(°C)

5.1.2 Psychrometric coefficient (ASCE, 1990)

$$\gamma = c_p P / 0.622\,\lambda \qquad (kPa°C^{-1})$$

where

cp	specific heat at constant pressure	($kJkg^{-1}°C^{-1}$)
P	atmospheric pressure $P = 101.3\,(288 - 0.01\,Elev)/288^{\,g/(\alpha R)}$	(kPa)
λ	latent heat of vaporization	($MJkg^{-1}$)
g	acceleration of gravity; $g = 9.8\ ms^{-1}$	(ms^{-1})
α	the lapse rate $\alpha = 0.0065\ Km^{-1}$, for saturated air;	(Km^{-1})
R	specific gas constant for dry air; $R = 287.0\ Jkg^{-1}K^{-1}$	($Jkg^{-1}K^{-1}$)

5.1.3 Slope of vapour pressure and temperature relationship (ASCE, 1990)

$$\Delta = 0.200*(0.00738\,T + 0.8072)^7 - 0.000116 \qquad (kPa°C^{-1})$$

where

T	mean temperature	(°C)

5.1.4 Soil heat flux [x]

$$G = 4.2\,(T_{i+1} - T_{i-1})/\Delta t \qquad (MJm^{-2}d^{-1})$$

where

i	time period	
T	mean temperature for the period i	(°C)

---

[x]As soil heat flux is relatively small compared to other terms in ET calculations, G is assumed to be 0 (Burman, 1995)

Δt	time in days between the midpoints of the 2 time periods	(days)

5.1.5 Dew point temperature (ASCE, 1990)

$$T_d = (116.9 + 237.3 \ln(e_a))/(16.78 - \ln(e_a)) \quad (°C)$$

where

e_a	actual vapour pressure	(kPa)

5.2 Solar and Net Radiation Estimates

5.2.1 Extraterrestrial radiation (Duffie and Beckman, 1980)

$$R_a = (24(60)/\pi)G_{SC}d_r{*}[(w_S)\sin(\phi)\sin(\delta)+\cos(\phi)\cos(\delta)\sin(w_S)] \quad (MJm^{-2}d^{-1})$$

where

G_{sc}	solar constant [xi]; $G_{sc} = 0.0820$	($MJm^{-2}min^{-1}$)
δ	declination $\delta = 0.4093*\sin(2\pi)*((284+J)/365)$	(radians)
d_r	relative distance of the earth from the sun $d_r = 1 + 0.033\cos(2\pi J/365)$	
w_S	sunset hour angle $w_S = \cos\text{-}1(-\tan(\phi)\tan(\delta))$	(radians)
ϕ	location latitude, positive for north latitudes and negative for south latitudes	(radians)
J	day of the year (1-366)	

5.2.2 Solar radiation (Doorenbos and Pruitt, 1977)

$$R_s = (a+b(n/N))R_a \quad (MJm^{-2}d^{-1})$$

where

a,b	constants[xii]	
n/N	ratio between actual measured bright sunshine hours to maximum possible sunshine hours	

[xi] As evaluated by the International Association of Meteorology and Atmospheric Physics (IAMAP) (London and Fröhlich, 1982, cited in ASCE 1990)

[xii] Values for a and b were taken from the experimentally determined constants for the radiation equation for a latitude of 24°, reported in Appendix VI, Doorenbos and Pruitt (1977); a = 0.28; b = 0.49

5.2.3 Clear sky solar radiation (Doorenbos and Pruitt, 1977)

$$R_{so} = 0.75\ R_a \qquad (MJm^2d^{-1})$$

where

R_a	extraterrestrial radiation	(MJm^2d^{-1})

5.2.4 Net long wave radiation

5.2.4.1 FAO 24 method

$$R_n = (1 - \alpha)R_s - R_b \qquad (MJm^{-2}d^{-1})$$

where

α [xiii]	albedo	
R_b	net thermal radiation for clear skies or partly cloudy conditions; $R_b = [0.9*(R_s/R_{so})+b]*R_{bo}$	
R_{bo}	net outgoing long-wave radiation on a clear day $R_{bo} = \varepsilon^1\sigma T^4$	
b	constant [xiv];	
ε^1	net emittance expression (Brunt (1932) $\varepsilon^1=[a_1+b_1*e_d^{1/2}]$	
a1,b1[xv]	coefficients	
σ	Stefan-Boltzmann constant $\sigma = 4.903x10^{-9}$	$(MJm^{-2}d^{-2}K^{-4})$
T	mean temperature	(°K)
R_s	solar radiation	$(MJm^{-2}d^{-1})$
R_{so}	clear sky solar radiation	$(MJm^{-2}d^{-1})$
e_d	vapour pressure at dew point temperature	(kPa)

[xiii] Albedo is set to 0.23, representing an average value of the full cover range of most green field crops (ASCE, 1990)

[xiv] value taken from Doorenbos and Pruitt (1977); b = 0.1

[xv] The regression coefficients a_1 and b_1 are assigned the general values for arid areas suggested by Budyko (1956) presented in table 3.3 (ASCE, 1990); $a_1 = 0.39$; $b_1 = 0.158$

5.2.4.2 Wright, 1982 method

$$R_n = (1 - \alpha)R_s - R_b \qquad (MJm^{-2}d^{-1})$$

where

α	albedo $\alpha = 0.29 + 0.06 \sin[30 (m + 0.0333 N + 2.25)]$	
m	month (1-12)	
N	the day of the month (1-31)	
R_b	net thermal radiation for clear skies or partly cloudy conditions; $R_b = [a (R_s / R_{so}) + b] R_{bo}$	
R_{bo}	net outgoing long-wave radiation on a clear day $R_{bo} = \varepsilon^1 \sigma T^4$	
a,b	constants; for R_s/R_{so} values > 0.7 a = 1.126 b = -0.07 for R_s/R_{so} values $\leq$ 0.7 a = 1.017 b = - 0.06	
ε^1	net emittance expression (Brunt (1932) $\varepsilon^1=[a_1+b_1*e_d^{1/2}]$	
a_1,b_1	coefficients; $a_1 = 0.26+0.1\exp\{-[0.0154(30m+N-207)]^2\}$ $b_1 = 0.139$	
σ	Stefan-Boltzmann constant $\sigma = 4.903\times10^{-9}$	$(MJm^{-2}d^{-2}K^{-4})$
T	mean temperature	(°K)
R_s	solar radiation	$(MJm^{-2}d^{-1})$
R_{so}	clear sky solar radiation	$(MJm^{-2}d^{-1})$
e_d	vapour pressure at dew point temperature	(kPa)

5.3.0 Vapour pressure

5.3.1 Saturation vapour pressure (Tetens, 1930; Murray, 1967)

$$e_s = \exp [(16.78\, T - 116.9) / (T + 237.3)] \qquad \text{(kPa)}$$

where

T	mean temperature	(°C)

5.3.2 Actual vapour pressure (ASCE 1990)

$$e_a = e_s\, [RH_{max} - RH_{min} / 2) / 100] \qquad \text{(kPa)}$$

where

e_s	saturation vapour pressure	(kPa)
RH_{max}	maximum relative humidity in percent	
RH_{min}	minimum relative humidity in percent	

5.3.3 Vapour pressure deficit method 1 (ASCE 1990)

$$(e_z° - e_z) = e°(T) - e°(T_d)$$

where

$e°(T)$	vapour pressure at temperature	(kPa)
$e°(T_d)$	vapour pressure at dew point temperature	(kPa)

5.3.4 Vapour pressure deficit method 3 (ASCE 1990)

$$(e_z° - e_z) = [e°(T_x) + e°(T_n)] / 2 - e°(T_d)$$

where

$e°(T_x)$	vapour pressure at maximum daily temperature	(kPa)
$e°(T_n)$	vapour pressure at minimum daily temperature	(kPa)
$e°(T_d)$	vapour pressure at dew point temperature	(kPa)

5.4.0 Aerodynamic parameters

5.4.1 Original Wind function (Jensen, 1974)

$$W_f = 1 + 0.536\, u_d$$

where

u_d	mean daytime wind speed at 2 meters	(ms^{-1})

5.4.2 Wright and Jensen (1972) wind function

$$W_f = 0.75 + 0.993\ u_2$$

where

u_d	mean daytime wind speed at 2 meters	(ms^{-1})

5.4.3 FAO-24, Doorenbos and Pruitt (1977)

$$W_f = 1 + 0.864 * u_2$$

where

u_d	mean daytime wind speed at 2 meters	(ms^{-1})

5.4.4 Wright (1982) wind function

$$W_f = a_w + b_w * u_d$$

where

u_d	mean daytime wind speed at 2 meters	(ms^{-1})
a_w, b_w	coefficients $a_w = 0.4 + 1.4\ \exp\{-[(J - 173) / 58]^2\}$ $b_w = 0.007 + 0.004\ \exp\{-[(J - 243) / 80]^2\}$	
J	calendar day of the year (1-366)	

5.4.5 Daytime wind speed

$$U_d = [2\ U_{24}\ (U_d / U_n)] / (1 + U_d / U_n) \qquad (ms^{-1})$$

where

U_d/U_n	ratio of daytime to nightime wind speeds, estimated at 2.0 (Doorenbos and Pruitt, 1977)	
U_{24}	24 hour average wind speed	(ms^{-1})

APPENDIX F
CHARACTERISTICS OF THE MONSOON SEASON

Appendix F Characteristics of the monsoon season

Table F-1 Summary of monsoon season characteristics

Year	Model monsoon season						Annual cycle length (days)[6]	Annual rainfall (mm)
	Start date[1]	First significant rainfall[2]	End date[3]	Length (days)[4]	Total rainfall (mm)	Rain days (number)[5]		
1970	1-Jun	17-Jun	12-Sep	103	632.00	37	---	681.80
1971	1-Jun	1-Jun	8-Sep	99	1382.90	44	365	1506.80
1972	9-Jun	9-Jun	31-Aug	83	281.70	24	374	309.10
1973	13-Jun	13-Jun	12-Sep	91	739.30	40	369	804.50
1974	8-Jun	9-Jun	11-Oct	125	1207.80	36	360	1294.00
1975	4-Jun	9-Jun	13-Sep	101	912.30	57	361	1011.00
1976	7-Jun	7-Jun	23-Nov	169	838.80	56	369	900.10
1977	11-Jun	11-Jun	5-Sep	86	888.10	41	369	986.70
1978	12-Jun	12-Jun	1-Sep	81	907.20	41	366	991.60
1979	14-Jun	15-Jun	28-Nov	167	530.00	37	367	574.00
1980	9-Jun	13-Jun	3-Sep	86	534.00	39	361	561.10
1983	11-Jun	11-Jun	10-Oct	121	593.70	48	---	640.50
1984	13-Jun	13-Jun	5-Sep	84	676.40	26	368	724.30
1985	2-Jun	2-Jun	9-Oct	129	689.20	42	354	725.40
1986	20-Jun	20-Jun	17-Aug	58	722.60	29	383	791.30
1987	9-Jun	9-Jun	19-Oct	132	433.10	28	354	469.10
1988	6-Jun	6-Jun	23-Sep	109	794.70	42	363	848.80
1989	1-Jun	7-JUn	27-Aug	87	516.90	26	360	562.00
1990	13-Jun	19-Jun	15-Sep	94	597.40	38	377	656.10
1991	15-Jun	15-Jun	3-Sep	80	682.50	26	367	722.70
1992	8-Jun	14-Jun	11-Oct	125	589.40	28	359	634.00
1993	13-Jun	13-Jun	20-Sep	99	657.62	44	370	713.82

1 Defined as the first day of June with ≥ 0.1 mm of recorded rain

2 Defined as ≥ 5.0 mm of rainfall

3 Defined as the day on which 90% of yearly rainfall is recorded after the start of the monsoon season

4 Defined as the number of days between the start and end dates

5 Defined as the number of days between successive monsoon season start dates

6 Number of days with ≥ 0.1 mm of recorded rain, within the defined monsoon season

Figure F-1 Cumulative departure of model monsoon rainfall from mean

Note: Mean rainfall = 718.53 mm
Rainfall data unavailable in 1981 and 1982

APPENDIX G
MARKOV CHAIN ANALYSIS RESULTS

Figure G-1 10 day interval transition probability

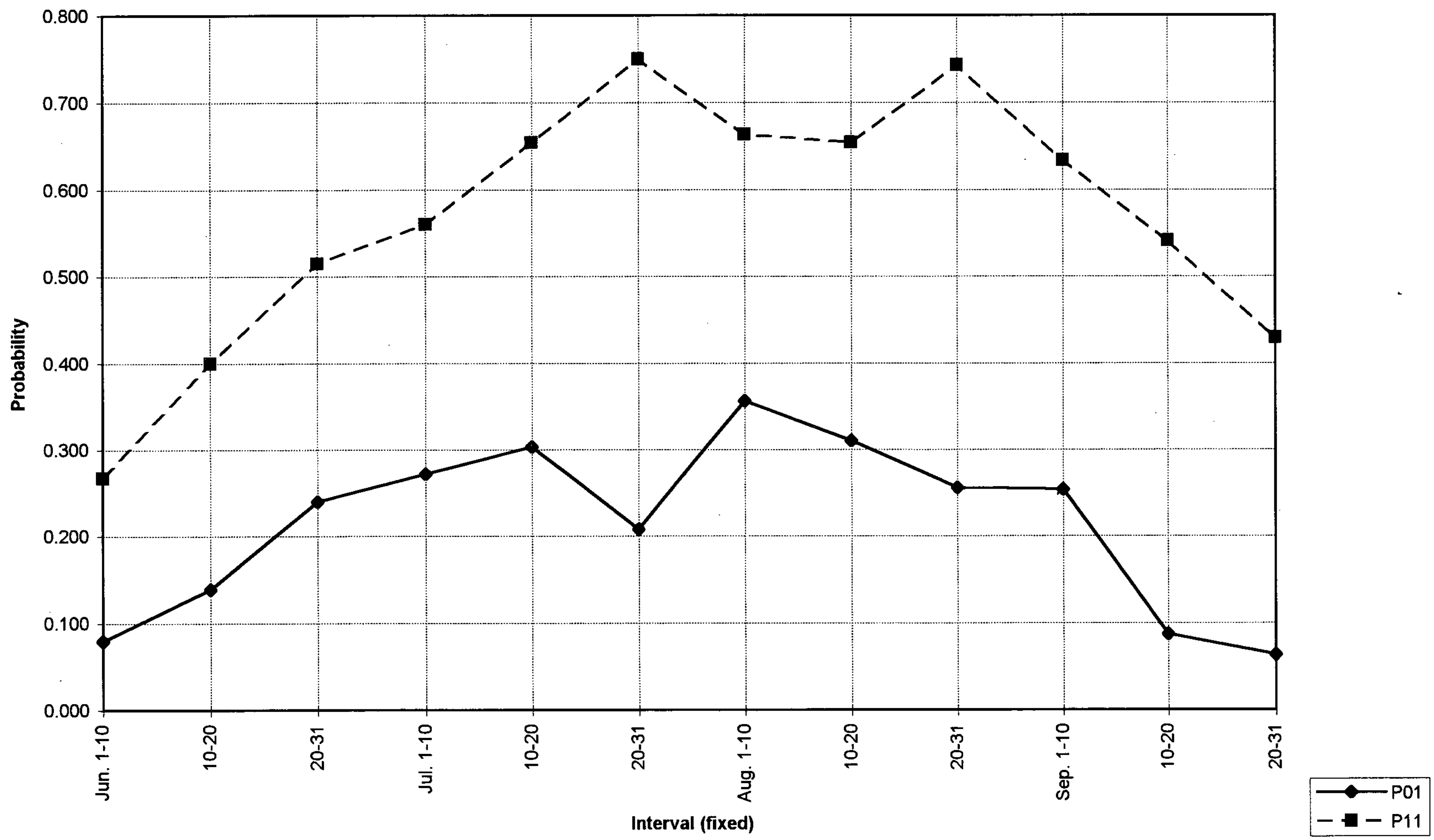


Table G-1 Transition probabilities over fixed 5 day intervals, by year

5 day Interval	Year	June		July		August		September	
		P_{01}	P_{11}	P_{01}	P_{11}	P_{01}	P_{11}	P_{01}	P_{11}
1-5	1970	0.50	0.00	1.00	1.00	0.50	0.67	0.67	0.50
	1971	0.50	0.33	0.25	0.00	1.00	0.33	0.50	0.00
	1972	0.00	0.00	0.33	0.50	0.00	0.00	0.33	0.50
	1973	0.00	0.00	0.25	0.00	0.25	0.00	1.00	0.67
	1974	0.00	0.00	0.25	0.00	0.50	0.67	0.00	0.00
	1975	0.25	0.00	1.00	0.67	0.33	1.00	0.67	0.50
	1976	0.00	0.00	0.20	0.00	0.00	1.00	1.00	0.67
	1977	0.00	0.00	0.00	0.80	0.00	1.00	1.00	1.00
	1978	0.00	0.00	0.00	0.80	0.00	0.00	0.25	0.00
	1979	0.00	0.00	0.00	0.00	1.00	0.75	0.00	0.00
	1980	0.00	0.00	0.25	0.00	1.00	1.00	0.33	1.00
	1983	0.00	0.00	0.50	0.67	1.00	0.50	0.50	1.00
	1984	0.00	0.00	1.00	0.67	1.00	0.75	0.50	1.00
	1985	0.33	0.50	0.00	0.00	1.00	0.75	0.50	0.67
	1986	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00
	1987	0.00	0.00	0.33	0.00	0.00	0.00	0.25	0.00
	1988	0.00	0.00	1.00	0.33	0.33	0.50	0.00	0.00
	1989	0.00	0.50	0.50	0.33	0.00	0.00	0.50	0.00
	1990	0.00	0.00	1.00	1.00	1.00	1.00	0.50	0.00
	1991	0.00	0.00	0.00	0.00	0.00	0.50	1.00	0.67
	1992	0.00	0.00	0.00	0.00	0.67	0.00	0.25	1.00
	1993	0.00	0.00	0.50	0.00	0.50	0.67	1.00	1.00
6-10	1970	0.00	0.00	0.25	0.00	0.50	1.00	1.00	0.75
	1971	0.25	0.00	0.67	0.00	0.25	0.00	0.00	1.00
	1972	0.25	1.00	0.33	0.50	0.50	1.00	0.00	0.00
	1973	0.00	0.00	0.67	0.00	0.50	0.33	0.00	0.75
	1974	0.33	0.50	0.20	0.00	0.50	0.67	0.00	0.00
	1975	0.25	0.00	0.50	0.67	1.00	0.75	1.00	0.33
	1976	0.50	1.00	0.00	0.75	1.00	0.50	0.00	0.80
	1977	0.00	0.00	0.50	0.67	0.00	0.80	0.33	0.00
	1978	0.00	0.00	1.00	1.00	0.67	0.00	0.00	0.00
	1979	0.00	0.00	0.33	1.00	1.00	0.75	0.00	0.00
	1980	0.25	0.00	1.00	0.67	0.00	0.75	0.00	0.00
	1983	0.00	0.00	0.00	0.67	0.25	0.00	0.50	0.33
	1984	0.00	0.00	0.50	0.33	0.25	0.00	0.00	0.50
	1985	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00
	1986	0.00	0.00	0.25	1.00	0.50	0.67	0.00	0.00
	1987	0.25	0.00	0.33	0.50	0.33	0.50	0.00	0.00
	1988	0.25	0.00	0.00	0.00	0.00	0.50	0.25	0.00
	1989	0.50	0.00	0.25	0.00	1.00	0.67	0.00	0.00
	1990	0.00	0.00	0.00	0.00	0.50	0.67	1.00	0.75
	1991	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1992	0.25	0.00	0.00	0.00	0.33	0.50	0.00	0.67
	1993	0.00	0.00	0.50	0.33	0.00	0.67	1.00	0.33

Table G-1 **Continued**

5 day Interval	Year	June P$_{01}$	June P$_{11}$	July P$_{01}$	July P$_{11}$	August P$_{01}$	August P$_{11}$	September P$_{01}$	September P$_{11}$
11-15	1970	0.00	0.00	0.00	0.50	1.00	0.75	0.00	0.80
	1971	0.00	0.00	0.25	0.00	1.00	0.50	0.33	0.00
	1972	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1973	0.25	0.00	1.00	1.00	0.50	0.67	0.33	0.50
	1974	0.00	0.00	1.00	0.75	1.00	0.00	0.00	0.00
	1975	0.00	0.00	1.00	0.75	0.00	1.00	0.00	1.00
	1976	0.00	0.00	1.00	0.67	0.25	1.00	0.25	0.00
	1977	0.50	0.67	1.00	0.67	0.00	0.00	0.50	0.00
	1978	0.33	0.50	0.00	0.80	1.00	0.67	0.00	0.00
	1979	0.25	1.00	0.00	1.00	0.50	0.67	0.00	0.00
	1980	0.50	0.00	0.00	0.75	0.00	0.00	0.00	0.00
	1983	0.67	0.00	1.00	0.67	1.00	0.75	0.00	0.00
	1984	0.25	0.00	0.00	0.00	0.00	0.50	0.00	0.00
	1985	0.25	0.00	0.33	0.50	1.00	0.75	0.25	0.00
	1986	0.00	0.00	0.00	0.00	0.33	0.50	0.00	0.00
	1987	0.25	0.00	0.33	0.50	0.00	0.00	0.00	0.00
	1988	0.00	0.00	0.67	0.00	0.50	0.67	0.00	0.00
	1989	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
	1990	0.25	0.00	0.25	0.00	0.25	0.00	0.25	0.00
	1991	0.20	0.00	0.20	0.00	0.00	0.00	0.00	0.00
	1992	0.00	0.00	0.25	0.00	0.50	0.33	0.00	0.00
	1993	0.33	1.00	0.33	0.50	0.00	0.00	0.00	0.80
16-20	1970	0.25	0.00	0.00	0.00	0.50	0.33	0.00	0.00
	1971	0.00	0.00	0.67	0.00	0.50	0.67	0.00	0.00
	1972	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00
	1973	0.00	0.00	1.00	0.75	0.25	0.00	0.00	0.00
	1974	0.00	0.00	0.00	1.00	0.20	0.00	0.00	0.00
	1975	0.25	1.00	0.00	1.00	0.00	1.00	0.33	0.00
	1976	0.67	0.50	0.33	0.00	0.00	0.80	0.00	0.00
	1977	0.00	0.00	0.00	0.75	0.00	0.00	0.00	0.50
	1978	0.50	1.00	0.25	0.00	0.50	0.67	0.33	0.50
	1979	0.00	0.00	1.00	0.75	0.00	0.00	0.00	0.00
	1980	0.33	0.00	0.00	0.00	0.20	0.00	0.00	0.00
	1983	0.00	0.00	0.50	0.33	1.00	0.67	0.20	0.00
	1984	0.00	0.00	0.33	1.00	1.00	1.00	0.00	0.00
	1985	0.00	0.00	0.25	0.00	1.00	0.50	0.00	0.00
	1986	0.20	0.00	1.00	1.00	0.67	0.50	0.00	0.00
	1987	0.25	0.00	0.25	0.00	0.25	0.00	0.33	0.50
	1988	0.33	0.50	0.33	1.00	0.25	0.00	0.67	0.50
	1989	0.25	0.00	0.25	0.00	0.50	0.33	0.00	0.00
	1990	0.25	0.00	1.00	0.33	0.50	0.33	0.50	0.67
	1991	0.00	0.00	0.50	0.67	0.50	1.00	0.00	0.00
	1992	0.00	0.00	0.25	0.00	1.00	0.75	0.25	0.00
	1993	0.00	0.80	1.00	0.75	0.50	0.67	0.20	0.00

Table G-1 **Continued**

5 day Interval	Year	June		July		August		September	
		P_{01}	P_{11}	P_{01}	P_{11}	P_{01}	P_{11}	P_{01}	P_{11}
21-25	1970	0.00	0.00	0.00	0.00	0.25	0.00	0.33	0.50
	1971	0.67	0.00	1.00	1.00	0.50	0.67	0.00	0.00
	1972	0.67	0.00	0.00	0.00	0.33	0.50	0.00	0.00
	1973	0.00	0.00	0.00	0.75	1.00	0.80	0.33	0.50
	1974	0.20	0.00	0.00	1.00	0.00	0.80	0.20	0.00
	1975	0.00	0.50	1.00	0.75	0.00	0.75	0.00	0.00
	1976	0.00	0.50	0.50	0.67	0.25	1.00	0.00	0.00
	1977	0.50	0.00	0.67	0.50	0.20	0.00	0.00	0.00
	1978	0.50	0.33	0.25	1.00	1.00	0.75	0.00	0.00
	1979	1.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00
	1980	1.00	0.75	0.25	0.00	0.33	0.50	0.00	0.00
	1983	0.25	0.00	0.50	1.00	1.00	0.33	0.00	0.00
	1984	0.00	0.00	0.00	0.00	1.00	0.75	0.00	0.00
	1985	0.00	0.00	0.50	1.00	0.25	0.00	0.33	1.00
	1986	0.00	0.80	0.00	1.00	0.00	0.00	0.00	0.00
	1987	0.25	0.00	0.00	0.00	1.00	1.00	0.25	0.00
	1988	0.50	0.00	0.00	1.00	0.33	1.00	1.00	0.50
	1989	0.25	0.00	1.00	0.67	0.33	1.00	0.20	0.00
	1990	0.25	0.00	0.20	0.00	0.67	0.00	0.00	0.50
	1991	0.00	0.00	0.00	1.00	1.00	0.75	0.00	0.00
	1992	0.00	0.00	1.00	0.67	0.20	0.00	0.00	0.00
	1993	0.67	0.50	0.00	0.00	0.00	0.00	0.50	0.67
26-31	1970	1.00	0.00	0.20	0.00	0.25	1.00	0.25	0.00
	1971	1.00	1.00	0.00	0.83	0.67	0.67	0.25	0.00
	1972	1.00	0.67	0.00	0.00	0.33	0.67	0.00	0.00
	1973	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00
	1974	0.00	0.50	0.00	0.50	0.00	0.00	0.33	0.00
	1975	0.25	1.00	0.00	0.00	0.50	1.00	0.00	0.00
	1976	0.00	0.00	0.50	0.50	1.00	0.80	0.00	0.00
	1977	0.00	1.00	1.00	0.80	0.00	1.00	0.00	0.00
	1978	0.67	0.50	0.50	0.50	0.00	1.00	0.00	0.00
	1979	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1980	0.50	0.67	1.00	1.00	0.25	0.50	0.00	0.00
	1983	0.25	1.00	0.00	0.83	0.20	0.00	0.00	0.00
	1984	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00
	1985	0.00	0.00	0.50	0.75	0.17	0.00	0.00	0.75
	1986	0.00	0.00	0.00	1.00	0.00	0.00	0.25	0.00
	1987	0.25	0.00	0.00	0.00	1.00	0.80	0.00	0.00
	1988	1.00	0.33	1.00	0.50	0.00	0.75	0.00	0.00
	1989	0.25	0.00	0.00	0.50	0.00	0.83	0.00	0.00
	1990	0.33	1.00	0.00	0.50	0.20	1.00	0.00	0.00
	1991	0.00	0.00	0.33	0.67	0.33	0.67	0.00	0.00
	1992	0.00	0.00	1.00	0.25	0.25	0.50	0.00	0.00
	1993	0.50	0.33	0.25	0.50	0.00	0.00	0.00	0.00

Table G-2 Markov Chain Analysis, monthly

Month - Jun.

Sequence	Actual[xvi]	Transition probability
dry-dry	446.00	P_{00} = 0.853
dry-wet	77.00	P_{01} = 0.147
wet-dry	78.00	P_{10} = 0.574
wet-wet	58.00	P_{11} = 0.426

Test of Independence: second preceding day

Sequence	Actual	Predicted[xvii]	Chi-square
dry-dry-dry	389.00	379.50	0.24
dry-dry-wet	56.00	65.52	1.38
dry-wet-dry	48.00	44.16	0.33
dry-wet-wet	29.00	32.84	0.45
wet-dry-dry	57.00	66.52	1.36
wet-dry-wet	21.00	11.48	7.89
wet-wet-dry	29.00	33.26	0.55
wet-wet-wet	29.00	24.74	0.74
Chi-square sum	12.93	with 2 d.f.	
Prob.	0.002		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	342.00	331.70	0.32
dry-dry-dry-wet	47.00	57.27	1.84
dry-dry-wet-dry	36.00	32.12	0.47
dry-dry-wet-wet	20.00	23.88	0.63
dry-wet-dry-dry	33.00	40.93	1.54
dry-wet-dry-wet	15.00	7.07	8.91
dry-wet-wet-dry	15.00	16.63	0.16
dry-wet-wet-wet	14.00	12.37	0.22
wet-dry-dry-dry	47.00	47.76	0.01
wet-dry-dry-wet	9.00	8.24	0.07
wet-dry-wet-dry	12.00	12.04	0.00
wet-dry-wet-wet	9.00	8.96	0.00
wet-wet-dry-dry	23.00	24.73	0.12
wet-wet-dry-wet	6.00	4.27	0.70
wet-wet-wet-dry	14.00	16.63	0.42
wet-wet-wet-wet	15.00	12.37	0.56
Chi-square sum	15.96	with 6 d.f.	
Prob.	0.002		

[xvi] Number of occurrences of the indicated combination of wet and dry states in the interval

[xvii] Number of occurrences predicted by the Markov Chain analysis

Table G-2 **Continued**
Month - Jul

Sequence	Actual	Transition probability
dry-dry	285.00	P_{00} = 0.740
dry-wet	100.00	P_{01} = 0.260
wet-dry	100.00	P_{10} = 0.337
wet-wet	197.00	P_{11} = 0.663

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	225.00	211.00	0.93
dry-dry-wet	60.00	74.03	2.66
dry-wet-dry	42.00	33.67	2.06
dry-wet-wet	58.00	66.33	1.05
wet-dry-dry	60.00	74.03	2.66
wet-dry-wet	40.00	25.97	7.57
wet-wet-dry	58.00	66.33	1.05
wet-wet-wet	139.00	130.70	0.53
Chi-square sum	18.51	with 2 d.f.	
Prob.	0.000		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	184.00	165.80	1.99
dry-dry-dry-wet	40.00	58.18	5.68
dry-dry-wet-dry	25.00	20.20	1.14
dry-dry-wet-wet	35.00	39.80	0.58
dry-wet-dry-dry	28.00	31.09	0.31
dry-wet-dry-wet	14.00	10.91	0.88
dry-wet-wet-dry	22.00	19.53	0.31
dry-wet-wet-wet	36.00	38.47	0.16
wet-dry-dry-dry	41.00	45.16	0.38
wet-dry-dry-wet	20.00	15.84	1.09
wet-dry-wet-dry	17.00	13.47	0.93
wet-dry-wet-wet	23.00	26.53	0.47
wet-wet-dry-dry	32.00	42.94	2.79
wet-wet-dry-wet	26.00	15.06	7.94
wet-wet-wet-dry	36.00	46.80	2.49
wet-wet-wet-wet	103.00	92.20	1.27
Chi-square sum	28.40	with 6 d.f.	
Prob.	0.000		

Table G-2 **Continued**
Month - Aug

Sequence	Actual	Transition probability
dry-dry	242.00	P_{00} = 0.697
dry-wet	105.00	P_{01} = 0.303
wet-dry	105.00	P_{10} = 0.313
wet-wet	230.00	P_{11} = 0.687

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	181.0	168.8	0.89
dry-dry-wet	61.00	73.23	2.04
dry-wet-dry	34.00	32.91	0.04
dry-wet-wet	71.00	72.09	0.02
wet-dry-dry	61.00	73.23	2.04
wet-dry-wet	44.00	31.77	4.71
wet-wet-dry	71.00	72.09	0.02
wet-wet-wet	159.0	157.9	0.01
Chi-square sum	9.75	with 2 d.f.	
Prob.	0.008		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	133.00	126.20	0.36
dry-dry-dry-wet	48.00	54.77	0.84
dry-dry-wet-dry	18.00	19.12	0.07
dry-dry-wet-wet	43.00	41.88	0.03
dry-wet-dry-dry	20.00	23.71	0.58
dry-wet-dry-wet	14.00	10.29	1.34
dry-wet-wet-dry	17.00	22.25	1.24
dry-wet-wet-wet	54.00	48.75	0.57
wet-dry-dry-dry	48.00	42.54	0.70
wet-dry-dry-wet	13.00	18.46	1.61
wet-dry-wet-dry	16.00	13.79	0.35
wet-dry-wet-wet	28.00	30.21	0.16
wet-wet-dry-dry	41.00	49.52	1.46
wet-wet-dry-wet	30.00	21.48	3.38
wet-wet-wet-dry	54.00	49.84	0.35
wet-wet-wet-wet	105.0	109.2	0.16
Chi-square sum	13.20	with 6 d.f.	
Prob.	0.040		

Table G-2 **Continued**
Month - Sep

Sequence	Actual	Transition probability
dry-dry	450.00	P_{00} = 0.877
dry-wet	63.00	P_{01} = 0.123
wet-dry	63.00	P_{10} = 0.429
wet-wet	84.00	P_{11} = 0.571

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	401.00	394.70	0.10
dry-dry-wet	49.00	55.26	0.71
dry-wet-dry	28.00	27.00	0.04
dry-wet-wet	35.00	36.00	0.03
wet-dry-dry	49.00	55.26	0.71
wet-dry-wet	14.00	7.74	5.07
wet-wet-dry	35.00	36.00	0.03
wet-wet-wet	49.00	48.00	0.02
Chi-square sum	6.70	with 2 d.f.	
Prob.	0.035		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	361.00	351.80	0.24
dry-dry-dry-wet	40.00	49.25	1.74
dry-dry-wet-dry	24.00	21.00	0.43
dry-dry-wet-wet	25.00	28.00	0.32
dry-wet-dry-dry	23.00	24.56	0.10
dry-wet-dry-wet	5.00	3.44	0.71
dry-wet-wet-dry	14.00	15.00	0.07
dry-wet-wet-wet	21.00	20.00	0.05
wet-dry-dry-dry	40.00	42.98	0.21
wet-dry-dry-wet	9.00	6.02	1.48
wet-dry-wet-dry	4.00	6.00	0.67
wet-dry-wet-wet	10.00	8.00	0.50
wet-wet-dry-dry	26.00	30.70	0.72
wet-wet-dry-wet	9.00	4.30	5.14
wet-wet-wet-dry	21.00	21.00	0.00
wet-wet-wet-wet	28.00	28.00	0.00
Chi-square sum	12.37	with 6 d.f.	
Prob.	0.054		

Table G-3 Markov chain analysis - 10 day intervals
Month - Jun 1-10

Sequence	Actual	Transition probability
dry-dry	174.00	P_{00} = 0.921
dry-wet	15.00	P_{01} = 0.079
wet-dry	22.00	P_{10} = 0.733
wet-wet	8.00	P_{11} = 0.267

Test of Independence: second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	156.00	156.50	0.00
dry-dry-wet	14.00	13.49	0.02
dry-wet-dry	11.00	11.73	0.05
dry-wet-wet	5.00	4.27	0.13
wet-dry-dry	18.00	17.49	0.01
wet-dry-wet	1.00	1.51	0.17
wet-wet-dry	10.00	9.53	0.02
wet-wet-wet	3.00	3.47	0.06
Chi-square sum	0.46	with 2 d.f.	
Prob.	0.793		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	140.0	139.0	0.01
dry-dry-dry-wet	11.00	11.98	0.08
dry-dry-wet-dry	9.00	9.53	0.03
dry-dry-wet-wet	4.00	3.47	0.08
dry-wet-dry-dry	9.00	8.29	0.06
dry-wet-dry-wet	0.00	0.71	0.71
dry-wet-wet-dry	5.00	5.13	0.00
dry-wet-wet-wet	2.00	1.87	0.01
wet-dry-dry-dry	16.00	17.49	0.13
wet-dry-dry-wet	3.00	1.51	1.48
wet-dry-wet-dry	2.00	2.20	0.02
wet-dry-wet-wet	1.00	0.80	0.05
wet-wet-dry-dry	8.00	8.29	0.01
wet-wet-dry-wet	1.00	0.71	0.11
wet-wet-wet-dry	5.00	4.40	0.08
wet-wet-wet-wet	1.00	1.60	0.23
Chi-square sum	3.09	with 6 d.f.	
Prob.	0.797		

Table G-3 **Continued**
Month - Jun **10-20**

Sequence	Actual	Transition probability
dry-dry	155.00	P_{00} = 0.861
dry-wet	25.00	P_{01} = 0.139
wet-dry	24.00	P_{10} = 0.600
wet-wet	16.00	P_{11} = 0.400

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	133.00	132.60	0.00
dry-dry-wet	21.00	21.39	0.01
dry-wet-dry	16.00	14.40	0.18
dry-wet-wet	8.00	9.60	0.27
wet-dry-dry	22.00	22.39	0.01
wet-dry-wet	4.00	3.61	0.04
wet-wet-dry	8.00	9.60	0.27
wet-wet-wet	8.00	6.40	0.40
Chi-square sum	1.17	with 2 d.f.	
Prob.	0.558		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	112.0	113.7	0.02
dry-dry-dry-wet	20.00	18.33	0.15
dry-dry-wet-dry	13.00	12.60	0.01
dry-dry-wet-wet	8.00	8.40	0.02
dry-wet-dry-dry	15.00	15.50	0.02
dry-wet-dry-wet	3.00	2.50	0.10
dry-wet-wet-dry	5.00	4.80	0.01
dry-wet-wet-wet	3.00	3.20	0.01
wet-dry-dry-dry	21.00	18.94	0.22
wet-dry-dry-wet	1.00	3.06	1.38
wet-dry-wet-dry	3.00	1.80	0.80
wet-dry-wet-wet	0.00	1.20	1.20
wet-wet-dry-dry	7.00	6.89	0.00
wet-wet-dry-wet	1.00	1.11	0.01
wet-wet-wet-dry	3.00	4.80	0.68
wet-wet-wet-wet	5.00	3.20	1.01
Chi-square sum	5.65	with 6 d.f.	
Prob.	0.463		

Table G-3 **Continued**
Month - Jun 20-30

Sequence	Actual	Transition probability
dry-dry	117.00	P_{00} = 0.760
dry-wet	37.00	P_{01} = 0.240
wet-dry	32.00	P_{10} = 0.485
wet-wet	34.00	P_{11} = 0.515

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	100.00	91.93	0.71
dry-dry-wet	21.00	29.07	2.24
dry-wet-dry	21.00	17.94	0.52
dry-wet-wet	16.00	19.06	0.49
wet-dry-dry	17.00	25.07	2.60
wet-dry-wet	16.00	7.93	8.22
wet-wet-dry	11.00	14.06	0.67
wet-wet-wet	18.00	14.94	0.63
Chi-square sum	16.07	with 2 d.f.	
Prob.	0.000		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	90.00	80.53	1.11
dry-dry-dry-wet	16.00	25.47	3.52
dry-dry-wet-dry	14.00	10.67	1.04
dry-dry-wet-wet	8.00	11.33	0.98
dry-wet-dry-dry	9.00	15.95	3.03
dry-wet-dry-wet	12.00	5.05	9.59
dry-wet-wet-dry	5.00	6.79	0.47
dry-wet-wet-wet	9.00	7.21	0.44
wet-dry-dry-dry	10.00	11.40	0.17
wet-dry-dry-wet	5.00	3.60	0.54
wet-dry-wet-dry	7.00	7.27	0.01
wet-dry-wet-wet	8.00	7.73	0.01
wet-wet-dry-dry	8.00	9.12	0.14
wet-wet-dry-wet	4.00	2.88	0.43
wet-wet-wet-dry	6.00	7.27	0.22
wet-wet-wet-wet	9.00	7.73	0.21
Chi-square sum	21.92	with 6 d.f.	
Prob.	0.001		

Table G-3 **Continued**
Month - Jul **1-10**

Sequence	Actual	Transition probability
dry-dry	99.00	P_{00} = 0.728
dry-wet	37.00	P_{01} = 0.272
wet-dry	37.00	P_{10} = 0.440
wet-wet	47.00	P_{11} = 0.560

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	77.00	72.07	0.34
dry-dry-wet	22.00	26.93	0.90
dry-wet-dry	17.00	15.86	0.08
dry-wet-wet	19.00	20.14	0.06
wet-dry-dry	22.00	26.93	0.90
wet-dry-wet	15.00	10.07	2.42
wet-wet-dry	20.00	21.14	0.06
wet-wet-wet	28.00	26.86	0.05
Chi-square sum	4.82	with 2 d.f.	
Prob.	0.090		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	64.00	58.24	0.57
dry-dry-dry-wet	16.00	21.76	1.53
dry-dry-wet-dry	10.00	8.81	0.16
dry-dry-wet-wet	10.00	11.19	0.13
dry-wet-dry-dry	11.00	11.65	0.04
dry-wet-dry-wet	5.00	4.35	0.10
dry-wet-wet-dry	8.00	8.81	0.07
dry-wet-wet-wet	12.00	11.19	0.06
wet-dry-dry-dry	13.00	13.83	0.05
wet-dry-dry-wet	6.00	5.17	0.13
wet-dry-wet-dry	7.00	7.05	0.00
wet-dry-wet-wet	9.00	8.95	0.00
wet-wet-dry-dry	11.00	15.29	1.20
wet-wet-dry-wet	10.00	5.71	3.22
wet-wet-wet-dry	12.00	12.33	0.01
wet-wet-wet-wet	16.00	15.67	0.01
Chi-square sum	7.27	with 6 d.f.	
Prob.	0.297		

Table G-3 **Continued**
Month - Jul **10-20**

Sequence	Actual	Transition probability
dry-dry	83.00	P_{00} = 0.697
dry-wet	36.00	P_{01} = 0.303
wet-dry	35.00	P_{10} = 0.347
wet-wet	66.00	P_{11} = 0.653

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	62.00	58.59	0.20
dry-dry-wet	22.00	25.41	0.46
dry-wet-dry	18.00	13.51	1.49
dry-wet-wet	21.00	25.49	0.79
wet-dry-dry	21.00	24.41	0.48
wet-dry-wet	14.00	10.59	1.10
wet-wet-dry	17.00	21.49	0.94
wet-wet-wet	45.00	40.51	0.50
Chi-square sum	5.94	with 2 d.f.	
Prob.	0.051		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	48.00	43.94	0.37
dry-dry-dry-wet	15.00	19.06	0.86
dry-dry-wet-dry	12.00	8.66	1.29
dry-dry-wet-wet	13.00	16.34	0.68
dry-wet-dry-dry	12.00	12.55	0.02
dry-wet-dry-wet	6.00	5.45	0.06
dry-wet-wet-dry	9.00	7.62	0.25
dry-wet-wet-wet	13.00	14.38	0.13
wet-dry-dry-dry	14.00	14.65	0.03
wet-dry-dry-wet	7.00	6.35	0.07
wet-dry-wet-dry	6.00	4.85	0.27
wet-dry-wet-wet	8.00	9.15	0.14
wet-wet-dry-dry	9.00	11.86	0.69
wet-wet-dry-wet	8.00	5.14	1.59
wet-wet-wet-dry	8.00	13.86	2.48
wet-wet-wet-wet	32.00	26.14	1.31
Chi-square sum	10.25	with 6 d.f.	
Prob.	0.115		

Table G-3 **Continued**
Month - Jul **20-31**

Sequence	Actual	Transition probability
dry-dry	103.00	P_{00} = 0.792
dry-wet	27.00	P_{01} = 0.208
wet-dry	28.00	P_{10} = 0.250
wet-wet	84.00	P_{11} = 0.750

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	86.00	80.82	0.33
dry-dry-wet	16.00	21.18	1.27
dry-wet-dry	7.00	6.25	0.09
dry-wet-wet	18.00	18.75	0.03
wet-dry-dry	17.00	22.18	1.21
wet-dry-wet	11.00	5.82	4.62
wet-wet-dry	21.00	21.75	0.03
wet-wet-wet	66.00	65.25	0.01
Chi-square sum	7.59	with 2 d.f.	
Prob.	0.022		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	72.00	64.18	0.95
dry-dry-dry-wet	9.00	16.82	3.64
dry-dry-wet-dry	3.00	3.75	0.15
dry-dry-wet-wet	12.00	11.25	0.05
dry-wet-dry-dry	5.00	6.34	0.28
dry-wet-dry-wet	3.00	1.66	1.08
dry-wet-wet-dry	5.00	4.00	0.25
dry-wet-wet-wet	11.00	12.00	0.08
wet-dry-dry-dry	14.00	16.64	0.42
wet-dry-dry-wet	7.00	4.36	1.60
wet-dry-wet-dry	4.00	2.50	0.90
wet-dry-wet-wet	6.00	7.50	0.30
wet-wet-dry-dry	12.00	15.85	0.93
wet-wet-dry-wet	8.00	4.15	3.56
wet-wet-wet-dry	16.00	17.75	0.17
wet-wet-wet-wet	55.00	53.25	0.06
Chi-square sum	14.43	with 6 d.f.	
Prob.	0.025		

Table G-3 **Continued**
Month - Aug **1-10**

Sequence	Actual	Transition probability
dry-dry	65.00	P_{00} = 0.644
dry-wet	36.00	P_{01} = 0.356
wet-dry	40.00	P_{10} = 0.336
wet-wet	79.00	P_{11} = 0.664

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	42.00	41.19	0.02
dry-dry-wet	22.00	22.81	0.03
dry-wet-dry	13.00	12.10	0.07
dry-wet-wet	23.00	23.90	0.03
wet-dry-dry	23.00	23.81	0.03
wet-dry-wet	14.00	13.19	0.05
wet-wet-dry	27.00	27.90	0.03
wet-wet-wet	56.00	55.10	0.01
Chi-square sum	0.27	with 2 d.f.	
Prob.	0.875		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	29.00	28.32	0.02
dry-dry-dry-wet	15.00	15.68	0.03
dry-dry-wet-dry	7.00	7.73	0.07
dry-dry-wet-wet	16.00	15.27	0.04
dry-wet-dry-dry	6.00	6.44	0.03
dry-wet-dry-wet	4.00	3.56	0.05
dry-wet-wet-dry	6.00	8.40	0.69
dry-wet-wet-wet	19.00	16.60	0.35
wet-dry-dry-dry	13.00	12.87	0.00
wet-dry-dry-wet	7.00	7.13	0.00
wet-dry-wet-dry	6.00	4.37	0.61
wet-dry-wet-wet	7.00	8.63	0.31
wet-wet-dry-dry	17.00	17.38	0.01
wet-wet-dry-wet	10.00	9.62	0.01
wet-wet-wet-dry	21.00	19.50	0.12
wet-wet-wet-wet	37.00	38.50	0.06
Chi-square sum	2.39	with 6 d.f.	
Prob.	0.881		

Table G-3 **Continued**
Month - Aug **10-20**

Sequence	Actual	Transition probability
dry-dry	78.00	P_{00} = 0.690
dry-wet	35.00	P_{01} = 0.310
wet-dry	37.00	P_{10} = 0.346
wet-wet	70.00	P_{11} = 0.654

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	60.00	53.84	0.70
dry-dry-wet	18.00	24.16	1.57
dry-wet-dry	11.00	11.41	0.01
dry-wet-wet	22.00	21.59	0.01
wet-dry-dry	18.00	24.16	1.57
wet-dry-wet	17.00	10.84	3.50
wet-wet-dry	26.00	25.59	0.01
wet-wet-wet	48.00	48.41	0.00
Chi-square sum	7.38	with 2 d.f.	
Prob.	0.025		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	48.00	42.11	0.82
dry-dry-dry-wet	13.00	18.89	1.84
dry-dry-wet-dry	6.00	5.53	0.04
dry-dry-wet-wet	10.00	10.47	0.02
dry-wet-dry-dry	6.00	8.28	0.63
dry-wet-dry-wet	6.00	3.72	1.40
dry-wet-wet-dry	7.00	8.64	0.31
dry-wet-wet-wet	18.00	16.36	0.17
wet-dry-dry-dry	12.00	11.73	0.01
wet-dry-dry-wet	5.00	5.27	0.01
wet-dry-wet-dry	5.00	5.88	0.13
wet-dry-wet-wet	12.00	11.12	0.07
wet-wet-dry-dry	12.00	15.88	0.95
wet-wet-dry-wet	11.00	7.12	2.11
wet-wet-wet-dry	19.00	16.94	0.25
wet-wet-wet-wet	30.00	32.06	0.13
Chi-square sum	8.89	with 6 d.f.	
Prob.	0.180		

Table G-3 **Continued**
Month - Aug **20-31**

Sequence	Actual	Transition probability
dry-dry	99.00	P_{00} = 0.744
dry-wet	34.00	P_{01} = 0.256
wet-dry	28.00	P_{10} = 0.257
wet-wet	81.00	P_{11} = 0.743

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	79.00	74.44	0.28
dry-dry-wet	21.00	25.56	0.81
dry-wet-dry	10.00	9.25	0.06
dry-wet-wet	26.00	26.75	0.02
wet-dry-dry	20.00	24.56	0.85
wet-dry-wet	13.00	8.44	2.47
wet-wet-dry	18.00	18.75	0.03
wet-wet-wet	55.00	54.25	0.01
Chi-square sum	4.53	with 2 d.f.	
Prob.	0.104		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	56.00	56.57	0.01
dry-dry-dry-wet	20.00	19.43	0.02
dry-dry-wet-dry	5.00	5.65	0.08
dry-dry-wet-wet	17.00	16.35	0.03
dry-wet-dry-dry	8.00	8.93	0.10
dry-wet-dry-wet	4.00	3.07	0.28
dry-wet-wet-dry	4.00	5.39	0.36
dry-wet-wet-wet	17.00	15.61	0.12
wet-dry-dry-dry	23.00	17.86	1.48
wet-dry-dry-wet	1.00	6.14	4.30
wet-dry-wet-dry	5.00	3.60	0.55
wet-dry-wet-wet	9.00	10.40	0.19
wet-wet-dry-dry	12.00	15.63	0.84
wet-wet-dry-wet	9.00	5.37	2.46
wet-wet-wet-dry	14.00	13.36	0.03
wet-wet-wet-wet	38.00	38.64	0.01
Chi-square sum	10.84	with 6 d.f.	
Prob.	0.093		

Table G-3 **Continued**
Month - Sep **1-10**

Sequence	Actual	Transition probability
dry-dry	103.00	P_{00} = 0.746
dry-wet	35.00	P_{01} = 0.254
wet-dry	30.00	P_{10} = 0.366
wet-wet	52.00	P_{11} = 0.634

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	85.00	82.10	0.10
dry-dry-wet	25.00	27.90	0.30
dry-wet-dry	12.00	11.71	0.01
dry-wet-wet	20.00	20.29	0.00
wet-dry-dry	18.00	20.90	0.40
wet-dry-wet	10.00	7.10	1.18
wet-wet-dry	18.00	18.29	0.00
wet-wet-wet	32.00	31.71	0.00
Chi-square sum	2.01	with 2 d.f.	
Prob.	0.367		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	71.00	67.92	0.14
dry-dry-dry-wet	20.00	23.08	0.41
dry-dry-wet-dry	10.00	9.15	0.08
dry-dry-wet-wet	15.00	15.85	0.05
dry-wet-dry-dry	8.00	8.96	0.10
dry-wet-dry-wet	4.00	3.04	0.30
dry-wet-wet-dry	5.00	6.95	0.55
dry-wet-wet-wet	14.00	12.05	0.32
wet-dry-dry-dry	14.00	14.18	0.00
wet-dry-dry-wet	5.00	4.82	0.01
wet-dry-wet-dry	2.00	2.56	0.12
wet-dry-wet-wet	5.00	4.44	0.07
wet-wet-dry-dry	10.00	11.94	0.32
wet-wet-dry-wet	6.00	4.06	0.93
wet-wet-wet-dry	13.00	11.34	0.24
wet-wet-wet-wet	18.00	19.66	0.14
Chi-square sum	3.77	with 6 d.f.	
Prob.	0.707		

Table G-3 **Continued**
Month - Sep **10-20**

Sequence	Actual	Transition probability
dry-dry	167.00	P_{00} = 0.913
dry-wet	16.00	P_{01} = 0.087
wet-dry	17.00	P_{10} = 0.459
wet-wet	20.00	P_{11} = 0.541

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	151.00	150.60	0.00
dry-dry-wet	14.00	14.43	0.01
dry-wet-dry	7.00	7.35	0.02
dry-wet-wet	9.00	8.65	0.01
wet-dry-dry	16.00	16.43	0.01
wet-dry-wet	2.00	1.57	0.12
wet-wet-dry	10.00	9.65	0.01
wet-wet-wet	11.00	11.35	0.01
Chi-square sum	0.20	with 2 d.f.	
Prob.	0.907		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	137.00	135.10	0.03
dry-dry-dry-wet	11.00	12.94	0.29
dry-dry-wet-dry	6.00	5.05	0.18
dry-dry-wet-wet	5.00	5.95	0.15
dry-wet-dry-dry	6.00	6.39	0.02
dry-wet-dry-wet	1.00	0.61	0.25
dry-wet-wet-dry	5.00	4.14	0.18
dry-wet-wet-wet	4.00	4.86	0.15
wet-dry-dry-dry	14.00	15.51	0.15
wet-dry-dry-wet	3.00	1.49	1.54
wet-dry-wet-dry	1.00	2.30	0.73
wet-dry-wet-wet	4.00	2.70	0.62
wet-wet-dry-dry	10.00	10.04	0.00
wet-wet-dry-wet	1.00	0.96	0.00
wet-wet-wet-dry	5.00	5.51	0.05
wet-wet-wet-wet	7.00	6.49	0.04
Chi-square sum	4.38	with 6 d.f.	
Prob.	0.625		

Table G-3 **<u>Continued</u>**
Month - Sep **20-30**

Sequence	Actual	Transition probability
dry-dry	180.00	P_{00} = 0.938
dry-wet	12.00	P_{01} = 0.063
wet-dry	16.00	P_{10} = 0.571
wet-wet	12.00	P_{11} = 0.429

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	165.00	164.10	0.01
dry-dry-wet	10.00	10.94	0.08
dry-wet-dry	9.00	8.57	0.02
dry-wet-wet	6.00	6.43	0.03
wet-dry-dry	15.00	15.94	0.06
wet-dry-wet	2.00	1.06	0.83
wet-wet-dry	7.00	7.43	0.02
wet-wet-wet	6.00	5.57	0.03
Chi-square sum	1.08	with 2 d.f.	
Prob.	0.584		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	153.00	151.09	0.01
dry-dry-dry-wet	9.00	10.13	0.13
dry-dry-wet-dry	8.00	7.43	0.04
dry-dry-wet-wet	5.00	5.57	0.06
dry-wet-dry-dry	9.00	8.44	0.04
dry-wet-dry-wet	0.00	0.56	0.56
dry-wet-wet-dry	4.00	4.00	0.00
dry-wet-wet-wet	3.00	3.00	0.00
wet-dry-dry-dry	12.00	12.19	0.00
wet-dry-dry-wet	1.00	0.81	0.04
wet-dry-wet-dry	1.00	1.14	0.02
wet-dry-wet-wet	1.00	0.86	0.02
wet-wet-dry-dry	6.00	7.50	0.30
wet-wet-dry-wet	2.00	0.50	4.50
wet-wet-wet-dry	3.00	3.43	0.05
wet-wet-wet-wet	3.00	2.57	0.07
Chi-square sum	5.85	with 6 d.f.	
Prob.	0.440		

Table G-4 Markov chain analysis, 5 day intervals
Month - Jun 1-5

Sequence	Actual	Transition probability
dry-dry	88.00	P_{00} = 0.957
dry-wet	4.00	P_{01} = 0.043
wet-dry	14.00	P_{10} = 0.824
wet-wet	3.00	P_{11} = 0.176

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	76.00	75.57	0.00
dry-dry-wet	3.00	3.43	0.06
dry-wet-dry	4.00	4.94	0.18
dry-wet-wet	2.00	1.06	0.84
wet-dry-dry	12.00	12.43	0.02
wet-dry-wet	1.00	0.57	0.33
wet-wet-dry	9.00	8.24	0.07
wet-wet-wet	1.00	1.76	0.33
Chi-square sum	1.83	with 2 d.f.	
Prob.	0.401		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	65.00	64.09	0.01
dry-dry-dry-wet	2.00	2.91	0.29
dry-dry-wet-dry	2.00	2.47	0.09
dry-dry-wet-wet	1.00	0.53	0.42
dry-wet-dry-dry	3.00	2.87	0.01
dry-wet-dry-wet	0.00	0.13	0.13
dry-wet-wet-dry	4.00	4.12	0.00
dry-wet-wet-wet	1.00	0.88	0.02
wet-dry-dry-dry	11.00	11.48	0.02
wet-dry-dry-wet	1.00	0.52	0.44
wet-dry-wet-dry	2.00	2.47	0.09
wet-dry-wet-wet	1.00	0.53	0.42
wet-wet-dry-dry	8.00	8.61	0.04
wet-wet-dry-wet	1.00	0.39	0.95
wet-wet-wet-dry	5.00	4.12	0.19
wet-wet-wet-wet	0.00	0.88	0.88
Chi-square sum	3.99	with 6 d.f.	
Prob.	0.678		

Table G-4 **Continued**
Month - Jun **6-10**

Sequence	Actual	Transition probability
dry-dry	86.00	P_{00} = 0.887
dry-wet	11.00	P_{01} = 0.113
wet-dry	8.00	P_{10} = 0.615
wet-wet	5.00	P_{11} = 0.385

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	80.00	80.68	0.01
dry-dry-wet	11.00	10.32	0.04
dry-wet-dry	7.00	6.15	0.12
dry-wet-wet	3.00	3.85	0.19
wet-dry-dry	6.00	5.32	0.09
wet-dry-wet	0.00	0.68	0.68
wet-wet-dry	1.00	1.85	0.39
wet-wet-wet	2.00	1.15	0.62
Chi-square sum	2.13	with 2 d.f.	
Prob.	0.345		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	75.00	74.47	0.00
dry-dry-dry-wet	9.00	9.53	0.03
dry-dry-wet-dry	7.00	6.15	0.12
dry-dry-wet-wet	3.00	3.85	0.19
dry-wet-dry-dry	6.00	5.32	0.09
dry-wet-dry-wet	0.00	0.68.	0.68
dry-wet-wet-dry	1.00	1.23	0.04
dry-wet-wet-wet	1.00	0.77	0.07
wet-dry-dry-dry	5.00	6.21	0.23
wet-dry-dry-wet	2.00	0.79	1.83
wet-dry-wet-dry	0.00	0.00.	0.00
wet-dry-wet-wet	0.00	0.00.	0.00
wet-wet-dry-dry	0.00	0.00.	0.00
wet-wet-dry-wet	0.00	0.00.	0.00
wet-wet-wet-dry	0.00	0.62	0.62
wet-wet-wet-wet	1.00	0.38	0.98
Chi-square sum	4.88	with 6 d.f.	
Prob.	0.559		

Table G-4 **Continued**
Month - Jun **11-15**

Sequence	Actual	Transition probability
dry-dry	77.00	P_{00} = 0.846
dry-wet	14.00	P_{01} = 0.154
wet-dry	13.00	P_{10} = 0.684
wet-wet	6.00	P_{11} = 0.316

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	62.00	62.62	0.01
dry-dry-wet	12.00	11.38	0.03
dry-wet-dry	9.00	8.89	0.00
dry-wet-wet	4.00	4.11	0.00
wet-dry-dry	15.00	14.38	0.03
wet-dry-wet	2.00	2.62	0.14
wet-wet-dry	4.00	4.11	0.00
wet-wet-wet	2.00	1.89	0.01
Chi-square sum	0.22	with 2 d.f.	
Prob.	0.895		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	54.00	55.00	0.02
dry-dry-dry-wet	11.00	10.00	0.10
dry-dry-wet-dry	8.00	8.21	0.01
dry-dry-wet-wet	4.00	3.79	0.01
dry-wet-dry-dry	10.00	10.15	0.00
dry-wet-dry-wet	2.00	1.85	0.01
dry-wet-wet-dry	2.00	2.74	0.20
dry-wet-wet-wet	2.00	1.26	0.43
wet-dry-dry-dry	8.00	7.62	0.02
wet-dry-dry-wet	1.00	1.38	0.11
wet-dry-wet-dry	1.00	0.68	0.15
wet-dry-wet-wet	0.00	0.32	0.32
wet-wet-dry-dry	5.00	4.23	0.14
wet-wet-dry-wet	0.00	0.77	0.77
wet-wet-wet-dry	2.00	1.37	0.29
wet-wet-wet-wet	0.00	0.63	0.63
Chi-square sum	3.20	with 6 d.f.	
Prob.	0.784		

Table G-4 **Continued**
Month - Jun **16-20**

Sequence	Actual	Transition probability
dry-dry	78.00	P_{00} = 0.876
dry-wet	11.00	P_{01} = 0.124
wet-dry	11.00	P_{10} = 0.524
wet-wet	10.00	P_{11} = 0.476

Test of Independence: second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	71.00	70.11	0.01
dry-dry-wet	9.00	9.89	0.08
dry-wet-dry	7.00	5.76	0.27
dry-wet-wet	4.00	5.24	0.29
wet-dry-dry	7.00	7.89	0.10
wet-dry-wet	2.00	1.11	0.71
wet-wet-dry	4.00	5.24	0.29
wet-wet-wet	6.00	4.76	0.32
Chi-square sum	2.07	with 2 d.f.	
Prob.	0.355		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	58.00	58.72	0.01
dry-dry-dry-wet	9.00	8.28	0.06
dry-dry-wet-dry	5.00	4.71	0.02
dry-dry-wet-wet	4.00	4.29	0.02
dry-wet-dry-dry	5.00	5.26	0.01
dry-wet-dry-wet	1.00	0.74	0.09
dry-wet-wet-dry	3.00	2.10	0.39
dry-wet-wet-wet	1.00	1.90	0.43
wet-dry-dry-dry	13.00	11.39	0.23
wet-dry-dry-wet	0.00	1.61	1.61
wet-dry-wet-dry	2.00	1.05	0.87
wet-dry-wet-wet	0.00	0.95	0.95
wet-wet-dry-dry	2.00	2.63	0.15
wet-wet-dry-wet	1.00	0.37	1.07
wet-wet-wet-dry	1.00	3.14	1.46
wet-wet-wet-wet	5.00	2.86	1.61
Chi-square sum	8.97	with 6 d.f.	
Prob.	0.175		

Table G-4 **<u>Continued</u>**
Month - Jun **21-25**

Sequence	Actual	Transition probability
dry-dry	60.00	P_{00} = 0.759
dry-wet	19.00	P_{01} = 0.241
wet-dry	18.00	P_{10} = 0.581
wet-wet	13.00	P_{11} = 0.419

Test of Independence: second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	52.00	49.37	0.14
dry-dry-wet	13.00	15.63	0.44
dry-wet-dry	11.00	9.29	0.31
dry-wet-wet	5.00	6.71	0.44
wet-dry-dry	8.00	10.63	0.65
wet-dry-wet	6.00	3.37	2.06
wet-wet-dry	7.00	8.71	0.34
wet-wet-wet	8.00	6.29	0.46
Chi-square sum	4.85	with 2 d.f.	
Prob.	0.089		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	46.00	42.53	0.28
dry-dry-dry-wet	10.00	13.47	0.89
dry-dry-wet-dry	8.00	6.39	0.41
dry-dry-wet-wet	3.00	4.61	0.56
dry-wet-dry-dry	4.00	6.08	0.71
dry-wet-dry-wet	4.00	1.92	2.24
dry-wet-wet-dry	2.00	3.48	0.63
dry-wet-wet-wet	4.00	2.52	0.88
wet-dry-dry-dry	6.00	6.84	0.10
wet-dry-dry-wet	3.00	2.16	0.32
wet-dry-wet-dry	3.00	2.90	0.00
wet-dry-wet-wet	2.00	2.10	0.00
wet-wet-dry-dry	4.00	4.56	0.07
wet-wet-dry-wet	2.00	1.44	0.21
wet-wet-wet-dry	5.00	5.23	0.01
wet-wet-wet-wet	4.00	3.77	0.01
Chi-square sum	7.34	with 6 d.f.	
Prob.	0.290		

Table G-4 **Continued**
Month - Jun **26-30**

Sequence	Actual	Transition probability
dry-dry	57.00	P_{00} = 0.760
dry-wet	18.00	P_{01} = 0.240
wet-dry	14.00	P_{10} = 0.400
wet-wet	21.00	P_{11} = 0.600

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	48.00	42.56	0.70
dry-dry-wet	8.00	13.44	2.20
dry-wet-dry	10.00	8.40	0.30
dry-wet-wet	11.00	12.60	0.20
wet-dry-dry	9.00	14.44	2.05
wet-dry-wet	10.00	4.56	6.49
wet-wet-dry	4.00	5.60	0.46
wet-wet-wet	10.00	8.40	0.30
Chi-square sum	12.71	with 2 d.f.	
Prob.	0.002		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	44.00	38.00	0.95
dry-dry-dry-wet	6.00	12.00	3.00
dry-dry-wet-dry	6.00	4.40	0.58
dry-dry-wet-wet	5.00	6.60	0.39
dry-wet-dry-dry	5.00	9.88	2.41
dry-wet-dry-wet	8.00	3.12	7.63
dry-wet-wet-dry	3.00	3.20	0.01
dry-wet-wet-wet	5.00	4.80	0.01
wet-dry-dry-dry	4.00	4.56	0.07
wet-dry-dry-wet	2.00	1.44	0.22
wet-dry-wet-dry	4.00	4.00	0.00
wet-dry-wet-wet	6.00	6.00	0.00
wet-wet-dry-dry	4.00	4.56	0.07
wet-wet-dry-wet	2.00	1.44	0.22
wet-wet-wet-dry	1.00	2.40	0.82
wet-wet-wet-wet	5.00	3.60	0.54
Chi-square sum	16.92	with 6 d.f.	
Prob.	0.010		

Table G-4 **Continued**
Month - Jul **1-5**

Sequence	Actual	Transition probability
dry-dry	47.00	P_{00} = 0.712
dry-wet	19.00	P_{01} = 0.288
wet-dry	19.00	P_{10} = 0.432
wet-wet	25.00	P_{11} = 0.568

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	37.00	33.47	0.37
dry-dry-wet	10.00	13.53	0.92
dry-wet-dry	11.00	8.20	0.95
dry-wet-wet	8.00	10.80	0.72
wet-dry-dry	10.00	13.53	0.92
wet-dry-wet	9.00	5.47	2.28
wet-wet-dry	8.00	10.80	0.72
wet-wet-wet	17.00	14.20	0.55
Chi-square sum	7.44	with 2 d.f.	
Prob.	0.024		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	29.00	26.35	0.27
dry-dry-dry-wet	8.00	10.65	0.66
dry-dry-wet-dry	5.00	3.89	0.32
dry-dry-wet-wet	4.00	5.11	0.24
dry-wet-dry-dry	7.00	7.12	0.00
dry-wet-dry-wet	3.00	2.88	0.01
dry-wet-wet-dry	3.00	4.75	0.64
dry-wet-wet-wet	8.00	6.25	0.49
wet-dry-dry-dry	8.00	7.12	0.11
wet-dry-dry-wet	2.00	2.88	0.27
wet-dry-wet-dry	6.00	4.32	0.66
wet-dry-wet-wet	4.00	5.68	0.50
wet-wet-dry-dry	3.00	6.41	1.81
wet-wet-dry-wet	6.00	2.59	4.49
wet-wet-wet-dry	5.00	6.05	0.18
wet-wet-wet-wet	9.00	7.95	0.14
Chi-square sum	10.78	with 6 d.f.	
Prob.	0.096		

Table G-4 **Continued**
Month - Jul **6-10**

Sequence	Actual	Transition probability
dry-dry	52.00	P_{00} = 0.743
dry-wet	18.00	P_{01} = 0.257
wet-dry	18.00	P_{10} = 0.450
wet-wet	22.00	P_{11} = 0.550

Test of Independence: second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	40.00	38.63	0.05
dry-dry-wet	12.00	13.37	0.14
dry-wet-dry	6.00	7.65	0.36
dry-wet-wet	11.00	9.35	0.29
wet-dry-dry	12.00	13.37	0.14
wet-dry-wet	6.00	4.63	0.41
wet-wet-dry	12.00	10.35	0.26
wet-wet-wet	11.00	12.65	0.22
Chi-square sum	1.86	with 2 d.f.	
Prob.	0.394		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	35.00	31.94	0.29
dry-dry-dry-wet	8.00	11.06	0.85
dry-dry-wet-dry	5.00	4.95	0.00
dry-dry-wet-wet	6.00	6.05	0.00
dry-wet-dry-dry	4.00	4.46	0.05
dry-wet-dry-wet	2.00	1.54	0.14
dry-wet-wet-dry	5.00	4.05	0.22
dry-wet-wet-wet	4.00	4.95	0.18
wet-dry-dry-dry	5.00	6.69	0.43
wet-dry-dry-wet	4.00	2.31	1.23
wet-dry-wet-dry	1.00	2.70	1.07
wet-dry-wet-wet	5.00	3.30	0.88
wet-wet-dry-dry	8.00	8.91	0.09
wet-wet-dry-wet	4.00	3.09	0.27
wet-wet-wet-dry	7.00	6.30	0.08
wet-wet-wet-wet	7.00	7.70	0.06
Chi-square sum	5.83	with 6 d.f.	
Prob.	0.442		

Table G-4 **Continued**
Month - Jul **11-15**

Sequence	Actual	Transition probability
dry-dry	43.00	P_{00} = 0.705
dry-wet	18.00	P_{01} = 0.295
wet-dry	17.00	P_{10} = 0.347
wet-wet	32.00	P_{11} = 0.653

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	35.00	32.43	0.20
dry-dry-wet	11.00	13.57	0.49
dry-wet-dry	8.00	6.94	0.16
dry-wet-wet	12.00	13.06	0.09
wet-dry-dry	8.00	10.57	0.63
wet-dry-wet	7.00	4.43	1.50
wet-wet-dry	9.00	10.06	0.11
wet-wet-wet	20.00	18.94	0.06
Chi-square sum	3.24	with 2 d.f.	
Prob.	0.198		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	27.00	24.67	0.22
dry-dry-dry-wet	8.00	10.33	0.52
dry-dry-wet-dry	7.00	4.51	1.37
dry-dry-wet-wet	6.00	8.49	0.73
dry-wet-dry-dry	3.00	4.93	0.76
dry-wet-dry-wet	4.00	2.07	1.81
dry-wet-wet-dry	7.00	4.51	1.37
dry-wet-wet-wet	6.00	8.49	0.73
wet-dry-dry-dry	8.00	7.75	0.01
wet-dry-dry-wet	3.00	3.25	0.02
wet-dry-wet-dry	1.00	2.43	0.84
wet-dry-wet-wet	6.00	4.57	0.45
wet-wet-dry-dry	5.00	5.64	0.07
wet-wet-dry-wet	3.00	2.36	0.17
wet-wet-wet-dry	2.00	5.55	2.27
wet-wet-wet-wet	14.00	10.45	1.21
Chi-square sum	12.56	with 6 d.f.	
Prob.	0.051		

Table G-4 **Continued**
Month - Jul **16-20**

Sequence	Actual	Transition probability
dry-dry	40.00	P_{00} = 0.690
dry-wet	18.00	P_{01} = 0.310
wet-dry	18.00	P_{10} = 0.346
wet-wet	34.00	P_{11} = 0.654

Test of Independence: second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	27.00	26.21	0.02
dry-dry-wet	11.00	11.79	0.05
dry-wet-dry	10.00	6.58	1.78
dry-wet-wet	9.00	12.42	0.94
wet-dry-dry	13.00	13.79	0.05
wet-dry-wet	7.00	6.21	0.10
wet-wet-dry	8.00	11.42	1.03
wet-wet-wet	25.00	21.58	0.54
Chi-square sum	4.52	with 2 d.f.	
Prob.	0.104		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	21.00	19.31	0.15
dry-dry-dry-wet	7.00	8.69	0.33
dry-dry-wet-dry	5.00	4.15	0.17
dry-dry-wet-wet	7.00	7.85	0.09
dry-wet-dry-dry	9.00	7.59	0.26
dry-wet-dry-wet	2.00	3.41	0.59
dry-wet-wet-dry	2.00	3.12	0.40
dry-wet-wet-wet	7.00	5.88	0.21
wet-dry-dry-dry	6.00	6.90	0.12
wet-dry-dry-wet	4.00	3.10	0.26
wet-dry-wet-dry	5.00	2.42	2.74
wet-dry-wet-wet	2.00	4.58	1.45
wet-wet-dry-dry	4.00	6.21	0.78
wet-wet-dry-wet	5.00	2.79	1.74
wet-wet-wet-dry	6.00	8.31	0.64
wet-wet-wet-wet	18.00	15.69	0.34
Chi-square sum	10.28	with 6 d.f.	
Prob.	0.114		

Table G-4 **Continued**
Month - Jul **21-25**

Sequence	Actual	Transition probability
dry-dry	43.00	P_{00} = 0.754
dry-wet	14.00	P_{01} = 0.246
wet-dry	9.00	P_{10} = 0.170
wet-wet	44.00	P_{11} = 0.830

Test of Independence: second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	35.00	34.70	0.00
dry-dry-wet	11.00	11.30	0.01
dry-wet-dry	2.00	1.87	0.01
dry-wet-wet	9.00	9.13	0.00
wet-dry-dry	8.00	8.30	0.01
wet-dry-wet	3.00	2.70	0.03
wet-wet-dry	7.00	7.13	0.00
wet-wet-wet	35.00	34.87	0.00
Chi-square sum	0.07	with 2 d.f.	
Prob.	0.966		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	29.00	25.65	0.44
dry-dry-dry-wet	5.00	8.35	1.34
dry-dry-wet-dry	2.00	1.70	0.05
dry-dry-wet-wet	8.00	8.30	0.01
dry-wet-dry-dry	3.00	2.26	0.24
dry-wet-dry-wet	0.00	0.74	0.74
dry-wet-wet-dry	0.00	1.36	1.36
dry-wet-wet-wet	8.00	6.64	0.28
wet-dry-dry-dry	6.00	9.05	1.03
wet-dry-dry-wet	6.00	2.95	3.16
wet-dry-wet-dry	0.00	0.17	0.17
wet-dry-wet-wet	1.00	0.83	0.03
wet-wet-dry-dry	5.00	6.04	0.18
wet-wet-dry-wet	3.00	1.96	0.55
wet-wet-wet-dry	7.00	5.77	0.26
wet-wet-wet-wet	27.00	28.23	0.05
Chi-square sum	9.89	with 6 d.f.	
Prob.	0.129		

Table G-4 **Continued**
Month - Jul **26-31**

Sequence	Actual	Transition probability
dry-dry	60.00	P_{00} = 0.822
dry-wet	13.00	P_{01} = 0.178
wet-dry	19.00	P_{10} = 0.322
wet-wet	40.00	P_{11} = 0.678

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	51.00	46.03	0.54
dry-dry-wet	5.00	9.97	2.48
dry-wet-dry	5.00	4.51	0.05
dry-wet-wet	9.00	9.49	0.03
wet-dry-dry	9.00	13.97	1.77
wet-dry-wet	8.00	3.03	8.17
wet-wet-dry	14.00	14.49	0.02
wet-wet-wet	31.00	30.51	0.01
Chi-square sum	13.06	with 2 d.f.	
Prob.	0.001		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	43.00	38.63	0.49
dry-dry-dry-wet	4.00	8.37	2.28
dry-dry-wet-dry	1.00	1.61	0.23
dry-dry-wet-wet	4.00	3.39	0.11
dry-wet-dry-dry	2.00	4.11	1.08
dry-wet-dry-wet	3.00	0.89	5.00
dry-wet-wet-dry	5.00	2.58	2.28
dry-wet-wet-wet	3.00	5.42	1.08
wet-dry-dry-dry	8.00	7.40	0.05
wet-dry-dry-wet	1.00	1.60	0.23
wet-dry-wet-dry	4.00	2.90	0.42
wet-dry-wet-wet	5.00	6.10	0.20
wet-wet-dry-dry	7.00	9.86	0.83
wet-wet-dry-wet	5.00	2.14	3.84
wet-wet-wet-dry	9.00	11.92	0.71
wet-wet-wet-wet	28.00	25.08	0.34
Chi-square sum	19.17	with 6 d.f.	
Prob.	0.004		

Table G-4 **Continued**
Month - Aug **1-5**

Sequence	Actual	Transition probability
dry-dry	34.00	P_{00} = 0.667
dry-wet	17.00	P_{01} = 0.333
wet-dry	19.00	P_{10} = 0.322
wet-wet	40.00	P_{11} = 0.678

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	24.00	22.00	0.18
dry-dry-wet	9.00	11.00	0.36
dry-wet-dry	6.00	5.47	0.05
dry-wet-wet	11.00	11.53	0.02
wet-dry-dry	10.00	12.00	0.33
wet-dry-wet	8.00	6.00	0.67
wet-wet-dry	13.00	13.53	0.02
wet-wet-wet	29.00	28.47	0.01
Chi-square sum	1.65	with 2 d.f.	
Prob.	0.438		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	18.00	16.00	0.25
dry-dry-dry-wet	6.00	8.00	0.50
dry-dry-wet-dry	4.00	3.54	0.06
dry-dry-wet-wet	7.00	7.46	0.03
dry-wet-dry-dry	2.00	3.33	0.53
dry-wet-dry-wet	3.00	1.67	1.07
dry-wet-wet-dry	4.00	4.19	0.01
dry-wet-wet-wet	9.00	8.81	0.00
wet-dry-dry-dry	6.00	6.00	0.00
wet-dry-dry-wet	3.00	3.00	0.00
wet-dry-wet-dry	2.00	1.93	0.00
wet-dry-wet-wet	4.00	4.07	0.00
wet-wet-dry-dry	8.00	8.67	0.05
wet-wet-dry-wet	5.00	4.33	0.10
wet-wet-wet-dry	9.00	9.34	0.01
wet-wet-wet-wet	20.00	19.66	0.01
Chi-square sum	2.62	with 6 d.f.	
Prob.	0.854		

Table G-4 **Continued**
Month - Aug **6-10**

Sequence	Actual	Transition probability
dry-dry	31.00	P_{00} = 0.620
dry-wet	19.00	P_{01} = 0.380
wet-dry	21.00	P_{10} = 0.350
wet-wet	39.00	P_{11} = 0.650

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	18.00	19.22	0.08
dry-dry-wet	13.00	11.78	0.13
dry-wet-dry	7.00	6.65	0.02
dry-wet-wet	12.00	12.35	0.01
wet-dry-dry	13.00	11.78	0.13
wet-dry-wet	6.00	7.22	0.21
wet-wet-dry	14.00	14.35	0.01
wet-wet-wet	27.00	26.65	0.00
Chi-square sum	0.58	with 2 d.f.	
Prob.	0.749		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	11.00	12.40	0.16
dry-dry-dry-wet	9.00	7.60	0.26
dry-dry-wet-dry	3.00	4.20	0.34
dry-dry-wet-wet	9.00	7.80	0.18
dry-wet-dry-dry	4.00	3.10	0.26
dry-wet-dry-wet	1.00	1.90	0.43
dry-wet-wet-dry	2.00	4.20	1.15
dry-wet-wet-wet	10.00	7.80	0.62
wet-dry-dry-dry	7.00	6.82	0.00
wet-dry-dry-wet	4.00	4.18	0.01
wet-dry-wet-dry	4.00	2.45	0.98
wet-dry-wet-wet	3.00	4.55	0.53
wet-wet-dry-dry	9.00	8.68	0.01
wet-wet-dry-wet	5.00	5.32	0.02
wet-wet-wet-dry	12.00	10.15	0.34
wet-wet-wet-wet	17.00	18.85	0.18
Chi-square sum	5.47	with 6 d.f.	
Prob.	0.484		

Table G-4 **Continued**
Month - Aug **11-15**

Sequence	Actual	Transition probability
dry-dry	44.00	P_{00} = 0.746
dry-wet	15.00	P_{01} = 0.254
wet-dry	18.00	P_{10} = 0.353
wet-wet	33.00	P_{11} = 0.647

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	35.00	32.07	0.27
dry-dry-wet	8.00	10.93	0.79
dry-wet-dry	4.00	4.94	0.18
dry-wet-wet	10.00	9.06	0.10
wet-dry-dry	9.00	11.93	0.72
wet-dry-wet	7.00	4.07	2.11
wet-wet-dry	14.00	13.06	0.07
wet-wet-wet	23.00	23.94	0.04
Chi-square sum	4.27	with 2 d.f.	
Prob.	0.118		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	27.00	23.86	0.41
dry-dry-dry-wet	5.00	8.14	1.21
dry-dry-wet-dry	2.00	2.82	0.24
dry-dry-wet-wet	6.00	5.18	0.13
dry-wet-dry-dry	2.00	3.73	0.80
dry-wet-dry-wet	3.00	1.27	2.35
dry-wet-wet-dry	3.00	3.88	0.20
dry-wet-wet-wet	8.00	7.12	0.11
wet-dry-dry-dry	8.00	8.20	0.01
wet-dry-dry-wet	3.00	2.80	0.01
wet-dry-wet-dry	2.00	2.12	0.01
wet-dry-wet-wet	4.00	3.88	0.00
wet-wet-dry-dry	7.00	8.20	0.18
wet-wet-dry-wet	4.00	2.80	0.52
wet-wet-wet-dry	11.00	9.18	0.36
wet-wet-wet-wet	15.00	16.82	0.20
Chi-square sum	6.74	with 6 d.f.	
Prob.	0.346		

Table G-4 **Continued**
Month - Aug **16-20**

Sequence	Actual	Transition probability
dry-dry	34.00	P_{00} = 0.630
dry-wet	20.00	P_{01} = 0.370
wet-dry	19.00	P_{10} = 0.339
wet-wet	37.00	P_{11} = 0.661

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	25.00	22.04	0.40
dry-dry-wet	10.00	12.96	0.68
dry-wet-dry	7.00	6.45	0.05
dry-wet-wet	12.00	12.55	0.02
wet-dry-dry	9.00	11.96	0.73
wet-dry-wet	10.00	7.04	1.25
wet-wet-dry	12.00	12.55	0.02
wet-wet-wet	25.00	24.45	0.01
Chi-square sum	3.17	with 2 d.f.	
Prob.	0.205		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	21.00	18.26	0.41
dry-dry-dry-wet	8.00	10.74	0.70
dry-dry-wet-dry	4.00	2.71	0.61
dry-dry-wet-wet	4.00	5.29	0.31
dry-wet-dry-dry	4.00	4.41	0.04
dry-wet-dry-wet	3.00	2.59	0.06
dry-wet-wet-dry	4.00	4.75	0.12
dry-wet-wet-wet	10.00	9.25	0.06
wet-dry-dry-dry	4.00	3.78	0.01
wet-dry-dry-wet	2.00	2.22	0.02
wet-dry-wet-dry	3.00	3.73	0.14
wet-dry-wet-wet	8.00	7.27	0.07
wet-wet-dry-dry	5.00	7.56	0.86
wet-wet-dry-wet	7.00	4.44	1.47
wet-wet-wet-dry	8.00	7.80	0.00
wet-wet-wet-wet	15.00	15.20	0.00
Chi-square sum	4.91	with 6 d.f.	
Prob.	0.556		

Table G-4 **Continued**
Month - Aug **21-25**

Sequence	Actual	Transition probability
dry-dry	42.00	P_{00} = 0.689
dry-wet	19.00	P_{01} = 0.311
wet-dry	16.00	P_{10} = 0.320
wet-wet	34.00	P_{11} = 0.680

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	32.00	29.61	0.19
dry-dry-wet	11.00	13.39	0.43
dry-wet-dry	8.00	6.72	0.24
dry-wet-wet	13.00	14.28	0.11
wet-dry-dry	10.00	12.39	0.46
wet-dry-wet	8.00	5.61	1.02
wet-wet-dry	8.00	9.28	0.18
wet-wet-wet	21.00	19.72	0.08
Chi-square sum	2.72	with 2 d.f.	
Prob.	0.256		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	20.00	21.34	0.08
dry-dry-dry-wet	11.00	9.66	0.19
dry-dry-wet-dry	4.00	4.16	0.01
dry-dry-wet-wet	9.00	8.84	0.00
dry-wet-dry-dry	5.00	6.20	0.23
dry-wet-dry-wet	4.00	2.80	0.51
dry-wet-wet-dry	0.00	2.24	2.24
dry-wet-wet-wet	7.00	4.76	1.05
wet-dry-dry-dry	12.00	8.26	1.69
wet-dry-dry-wet	0.00	3.74	3.74
wet-dry-wet-dry	4.00	2.56	0.81
wet-dry-wet-wet	4.00	5.44	0.38
wet-wet-dry-dry	5.00	6.20	0.23
wet-wet-dry-wet	4.00	2.80	0.51
wet-wet-wet-dry	8.00	7.04	0.13
wet-wet-wet-wet	14.00	14.96	0.06
Chi-square sum	11.87	with 6 d.f.	
Prob.	0.065		

Table G-4 **Continued**
Month - Aug **26-31**

Sequence	Actual	Transition probability
dry-dry	57.00	P_{00} = 0.792
dry-wet	15.00	P_{01} = 0.208
wet-dry	12.00	P_{10} = 0.203
wet-wet	47.00	P_{11} = 0.797

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	47.00	45.13	0.08
dry-dry-wet	10.00	11.88	0.30
dry-wet-dry	2.00	3.05	0.36
dry-wet-wet	13.00	11.95	0.09
wet-dry-dry	10.00	11.88	0.30
wet-dry-wet	5.00	3.13	1.13
wet-wet-dry	10.00	8.95	0.12
wet-wet-wet	34.00	35.05	0.03
Chi-square sum	2.40	with 2 d.f.	
Prob.	0.301		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	36.00	35.63	0.00
dry-dry-dry-wet	9.00	9.38	0.02
dry-dry-wet-dry	1.00	1.83	0.38
dry-dry-wet-wet	8.00	7.17	0.10
dry-wet-dry-dry	3.00	2.38	0.16
dry-wet-dry-wet	0.00	0.63	0.63
dry-wet-wet-dry	4.00	2.85	0.47
dry-wet-wet-wet	10.00	11.15	0.12
wet-dry-dry-dry	11.00	9.50	0.24
wet-dry-dry-wet	1.00	2.50	0.90
wet-dry-wet-dry	1.00	1.22	0.04
wet-dry-wet-wet	5.00	4.78	0.01
wet-wet-dry-dry	7.00	9.50	0.66
wet-wet-dry-wet	5.00	2.50	2.50
wet-wet-wet-dry	6.00	6.10	0.00
wet-wet-wet-wet	24.00	23.90	0.00
Chi-square sum	6.21	with 6 d.f.	
Prob.	0.400		

Table G-4 **Continued**
Month - Sep **1-5**

Sequence	Actual	Transition probability
dry-dry	44.00	P_{00} = 0.629
dry-wet	26.00	P_{01} = 0.371
wet-dry	12.00	P_{10} = 0.300
wet-wet	28.00	P_{11} = 0.700

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	35.00	35.83	0.02
dry-dry-wet	22.00	21.17	0.03
dry-wet-dry	7.00	6.00	0.17
dry-wet-wet	13.00	14.00	0.07
wet-dry-dry	9.00	8.17	0.08
wet-dry-wet	4.00	4.83	0.14
wet-wet-dry	5.00	6.00	0.17
wet-wet-wet	15.00	14.00	0.07
Chi-square sum	0.75	with 2 d.f.	
Prob.	0.686		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	29.00	29.54	0.01
dry-dry-dry-wet	18.00	17.46	0.02
dry-dry-wet-dry	7.00	5.40	0.47
dry-dry-wet-wet	11.00	12.60	0.20
dry-wet-dry-dry	6.00	5.03	0.19
dry-wet-dry-wet	2.00	2.97	0.32
dry-wet-wet-dry	3.00	3.60	0.10
dry-wet-wet-wet	9.00	8.40	0.04
wet-dry-dry-dry	6.00	6.29	0.01
wet-dry-dry-wet	4.00	3.71	0.02
wet-dry-wet-dry	0.00	0.60	0.60
wet-dry-wet-wet	2.00	1.40	0.26
wet-wet-dry-dry	3.00	3.14	0.01
wet-wet-dry-wet	2.00	1.86	0.01
wet-wet-wet-dry	2.00	2.40	0.07
wet-wet-wet-wet	6.00	5.60	0.03
Chi-square sum	2.36	with 6 d.f.	
Prob.	0.884		

Table G-4 **Continued**
Month - Sep **6-10**

Sequence	Actual	Transition probability
dry-dry	59.00	P_{00} = 0.868
dry-wet	9.00	P_{01} = 0.132
wet-dry	18.00	P_{10} = 0.429
wet-wet	24.00	P_{11} = 0.571

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	50.00	45.99	0.35
dry-dry-wet	3.00	7.01	2.30
dry-wet-dry	5.00	5.14	0.00
dry-wet-wet	7.00	6.86	0.00
wet-dry-dry	9.00	13.01	1.24
wet-dry-wet	6.00	1.99	8.12
wet-wet-dry	13.00	12.86	0.00
wet-wet-wet	17.00	17.14	0.00
Chi-square sum	12.02	with 2 d.f.	
Prob.	0.002		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	42.00	38.18	0.38
dry-dry-dry-wet	2.00	5.82	2.51
dry-dry-wet-dry	3.00	3.00	0.00
dry-dry-wet-wet	4.00	4.00	0.00
dry-wet-dry-dry	2.00	3.47	0.62
dry-wet-dry-wet	2.00	0.53	4.08
dry-wet-wet-dry	2.00	3.00	0.33
dry-wet-wet-wet	5.00	4.00	0.25
wet-dry-dry-dry	8.00	7.81	0.00
wet-dry-dry-wet	1.00	1.19	0.03
wet-dry-wet-dry	2.00	2.14	0.01
wet-dry-wet-wet	3.00	2.86	0.01
wet-wet-dry-dry	7.00	9.54	0.68
wet-wet-dry-wet	4.00	1.46	4.45
wet-wet-wet-dry	11.00	9.86	0.13
wet-wet-wet-wet	12.00	13.14	0.10
Chi-square sum	13.59	with 6 d.f.	
Prob.	0.035		

Table G-4 **Continued**
Month - Sep **11-15**

Sequence	Actual	Transition probability
dry-dry	81.00	P_{00} = 0.920
dry-wet	7.00	P_{01} = 0.080
wet-dry	9.00	P_{10} = 0.391
wet-wet	14.00	P_{11} = 0.609

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	73.00	71.80	0.02
dry-dry-wet	5.00	6.20	0.23
dry-wet-dry	4.00	3.13	0.24
dry-wet-wet	4.00	4.87	0.16
wet-dry-dry	8.00	9.20	0.16
wet-dry-wet	2.00	0.80	1.82
wet-wet-dry	5.00	5.87	0.13
wet-wet-wet	10.00	9.13	0.08
Chi-square sum	2.84	with 2 d.f.	
Prob.	0.241		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	67.00	65.35	0.04
dry-dry-dry-wet	4.00	5.65	0.48
dry-dry-wet-dry	3.00	1.57	1.32
dry-dry-wet-wet	1.00	2.43	0.85
dry-wet-dry-dry	4.00	4.60	0.08
dry-wet-dry-wet	1.00	0.40	0.91
dry-wet-wet-dry	2.00	1.96	0.00
dry-wet-wet-wet	3.00	3.04	0.00
wet-dry-dry-dry	6.00	6.44	0.03
wet-dry-dry-wet	1.00	0.56	0.35
wet-dry-wet-dry	1.00	1.57	0.20
wet-dry-wet-wet	3.00	2.43	0.13
wet-wet-dry-dry	4.00	4.60	0.08
wet-wet-dry-wet	1.00	0.40	0.91
wet-wet-wet-dry	3.00	3.91	0.21
wet-wet-wet-wet	7.00	6.09	0.14
Chi-square sum	5.73	with 6 d.f.	
Prob.	0.454		

Table G-4 **Continued**
Month - Sep **16-20**

Sequence	Actual	Transition probability
dry-dry	86.00	P_{00} = 0.905
dry-wet	9.00	P_{01} = 0.095
wet-dry	8.00	P_{10} = 0.571
wet-wet	6.00	P_{11} = 0.429

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	78.00	78.76	0.01
dry-dry-wet	9.00	8.24	0.07
dry-wet-dry	3.00	4.57	0.54
dry-wet-wet	5.00	3.43	0.72
wet-dry-dry	8.00	7.24	0.08
wet-dry-wet	0.00	0.76	0.76
wet-wet-dry	5.00	3.43	0.72
wet-wet-wet	1.00	2.57	0.96
Chi-square sum	3.86	with 2 d.f.	
Prob.	0.145		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	70.00	69.71	0.00
dry-dry-dry-wet	7.00	7.29	0.01
dry-dry-wet-dry	3.00	4.00	0.25
dry-dry-wet-wet	4.00	3.00	0.33
dry-wet-dry-dry	2.00	1.81	0.02
dry-wet-dry-wet	0.00	0.19	0.19
dry-wet-wet-dry	3.00	2.29	0.22
dry-wet-wet-wet	1.00	1.71	0.30
wet-dry-dry-dry	8.00	9.05	0.12
wet-dry-dry-wet	2.00	0.95	1.17
wet-dry-wet-dry	0.00	0.57	0.57
wet-dry-wet-wet	1.00	0.43	0.76
wet-wet-dry-dry	6.00	5.43	0.06
wet-wet-dry-wet	0.00	0.57	0.57
wet-wet-wet-dry	2.00	1.14	0.64
wet-wet-wet-wet	0.00	0.86	0.86
Chi-square sum	6.08	with 6 d.f.	
Prob.	0.414		

Table G-4 **Continued**
Month - Sep **21-25**

Sequence	Actual	Transition probability
dry-dry	85.00	P_{00} = 0.914
dry-wet	8.00	P_{01} = 0.086
wet-dry	8.00	P_{10} = 0.471
wet-wet	9.00	P_{11} = 0.529

Test of Independence: second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	79.00	78.60	0.00
dry-dry-wet	7.00	7.40	0.02
dry-wet-dry	3.00	4.24	0.36
dry-wet-wet	6.00	4.76	0.32
wet-dry-dry	6.00	6.40	0.02
wet-dry-wet	1.00	0.60	0.26
wet-wet-dry	5.00	3.76	0.41
wet-wet-wet	3.00	4.24	0.36
Chi-square sum	1.76	with 2 d.f.	
Prob.	0.415		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	74.00	73.12	0.01
dry-dry-dry-wet	6.00	6.88	0.11
dry-dry-wet-dry	3.00	3.76	0.16
dry-dry-wet-wet	5.00	4.24	0.14
dry-wet-dry-dry	3.00	2.74	0.02
dry-wet-dry-wet	0.00	0.26	0.26
dry-wet-wet-dry	4.00	3.29	0.15
dry-wet-wet-wet	3.00	3.71	0.13
wet-dry-dry-dry	5.00	5.48	0.04
wet-dry-dry-wet	1.00	0.52	0.45
wet-dry-wet-dry	0.00	0.47	0.47
wet-dry-wet-wet	1.00	0.53	0.42
wet-wet-dry-dry	3.00	3.66	0.12
wet-wet-dry-wet	1.00	0.34	1.25
wet-wet-wet-dry	1.00	0.47	0.60
wet-wet-wet-wet	0.00	0.53	0.53
Chi-square sum	4.86	with 6 d.f.	
Prob.	0.561		

Table G-4 **Continued**
Month - Sep **26-30**

Sequence	Actual	Transition probability
dry-dry	95.00	P_{00} = 0.960
dry-wet	4.00	P_{01} = 0.040
wet-dry	8.00	P_{10} = 0.727
wet-wet	3.00	P_{11} = 0.273

Test of Independence:second preceding day

Sequence	Actual	Predicted	Chi-square
dry-dry-dry	86.00	85.40	0.00
dry-dry-wet	3.00	3.60	0.10
dry-wet-dry	6.00	4.36	0.61
dry-wet-wet	0.00	1.64	1.64
wet-dry-dry	9.00	9.60	0.04
wet-dry-wet	1.00	0.40	0.88
wet-wet-dry	2.00	3.64	0.74
wet-wet-wet	3.00	1.36	1.96
Chi-square sum	5.97	with 2 d.f.	
Prob.	0.051		

Test of Independence: second and third preceding days

Sequence	Actual	Predicted	Chi-square
dry-dry-dry-dry	79.00	78.69	0.00
dry-dry-dry-wet	3.00	3.31	0.03
dry-dry-wet-dry	5.00	3.64	0.51
dry-dry-wet-wet	0.00	1.36	1.36
dry-wet-dry-dry	6.00	5.76	0.01
dry-wet-dry-wet	0.00	0.24	0.24
dry-wet-wet-dry	0.00	0.00	0.00
dry-wet-wet-wet	0.00	0.00	0.00
wet-dry-dry-dry	7.00	6.72	0.01
wet-dry-dry-wet	0.00	0.28	0.28
wet-dry-wet-dry	1.00	0.73	0.10
wet-dry-wet-wet	0.00	0.27	0.27
wet-wet-dry-dry	3.00	3.84	0.18
wet-wet-dry-wet	1.00	0.16	4.35
wet-wet-wet-dry	2.00	3.64	0.74
wet-wet-wet-wet	3.00	1.36	1.96
Chi-square sum	10.06	with 6 d.f.	
Prob.	0.122		

APPENDIX H
DAILY RAINFALL MODELLING RESULTS

Appendix H Daily rainfall modelling results

Table H-1 1 day rainfall depths, daily model

Month	Year	1 day rainfall, categorized by depth (mm)																Total
		<10[1]	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120-130	130-140	140-150	ge 150	
Jun.	1970	4	1						1									6
	1971	3	3	2			2											10
	1972	8																8
	1973		1															1
	1974	3	1															4
	1975	4		1	2													7
	1976	2	5	1														8
	1977	7	2						1									10
	1978	6	3	1				1										11
	1979	6	1															7
	1980	8	1		1									1				11
	1983	3	2															5
	1984		1															1
	1985	3																3
	1986	3	2															5
	1987	2	2	1														5
	1988	3	2			1		2										8
	1989	4	2															6
	1990	4	1				1											6
	1991		1															1
	1992	1																1
	1993	5	7															12
	Total	**79**	**38**	**6**	**3**	**1**	**3**	**3**	**2**					**1**				**136**

Table H-1 **Continued**

Month	Year	1 day rainfall, categorized by depth (mm)																Total
		<10[1]	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120-130	130-140	140-150	ge 150	
Jul.	1970	4		2		1			1									8
	1971	3	4	4	1	2						1					1	16
	1972	1	2	1														4
	1973	8	2	2				1			1	1						15
	1974	4	2	3	3	1	1		1		1						1	17
	1975	12	4		2	1					1							20
	1976	11	2						1	1								15
	1977	9	5	4	1	2	1											22
	1978	11	4	2						1	1							19
	1979	7	1	1	1							1		1				12
	1980	10	2	2	1													15
	1983	13	3	4														20
	1984	4	2		2			1										9
	1985	5	2	1	1	2												11
	1986	5	3	5	2	1			1		1							18
	1987	4	1		1													6
	1988	11	2	3		1												17
	1989	6	1		1	1												9
	1990	4	4	1	1			1										11
	1991	7	1	1	1		1							1				12
	1992	5	2	1		1												9
	1993	4	4		3		1											12
	Total	**148**	**53**	**37**	**21**	**13**	**4**	**3**	**4**	**2**	**5**	**3**		**2**			**2**	**297**

Table H-1 Continued

Month	Year	1 day rainfall, categorized by depth (mm)																Total #
		<10[1]	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120-130	130-140	140-150	ge 150	of periods
Aug.	1970	8	5	2		2												17
	1971	10	4	1		1				1								17
	1972	7	4	1	2													14
	1973	8	4	2	1		1		1									17
	1974	5	2		2	2			1		1							13
	1975	15	4	1	1	2	1			1								25
	1976	10	6	4						1								21
	1977	10	1	1	2		1		1									16
	1978	9	5	2	1	1											1	19
	1979	9	1	1														11
	1980	9	2		2													13
	1983	11	1		2	1		1										16
	1984	8		4	2		1			1								16
	1985	10	1	5		1		1										18
	1986	4	1	1	1	1				1								9
	1987	5	6	1	1													13
	1988	5	3	1	2		1		1									13
	1989	12	3		1			2					1					19
	1990	8	3	2	1						1							15
	1991	4	3	1		2	1	1										12
	1992	4	2	2	2	1	1					1						13
	1993	2	3	1	1			1										8
	Total	**173**	**64**	**33**	**24**	**14**	**7**	**6**	**4**	**5**	**2**	**1**	**1**				**1**	**335**

Table H-1 **Continued**

Month	Year	1 day rainfall, categorized by depth (mm)																Total
		<10[1]	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120-130	130-140	140-150	ge 150	
Sept.	1970	9	4				1											14
	1971	4				1	1	1				1			1			9
	1972	1	1															2
	1973	7	1	3														11
	1974	2																2
	1975	10		1				1										12
	1976	6		1	2													9
	1977	4	1	2	1		1											9
	1978	1	1			1												3
	1980	1	1					1										3
	1983	4	1	1			1											7
	1984	3				1											1	5
	1985	5	5															10
	1986	1																1
	1987	2		1		1												4
	1988	5	1			1												7
	1989	3																3
	1990	4	7															11
	1991	1	1		1				1									4
	1992	1	3	1														5
	1993	7	6	2	1													16
	Total	**81**	**33**	**12**	**5**	**5**	**4**	**3**	**1**			**1**			**1**		**1**	**147**

[1] Excludes days with 0.0 mm of rain

Table H-2 2 day rainfall depths, daily model

Month	Year	2 day rainfall, categorized by depth (mm)																Total #
		<10[1]	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120-130	130-140	140-150	ge 150	of periods
Jun.	1970	8	2						1									11
	1971	4	2	4	1			2		1		1						15
	1972	12	1															13
	1973	1	2															3
	1974	3	3															6
	1975	4	1	2	2	1												10
	1976	2	6	1	3													12
	1977	7	3						1		1							12
	1978	7	5	1		1		2										16
	1979	10	2															12
	1980	10	3		2									2				17
	1983	5	3															8
	1984		3															3
	1985	5																5
	1986	2	3	1														6
	1987	4	4	2														10
	1988	5	4			1	1	1						1				13
	1989	7	4					1										12
	1990	6	2				1											9
	1991		2				1											3
	1992	2																2
	1993	6	6	4														16
	Total	**110**	**61**	**15**	**8**	**3**	**3**	**6**	**2**	**1**	**1**	**1**		**3**				**214**

Table H-2 **Continued**

Month	Year	2 day rainfall, categorized by depth (mm)																Total #
		<10[1]	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120-130	130-140	140-150	ge 150	of periods
Jul.	1970	3		4		2			1	1								11
	1971	6	2	4	3	2		2							1		3	23
	1972	1	2	2	1													6
	1973	7	2	6				2			1	1					1	20
	1974	3	1	2	4		2	1		2	1	1		1			2	20
	1975	11	7		1	3			1		1	1						25
	1976	14	3	1					2		1							21
	1977	8	4	5	3	4	3							1				28
	1978	8	6	5		1				1	2		1					24
	1979	5	2	1	2	1						1		1			1	14
	1980	10	3	3	3													19
	1983	9	7	10														26
	1984	4	3		3	1		2										13
	1985	4	2	1	2	3	1		1									14
	1986	5	1	2	4	1		2	2			1		1		1		20
	1987	7	1	1	2													11
	1988	11	4	4	2	1		1										23
	1989	9	2		2		2											15
	1990	5	6		2	1				1	1							16
	1991	6	1	3	1			1									2	14
	1992	9	2	3		2												16
	1993	4	6		4	2	1			1								18
	Total	**149**	**67**	**57**	**39**	**24**	**9**	**11**	**7**	**6**	**7**	**5**	**1**	**4**	**1**	**1**	**9**	**397**

Table H-2 Continued

Month	Year	2 day rainfall, categorized by depth (mm)																Total #
		<10[1]	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120-130	130-140	140-150	ge 150	of periods
Aug.	1970	6	7	4	1	3	1											22
	1971	13	5	2		2	1			1	1							25
	1972	6	4	3	3		2											18
	1973	5	6	4	3	1	2		2									23
	1974	7	2		3	1	2		1		1		1				1	19
	1975	8	8	1	3	2	3			1				1				27
	1976	8	7	5	1	2						1	1					25
	1977	7	3	1	1	1		3				1						17
	1978	7	4	6	3	3			1								1	25
	1979	10	1	3													1	15
	1980	8	2	2	3	1												16
	1983	15	1	1	3	2		2										24
	1984	8		5	4		3				1				1			22
	1985	8	3	6	2	1	1		1				1					23
	1986	6	2	1	1	2	1				2							15
	1987	4	4	3	2	3												16
	1988	5	4	3	1	1			2	1					1			18
	1989	11	5			1		2	1			1		2				23
	1990	11	2	4	1		1				1			1				21
	1991	4	2	1	1		5	1	1									15
	1992	5	2	2	2	3	3	1				2						20
	1993	1	3	2	1	1	1	1	1									11
	Total	**163**	**77**	**59**	**39**	**30**	**26**	**10**	**10**	**3**	**6**	**5**	**3**	**4**	**2**		**3**	**440**

Table H-2 **Continued**

Month	Year	2 day rainfall, categorized by depth (mm)																Total #
		<10[1]	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120-130	130-140	140-150	ge 150	of periods
Sept.	1970	10	6	1			1		1									19
	1971	7					1					1			1		3	13
	1972	1	2															3
	1973	6	3	5		1												15
	1974	4																4
	1975	13		2				1	1									17
	1976	6		1	5													12
	1977	6		2	2		2		1									13
	1978	1	2			2												5
	1980		2					2										4
	1983	2	4	2			2											10
	1984	2	1			1											2	6
	1985	5	6	2														13
	1986	2																2
	1987	3		2		2												7
	1988	7	2			1	1											11
	1989	6																6
	1990	5	8	2	1													16
	1991		1	1	2				2									6
	1992	2	1	3	1													7
	1993	6	6	5	4													21
	Total	**94**	**44**	**28**	**15**	**7**	**7**	**3**	**5**			**1**			**1**		**5**	**210**

[1] Excludes days with 0.0 mm of rain

Table H-3 3 day rainfall depths, daily model

Month	Year	3 day rainfall, categorized by depth (mm)																Total #
		<10[1]	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120-130	130-140	140-150	ge 150	of periods
Jun.	1970	9	4							1								14
	1971	2	3	5	1			1		3			1	1				17
	1972	12	2		1													15
	1973	2	3															5
	1974	3	5															8
	1975	5	1	3	2	2												13
	1976	2	5	3	3	1	1											15
	1977	6	4	1							2							13
	1978	6	6	2		2		1	3									20
	1979	13	3															16
	1980	10	4	1	2									1	1		1	20
	1983	6	4															10
	1984		5															5
	1985	7																7
	1986	1	3	2	1													7
	1987	5	6	3														14
	1988	5	7			1	2	1						1				17
	1989	10	6					1						1				18
	1990	7	2	1			1											11
	1991		3				2											5
	1992	3																3
	1993	7	2	8	1													18
	Total	**121**	**78**	**29**	**11**	**6**	**6**	**4**	**3**	**4**	**2**		**1**	**4**	**1**		**1**	**271**

Table H-3 **Continued**

Month	Year	3 day rainfall, categorized by depth (mm)																Total #
		<10[1]	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120-130	130-140	140-150	ge 150	of periods
Jul.	1970	4		4		2				1		2						13
	1971	8	1	3	2	2	3	1		1							6	27
	1972	1	1	3	3													8
	1973	4	3	7	2			1	2		1	1					2	23
	1974		2	3	4	1	2	1		1			2	1	1		4	22
	1975	7	11			4				2		2			1			27
	1976	15	4	2					3		1							25
	1977	8	2	5	4	2	4	2		2				1	1			31
	1978	6	4	7	2	1			1	1	3		2					27
	1979	4	3		1	1	1	1				1				1	2	15
	1980	5	6	4	5													20
	1983	8	6	10	6													30
	1984	2	4		4	2		3										15
	1985	4	2	1	1	4			2	2								16
	1986	5	1	1	2	1	3		2		1	2	1			1	2	22
	1987	7	2	2	3													14
	1988	7	5	5	4	2		2										25
	1989	10	3		2	1	2	1										19
	1990	5	8		2	2				1	1	1						20
	1991	7		3	1		1	1									3	16
	1992	11		5		2	1											19
	1993	4	7	1	3	4	1	1		2								23
	Total	**132**	**75**	**66**	**51**	**31**	**18**	**14**	**10**	**13**	**7**	**9**	**5**	**2**	**3**	**2**	**19**	**457**

Table H-3 <u>Continued</u>

Month	Year	3 day rainfall, categorized by depth (mm)																Total #
		<10[1]	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120-130	130-140	140-150	ge 150	of periods
Aug.	1970	3	8	5	3	4	2											25
	1971	11	5	4		3	1	1		1	1	1						28
	1972	7	2	7	2	1	2		1									22
	1973	5	4	3	6	2	4		2				1					27
	1974	6	4		3	2	2		1		2					1	2	23
	1975	5	6	2	3	2	4	2	1		1			1	1			28
	1976	5	7	6	2	2	2						2		1			27
	1977	4	5	1		2		3	1	1			1					18
	1978	5	4	3	6	3	1	2	1			1					1	27
	1979	10		4		1											2	17
	1980	8	2	3	4	2												19
	1983	14	1	2	3	1	2	2	2									27
	1984	6		5	6		4				2				1	1		25
	1985	6	3	3	4	3	1	1	1					2				24
	1986	7	2		2	2	3				2	1						19
	1987	4	2	3	3	2	2	1										17
	1988	6	4	5	1	1			2	1			1		1		1	23
	1989	5	8	1		1		2	2			1	1	1	2			24
	1990	12	1	7		1			1		1			1		1		25
	1991	5	1	1	1		3	2	1	2			1					17
	1992	5	2	3	2	3	5	1			1	2				1		25
	1993	1	3	2	2			3	2	1								14
	Total	**140**	**74**	**70**	**53**	**38**	**38**	**20**	**18**	**6**	**10**	**6**	**7**	**5**	**6**	**4**	**6**	**501**

Table H-3 **Continued**

Month	Year	3 day rainfall, categorized by depth (mm)															Total #
		<10[1]	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120-130	130-140	140-150	ge 150	of periods
Sept.	1970	7	11	1			1		2									22
	1971	8	1				1								1		5	16
	1972	1	3															4
	1973	6	3	6	1	2												18
	1974	5																5
	1975	13	1	3					3									20
	1976	6			7			1										14
	1977	6	1	3	1		1	1	2		1							16
	1978	1	3			3												7
	1980		2					2	1									5
	1983	2	5	2	1		2	1										13
	1984	2	1			1											3	7
	1985	5	8	2	1													16
	1986	3																3
	1987	4		3		3												10
	1988	8	2	1		1	2											14
	1989	9																9
	1990	6	7	4	3													20
	1991		1	1	2				1		1	1						7
	1992	3	1	2	2	1												9
	1993	5	5	5	7	1	1											24
	Total	**100**	**55**	**33**	**25**	**12**	**8**	**5**	**9**		**2**	**1**			**1**		**8**	**259**

[1] Excludes days with 0.0 mm of rain

Table H-4 **4 day rainfall depths, daily model**

Month	Year	4 day rainfall, categorized by depth (mm)																Total #
		<10[1]	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120-130	130-140	140-150	ge 150	of periods
Jun.	1970	9	6							1								16
	1971	1	3	5	1	1		1		1	1		2		1	1		18
	1972	12	3		1					1								17
	1973	2	5															7
	1974	3	7															10
	1975	6	1	4	2	3												16
	1976	2	5	3	5	1	2											18
	1977	5	6	1							2							14
	1978	4	5	4		3		1	3	1	1							22
	1979	14	4															18
	1980	11	5	2	1										2		2	23
	1981				1													1
	1983	7	5															12
	1984		7															7
	1985	9																9
	1986	1	3	1	3													8
	1987	6	7	3	1													17
	1988	5	9				3	2						1				20
	1989	12	8					1						2				23
	1990	8	2	2			1											13
	1991		4				3											7
	1992	4																4
	1993	6	1	4	7													18
	Total	**127**	**96**	**29**	**22**	**8**	**9**	**5**	**3**	**4**	**4**		**2**	**3**	**3**	**1**	**2**	**318**

Table H-4 **Continued**

Month	Year	4 day rainfall, categorized by depth (mm)																Total #
		<10[1]	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120-130	130-140	140-150	ge 150	of periods
Jul.	1970	5		4		2						4						15
	1971	9		1	2	2	5	1			1						8	29
	1972	1	1	4	2		2											10
	1973	1	4	4	6	1			3		1						4	24
	1974		1	4	4	1	1	1		1	1		2		1		7	24
	1975	5	12			1	3			3		2			1	1		28
	1976	13	6	3					3	1	1							27
	1977	5	2	3	6	2	3	3		2	1	1		1	1	1		31
	1978	6	2	6	4	1			1	1	4	1	2				1	29
	1979	4	3	1		1		1	2				1				4	17
	1980	4	4	5	7		1											21
	1983	4	7	10	6	3	1											31
	1984	2	3		4	4		3	1									17
	1985	3	2	1	1	4			1	4	1							17
	1986	6		1	2		2	1	2		1	4				2	3	24
	1987	6	3	4	4													17
	1988	6	4	5	4	4	1	1	2									27
	1989	10	4		2	1	3	2										22
	1990	5	8	1	2	3				1	1	1	1					23
	1991	6	1	2	1	1	1	1									4	17
	1992	12		5		2	1		1									21
	1993	4	6	2	5	5	1			3			1					27
	Total	**117**	**73**	**66**	**62**	**38**	**25**	**14**	**16**	**16**	**12**	**13**	**7**	**1**	**3**	**4**	**31**	**498**

Table H-4 **Continued**

Month	Year	4 day rainfall, categorized by depth (mm)																Total #
		<10[1]	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120-130	130-140	140-150	ge 150	of periods
Aug.	1970	2	7	4	6	5	2	2										28
	1971	8	6	5		3	1	3			2	2						30
	1972	8	2	8	3	1	2		2									26
	1973	4	3	3	6	3	6		1				2	1				29
	1974	4	5	1	2	1	3		2		3					1	3	25
	1975	4	1	6	2	3	4	2	2	1					3	1		29
	1976	5	3	6	3	4	3	1					2		2			29
	1977	3	4	2		2		3	2	2			1					19
	1978	4	3	1	3	7	2	4	1			1	1				1	28
	1979	9		3	1	1	1										3	18
	1980	9	2	3	5	2		1										22
	1983	12	2	2	3		4	3	3									29
	1984	5		6	5		5	1	1		2					2	1	28
	1985	5	3		6	3	2	2				1		2	1			25
	1986	7	2		2	2	4	1			2	2						22
	1987	4	1	4	2	1	1	4	1									18
	1988	7	4	7	1	1	1		2	1							4	28
	1989	4	6	2			1	2	2	1		1	2	1	2	1		25
	1990	12	1	8	1	1			1		1			1		1	1	28
	1991	6		1	1		3		3	1	2			2				19
	1992	6	2	3	1	1	6	1	1		2	2		1		1	1	28
	1993	1	2	1	4			2	3	3								16
	Total	**129**	**59**	**76**	**57**	**41**	**51**	**32**	**27**	**9**	**14**	**9**	**8**	**8**	**8**	**7**	**14**	**549**

Table H-4 <u>Continued</u>

Month	Year	4 day rainfall, categorized by depth (mm)																Total #
		<10[1]	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120-130	130-140	140-150	ge 150	of periods
Sept.	1970	5	13	2			1		3									24
	1971	10	1					1							1		6	19
	1972	1	4															5
	1973	6	3	7	2	3												21
	1974	6																6
	1975	12	2	3	1				3	1								22
	1976	5			8			1	1									15
	1977	6	2	4	1		1	1	2		1				1			19
	1978	1	4			4												9
	1980		2					2	2									6
	1983	1	7	2	1		2	1		1								15
	1984	2	1			1											4	8
	1985	4	10	2	2													18
	1986	4																4
	1987	5		4		4												13
	1988	9	2	1		1	2	1										16
	1989	11																11
	1990	6	8	5	2	2												23
	1991		1	1	2						2	1	1					8
	1992	4	1	2	2	1	1											11
	1993	4	3	6	6	5	1	1										26
	Total	**102**	**64**	**39**	**27**	**21**	**8**	**8**	**11**	**2**	**3**	**1**	**1**		**2**		**10**	**299**

[1] Excludes days with 0.0 mm of rain

APPENDIX I
RAINFALL EVENT MODEL RESULTS, 0.1 MM THRESHOLD

Figure I-1 Distribution of rainfall events per season, 0.1 mm threshold rainfall

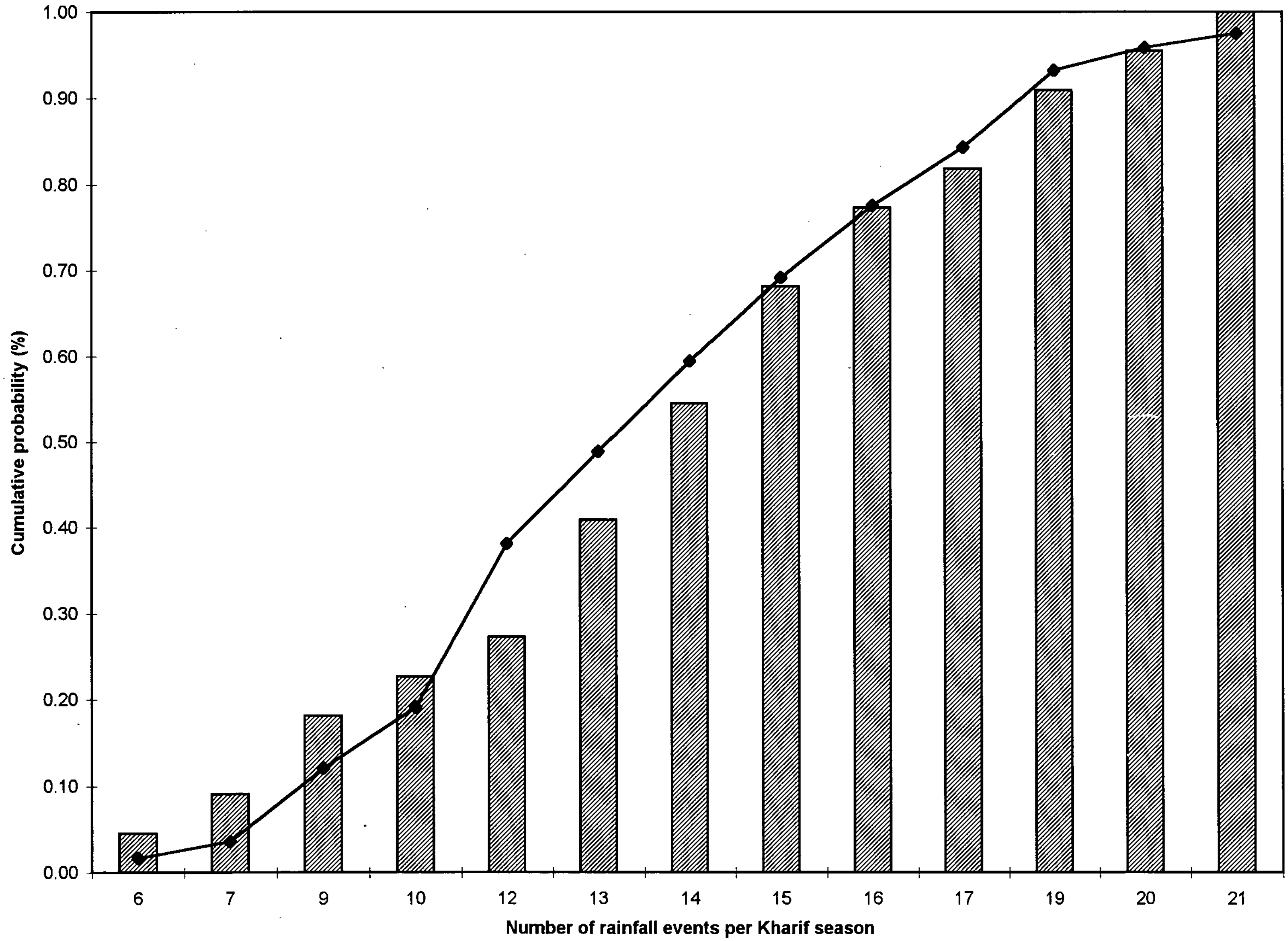


Figure I-2 Distribution of rainfall event duration, 0.1 mm threshold rainfall

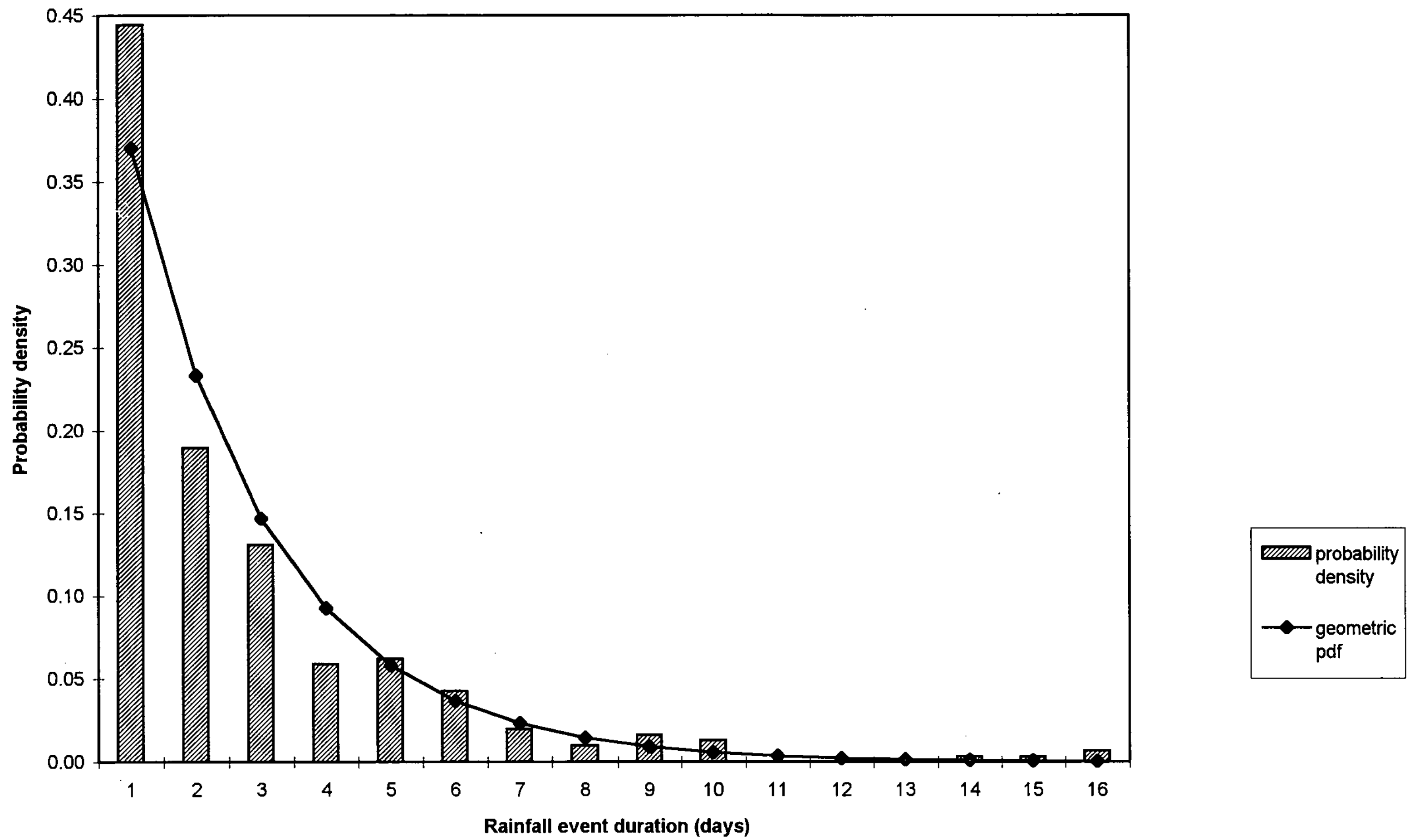


Table I-1 **Rainfall depth per event , 0.1 mm threshold**

Depth (mm)	Number of rainfall events categorized by duration (days)										Total # of events
	1 day	2 days	3 days	4 days	5 days	6 days	7 days	8 days	9 days	>=10 days	
< 10	83	15	3	1							102
10-20	24	11	8	3							46
20-30	12	13	7	2	1						35
30-40	7	6	2		3						18
40-50	7	5	5	1	5	4					27
50-60	2	4	2	3	1		1				13
60-70		2	5			2	1				10
70-80	1			3	1		1	1	1		8
80-90		1	2	1	1	1			1		7
90-100			2		1						3
100-110		1	2	1		1	1		1		7
110-120			1		2						3
120-130				2							2
130-140						1	1			1	3
140-150				1	1	2					4
>=150			1		3	2	1	2	2	7	18
Total	**136**	**58**	**40**	**18**	**19**	**13**	**6**	**3**	**5**	**8**	**306**
Max. depth (mm)	**71.0**	**107.4**	**163.0**	**146.2**	**263.1**	**237.9**	**176.6**	**172.6**	**317.3**	**598.8**	

Mean event duration = 2.71 days
Maximum event duration = 16 days
Standard deviation = 2.52
Variance = 6.35
Skewness = 2.42

Table I-2 Rainfall depth and probability for 1-4 day event duration, 0.1 mm threshold

Depth (mm)	Event Duration											
	1 day			2 days			3 days			4 days		
	# of events	P.[1]	Cond. P.[2]	# of events	P.	Cond. P.	# of events	P.	Cond. P.	# of events	P.	Cond. P.
0.1-5	58	0.426	0.190	7	0.121	0.023	2	0.050	0.007			
5-10	25	0.184	0.082	8	0.138	0.026	1	0.025	0.003	1	0.056	0.003
10-15	16	0.118	0.052	6	0.103	0.020	1	0.025	0.003	2	0.111	0.007
15-20	8	0.059	0.026	5	0.086	0.016	7	0.175	0.023	1	0.056	0.003
20-25	7	0.051	0.023	7	0.121	0.023	4	0.100	0.013			
25-30	5	0.037	0.016	6	0.103	0.020	3	0.075	0.010	2	0.111	0.007
30-35	5	0.037	0.016	5	0.086	0.016	1	0.025	0.003			
35-40	2	0.015	0.007	1	0.017	0.003	1	0.025	0.003			
40-45	3	0.022	0.010	2	0.034	0.007	1	0.025	0.003			
45-50	4	0.029	0.013	3	0.052	0.010	4	0.100	0.013	1	0.056	0.003
50-55				1	0.017	0.003	1	0.025	0.003	2	0.111	0.007
55-60	2	0.015	0.007	3	0.052	0.010	1	0.025	0.003	1	0.056	0.003
60-65							4	0.100	0.013			
65-70				2	0.034	0.007	1	0.025	0.003			
70-75	1	0.007	0.003									
75-80										3	0.167	0.010
80-85							2	0.050	0.007	1	0.056	0.003
85-90				1	0.017	0.003						
90-95							1	0.025	0.003			
95-100							1	0.025	0.003			
100-105							2	0.050	0.007	1	0.056	0.003
105-110				1	0.017	0.003						
110-115							1	0.025	0.003			
115-120												
ge 120							1	0.025	0.003	3	0.167	0.010
Total[3]	**136**			**58**			**40**			**18**		

[1] Probability of rainfall event of given depth within the event duration category
[2] Probability of rainfall event of given depth, conditional on probability of occurrence of event of stated duration
[3] Total number of events within the event duration category

Table I-3 Rainfall depth of 2 day events by day, 0.1 mm threshold

Depth (mm)	Day of event, categorized by depth			
	Day 1		Day 2	
	Number	Cum. %[1]	Number	Cum. %
0.1-5	23	39.7	18	31.0
5-10	8	53.4	12	51.7
10-15	12	74.1	7	63.8
15-20	5	82.8	6	74.1
20-25			6	84.5
25-30	3	87.9	2	87.9
30-35	2	91.4	2	91.4
35-40	2	94.8		
40-45			3	96.6
45-50	1	96.6		
ge 50	2	100.0	2	100.0

[1] Cumulative percent

Table I-4 Rainfall depth of 3 day events by day, 0.1 mm threshold

Depth (mm)	Day of event, categorized by depth					
	Day 1		Day 2		Day 3	
	Number	Cum. %[1]	Number	Cum. %	Number	Cum. %
0.1-5	13	32.5	15	37.5	18	45.0
5-10	7	50.0	4	47.5	4	55.0
10-15	6	65.0	6	62.5	7	72.5
15-20	4	75.0	3	70.0	2	77.5
20-25	3	82.5	2	75.0	2	82.5
25-30			1	77.5	2	87.5
30-35	4	92.5	2	82.5		
35-40	2	97.5	1	85.0	1	90.0
40-45			2	90.0		
45-50			2	95.0	2	95.0
ge 50	1	100.0	2	100	2	100.0

[1] Cumulative percent

Table I-5 Rainfall depth of 4 day events by day, 0.1 mm threshold

Depth (mm)	Day of event, categorized by depth							
	Day 1		Day 2		Day 3		Day 4	
	Number	Cum[1]. %	Number	Cum. %	Number	Cum. %	Number	Cum. %
0.1-5	10	55.6	7	38.9	6	33.3	8	44.4
5-10	3	72.2	6	72.2	3	50.0	2	55.6
10-15	1	77.8	4	94.4	1	55.6	1	61.1
15-20	2	88.9	1	100.0				
20-25	1	94.4			3	72.2	2	72.2
25-30								
30-35					1	77.8		
35-40	1	100.0						
40-45								
45-50								
ge 50					4	100.0	5	100.0

[1] Cumulative percent

APPENDIX J
RAINFALL EVENT MODEL RESULTS, 5.0 MM THRESHOLD

Figure J-1 Distribution of rainfall events per season, 5.0 mm threshold rainfall

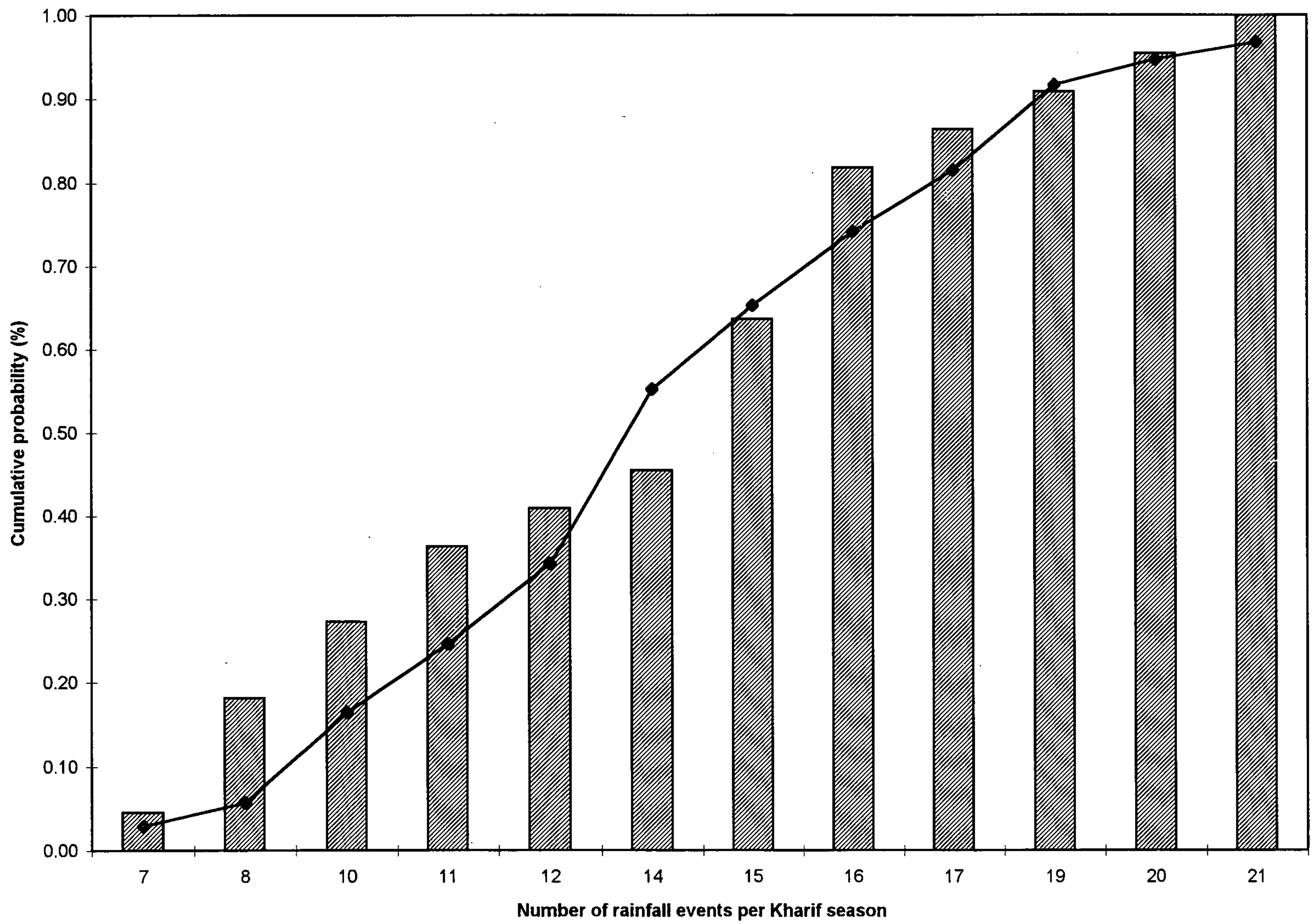


Figure J-2 Distribution of rainfall event duration, 5.0 mm threshold rainfall

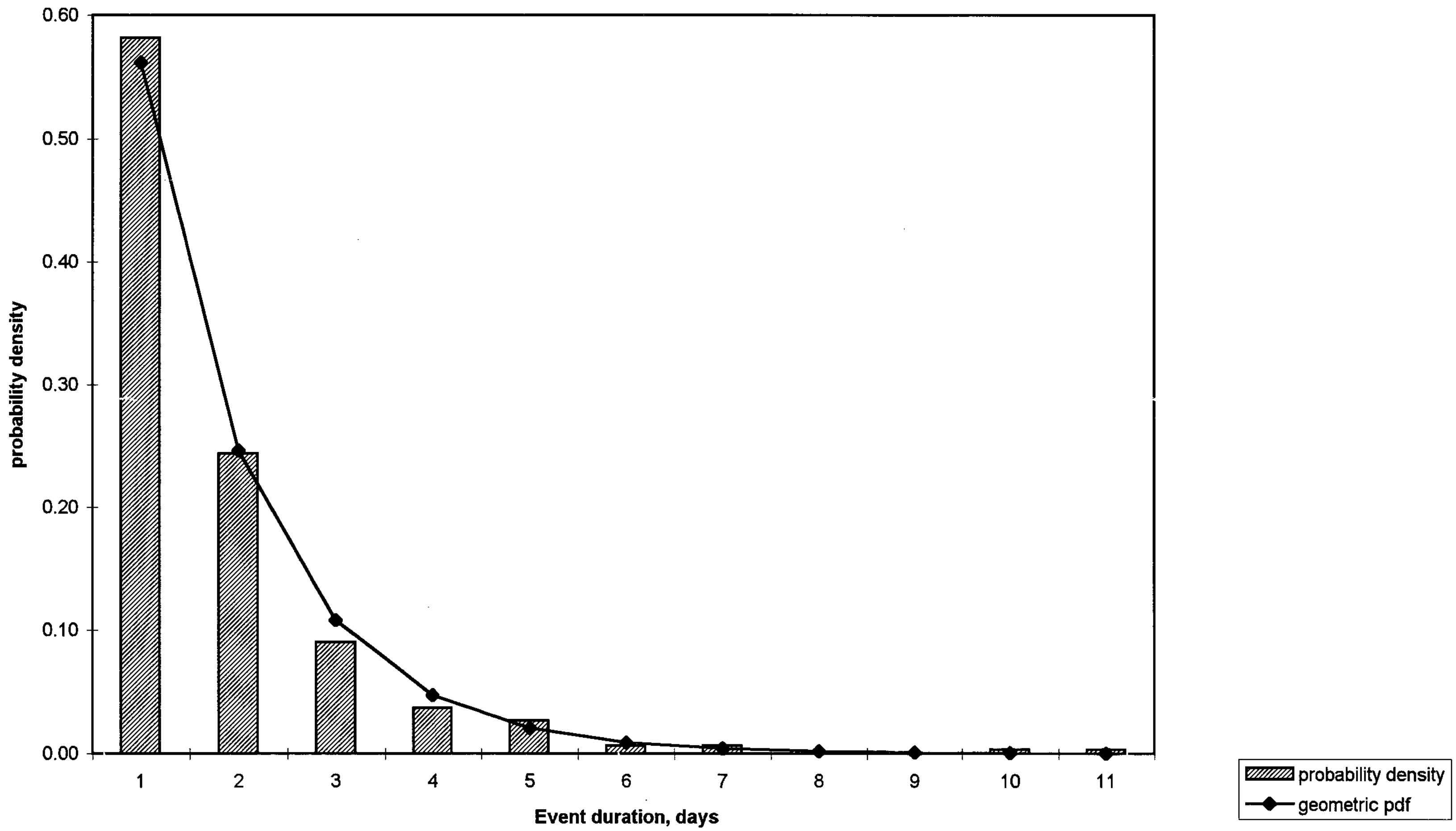


Table J-1 Rainfall depth per event, 5.0 mm threshold

Depth (mm)	Number of rainfall events, categorized by duration (days)							Total # of events
	1 day	2 days	3 days	4 days	5 days	6 days	>=7 days	
< 10	53							53
10-20	58	7						65
20-30	27	22	2					51
30-40	14	8	3	2				27
40-50	8	10	5					23
50-60	5	10	2	2	1			20
60-70	6	2	3	1	1			13
70-80	1	2	1					4
80-90		1	1		2			4
90-100	1	3	1		1			6
100-110		5	4			1		10
110-120			2	1	1			4
120-130	1	1	1					3
130-140				2				3
140-150			1		1			2
>=150		2	1	3	1	1	4	12
Total	**174**	**73**	**27**	**11**	**8**	**2**	**4**	**299**
Max. depth (mm)	**127.0**	**229.1**	**163.0**	**223.2**	**163.1**	**169.0**	**473.8**	

Mean event duration = 1.78 days
Maximum event duration = 11 days
Standard deviation = 1.33
Variance = 1.78
Skewness = 3.04

Table J-2 **Rainfall depth and probability for 1-4 day event duration, 5.0 mm threshold**

Depth (mm)	Event duration											
	1 day			2 days			3 days			4 days		
	# of events	P.[1]	Cond. P.[2]	# of events	P.	Cond. P.	# of events	P.	Cond. P.	# of events	P.	Cond. P.
5-10	53	0.305	0.177									
10-15	39	0.224	0.130	2	0.027	0.007						
15-20	19	0.109	0.064	5	0.068	0.017						
20-25	16	0.092	0.054	8	0.110	0.027						
25-30	11	0.063	0.037	14	0.192	0.047	2	0.074	0.007			
30-35	9	0.052	0.030	7	0.096	0.023				1	0.091	0.003
35-40	5	0.029	0.017	1	0.014	0.003	3	0.111	0.010	1	0.091	0.003
40-45	3	0.017	0.010	6	0.082	0.020	1	0.037	0.003			
45-50	5	0.029	0.017	4	0.055	0.013	4	0.148	0.013			
50-55	2	0.011	0.007	4	0.055	0.013	1	0.037	0.003	1	0.091	0.003
55-60	3	0.017	0.010	6	0.082	0.020	1	0.037	0.003	1	0.091	0.003
60-65	1	0.006	0.003	1	0.014	0.003	3	0.111	0.010	1	0.091	0.003
65-70	5	0.029	0.017	1	0.014	0.003						
70-75	1	0.006	0.003	1	0.014	0.003						
75-80				1	0.014	0.003	1	0.037	0.003			
80-85												
85-90				1	0.014	0.003	1	0.037	0.003			
90-95	1	0.006	0.003	2	0.027	0.007	1	0.037	0.003			
95-100				1	0.014	0.003						
100-105				2	0.027	0.007	3	0.111	0.010			
105-110				3	0.041	0.010	1	0.037	0.003			
110-115	1	0.006	0.003				1	0.037	0.003	1	0.091	0.003
115-120							1	0.037	0.003			
ge 120				3	0.041	0.010	3	0.111	0.010	5	0.455	0.017
Total[3]	**174**			**73**			**27**			**11**		

[1] Probability of rainfall event of given depth within the event duration category
[2] Probability of rainfall event of given depth, conditional on probability of occurrence of event of stated duration
[3] Total number of events within the event duration category

Table J-3 Rainfall depth of 2 day events by day, 5.0 mm threshold

Depth (mm)	Day of event, categorized by depth			
	Day 1		Day 2	
	Number	Cum %[1]	Number	Cum. %
5-10	17	23.3	16	21.9
10-15	15	43.8	17	45.2
15-20	11	58.9	9	57.5
20-25	7	68.5	7	67.1
25-30	4	74.0	2	69.9
30-35	3	78.1	6	78.1
35-40	4	83.6	3	82.2
40-45	2	86.3	3	86.3
45-50	3	90.4	3	90.4
ge 50	7	100.0	7	100.0

[1] Cumulative percent

Table J-4 Rainfall depth of 3 day events by day, 5.0 mm threshold

Depth (mm)	Day of event, categorized by depth					
	Day 1		Day 2		Day 3	
	Number	Cum. %[1]	Number	Cum. %	Number	Cum. %
5-10	10	37.0	4	14.8	8	29.6
10-15	7	63.0	4	29.6	4	44.4
15-20			4	44.4	2	51.9
20-25	3	74.1	4	59.3	4	66.7
25-30	1	77.8	1	63.0	2	74.1
30-35	2	85.2	2	70.4		
35-40	2	92.6	1	74.1	1	77.8
40-45	1	96.3	1	77.8	1	81.5
ge 50	1	100.0	6	100.0	5	100.0

[1] Cumulative percent

Table J-5 Rainfall depth of 4 day events by day, 5.0 mm threshold

Depth (mm)	Day of event, categorized by depth							
	Day 1		Day 2		Day 3		Day 4	
	Number	Cum. %[1]	Number	Cum. %	Number	Cum. %	Number	Cum. %
5-10	4	36.4	1	9.1	1	9.1	6	54.5
10-15	4	72.7	3	36.4	4	45.5		
15-20			1	45.5	1	54.5		
20-25	1	81.8			1	63.6	3	81.8
25-30			1	54.5				
30-35	1	90.9	1	63.6				
35-40					1	72.7	1	90.9
40-45								
45-50					1	81.8		
ge 50	1	100.0	4	100.0	2	100.0	1	100.0

[1] Cumulative percent

APPENDIX K
FREQUENCY ANALYSIS RESULTS

Appendix K Frequency analysis results

Table K-1 Annual rainfall and rain days, ranked

Rank	F[1]	1-F[2]	Reduced variate	z[3]	Total rainfall (mm)	# of rain days[4]
1	0.04	0.96	3.11	1.71	1506.80	64
2	0.09	0.91	2.40	1.36	1294.00	57
3	0.13	0.87	1.97	1.12	1011.00	53
4	0.17	0.83	1.66	0.94	991.60	52
5	0.22	0.78	1.41	0.78	986.70	52
6	0.26	0.74	1.20	0.64	900.10	48
7	0.30	0.70	1.01	0.51	848.80	48
8	0.35	0.65	0.85	0.39	804.50	45
9	0.39	0.61	0.70	0.28	791.30	45
10	0.43	0.57	0.56	0.16	725.40	44
11	0.48	0.52	0.43	0.05	724.30	43
12	0.52	0.48	0.30	-0.05	722.70	42
13	0.57	0.43	0.18	-0.16	713.82	42
14	0.61	0.39	0.06	-0.28	681.80	37
15	0.65	0.35	-0.05	-0.39	656.10	36
16	0.70	0.30	-0.17	-0.51	640.50	33
17	0.74	0.26	-0.30	-0.64	634.00	31
18	0.78	0.22	-0.42	-0.78	574.00	30
19	0.83	0.17	-0.56	-0.94	562.00	29
20	0.87	0.13	-0.71	-1.12	561.10	28
21	0.91	0.09	-0.89	-1.36	469.10	28
22	0.96	0.04	-1.14	-1.71	309.10	28

[1] F = Exceedence probability
[2] 1-F = Non-exceedence probability
[3] z = standard normal variable
[4] rain days are defined as those days on which at least 0.1 mm of rain is recorded

Table K-2 Probability distribution ,annual rainfall and number of rain days

Return period (years)	Reduced variate	Standard normal variable (z)	Total rainfall (mm)		# of rain days	
			Gumbel	Log-Pearson Type III	Gumbel	Log Pearson Type III
2	0.37	0.00	733.93	746.72	39.88	40.50
3	0.90	0.43	845.25	861.36	44.24	45.15
4	1.25	0.67	916.50	932.00	47.03	48.00
5	1.50	0.84	969.24	982.89	49.10	50.03
10	2.25	1.28	1125.03	1126.71	55.20	55.76
15	2.67	1.50	1212.93	1203.96	58.64	58.83
25	3.20	1.75	1321.88	1296.33	62.91	62.49
50	3.90	2.05	1467.91	1415.13	68.63	67.19

Table K-3 Monthly rainfall and rain days, ranked

Rank	F	1-F	Reduced variate	z[1]	Total rainfall (mm)				# of rain days			
					Jun.	Jul.	Aug.	Sep.	Jun.	Jul.	Aug.	Sept.
1	0.04	0.96	3.11	1.71	219.80	657.60	410.10	412.90	12	22	25	16
2	0.09	0.91	2.40	1.36	218.50	568.00	389.30	221.00	11	20	21	14
3	0.13	0.87	1.97	1.12	204.30	467.30	373.80	186.30	11	20	19	12
4	0.17	0.83	1.66	0.94	158.40	369.90	362.00	175.70	10	19	19	11
5	0.22	0.78	1.41	0.78	126.20	361.40	356.70	141.80	10	18	18	11
6	0.26	0.74	1.20	0.64	115.50	328.70	324.00	131.80	8	17	17	10
7	0.30	0.70	1.01	0.51	112.30	321.30	303.40	123.40	8	17	17	9
8	0.35	0.65	0.85	0.39	103.02	288.70	294.70	111.60	8	16	17	9
9	0.39	0.61	0.70	0.28	95.30	281.60	294.60	109.60	7	15	16	9
10	0.43	0.57	0.56	0.16	86.80	234.40	289.10	106.00	7	15	16	7
11	0.48	0.52	0.43	0.05	54.10	222.00	285.80	103.60	6	15	16	7
12	0.52	0.48	0.30	-0.05	53.20	205.70	266.60	76.40	6	12	15	5
13	0.57	0.43	0.18	-0.16	41.90	202.20	247.90	75.50	6	12	14	5
14	0.61	0.39	0.06	-0.28	30.30	186.80	241.20	70.50	5	12	13	4
15	0.65	0.35	-0.05	-0.39	30.20	181.60	227.30	70.50	5	11	13	4
16	0.70	0.30	-0.17	-0.51	29.90	176.20	226.70	63.40	5	11	13	3
17	0.74	0.26	-0.30	-0.64	25.40	161.60	217.80	60.20	4	9	13	3
18	0.78	0.22	-0.42	-0.78	14.10	148.80	187.20	18.20	3	9	13	3
19	0.83	0.17	-0.56	-0.94	14.00	113.30	181.80	8.10	1	9	12	2
20	0.87	0.13	-0.71	-1.12	12.00	105.90	180.30	4.00	1	8	11	2
21	0.91	0.09	-0.89	-1.36	11.70	75.50	120.90	2.00	1	6	9	1
22	0.96	0.04	-1.14	-1.71	3.00	64.20	65.60	0.00	1	4	8	0

[1] standard normal variable

Table K-4 Gumbel probability distribution results, monthly rainfall and rain days

Return period (years)	Reduced variate	Rainfall (mm)					Number of rain days				
		Jun.	Jul.	Aug.	Sep.	Kharif season total	Jun.	Jul.	Aug.	Sep.	Kharif season total
2	0.37	68.51	234.91	251.40	88.14	642.95	5.62	12.70	14.58	5.95	38.85
3	0.90	97.75	299.08	287.95	126.72	811.50	7.05	14.74	16.22	7.81	45.82
4	1.25	116.47	340.14	311.35	151.41	919.37	7.97	16.05	17.27	9.00	50.29
5	1.50	130.33	370.54	328.67	169.69	999.23	8.65	17.02	18.04	9.88	53.59
10	2.25	171.26	460.34	379.82	223.69	1235.11	10.66	19.88	20.33	12.48	63.35
15	2.67	194.35	511.01	408.68	254.15	1368.20	11.79	21.49	21.63	13.95	68.86
25	3.20	222.98	573.81	444.46	291.91	1533.15	13.20	23.49	23.23	15.77	75.69
50	3.90	261.34	657.98	492.41	342.53	1754.26	15.08	26.17	25.38	18.20	84.83

Table K-5 Log Pearson Type III probability distribution results, monthly rainfall and rain days

Return period (years)	z[1]	Rainfall (mm)					Number of rain days				
		Jun.	Jul.	Aug.	Sep.	Kharif season total	Jun.	Jul.	Aug.	Sept.	Kharif season total
2	0.00	55.04	225.62	276.14	88.46	645.25	5.65	13.40	15.01	6.03	40.09
3	0.43	87.39	291.03	316.02	138.85	833.28	7.66	15.74	16.75	8.13	48.30
4	0.67	111.49	334.98	335.78	171.27	953.52	8.90	17.06	17.78	9.53	53.27
5	0.84	130.78	368.34	347.96	194.33	1041.41	9.77	17.96	18.49	10.57	56.79
10	1.28	193.51	470.17	374.33	254.64	1292.64	12.09	20.22	20.42	13.63	66.36
15	1.50	231.83	529.41	384.37	282.64	1428.25	13.22	21.29	21.41	15.32	71.24
25	1.75	281.42	604.36	393.40	311.37	1590.55	14.45	22.43	22.54	17.38	76.80
50	2.05	350.44	707.25	401.25	340.64	1799.58	15.83	23.71	23.94	20.05	83.52

[1] standard normal variable

Table K-6 Maximum and minimum rainfall depths, daily model

Rank	F[1]	1-F[2]	Reduced Variate	z[3]	Maximum rainfall depths (mm) categorized by duration				Minimum rainfall depths (mm) categorized by duration			
					1 day	2 day	3 day	4 day	1 day	2 day	3 day	4 day
1	0.04	0.96	3.11	1.71	174.00	249.80	273.60	352.20	0.20	0.20	0.20	0.20
2	0.09	0.91	2.40	1.36	171.20	229.10	242.30	347.30	0.20	0.20	0.20	0.20
3	0.13	0.87	1.97	1.12	167.90	210.10	231.90	251.90	0.20	0.20	0.20	0.20
4	0.17	0.83	1.66	0.94	167.40	193.00	216.20	223.20	0.20	0.20	0.30	0.30
5	0.22	0.78	1.41	0.78	127.00	191.40	215.20	220.40	0.30	0.30	0.40	0.40
6	0.26	0.74	1.20	0.64	123.60	184.80	200.00	218.40	0.30	0.30	0.40	0.40
7	0.30	0.70	1.01	0.51	122.50	179.60	194.50	209.40	0.30	0.40	0.40	0.40
8	0.35	0.65	0.85	0.39	115.50	143.20	171.80	196.10	0.30	0.40	0.40	0.50
9	0.39	0.61	0.70	0.28	101.00	134.50	163.00	180.80	0.40	0.40	0.50	0.50
10	0.43	0.57	0.56	0.16	100.60	129.40	163.00	174.70	0.40	0.40	0.50	0.60
11	0.48	0.52	0.43	0.05	96.10	128.00	147.80	164.90	0.40	0.50	0.50	0.60
12	0.52	0.48	0.30	-0.05	92.20	127.00	144.50	163.00	0.50	0.50	0.60	0.60
13	0.57	0.43	0.18	-0.16	91.50	125.80	135.10	153.80	0.60	0.60	0.60	0.60
14	0.61	0.39	0.06	-0.28	88.30	118.00	132.40	143.10	0.60	0.60	0.60	0.70
15	0.65	0.35	-0.05	-0.39	79.00	111.80	131.00	141.70	0.60	0.60	0.70	0.80
16	0.70	0.30	-0.17	-0.51	78.00	107.00	126.90	140.70	0.60	0.70	0.80	0.80
17	0.74	0.26	-0.30	-0.64	75.90	105.50	112.80	138.20	0.70	0.80	0.80	1.00
18	0.78	0.22	-0.42	-0.78	69.90	103.00	104.80	135.60	0.80	0.80	1.00	1.00
19	0.83	0.17	-0.56	-0.94	68.80	85.20	92.60	117.80	0.80	1.00	1.00	1.00
20	0.87	0.13	-0.71	-1.12	65.70	69.70	87.70	98.60	1.00	1.00	1.00	1.00
21	0.91	0.09	-0.89	-1.36	43.40	54.30	85.20	88.90	1.00	1.00	2.00	2.00
22	0.96	0.04	-1.14	-1.71	37.20	53.50	76.90	77.60	1.00	2.20	2.20	2.20

[1] F = Exceedence probability
[2] 1-F = Non-exceedence probability
[3] z = standard normal variable

Table K-7 Gumbel extreme value probability distribution, daily model

Return period (years)	Reduced variate	Maximum rainfall depths (mm), categorized by event duration				Minimum rainfall depths (mm), categorized by event duration			
		1 day	2 day	3 day	4 day	1 day	2 day	3 day	4 day
2	0.37	96.01	128.96	147.64	167.26	0.56	0.68	0.78	0.81
3	0.90	112.73	151.71	170.91	197.17	0.45	0.49	0.56	0.60
4	1.25	123.43	166.27	185.80	216.32	0.38	0.37	0.43	0.46
5	1.50	131.35	177.05	196.82	230.49	0.32	0.29	0.32	0.36
10	2.25	154.75	208.90	229.38	272.35	0.16	0.03	0.02	0.05
15	2.67	167.95	226.86	247.75	295.97	0.07	0.00	0.00	0.00
25	3.20	184.31	249.13	270.51	325.24	0.00	0.00	0.00	0.00
50	3.90	206.24	278.98	301.03	364.48	0.00	0.00	0.00	0.00

Table K-8 Log Pearson Type III extreme value probability distribution, daily model

Return period (years)	Standard normal value (z)	Maximum rainfall depths (mm) categorized by duration				Minimum rainfall depths (mm) categorized by duration			
		1 day	2 day	3 day	4 day	1 day	2 day	3 day	4 day
2	0.00	97.85	131.53	148.60	166.11	0.45	0.51	0.58	0.60
3	0.43	116.03	156.62	173.55	196.25	0.35	0.39	0.44	0.45
4	0.67	127.18	171.99	189.26	215.83	0.31	0.33	0.37	0.38
5	0.84	135.19	183.00	200.72	230.43	0.28	0.29	0.33	0.34
10	1.28	157.57	213.67	233.84	274.00	0.22	0.22	0.24	0.25
15	1.50	169.42	229.83	252.05	298.88	0.20	0.19	0.20	0.22
25	1.75	183.41	248.83	274.23	330.04	0.17	0.15	0.17	0.19
50	2.05	201.08	272.70	303.38	372.49	0.15	0.12	0.13	0.15

Table K-9 **Rainfall depth ranked, 0.1 mm threshold event model**

Rank	F[1]	1-F[2]	Reduced variate	z[3]	Maximum rainfall depth (mm) categorized by event duration				Minimum rainfall depths (mm) categorized by event duration			
					1 day	2 day	3 day	4 day	1 day	2 day	3 day	4 day
1	0.04	0.96	3.11	1.71	71.00	107.40	163.00	146.20	0.40	0.80	1.70	8.70
2	0.09	0.91	2.40	1.36	55.60	85.20	114.70	129.80	0.40	3.00	2.90	11.60
3	0.13	0.87	1.97	1.12	55.00	69.40	100.80	124.80	0.50	3.00	6.80	13.60
4	0.17	0.83	1.66	0.94	49.00	68.00	100.60	100.90	0.50	3.60	17.40	16.40
5	0.22	0.78	1.41	0.78	47.60	59.60	96.40	81.30	0.60	7.80	18.90	27.90
6	0.26	0.74	1.20	0.64	43.10	56.20	91.50	77.60	0.80	8.00	19.60	47.40
7	0.30	0.70	1.01	0.51	42.60	48.10	83.40	76.60	1.00	8.40	24.20	57.40
8	0.35	0.65	0.85	0.39	37.00	45.10	80.70	54.90	1.00	11.70	24.80	75.10
9	0.39	0.61	0.70	0.28	36.70	41.80	67.20	50.90	1.20	11.80	33.50	76.60
10	0.43	0.57	0.56	0.16	34.30	40.00	62.90	47.40	1.20	12.80	37.40	77.60
11	0.48	0.52	0.43	0.05	32.20	35.60	62.40	27.90	2.30	20.50	56.80	100.90
12	0.52	0.48	0.30	-0.05	32.00	31.20	56.80	16.40	2.30	21.40	80.70	129.80
13	0.57	0.43	0.18	-0.16	28.10	30.20	53.10	13.60	4.60	24.80	163.00	146.20
14	0.61	0.39	0.06	-0.28	26.60	30.00	50.00	.	.	.	.	.
15	0.65	0.35	-0.05	-0.39	22.20	27.60	48.90	.	.	.	.	.
16	0.70	0.30	-0.17	-0.51	17.00	27.20	37.40	.	.	.	.	.
17	0.74	0.26	-0.30	-0.64	12.00	20.00	29.80	.	.	.	.	.
18	0.78	0.22	-0.42	-0.78	11.70	17.00	27.90	.	.	.	.	.
19	0.83	0.17	-0.56	-0.94	11.00	9.00	24.20	.	.	.	.	.
20	0.87	0.13	-0.71	-1.12	7.00	9.00	19.70	.	.	.	.	.
21	0.91	0.09	-0.89	-1.36	5.00	8.20	11.40	.	.	.	.	.
22	0.96	0.04	-1.14	-1.71	3.20	2.00	.	.	.	.	.	.

[1] F = Exceedence probability
[2] 1-F = Non-exceedence probability
[3] z = standard normal variable

Table K-10 Gumbel extreme value probability distribution, 0.1 mm threshold event model

Return period (years)	Reduced variate	Maximum rainfall depths (mm) categorized by event duration				Minimum rainfall depths (mm) categorized by event duration			
		1 day	2 day	3 day	4 day	1 day	2 day	3 day	4 day
2	0.37	27.86	35.07	59.75	65.85	4.95	12.02	52.70	68.21
3	0.90	35.61	46.20	75.27	83.91	1.25	8.69	34.34	49.12
4	1.25	40.56	53.33	85.20	95.47	0.00	6.56	22.59	36.91
5	1.50	44.23	58.60	92.55	104.02	0.00	4.98	13.89	27.87
10	2.25	55.07	74.18	114.27	129.29	0.00	0.31	0.00	1.16
15	2.67	61.18	82.97	126.53	143.55	0.00	0.00	0.00	0.00
25	3.20	68.76	93.86	141.71	161.22	0.00	0.00	0.00	0.00
50	3.90	78.91	108.46	162.07	184.91	0.00	0.00	0.00	0.00

Table K-11 Log Pearson Type III extreme value probability distribution, 0.1 mm thresold event model

Return period (years)	Standard normal value (z)	Maximum rainfall depths (mm) categorized by event duration				Minimum rainfall depths (mm) categorized by event duration			
		1 day	2 day	3 day	4 day	1 day	2 day	3 day	4 day
2	0.00	27.43	35.27	59.49	64.80	1.86	6.91	23.83	39.60
3	0.43	37.59	49.03	77.24	87.26	1.20	4.78	14.89	26.56
4	0.67	44.02	57.45	88.49	101.67	0.89	3.95	11.64	21.42
5	0.84	48.64	63.33	96.68	112.20	0.71	3.48	9.91	18.57
10	1.28	61.35	78.69	119.83	142.00	0.35	2.57	6.68	12.97
15	1.50	67.82	85.97	132.12	157.77	0.24	2.24	5.58	10.94
25	1.75	75.11	93.68	146.55	176.17	0.14	1.93	4.60	9.09
50	2.05	83.69	102.02	164.54	198.85	0.07	1.64	3.70	7.33

Table K-12 Maximum and minimum rainfall depths, 5.0 mm threshold event model

Rank	F[1]	1-F[2]	Reduced variate	z[3]	Maximum rainfall depths (mm) categorized by event duration				Minimum rainfall depths (mm) categorized by event duration			
					1 day	2 day	3 day	4 day	1 day	2 day	3 day	4 day
1	0.04	0.96	3.11	1.71	127.00	229.10	163.00	138.20	5.70	14.10	48.90	31.00
2	0.09	0.91	2.40	1.36	94.60	193.00	145.30	135.60	6.20	17.70	56.80	37.10
3	0.13	0.87	1.97	1.12	71.00	129.40	118.20	57.40	7.00	24.80	76.90	57.40
4	0.17	0.83	1.66	0.94	69.90	107.40	114.70	31.00	15.60	30.00	91.50	64.40
5	0.22	0.78	1.41	0.78	67.00	107.00	105.90	.	.	.	.	.
6	0.26	0.74	1.20	0.64	67.00	105.50	105.00	.	.	.	.	.
7	0.30	0.70	1.01	0.51	65.70	103.00	103.20	.	.	.	.	.
8	0.35	0.65	0.85	0.39	61.80	99.60	100.80	.	.	.	.	.
9	0.39	0.61	0.70	0.28	55.60	93.80	91.50	.	.	.	.	.
10	0.43	0.57	0.56	0.16	55.00	85.20	85.80	.	.	.	.	.
11	0.48	0.52	0.43	0.05	53.60	78.60	76.90	.	.	.	.	.
12	0.52	0.48	0.30	-0.05	49.00	73.60	56.80	.	.	.	.	.
13	0.57	0.43	0.18	-0.16	47.60	56.00	49.60	.	.	.	.	.
14	0.61	0.39	0.06	-0.28	43.10	53.70	35.80	.	.	.	.	.
15	0.65	0.35	-0.05	-0.39	42.60	48.10	.	.	.	.	.	.
16	0.70	0.30	-0.17	-0.51	37.60	45.10	.	.	.	.	.	.
17	0.74	0.26	-0.30	-0.64	34.30	41.80	.	.	.	.	.	.
18	0.78	0.22	-0.42	-0.78	32.20	41.20	.	.	.	.	.	.
19	0.83	0.17	-0.56	-0.94	28.10	40.00	.	.	.	.	.	.
20	0.87	0.13	-0.71	-1.12	23.40	34.20	.	.	.	.	.	.
21	0.91	0.09	-0.89	-1.36	18.40	27.20	.	.	.	.	.	.
22	0.96	0.04	-1.14	-1.71	13.20	.	.	.	.	.	.	.

[1] F = Exceedence probability
[2] 1-F = Non-exceedence probability
[3] z = standard normal variable

Table K-13 Gumbel extreme value probability distribution, 5.0 mm threshold event model

Return period (years)	Reduced variate	Maximum rainfall depths (mm) categorized by event duration				Minimum rainfall depths (mm) categorized by event duration			
		1 day	2 day	3 day	4 day	1 day	2 day	3 day	4 day
2	0.37	48.38	76.89	88.66	114.94	7.16	44.78	62.80	119.94
3	0.90	59.18	98.43	103.17	144.19	6.14	25.70	52.67	87.74
4	1.25	66.09	112.22	112.46	162.92	5.50	13.49	46.19	67.12
5	1.50	71.20	122.43	119.34	176.78	5.02	4.46	41.39	51.87
10	2.25	86.31	152.57	139.65	217.72	3.60	0.00	27.21	6.79
15	2.67	94.84	169.58	151.11	240.82	2.80	0.00	19.21	0.00
25	3.20	105.40	190.66	165.32	269.45	1.80	0.00	9.30	0.00
50	3.90	119.56	218.92	184.36	307.82	0.48	0.00	0.00	0.00

Table K-14 Log Pearson Type III extreme value probability distribution, 5.0 mm event model

Return period (years)	Standard normal value (z)	Maximum rainfall depths (mm), categorized by event duration				Minimum rainfall depths (mm), categorized by event duration			
		1 day	2 day	3 day	4 day	1 day	2 day	3 day	4 day
2	0.00	49.08	71.77	92.16	114.61	6.97	33.97	54.88	85.62
3	0.43	60.76	91.87	108.46	150.77	6.20	26.50	46.02	61.65
4	0.67	68.02	106.00	118.05	173.85	5.73	22.24	41.60	51.00
5	0.84	73.24	117.07	124.73	190.67	5.39	19.41	38.79	44.72
10	1.28	87.88	152.81	142.53	238.43	4.48	12.69	32.20	31.47
15	1.50	95.61	175.01	151.44	263.83	4.02	9.87	29.31	26.32
25	1.75	104.68	204.64	161.49	293.68	3.51	7.17	26.32	21.44
50	2.05	116.01	248.21	173.48	330.86	2.93	4.62	23.06	16.65

Table K-15 1 in 5 dry and wet year sumary

Month	Interval[1]	P. of wet day[2]	# of rain days[3]	1 in 5 wet year		1 in 5 dry year	
				Total rainfall (mm)[4]	Cum. rainfall (mm)	Total rainfall (mm)[5]	Cum. rainfall (mm)
Jun.	1-5	0.16	1	44.23	44.23	0.71	0.71
	6-10	0.12	1	44.23	88.46	0.71	1.42
	11-15	0.17	1	44.23	132.69	0.71	2.13
	16-20	0.19	1	44.23	176.92	0.71	2.84
	21-25	0.28	1	44.23	221.15	0.71	3.55
	26-30	0.32	2	88.46	309.61	1.42	4.97
Jul.	1-5	0.40	2	88.46	398.07	1.42	6.39
	6-10	0.36	2	88.46	486.53	1.42	7.81
	11-15	0.45	2	88.46	574.99	1.42	9.23
	16-20	0.47	2	88.46	663.45	1.42	10.65
	21-25	0.48	2	88.46	751.91	1.42	12.07
	26-31	0.45	3	132.69	884.60	2.13	14.20
Aug.	1-5	0.54	3	132.69	1017.29	2.13	16.33
	6-10	0.55	3	132.69	1149.98	2.13	18.46
	11-15	0.46	2	88.46	1238.44	1.42	19.88
	16-20	0.51	3	132.69	1371.13	2.13	22.01
	21-25	0.45	2	88.46	1459.59	1.42	23.43
	26-31	0.45	3	132.69	1592.28	2.13	25.56
Sept.	1-5	0.36	2	88.46	1680.74	1.42	26.98
	6-10	0.38	2	88.46	1769.20	1.42	28.40
	11-15	0.21	1	44.23	1813.43	0.71	29.11
	16-20	0.13	1.00	44.23	1857.66	0.71	29.82
	21-25	0.15	1.00	44.23	1901.89	0.71	30.53
	26-30	0.10	1.00	44.23	1946.12	0.71	31.24
Total			**44**	**1946.12**		**31.24**	

[1] Fixed intervals
[2] total # of rain days/total # of days, in each interval from 1970 - 1993
[3] (P. of wet day) * (# of days) for each interval
[4] [1 day maximum rainfall depth (0.1 mm model)] * (# of rain days in the interval)
[5] [1 day minimum rainfall depth (0.1 mm model)] * (# of rain days in the interval)

Table K-16 1 in 10 wet and dry year summary

Month	Interval[1]	P. of wet day[2]	# of rain days[3]	1 in 10 wet year Total rainfall (mm)[4]	1 in 10 wet year Cum. rainfall (mm)	1 in 10 dry year Total rainfall (mm)[5]	1 in 10 dry year Cum. rainfall (mm)
June	1-5	0.16	1	55.07	55.07	0.35	0.35
	6-10	0.12	1	55.07	110.14	0.35	0.70
	11-15	0.17	1	55.07	165.21	0.35	1.05
	16-20	0.19	1	55.07	220.28	0.35	1.40
	21-25	0.28	1	55.07	275.35	0.35	1.75
	26-30	0.32	2	110.14	385.49	0.70	2.45
July	1-5	0.40	2	110.14	495.63	0.70	3.15
	6-10	0.36	2	110.14	605.77	0.70	3.85
	11-15	0.45	2	110.14	715.91	0.70	4.55
	16-20	0.47	2	110.14	826.05	0.70	5.25
	21-25	0.48	2	110.14	936.19	0.70	5.95
	26-31	0.45	3	165.21	1101.40	1.05	7.00
August	1-5	0.54	3	165.21	1266.61	1.05	8.05
	6-10	0.55	3	165.21	1431.82	1.05	9.10
	11-15	0.46	2	110.14	1541.96	0.70	9.80
	16-20	0.51	3	165.21	1707.17	1.05	10.85
	21-25	0.45	2	110.14	1817.31	0.70	11.55
	26-31	0.45	3	165.21	1982.52	1.05	12.60
Sept.	1-5	0.36	2	110.14	2092.66	0.70	13.30
	6-10	0.38	2	110.14	2202.80	0.70	14.00
	11-15	0.21	1	55.07	2257.87	0.35	14.35
	16-20	0.13	1	55.07	2312.94	0.35	14.70
	21-25	0.15	1	55.07	2368.01	0.35	15.05
	26-30	0.10	1	55.07	2423.08	0.35	15.40
Total			**44**	**2423.08**		**15.40**	

[1] Fixed intervals
[2] total # of rain days/total # of days, in each interval from 1970 - 1993
[3] (P. of wet day) * (# of days) for each interval
[4] [1 day maximum rainfall depth (0.1 mm model)] * (# of rain days in the interval)
[5] [1 day minimum rainfall depth (0.1 mm model)] * (# of rain days in the interval)

APPENDIX L
CROP AND EVAPOTRANSPIRATION SUMMARY

Appendix L Crop and evapotranspiration summary

Table L-1 Comparison of 10 Day Moving and Fixed Averages, Irrigated Months

Parameter	Corr. coeff.[1]	Mean difference (%)[2]	Mean difference by month (%)				
			Nov	Dec	Jan	Feb	Mar
Average temperature	0.98	0.56	0.08	0.73	-4.04	4.03	1.97
Minimum temperature	0.98	1.41	-2.24	2.70	-6.26	7.84	5.01
Maximum temperature	0.98	0.38	0.72	0.23	-3.08	3.13	0.91
Average humidity	0.98	1.63	-6.02	8.30	8.53	-2.60	-0.07
Minimum humidity	0.95	2.31	-10.98	17.55	7.91	2.41	-5.34
Maximum humidity	0.98	1.25	-3.99	5.04	8.68	-5.13	1.64
Average wind speed	0.98	0.59	-3.60	4.18	-1.44	6.95	-1.84
Average hours of sunshine	0.95	0.85	2.29	-0.26	0.69	0.81	0.67
Average solar radiation[3]	0.97	0.31	-0.83	0.63	-1.68	3.90	0.96

[1] Corr. coeff. = Pearson correlation coefficient
[3] mean difference = 10 day movng average - 10 day fixed average
[3] Doorenbos and Pruitt, 1977 method

Table L-2 Crop information and coefficients, selected crops

Crop	Sowing Date[a]	Growing Season[a] (days)	Crop Development Stage							
			Initial		Development		Mid-Season		Late	
			Length (days)	K_c[d]	Length (days)	K_c[d]	Length (days)	K_c[d]	Length (days)	K_c[d]
Kharif Season										
Soybean	8-Jul	100	15	0.48	30[c]	0.74	50	1.00	15	0.72
Groundnut	7-Jul	106	20	0.48	35[b]	0.72	30	0.95	25	0.78
Sorghum	18-Jul	110	20	0.48	40[b]	0.74	30	1.00	20	0.78
Maize	20-Jul	115	20	0.48	30[b]	0.80	50	1.10	15	0.83
Paddy Rice	7-Jul	125	20	1.15	35[b]	1.10	50	1.05	20	0.95
Rabi Season										
Mustard	12-Oct	132	20	0.20	40[c]	0.65	45	1.10[e]	25	0.70
Gram (Chickpea)	1-Nov	131	20	0.23	30[c]	0.67	60	1.10[e]	20	0.73
Wheat	15-Nov	120	15	0.23	25[b]	0.67	50	1.10[e]	30	0.67

[a] Chieng, 1993
[b] Development stage length from Subramaniam (1989)
[c] Development stage length adapted from Doorenbos and Pruitt (1977)
[d] K_c values from Doorenbos and Pruitt (1977) unless otherwise noted
[e] K_c value averaged between Doorenbos and Pruitt (1977) and Subramaniam (1989)

Table L-3 Summary of k factors for relevant months

Month	Frequency of irrigation/rain (days)	ET_{grass}[1] (mmd^{-1})	k factor[2]
Jan.	20	3.42	0.28
Feb.	20	5.15	0.22
Mar.	20	6.95	0.18
Jun.	6	11.54	0.41
Jul.	5	9.44	0.48
Aug.	5	4.83	0.61
Sep.	5	5.14	0.58
Oct.	20	6.58	0.20
Nov.	20	4.33	0.23
Dec.	20	3.46	0.28

[1] mean ETgrass averaged over all methods
[2] Doorenbos and Pruitt, 1977

Table L-4 Estimates of ET

Month	Alfalfa Reference				Grass Reference							
	Penman Monteith	Kimberly Penman (1972)	Kimberly Penman (1982)	Jensen Haise	Original Penman	FAO Penman	FAO Penman corrected	FAO Radiation	FAO Blaney-Criddle	Hargreaves	FAO Pan	Christensen Pan
Jan	5.10	4.88	3.75	3.67	3.95	4.00	3.90	3.73	3.33	3.00	2.11	1.89
Feb	8.27	7.63	5.76	4.90	6.04	6.40	5.93	5.63	4.99	3.64	3.10	2.88
Mar	11.46	10.14	7.55	6.44	7.99	8.68	7.55	7.27	6.95	5.22	4.52	4.22
Apr	18.99	16.64	12.42	9.11	12.15	14.19	10.69	9.73	10.13	6.83	5.95	5.82
May	23.03	21.28	16.80	10.29	14.87	18.20	14.06	10.87	11.71	7.82	7.02	8.87
Jun	16.91	17.88	15.20	9.99	12.61	15.41	13.83	8.97	8.98	7.13	6.79	11.23
Jul	12.92	14.44	13.22	8.28	10.48	12.86	12.14	7.68	7.11	5.27	6.02	8.39
Aug	5.70	6.35	5.97	6.18	5.35	5.81	5.52	4.69	3.83	4.48	3.82	3.52
Sep	6.59	6.88	6.51	6.44	5.71	6.27	6.12	4.70	4.17	4.56	3.53	3.39
Oct	9.13	8.26	7.52	6.75	6.77	7.20	7.16	6.43	6.49	4.90	----	----
Nov	6.17	5.58	4.78	4.94	4.80	4.67	4.62	5.00	4.99	3.96	2.78	2.63
Dec	5.11	4.66	3.80	3.75	3.95	3.89	3.80	4.00	3.73	3.05	2.19	2.06

Note: All values in mmd^{-1}

Table L-5 Lysimeter vs. estimated ET for selected Kharif crops

Type of method	Method	Kharif crops											
		Soybean				Sorghum				Groundnut			
		ET[1] Estimate	ET[2] Actual	Ratio[5]	Rank	ET[1] Estimate	ET[3] Actual	Ratio[5]	Rank	ET[1] Estimate	ET[4] Actual	Ratio[5]	Rank
Combination	Penman	594.29	617.98	0.96	2	535.12	548.70	0.98	2	547.74	518.67	1.06	3
	Kimberly-Penman (1972)	629.31	617.98	1.02	1	558.13	548.70	1.02	2	580.71	518.67	1.12	7
	Kimberly-Penman (1982)	584.28	617.98	0.95	3	516.75	548.70	0.94	4	539.16	518.67	1.04	1
	FAO Penman (c=1)	664.30	617.98	1.07	4	586.53	548.70	1.07	5	613.01	518.67	1.18	9
	FAO Corrected Penman	641.47	617.98	1.04	2	570.28	548.70	1.04	3	591.87	518.67	1.14	8
	Penman-Monteith	605.37	617.98	0.98	1	553.14	548.70	1.01	1	558.14	518.67	1.08	4
Radiation	Modified Jensen-Haise	515.28	617.98	0.83	5	473.27	548.70	0.86	6	473.86	518.67	0.91	5
	Adjusted Jensen-Haise	592.57	617.98	0.96	2	544.26	548.70	0.99	1	544.94	518.67	1.05	2
	FAO Radiation	501.07	617.98	0.81	6	466.97	548.70	0.85	7	460.74	518.67	0.89	6
Temperature	FAO Blaney-Criddle	456.40	617.98	0.74	7	432.36	548.70	0.79	8	419.80	518.67	0.81	10
	Hargreaves	426.06	617.98	0.69	8	397.07	548.70	0.72	9	391.38	518.67	0.75	11
Pan	FAO Pan	286.82	617.98	0.46	10	222.86	548.70	0.41	11	265.54	518.67	0.51	13
Evaporation	Christiansen	307.83	617.98	0.50	9	228.27	548.70	0.42	10	286.12	518.67	0.55	12

Note: all ET measurements in mm

1 Estimated ET calculated using climatic data collected from 1970-1993 at Kota Station

2 Actual ET represents measured lysimeter data averaged over 1985-88 at Kota Station (Chieng, 1993)

3 Actual ET represents measured lysimeter data averaged over 1978-83 at Kota Station (Chieng, 1993)

4 Actual ET represents measured lysimeter data averaged over 1989-91 at Kota Station (Chieng, 1993)

5 Ratio = estimated ET/actual ET

Table L-6 Lysimeter vs estimated ET for selected Rabi crops

Type of method	Method	Rabi crops											
		Wheat				Mustard				Gram (Chickpea)			
		ET[1] Estimate	ET[2] Actual	Ratio[5]	Rank	ET[1] Estimate	ET[3] Actual	Ratio[5]	Rank	ET[1] Estimate	ET[4] Actual	Ratio[5]	Rank
Combination	Penman	491.96	527.10	0.93	4	465.26	428.57	1.09	3	511.94	416.67	1.23	8
	Kimberly-Penman (1972)	516.96	527.10	0.98	1	478.50	428.57	1.12	5	534.84	416.67	1.28	10
	Kimberly-Penman (1982)	398.73	527.10	0.76	10	384.07	428.57	0.90	4	416.45	416.67	1.00	1
	FAO Penman (c=1)	508.65	527.10	0.96	2	469.16	428.57	1.09	3	525.50	416.67	1.26	9
	FAO Corrected Penman	477.69	527.10	0.91	5	455.12	428.57	1.06	2	497.71	416.67	1.19	7
	Penman-Monteith	560.91	527.10	1.06	3	516.51	428.57	1.21	8	579.48	416.67	1.39	12
Radiation	Modified Jensen-Haise	366.80	527.10	0.70	9	371.16	428.57	0.87	6	387.92	416.67	0.93	3
	Adjusted Jensen-Haise	421.82	527.10	0.89	8	426.83	428.57	1.00	1	446.11	416.67	1.07	2
	FAO Radiation	467.54	527.10	0.89	6	455.28	428.57	1.06	2	491.20	416.67	1.18	6
Temperature	FAO Blaney-Criddle	427.50	527.10	0.81	7	423.82	428.57	0.99	2	450.72	416.67	1.08	4
	Hargreaves	342.36	527.10	0.65	11	347.89	428.57	0.81	7	361.57	416.67	0.87	5
Pan	FAO Pan	265.29	527.10	0.50	12	239.10	428.57	0.56	9	276.40	416.67	0.66	11
Evaporation	Christiansen	244.81	527.10	0.46	13	220.73	428.57	0.52	10	255.41	416.67	0.61	12

Note: all ET measurements in mm

1 Estimated ET calculated using climatic data collected from 1970-1993 at Kota Station

2 Actual ET represents measured lysimeter data averaged over 1978-83 at Kota Station (Chieng, 1993)

3 Actual ET represents measured lysimeter data averaged over 1985-88 at Kota Station (Chieng, 1993)

4 Actual ET represents measured lysimeter data averaged over 1989-91 at Kota Station (Chieng, 1993)

5 Ratio = estimated ET/actual ET

Table L-7 Summary of lysimeter and ET_c correlation for selected kharif season crops

Method	Crop						Ranking			
	Soybean		Sorghum		Groundnut		Unweighted		Weighted	
	Ratio	Weighting[1] Factor	Ratio	Weighting[1] Factor	Ratio	Weighting[1] Factor	Ratio	Rank	Ratio	Rank
Penman	0.96	0.49	0.98	0.26	1.06	0.25	1.00	1	0.99	1
Kimberly-Penman (1972)	1.02	0.49	1.02	0.26	1.12	0.25	1.05	3	1.04	3
Kimberly-Penman (1982)	0.95	0.49	0.94	0.26	1.04	0.25	0.98	2	0.97	2
FAO Penman (c=1)	1.07	0.49	1.07	0.26	1.18	0.25	1.11	5	1.10	5
FAO Corrected Penman	1.04	0.49	1.04	0.26	1.14	0.25	1.07	4	1.06	4
Penman-Monteith	0.98	0.49	1.01	0.26	1.08	0.25	1.02	2	1.01	1
Modified Jensen-Haise	0.83	0.49	0.86	0.26	0.91	0.25	0.87	6	0.86	6
Adjusted Jesen-Haise	0.96	0.49	0.99	0.26	1.05	0.25	1.00	1	0.99	1
FAO Radiation	0.81	0.49	0.85	0.26	0.89	0.25	0.85	7	0.84	7
FAO Blaney-Criddle	0.74	0.49	0.79	0.26	0.81	0.25	0.78	8	0.77	8
Hargreaves	0.69	0.49	0.72	0.26	0.75	0.25	0.72	9	0.71	9
FAO Pan	0.46	0.49	0.41	0.26	0.51	0.25	0.46	11	0.46	11
Christiansen	0.50	0.49	0.42	0.26	0.55	0.25	0.49	10	0.49	10

1 Weighting factor represents %crop/(%soybean+%sorghum+%groundnut) recalculated to 100%

Table L-8 Summary of lysimeter and ET_c for selected rabi season crops

Method	Crop						Ranking			
	Wheat		Mustard		Gram (Chickpea)		Unweighted		Weighted	
	Ratio	Weighting[1] Factor	Ratio	Weighting[1] Factor	Ratio	Weighting[1] Factor	Ratio	Rank	Ratio	Rank
Penman	0.93	0.30	1.09	0.61	1.23	0.10	1.08	3	1.05	3
Kimberly-Penman (1972)	0.98	0.30	1.12	0.61	1.28	0.10	1.13	6	1.09	6
Kimberly-Penman (1982)	0.76	0.30	0.90	0.61	1.00	0.10	0.88	5	0.86	7
FAO Penman (c=1)	0.96	0.30	1.09	0.61	1.26	0.10	1.11	4	1.07	5
FAO Corrected Penman	0.91	0.30	1.06	0.61	1.19	0.10	1.05	2	1.03	2
Penman-Monteith	1.06	0.30	1.21	0.61	1.39	0.10	1.22	8	1.18	8
Modified Jensen-Haise	0.70	0.30	0.87	0.61	0.93	0.10	0.83	7	0.82	8
Adjusted Jensen-Haise	0.80	0.30	1.00	0.61	1.07	0.10	0.96	1	0.94	4
FAO Radiation	0.89	0.30	1.06	0.61	1.18	0.10	1.04	1	1.02	1
FAO Blaney-Criddle	0.81	0.30	0.99	0.61	1.08	0.10	0.96	2	0.94	4
Hargreaves	0.65	0.30	0.81	0.61	0.87	0.10	0.78	8	0.77	9
FAO Pan	0.50	0.30	0.56	0.61	0.66	0.10	0.57	9	0.55	10
Christiansen	0.46	0.30	0.52	0.61	0.61	0.10	0.53	10	0.51	11

1 Weighting factor represents %crop/(%wheat+%mustard+%gram) recalculated to 100%

Table L-9 Summary of lysimeter and ET_c results, kharif and rabi seasons

Method	Ratio of $ET_{lysimeter}$ to ET_c						Average	Relative
	Soybean	Sorghum	Groundnut	Wheat	Mustard	Chickpea	ratio	Rank
Penman	0.96	0.98	1.06	0.93	1.09	1.23	1.02	1
Kimberly-Penman (1972)	1.02	1.02	1.12	0.98	1.12	1.28	1.07	4
Kimberly-Penman (1982)	0.95	0.94	1.04	0.76	0.90	1.00	0.92	5
FAO Penman (c=1)	1.07	1.07	1.18	0.96	1.09	1.26	1.09	6
FAO Corrected Penman	1.04	1.04	1.14	0.91	1.06	1.19	1.05	3
Penman-Monteith	0.98	1.01	1.08	1.06	1.21	1.39	1.10	7
Modified Jensen-Haise	0.83	0.85	0.91	0.70	0.87	0.93	0.84	9
Adjusted Jensen-Haise	0.96	0.99	1.05	0.80	1.00	1.07	0.97	2
FAO Radiation	0.81	0.85	0.89	0.89	1.06	1.18	0.93	4
FAO Blaney-Criddle	0.74	0.79	0.81	0.81	0.99	1.08	0.86	8
Hargreaves	0.69	0.72	0.75	0.65	0.81	0.87	0.74	10
FAO Pan	0.46	0.41	0.51	0.50	0.56	0.66	0.51	11
Christiansen	0.50	0.42	0.55	0.46	0.52	0.61	0.50	12

Note: ratios are weighted

APPENDIX M
EFFECTIVE RAINFALL SUMMARY

Table M-1 Effective rainfall summary, normal rainfall

Month	Interval[1]	ETc (mm)	1 in 2 normal year			1 in 5 normal year			1 in 10 normal year		
			Total rain (mm)[2]	Effective rain (mm)		Total rain (mm)	Effective rain (mm)		Total rain (mm)	Effective rain (mm)	
				USDA method	70% method		USDA method	70% method		USDA method	70% method
Jun.	1-5	24.09	7.86	4.12	5.50	18.68	11.62	13.08	27.64	17.22	19.35
	6-10	23.08	7.86	4.11	5.50	18.68	11.59	13.08	27.64	17.19	19.35
	11-15	20.71	7.86	4.09	5.50	18.68	11.53	13.08	27.64	17.10	19.35
	16-20	20.85	7.86	4.09	5.50	18.68	11.54	13.08	27.64	17.10	19.35
	21-25	20.71	7.86	4.09	5.50	18.68	11.53	13.08	27.64	17.10	19.35
	26-30	18.19	15.73	9.55	11.01	37.37	22.65	26.16	55.29	32.45	38.70
Jul.	1-5	29.12	34.71	21.65	24.30	56.67	33.98	39.67	72.33	42.25	50.63
	6-10	26.47	34.71	21.53	24.30	56.67	33.79	39.67	72.33	42.01	50.63
	11-15	23.18	34.71	21.37	24.30	56.67	33.54	39.67	72.33	41.70	50.63
	16-20	19.09	34.71	21.18	24.30	56.67	33.24	39.67	72.33	41.33	50.63
	21-25	19.70	34.71	21.21	24.30	56.67	33.29	39.67	72.33	41.39	50.63
	26-31	34.21	52.07	31.84	36.45	85.00	49.25	59.50	108.50	60.93	75.95
Aug.	1-5	34.79	51.78	31.72	36.24	65.24	39.04	45.67	70.19	41.65	49.13
	6-10	29.32	51.78	31.34	36.24	65.24	38.57	45.67	70.19	41.16	49.13
	11-15	26.85	34.52	21.43	24.16	43.50	26.58	30.45	46.79	28.43	32.75
	16-20	27.30	51.78	31.20	36.24	65.24	38.40	45.67	70.19	40.97	49.13
	21-25	23.69	34.52	21.28	24.16	43.50	26.40	30.45	46.79	28.23	32.75
	26-31	33.47	51.78	31.63	36.24	65.24	38.92	45.67	70.19	41.53	49.13
Sept.	1-5	35.25	22.12	14.16	15.48	48.58	29.96	34.01	63.66	38.23	44.56
	6-10	37.47	22.12	14.23	15.48	48.58	30.11	34.01	63.66	38.42	44.56
	11-15	39.29	11.06	6.68	7.74	24.29	15.69	17.00	31.83	20.40	22.28
	16-20	39.34	11.06	6.68	7.74	24.29	15.69	17.00	31.83	20.40	22.28
	21-25	39.24	11.06	6.68	7.74	24.29	15.69	17.00	31.83	20.40	22.28
	26-30	39.59	11.06	6.68	7.74	24.29	15.70	17.00	31.83	20.41	22.28
Total		**685.00**	**645.26**	**392.52**	**451.68**	**1041.41**	**628.32**	**728.99**	**1292.65**	**767.99**	**904.86**

[1] Fixed intervals

[2] total rainfall = [(normal monthly rainfall depth) / (# of rain days in month)] * (# of rain days in the interval)
where # of rain days in interval= [(total # of rain days/total number of days)*days] for each interval

Table M-2 Effective rainfall summary, wet year rainfall

Month	Interval[1]	ETc (mm)	1 in 2 wet year			1 in 5 wet year			1 in 10 wet year		
			Total rain (mm)[2]	Effective rain (mm)		Total rain (mm)	Effective rain (mm)		Total rain (mm)	Effective rain (mm)	
				USDA method	70% method		USDA method	70% method		USDA method	70% method
Jun.	1-5	24.09	27.86	17.36	19.50	44.23	26.83	30.96	55.07	32.76	38.55
	6-10	23.08	27.86	17.32	19.50	44.23	26.77	30.96	55.07	32.68	38.55
	11-15	20.71	27.86	17.23	19.50	44.23	26.63	30.96	55.07	32.51	38.55
	16-20	20.85	27.86	17.23	19.50	44.23	26.64	30.96	55.07	32.52	38.55
	21-25	20.71	27.86	17.23	19.50	44.23	26.63	30.96	55.07	32.51	38.55
	26-30	18.19	55.72	32.68	39.00	88.46	49.24	61.92	110.14	59.59	77.10
Jul.	1-5	29.12	55.72	33.47	39.00	88.46	50.44	61.92	110.14	61.04	77.10
	6-10	26.47	55.72	33.28	39.00	88.46	50.14	61.92	110.14	60.68	77.10
	11-15	23.18	55.72	33.04	39.00	88.46	49.78	61.92	110.14	60.25	77.10
	16-20	19.09	55.72	32.74	39.00	88.46	49.34	61.92	110.14	59.71	77.10
	21-25	19.70	55.72	32.79	39.00	88.46	49.40	61.92	110.14	59.79	77.10
	26-31	34.21	83.58	48.53	58.51	132.69	72.49	92.88	165.21	87.47	115.65
Aug.	1-5	34.79	83.58	48.59	58.51	132.69	72.58	92.88	165.21	87.58	115.65
	6-10	29.32	83.58	48.01	58.51	132.69	71.71	92.88	165.21	86.53	115.65
	11-15	26.85	55.72	33.31	39.00	88.46	50.19	61.92	110.14	60.74	77.10
	16-20	27.30	83.58	47.80	58.51	132.69	71.40	92.88	165.21	86.15	115.65
	21-25	23.69	55.72	33.08	39.00	88.46	49.84	61.92	110.14	60.31	77.10
	26-31	33.47	83.58	48.45	58.51	132.69	72.37	92.88	165.21	87.32	115.65
Sept.	1-5	35.25	55.72	33.93	39.00	88.46	51.12	61.92	110.14	61.87	77.10
	6-10	37.47	55.72	34.09	39.00	88.46	51.37	61.92	110.14	62.17	77.10
	11-15	39.29	27.86	17.95	19.50	44.23	27.74	30.96	55.07	33.87	38.55
	16-20	39.34	27.86	17.95	19.50	44.23	27.75	30.96	55.07	33.87	38.55
	21-25	39.24	27.86	17.94	19.50	44.23	27.74	30.96	55.07	33.87	38.55
	26-30	39.59	27.86	17.96	19.50	44.23	27.76	30.96	55.07	33.89	38.55
Total		**685.00**	**1225.84**	**731.92**	**858.09**	**1946.12**	**1105.91**	**1362.28**	**2423.08**	**1339.67**	**1696.16**

[1] Fixed intervals
[2] total rainfall = [1 day maximum rainfall depth (0.1 mm model)] (# of rain days in the interval)
where # of rain days = [(total # of rain days/total number of days)*days] for each interval