# Rainfall Interception Loss in the Unlogged and Logged Forest Areas of Central Kalimantan, Indonesia

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## Abstract

Measurements of throughfall, stemflow and interception loss were made in unlogged and logged forest areas of Central Kalimantan, Indonesia. The literature related to interception loss changes due to changes in canopy cover conditions is reviewed and discussed. The characteristics of the experimental site and the various experiments carried out are described in detail. Two methods, the volume balance method and the mass exchange method, were employed to derive the model parameters from both the unlogged and logged plots. The experiments were carried out from 1 November 1993 to 14 April 1994 in the unlogged plot and from 11 June 1994 to 2 July 1995 in the logged plot.

The results obtained showed that, on average, total interception loss was reduced from 11 % of gross rainfall in the unlogged plot to 6 % in the logged plot. In the logged plot, logging activities had reduced tree density from 581 to 278 trees per hectare. Within the logged plot, interception loss was closely associated with the canopy cover condition (closed canopy, partial canopy and canopy gap) resulted from logging activities. The canopy properties: canopy storage capacity, free throughfall coefficient and boundary layer conductance, were identified as responsible for the changes in interception loss following logging.

Together with measurements of microclimatic variables above and within the forest canopy, the canopy structure parameters derived from the measurements of throughfall and stemflow were used to parameterise two models which predict rainfall interception loss: the Rutter-type model and the analytical model of Gash. These models were applied to both the unlogged and logged forest areas and showed relatively good agreement with observed interception loss. With both models, the difference between observed and predicted cumulative interception loss, expressed as percentage of the gross rainfall, was less than 2 %. However, the models were not adequate in predicting interception loss on a storm by storm basis.

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## Contents

## Symbols

*Roman alphabet*

$A$ available energy (J m$^{-2}$ s$^{-1}$)

$C_j$ amount of water stored on the tree canopy in the *j*th time period (mm)

$C_t$ amount of water stored on the stems (mm)

$c_p$ specific heat of air at constant pressure (J kg$^{-1}$ °C)

$c$ proportion of covered area relative to the ground area (dimensionless)

$D$ drainage rate at the canopy surface (mm min$^{-1}$, mm s$^{-1}$)

$D_t$ drainage rate at the canopy surface (mm min$^{-1}$, mm s$^{-1}$)

$D_{vp}$ vapour pressure deficit (Pa, kPa)

$E_c$, $E_{ic}$ evaporation rate from the wet tree canopy (mm s$^{-1}$)

$E_e$ actual evaporation (mm s$^{-1}$)

$E_{it}$ evaporation rate from the wet trunks (mm s$^{-1}$)

$E_p$ evaporation rate by Penman equation (mm s$^{-1}$)

$E_{pot}$ potential evaporation (mm s$^{-1}$)

$\overline{E}$ mean evaporation rate per unit ground area (mm h$^{-1}$)

$e_a$ vapour pressure of air (Pa)

$e_s$ saturation vapour pressure of air (Pa)

$G$ soil heat flux density (J m$^{-2}$ s$^{-1}$)

$g_a$ boundary layer conductance (m s$^{-1}$)

$H$ sensible heat flux density (J m$^{-2}$ s$^{-1}$)

$I$ interception loss (mm, mm s$^{-1}$)

$P_g$ gross rainfall (mm)

$P_n$ net rainfall (mm)

$p$ free throughfall coefficient (dimensionless)

$p_t$ proportion of rain diverted to stemflow (dimensionless)

$Q$ quantum flux (μmol m$^{-2}$ s$^{-1}$)

$R_h$ relative humidity (%)

$R_n$ net radiation (J m$^{-2}$ s$^{-1}$)

$\overline{R}$ mean rainfall rate (mm h$^{-1}$)

$r_a$ aerodynamic resistance (s m$^{-1}$)

$r_c$ canopy resistance (s m$^{-1}$)

$r_s$ stomatal resistance (s m$^{-1}$)

$S$ canopy storage capacity per unit ground area (mm)

$S_c$ canopy storage capacity per unit area of cover (mm)

$S_f$ stemflow (mm)

$S_t$ trunk storage capacity (mm)

$s$ rate of change of saturated vapour pressure with temperature (Pa °C)

$S_b$ direct solar irradiance (J m$^{-2}$ s$^{-1}$)

$T$, $T_a$ temperature at the reference height (°C)

$T_f$ throughfall (mm)

$T_o$ temperature at the canopy surface (°C)

$u$ windspeed (m s$^{-1}$)

*Greek alphabet*

$\alpha$ empirical Priestley-Taylor coefficient (dimensionless)

$\Delta t$ time period in the model (hour)

$\rho$ density of air (kg m$^{-3}$)

$\lambda$ latent heat of vaporization of water (J kg$^{-1}$)

$\gamma$ psychrometric constant (Pa °C$^{-1}$)

*Statistics*

*CV* coefficient of variance (percentage)

df degree of freedom (dimensionless)

*F* calculated ratio of variability (dimensionless)

*F*crit ratio of variability from the statistic textbook (dimensionless)

MS mean of square (mm)

*n* number of measurement (dimensionless)

*p* probability (percentage)

SE standard error (mm)

SS sum of square (mm)

$r^2$ coefficient of determination (percentage)

# Chapter 1

# Introduction

## 1.1. Background

There is concern about the environmental effects of forest extraction in tropical countries, as the rainforests are a major natural and economic resource. Basic information on forest ecology, including effects of the forest on the environment, is essential for better management of the forest resource. The water relations of forest stands are of major interest at a local scale because cutting of forest may affect water yield (Lee, 1980; Bosch and Hewlett, 1982; Hamilton and King, 1984; Bruijnzeel, 1990; Malmer, 1992). At a global scale, reduction of forest reduces evaporation and, hence, precipitation and regional and global climate may be affected (Henderson-Sellers and Gornitz, 1984; Shuttleworth, 1988; Dickinson, 1989; Lean and Warrilow, 1989; Shukla *et al.*, 1990). A number of rainfall interception studies have shown that interception losses are of major importance in determining the water yield of forested areas relative to yields from other vegetative cover, and the evaporation of intercepted water contributes a major part of the overall process of evapotranspiration (Calder, 1976; Gash and Stewart, 1977; Murdiyarso, 1986; Scatena, 1990; Loustau *et al.*, 1992). These results indicate that an understanding of the processes influencing rainfall interception loss for different vegetative covers is required for the prediction of the change in water yield resulting from vegetation changes. Measurements and models of rainfall interception loss are a prerequisite to any quantitative prediction of the effects of forest management on water relations.

From the perspective of catchment water balance, it is widely accepted that, while one can exert little influence on rainfall as primary source of streamflow, the manipulative changes of forest cover, and hence evapotranspiration, can influence streamflow both in terms of gross yield and flow characteristics. Catchment experiments to determine vegetation effects on streamflow have demonstrated streamflow changes that, on a long-term scale, may be attributed entirely to changes in evapotranspiration, of which rainfall interception loss may be the major part. Rainfall interception loss has, therefore, been identified as the process within the evapotranspiration component which may explain much of the change in streamflow that is attributed to afforestation (Bosch and Hewlett, 1982).

Many research reports indicate that interception loss from different forests in temperate regions ranges from 35 to 75 % of the total annual losses by evaporation and transpiration together (McNaughton and Jarvis, 1983). Expressed as a fraction of gross annual rainfall, interception loss ranges from 10 to 55 % depending on the tree spacing, the leaf area index and the crown structure of the forest, and the climate (Rutter, 1975). In tropical rainforest environments, estimates of rainfall interception loss vary from place to place depending upon sampling strategy used and as a consequence of high variability in rainfall regime and stand structure. Of a number of rainfall interception studies made in the tropical rainforest only a small percentage is considered to be reliable (Bruijnzeel, 1990). This suggests that more studies of rainfall interception loss in tropical areas need to be carried out in an intensive and adequate manner in order to obtain more reliable results. A review of the present literature indicates that rainfall interception loss in the tropical rainforest ranges from 5 to 31 % of gross annual rainfall (Jackson, 1975; Lloyd *et al.*, 1988; de Paula Lima, 1990; Sinun *et al.*, 1992). Rainfall interception loss in the tropical region is less than in the temperate region. This is probably caused by the difference in the environmental microclimate and canopy structure conditions. In the temperate region, windspeeds are higher than in the tropical area, while the rainfall regime in terms of the amount and intensity is generally higher in the tropical region. With higher windspeeds and lower rainfall intensity, the possibility of evaporation of intercepted water in the temperate region is greater and thus there is greater rainfall interception loss.

Rainfall interception loss is generally defined as the process by which part of the rainfall is caught by the vegetation canopy and redistributed as throughfall, stemflow, absorption and evaporation from the canopy. As explained by Horton (1919), in Teklehaimanot (1990), when rain starts to fall on a forest some of the raindrops striking the leaves are largely retained and spread out from the point of drop impact into a thin film. This continues until the storage capacity of the leaf is filled or the surface tension forces are in balance with the gravitational forces. Thereafter, raindrops striking the leaf form miniature pools and rivulets, channeling the moisture to the tips or lower edges of the leaves, where they form large drops. Drop size gradually increases until forces due to gravity overcome the forces due to surface tension. When the ratio of gravitational forces to surface tension forces exceeds unity, the drops will separate from the edge of the leaf, falling downward to strike a lower leaf or be shaken off by wind. The leaf system, therefore, temporarily stores the rain in films and drops which are freely exposed to evaporation. After the rain ceases, the forest canopy dries by evaporation and remains dry until the next rain event, when the process repeats itself.

A number of studies of rainfall interception and water use of tropical forests have been reported (e.g. Jackson, 1975; Edwards and Blackie, 1981; Calder *et al.*, 1986; Rao, 1987; Lloyd *et al.*, 1988; Hutjes *et al.*, 1990; Scatena, 1990; Sinun *et al.*, 1992). However, the water use of these tropical forests still remains unclear and it is very difficult to estimate or model evaporative losses from them with the same degree of confidence that is now possible for forests growing in temperate climates (Jarvis and Stewart, 1979; Calder, 1982; Roberts, 1983; Calder *et al.*, 1986). This, in part, is caused by the difficult conditions in which the rainfall interception loss studies in the tropical forest areas were carried out, less than adequately (Lloyd and Marques, 1988; Bruijnzeel, 1990), while the models used for prediction in the tropical rainforest environment were originally derived for temperate climates. Other reasons which make interception estimates in the tropical area unreliable are the high variability of storm regimes and the complex, variable stand structures (Jackson, 1971; Lloyd and Marques, 1988; Bruijnzeel, 1990).

A few studies on the application of rainfall interception models to tropical forest have been done using either Rutter's (e.g. Calder *et al.*, 1986) or Gash's analytical model (Rao, 1987; Lloyd *et al.*, 1988; Hutjes *et al.*, 1990). The latter is a storm-based simplification of the more rigorous Rutter model (Gash, 1979). The results indicate that the application of these models in tropical areas is not always appropriate, unless modified or adjusted to local condition (Pearce and Rowe, 1981; Calder *et al.*, 1986; Rao, 1987; Lloyd *et al.*, 1988; Hutjes *et al.*, 1990), though the models have been successfully tested against data from coniferous plantation forests in Great Britain (Gash and Morton, 1978; Gash *et al.*, 1980), from an oak plantation in the Netherlands (Dolman, 1987), and from mixed evergreen forest in New Zealand (Pearce and Rowe, 1981). This is very understandable since the models were initially derived for the temperate environment, which is considerably different in climate, intensity of precipitation and vegetation structure from the tropical environment.

### 1.2. Research site

The field site is in the rainforest area of Central Kalimantan, Indonesia, 1° 17′ 46″ S and 112° 22′ 42″ E, within a forest concession area operated by PT Kayu Mas International, as shown in Fig. 1.1a and Fig. 1.1b of Appendix VIII. It lies in the headwaters of the Mentaya river, about 175 km NNW of the town of Sampit. This is a hilly area with altitude ranging from 100-300 m above sea level. Slopes are variable but can be as steep as 35°. It was selected as being representative of the natural vegetation and regional topography of the upper parts of the island of Kalimantan and so far the area has been given low priority for scientific study. The name of this research site is Wanariset Sangai. The Wanariset Sangai occupies an area of 600 ha of primary rainforest containing 15 nine hectare plots that were established in 1993 for tropical forest management research activities. This study was carried out in a one hectare plot of the unlogged forest and in a one-year-old, logged-over area which is located close by but outside the Wanariset Sangai research station.

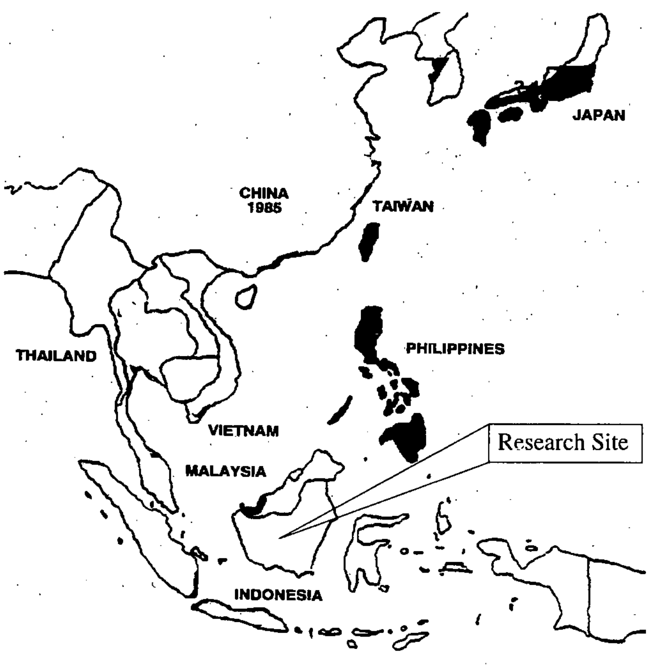



**Figure 1.1a** Location of the research site at Wanariset Sangai, Central Kalimantan, Indonesia.

The research area is a typical lowland dipterocarp rainforest in an area of hilly terrain which contains a large number of species. Field measurements by the botanical teams indicate that the average height of the topmost tree layer is about 45-47 m, with an understorey consisting of shrubs/small trees of 2-5 m in height. This stand structure is very similar to the neighbouring area of East Kalimantan. Kartawinata *et al.* (1981) reported that a typical lowland rainforest of East Kalimantan contains between 138-180 tree species in one hectare of forest area (specimens with diameter at breast height over 10 cm). The average height of the topmost tree layer is about 40-55 m and the understorey usually consists of shrubs/small trees of 2-8 m in height. The forest stand is dominated by such families as Dipterocarpaceae, Caesalpinaceae, Euphorbiaceae, and Myrtaceae. The density of trees (diameter at breast height over 10 cm) in the research site (Plot 9) is 581 trees per hectare (field data, 1993). This is comparable to data from other parts of Kalimantan where the number of trees per hectare ranges between 450-1300, with an average of 870 (Giesen, 1987). The density and basal area of trees larger than or equal to 10 cm diameter at breast height in the study area and other tropical rainforests in the island of Kalimantan is shown in Table 1.1. The table indicates that the tree density in the study area is 31 % higher than that in Lempake, East Kalimantan, 7 % higher than that in Wanariset Samboja, another forest site in East Kalimantan. The basal area per hectare is also larger than in neighbouring forests of East Kalimantan.

The Wanariset Sangai is in the upstream of Mentaya catchment area approximately 300 m above sea level. The topographical feature of the research site is mostly undulating terrain with slopes ranged from $0^\circ$ to $35^\circ$.

**Table 1.1** Comparison of the basal area and tree density at the research site with those at other sites (Newbery *et al.*, 1992).

| Site | Gbh* (cm) | Density (per ha) | Basal Area ($m^2\ ha^{-1}$) | Reference |
|---|---|---|---|---|
| Present study | | | | |
| a. Unlogged forest | 30.0 | 581 | 38.6 | |
| b. Logged forest | 30.0 | 278 | 13.8 | |
| Sepilok, Sabah | 30.5 | 608 | 37.8 | Nicholson (1965) |
| Silam, Sabah | 31.4 | 573 | 42.2 | Proctor *et al.* (1988) |
| Danum Valley, Sabah | 30.0 | 470 | 26.6 | Newbery *et al.*(1992) |
| Andalau, Brunei | 30.0 | 628 | 35.2 | Ashton (1964) |
| Mulu, Serawak | 31.4 | 739 | 57.0 | Proctor *et al.* (1983) |
| Samboja, East Kalimantan | 31.4 | 541 | 29.7 | Kartawinata *et al.* (1981) |
| Lempake, East Kalimantan | 31.4 | 445 | 33.7 | Riswan (1987) |
| Pasoh, Penang Malaysia | 31.4 | 530 | 25.2 | Manokaran & Frankie (1990) |

Note: *Gbh = girth at breast height ≥ 30 cm ≅ diameter at breast height (dbh) ≥ 10 cm.

In the unlogged forest area, the height of the trees with diameter at breast height equal or greater than 10 cm varies between 8.5 and 48 m, while in the logged-over forest area the height of the trees ranges from 6.8 to 20 m. The number of trees with dbh ≥ 10 cm is 581 trees per hectare in the unlogged forest and 278 trees in the logged-over area. The distribution of the trees by basal area and diameter classes in each plot are given in Fig. 1.2 and 1.3. The basal area per hectare in the unlogged and logged-over areas are 38.6 and 13.8 $m^2\ ha^{-1}$, respectively.

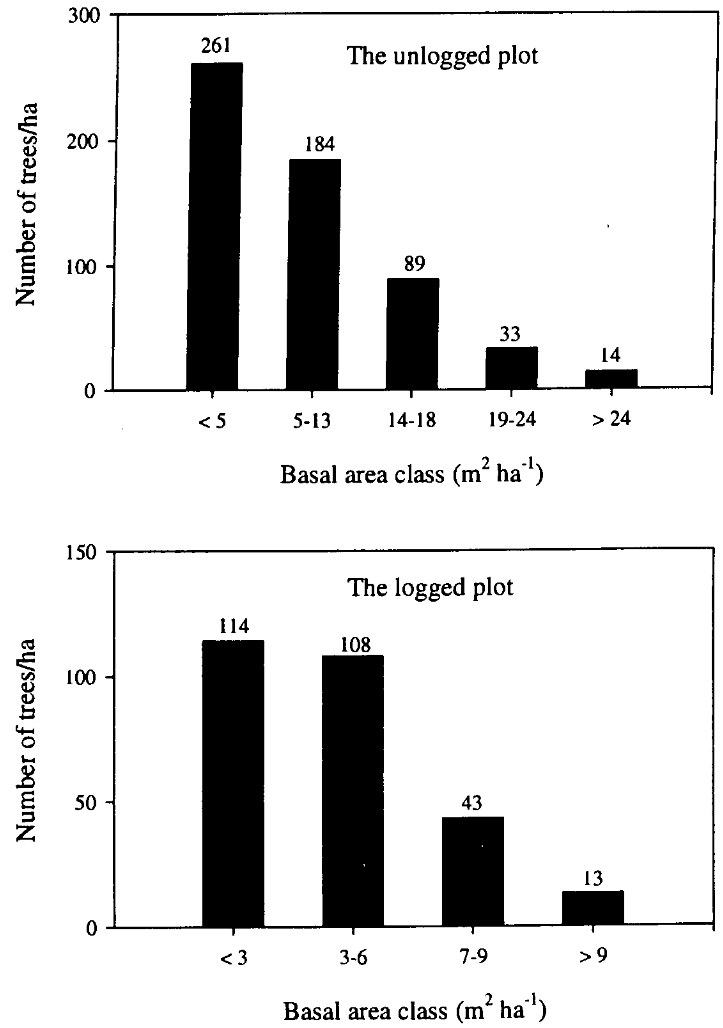



**Figure 1.2** Number of trees per hectare by the basal area class in each plot.

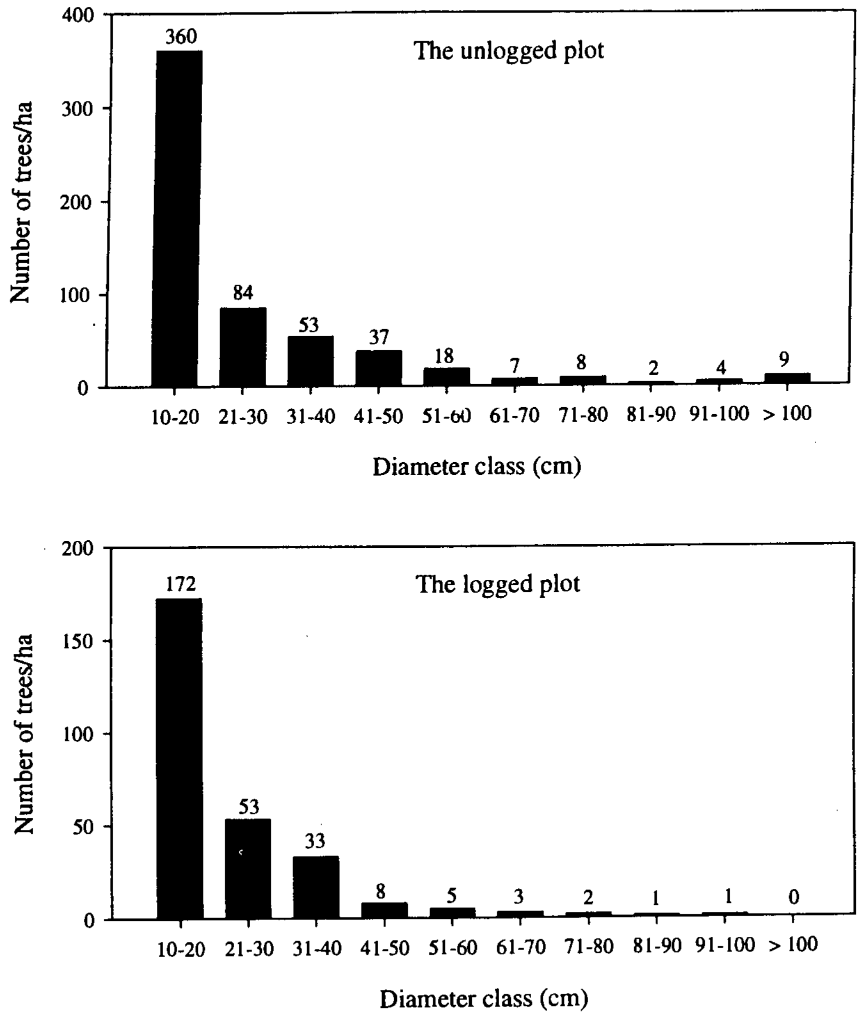



**Figure 1.3** Number of trees per hectare by diameter class in each plot.

The climate of this region is determined primarily by East and West monsoons and by movement of the intertropical convergence zone. At the research site, the average monthly rainfall collected for a twelve month period (June 1994 - July 1995) was 356 mm (Table 3.12). The closest national weather station to the research site is located in Kuala Kuayan, some 75 km downstream of the research site. At this weather station, rainfall is seasonally distributed, with the maximum mean monthly rainfall of 305 mm occuring in November and the minimum of 154 mm in July, and with an average monthly rainfall of 239 mm (BMG, 1981-1993). Mean monthly rainfall at the research site is higher than that of the weather station because the research site is located in the upland area. Normally, the wet season is from October to April each year, and November, December, January, and February are the wettest months. The driest months are usually June and July. Table 1.2 shows mean monthly rainfall and number of raindays at the weather station for the last thirteen consecutive years.

**Table 1.2** Mean monthly rainfall (mm) and number of raindays in Kuala Kuayan, Central Kalimantan, for thirteen years (rainfall period: 1981-1993).

| Mean monthly rainfall | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year |
| 296 | 214 | 260 | 283 | 235 | 164 | 154 | 208 | 193 | 275 | 305 | 275 | 2862 |
| Number of raindays | | | | | | | | | | | | |
| 17 | 16 | 16 | 19 | 14 | 12 | 10 | 15 | 15 | 15 | 21 | 21 | 191 |

Source: Badan Meteorologi dan Geofisika (BMG), Jakarta (1981-1993)

Most of the rain is convectional in origin. Storm size can exceed 100 mm on occasion, and intensities can average 20-25 mm per hour for considerable periods.

## 1.3. Aims of the project

A literature review indicates that there have not yet been any experiments carried out to establish the relationship between rainfall interception loss and forest felling (logging) activity and no work has so far been done to modify existing models or develop a new model to predict rainfall interception loss in the unlogged and logged-over area of tropical forest. Therefore, it is a major objective of this project to determine whether logging has an impact on rainfall interception loss and to test whether the Rutter and Gash analytical models, which were originally developed and tested against data from temperate mono-culture plantations and have received little testing in forests with more than one canopy level, can successfully estimate the evaporation of intercepted water from tropical rainforest in Central Kalimantan, Indonesia.

The literature review also indicates that there have been only a few rainfall interception loss studies in tropical rainforests, especially in South East Asia, that have been carried out in a proper and serious way (e.g. Bruijnzeel, 1990). Therefore, this research experiment was undertaken to:

(1) evaluate rainfall interception loss in the unlogged and logged-over areas of tropical rainforest and hence evaluate some possible hydrological impacts of forest practices on forest-water relations;

(2) test the hypothesis that forest felling will decrease leaf area index and hence canopy storage capacity, leading to a reduction of rainfall interception loss;

(3) test the hypothesis that forest felling has a direct effect on the micrometeorology of the logged-over areas and can influence the rate of evaporation of intercepted water by the tree canopy and by the understorey; and

(4) test and adapt the Rutter and Gash analytical interception models in a tropical rainforest environment.

The practical objective of this research is to provide forestry policy makers with some scientific evidence on forest-water relationships for logged and unlogged forest areas so that a scientific-based evaluation can be applied to current forest felling policies (The Indonesia Selective Felling and Planting System, **TPTI**).

**1.4. Tropical rainforest and the TPTI system**

Tropical rainforests, whether they are mangrove forests, lowland rainforests or montane rainforests, are all remarkably complex systems (Whitmore, 1985; Longman and Jenik, 1987). The canopy of tropical rainforest is often considered to be stratified. Strata (layers) are sometimes easy to see in the forest but sometimes not. Different authors have referred to different aspects of layering, which they have not always clearly distinguished. The classical view of layering in tropical lowland rainforest is that there are five strata (Whitmore, 1985). The first stratum comprises the top layer of the biggest trees, which commonly stand as isolated or grouped emergents above a continuous second layer, the main canopy. Under the main canopy is the third stratum, which in many cases merges into the main canopy. The fourth and fifth layers usually comprise the shrubby understorey and forest-floor herbs with small seedlings.

In Sabah (the northern part of Kalimantan), the topmost or emergent layer is composed mostly of groups of trees of the Dipterocarpaceae (*Dipterocarpus, Dryobalanops,* and *Shorea*). In Dipterocarp lowland forest the top of the canopy is usually at about 45 m and individual trees reaching a height of 60 m are common (Whitmore, 1985). The lower parts of the canopy contain young individuals of growing trees that will become taller, as well as mature short trees.

The Indonesia Selective Felling and Planting System (TPTI) is a silvicultural system of managing the tropical rainforest in Indonesia. Other silvicultural systems used in the management of tropical forest in Indonesia as well as in South East Asia are clear felling with natural regeneration and clear felling with artificial regeneration. These last two systems have been practised in a less extensive way (Anonymous, 1992). The aim of TPTI is to regulate the utilisation of the natural production forests and to enhance the value of residual stands for the next felling cycle so as to ensure the continuity of wood supply for various wood-based industries (Anonymous, 1990). The general requirements of the TPTI are that one hectare of forest area (other than peat/swamp forests) should have a minimum nucleus of 25 commercial trees with diameter at breast height between 20-29 cm. This nucleus of trees will ensure that in the next 35 years felling cycle there will be enough timber to be harvested. The dbh limit of trees allowed to be felled is 50 cm and over.

The scale of canopy opening as a result of applying this silvicultural system has been described by Butarbutar (1985). In his study on the impact of the TPTI felling system on stand structure, he reported that, in one hectare of forest, the number of trees allowed to be felled ranged from 6 to 11. Cutting these trees resulted in opening up gaps in the forest canopy from about 1520 to 2500 $m^2$ per hectare. If the impact caused by making access and skid trail roads were also included, the total opening up of the canopy cover would be between 2500 and 5000 $m^2$ per hectare of forest area. On average, the number of trees allowed to be harvested was 9 per hectare and the scale of canopy opening that resulted was 3570 $m^2$ per hectare or 36 % of the forest area. In this experiment, in a one hectare plot, the open space (canopy gaps) resulting from forest felling in 1992 and its associated activities was 3775 $m^2$ per hectare or 38 %.

### 1.5. Organisation of the thesis

Review of the literature indicates that only a few reliable studies (measurement as well as simulation modelling) on rainfall interception loss have been carried out in primary tropical rainforest and that there have been no studies on the measurement and modelling of the evaporation of intercepted water in a logged-over area of tropical rainforest. There is therefore a clear need to investigate the effects of forest felling practice on the interception loss of tropical rainforest.

The difficulties in obtaining reliable results on the measurement and modeling of rainfall interception loss in tropical forest environment are mainly caused by high spatial as well as temporal variability of both stand structure and rainfall regimes. This high variability occurs in both unlogged and logged-over forest areas. Because of this high variability, an intensive sampling strategy was applied, involving large numbers of throughfall as well as stemflow measurements.

This thesis comprises six Chapters:

Chapter One gives a general introduction to the thesis, including the background of the study covering the descriptions of the research site, tropical rainforest systems in general, and the Indonesia Selective Felling and Planting system in particular. This chapter also outlines the aims of the study, including research methodology and the hypothesis, the concept of rainfall interception loss, a statement of the problem and why an interception study in tropical rainforest need to be done.

Chapter Two describes the interception study, which was based on a volume balance approach in the unlogged and logged forest areas, and describes the experimental design and instrumentation required for this approach. Some notes regarding the problems with this approach, especially with respect to the tropical rainforest environment, are included.

Chapter Three contains the results and discussion of the rainfall interception study based on the volume balance approach. The results are partitioned into such subjects as gross rainfall, throughfall, stemflow and rainfall interception loss, compared between the two research sites.

Chapter Four deals with the derivation of canopy properties from inversion of the Penman equation. This chapter covers the background theory as well as the procedures for measuring the environmental variables and for deriving canopy parameters.

Chapter Five reviews the modelling of rainfall interception loss, including the derivation of model parameters. The physically-based models considered are the Rutter (1971, 1975) and the Gash (1979) analytical models. These models were tested and adapted using data collected in this study. Some notes regarding a suitable model for predicting rainfall interception loss in the tropical rainforest environment are included.

Finally, Chapter Six presents the conclusions and recommendations resulting from this study.

# Chapter 2

## Rainfall interception study based on a volume balance approach

### 2.1. Introduction

The rainfall interception loss from a forested area can be indirectly measured as the difference between the volumes of gross rainfall falling on the vegetation canopy and of net rainfall reaching the ground as throughfall and stemflow. In other words, interception loss in a volume balance approach is an indirect measurement of canopy parameters by subtracting throughfall and stemflow from gross rainfall. Therefore, to calculate rainfall interception loss in a forested area, gross rainfall, throughfall and stemflow have to be measured. This chapter covers the procedure for obtaining those variables, the physical condition of the research sites, and data handling.

To estimate the evaporation of intercepted rainfall one needs to measure gross rainfall, throughfall and stemflow as accurately as possible, as they represent the accuracy of the estimate of rainfall interception loss.

In a forested area, gross rainfall may be measured either above the forest canopy or in a cleared forest area. Measurement of gross rainfall above the forest canopy is known to be prone to error because of the modification of the air flow around the raingauge (Mueller and Kidder, 1972). A similar problem is found when gross rainfall is measured by an elevated raingauge in a cleared forest site. Errors are largest when windspeeds are high and raindrop size is small (Mueller and Kidder, 1972; Lloyd and Marques, 1988). Nevertheles, any such error should be apparent from comparison of the measurements of a raingauge exposed at the top of a tower and other raingauges situated above the ground. For practical reasons, the measurement of gross rainfall at a certain height above the ground surface in a cleared area was preferred, and it was considered that the surrounding trees would act as a buffer. Statistically, the more raingauges used in measuring gross rainfall the more reliable the result is going to be, especially when the study area is large. However, when the study area is small, three raingauges can be considered sufficient, since rainfall is likely to be distributed fairly evenly over the study plot.

The canopy of tropical forest is generally rather uneven and complex in structure with numerous layers, branches and leaves. Natural forest gaps of various sizes are commonly found in a one hectare plot. Through the gaps raindrops can fall directly down to the ground surface without touching any branches or leaves. Since the size and location of these gaps are unevenly distributed, so is the penetration of rain. In addition to this situation, there is an uneven random distribution of intercepted water falling off the branches, twigs and leaves. Thus, the distribution of throughfall is particularly spatially and temporally variable in tropical rainforest. A major concern is then to design a sampling strategy for the measurement of throughfall which ensures that the variation is adequately sampled.

There are several techniques and different types of gauges used to measure throughfall. These vary from a simple combination of funnel and bottle, troughs, standard or automatic raingauge, to plastic-sheet gauge. These throughfall gauges are usually set up in the field in one of two ways; that is, randomly distributed at fixed position or randomly redistributed to moving positions. The fixed sampling technique is intended to investigate interception loss based on storm events (interception modeling) and the relocation sampling technique is intended to investigate the spatial variability of throughfall. The first sampling strategy is commonly used with plastic-sheeting or trough gauges, while the latter is used in most cases with a combination of funnel and bottle gauges or other similar devices, which are easily relocated. In the measurement of throughfall using such gauges, the efficiency of sampling, which is dependent on the number of gauges and their total receiving area, is crucial. Therefore, in order to sample spatial variability effectively, a large number of easy-to-move throughfall gauges are often used.

If the purpose of throughfall measurement is to obtain a mean value, the use of a large number of gauges can sometimes be avoided by increasing gauge size, so as to integrate the spatial variability over a larger area (Reynolds and Leyton, 1963). Rectangular troughs and plastic-sheet gauge are often used for this purposes (Calder *et al.*, 1986; Bruijnzeel and Wiersum, 1987; Teklehaimanot, 1990). The advantages of using a plastic-sheet gauge are its capability to collect all throughfall and stemflow over a wide area, and hence avoid the problems related to calibrating and correcting for splash in other gauges (Calder and Rosier, 1976). The disadvantages of using this gauge, on the other hand, include the difficulties in locating the gauge beneath the forest canopy, particularly in a tropical forest environment with dense and thick understorey, high rate of evaporation from the plastic-sheet, the difficulty in maintaining the gauge in good condition and free from clogging materials, and the risk of losing the throughfall data at the one sampling site, if the plastic-sheet gauge becomes faulty. Rectangular trough gauges can produce relatively good throughfall data if large numbers are used. If the number of gauges is limited, the gauges should be relocated at intervals within given grid points. However, because each trough is large, the relocation technique seems to be impractical in tropical forest. This makes a combination of funnel and bottle gauges and tipping bucket gauges the most practical and reliable instruments to be used for throughfall measurement. Bottle gauges were also found to be superior to troughs in that they are not subject to excessive losses by evaporation or raindrop splash (Scatena, 1990).

Stemflow measurements are commonly carried out using various methods and materials to construct collars to channel the water into containers. For example, flashing (flexible, self-adhesive bitumen-lead building material) was used to make collars for measuring stemflow in interception loss studies conducted by Lloyd and Marques (1988) and Teklehaimanot (1990). Other research workers have used aluminium sheet to construct the collars (Rao, 1987). Differences with respect to crown properties and size lead to variability in stemflow. The trees on which stemflow is measured have sometimes been chosen randomly, but it is more usual to take into account the distribution of tree size and tree characteristics in a given plot in the selection of the trees.

**2.2. Research site**

The rainfall interception loss study was carried out in an unlogged forest area and a logged-over forest area in the tropical rainforest of Central Kalimantan. In general, these two forest sites are very similar in rainfall regime and topographical features since they are located close to each other. Following logging activities, differences in the physical environment between the two sites were greatly changed and are characterised as follows.

**2.2.1. The unlogged forest site**

The experimental site for the unlogged forest was in the central hectare of a nine hectare plot. As in any other tropical rainforest, the undisturbed forest is characterised by structural complexity in the different aspects of layering, which is often not clear (Whitmore, 1985;

Longman and Jenik, 1987). In this experimental site, the topmost forest stratum was about 45 m in height, with some emergent trees of about 55 m. The understorey consisted of shrubs or small trees of 2-10 m. The height of the trees with diameter at breast height (dbh) equal to or greater than 10 cm varied between 8.5 and 55 m. Tree density was 581 trees per hectare (field data, 1993). The leaf area index (i.e. leaf area per unit ground area) in this undisturbed forest was 4.97 (van Gardingen *et al.*, 1995). The forest stand is primarily dominated by Dipterocarpaceae, while other families such as Caesalpinaceae, Euphorbiaceae and Myrtaceae were represented.

### 2.2.2. The logged forest site

The complexity of canopy and stand structure was greatly increased after selective logging of the undisturbed rainforest following the Indonesian selective felling and planting system (TPTI). The forest was then characterised by a mosaic of disturbance resulting in a range of canopy cover from areas of relatively undisturbed forest under closed canopy to areas with partial canopy on the margin of canopy gaps and large canopy gaps or open areas, as mapped in Plate 2.5. In the one hectare plot, the total canopy opening (canopy gap), as a result of forest felling in 1992 and its associated activities, was 3775 $m^2$ (38 % of the plot). Following the 1992 logging, the height of the average topmost stratum of the forest changed from 45 to 20 m (field observation, 1995). The height of the sample trees used in this experiment ranged from 6.8 to 20 m. The number of trees with diameter at breast height (dbh) equal to or more than 10 cm was 278.

The distribution of trees by basal area and diameter classes for the unlogged forest area and logged forest area are given in Fig. 1.2 and 1.3. The basal areas per hectare in the unlogged and logged forest areas were 38.6 and 13.8 $m^2$ per ha, respectively, while the individual basal areas varied from 0.01 to 1.04 $m^2$ per tree in the unlogged plot and from 0.01 to 0.41 $m^2$ per tree in the logged plot.

## 2.3. Experimental design and instrumentation

Most rainfall interception studies have been in the middle of forest areas in plots which were divided by grid/transect lines (Jackson, 1971; Lloyd *et al.*, 1988; Hutjes *et al.*, 1990; Sinun *et al.*, 1992), with a few exceptions in which the plot was circular (e.g. Neal *et al.*, 1993).

The measurements of gross rainfall are made either above the forest canopy or in a clearing site close to the measurements of throughfall and stemflow. The most common gross rainfall measurements are in a cleared forest area as they are the most practical in a natural rainforest situation.

Measurement systems for net rainfall in the past have usually relied upon separate measurements of the throughfall and stemflow components. The types of gauges used have not been standardized and have included bottle gauges (e.g. Lloyd and Marques, 1988; Scatena, 1990), open containers ( e.g. Sinun *et al.*, 1992; Navar and Bryan, 1994), tipping bucket raingauges (e.g. Lloyd *et al.*, 1988), and specially designed troughs for measuring throughfall (e.g. Bruijnzeel and Wiersum, 1987), while metal, rubber and plastic tubes have been used for collecting stemflow from collars. Net rainfall has also been measured using large plastic-sheet gauges in some interception studies (Calder *et al.*, 1986; Rao, 1987; Lloyd *et al.* , 1988; Teklehaimanot *et al.*, 1991).

**The unlogged forest site**

The measurement of gross rainfall, throughfall and stemflow was carried out from 1 November 1993 to 14 April 1994. During this six month period of field measurement, total volumes of gross rainfall, throughfall, and stemflow were recorded in order to calculate rainfall interception loss. Errors in measurements of these variables, especially those caused by high variability of the rainfall regime, were minimised by a regular check on the instruments in use and careful calibration of the tipping bucket gauges used. Both 0.2 mm and 1 $dm^3$ tipping bucket gauges used in this experiment were calibrated following the completion of measurements of gross rainfall, throughfall, and stemflow in the unlogged and logged plots. The calibration values for these tipping bucket gauges were tabulated in Table VII.1 (Appendix VII). The variability of interception loss estimates within the unlogged and logged plots will necessarily be regarded as site specific. Consequently, the sites will be characterised in considerable detail. The following details of experimental design and instrumentation are presented according to the component measurements required for a rainfall interception loss study.

## 2.4. Measurement of gross rainfall

In the unlogged forest, gross rainfall was measured using one 0.2 mm tipping bucket raingauge (ARG100, Campbell Scientific (UK) Ltd., Loughborough, UK) and two simple raingauges, each of which was a combination of an 18.3 cm diameter funnel and a 5 $dm^3$ plastic container. The gross rainfall measurements were made at a cleared site of about 2 ha, located some 300 m from the measurements of throughfall and stemflow. The tipping bucket was erected at a height of 15 m above the ground surface to reduce disturbance caused by its surrounding environment. This tipping bucket raingauge was connected to a data logger (Delta-T Devices Ltd., Cambridge, UK) with a 30 minute scan interval to get continuous readings. The two funnel and plastic container raingauges were installed in a large gap, 1 m above the ground. For data analysis, gross rainfall was partitioned into rainfall events, where one rainfall event is defined as two consecutive rainfall events separated by at least an eight hour interval with no rainfall (Rao, 1987; Lloyd and Marques, 1988). The data were retrieved from the logger using a portable computer (TP 720, IBM Corp., USA) once every two weeks. Rainfall data for the same period of measurement were read manually from the plastic container raingauges using a 1 $dm^3$ graduated measuring cylinder. Plate 2.1 shows the tipping bucket raingauge used in the unlogged plot.

Unreliable data containing spurious counts that resulted from electrical interference and failure in the cable connection were discarded. Because of these problems, the data on gross rainfall selected for analysis were fewer than all the data collected during the period of field measurement. Data for the analysis of rainfall interception loss based on a volume balance approach amounted, therefore, to 55 rainfall events.

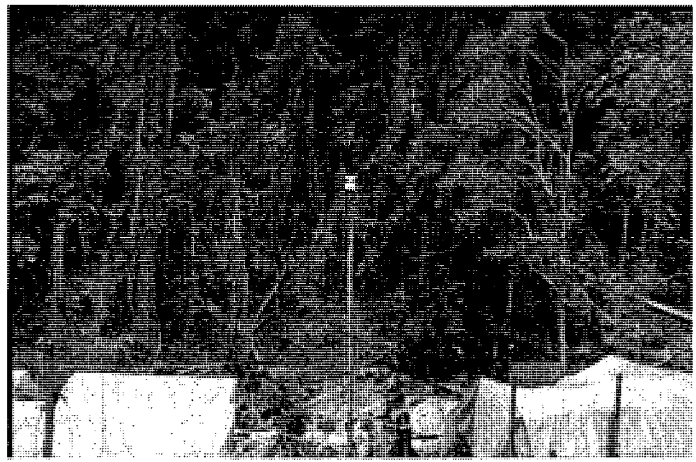


**Plate 2.1** The ARG100 tipping bucket raingauge used in the unlogged plot. The gauge was placed on top of a wooden post 15 m above the ground

## 2.5. Measurement of throughfall

In the unlogged plot, throughfall was measured in a 100 x 40 m plot along five parallel transects of 100 m in length separated by 10 m. Each transect contained 101 sampling positions at 1 m intervals giving a total of 505 sampling positions. The measurements of throughfall obtained at each position in a grid can be viewed as a coarse definition of the canopy structure, since the effect of canopy structure is a unique function of sampling position; thus increasing the number of gauges increases the definition of the canopy structure surface. In this experiment, the canopy structure function is defined at 505 individual points in the 100 x 40 m area following the general rule of probable standard errors in measuring throughfall defined by Lloyd and Marques (1988) and it was twice as large as the number of throughfall gauges suggested by Helvey and Patric (1965) as sufficient.

The gauges for throughfall measurement consisted of 10 tipping bucket raingauges and 40 combinations of 18.3 cm diameter funnel and 5 $dm^3$ plastic container (Plate 2.2). These 50 gauges were equally distributed in the five lines in which, for each line, eight plastic containers were randomly relocated after every rainfall event. Steep angle funnels were used to minimise any splash out from the gauges during rainstorms and, with the funnel of each gauge about 0.5 m above the ground, there was little opportunity for water to splash in after hitting the forest floor. Observation of the height to which soil particles had been deposited on the sides of a standing board showed a maximum splash height of about 0.2 m.

**Plate 2.2** A combination of 18.3 cm diameter funnel and 5 $dm^3$ bottle container for the measurement of throughfall.

Statistical tests used to assess sample size and number of gauges indicate that relocation of throughfall gauges is better than fixed position gauges, and that random relocation of gauges on a transect line is better than over an area, in minimising the standard error of the mean of measured throughfall (Lloyd and Marques, 1988; Scatena, 1990; Sinun *et al.*, 1992). Measurements of throughfall from the plastic containers were made after each rainfall event using a 1 $dm^3$ measuring cylinder, while throughfall measurements by the tipping bucket raingauges were collected from the data logger at two weeks interval using a portable computer. As with the gross rainfall measurements, the measurement of throughfall by the data logger was also in a 30 minute scan interval. This experimental design results in a percentage error in mean throughfall of less than 5 % (Lloyd and Marques, 1988).

## 2.6. Measurement of stemflow

Stemflow measurement for large trees was done using a composite flashing aluminum material (0.5 mm thick building material, Gadjah Tunggal Co., Indonesia) which was fitted at an angle around the stem below the lowest branch and above the highest buttress at a height between 1 to 5 m from the base of the sample tree. For smaller trees, a half-section plastic tube was used as a collar to channel the stemflow water down to a 65 $dm^3$ plastic container or to direct it into a 1 $dm^3$ tipping bucket gauge which was made at the University of Edinburgh. This tipping bucket consists of a pair of buckets of 1 $dm^3$ capacity and an electrical switching mechanism to be connected to a data logger. Teklehaimanot *et al.* (1991) used the same tipping bucket in his study on rainfall interception loss in a plantation of *Picea sitchensis*. Installation of the collar (both for plastic tube or aluminum material) consisted of initially shaving the bark to provide a fairly clean, smooth surface. A considerable length of aluminum collar, 200-250 mm in width, was cut to surround the circumference of the tree. To seal the aluminum collar to the tree trunk, the collar was first nailed to the trunk and then, using a local sealer (mastik-like substance made from the resin of *Shorea* sp.), the collar and the surface of the cleaned bark were sealed together. A tube connector (± 20 mm diameter) was then driven into the middle of the aluminum collar and sealed. With a similar procedure (except that the tube connector was connected at the lower end of the half-section plastic tube), the half-section plastic tube was installed on smaller trees for stemflow measurement, as shown in Plate 2.3.

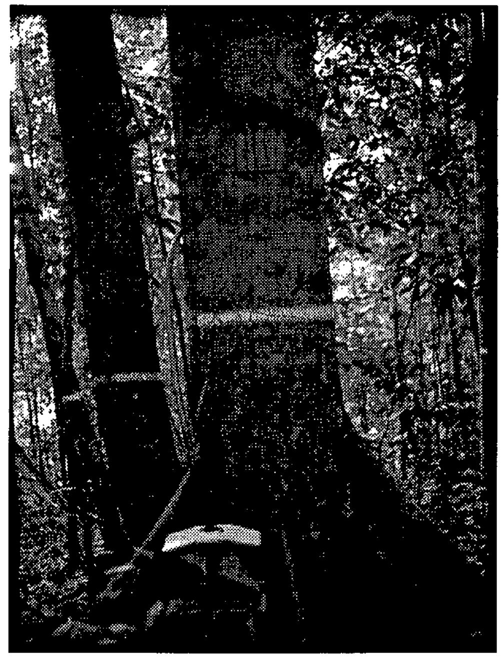


**Plate 2.3** Stemflow measurement using a half-section plastic tube. The 1 $dm^3$ tipping bucket shown at the bottom of the tree was connected to the plastic tube and to the data logger.

Stemflow was measured on 16 trees scattered within the area defined by the transect lines. The diameter of the trees sampled for stemflow measurement ranged from 10 to 115 cm, and the height from 5 to 45 m. The bark texture ranged from very smooth to fibrous, often with lichens or some other epiphytic plant cover. The stemflow volumes of five trees, each representing a diameter class, were measured using 1 $dm^3$ tipping bucket gauges in a 30 minute scan interval as used for measurement of throughfall and gross rainfall. The remaining stemflow volumes were collected in 65 $dm^3$ plastic containers and were measured using a 2 $dm^3$ graduated measuring cylinder after every rainfall event, on the same day that the rest of the data from the manually recorded gauges were collected.

The sixteen trees were classified according to their diameter class, as shown in Table 2.1. The sample trees fell into five diameter classes, four of which have three trees each and the other one has four trees. The table also shows that the basal area of the sample trees ranges from 0.01 to 1.04 $m^2$, with the total basal area per ha of 38.64 $m^2$.

**Table 2.1** Number of trees, their diameter distribution and basal area (*BA*) in the unlogged plot.

| Sample tree No. | Diameter (cm) | Diameter class* | Number of trees/ha | *BA* of tree ($m^2$) | *BA* per unit ground area ($m^2$ $ha^{-1}$) |
|---|---|---|---|---|---|
| 1 | 115 | I | 14 | 1.04 | 13.55 |
| 2 | 111 | I | | 0.97 | |
| 3 | 107 | I | | 0.90 | |
| | | | | 2.90 | |
| 4 | 60 | II | 33 | 0.28 | 8.62 |
| 5 | 58 | II | | 0.26 | |
| 6 | 55 | II | | 0.24 | |
| | | | | 0.79 | |
| 7 | 42 | III | 89 | 0.14 | 9.44 |
| 8 | 37 | III | | 0.11 | |
| 9 | 35 | III | | 0.10 | |
| 10 | 33 | III | | 0.10 | |
| | | | | 0.43 | |
| 11 | 17 | IV | 184 | 0.02 | 3.70 |
| 12 | 16 | IV | | 0.01 | |
| 13 | 15 | IV | | 0.02 | |
| | | | | 0.06 | |
| 14 | 14 | V | 264 | 0.02 | 3.33 |
| 15 | 13 | V | | 0.01 | |
| 16 | 11 | V | | 0.01 | |
| | | | | 0.04 | |
| Total per plot | 16 | | 581 | | 38.64 |

*Diameter class I = > 80 cm; II = 50 – 80 cm; III = 30 – 50 cm; IV = 15 – 30 cm; V = < 15 cm
*BA* = basal area

The stemflow data are given in Table I.1 (Appendix I). To obtain the value of stemflow volume per ha, the stemflow values were scaled based on basal area (Teklehaimanot, 1990). First, the total volume of stemflow for the sample trees in each size class (see Table 2.1) was calculated. The volume of stemflow for each size class was then calculated by multiplying the total volume in the size class by the total basal area in that size class (Table I.2, Appendix I). The total volume of stemflow per hectare was calculated by summing up all volumes of stemflow for size class I to size class V, as shown in Table I.3 (Appendix I). The following is the step by step procedure for scaling up stemflow volume from individual trees to a unit area (hectare).

| Size class | Tree No. | Volume ($m^3$) | *BA* of tree ($m^2$) | *BA* per unit ground area ($m^2\ ha^{-1}$) |
|---|---|---|---|---|
| I | 1 | $v_1$ | $a_1$ | x |
| | 2 | $v_2$ | $a_2$ | |
| | 3 | $v_3$ | $a_3$ | |
| Sub total | | $v_{1,3}$ | $a_{1,3}$ | |

Note: $v_1$ = stemflow volume of tree No.1; $a_1$ = basal area of tree No. 1; x = total basal area of size class I

Volume of stemflow of class I ($V_I$) = $v_{1,3} \times (x/a_{1,3})$ ($m^3$)

Repeat the above procedure for size classes II to V. The overall stemflow volume for all classes per hectare is the following (Table I.2, Appendix I):

Volume of stemflow of class I to V = $V_I + V_{II} + .....+ V_V$ ($m^3\ ha^{-1}$)

The stemflow volume is then converted from cubic metres to millimetres by dividing it by 10, as shown in Table I.3 (Appendix I).

**The logged forest site**

The rainfall interception loss study for logged forest was carried out at PT Kayu Mas International logging area, outside but close to the permanent sample plots of the ECTF-BPK research station. The research site was established in the area one year after the TPTI logging activity had been completed. The measurements of gross rainfall, throughfall and stemflow began on 11 June 1994 and continued to 2 July 1995, during which period there were 107 rainfall events. Because of failure in the data logger on some occasions during the period, only 95 rainfall events were available for the analysis.

The sampling strategy employed here was very similar to that used in the unlogged plot, except for the throughfall measurements, for which the arrangement of throughfall gauges was not based on fixed transect lines. Instead, the gauges were randomly distributed within the three areas of different canopy cover that resulted from the logging activities, i.e. there the three areas of different canopy cover that resulted from the logging activities, i.e. there was a stratified random sampling design. The procedures for measurements of gross rainfall and stemflow were similar to those used in the unlogged plot. Micrometeorological data were obtained from an automatic weather station (CR10, Campbell Scientific (UK) Ltd., Leicester, UK) located in a large canopy gap.

### 2.7. Measurement of gross rainfall

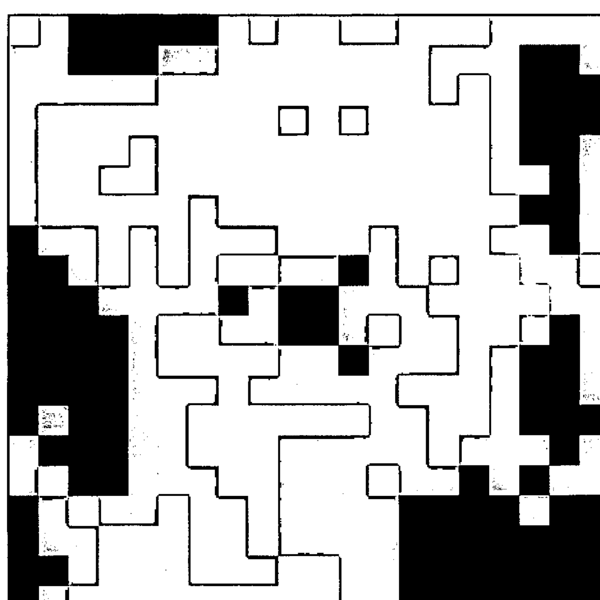
Gross rainfall was measured using three 0.2 mm tipping bucket raingauges: two were sited 15 m above the ground and one was 1 m above the ground, as part of the automatic weather station (Plate 2.4). These raingauges were not located above the forest canopy but they measured gross rainfall effectively because they were situated in the most open logged area, and were protected from strong winds by the surrounding trees. The procedures in recording and retrieving rainfall data from the data logger were the same as for the unlogged plot.

**Plate 2.4** The ARG100 0.2 mm tipping bucket raingauges for gross rainfall measurement in the logged-over area (front left). The automatic weather station for microclimate measurements is in the centre.

## 2.8. Measurement of throughfall

In this experiment, 40 throughfall gauges, consisting of a combination of 18.3 cm diameter funnels and 5 $dm^3$ plastic containers, were allocated to the logged forest site. Another thirteen 0.2 mm tipping bucket raingauges were used for continuous measurement of throughfall. The arrangement of these gauges in the field is outlined below.

In the logged-over area a simple stratified sampling technique was utilised, based on a grid map of canopy cover. This map was produced from a 100 × 100 m plot in which canopy cover was assessed on a three point scale from closed canopy, partial canopy and no canopy (canopy gap), as shown in Plate 2.5. The grid map of the canopy was produced by dividing the 100 × 100 m plot into 10 × 10 m sections. Each section was then further devided into 5 × 5 m grid for which a gridded map of the canopy was drawn using the three point scale.



Post Logging Plot Map

**Plate 2.5** The gridded map of the canopy cover following logging. The map represents 1 hectare of the logged-over area. Closed canopy = black; partial canopy = grey and canopy gap = white.

The distribution of throughfall gauges in the plot was based on the proportion of each crown cover in the one hectare plot. The gauges were allocated with 19 gauges (5 tipping bucket gauges and 14 plastic containers) in canopy gaps, 19 gauges (5 tipping bucket gauges and 14 plastic containers) in areas of partial canopy cover and 17 gauges (5 tipping bucket gauges and 12 plastic containers) under closed canopy. Within these three degrees of canopy cover, the 40 5 $dm^3$ containers were randomly relocated after every rainfall event. This relocation was based on random numbers generated by the computer (Microsoft EXCEL, Microsoft Inc., USA). The 13 tipping bucket raingauges were randomly located in fixed positions and were all connected to two data loggers (Delta-T Devices Ltd., Cambridge, UK).

## 2.9. Measurement of stemflow

Stemflow measurements in the logged plot were made on 20 sample trees in four diameter classes, as shown in Table I.4 (Appendix I). The value of stemflow per hectare was obtained using the same method as in the unlogged forest. Stemflow volumes were calculated on the basis of the basal areas in Table 2.2, which shows that basal area for the sample trees ranges from 0.008 to 0.41 $m^2$ with a total basal area per hectare of 13.83 $m^2$. The calculated stemflow volumes are tabulated in Tables I.5 and I.6 (Appendix I).

**Table 2.2** Number of trees, their diameter distribution and the basal area (*BA*) in the logged plot.

| Sample tree No. | Diameter (cm) | Diameter class* | Number of trees/ha | *BA* of tree ($m^2$) | *BA* per unit ground area ($m^2$ $ha^{-1}$) |
|---|---|---|---|---|---|
| 1 | 72.7 | I | 13 | 0.42 | 4.20 |
| 6 | 53.3 | I | | 0.22 | |
| 9 | 55.5 | I | | 0.24 | |
| | | | | 0.88 | |
| 5 | 38.6 | II | 43 | 0.12 | 4.40 |
| 8 | 32.4 | II | | 0.08 | |
| 10 | 33.8 | II | | 0.09 | |
| 18 | 32.3 | II | | 0.08 | |
| | | | | 0.37 | |
| 2 | 18.9 | III | 108 | 0.03 | 3.91 |
| 4 | 20.6 | III | | 0.03 | |
| 11 | 23.6 | III | | 0.04 | |
| 12 | 29.2 | III | | 0.06 | |
| 13 | 15.3 | III | | 0.02 | |
| 16 | 25.0 | III | | 0.05 | |
| 17 | 17.6 | III | | 0.02 | |
| | | | | 0.26 | |
| 3 | 11.0 | IV | 114 | 0.01 | 1.32 |
| 7 | 12.4 | IV | | 0.01 | |
| 14 | 10.0 | IV | | 0.01 | |
| 15 | 11.9 | IV | | 0.01 | |
| 19 | 12.7 | IV | | 0.01 | |
| 20 | 14.8 | IV | | 0.02 | |
| | | | | 0.07 | |
| Total per plot | 20.0 | | 278 | | 13.83 |

*Diameter class I = > 50 cm; II = 30 – 50 cm; III = 15 – 30 cm; IV = < 15 cm. *BA* = basal area

## 2.10. Data processing

Raw data of gross rainfall, throughfall, stemflow and micrometeorological variables were processed using various computer softwares. Spreadsheet software (Microsoft EXCEL, Microsoft Inc., USA) and statistical package (MINITAB, Minitab Inc., State College, PA, USA) were used to analyse the field data, while graphic software (SIGMA PLOT, Jandel Corp., Erkrath, Germany) was used to produce different types of graphs.

# Chapter 3

## Results and discussion of the rainfall interception study based on a volume balance approach

This chapter covers the results of a study on rainfall interception loss based on a volume balance approach. The study was carried out in the undisturbed rainforest area and in the logged-over area of the same forest type. One of the primary objectives of this study is to compare rainfall interception loss in unlogged forest and logged forest areas. To make the comparison systematic and logical, the results of the study from the unlogged forest will be presented first and later the results from the logged forest. These results will be compared and discussed at the end of this chapter.

## The unlogged forest site

### 3.1. Gross rainfall

The data on gross rainfall are presented in Table II.1 (Appendix II). During the six month period of field measurement, the average total gross rainfall measured from the two plastic container raingauges and the tipping bucket gauge was 1878 ± 15.4 mm. The data were tested by analysis of variance to indicate whether there were any significant differences between the rainfall gauges. Table 3.1 indicates that the differences were not significant.

**Table 3.1** Analysis of variance of the gross rainfall measurements for 45 rainfall events in the unlogged plot. The differences were not significant at $p = 0.05$. The number of rainfall events used in this analysis is fewer than 55 because of the unavailability of rainfall data from the container rain gauge.

| Source of variance | SS | df | MS | $F$ | $p$ | Significance |
|---|---|---|---|---|---|---|
| Between gauges | 30 | 2 | 15 | 0.02 | 0.98 | n.s. |
| Error | 110888 | 132 | 840 | | | |
| Total | 110918 | 134 | | | | |
| Pooled SD = 28.98 | | | | | | |

n.s. = not significant at $p = 0.05$.

## 3.2. Throughfall

The amounts of throughfall associated with the rainfall events are tabulated in Table III.1 (Appendix III). The summary of throughfall variation between gauges can be seen in Table III.2 (Appendix III). The variability of throughfall values between gauges in the study area was relatively constant with time and did not change much with gross rainfall, as shown in Fig. 3.1. Throughfall was measured with 10 0.2 mm tipping bucket gauges and 40 funnel gauges.

The total amount of throughfall during the 55 rainfall events was 1918 mm with standard error of 14.9 mm (Table III.1, Appendix III). This is 87 ± 0.7 % of the gross rainfall of 2199 mm. This value is slightly lower than the throughfall percentage (92 %) given in the regression equation (Fig. 3.2).

### 3.2.1. Throughfall variation between gauges

The pattern of variation in throughfall beneath the canopy in the unlogged plot is not clear; the spatial variability of throughfall did not change as gross rainfall increased (Fig. 3.1). No direct relation exists between measured throughfall and gaps in the canopy.

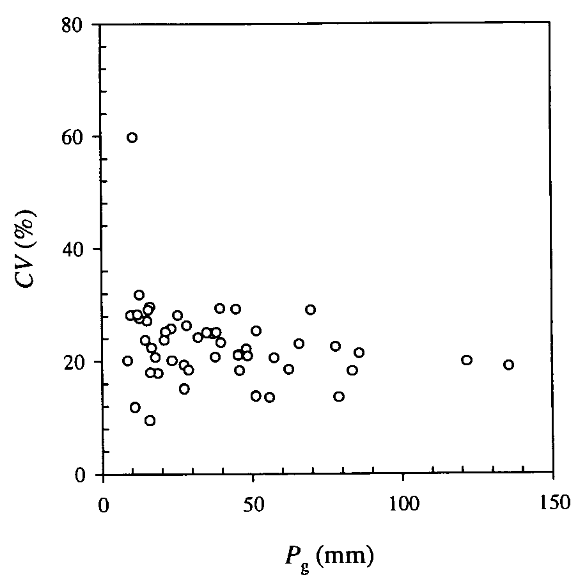



**Figure 3.1** Relationship between throughfall coefficient of variance, *CV*, and gross rainfall, $P_g$, for 55 rainfall events in the unlogged plot. The coefficient of variance does not change much with gross rainfall. There is one extreme outlier that may be caused by measurement error.

The throughfall data in Table III.1 (Appendix III) were tested for significant differences between the throughfall gauges distributed within lines by analysis of variance (ANOVA). This analysis indicates that there were significant differences between gauges, as shown in Table 3.2.

**Table 3.2** Analysis of variance of the throughfall measurements for 55 rainfall events in the unlogged plot. The difference is significant at $p = 0.01$.

| Source of variation | SS | df | MS | *F* | *F*crit- |
|---|---|---|---|---|---|
| Between gauges (within line) | 1425174.00 | 508 | 2805.46 | 33.27 | 1.12 |
| Between lines | 2158.04 | 3 | 719.34 | 8.53 | 2.61 |
| Error | 128527.50 | 1524 | 84.33 | | |
| Total | 1555859.00 | 2035 | | | |

### 3.2.2. Throughfall in relation to gross rainfall

Fig. 3.2 shows the relationship between gross rainfall, $P_g$, and mean throughfall, $T_f$, per rainfall event. The regression between those two variables for 55 rainfall events indicates that throughfall is linearly related to gross rainfall and is significant at $p = 0.01$.

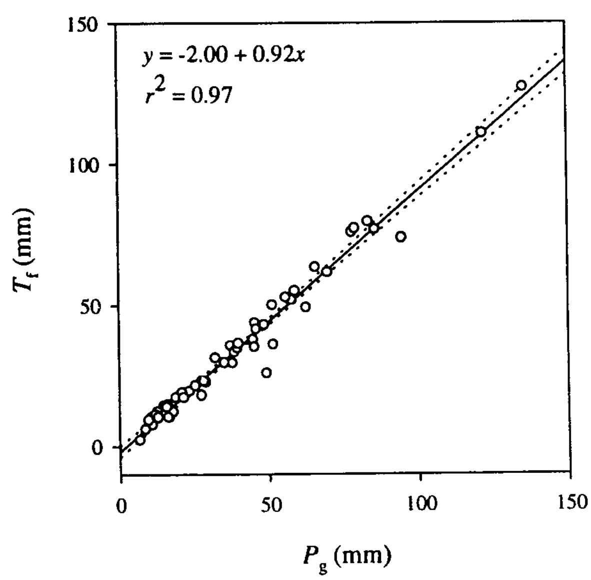



**Figure 3.2** Throughfall, $T_f$, as a function of gross rainfall, $P_g$, measured in the unlogged plot. The data used in this regression analysis were based on 55 rainfall events (mean ± 3.6 mm). The broken lines are 95 % confidence limits for variances.

### 3.3. Stemflow

The total amount of stemflow per hectare was 30 ± 0.13 mm or about 1.4 ± 0.005 % of total gross rainfall (Table I.1, Appendix I). The relationships between stemflow and gross rainfall and between tree basal area and stemflow volume will be explained in the following paragraphs.

Table 3.3 shows the relationship between tree basal area and mean stemflow for 55 rainfall events. Fig. 3.3 indicates that the mean stemflow increases with tree basal area. The standard error, calculated from the analysis of variance of the regression, also increased with tree basal area.

**Table 3.3** Arithmetic mean of stemflow ($m^3$) for each sample tree for 55 rainfall events in the unlogged plot. Standard errors were calculated based on the ANOVA of the regression of mean stemflow on gross rainfall. *BA* is basal area and SE is standard error.

| Sample tree | Diameter class | Diameter (cm) | *BA* of tree ($m^2$) | Mean ± SE | Ave. of the mean ± SE |
|---|---|---|---|---|---|
| 1 | I | 115 | 1.04 | 0.0292 ± 0.0225 | 0.0239 ± 0.0239 |
| 2 | I | 111 | 0.97 | 0.0194 ± 0.0241 | |
| 3 | I | 107 | 0.90 | 0.0320 ± 0.0251 | |
| 4 | II | 60 | 0.28 | 0.0057 ± 0.0065 | 0.0097 ± 0.0081 |
| 5 | II | 58 | 0.26 | 0.0185 ± 0.0128 | |
| 6 | II | 55 | 0.24 | 0.0049 ± 0.0049 | |
| 7 | III | 42 | 0.14 | 0.0304 ± 0.0221 | 0.0180 ± 0.0160 |
| 8 | III | 37 | 0.11 | 0.0160 ± 0.0167 | |
| 9 | III | 35 | 0.10 | 0.0068 ± 0.0069 | |
| 10 | III | 33 | 0.10 | 0.0189 ± 0.0182 | |
| 11 | IV | 17 | 0.02 | 0.0066 ± 0.0057 | 0.0129 ± 0.0129 |
| 12 | IV | 16 | 0.01 | 0.0063 ± 0.0063 | |
| 13 | IV | 15 | 0.02 | 0.0023 ± 0.0027 | |
| 14 | V | 14 | 0.02 | 0.0065 ± 0.0071 | 0.0081 ± 0.0069 |
| 15 | V | 13 | 0.01 | 0.0083 ± 0.0082 | |
| 16 | V | 11 | 0.01 | 0.0095 ± 0.0053 | |

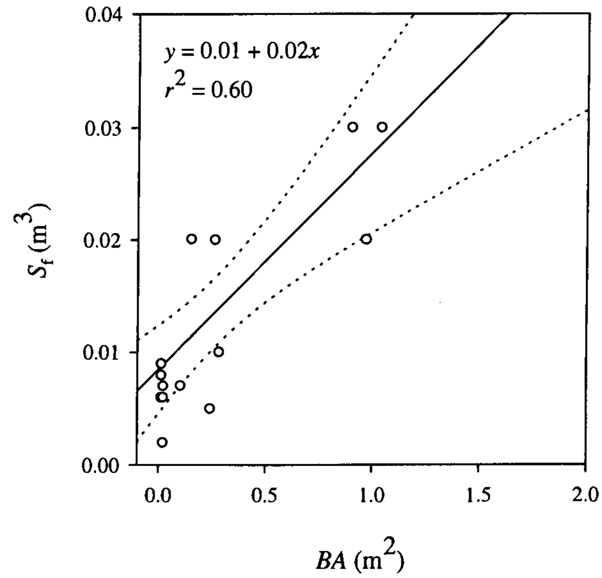



**Figure 3.3** The relationship between basal area of sample trees, *BA*, and the arithmetic mean of stemflow, $S_f$, for each sample tree for 55 rainfall events in the unlogged plot. The broken lines are 95 % confidence limits for variances.

### 3.3.1. Stemflow variation between sample trees (stemflow per tree)

The stemflow data from Table I.1 (Appendix I) were analysed by ANOVA as shown in Table 3.4. The data were transformed into logarithmic form to equalise the variances. This analysis of variance was intended to show if there is a significant different in mean stemflow of the five groups of sample trees in different diameter classes. It was found that there were significant differences between the five diameter classes.

**Table 3.4** Analysis of variance of the stemflow data according to diameter classes for 55 rainfall events in the unlogged plot. The difference is significant at $p = 0.01$.

| Source | df | SS | MS | *F* | *F*crit |
|---|---|---|---|---|---|
| Between size class | 4 | 40.18 | 10.04 | 31.86 | 2.40 |
| Within size class | 270 | 85.13 | 0.31 | | |
| Total | 274 | 125.32 | | | |

Table 3.5 lists the regression equations for the relationship between gross rainfall and stemflow for each of the sample trees. The table shows that there is a positive relationship

between stemflow and gross rainfall. The minimum gross rainfall required to generate stemflow is indicated, but no distinctive pattern was found in these relationships. On average, the production of stemflow requires 9.1 mm of preceding rainfall. However, small amounts of stemflow were produced from small trees after as little as 1.3 mm of gross rainfall (Table 3.5).

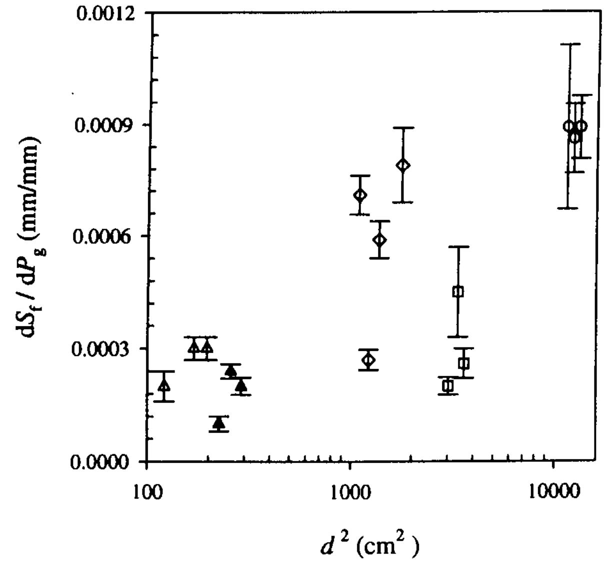
**Table 3.5** Regression equations of stemflow, $S_f$, on gross rainfall, $P_g$, for the different sample trees for 55 rainfall events in the unlogged plot.

| Sample tree | Regression equation | $r^2$ | SE [1] | Rainfall required to generate $S_f$ (mm) | Significance |
|---|---|---|---|---|---|
| 1 | $S_f = -0.0049 + 0.0009\ P_g$ | 0.68 | 0.0225 | > 5.5 (0.0039) [2] | ** |
| 2 | $S_f = -0.0148 + 0.0009\ P_g$ | 0.61 | 0.0241 | > 17.2 (0.0046) | * |
| 3 | $S_f = -0.0035 + 0.0009\ P_g$ | 0.24 | 0.0251 | > 3.9 (0.0106) | n.s. |
| 4 | $S_f = -0.0041 + 0.0003\ P_g$ | 0.45 | 0.0065 | > 15.7 (0.0018) | * |
| 5 | $S_f = -0.0003 + 0.0005\ P_g$ | 0.25 | 0.0128 | > 0.6 (0.0053) | n.s. |
| 6 | $S_f = -0.0026 + 0.0002\ P_g$ | 0.58 | 0.0050 | > 13.0 (0.0011) | * |
| 7 | $S_f = -0.0010 + 0.0008\ P_g$ | 0.52 | 0.0221 | > 1.3 (0.0051) | * |
| 8 | $S_f = -0.0076 + 0.0006\ P_g$ | 0.73 | 0.0167 | > 12.8 (0.0024) | ** |
| 9 | $S_f = -0.0037 + 0.0003\ P_g$ | 0.66 | 0.0069 | > 13.7 (0.0013) | ** |
| 10 | $S_f = -0.0081 + 0.0007\ P_g$ | 0.79 | 0.0182 | > 11.4 (0.0024) | ** |
| 11 | $S_f = -0.0016 + 0.0002\ P_g$ | 0.59 | 0.0057 | > 8.0 (0.0011) | * |
| 12 | $S_f = -0.0032 + 0.0002\ P_g$ | 0.76 | 0.0063 | > 13.3 (0.0009) | ** |
| 13 | $S_f = -0.0017 + 0.0001\ P_g$ | 0.46 | 0.0027 | > 17.0 (0.0007) | ** |
| 14 | $S_f = -0.0042 + 0.0003\ P_g$ | 0.68 | 0.0071 | > 14.0 (0.0012) | ** |
| 15 | $S_f = -0.0035 + 0.0003\ P_g$ | 0.72 | 0.0082 | > 11.7 (0.0013) | ** |
| 16 | $S_f = 0.0020 + 0.0002\ P_g$ | 0.28 | 0.0053 | > 10.0 (0.0020) | n.s. |

Note: [1] standard error from the regression (ANOVA)
[2] error value associated with the y-intercept of the regression
* significant at $p = 0.05$
** significant at $p = 0.01$
n.s. = not significant

The relationship between the diameter of each sample tree and the amount of stemflow for 55 rainfall events is shown in Fig. 3.4. This figure was generated by plotting the diameter squared of the sample trees (from the second column of Table 3.3) against the slope of the regression (from the second column of Table 3.5). The figure indicates a tendency for more stemflow volume to be produced as tree diameter gets larger. The pattern of relationship between tree size and stemflow volume did not change when stemflow volume for all the rainfall events was regressed on the basal area of each sample tree (slope = 0.02, $r^2 = 0.50$).

The regression equations listed in Table 3.5 are also useful to scale up the stemflow volume to any area of forest, once the density of trees of a particular diameter is known.




Note: $dS_f / dP_g$ = change of stemflow resulting from the change in gross rainfall (i.e. the slope of the regression equations in Table 3.5)
○ = size class 1 (diameter > 80 cm)
□ = size class 2 (diameter 50 - 80 cm)
◇ = size class 3 (diameter 30 - 50 cm)
▲ = size class 4 (diameter 15 - 30 cm)
△ = size class 5 (diameter < 15 cm)

**Figure 3.4** The relationship between stemflow volume, $S_f$, and the diameter of each sample tree, *d*, for 55 rainfall events (each points represents the mean ± SE ; $n$ = 55) in the unlogged plot. The changes in stemflow as a result of changes of the sample tree diameter for 55 rainfall events were represented by the changes of slope of the regression of stemflow for each sample tree on gross rainfall.

### 3.3.2. Stemflow in relation to gross rainfall (stemflow per hectare)

Stemflow of the sample trees was scaled up to total stemflow on the plot for each rainfall event as described in Section 2.6. The data of mean stemflow per hectare and its associated gross rainfall per rainfall event (Table I.1, Appendix I) were used to establish the relationship between stemflow and gross rainfall (Fig. 3.5). The regression equation is significant at $p = 0.01$.

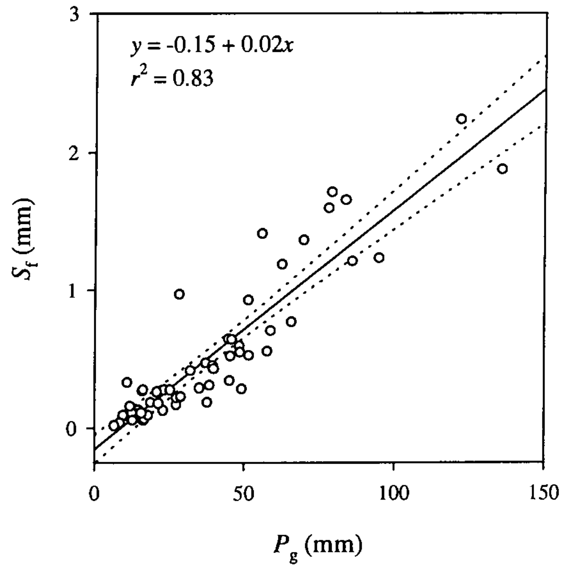



**Figure 3.5** Stemflow on a per hectare basis as a function of gross rainfall measured in the unlogged plot. The regression analysis was based on 55 rainfall events (mean ± 0.48 mm). The broken lines are 95 % confidence limits for variances.

### 3.4. Rainfall interception loss

Rainfall interception loss per rainfall event was obtained by subtracting the sum of throughfall and stemflow values from the corresponding gross rainfall and is given in millimetres and percentage of gross rainfall in Table 3.6. Table 3.6 shows that during the six month period, the amount of rainfall interception loss per rainfall event varied. During that period, the total amount of rainfall interception loss was 251± 21.4 mm or about 11 ± 1.0 % of total gross rainfall.

**Table 3.6** Rainfall interception loss (mm) in the unlogged plot. $P_g$ = gross rainfall, $T_f$ = throughfall, $S_f$ = stemflow, and $I$ = interception loss. Gross rainfall, stemflow and throughfall were all measured in the field. Interception loss was the difference between gross rainfall and net rainfall ($T_f + S_f$).

| Rainfall Event | Date | $P_g$ | $S_f$ | $T_f$ | $I$ | $S_f / P_g$ (%) | $T_f / P_g$ (%) | $I / P_g$ (%) |
|---|---|---|---|---|---|---|---|---|
| 1 | 01/11/93 | 23.09 | 0.13 | 19.38 | 3.58 | 0.55 | 83.94 | 15.51 |
| 2 | 03/11/93 | 16.35 | 0.06 | 13.02 | 3.27 | 0.34 | 79.65 | 20.01 |
| 3 | 06/11/93 | 27.52 | 0.17 | 18.19 | 9.16 | 0.61 | 66.11 | 33.28 |
| 4 | 08/11/93 | 51.40 | 0.93 | 50.20 | 0.28 | 1.81 | 97.66 | 0.54 |
| 5 | 09/11/93 | 62.70 | 1.19 | 49.24 | 12.28 | 1.89 | 78.53 | 19.58 |
| 6 | 12/11/93 | 37.26 | 0.47 | 35.72 | 1.07 | 1.26 | 95.87 | 2.87 |
| 7 | 16/11/93 | 38.56 | 0.31 | 33.44 | 4.81 | 0.81 | 86.72 | 12.48 |
| 8 | 17/11/93 | 44.86 | 0.64 | 37.88 | 6.34 | 1.43 | 84.44 | 14.13 |
| 9 | 18/11/93 | 14.83 | 0.13 | 14.59 | 0.11 | 0.89 | 98.38 | 0.73 |
| 10 | 25/11/93 | 45.30 | 0.34 | 35.21 | 9.75 | 0.76 | 77.72 | 21.52 |
| 11 | 27/11/93 | 86.00 | 1.21 | 76.92 | 7.87 | 1.41 | 89.45 | 9.15 |
| 12 | 28/11/93 | 78.03 | 1.59 | 75.80 | 0.63 | 2.04 | 97.15 | 0.81 |
| 13 | 30/11/93 | 83.68 | 1.65 | 79.61 | 2.42 | 1.98 | 95.13 | 2.89 |
| 14 | 03/12/93 | 48.41 | 0.59 | 43.01 | 4.81 | 1.23 | 88.85 | 9.93 |
| 15 | 06/12/93 | 14.56 | 0.10 | 12.57 | 1.89 | 0.71 | 86.30 | 12.98 |
| 16 | 09/12/93 | 79.09 | 1.72 | 77.15 | 0.22 | 2.17 | 97.55 | 0.28 |
| 17 | 10/12/93 | 11.01 | 0.33 | 10.60 | 0.08 | 2.99 | 96.28 | 0.73 |
| 18 | 12/12/93 | 15.99 | 0.27 | 14.83 | 0.89 | 1.68 | 92.77 | 5.55 |
| 19 | 18/12/93 | 57.73 | 0.55 | 52.05 | 5.13 | 0.96 | 90.16 | 8.88 |
| 20 | 21/12/93 | 49.19 | 0.28 | 25.92 | 22.99 | 0.57 | 52.69 | 46.73 |
| 21 | 23/12/93 | 39.62 | 0.45 | 34.73 | 4.44 | 1.14 | 87.66 | 11.20 |
| 22 | 06/01/94 | 37.83 | 0.18 | 29.54 | 8.10 | 0.49 | 78.09 | 21.42 |
| 23 | 09/01/94 | 27.56 | 0.22 | 23.21 | 4.13 | 0.79 | 84.22 | 14.98 |
| 24 | 12/01/94 | 45.43 | 0.52 | 43.85 | 1.06 | 1.14 | 96.52 | 2.34 |
| 25 | 13/01/94 | 58.93 | 0.70 | 55.10 | 3.13 | 1.20 | 93.50 | 5.30 |
| 26 | 17/01/94 | 48.66 | 0.55 | 43.10 | 5.01 | 1.12 | 88.58 | 10.29 |
| 27 | 19/01/94 | 16.71 | 0.07 | 10.51 | 6.13 | 0.40 | 62.91 | 36.69 |
| 28 | 23/01/94 | 39.89 | 0.43 | 36.51 | 2.95 | 1.08 | 91.52 | 7.40 |
| 29 | 27/01/94 | 32.10 | 0.42 | 31.45 | 0.23 | 1.30 | 97.98 | 0.72 |
| 30 | 05/02/94 | 121.82 | 2.24 | 110.72 | 8.86 | 1.83 | 90.89 | 7.27 |
| 31 | 08/02/94 | 94.86 | 1.23 | 73.79 | 19.84 | 1.30 | 77.78 | 20.92 |
| 32 | 10/02/94 | 10.84 | 0.09 | 7.68 | 3.07 | 0.84 | 70.85 | 28.31 |
| 33 | 11/02/94 | 12.69 | 0.11 | 12.43 | 0.15 | 0.87 | 97.95 | 1.18 |
| 34 | 12/02/94 | 18.81 | 0.18 | 17.35 | 1.28 | 0.98 | 92.22 | 6.80 |
| 35 | 14/02/94 | 28.93 | 0.23 | 22.95 | 5.76 | 0.78 | 79.31 | 19.91 |
| 36 | 15/02/94 | 23.37 | 0.27 | 19.69 | 3.41 | 1.18 | 84.23 | 14.59 |
| 37 | 17/02/94 | 17.97 | 0.09 | 12.35 | 5.53 | 0.52 | 68.71 | 30.77 |
| 38 | 19/02/94 | 9.69 | 0.09 | 9.40 | 0.20 | 0.95 | 97.01 | 2.04 |
| 39 | 05/03/94 | 35.09 | 0.29 | 29.74 | 5.06 | 0.82 | 84.76 | 14.42 |
| 40 | 07/03/94 | 20.93 | 0.26 | 19.32 | 1.35 | 1.25 | 92.33 | 6.43 |
| 41 | 08/03/94 | 45.98 | 0.64 | 41.68 | 3.66 | 1.39 | 90.64 | 7.97 |
| 42 | 21/03/94 | 11.98 | 0.16 | 11.22 | 0.60 | 1.33 | 93.62 | 5.04 |
| 43 | 22/03/94 | 28.29 | 0.97 | 23.33 | 3.99 | 3.43 | 82.45 | 14.12 |
| 44 | 24/03/94 | 55.89 | 1.41 | 52.85 | 1.62 | 2.53 | 94.57 | 2.90 |
| 45 | 25/03/94 | 16.32 | 0.28 | 10.43 | 5.61 | 1.70 | 63.89 | 34.40 |
| 46 | 27/03/94 | 12.83 | 0.06 | 10.28 | 2.49 | 0.45 | 80.16 | 19.39 |
| 47 | 28/03/94 | 25.38 | 0.28 | 21.63 | 3.47 | 1.09 | 85.24 | 13.68 |
| 48 | 29/03/94 | 8.69 | 0.04 | 6.08 | 2.57 | 0.43 | 70.00 | 29.56 |
| 49 | 30/03/94 | 69.90 | 1.37 | 61.70 | 6.84 | 1.95 | 88.27 | 9.78 |
| 50 | 04/04/94 | 51.66 | 0.53 | 36.20 | 14.93 | 1.02 | 70.08 | 28.90 |
| 51 | 06/04/94 | 21.44 | 0.18 | 17.46 | 3.80 | 0.84 | 81.44 | 17.72 |

(Table 3.6 continued)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 52 | 09/04/94 | 6.65 | 0.02 | 2.32 | 4.31 | 0.30 | 34.88 | 64.86 |
| 53 | 10/04/94 | 15.70 | 0.11 | 13.93 | 1.66 | 0.70 | 88.75 | 10.55 |
| 54 | 11/04/94 | 65.81 | 0.77 | 63.40 | 1.64 | 1.17 | 96.34 | 2.50 |
| 55 | 14/04/94 | 135.75 | 1.87 | 126.94 | 6.94 | 1.38 | 93.51 | 5.11 |
| Mean | | 39.99 | 0.54 | 34.88 | 4.57 | | | |
| SD | | 28.43 | 0.54 | 26.54 | 4.58 | | | |
| SE | | 3.83 | 0.48 | 3.58 | 1.70 | | | |
| Total | | 2199.56 | 29.97 | 1918.21 | 251.39 | | | |
| % | | | 1.36 | 87.21 | 11.43 | | | |

In some cases, the amount of net rainfall (throughfall + stemflow) was larger than the gross rainfall. Of the 63 rainfall events recorded in the unlogged plot, 13 % of them had net rainfall larger than gross rainfall. This phenomenon was present in both large and small storms. The relationships of net rainfall and throughfall with gross rainfall can be seen in Fig. 3.6 which shows that incorporating stemflow in net rainfall does not significantly alter the slope of this relationship because stemflow is very small.

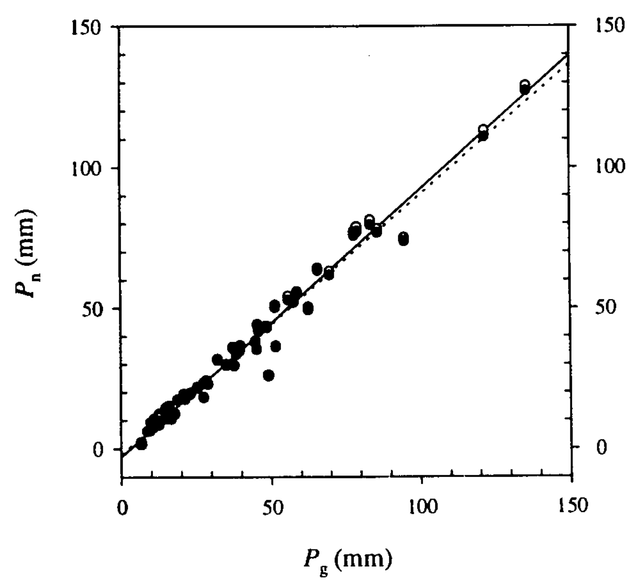



**Figure 3.6** The relationships of net rainfall, $P_n$ ( o ) and throughfall, $T_f$ ( ● ) with gross rainfall, $P_g$, in the unlogged plot. The regression analysis was based on 55 rainfall events. The regression equations are $y = -2.8{+}0.97\ x$, $r^2 = 0.97$ for net rainfall (———) and $y = -2.0{+}0.92\ x$, $r^2 = 0.97$ for throughfall (·········).

Fig. 3.7 shows rainfall interception loss plotted against the corresponding gross rainfall for the 55 rainfall events. There is a considerable scatter in the plots and the regression line does not explain much of the variation. This scatter seems to be attributable to the errors in measurement of two large variables, rainfall and throughfall. However, in general, for moderate falls of up to about 70 mm, there is a trend for rainfall interception loss to increase as gross rainfall gets larger. A similar trend was also found when rainfall interception loss was regressed on rainfall intensity. However, when interception loss as a percentage of gross rainfall is plotted against gross rainfall, there is a marked reduction in interception loss for storms lesser than about 50 mm as shown in Fig. 3.8.

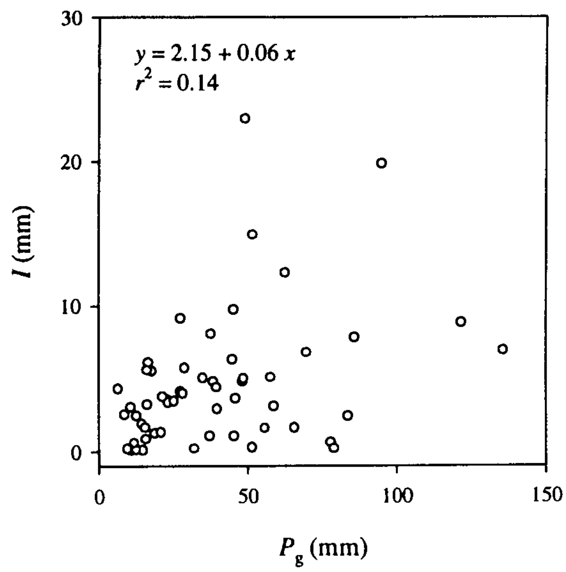



**Figure 3.7** Rainfall interception loss, $I$, as a function of gross rainfall, $P_g$, measured in the unlogged plot based on 55 rainfall events.

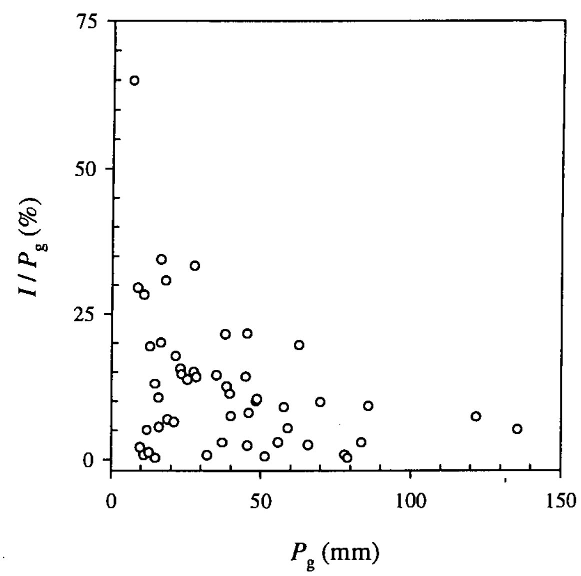



**Figure 3.8** Percentage interception loss, $I/P_g$, in relation to gross rainfall, $P_g$, in the unlogged plot. The data used in this analysis were taken from Table 3.6.

The gross rainfall recorded during the 55 rainfall events was 2199 mm (Table 3.6). Total measured throughfall was 1918 mm with a standard error of 14.9 mm. Throughfall was therefore 87 ± 0.7 % of gross rainfall. The total interception loss from these measurements was 251 mm with a standard error of 21.4 mm which is 11 ± 1.0 % of gross rainfall.

**The logged forest site**

### 3.5. Gross rainfall

The data on gross rainfall are presented in Table 3.12. During one year of field measurement, total gross rainfall measured from the three 0.2 mm tipping bucket raingauges was 3563 ± 96.1 mm .

The data on gross rainfall used for the analysis of variance of the three rainfall gauges are presented in Table II.2 (Appendix II). Analysis of variance showed that there were no significant differences between the raingauges (Table 3.7).

**Table 3.7** Analysis of variance of the gross rainfall measurements for 84 rainfall events. Two rain gauges were sited at 15 m above the ground surface on wooden posts, and one was 1 m above the ground. The difference is not significant at $p = 0.05$.

| Source of variance | SS | df | MS | $F$ | $F$crit |
|---|---|---|---|---|---|
| Between gauges | 625.74 | 2 | 312.87 | 0.35 | 3.03 |
| Within gauges | 224079.80 | 249 | 899.92 | | |
| Total | 224705.50 | 251 | | | |

### 3.6. Throughfall

Throughfall volumes in the one hectare logged plot were divided into two categories: total throughfall volume, and throughfall volume according to the degree of canopy cover. The total throughfall volume during 95 rainfall events was 3334 mm (Table 3.12). This is 93 ± 0.8 % of the total gross rainfall (Table III.3, Appendix III). The total throughfall was obtained by averaging throughfall volume from three different canopy areas. Throughfall measurements were based on thirteen 0.2 mm tipping bucket gauges and 40 18.3 cm funnel gauges.

As mentioned in the Section 2.5.2, throughfall volumes in the logged plot were collected from three different areas, namely a closed canopy area, partial canopy area and canopy gap. The regression relationships between throughfall volumes in each area and the associated gross rainfall show that the throughfall in the closed canopy area was 83 ± 0.9 % of gross rainfall, while throughfall volumes for the partial canopy area and canopy gap were 93 ± 0.9 and 100 ± 0.5 % of incident gross rainfall, respectively (Table III.3, Appendix III).

#### 3.6.1. Throughfall variation between gauges

Throughfall data from Table III.3 (Appendix III) were tested for significant differences between throughfall gauges in the three different canopy cover areas by analysis of variance (ANOVA). This analysis indicates that there were significant differences between gauges as shown in Table 3.8 and that spatial variability of throughfall for different canopy coverage is very large and significant. As in the case of the unlogged plot, the pattern of throughfall variation beneath the canopy in the logged plot is not clear.

**Table 3.8** Analysis of variance of the throughfall measurements at different canopy cover for 102 rainfall events in the logged plot. The difference is significant at $p = 0.01$.

| Source of variation | SS | df | MS | $F$ | $F$crit |
|---|---|---|---|---|---|
| Within canopy cover | 252762.90 | 101 | 2502.60 | 126.5 | 1.31 |
| Between canopy cover | 1551.00 | 2 | 775.50 | 39.9 | 3.04 |
| Error | 3995.90 | 202 | 19.80 | | |
| Total | 258309.90 | 305 | | | |

### 3.6.2. Throughfall in relation to gross rainfall

Fig. 3.9 shows that throughfall in the logged-over area was linearly and positively related to gross rainfall and that throughfall varied with canopy cover. In general, the largest amounts of throughfall were found in the canopy gap, followed by the area with partial canopy cover; the area with closed canopy contributed the smallest throughfall amounts. The functional relationships between throughfall volumes in three different areas and gross rainfall are shown in Fig. 3.9.

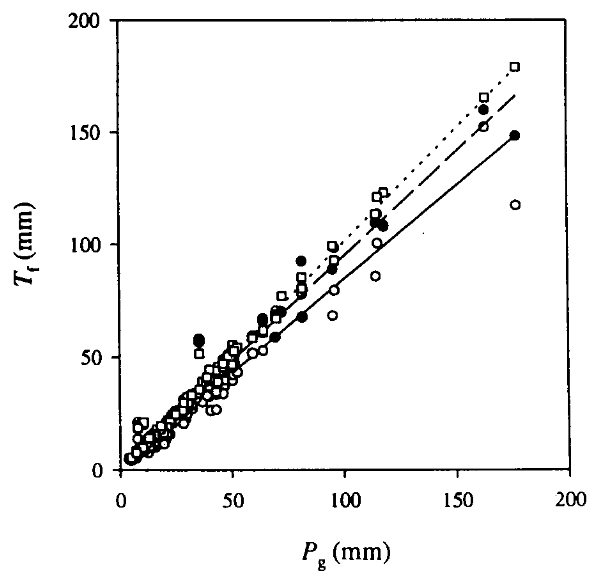



**Figure 3.9** The relationships between throughfall, $T_f$, and gross rainfall, $P_g$, in areas with different canopy cover in the logged plot (□ = canopy gap, ● = partial canopy, ○ = closed canopy). The regression equations for each of these relationships are given below.

The slopes of these relationships in the following regression equations give an indication of the proportion of throughfall to gross rainfall:

*Closed canopy area*:

$$T_f = 1.39 + 0.83\ P_g \qquad (3.1a)$$
$r^2 = 0.95$, significant at $p = 0.01$

*Partial canopy area*:

$$T_f = 1.77 + 0.93\ P_g \qquad (3.1b)$$
$r^2 = 0.98$, significant at $p = 0.01$

*Canopy gap*:

$$T_f = 0.04 + 1.01\ P_g \qquad (3.1c)$$
$r^2 = 0.99$, significant at $p = 0.01$

Fig. 3.10 shows the relationship between throughfall volume and gross rainfall in the plot. The overall throughfall volume was obtained by taking the average of throughfall volume from the three different canopy areas. The fitted regression line indicates that there is a strong linear and positive relationship between those two variables and that approximately 99 % of the variance in the data set has been accounted for by the regression equation.

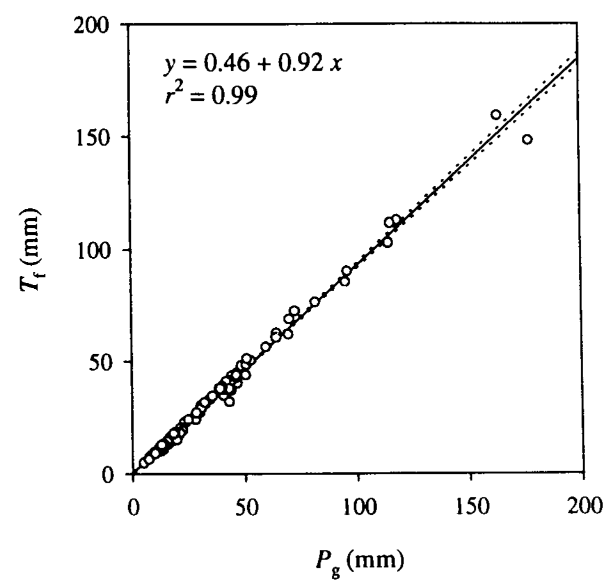



**Figure 3.10** Throughfall as a function of gross rainfall measured in the logged plot. The data used in this regression analysis were based on 95 rainfall events (mean ± 2.9 mm). The broken lines are 95 % confidence limits for variances.

### 3.7. Stemflow

The amount of stemflow per hectare in the logged-over area was 9.6 ± 0.1 mm or 0.3 ± 0.003 % of the gross rainfall (Table 3.12). This amount was about the same as the stemflow volume given in the regression equation (Fig. 3.13) and was much smaller than that in the unlogged plot (1.4 %). Table 3.9 shows the mean stemflow and standard error for each sample tree for 95 rainfall events taken from Table I.4 (Appendix I). Even though there is not a strong relationship between basal area and the corresponding stemflow volume, there is a general increase in stemflow with tree basal area, as shown in Fig. 3.11. Trees with small basal areas generate small stemflow volume, while trees with moderate and large basal areas have more stemflow. There was a similar trend in the relationship between tree basal area and the standard error associated with the stemflow volume.

**Table 3.9** Arithmetic mean of stemflow ($m^3$) for each sample tree for 95 rainfall events in the logged plot. Standard errors.were calculated based on the ANOVA of the regression of mean stemflow on gross rainfall.

| Sample tree | Diameter class | Diameter (cm) | *BA* of tree ($m^2$) | Mean ± SE | Ave. of the mean ± SE |
|---|---|---|---|---|---|
| 1 | I | 72.7 | 0.42 | 0.0063 ± 0.0072 | 0.0052 ± 0.0057 |
| 6 | I | 53.3 | 0.22 | 0.0053 ± 0.0054 | |
| 9 | I | 55.5 | 0.24 | 0.0061 ± 0.0046 | |
| 5 | II | 38.6 | 0.12 | 0.0041 ± 0.0043 | 0.0048 ± 0.0054 |
| 8 | II | 32.4 | 0.08 | 0.0036 ± 0.0040 | |
| 10 | II | 33.8 | 0.09 | 0.0075 ± 0.0085 | |
| 18 | II | 32.3 | 0.08 | 0.0039 ± 0.0047 | |
| 2 | III | 18.9 | 0.03 | 0.0009 ± 0.0009 | 0.0049 ± 0.0043 |
| 4 | III | 20.6 | 0.03 | 0.0027 ± 0.0028 | |
| 11 | III | 23.6 | 0.04 | 0.0013 ± 0.0019 | |
| 12 | III | 29.2 | 0.07 | 0.0021 ± 0.0025 | |
| 13 | III | 15.3 | 0.02 | 0.0046 ± 0.0049 | |
| 16 | III | 25.0 | 0.05 | 0.0023 ± 0.0026 | |
| 17 | III | 17.6 | 0.02 | 0.0207 ± 0.0145 | |
| 3 | IV | 11.0 | 0.01 | 0.0015 ± 0.0010 | 0.0019 ± 0.0017 |
| 7 | IV | 12.4 | 0.01 | 0.0020 ± 0.0015 | |
| 14 | IV | 10.0 | 0.01 | 0.0025 ± 0.0027 | |
| 15 | IV | 11.9 | 0.01 | 0.0015 ± 0.0019 | |
| 19 | IV | 12.7 | 0.02 | 0.0011 ± 0.0013 | |
| 20 | IV | 14.8 | 0.07 | 0.0016 ± 0.0015 | |

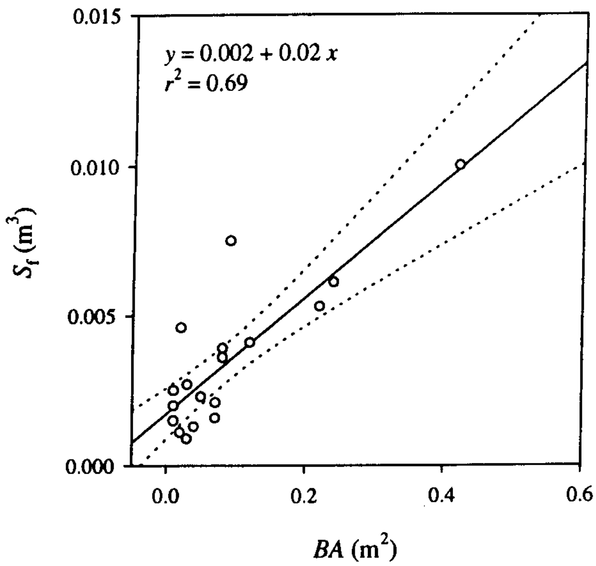



**Figure 3.11** The relationship between basal area, *BA*, and the arithmetic mean of stemflow , $S_f$, for each sample tree for 95 rainfall events in the logged plot. The broken lines are 95 % confidence limits for variances.

### 3.7.1. Stemflow variation amongst the sample trees (stemflow per tree)

The stemflow data from Table I.4 (Appendix I) were analysed by ANOVA for significant differences in mean stemflow amongst the four groups of sample trees in different diameter classes (Table 3.10). It was found that there were significant differences amongst the four diameter classes.

**Table 3.10** Analysis of variance of the stemflow data according to the diameter classes for 99 rainfall events in the logged plot. The difference is significant at $p = 0.01$.

| Source | df | SS | MS | *F* | *F*crit |
|---|---|---|---|---|---|
| Between size class | 3 | 10.31 | 3.44 | 36.45 | 2.63 |
| Within size class | 392 | 36.96 | 0.09 | | |
| Total | 395 | 47.28 | | | |

Table 3.11 lists the regression equations for the relationships between gross rainfall and stemflow for each of the sample trees. There is a positive relationship between stemflow and

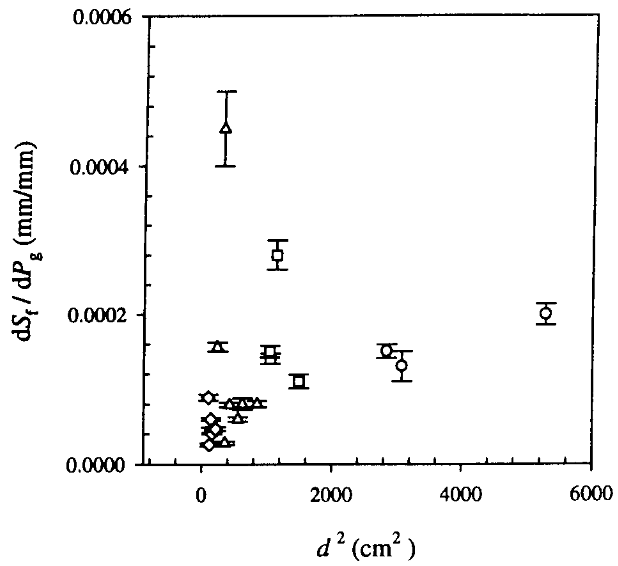
gross rainfall but no distinctive pattern was found in this relationship. On average, the production of stemflow requires 8.9 mm of preceding rainfall but small amounts of stemflow were produced from small trees after as little as 2.0 mm of gross rainfall (Table 3.11). These results are comparable with those found in the unlogged plot.

**Table 3.11** Regression equations for stemflow, $S_f$, on gross rainfall, $P_g$, for the different sample trees for 99 rainfall events in the logged plot.

| Tree No. | Regression equation | $r^2$ | SE [1] | Rainfall needed to generate $S_f$ (mm) | Significance |
|---|---|---|---|---|---|
| 1 | $S_f = -0.0043 + 0.00020\ P_g$ | 0.71 | 0.0072 | > 21.50 | ** |
| 2 | $S_f = -0.0002 + 0.00003\ P_g$ | 0.79 | 0.0009 | > 6.67 | ** |
| 3 | $S_f = -0.0003 + 0.00003\ P_g$ | 0.59 | 0.0010 | > 10.00 | * |
| 4 | $S_f = -0.0006 + 0.00008\ P_g$ | 0.89 | 0.0028 | > 7.50 | ** |
| 5 | $S_f = -0.0011 + 0.00014\ P_g$ | 0.62 | 0.0043 | > 7.86 | * |
| 6 | $S_f = -0.0012 + 0.00020\ P_g$ | 0.70 | 0.0054 | > 6.00 | ** |
| 7 | $S_f = -0.0010 + 0.00005\ P_g$ | 0.61 | 0.0015 | > 2.00 | * |
| 8 | $S_f = -0.0013 + 0.00013\ P_g$ | 0.83 | 0.0040 | > 7.78 | ** |
| 9 | $S_f = -0.0005 + 0.00015\ P_g$ | 0.35 | 0.0046 | > 3.33 | n.s. |
| 10 | $S_f = -0.0027 + 0.00027\ P_g$ | 0.69 | 0.0085 | > 10.00 | * |
| 11 | $S_f = -0.0009 + 0.00006\ P_g$ | 0.85 | 0.0019 | > 15.00 | ** |
| 12 | $S_f = -0.0009 + 0.00008\ P_g$ | 0.86 | 0.0025 | > 11.25 | ** |
| 13 | $S_f = -0.0013 + 0.00016\ P_g$ | 0.90 | 0.0049 | > 8.12 | ** |
| 14 | $S_f = -0.0007 + 0.00008\ P_g$ | 0.86 | 0.0027 | > 8.75 | ** |
| 15 | $S_f = -0.0007 + 0.00006\ P_g$ | 0.90 | 0.0019 | > 11.67 | ** |
| 16 | $S_f = -0.0007 + 0.00008\ P_g$ | 0.58 | 0.0026 | > 8.75 | * |
| 17 | $S_f = -0.0034 + 0.00046\ P_g$ | 0.51 | 0.0145 | > 7.39 | * |
| 18 | $S_f = -0.0018 + 0.00015\ P_g$ | 0.82 | 0.0047 | > 12.00 | ** |
| 19 | $S_f = -0.0004 + 0.00004\ P_g$ | 0.91 | 0.0013 | > 10.00 | ** |
| 20 | $S_f = -0.0002 + 0.00005\ P_g$ | 0.80 | 0.0015 | > 4.00 | ** |

Note: [1] standard error calculated from ANOVA of the regression
* significant at $p = 0.05$
** significant at $p = 0.01$
n.s. = not significant

The relationship between the diameter of each sample tree and the stemflow volume for the 95 rainfall events can be seen in Fig. 3.12. The changes in stemflow volume as a result of changes of the diameter of sample trees are represented by the changes of the slope of the regression of stemflow on gross rainfall for each sample tree (Table 3.11): there is a tendency for more stemflow as tree diameter gets larger. There was one tree (tree No. 17) in the logged-over area that produced unusually large amounts of stemflow. This particular tree, with the largest error bars, is a species of *Nephellium* which has a very smooth bark and straight stem.




Note: $dS_f / dP_g$ = change of stemflow resulting from the change in gross rainfall (i.e. the slope of the regression equations in Table 3.11)
○ = size class 1 (diameter > 50 cm)
□ = size class 2 (diameter 30-50 cm)
△ = size class 3 (diameter 15-30 cm)
◇ = size class 4 (diameter < 15 cm)

**Figure 3.12** The relationship between stemflow volume and the diameter of each sample tree for 95 rainfall events (each points represents the mean ± SE; $n$ = 95). The changes in stemflow volume as a result of changes of the sample tree diameter are represented by the changes of slope of the regression of stemflow for each sample tree on gross rainfall.

### 3.7.2. Stemflow in relation to gross rainfall (stemflow per hectare)

The data of mean stemflow per hectare (Table I.6, Appendix I) and the associated gross rainfall per rainfall event were used to establish the relationship between gross rainfall and stemflow, shown in Fig. 3.13. The slope of the regression equation, significant at $p$ = 0.01, shows that stemflow did not exceed 1.0 % of gross rainfall.

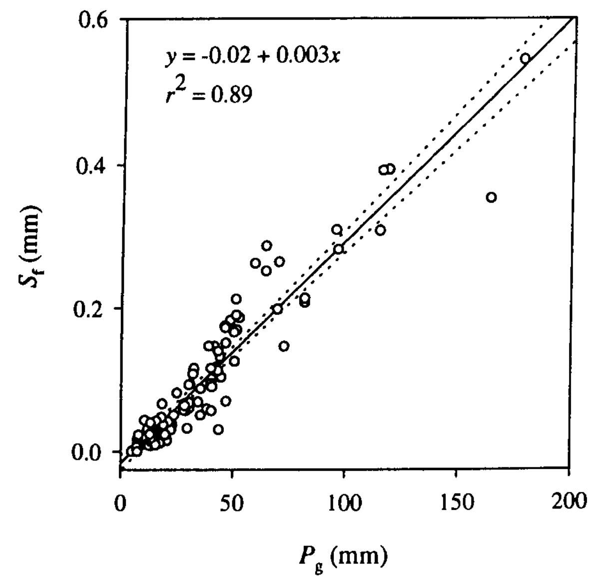



**Figure 3.13** Stemflow, $S_f$, as a function of gross rainfall, $P_g$, measured in the logged plot. The regression analysis was based on 95 rainfall events (mean ± 0.1 mm). The broken lines are 95 % of confidence limits for variances.

### 3.8. Rainfall interception loss

Rainfall interception loss based on 95 rainfall events, was only weakly related to the gross rainfall (Fig. 3.14). The regression equation of the rainfall interception loss on gross rainfall accounts for only 45 % of the variability in the data set. Interception loss and rainfall intensity were also inadequately related. In general, there is a tendency for interception loss to increase with rainfall intensity.

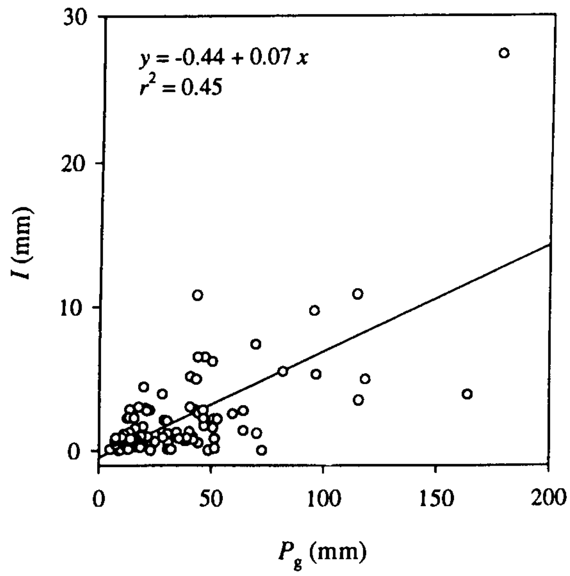



**Figure 3.14** Rainfall interception loss, $I$, as a function of gross rainfall, $P_g$, measured in the logged plot. Data are for all three canopy cover areas for which 95 rainfall events were used for the analysis.

Incorporating stemflow in net rainfall does not significantly alter the slope of the relationship between net and gross rainfall because the stemflow contribution to this relationship is very small (Fig. 3.15).

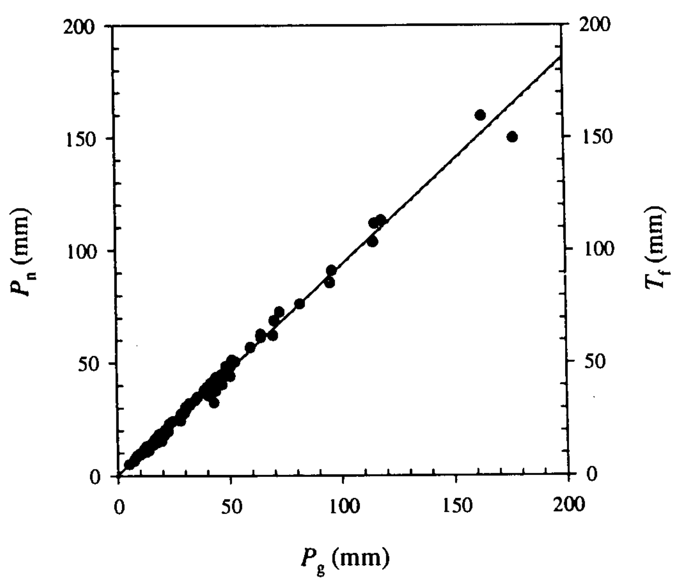



**Figure 3.15** The relationships of net rainfall, $P_n$ ( o ) and throughfall, $T_f$ ( ● ) with gross rainfall, $P_g$, in the logged plot. The regression equations ($n$ = 95) are $y = 0.45+0.92\,x$, $r^2$ = 0.99 for net rainfall (———) and $y = 0.45+0.92\,x$, $r^2$ = 0.99 for throughfall (·········).

Fig. 3.16 shows the functional relationship between interception loss and gross rainfall for the different canopy cover areas. There is considerable scatter and the regression lines do not explain much of the variation. For the closed and partial canopy cover areas, the coefficients of correlation between gross rainfall and interception loss were larger than for the canopy gap. Fig. 3.16 also shows that, in general, interception loss in the closed canopy area was the most affected by gross rainfall. In the canopy gap area, the amounts of gross rainfall was more or less the same as throughfall. When interception loss as a percentage of gross rainfall is plotted against gross rainfall, the interception loss decreases markedly for storms more than about 70 mm, as shown in Fig. 3.17.

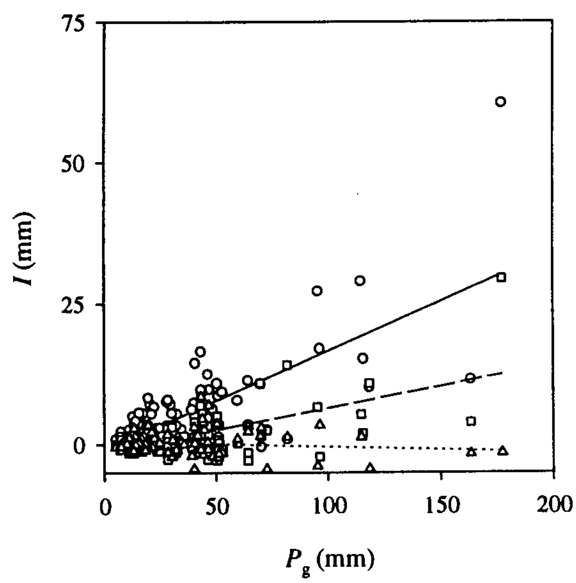



**Figure 3.16** Rainfall interception loss, *I*, for different canopy cover areas as a function of gross rainfall, $P_g$, measured in the logged plot (○ = closed canopy area, □ = partial canopy area, and △ = canopy gap). Data were selected for all 95 events including those of throughfall larger than gross rainfall. Stemflow data were not included in the analysis. The linear regressions of interception loss on gross rainfall are $y = -0.93 + 0.17x$; $r^2 = 0.50$ for the closed canopy area; $y = -1.19 + 0.07x$; $r^2 = 0.35$ for the partial canopy area, and $y = 0.63 - 0.01x$; $r^2 = 0.03$ for the canopy gap.

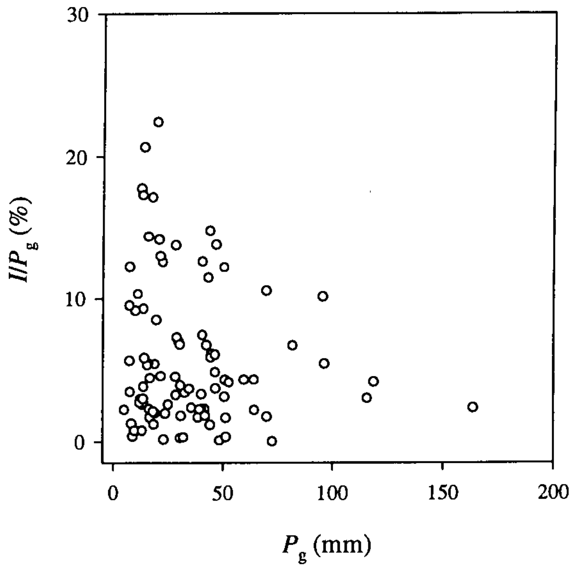



**Figure 3.17** Percentage interception loss, $I/P_g$, against gross rainfall, $P_g$, in the logged plot. The data used in this analysis were taken from Table 3.12.

The gross rainfall recorded during the 95 rainfall events was 3563 mm (Table 3.12). Total measured throughfall was 3334 mm with a standard error of 30.9 mm. Throughfall was therefore 93 ± 0.8 % of gross rainfall (Table III.3, Appendix III). The total rainfall interception loss from these measurements was 219 mm with a standard error of 100.9 mm, which is 6 ± 2.7 % of gross rainfall.

As in the unlogged plot, there were cases where net rainfall was larger than the gross rainfall. Of the 107 rainfall events recorded in the logged plot, 11 % of them (12 rainfall events) had net rainfall greater than gross rainfall. On average, net rainfall was 3 mm larger than the gross rainfall. This phenomenon was also present in both large and small storms. These recorded storms smaller than net rainfall were not included in Table 3.12.

**Table 3.12** Rainfall interception loss (mm) in the logged plot. $P_g$ = gross rainfall, $T_f$ = throughfall, $S_f$ = stemflow, and $I$ = interception loss. Interception loss is the difference between gross rainfall and the net rainfall, $P_n$ (= $T_f$+ $S_f$).

| Rainfall event | Date | $P_g$ | $S_f$ | $T_f$ | $I$ | $S_f / P_g$ (%) | $T_f / P_g$ (%) | $I / P_g$ (%) |
|---|---|---|---|---|---|---|---|---|
| 1 | 25/06/94 | 20.70 | 0.02 | 17.75 | 2.93 | 0.07 | 85.75 | 14.18 |
| 2 | 26/06/94 | 23.67 | 0.05 | 23.15 | 0.47 | 0.21 | 97.80 | 1.98 |
| 3 | 28/06/94 | 19.60 | 0.04 | 17.90 | 1.66 | 0.19 | 91.33 | 8.49 |
| 4 | 30/06/94 | 38.57 | 0.06 | 37.86 | 0.65 | 0.15 | 98.16 | 1.69 |
| 5 | 05/07/94 | 81.77 | 0.21 | 76.10 | 5.46 | 0.25 | 93.07 | 6.68 |
| 6 | 07/07/94 | 23.10 | 0.04 | 23.03 | 0.03 | 0.16 | 99.70 | 0.14 |
| 7 | 18/11/94 | 72.70 | 0.15 | 72.54 | 0.01 | 0.20 | 99.78 | 0.02 |
| 8 | 19/11/94 | 44.20 | 0.10 | 43.58 | 0.52 | 0.23 | 98.60 | 1.17 |
| 9 | 29/11/94 | 163.60 | 0.35 | 159.40 | 3.83 | 0.22 | 97.43 | 2.35 |
| 10 | 01/12/94 | 32.53 | 0.12 | 31.31 | 1.10 | 0.35 | 96.25 | 3.40 |
| 11 | 02/12/94 | 41.53 | 0.15 | 40.43 | 0.95 | 0.35 | 97.36 | 2.29 |
| 12 | 04/12/94 | 30.90 | 0.09 | 30.26 | 0.55 | 0.30 | 97.91 | 1.78 |
| 13 | 08/12/94 | 13.30 | 0.02 | 12.94 | 0.34 | 0.12 | 97.29 | 2.59 |
| 14 | 18/12/94 | 8.27 | 0.01 | 8.16 | 0.10 | 0.15 | 98.61 | 1.24 |
| 15 | 19/12/94 | 7.60 | 0.02 | 7.32 | 0.26 | 0.22 | 96.30 | 3.48 |
| 16 | 20/12/94 | 21.57 | 0.04 | 20.55 | 0.98 | 0.18 | 95.27 | 4.56 |
| 17 | 21/12/94 | 12.23 | 0.02 | 11.85 | 0.36 | 0.14 | 96.89 | 2.96 |
| 18 | 23/12/94 | 18.83 | 0.03 | 17.78 | 1.02 | 0.16 | 94.42 | 5.41 |
| 19 | 25/12/94 | 22.37 | 0.03 | 19.52 | 2.82 | 0.13 | 87.27 | 12.59 |
| 20 | 27/12/94 | 118.47 | 0.39 | 113.17 | 4.90 | 0.33 | 95.53 | 4.14 |
| 21 | 30/12/94 | 95.43 | 0.31 | 85.45 | 9.67 | 0.32 | 89.54 | 10.13 |
| 22 | 05/01/95 | 96.33 | 0.28 | 90.80 | 5.24 | 0.29 | 94.26 | 5.44 |
| 23 | 09/01/95 | 8.83 | 0.01 | 8.79 | 0.03 | 0.10 | 99.52 | 0.38 |
| 24 | 11/01/95 | 40.23 | 0.09 | 39.22 | 0.92 | 0.23 | 97.48 | 2.28 |
| 25 | 16/01/95 | 13.80 | 0.01 | 10.94 | 2.85 | 0.06 | 79.28 | 20.67 |
| 26 | 17/01/95 | 16.33 | 0.04 | 14.74 | 1.55 | 0.23 | 97.48 | 2.28 |
| 27 | 18/01/95 | 9.80 | 0.01 | 9.71 | 0.07 | 0.13 | 99.12 | 0.75 |
| 28 | 19/01/95 | 13.57 | 0.03 | 13.17 | 0.37 | 0.20 | 97.04 | 2.76 |
| 29 | 20/01/95 | 51.40 | 0.17 | 50.39 | 0.84 | 0.33 | 98.04 | 1.64 |
| 30 | 21/01/95 | 16.60 | 0.04 | 16.28 | 0.28 | 0.23 | 98.08 | 1.69 |
| 31 | 23/01/95 | 69.70 | 0.20 | 62.15 | 7.35 | 0.28 | 89.16 | 10.55 |
| 32 | 26/01/95 | 29.77 | 0.03 | 27.66 | 2.07 | 0.11 | 92.93 | 6.97 |
| 33 | 27/01/95 | 42.45 | 0.12 | 39.48 | 2.85 | 0.28 | 93.01 | 6.71 |
| 34 | 28/01/95 | 13.70 | 0.02 | 12.41 | 1.28 | 0.12 | 90.57 | 9.31 |
| 35 | 01/02/95 | 40.60 | 0.09 | 35.40 | 5.11 | 0.22 | 87.18 | 12.60 |
| 36 | 02/02/95 | 12.63 | 0.01 | 10.37 | 2.25 | 0.07 | 82.14 | 17.79 |
| 37 | 04/02/95 | 44.70 | 0.10 | 41.87 | 2.72 | 0.23 | 93.68 | 6.09 |
| 38 | 06/02/95 | 30.53 | 0.06 | 30.39 | 0.08 | 0.20 | 99.55 | 0.25 |
| 39 | 07/02/95 | 28.85 | 0.06 | 26.69 | 2.10 | 0.20 | 92.53 | 7.28 |
| 40 | 09/02/95 | 34.60 | 0.07 | 33.26 | 1.27 | 0.20 | 96.13 | 3.67 |
| 41 | 10/02/95 | 13.30 | 0.01 | 10.98 | 2.30 | 0.11 | 82.58 | 17.31 |
| 42 | 11/02/95 | 5.00 | 0.00 | 4.89 | 0.11 | 0.07 | 97.70 | 2.23 |
| 43 | 14/02/95 | 17.70 | 0.01 | 14.65 | 3.04 | 0.06 | 82.58 | 17.15 |
| 44 | 16/02/95 | 15.75 | 0.01 | 13.47 | 2.27 | 0.06 | 85.55 | 14.39 |
| 45 | 17/02/95 | 50.63 | 0.13 | 48.93 | 1.58 | 0.25 | 96.64 | 3.12 |
| 46 | 18/02/95 | 13.70 | 0.02 | 13.15 | 0.53 | 0.14 | 96.02 | 3.84 |
| 47 | 19/02/95 | 21.25 | 0.04 | 18.44 | 2.76 | 0.19 | 86.80 | 13.01 |
| 48 | 23/02/95 | 46.85 | 0.07 | 40.31 | 6.48 | 0.15 | 86.03 | 13.82 |
| 49 | 24/02/95 | 19.03 | 0.04 | 18.62 | 0.38 | 0.19 | 97.82 | 1.99 |
| 50 | 25/02/95 | 28.25 | 0.07 | 26.91 | 1.28 | 0.23 | 95.25 | 4.52 |

(Table 3.12, continued)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 51 | 26/02/95 | 115.47 | 0.39 | 111.59 | 3.49 | 0.34 | 96.64 | 3.02 |
| 52 | 02/03/95 | 114.70 | 0.31 | 103.55 | 10.84 | 0.27 | 90.28 | 9.45 |
| 53 | 09/03/95 | 40.55 | 0.06 | 37.48 | 3.01 | 0.14 | 92.44 | 7.43 |
| 54 | 13/03/95 | 16.77 | 0.03 | 16.00 | 0.74 | 0.15 | 95.42 | 4.43 |
| 55 | 14/03/95 | 44.30 | 0.13 | 41.57 | 2.60 | 0.30 | 93.84 | 5.87 |
| 56 | 16/03/95 | 41.80 | 0.11 | 40.93 | 0.75 | 0.27 | 97.93 | 1.80 |
| 57 | 20/03/95 | 19.75 | 0.02 | 15.30 | 4.43 | 0.12 | 77.46 | 22.42 |
| 58 | 23/03/95 | 43.90 | 0.03 | 37.38 | 6.49 | 0.07 | 85.14 | 14.79 |
| 59 | 24/03/95 | 50.45 | 0.17 | 44.12 | 6.16 | 0.33 | 87.46 | 12.22 |
| 60 | 27/03/95 | 28.20 | 0.06 | 24.26 | 3.89 | 0.20 | 86.02 | 13.78 |
| 61 | 28/03/95 | 18.23 | 0.05 | 17.80 | 0.38 | 0.26 | 97.63 | 2.11 |
| 62 | 29/03/95 | 11.10 | 0.02 | 9.93 | 1.15 | 0.16 | 89.50 | 10.34 |
| 63 | 01/04/95 | 43.15 | 0.11 | 38.09 | 4.95 | 0.26 | 88.27 | 11.47 |
| 64 | 03/04/95 | 30.27 | 0.09 | 28.12 | 2.05 | 0.31 | 92.91 | 6.78 |
| 65 | 04/04/95 | 7.47 | 0.01 | 7.04 | 0.42 | 0.12 | 94.22 | 5.66 |
| 66 | 06/04/95 | 70.17 | 0.26 | 68.69 | 1.22 | 0.38 | 97.89 | 1.74 |
| 67 | 07/04/95 | 64.27 | 0.29 | 62.58 | 1.41 | 0.45 | 97.36 | 2.19 |
| 68 | 08/04/95 | 12.00 | 0.03 | 11.64 | 0.33 | 0.25 | 97.03 | 2.72 |
| 69 | 10/04/95 | 46.65 | 0.15 | 44.78 | 1.72 | 0.32 | 95.99 | 3.69 |
| 70 | 12/04/95 | 15.90 | 0.04 | 14.99 | 0.87 | 0.27 | 94.27 | 5.46 |
| 71 | 14/04/95 | 10.10 | 0.02 | 9.15 | 0.93 | 0.21 | 90.63 | 9.17 |
| 72 | 15/04/95 | 59.50 | 0.26 | 56.68 | 2.56 | 0.44 | 95.26 | 4.30 |
| 73 | 18/04/95 | 7.25 | 0.01 | 6.55 | 0.69 | 0.09 | 90.39 | 9.52 |
| 74 | 22/04/95 | 40.20 | 0.12 | 38.76 | 1.32 | 0.29 | 96.42 | 3.29 |
| 75 | 23/04/95 | 39.20 | 0.15 | 38.17 | 0.89 | 0.37 | 97.36 | 2.26 |
| 76 | 26/04/95 | 48.55 | 0.18 | 48.33 | 0.03 | 0.38 | 99.55 | 0.07 |
| 77 | 04/05/95 | 43.23 | 0.14 | 32.30 | 10.79 | 0.32 | 74.71 | 24.97 |
| 78 | 05/05/95 | 13.40 | 0.04 | 12.96 | 0.40 | 0.30 | 96.72 | 2.99 |
| 79 | 13/05/95 | 177.53 | 0.54 | 149.63 | 27.36 | 0.31 | 84.28 | 15.41 |
| 80 | 15/05/95 | 50.87 | 0.21 | 48.47 | 2.19 | 0.42 | 95.28 | 4.30 |
| 81 | 19/05/95 | 30.60 | 0.07 | 29.34 | 1.20 | 0.22 | 95.87 | 3.91 |
| 82 | 25/05/95 | 35.67 | 0.09 | 34.73 | 0.85 | 0.24 | 97.38 | 2.38 |
| 83 | 26/05/95 | 18.40 | 0.07 | 18.11 | 0.22 | 0.36 | 98.43 | 1.21 |
| 84 | 31/05/95 | 64.23 | 0.25 | 61.22 | 2.76 | 0.39 | 95.32 | 4.29 |
| 85 | 01/06/95 | 32.13 | 0.11 | 31.93 | 0.10 | 0.34 | 99.37 | 0.30 |
| 86 | 03/06/95 | 15.43 | 0.03 | 14.58 | 0.82 | 0.18 | 94.49 | 5.33 |
| 87 | 06/06/95 | 28.50 | 0.06 | 27.51 | 0.93 | 0.22 | 96.52 | 3.26 |
| 88 | 09/06/95 | 14.10 | 0.03 | 13.25 | 0.82 | 0.19 | 93.97 | 5.84 |
| 89 | 14/06/95 | 46.30 | 0.17 | 43.32 | 2.81 | 0.38 | 93.56 | 6.06 |
| 90 | 19/06/95 | 52.77 | 0.19 | 50.41 | 2.17 | 0.35 | 95.53 | 4.12 |
| 91 | 20/06/95 | 24.90 | 0.08 | 24.18 | 0.64 | 0.33 | 97.11 | 2.57 |
| 92 | 22/06/95 | 46.37 | 0.17 | 43.96 | 2.24 | 0.37 | 94.80 | 4.83 |
| 93 | 24/06/95 | 51.50 | 0.19 | 51.15 | 0.16 | 0.37 | 99.32 | 0.31 |
| 94 | 30/06/95 | 7.37 | 0.00 | 6.46 | 0.90 | 0.07 | 87.70 | 12.24 |
| 95 | 02/07/95 | 13.10 | 0.02 | 12.97 | 0.10 | 0.18 | 99.04 | 0.78 |
| Mean | | 37.51 | 0.10 | 35.10 | 2.31 | | | |
| SD | | 31.48 | 0.10 | 29.18 | 3.45 | | | |
| SE | | 3.25 | 0.01 | 3.01 | 0.36 | | | |
| Total | | 3563.12 | 9.60 | 3334.10 | 219.42 | | | |
| % | | | 0.27 | 93.57 | 6.16 | | | |

### 3.9. Comparison and discussion

The results of the study, running from November 1993 to July 1995, are summarised in Table 3.13.

**Table 3.13** Comparisons of gross rainfall, $P_g$, throughfall, $T_f$, stemflow, $S_f$, and rainfall interception loss, $I$, (mm) in the unlogged and logged plots.

| Variables | Units | Unlogged plot [1] | Logged plot [2] | | | |
|---|---|---|---|---|---|---|
| | | | Overall | Closed canopy | Partial canopy | Canopy gap |
| $P_g$ | mm | 2199 | 3563 | 3563 | 3563 | 3563 |
| $T_f$ | mm | 1918 | 3334 | 3027 | 3403 | 3539 |
| | (%) | **(87.2)** | **(93.5)** | **(85.0)** | **(95.0)** | **(99.0)** |
| $S_f$ | mm | 30 | 9.6 | - | - | - |
| | (%) | **(1.4)** | **(0.3)** | | | |
| $I$ | mm | 251 | 219 | 536 | 160 | 24 |
| | (%) | **(11.4)** | **(6.2)** | **(15.0)** | **(4.5)** | **(0.7)** |

Note: [1] based on a six months of measurement (55 rainfall events).
[2] based on one year of measurement (95 rainfall events).

### 3.9.1. Gross rainfall

The gross rainfall data for the unlogged plot (1878 ± 15.4 mm) were from one 0.2 mm tipping bucket and two funnel and plastic container combination raingauges (Table II.1, Appendix II). The data were tested by ANOVA showed that there were no significant differences between the raingauges. The same result was also found for the logged plot in which three 0.2 mm tipping bucket raingauges were used. These results suggest that the gross rainfall data were sufficiently reliable to be used for the analysis. These were the average of three rainfall measurements on each plot.

### 3.9.2. Throughfall

Table 3.13 shows that the throughfall volume in the undisturbed rainforest was 1918 ± 14.9 mm or 87 ± 0.7 % of the gross rainfall (Table III.1, Appendix III). This value is comparable to findings from the neighbouring area of Ulu Segama rainforest, Sabah, Malaysia, in which, on an annual basis, throughfall was 81 % of the gross rainfall (Sinun *et al.*, 1992). From Amazonian rainforest, Lloyd and Marques (1988) reported that throughfall accounted for 91 % of the gross rainfall. Both these two interception studies were carried out using the same sampling strategy that was employed here. In a secondary lowland tropical rainforest of West Java, Indonesia, a rather smaller throughfall was reported by Calder *et al.* (1986); there annual throughfall volume was about 79 % of the gross rainfall.

Tables 3.2 and 3.8 indicate that there were highly significant differences in mean throughfall between throughfall gauges for both the unlogged and logged plots. These differences suggest that the spatial variability of throughfall in tropical rainforest is statistically significant and, since this study was conducted in a relatively small space (within the same rainfall regime), this throughfall variability may be attributed to the stand structure. This can be observed from Table 3.13, where the percentage of throughfall to gross rainfall increased from 85 % in the closed canopy area to 95 and 99 % in the partial canopy area and canopy gap, respectively. This high variability in throughfall volume was also found in the unlogged forest area. In a single storm (either small or large), the amount of rainfall caught in 40 throughfall gauges varied from 45 to 105 % of the gross rainfall. No attempt was made in this study to relate this throughfall variability either to gap sizes in the canopy or to particular type of tree species. However, it seemed that situations in which water is funneled down the leaves do seem to give high rates of collection, as reported by Sinun *et al.* (1992).

Figure 3.9 shows that throughfall in the logged plot varied with the canopy cover. As would be expected, the largest throughfall was found in the area with no canopy cover, where almost all the gross rainfall (99 %) became throughfall (Table 3.13). This was followed by the areas with partial canopy cover (95 % of gross rainfall). The area with a closed forest canopy contributed the smallest throughfall volume (85 %). This is in line with the hypothesis that larger basal area is correlated with a larger leaf area index, and hence increases the canopy storage capacity. Forest with a larger canopy storage capacity (i.e. with a closed canopy) produces less throughfall volume; logged areas with less canopy cover generate more throughfall volume (Table 3.13). The measured throughfall (85 % of gross rainfall) in the closed canopy area of the logged plot is slightly less than that in the unlogged plot (87 %). But if we compare the calculated throughfalls (83 %, Eq. 3.1a and 92 %, Fig.

3.2, respectively), the difference is much more obvious. These results were unexpected since both these areas are closed canopy forest. If there were to be differences, throughfall in the closed canopy area of the logged plot would be expected to be larger than the throughfall in the unlogged plot, which usually has the denser canopy cover. A possible explanation is that, here in the areas of the logged plot with complete canopy cover the trees were shorter and denser, especially on the steep slopes occurring in almost half of the area. It is likely that a combination of denser canopy cover and higher turbulence effects resulting from logging practices lead to more evaporation of intercepted water in the closed canopy area of the logged plot, and hence, less throughfall volume.

Logging activities reduced the number of trees per hectare from 581 to 278, to about 52 % of the original number, and decreased the basal area per hectare from 38.6 to 13.8 $m^2$ $ha^{-1}$ (38 %). This reduction of basal area per hectare decreased the canopy cover, and hence increased the throughfall from 87 % of the gross rainfall in the unlogged plot to 93 % in the logged plot or by 6 % (Table 3.13). This result is consistent with the estimate that the logging activity reduced the canopy storage capacity from 1.35 to 1.0 mm (Table 4.11).

### 3.9.3. Stemflow

Table 3.13 shows that stemflow in the unlogged plot was 30 ± 0.13 mm, or 1.4 ± 0.005 % of gross rainfall (Table I.1, Appendix I). This is slightly less than was found in similar studies carried out by Lloyd *et al.* (1988) in the Amazonian rainforest and by Sinun *et al.* (1992) in the Ulu Segama rainforest, Sabah, Malaysia. Lloyd reported that the amount of stemflow was 1.8 % of gross rainfall during his one year measurement period, while stemflow measurements conducted by Sinun *et al.* (1992) accounted for 1.9 % of gross rainfall. These amounts are also comparable to findings from other tropical rainforests (Bruijnzeel, 1989). These findings and Figs. 3.6 and 3.15 indicate that stemflow is a small portion of net rainfall.

The stemflow in the unlogged plot was more than twice as much as in the logged plot, where it was only 0.3 % of gross rainfall (Table 3.13). This is not surprising since there were far fewer trees left in the logged plot, even though most of the sample trees for stemflow measurements in the unlogged and logged plots were similar in size and species. These small proportion of stemflow in the logged plot can be attributed largely to the reduction in the number of trees and, in part, to the specific characteristics of stand and canopy structures in the logged-over area as a result of the logging activities. In the logged plot, 85 % of all the sample trees contributed to the top and second layers of the forest canopy, whereas in the unlogged plot, 81 % of all the sample trees occupied the second and third layers of the forest canopy. These canopy and stand structure related factors suggest that more stemflow is usually generated by trees below the canopy top, as also reported by Sinun *et al.*(1992) and Navar (1993).

There is some indication that stemflow volume increased as tree basal area increased, in both the unlogged and logged plots (Figs. 3.3 and 3.11). These relationships also indicate that there is more variation in stemflow between trees with larger diameters than with trees of smaller diameter (Figs. 3.4 and 3.12). This greater variability could be attributed to differences in bark characteristics. Large trees vary in their bark roughness, whereas the smaller trees have relatively homogeneous smoother skin bark. The determining factors in producing more stemflow also seem to be closely related to other properties such as tree diameter, tree stem condition and position, the orientation of crown cover and the position of other trees in the surrounding area. As an example, tree No. 17 (*Nephellium* sp.) in the logged plot contributed 26 % of the total stemflow volume produced by all the sample trees, while the rest of the sample trees each contributed less than 5 %. The crown position of this particular tree is just below the canopy top with a straight and very smooth tree stem. The tree was also surrounded by several smaller, broad-leaved trees with some of their leaves were touching the tree stem. This is in a good agreement with other studies (e.g. Navar, 1993), which suggested that the number of branches and position in the canopy, rather than total projected branch area, controls stemflow. There were also suggestions in the data that bark roughness and position of leaves and twigs in the overall canopy may also explain some of the interspecific stemflow variation.

The length of time required for stemflow to cease after a rainfall event increased with tree diameter in both the unlogged and logged plots. This was probably caused by interspecific variation in the characteristics of the tree stems: large trees, especially those belonging to the Dipterocarpaceae, have thicker and coarser tree bark, as do many of the sample trees in both plots. The thicker and coarser the bark, the more time is required for the stem to dry. After the stem has dried, more time is required for the stem to produce stemflow again, as compared to stems with a smoother and thinner bark surface. Bark roughness, therefore, explains some of the variation in stemflow, as also observed by Navar (1993), even though it is difficult to characterise; furthermore, younger peripheral branches are commonly found to have smoother bark than primary or secondary older branches.

### 3.9.4. Rainfall interception loss

The spatial and temporal variability of rainfall regimes and stand/canopy structures in a tropical rainforest is large and this results in a wide range of rainfall interception loss. In this experiment, rainfall interception loss for the unlogged forest was 11 ± 1.0 % of gross rainfall. This is less than in a similar study carried out in the neighbouring area of Sabah, Northern Borneo, where interception loss was 17 % of gross rainfall (Sinun *et al.*, 1992) and far less than the interception loss of 21 % measured in a region of secondary lowland tropical rainforest in West Java, Indonesia (Calder *et al.*, 1986). In Amazonian rainforest in Brazil, interception loss was 9 % of gross rainfall (Lloyd *et al.*, 1988), whereas in secondary tropical rainforest in Brazil, it varied from 12 to 20 % of gross rainfall (Castro *et al.*, 1983; Franken *et al.* in de Paula Lima, 1990). Bruijnzeel (1990) reported that the annual average interception loss varied from 4.5 to 22 % of gross rainfall in lowland tropical forests. These varied results indicate that, reported estimates of evaporation of intercepted water in the tropical rainforest environment vary considerably, and therefore suggest that more rainfall interception studies are necessary, especially those employing an intensive sampling strategy similar to that used by Lloyd *et al.*(1988), Sinun *et al.*(1992) and in this study.

In some previous studies (e.g. Jackson, 1971; Jackson 1975), there is a general pattern in which large interception losses were generated by small storms. In this study, this pattern was not so distinct, even though there were still tendencies for large interception losses to be generated by storms less than about 50 mm in the unlogged plot and less than 70 mm in the logged plot (Figs. 3.8 and 3.17). This is, mainly, explained by the nature of precipitation in tropical regions, where rainfall intensities are high and often of very short duration, as opposed to the common long duration of small storms found in temperate regions.

Of the 63 rainfall events recorded in the unlogged plot, 13 % had net rainfall larger than gross rainfall. There is no distinctive pattern in the data to indicate that this was related to the amount of gross rainfall; negative interception loss was found for both small and large storms. This phenomenon, which is not common in temperate forest plantation, seems to be a feature of natural tropical rainforest with multi-layer structure. Alternatively, this might be attributed to errors associated with the volume balance approach, in which interception loss is calculated by subtracting two large numbers to give a small number. In this case absolute errors in measuring gross rainfall and throughfall are additive. Another possible explanation is that the so-called "occult" precipitation (i.e. precipitation from sources other than rainfall such as mist, fog, and dew) contributed to the measured throughfall volume. This is commonly found in the headwaters of tropical forest of Central Kalimantan, where this study was carried out, but no attempt to measure "occult" precipitation was made in this study.

As explained in the preceeding sections, rainfall interception loss decreased as the area of canopy was reduced. The reduction in canopy area was mainly caused by reduction in the number of trees following logging practices. The logging affected local water balance through reduction of the amount of rainfall interception from 251 mm, or 11% of gross rainfall, in the unlogged plot to 219 mm (6 %) in the logged plot (Table 3.13). Literature searches indicate that no references to rainfall interception loss in logged-over areas of tropical rainforest are available, so no comparisons can be made with similar studies from other tropical areas. From the temperate region, Teklehaimanot *et al.* (1991) reported that, on average, annual interception loss decreased from 33 to 9 % of gross rainfall as a result of increasing tree spacing from $2 \times 2$ to $8 \times 8$ m in stands of Sitka spruce (*Picea sitchensis*) in southern Scotland.

Logging activities may lead to a situation in which the logged forest has coarser roughness of the surface, a higher windspeed regime and generates more turbulence than in the unlogged plot. A study conducted by Klaassen *et al.* (1996) showed that windspeed tended to increase around forest gaps, resulting in the increase of evaporation rate. These conditions might promote more evaporation of intercepted water in the parts of the logged plot where there is a complete cover, as shown in Table 3.13, where interception loss in the closed canopy area of the logged plot was 15 % of the gross rainfall, compared to only 11 % in the unlogged plot. This difference in evaporation of intercepted water between the two forest areas with complete cover could then be attributed to differences in coupling between leaves and the atmosphere. Leaves in the logged plot may be better coupled to the air around them than leaves in the unlogged plot, and the air within the canopy is better coupled to the atmosphere overhead, so that the rate of interception loss is increased, as suggested by McNaughton and Jarvis (1983) and by Jarvis and McNaughton (1986).

# Chapter 4

## Rainfall interception study based on a mass exchange approach

### 4.1. Introduction

Evaporation from a wetted vegetated surface is governed by a combination of radiant energy supply, atmospheric humidity deficit, atmospheric turbulence and surface conductance (Monteith and Unsworth, 1990). These governing factors provide the basic inputs to all models for vegetation-atmosphere energy exchange and evaporation. A well known model is the Penman-Monteith equation (Monteith, 1965), in which the temperature and humidity at the evaporating surface are eliminated algebraically in favour of net radiation and a surface conductance (boundary layer conductance). In this study, the boundary layer conductance is determined by measuring evaporation rate and its driving meteorological variables over vegetation, and then inverting the Penman-Monteith equation.

The mass exchange approach is a method of measuring rainfall interception loss by determining the rate of evaporation of intercepted water directly as a loss of mass (e.g. Teklehaimanot and Jarvis, 1991), by a direct eddy correlation method (e.g. Jensen and Hummelshoj, 1995) or by calculation, using an energy balance method (Monteith, 1965). This chapter deals with the calculation of rainfall interception loss using an energy balance method. This method basically relies on the calculation of evaporation of intercepted water using the modified Penman equation with directly determined microclimate and canopy structure variables controlling evaporation.

The atmospheric and canopy properties required to calculate evaporation rate of intercepted rainfall using the Penman equation will be elaborated in the following sections.

### 4.2. Determination of environmental variables

#### 4.2.1. Measurement of atmospheric variables

Meteorological observations were required for: 1) derivation of the canopy rainfall interception parameters during rainstorm periods, 2) derivation of the canopy boundary layer conductance, and 3) estimation of the long-term evaporation rate from the forest. To provide an illustration, a single record of typical hourly meteorological data was constructed from an automatic weather station sited above the forest canopy. The one day hourly meteorological automatic weather station sited above the forest canopy. The one day hourly meteorological data are presented for two different situations, a dry day and a rainy day. Daily means of meteorological variables in a cleared forest area are presented for September 1993 - June 1995.

Atmospheric variables required for the calculation of evaporation rate of intercepted rainfall were obtained by direct measurements of air temperature, relative humidity, wind speed and direction, quantum flux, and solar radiation. Other atmospheric properties such as air density, latent heat of vaporisation of water, atmospheric water saturation vapour pressure, and psychrometric constant were derived from the measured meteorological data, using information published in engineering texts. These micrometeorological data were collected at the research sites using three automatic weather stations. One weather station was on top of a 56 m tall tower above the unlogged forest canopy, as shown in Plate 4.1, and two other stations were located in the canopy gap of a logged forest and beneath the forest canopy of the unlogged forest. The weather station located above the forest canopy was equipped with a net radiometer. This allowed the establishment of a regression equation of net radiation against solar radiation and I use this functional relation to estimate net radiation in the canopy gap of the logged plot.

**Plate 4.1** The automatic weather station sited on top of a 56 m tall tower in the unlogged forest.

### 4.2.2. Calculation of canopy parameters

Hemispherical photography is a useful non-destructive/indirect technique to obtain information on plant canopy structure (e.g. Chen *et al.*, 1991). This technique has increasingly been used to estimate leaf area index from the gap fraction of canopies of different vegetation communities (e.g. Norman and Campbell, 1989). In this study, hemispherical photography was used to estimate gap fraction as well as leaf area index above the throughfall gauges. This analytical method assumes that: 1) canopy elements are randomly distributed in space, 2) atmospheric transmissivity is constant and 3) a standard overcast sky exists in the experimental area (Martens *et al.*, 1993; Whitmore *et al.*, 1993).

Hemispherical photos were taken at 1.2 m above the forest floor with a camera (Nikon FM2) and 8 mm fish-eye lens (Nikkor, Nikon Co., Japan) set in a self-levelling mount borne on a tripod. The camera was pointed upwards, and levelled right above each of the tipping bucket raingauges. The top of the image was oriented to the north. Colour slide film (Kodachrome 200 ISO, Kodak Co., USA) was used and the exposure was set using an electronic spot light meter (Spot Meter F, Minolta Co., Japan). The exposure settings were defined with the second and third f-stops below the meter reading.

The following is the procedure followed for image analysis of the digitised hemispherical photos. Negatives were scanned using a slide scanner (Model 35T, Microtek, USA) connected to a PC computer, producing a square image of approximately 1024 × 1024 pixels. These images were analysed using image analysis software (Optimas, Optimas Co., Washington, USA) and a program written by Dr Paul van Gardingen of the University of Edinburgh to determine the gap frequency as a function of zenith angle. A threshold level was set on the computer image differentiating between canopy elements and background sky. The image was then divided into five annuli representing different zenith angle classes and further divided into azimuth angle classes to give a total of 84 sectors, as done by Levy (1995). Within each sector, the proportion of sky to canopy area was calculated and transformed to its natural logarithm, before averaging across sectors in each zenith angle class.

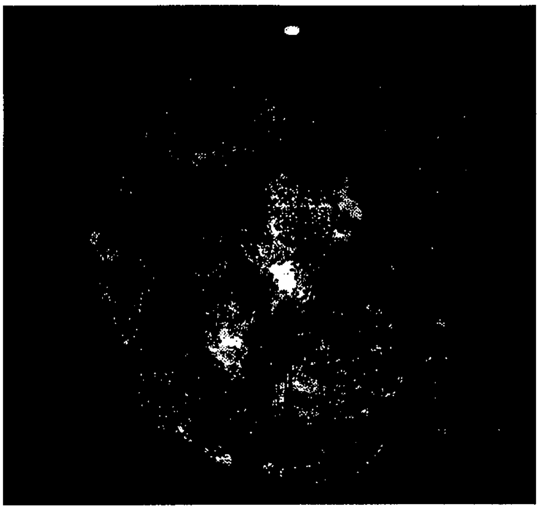
The calculation of leaf area index using the Optimas analysis software is very straightforward. The critical part in calculating gap fraction and leaf area index of a forest canopy is in determining the threshold level on the computer image. However, any inaccuracies in setting the threshold level were reduced by careful comparison between the digitised image on the computer screen and the negative of the same hemispherical photo using a light box. In analysing the images from each throughfall gauge, gap fractions were calculated from the centre of the image with zenith angles between 0 and 20 degrees (20 annuli of equal angle). The calculation of gap fraction for each angle was used to determine which zenith angle between 1 and 20 degrees had the highest correlation with throughfall volume measured at each tipping bucket gauge. Small zenith angles were expected to have the highest correlation, since rainfall in tropical areas is mainly vertical. In this study, a weighting factor was required to take into account the unequal areas of the annuli used in the calculation of gap fraction. The following is a brief description of the procedure used to calculate gap fraction above each tipping bucket gauge.

For each hemispherical photograph, the gap fraction was obtained by image analysis, for the five annuli between 0 and 5 degrees from the zenith. These first five zenith angles were chosen as representative, and hence the free throughfall coefficient, *p*, was based on the assumption that rainfall in this tropical region is mainly vertical. The average gap fraction was calculated as the average of these five values, weighted by annulus area:

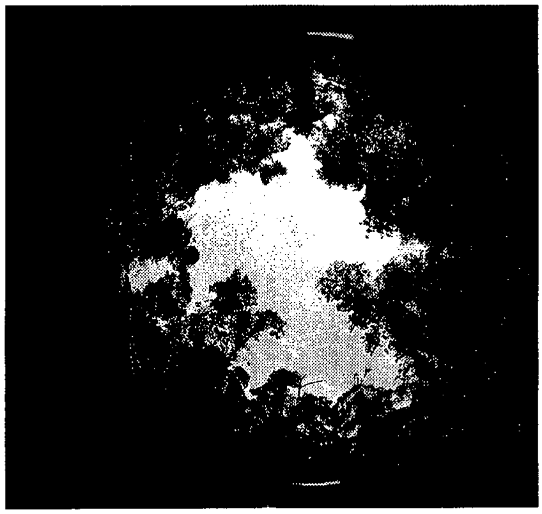
$$\text{Average gap fraction} = \sum_{i}^{n} G_i A_i / A_5$$

where $G_i$ is the *i*th gap fraction above each of the tipping buckets, $A_i$ is the area of the *i*th annulus ($n = 5$) and $A_5$ is the total area of the five annuli. The mean gap fraction over the one hectare unlogged plot was derived from 10 hemispherical photographs and over the logged plot from 15 hemispherical photographs. Plate. 4.2 shows hemispherical photographs of the undisturbed primary rainforest and artificially created canopy gaps resulting from logging practices.

Gap fractions estimated in the unlogged and logged plots were equated to the values of *p* following Dolman (1987) and Hutjes *et al.* (1990).



a) The unlogged plot



b) The logged plot

**Plate 4.2** Hemispherical photographs of: a) the unlogged plot (leaf area index 6.2) and b) the logged plot (leaf area index 1.8). North is at the top.

### 4.2.3. Data handling

Micrometeorological data were recorded at 20 second intervals using three automatic weather stations (CR10, Campbell Scientific (UK) Ltd., Leicester, UK). The data logger in each station was programmed to produce an output of micrometeorological data for 15 minute, 60 minute and 24 hour intervals.

The main components of the automatic weather stations were: a combined unit for air temperature and humidity measurement (HMP35, VAISALA Ltd., Cambridge, UK); a 0.2 mm tipping bucket (ARG100, Campbell Scientific (UK) Ltd., Leicester, UK) for rainfall measurement; a pyranometer sensor (SP1110, Skye Instruments Ltd., Llandrindod Wells, UK) for direct and diffuse solar radiation with wave lengths between 350 and 1100 nm; a quantum sensor (SKP215, Skye Instruments Ltd., Llandrindod Wells, UK) for measuring quantum flux; a cup anemometer and windvane (A100R and W200P, Vector Instruments Ltd., Rhyl, UK) for measuring wind speed and wind direction; and a net radiometer (Q6, Campbell Scientific (UK) Ltd., Leicester, UK) for measuring net radiation. The micrometeorological data were downloaded from the three data loggers into a portable computer using support software (PC208, Campbell Scientific (UK) Ltd., Leicester, UK).

## 4.3. Derivation of canopy and trunk parameters

### 4.3.1. Canopy storage capacity

The canopy storage capacity, *S*, is the amount of water present on the canopy in conditions of zero evaporation, when throughfall has ceased (Gash, 1979). The value of *S* is usually determined by plotting throughfall against gross rainfall following the method of Leyton *et al.* (1967). An outer envelope {line of slope $(1- p_t)$} is then drawn to enclose all the points above the inflection point and the intersection of the boundary line with the y-axis is read as the value of *S*. The $p_t$ is defined as a proportion of rain diverted to stemflow. The inflection point is defined as the point above which throughfall is assumed to be linearly related to gross rainfall. It is usually identified by plotting the residuals of a regression of net on gross rainfall (e.g. Hutjes *et al.*, 1990). The value of *S* at saturation is given by the negative intercept on the throughfall axis. This method seems to be subjective both in recognition of the inflection corresponding to the point of canopy saturation, and in fitting the upper envelope to the scattered points.

The Leyton method is appropriate where spatial variability of throughfall measurements is relatively low, e.g. in dense plantation coniferous forests (Lloyd *et al.*, 1988). However, with the high spatial variability of throughfall in tropical rainforests, this method is likely to be too subjective in the derivation of canopy storage capacity, and therefore a more objective method was needed. A more appropriate method of determining *S* in tropical rainforest is to use separate linear regressions of gross rainfall versus throughfall for individual small storms (Lloyd *et al.*, 1988). The value of *S* is given by the slope of the linear regression for zero throughfall. A correction factor of 0.05, to account for evaporation during rainfall, should also be used. In this study, the values of *S* were calculated by both the Leyton and the Lloyd methods.

The values of *S* were calculated for rainfall events larger than the defined inflection point, which in many rainfall interception studies has been determined to be above 1.5 mm (Rutter *et al.*, 1971; Gash and Morton, 1978; Navar and Bryan, 1994). Linear regressions of gross rainfall versus throughfall from individual storms were calculated for each of seven fixed position tipping bucket raingauges in the unlogged plot and for 13 raingauges in the logged plot.

Data required for the indirect derivation of *S* for the unlogged and logged plots were obtained from the throughfall data collected from both plastic container (40) and tipping bucket gauges. The data were grouped into a series of discrete storms separated by dry periods of at least eight hours, a long enough period for the canopy to dry completely. This gave a total of 55 rainfall events in the unlogged plot during the period of 1 November 1993 to 14 April 1994 (Table 3.6) and 95 rainfall events in the logged plot from 25 June 1994 to 2 July 1995 (Table 3.12).

### 4.3.2. Free throughfall coefficient

The free throughfall coefficient, $p$, is an estimate of that fraction of gross rainfall which arrives directly at the soil surface without striking any of the vegetation surfaces. In this project, two methods were used to estimate the values of $p$: 1) using the conventional technique of taking the slope of the regression of net rainfall on gross rainfall and 2) using the hemispherical photography technique previously described.

The value of $p$ is usually estimated from the slope of the regression between net rainfall and gross rainfall for storms smaller than 1.5 mm (Gash and Morton, 1978; Rao, 1987; Hutjes *et al.*, 1990) and is defined as the inflection point from where the boundary line was drawn. As the inflection point defines the minimum quantity of rain required to saturate the canopy, free throughfall can, therefore, be accurately determined only under rainfall conditions such that saturation of the canopy has not occurred. In the absence of rainfall events smaller than 1.5 mm, the value of $p$ was obtained by taking the ratio of net rainfall to gross rainfall for the smallest rainfall event (e.g. Navar and Bryan, 1994). The value of $p$ was also estimated from the analysis of the fish-eye photographs taken above each tipping bucket raingauge in both the unlogged and logged plots, using image analysis software as elaborated in Section 4.2.2.

### 4.3.3. Tree trunk parameters

A similar method to that used for estimating canopy structure was adopted for evaluating the trunk storage capacity, $S_t$, and the proportion of rainfall which is diverted onto the trunks, $p_t$. For a similar reason to that given for choosing a method for estimating canopy storage capacity, $S$, the conventional method used to estimate $S_t$, (Loustau *et al.*,1992), was not employed here and separate linear regressions of stemflow versus gross rainfall for each sample tree (Lloyd *et al.*, 1988) were calculated instead. For the estimation of the $S_t$ and $p_t$, gross rainfall and stemflow data were extracted for all rainfall events larger than 1.5 mm (which represents canopy saturation) i.e. that 55 rainfall events in the unlogged plot and 95 in the logged plot.

The intercept of the regressions of stemflow versus individual gross rainfall are estimates of $S_t$ and the gradients are estimates of $p_t$, i.e.

$$S_f = a + b\,P_g \tag{4.1}$$

where $S_f$ and $P_g$ are stemflow and gross rainfall, respectively; the slope, $b$, gives $p_t$; and the intercept, $a$, gives $S_t$. Average values were obtained by averaging the values of $a$ and $b$ for the individual regressions.

#### 4.3.4. Canopy drainage parameters

The rate of drainage from the canopy, $D$ (mm min$^{-1}$), when the depth of water on the canopy, $C$, was larger than canopy storage capacity, $S$, was determined using the following statistical function:

$$D = \mathrm{MAX}[0, \{(1 - p - p_t)\,P_g - E_c - S + C\}]. \tag{4.2}$$

Where the calculated values of $S$ are based on the methods suggested by Lloyd *et al.* (1988) and Leyton *et al.* (1967) (Section 4.3.1), $p$ is the value of the free throughfall coefficient, $p_t$ is the proportion of rainwater diverted onto the trunks, $C$ is the depth of water on the canopy, and $E_c$ is the evaporation rate from the wet canopy. The value of $D$ was assumed to be zero when $C \leq S$. When the amount of rainfall diverted to the canopy during a period $\Delta t$ was greater than $S$, $D$ was taken as equal to the amount of water on the canopy $[(1 - p - p_t)\,P_g - E_c]\,\Delta t$, which exceeds the remaining water storage capacity $(S - C_{j-1})$ (Whitehead and Kelliher, 1991).

Based on the Rutter model, it was assumed that $E_c$ from the partially wet canopy was equal to the rate which would be obtained if all the canopy surfaces were wet, multiplied by the fraction of the canopy that was wet during the preceding period (i.e. $C_{j-1}/S$). Individual leaves or fractions of the tree canopy were assumed to be either completely wet or completely dry (Monteith, 1977).

#### 4.3.5. Evaporation rate

The energy available for evaporation, $\lambda E_c$, is given by (Monteith and Unsworth, 1990):

$$\lambda E_c = R_n - G - H \tag{4.3}$$

where $R_n$ is the net radiation, $H$ is the sensible heat flux in the air and $G$ is the flux of heat to or from the soil. Following Monteith (1965):

$$H = \rho\, c_p\, (T_o - T) / r_a \qquad (4.4)$$

where $T_o$ is the temperature at the surface, $T$ is the temperature at the reference height and $r_a$ is the bulk aerodynamic transfer resistance between the surface and the reference height. Monteith (1965) proposed that the bulk stomatal resistance of an entire vegetation canopy could be represented by a single resistance, $r_s$, so that:

$$\lambda\, E_c = [(\rho\, c_p) / \gamma][e_s(T_o) - e_a] / [r_a + r_s] \qquad (4.5)$$

where $e_s(T_o)$ is the saturated vapour pressure inside the stomata at the leaf temperature ($T_o$) and $e_a$ is the vapour pressure at the reference height.

Eq. 4.5 requires a knowledge of the leaf or evaporating surface temperature ($T_o$), which in many cases is not available. To overcome this, Monteith (1965) used a linear approximation for the rate of change of saturated vapour pressure with temperature over a small temperature interval, $s$, as:

$$s = [e_s(T_o) - e_s(T)] / [T_o - T]. \qquad (4.6)$$

Substituting Eqs. 4.4 and 4.5 into Eq. 4.3 and eliminating $T_o$ and $e_s(T_o)$ by use of Eq. 4.6 gives $\lambda E_c$ as (Monteith and Unsworth, 1990):

$$\lambda E_c = [sA + \rho\, c_p\, \{e_s(T_a) - e_a\} / r_a] / [s + \gamma\, \{1 + (r_s / r_a)\}]. \qquad (4.7)$$

where $s$ = rate of change of the latent heat content with respect to sensible heat content of air,

$A$ = available energy ($R_n - G \cong R_n$),

$E_c$ = evaporation rate from the wet canopy,

$\rho$ = density of air,

$c_p$ = specific heat of air at constant pressure,

$e_s(T_a)$ = saturation vapour pressure of water vapour at air temperature,

$e_a$ = ambient vapour pressure,

$\lambda$ = latent heat of vaporization of water,

$\gamma$ = psychrometric constant,

$r_a$ = aerodynamic transfer resistance, and

$r_s$ = stomatal resistance.

Eq. 4.7 is generally referred to as the Penman-Monteith equation, and is the basic formula used in simple, one-dimensional single source descriptions of the evaporation process. When the source of water vapour is a completely wet vegetation canopy, the term $r_s$ in Eq. 4.7 is zero and the equation reduces to the Penman equation (Monteith and Unsworth, 1990) so that the resultant expression gives the rate of evaporation of intercepted water, $\lambda I$, as follows (Rutter *et al.*, 1975; Jarvis, 1985):

$$\lambda I = [s R_n + \rho c_p \{e_s(T_a) - e_a\} g_a] / [(s + \gamma)]. \quad (4.8)$$

It is clear from Eq. 4.8 that the rate of evaporation increases linearly with the absorption of net radiation, $R_n$, with the value of saturation deficit, $D_{vp}$ $\{= e_s(T_a) - e_a\}$, and with the boundary layer conductance, $g_a$ $(= 1/r_a)$.

When the canopy is unsaturated and partially wet ($C<S$), the actual evaporation rate, $E_c$, will be reduced below the potential evaporation rate, $E_{pot}$, by the ratio of the water on the canopy, $C$, to the canopy storage capacity, $S$, as shown in the following equation (Rutter *et al.*, 1975; Teklehaimanot and Jarvis, 1991):

$$E_c = E_{pot} \times C / S. \quad (4.9)$$

Another method of calculating evaporation rate, which will be compared with the Penman equation, is the Priestley-Taylor equation, which defines evaporation from large areas of vegetation when well supplied with water. The Priestley-Taylor equation was proposed as a large scale relationship (Priestley and Taylor, 1972) based on physical arguments about processes in the turbulent planetary boundary layer, up to thousands of square kilometers, and their arguments concerned the relative sizes of advective and radiant energy inputs to land areas of that size. Priestley and Taylor simplified the Penman equation by redefining potential evaporation on that scale as a function solely of available energy:

$$\lambda E_c = \alpha A\ [s / (s + \gamma)] \tag{4.10}$$

where $\alpha$ is the empirical Priestley-Taylor coefficient ($\alpha = \lambda E_c / \lambda E_{pot}$).

### 4.3.6. Boundary layer conductance

The boundary layer conductance, $g_a$, is the most important feature of a forest canopy determining the evaporation of intercepted water (Rutter *et al.*, 1975; Jarvis and Stewart, 1979; Teklehaimanot and Jarvis, 1991). In previous studies the boundary layer conductance of a forest canopy has been determined using measurements of weight losses from wetted paper leaf replicas (e.g. Roberts *et al.*, 1990) or using a heated leaf replica technique (Brenner and Jarvis, 1995). Teklehaimanot and Jarvis (1991) estimated the value of $g_a$ from the modified Penman equation with the evaporation rate derived directly from the change in weight of the artificially wetted tree. In this study, $g_a$ was calculated from rearrangement of the Penman equation (Rutter *et al.*, 1971; Campbell, 1977) given the micrometeorological and evaporation data at the research sites.

$$g_a = [I\,\lambda\,(s + \gamma) - s\,R_n\,] / [\rho\,c_p\,D_{vp}] \tag{4.11}$$

The rainfall interception loss was calculated from gross rainfall, throughfall and stemflow data collected in the field (Section 3.1). The values of $s$, $\gamma$, $\rho$, $\lambda$ and $e_s(T_a)$ were estimated from measured air temperature, and the ambient vapour pressure, $e_a$, and vapour pressure deficit, $D_{vp}$, were calculated from measured relative humidity.

To obtain air temperature, $T_a$, relative humidity, $R_h$, and windspeed, $u$, above the forest canopy in the unlogged plot, the following regression equations based on meteorological data collected from above and beneath the forest canopy at the tower site were used.

$$T_{ac} = -\,0.1 + 1.0\,T_{bc} \tag{4.12}$$

where $T_{ac}$ and $T_{bc}$ are air temperatures above and below the forest canopy at the tower site ($r^2 = 0.93$, n = 258).

$$R_{h\,ac} = -1.9 + 0.9\,R_{h\,bc} \quad (4.13)$$

where $R_{h\,ac}$ and $R_{h\,bc}$ are air humidities above and below the forest canopy at the tower site, respectively ($r^2 = 0.92$, n = 258).

$$u_{ac} = 0.4 + 3.8\,u_{bc} \quad (4.14)$$

where $u_{ac}$ and $u_{bc}$ are windspeeds above and below the forest canopy at the tower site, respectively ($r^2 = 0.93$, n = 258).

Net radiation was measured at the top of the tower above unlogged forest and the following regression ($r^2 = 0.92$, n = 233) estimated with quantum flux density measured in a large cleared forest near the unlogged plot, so that $R_n$ could be estimated elsewhere and on other days.

$$R_n = 2.9 + 0.43\,Q \quad (4.15)$$

$R_n$ used for calculating the value of $g_a$ in the logged plot was obtained directly from the automatic weather station sited at the top of the tower in the unlogged forest.

## 4.4. Results

### The unlogged forest site

### 4.4.1. Meteorological observations

Long-term daily means of temperature, $T_a$, vapour pressure deficit, $D_{vp}$, windspeed, $u$, net radiation, $R_n$, and gross precipitation, $P_g$, obtained from the automatic weather station located in a large canopy gap are shown in Fig. 4.1.

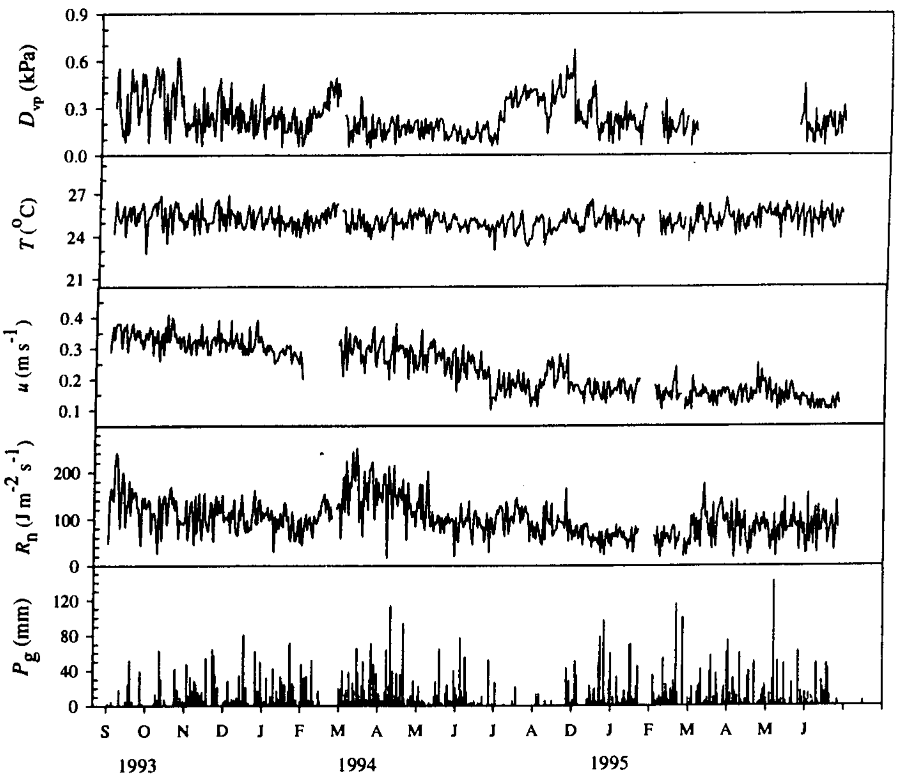



**Figure 4.1** Daily means of temperature ($T$), vapour pressure deficit ($D_{vp}$), windspeed ($u$), net radiation ($R_n$) and gross rainfall ($P_g$) recorded by the automatic weather station in a large canopy gap for September 1993 - June 1995. Net radiation in the canopy gap was calculated from quantum flux density data measured at the canopy gap using Eq. 4.15. The gaps in the curves indicate missing values.

Figs. 4.2 and 4.3 show the typical daily course of micrometeorological variables above the forest canopy during a rainy day and a dry day. The pattern of relationship amongst these variables was similar on these two consecutive days, except for $D_{vp}$. There is a consistent relationship between $T_a$ and $R_h$ for both days; $R_h$ increased as $T_a$ decreased. At night, atmospheric humidity often reached saturation. Decreasing $T_a$ (or increasing $R_h$) as a result of increasing cloud in the sky prior to the rain on the rainy day reduced $D_{vp}$ considerably (Fig. 4.2). $D_{vp}$ declined markedly following rainstorms, when the canopy was wet. The highest daily value of $D_{vp}$ declined from about 1.60 kPa on the dry day to 0.65 kPa on the rainy day. Fig. 4.4 shows the variation of measured $D_{vp}$ at three different locations, i.e. on top of the tower above the forest canopy, 2 m above the ground in a canopy gap of the logged plot, and 2 m above the ground beneath the forest canopy of the unlogged plot. During and immediately after rain, $D_{vp}$ in these three locations fell rapidly, but the canopy dried rapidly in the topmost canopy layer and this increased $D_{vp}$ above the forest canopy within a few hours. $D_{vp}$ beneath the forest canopy showed the smallest variation because of high humidity as a result of less turbulent mixing. Fig. 4.4 also shows a rather surprising feature when $D_{vp}$ in a canopy gap of the logged plot was slightly higher than $D_{vp}$ above the forest canopy. This may be attributed to the relatively high temperature above the ground in the canopy gap during the day; this was caused partly by reflected radiation from the soil surface in addition to the incident direct/diffuse solar radiation.

No distinctive patterns or relationship between $u$ and time were found in either dry or rainy conditions: $u$ varied from time to time but was not correlated with time of day, occurrence of $T_a$, $D_{vp}$ or $R_n$.

Storms that occurred at mid-day on 13 November 1994 affected both incident solar irradiance, $S_b$, and $R_n$. During this rainy day, the highest $S_b$ were 950 J $m^{-2}$ $s^{-1}$ and $R_n$ reached a peak of 480 J $m^{-2}$ $s^{-1}$. On the following dry day, the highest $S_b$ and $R_n$ reached 1400 and 800 J $m^{-2}$ $s^{-1}$, respectively. Thus, storms reduced both $S_b$ and $R_n$ and delayed the peak time of radiation by about two hours.

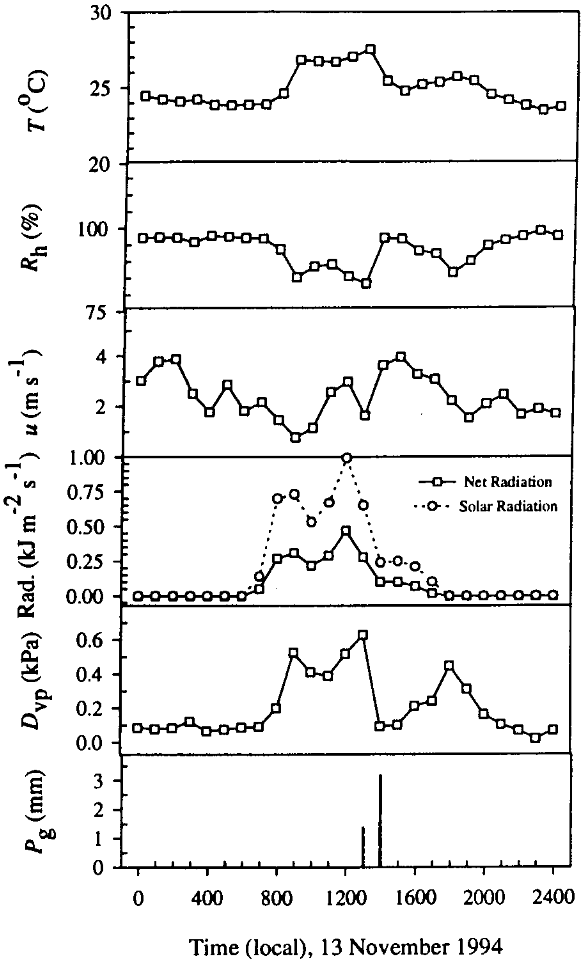



**Figure 4.2** Typical daily course of micrometeorological variables above the forest canopy during a rainy day. The micrometeorological variables consist of temperature, $T$; relative humidity, $R_h$; windspeed, $u$; net and solar radiation; vapour pressure deficit, $D_{vp}$; and gross precipitation, $P_g$.

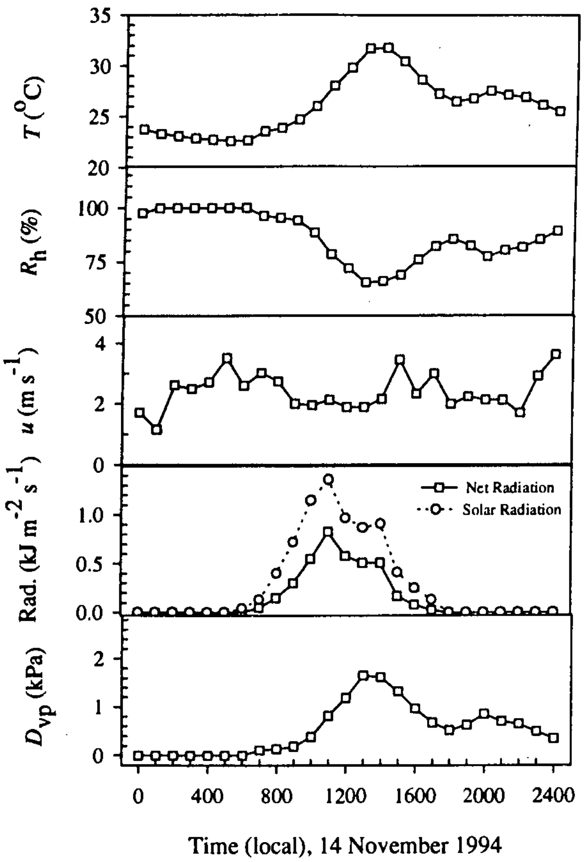



**Figure 4.3** Typical daily course of micrometeorological variables above the forest canopy during a dry day. The micrometeorological variables consist of temperature, $T$; relative humidity, $R_h$; windspeed, $u$; net and solar radiation; and vapour pressure deficit, $D_{vp}$.

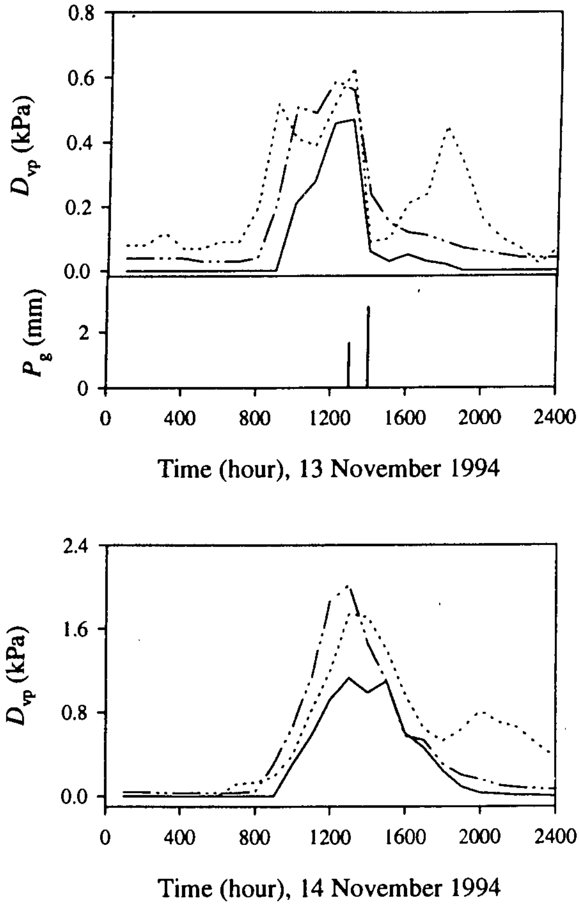



**Figure 4.4** The variation in measured vapour pressure deficit, $D_{vp}$, at three different locations: above the forest canopy (·········); 2 m above the ground in the canopy gap (—··—); and 2 m above the ground beneath the forest canopy (———), for two consecutive days with and without rainstorms.

### 4.4.2. Canopy storage capacity

The linear regressions of gross rainfall versus throughfall for individual storms greater than 1.5 mm for each tipping bucket gauge produced a mean value of $S$ equal to 1.34 mm, with a range from 0.68 to 2.32 mm, as shown in Table 4.1. These regressions gave a mean slope of 0.81 mm and a mean intercept of 0.91 mm. Using throughfall values from all the plastic containers used in this study, the mean value of $S$ was found to be 1.35 mm (Table 4.1). The value of $S$ based on the Leyton method (Leyton *et al.*, 1967) was also 1.35 mm (Fig. 4.5b).

**Table 4.1** Linear regressions of throughfall, $T_f$, against gross rainfall, $P_g$, from individual storms for each of the seven fixed position tipping bucket gauges and 40 plastic container gauges used in the unlogged plot. These analyses were based on 33 rainfall events. $S$ = canopy storage capacity.

| Tipping bucket No. | Equation | $r^2$ | Standard Error Intercept | Standard Error Slope | $S$ value |
|---|---|---|---|---|---|
| 3 | $T_f$ = -1.24 + 0.85 $P_g$ | 0.66 | 2.76 | 0.10 | 1.45 |
| 7 | $T_f$ = -0.84 + 0.63 $P_g$ | 0.62 | 2.41 | 0.10 | 1.33 |
| 11 | $T_f$ = -1.65 + 0.86 $P_g$ | 0.58 | 2.70 | 0.14 | 1.92 |
| 16 | $T_f$ = -0.81 + 0.94 $P_g$ | 0.89 | 1.25 | 0.05 | 2.32 |
| 26 | $T_f$ = -0.77 + 0.88 $P_g$ | 0.90 | 1.39 | 0.05 | 0.87 |
| 31 | $T_f$ = -0.89 + 0.70 $P_g$ | 0.57 | 2.88 | 0.11 | 1.27 |
| 45 | $T_f$ = -0.35 + 0.73 $P_g$ | 0.55 | 1.32 | 0.14 | 0.68 |
| 49 | $T_f$ = -0.79 + 0.89 $P_g$ | 0.77 | 2.54 | 0.09 | 0.89 |
| Average | $T_f$ = -0.91 + 0.81 $P_g$ | | | | 1.34 |
| All (40) plastic gauges: | | | | | |
| | $T_f$ = -1.21 + 0.89 $P_g$ | 0.95 | | | 1.35 |

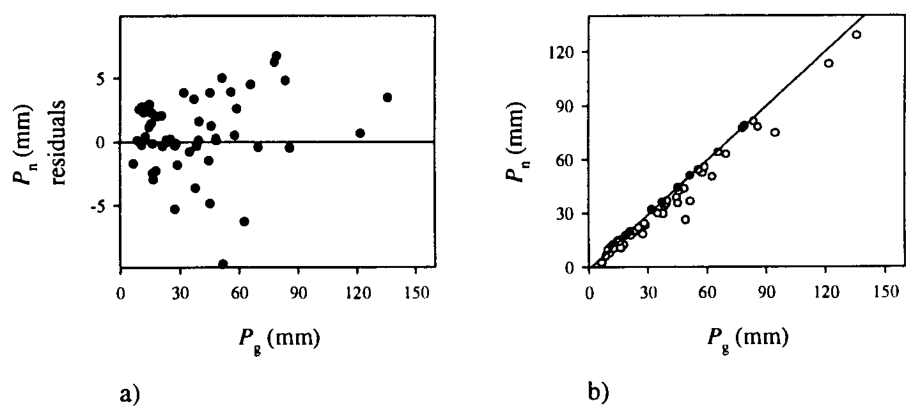



**Figure 4.5** The Leyton *et al.* (1967) analysis of daily rainfall totals in the unlogged plot. a). The residuals of the regression of net rainfall ($P_n$) on gross rainfall ($P_g$) are plotted ($P_n = -2.00 + 0.92\ P_g$ ; $r^2 = 0.97$, $n = 55$). This facilitates the identification of the inflection point, which is located around 10 mm. b). The regression through the upper envelope to the right of this point ($P_n = -1.35 + 1.01\ P_g$ ; $r^2 = 0.99$, $n = 8$). The canopy storage capacity, $S$, was taken to be 1.35 mm.

### 4.4.3. Free throughfall coefficient

Since storms smaller than 1.5 mm, which represents the condition of unsaturation (Rutter *et al.*, 1971; Rao, 1987), were not available in the data set, the method used by Navar and Bryan (1994) was adopted to calculate the free throughfall coefficient, $p$. The value of $p$ estimated from the smallest rainfall event, for which gross and net rainfall were 6.65 and

1.34 mm (Table 3.6), respectively, was 0.20. The value of $p$ was also calculated from the gap fraction in the centre of the image for 20 annuli of equal zenith angles between 0 and 20 degrees, resulting in 0.04 for the first five zenith angles (Table 4.2). Table 4.2 shows the leaf area index (LAI) and the gap fraction above each tipping bucket used in the unlogged plot.

**Table 4.2** Leaf area index (LAI) and gap fraction above each tipping bucket gauge used in the unlogged plot

| Tipping bucket No. | LAI Angle 60° | Gap fraction Angle 5° |
|---|---|---|
| 3 | 4.93 | 0.0085 |
| 7 | 4.51 | 0.0018 |
| 11 | 5.13 | 0.0020 |
| 16 | 4.14 | 0.0104 |
| 26 | 6.54 | 0.0183 |
| 31 | 6.95 | 0.0128 |
| 37 | 5.82 | 0.3051 |
| 45 | 5.28 | 0.0043 |
| 49 | 5.83 | 0.0000 |
| AWS | 5.41 | 0.0294 |
| Average | 5.48 | 0.04 |

### 4.4.4. Tree trunk parameters

Linear regressions of stemflow versus gross rainfall were calculated for each of the 16 trees for 55 rainfall events, as shown in Table 4.3. The intercepts of these regressions are estimates of the trunk capacities, $S_t$, and the gradients are estimates of the proportion of rainfall diverted to the trunks, $p_t$. By averaging both the set of intercepts and the set of gradients, the mean stemflow equation is given by:

$$S_f = 0.01\ (\pm\ 0.001) +\ 0.001\ (\pm\ 0.0001)\ P_g \tag{4.16}$$

where $S_f$ and $P_g$ are stemflow and gross rainfall, respectively. Values of 0.01 for $S_t$ and 0.001 mm for $p_t$ were therefore used as stemflow parameters for modelling interception loss.

**Table 4.3** Linear regressions of gross rainfall, $P_g$, against stemflow, $S_f$, for each sample tree used in the unlogged plot. The analysis was based on 55 rainfall events.

| Tree No. | Equation | $r^2$ | Standard Error Intercept | Standard Error Slope |
|---|---|---|---|---|
| 1 | $S_f = -0.0074 + 0.0009\ P_g$ | 0.79 | 0.0020 | 0.00007 |
| 2 | $S_f = -0.0148 + 0.0008\ P_g$ | 0.61 | 0.0040 | 0.00009 |
| 3 | $S_f = -0.0144 + 0.0011\ P_g$ | 0.42 | 0.0080 | 0.00020 |
| 4 | $S_f = -0.0040 + 0.0020\ P_g$ | 0.49 | 0.0010 | 0.00002 |
| 5 | $S_f = -0.0070 + 0.0006\ P_g$ | 0.49 | 0.0040 | 0.00010 |
| 6 | $S_f = -0.0030 + 0.0002\ P_g$ | 0.70 | 0.0010 | 0.00002 |
| 7 | $S_f = -0.0070 + 0.0009\ P_g$ | 0.65 | 0.0040 | 0.00010 |
| 8 | $S_f = -0.0090 + 0.0006\ P_g$ | 0.80 | 0.0010 | 0.00005 |
| 9 | $S_f = -0.0030 + 0.0002\ P_g$ | 0.72 | 0.0010 | 0.00003 |
| 10 | $S_f = -0.0110 + 0.0008\ P_g$ | 0.86 | 0.0020 | 0.00005 |
| 11 | $S_f = -0.0010 + 0.0002\ P_g$ | 0.81 | 0.0005 | 0.00002 |
| 12 | $S_f = -0.0040 + 0.0002\ P_g$ | 0.78 | 0.0009 | 0.00002 |
| 13 | $S_f = -0.0020 + 0.0001\ P_g$ | 0.46 | 0.0007 | 0.00002 |
| 14 | $S_f = -0.0050 + 0.0002\ P_g$ | 0.71 | 0.0010 | 0.00003 |
| 15 | $S_f = -0.0030 + 0.0003\ P_g$ | 0.72 | 0.0010 | 0.00003 |
| 16 | $S_f = -0.0003 + 0.0002\ P_g$ | 0.76 | 0.0008 | 0.00002 |
| Average | $S_f = -0.01 + 0.001\ P_g$ | | | |

### 4.4.5. Canopy drainage parameters

The values of canopy drainage rate, $D$, and the amount of water stored on the tree canopy, $C$, over the time period in the unlogged plot are varied according to $P_g$, $E$ and $S$.

### 4.4.6. Evaporation rate

The evaporation rate during and after rainfall has ceased in canopy-saturated conditions was calculated using the modified Penman equation (Eq. 4.8). The mean evaporation rate of intercepted water in terms of energy required in the unlogged plot was 468 J $m^{-2}$ $s^{-1}$ and varied from 72 to 1096 J $m^{-2}$ $s^{-1}$, as shown in Table 4.4.

Several values of latent heat flux, $\lambda E$, in Table 4.4 are unusually large. These seem to be associated with very large values of interception loss in strongly advective situations.

**Table 4.4** The rate of evaporation and the boundary layer conductance in the unlogged plot. Air temperature ($T$), relative humidity ($R_h$), windspeed ($u$) and net radiation ($R_n$) were calculated using regression equations 4.12, 4.13, 4.14 and 4.15, respectively. These equations were based on meteorological data from the automatic weather stations sited above and beneath the forest canopies. Interception loss ($I$) was calculated from measurements of gross rainfall, throughfall and stemflow. Vapour pressure deficit ($D_{vp}$), boundary layer conductance ($g_a$), latent heat flux ($\lambda$ $I$), radiative and advective energies were also calculated using Eqs. 4.8 and 4.11.

| Date | $T$ °C | $R_h$ % | $D_{vp}$ [1] Pa | $R_n$ [2] $J m^{-2} s^{-1}$ | $u$ $m s^{-1}$ | $g_a$ [3] $m s^{-1}$ | $\lambda I$ [4] $J m^{-2} s^{-1}$ | $I$ $mm h^{-1}$ | Rad.[5] $mm h^{-1}$ | Adv.[6] $mm h^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 01/11/93 | 24.3 | 94.5 | 164.07 | 117.1 | 1.93 | 1.21 | 1047.9 | 1.55 | 0.13 | 1.42 |
| 03/11/93 | 25.1 | 89.4 | 335.7 | 81.4 | 2.32 | 0.67 | 1096.2 | 1.62 | 0.09 | 1.53 |
| 12/11/93 | 24.7 | 95.2 | 152.0 | 87.9 | 1.55 | 0.01 | 72.35 | 0.11 | 0.10 | 0.01 |
| 16/11/93 | 24.5 | 88.2 | 373.7 | 87.4 | 2.32 | 0.11 | 263.2 | 0.39 | 0.10 | 0.30 |
| 17/11/93 | 24.2 | 92.4 | 226.7 | 144.2 | 1.92 | 0.39 | 536.1 | 0.79 | 0.16 | 0.64 |
| 25/11/93 | 23.8 | 96.0 | 119.3 | 99.6 | 1.93 | 1.25 | 794.5 | 1.17 | 0.11 | 1.08 |
| 27/11/93 | 24.5 | 91.7 | 262.9 | 62.4 | 2.32 | 0.32 | 431.4 | 0.64 | 0.07 | 0.58 |
| 30/11/93 | 24.4 | 92.2 | 232.7 | 68.7 | 2.32 | 0.24 | 309.5 | 0.46 | 0.07 | 0.39 |
| 03/12/93 | 24.9 | 90.2 | 310.4 | 171.5 | 2.10 | 0.10 | 268.1 | 0.40 | 0.19 | 0.21 |
| 06/12/93 | 24.2 | 88.7 | 337.1 | 149.4 | 2.50 | 0.02 | 153.5 | 0.23 | 0.16 | 0.07 |
| 12/12/93 | 25.4 | 85.4 | 462.4 | 153.8 | * | 0.04 | 199.8 | 0.30 | 0.17 | 0.12 |
| 18/12/93 | 24.0 | 93.1 | 205.8 | 113.2 | 1.60 | 0.26 | 341.2 | 0.50 | 0.12 | 0.38 |
| 23/12/93 | 24.4 | 91.3 | 259.5 | 147.1 | 2.30 | 0.32 | 499.6 | 0.74 | 0.16 | 0.60 |
| 19/01/94 | 24.4 | 91.5 | 253.6 | 108.4 | * | 0.73 | 962.6 | 1.42 | 0.12 | 1.32 |
| 23/01/94 | 23.9 | 86.1 | 414.6 | 128.9 | * | 0.04 | 177.9 | 0.26 | 0.14 | 0.11 |
| 05/02/94 | 23.9 | 90.3 | 289.4 | 152.4 | * | 0.13 | 294.9 | 0.44 | 0.16 | 0.27 |
| 12/02/94 | 23.9 | 95.3 | 140.2 | 81.4 | 1.08 | 0.13 | 137.5 | 0.20 | 0.09 | 0.13 |
| 14/02/94 | 23.4 | 93.9 | 171.4 | 146.9 | 1.08 | 0.92 | 902.1 | 1.33 | 0.16 | 1.18 |
| 15/02/94 | 24.1 | 94.4 | 167.0 | 162.4 | 1.24 | 1.21 | 1096.6 | 1.62 | 0.18 | 1.44 |
| 17/02/94 | 24.2 | 94.0 | 178.9 | 126.4 | 1.04 | 0.43 | 467.9 | 0.69 | 0.14 | 0.55 |
| 07/03/94 | 24.7 | 86.8 | 418.0 | 138.4 | * | 0.05 | 182.8 | 0.27 | 0.15 | 0.14 |
| 08/03/94 | 24.1 | 88.6 | 340.1 | 88.4 | * | 0.06 | 175.5 | 0.26 | 0.10 | 0.16 |
| 22/03/94 | 23.4 | 97.5 | 70.2 | 52.9 | 1.04 | 0.93 | 370.6 | 0.55 | 0.06 | 0.48 |
| 24/03/94 | 22.8 | 97.3 | 75.8 | 105.9 | 1.16 | 0.06 | 107.3 | 0.16 | 0.11 | 0.03 |
| 25/03/94 | 23.7 | 95.3 | 140.2 | 129.4 | 1.08 | 1.15 | 882.2 | 1.30 | 0.14 | 1.16 |
| 27/03/94 | 24.5 | 92.4 | 240.7 | 145.9 | 1.08 | 0.19 | 319.3 | 0.47 | 0.16 | 0.31 |
| 28/03/94 | 24.7 | 91.5 | 269.2 | 151.9 | 1.47 | 0.14 | 282.7 | 0.42 | 0.17 | 0.27 |
| 29/03/94 | 24.2 | 93.2 | 202.8 | 158.9 | 1.31 | 0.23 | 338.7 | 0.50 | 0.17 | 0.33 |
| 30/03/94 | 24.0 | 95.0 | 149.2 | 112.4 | 1.16 | 1.13 | 889.5 | 1.31 | 0.12 | 1.21 |

(Table 4.4, continued)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 04/04/94 | 23.7 | 94.7 | 158.1 | 129.9 | 1.12 | 0.99 | 843.2 | 1.25 | 0.14 | 1.12 |
| 06/04/94 | 24.2 | 94.2 | 173.0 | 114.9 | 1.12 | 0.39 | 406.9 | 0.60 | 0.12 | 0.49 |
| 10/04/94 | 25.1 | 93.7 | 199.5 | 119.4 | 1.20 | 0.10 | 177.8 | 0.26 | 0.13 | 0.13 |
| 11/04/94 | 23.4 | 98.4 | 44.9 | 115.0 | 1.08 | 1.12 | 336.4 | 0.50 | 0.12 | 0.38 |
| 14/04/94 | 23.8 | 97.0 | 89.5 | 106.4 | 1.28 | 1.13 | 565.4 | 0.84 | 0.11 | 0.72 |
| Mean | 24.2 | 92.6 | 224.4 | 119.4 | 1.56 | 0.47 | 468.5 | 0.69 | 0.13 | 0.56 |
| SD | 0.54 | 3.3 | 104.6 | 30.6 | 0.52 | 0.44 | 317.7 | 0.47 | 0.03 | 0.47 |
| SE | 0.09 | 0.5 | 18.0 | 5.3 | 0.09 | 0.08 | 54.7 | 0.08 | 0.01 | 0.08 |

Note:

Lists of values for $s$, $e_s(T_a)$, $e_a$, $\rho$, and $\gamma$ are included in Table IV.1 (Appendix IV)

1) $[\{e_s(T_a) - e_a\}]$

2) $R_n = 2.9 + 0.43\,Q$ ; $r^2 = 0.92$ , n = 233

3) $[I\lambda\,(s+\gamma) - s\,R_n] / [\rho\, c_p\, \{e_s(T_a) - e_a\}]$

4) $[s\,R_n / (s+\gamma)] + [c_p\, \rho\, D_{vp}\, g_a / (s+\gamma)]$

5) $[s\,R_n] / [\lambda\,(s+\gamma)]$

6) $[\rho\, c_p\, D_{vp}\, g_a] / [\lambda\,(s+\gamma)]$

### 4.4.7. Boundary layer conductance

The boundary layer conductance, $g_a$, in the unlogged plot was calculated using a modification of the Penman equation (Eq. 4.11). The mean boundary layer conductance for the unlogged plot was 0.47 m s$^{-1}$ and varied from 0.04 to 1.25 m s$^{-1}$ (Table 4.4).

### The logged forest site

### 4.4.8. Canopy storage capacity

In the logged plot, the canopy storage capacity, $S$, was determined, based on separate functional relationships between gross rainfall and throughfall values for closed and partial canopies and for the canopy gap.

The linear regressions of 43 rainfall events of greater than 1.5 mm for the closed canopy, and 41 rainfall events for both the partial canopy cover and for the canopy gap produced a mean value of $S$ equal to 1.0 mm, with a range from 0.25 to 1.89 mm for zero throughfall as shown in Table 4.5. These regressions gave standard error of the mean slope of 0.07 mm and mean intercept of 0.18 mm. Table 4.5 also indicates that for the closed canopy area, the value of canopy storage capacity of 1.21 mm, was slightly higher than for the partial canopy cover (1.14 mm) and considerably larger than for the canopy gap (0.69 mm). The mean value of $S$ based on the Leyton method, in which individual storms for 95 rainfall events were regressed against net rainfall (throughfall + stemflow) data obtained from all funnel and plastic container gauges, was 1.0 mm (Fig. 4.6b).

**Table 4.5** Linear regressions of gross rainfall, $P_g$, against throughfall, $T_f$, from individual storms for each of 14 tipping bucket gauges used in the logged plot. These analyses were based on 43 rainfall events for the closed canopy area and 41 rainfall events for both the partial canopy cover and for the canopy gap. $S$ = canopy storage capacity.

| Tipping bucket No. | Equation | $r^2$ | Standard Error Intercept | Standard Error Slope | $S$-value |
|---|---|---|---|---|---|
| Closed canopy: | | | | | |
| 10 | $T_f = -1.02 + 0.64\,P_g$ | 0.76 | 1.21 | 0.05 | 1.60 |
| 11 | $T_f = -1.10 + 0.58\,P_g$ | 0.68 | 1.19 | 0.06 | 1.89 |
| 12 | $T_f = -0.93 + 0.98\,P_g$ | 0.84 | 1.36 | 0.07 | 0.95 |
| 13 | $T_f = -0.84 + 0.89\,P_g$ | 0.86 | 1.05 | 0.05 | 0.94 |
| 14 | $T_f = -0.24 + 0.64\,P_g$ | 0.67 | 1.43 | 0.06 | 0.67 |
| Average | | | | | 1.21 |
| Partial canopy: | | | | | |
| 16 | $T_f = -0.23 + 0.66\,P_g$ | 0.65 | 1.51 | 0.07 | 0.34 |
| 17 | $T_f = -1.62 + 0.99\,P_g$ | 0.89 | 1.59 | 0.07 | 1.64 |
| 20 | $T_f = -1.56 + 0.85\,P_g$ | 0.93 | 0.77 | 0.03 | 1.85 |
| 21 | $T_f = -0.30 + 1.22\,P_g$ | 0.72 | 2.33 | 0.11 | 0.25 |
| 22 | $T_f = -1.72 + 1.06\,P_g$ | 0.91 | 0.96 | 0.04 | 1.62 |
| Average | | | | | 1.14 |
| Canopy gap: | | | | | |
| 1 | $T_f = -0.81 + 0.94\,P_g$ | 0.96 | 0.63 | 0.02 | 0.86 |
| 4 | $T_f = -0.72 + 1.04\,P_g$ | 0.97 | 0.54 | 0.02 | 0.69 |
| 7 | $T_f = -0.40 + 0.92\,P_g$ | 0.98 | 0.43 | 0.02 | 0.44 |
| 15 | $T_f = -0.76 + 0.98\,P_g$ | 0.93 | 0.46 | 0.05 | 0.77 |
| Average | | | | | 0.69 |
| Overall mean | | | | | 1.01 |

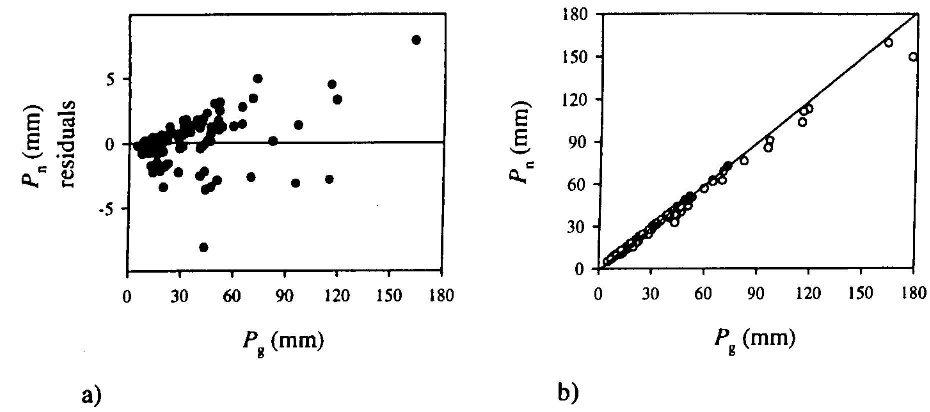



**Figure 4.6** The Leyton *et al.* (1967) analysis of daily rainfall totals in the logged plot. a). The residuals of the regression of net rainfall ($P_n$) on gross rainfall ($P_g$) are plotted ($P_n = 0.45 + 0.92\ P_g$ ; $r^2 = 0.99$, $n = 95$). This facilitates identification of the inflection point, which is located around 5 mm. b). The regression through the upper envelope right of this point ($P_n = -1.0 + 1.01\ P_g$ ; $r^2 = 0.99$, $n = 4$). The $S$ value was taken to be 1.0 mm.

### 4.4.9. Free throughfall coefficient

The free throughfall coefficient, $p$, was estimated from the average ratio of net rainfall to gross rainfall (Navar and Bryan, 1994) for the areas with three different canopy covers (closed canopy, partial canopy and canopy gap). The smallest amount of gross rainfall used in the analysis was 7.25 mm and the average associated net rainfall values for the three areas were 2.30, 3.46 and 5.34 mm, respectively. Using these values, the calculated $p$ values were 0.31, 0.47 and 0.73, respectively. The average value of $p$ for the whole one ha plot, taking no account of the canopy cover differences, was 0.50.

The value of $p$ was also calculated from the gap fraction in the centre of the hemispherical photography image, as the area weighted average of the first 5° zenith angles. The values of $p$ based on canopy cover in the logged plot were 0.13, 0.15 and 0.64 for the closed canopy, partial canopy cover and canopy gap areas, respectively (Table 4.6). The overall gap fraction for the whole one ha plot, taking no account of the canopy cover differences, was 0.30.

**Table 4.6** Leaf area index (LAI) and gap fraction above each tipping bucket used in the logged plot.

| Tipping bucket No. | LAI Angle 60° | Gap fraction Angle 5° | Canopy cover |
|---|---|---|---|
| 8 | 3.26 | 0.23 | closed canopy |
| 10 | 0.98 | 0.06 | closed canopy |
| 12 | 1.68 | 0.01 | closed canopy |
| 13 | 1.74 | 0.12 | closed canopy |
| 14 | 2.43 | 0.24 | closed canopy |
| Average | 2.02 | 0.13 | |
| 2 | 1.12 | 0.18 | partial canopy |
| 3 | 1.75 | 0.14 | partial canopy |
| 5 | 1.38 | 0.06 | partial canopy |
| 8 | 3.44 | 0.31 | partial canopy |
| 9 | 2.03 | 0.07 | partial canopy |
| Average | 1.94 | 0.15 | |
| 1 | 1.90 | 0.64 | canopy gap |
| 4 | 1.98 | 0.64 | canopy gap |
| 6 | 1.12 | 0.64 | canopy gap |
| 15 | 2.12 | 0.64 | canopy gap |
| AWS | 1.54 | 0.64 | canopy gap |
| Average | 1.73 | 0.64 | |
| Overall mean | 1.90 | 0.30 | |

### 4.4.10. Tree trunk parameters

The trunk storage capacity, $S_t$, and proportion of rainfall which is diverted onto the trunks, $p_t$, were estimated using a linear regression of stemflow versus individual gross rainfall for each sample tree. For the estimation of $S_t$ and $p_t$, gross rainfall and stemflow data were extracted for all rainfall events larger than 1.5 mm, so that 90 rainfall events were used in the analysis (Table 4.7).

Linear regressions of stemflow versus gross rainfall were calculated for each of the 20 trees. The intercept of these regressions are estimates of the trunk storage capacities and the gradients are estimates of the proportion of rainfall diverted to the trunks. By averaging both the set of intercepts and the set of gradients of the regression equations in Table 4.7, the mean stemflow equation is:

$$S_f = 0.001\ (\pm 0.0003) + 0.0001\ (\pm 0.0001)\ P_g \qquad (4.17)$$

Values of 0.001 mm for $S_t$ and 0.0001 mm for $p_t$ were therefore used as stemflow parameters. These values are much less than the values of the tree trunk parameters from the unlogged plot. The values in brackets are the standard error of the means of the intercepts and the slopes, respectively.

**Table 4.7** Linear regressions of gross rainfall, $P_g$, against stemflow, $S_f$, for each sample tree used in the logged plot. The analysis was based on 90 rainfall events.

| Tree No. | Equation | $r^2$ | Standard Error Intercept | Standard Error Slope |
|---|---|---|---|---|
| 1 | $S_f = -0.0043 + 0.00020\ P_g$ | 0.71 | 0.0018 | 0.00002 |
| 2 | $S_f = -0.0002 + 0.00003\ P_g$ | 0.79 | 0.0002 | 0.00000 |
| 3 | $S_f = -0.0003 + 0.00004\ P_g$ | 0.67 | 0.0001 | 0.00000 |
| 4 | $S_f = -0.0006 + 0.00008\ P_g$ | 0.89 | 0.0004 | 0.00000 |
| 5 | $S_f = -0.0011 + 0.00014\ P_g$ | 0.62 | 0.0014 | 0.00001 |
| 6 | $S_f = -0.0012 + 0.00020\ P_g$ | 0.70 | 0.0014 | 0.00001 |
| 7 | $S_f = -0.0001 + 0.00005\ P_g$ | 0.61 | 0.0005 | 0.00000 |
| 8 | $S_f = -0.0013 + 0.00013\ P_g$ | 0.83 | 0.0007 | 0.00000 |
| 9 | $S_f = -0.0020 + 0.00020\ P_g$ | 0.56 | 0.0007 | 0.00002 |
| 10 | $S_f = -0.0027 + 0.00027\ P_g$ | 0.69 | 0.0024 | 0.00002 |
| 11 | $S_f = -0.0009 + 0.00006\ P_g$ | 0.85 | 0.0003 | 0.00000 |
| 12 | $S_f = -0.0009 + 0.00008\ P_g$ | 0.86 | 0.0004 | 0.00000 |
| 13 | $S_f = -0.0013 + 0.00016\ P_g$ | 0.90 | 0.0006 | 0.00000 |
| 14 | $S_f = -0.0007 + 0.00008\ P_g$ | 0.86 | 0.0004 | 0.00000 |
| 15 | $S_f = -0.0007 + 0.00006\ P_g$ | 0.90 | 0.0003 | 0.00000 |
| 16 | $S_f = -0.0010 + 0.00009\ P_g$ | 0.85 | 0.0001 | 0.00000 |
| 17 | $S_f = 0.0050 + 0.00070\ P_g$ | 0.64 | 0.0020 | 0.00006 |
| 18 | $S_f = -0.0018 + 0.00015\ P_g$ | 0.82 | 0.0009 | 0.00000 |
| 19 | $S_f = -0.0004 + 0.00004\ P_g$ | 0.91 | 0.0001 | 0.00000 |
| 20 | $S_f = -0.0002 + 0.00005\ P_g$ | 0.80 | 0.0003 | 0.00000 |
| Average | $S_f = -0.001 + 0.0001\ P_g$ | | | |

### 4.4.11. Canopy drainage parameters

The values of canopy drainage rate, $D$, and the amount of water stored on the tree canopy, $C$, over the time period in the logged plot are varied according to $P_g$, $E$ and $S$.

### 4.4.12. Evaporation rate

The evaporation rate during and after the rainfall has ceased, in canopy-saturated conditions, was calculated using the modified Penman equation (Eq. 4.8). As in the calculations of stand and canopy parameters, the rate of evaporation in the logged plot was differentiated according to the canopy cover resulting from the logging activities. The values are based on meteorological data collected from above the forest canopy of the unlogged forest and from the canopy gap in the logged plot.The mean evaporation rate in the closed canopy area was 676 J $m^{-2}$ $s^{-1}$ and varied from 97 to 1534 J $m^{-2}$ $s^{-1}$ (Table 4.8). In the areas of partial canopy and canopy gap, the mean evaporation rates were 423 J $m^{-2}$ $s^{-1}$ (range 39 to 1023 J $m^{-2}$ $s^{-1}$) and 222 J $m^{-2}$ $s^{-1}$ (range 48 to 560 J $m^{-2}$ $s^{-1}$), respectively, as shown in Tables 4.9 and 4.10. The overall mean of evaporation rate of intercepted water over the one ha logged plot was 440 J $m^{-2}$ $s^{-1}$.

**Table 4.8** The rate of evaporation and the boundary layer conductance of the closed canopy area in the logged plot. Air temperature, *T*, relative humidity, $R_h$, net radiation, $R_n$, and windspeed, *u*, data were collected from the automatic weather station sited above the forest canopy. Interception loss, *I*, was calculated from field measurements of gross rainfall, throughfall and stemflow. Vapour pressure deficit, $D_{vp}$, boundary layer conductance, $g_a$, latent heat flux, $\lambda I$, and radiative and advective energies were all calculated using equations 4.8 and 4.11. The windspeed values starting from 16 January 1995 onwards are in error.

| Date | $T$ °C | $R_h$ % | $D_{vp}$[1)] Pa | $R_n$ J m$^{-2}$s$^{-1}$ | $u$ m s$^{-1}$ | $g_a$[2)] m s$^{-1}$ | $\lambda I$[3)] J m$^{-2}$s$^{-1}$ | $I$ mm h$^{-1}$ | Rad.[4)] mm h$^{-1}$ | Adv.[5)] mm h$^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 01/12/94 | 24.7 | 90.3 | 307.2 | 155.6 | 2.66 | 1.00 | 1534.6 | 2.27 | 0.17 | 2.10 |
| 04/12/94 | 24.0 | 92.7 | 217.7 | 147.9 | 2.90 | 0.11 | 219.3 | 0.32 | 0.16 | 0.16 |
| 20/12/94 | 24.5 | 92.8 | 228.0 | 120.9 | 2.00 | 0.38 | 487.2 | 0.72 | 0.13 | 0.59 |
| 23/12/94 | 24.4 | 91.3 | 259.5 | 147.1 | 2.30 | 0.09 | 219.3 | 0.32 | 0.16 | 0.17 |
| 05/01/95 | 23.7 | 91.9 | 241.6 | 104.3 | 0.56 | 0.97 | 1218.5 | 1.80 | 0.11 | 1.69 |
| 16/01/95 | 25.4 | 82.7 | 547.8 | 146.3 | 0.10 | 0.26 | 755.1 | 1.12 | 0.16 | 0.96 |
| 17/01/95 | 25.0 | 88.1 | 376.8 | 130.9 | 0.10 | 0.45 | 876.9 | 1.30 | 0.14 | 1.15 |
| 19/01/95 | 24.4 | 91.5 | 253.5 | 108.4 | 0.10 | 0.13 | 243.7 | 0.36 | 0.12 | 0.24 |
| 20/01/95 | 23.8 | 93.8 | 184.9 | 124.8 | 0.10 | 0.01 | 97.4 | 0.14 | 0.13 | 0.01 |
| 21/01/95 | 23.5 | 93.4 | 196.8 | 111.5 | 0.10 | 0.21 | 285.1 | 0.42 | 0.12 | 0.30 |
| 23/01/95 | 23.9 | 86.1 | 414.6 | 128.9 | 0.10 | 0.30 | 706.7 | 1.04 | 0.14 | 0.91 |
| 26/01/95 | 24.1 | 87.9 | 360.9 | 190.3 | 0.10 | 0.24 | 560.5 | 0.83 | 0.21 | 0.62 |
| 06/02/95 | 22.5 | 93.3 | 188.2 | 132.0 | 0.10 | 0.21 | 297.4 | 0.44 | 0.14 | 0.30 |
| 07/02/95 | 23.4 | 90.3 | 272.4 | 133.0 | 0.10 | 0.47 | 748.4 | 1.11 | 0.14 | 0.96 |
| 16/02/95 | 25.2 | 85.0 | 475.0 | 158.6 | 0.10 | 0.52 | 1266.7 | 1.87 | 0.17 | 1.70 |
| 18/02/95 | 23.5 | 90.3 | 289.3 | 117.6 | 0.10 | 0.55 | 852.9 | 1.26 | 0.13 | 1.31 |
| 23/02/95 | 24.8 | 86.8 | 393.7 | 179.0 | 0.10 | 0.31 | 731.1 | 1.08 | 0.19 | 0.89 |
| 24/02/95 | 25.0 | 86.2 | 437.0 | 168.8 | 0.10 | 0.32 | 779.5 | 1.15 | 0.18 | 0.97 |
| 25/02/95 | 23.5 | 93.9 | 181.9 | 118.7 | 0.10 | 0.32 | 365.5 | 0.54 | 0.13 | 0.41 |
| 09/03/95 | 25.6 | 85.7 | 480.6 | 157.5 | 0.10 | 0.17 | 479.7 | 0.71 | 0.17 | 0.53 |
| 13/03/95 | 24.3 | 87.1 | 384.8 | 154.5 | 0.10 | 0.15 | 399.6 | 0.59 | 0.17 | 0.42 |
| 20/03/95 | 23.8 | 90.8 | 274.4 | 123.8 | 0.10 | 0.35 | 560.5 | 0.83 | 0.13 | 0.69 |
| 01/06/95 | 25.9 | 85.2 | 497.4 | 125.0 | 0.10 | 0.48 | 1161.5 | 1.72 | 0.14 | 1.58 |
| 06/06/95 | 23.1 | 93.2 | 191.0 | 164.0 | 0.10 | 0.92 | 999.5 | 1.48 | 0.17 | 1.30 |
| 09/06/95 | 23.5 | 90.6 | 280.4 | 109.0 | 0.10 | 0.64 | 950.4 | 1.40 | 0.12 | 1.29 |
| 14/06/95 | 23.9 | 91.9 | 241.6 | 131.0 | 0.10 | 0.89 | 1145.3 | 1.69 | 0.14 | 1.55 |
| 19/06/95 | 23.2 | 91.1 | 250.0 | 170.0 | 0.10 | 0.89 | 1243.3 | 1.84 | 0.18 | 1.66 |
| 22/06/95 | 23.6 | 92.9 | 211.7 | 89.0 | 0.10 | 0.41 | 487.4 | 0.72 | 0.10 | 0.62 |

(Table 4.8, continued)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 24/06/95 | 23.4 | 94.3 | 160.1 | 131.0 | 0.10 | 0.02 | 112.1 | 0.17 | 0.14 | 0.03 |
| 30/06/95 | 25.0 | 90.0 | 316.7 | 109.0 | 0.10 | 0.29 | 511.5 | 0.76 | 0.12 | 0.64 |
| Mean | 24.1 | 90.0 | 303.8 | 136.2 | - | 0.40 | 676.5 | 1.00 | 0.15 | 0.85 |
| SD | 0.82 | 3.18 | 107.8 | 24.4 | - | 0.29 | 386.2 | 0.57 | 0.03 | 0.57 |
| SE | 0.15 | 0.59 | 19.9 | 4.5 | - | 0.05 | 71.5 | 0.11 | 0.00 | 0.10 |

Note:

Lists of values for $s$, $e_s$, $e_a$, $\rho$, and $\gamma$ are included in Table IV.2 (Appendix IV)

[1] $e_s(T_a) - e_a$

[2] $[I\lambda(s+\gamma) - s R_n] / [\rho c_p \{e_s(T_a) - e_a\}]$

[3] $[s R_n / (s+\gamma)] + [c_p \rho D_{vp} g_a / (s+\gamma)]$

[4] $[s R_n] / [\lambda(s+\gamma)]$

[5] $[\rho c_p D_{vp} g_a] / [\lambda(s+\gamma)]$

**Table 4.9** The rate of evaporation and the boundary layer conductance of the partial canopy area in the logged plot. Air temperature, $T$, relative humidity, $R_h$, net radiation, $R_n$, and windspeed, $u$, data were collected from the automatic weather station sited above the forest canopy. Interception loss, $I$, was calculated from field measurements of gross rainfall, throughfall and stemflow. Vapour pressure deficit, $D_{vp}$, boundary layer conductance, $g_a$, latent heat flux, $\lambda I$, and radiative and advective energies were all calculated using equations 4.8 and 4.11. The windspeed values starting from 9 January 1995 onwards are in error.

| Date | $T$ °C | $R_h$ % | $D_{vp}$[1] Pa | $R_n$ J $m^{-2}s^{-1}$ | $u$ m $s^{-1}$ | $g_a$[2] m $s^{-1}$ | $\lambda I$[3] J $m^{-2}s^{-1}$ | $I$ mm $h^{-1}$ | Rad.[4] mm $h^{-1}$ | Adv.[5] mm $h^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 02/12/94 | 24.9 | 88.9 | 351.5 | 156.3 | 3.10 | 0.42 | 791.7 | 1.17 | 0.17 | 1.00 |
| 08/12/94 | 24.9 | 86.7 | 421.2 | 166.0 | 3.00 | 0.00 | 129.1 | 0.19 | 0.18 | 0.01 |
| 20/12/94 | 24.5 | 92.8 | 228.0 | 120.9 | 2.00 | 0.54 | 657.7 | 0.97 | 0.13 | 0.84 |
| 25/12/94 | 24.7 | 92.9 | 224.8 | 99.6 | 1.60 | 0.33 | 414.12 | 0.61 | 0.11 | 0.50 |
| 30/12/94 | 23.8 | 94.1 | 176.0 | 68.7 | 1.97 | 1.11 | 999.1 | 1.48 | 0.07 | 1.40 |
| 09/01/95 | 24.2 | 91.1 | 265.4 | 135.0 | 0.10 | 0.45 | 682.3 | 1.01 | 0.15 | 0.86 |
| 11/01/95 | 23.1 | 95.2 | 134.8 | 119.7 | 0.10 | 0.01 | 92.6 | 0.14 | 0.13 | 0.01 |
| 16/01/95 | 25.4 | 82.7 | 547.8 | 146.3 | 0.10 | 0.15 | 487.2 | 0.72 | 0.16 | 0.56 |
| 20/01/95 | 23.8 | 93.8 | 184.9 | 124.8 | 0.10 | 1.04 | 1023.5 | 1.51 | 0.13 | 1.38 |
| 23/01/95 | 23.9 | 86.1 | 414.6 | 128.9 | 0.10 | 0.30 | 706.7 | 1.04 | 0.14 | 0.91 |
| 27/01/95 | 24.7 | 87.2 | 405.3 | 179.0 | 0.10 | 0.29 | 682.0 | 1.01 | 0.20 | 0.81 |
| 01/02/95 | 24.9 | 88.2 | 373.7 | 161.6 | 0.10 | 0.06 | 231.4 | 0.34 | 0.18 | 0.17 |
| 02/02/95 | 23.3 | 95.4 | 129.2 | 78.8 | 0.10 | 0.55 | 414.4 | 0.61 | 0.08 | 0.53 |
| 04/02/95 | 22.2 | 97.4 | 68.7 | 52.2 | 0.10 | 0.01 | 39.0 | 0.06 | 0.05 | 0.00 |
| 16/02/95 | 25.2 | 85.0 | 475.0 | 158.6 | 0.10 | 0.09 | 316.6 | 0.47 | 0.17 | 0.29 |
| 19/02/95 | 24.9 | 85.5 | 407.3 | 171.9 | 0.10 | 0.31 | 755.7 | 1.12 | 0.18 | 0.93 |
| 23/02/95 | 24.8 | 86.8 | 393.7 | 179.0 | 0.10 | 0.06 | 243.7 | 0.36 | 0.19 | 0.17 |
| 26/02/95 | 22.9 | 93.8 | 174.1 | 126.9 | 0.10 | 0.28 | 341.3 | 0.50 | 0.13 | 0.37 |
| 02/03/95 | 24.0 | 90.7 | 261.2 | 119.7 | 0.10 | 0.18 | 316.9 | 0.47 | 0.13 | 0.34 |
| 09/03/95 | 25.6 | 85.7 | 480.6 | 157.5 | 0.10 | 0.13 | 389.6 | 0.58 | 0.17 | 0.40 |
| 13/03/95 | 24.3 | 87.1 | 384.8 | 154.5 | 0.10 | 0.07 | 243.7 | 0.36 | 0.17 | 0.19 |
| 14/03/95 | 22.8 | 94.5 | 154.5 | 94.1 | 0.10 | 0.29 | 292.5 | 0.43 | 0.10 | 0.33 |
| 16/03/95 | 24.1 | 85.0 | 447.4 | 168.8 | 0.10 | 0.01 | 146.2 | 0.22 | 0.18 | 0.03 |
| 20/03/95 | 23.8 | 90.8 | 274.4 | 123.8 | 0.10 | 0.04 | 146.2 | 0.22 | 0.13 | 0.08 |
| 23/03/95 | 23.0 | 95.3 | 132.0 | 78.8 | 0.10 | 0.61 | 463.2 | 0.68 | 0.08 | 0.60 |
| 27/03/95 | 24.1 | 92.1 | 235.6 | 153.5 | 0.10 | 0.14 | 268.0 | 0.40 | 0.17 | 0.23 |
| 22/06/95 | 23.6 | 92.9 | 211.7 | 89.0 | 0.10 | 0.29 | 365.5 | 0.54 | 0.10 | 0.44 |
| 30/06/95 | 25.0 | 90.0 | 316.7 | 109.0 | 0.10 | 0.09 | 219.2 | 0.32 | 0.12 | 0.20 |

(Table 4.9, continued)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 24.1 | 90.2 | 295.5 | 129.3 | - | 0.28 | 423.5 | 0.63 | 0.14 | 0.49 |
| SD | 0.86 | 4.01 | 129.1 | 35.3 | - | 0.29 | 267.2 | 0.39 | 0.04 | 0.40 |
| SE | 0.16 | 0.76 | 24.3 | 6.6 | - | 0.05 | 50.4 | 0.07 | 0.01 | 0.07 |

Note:

List of values for $s$, $e_s$, $e_a$, $\rho$, and $\gamma$ are included in Table IV.3 (Appendix IV)

1) $e_s(T_a) - e_a$

2) $[I\lambda\,(s+\gamma) - s\,R_n] / [\rho\,c_p\,\{e_s(T_a) - e_a\}]$

3) $[s\,R_n / (s+\gamma)] + [c_p\,\rho\,D_{vp}\,g_a / (s+\gamma)]$

4) $[s\,R_n] / [\lambda\,(s+\gamma)]$

5) $[\rho\,c_p\,D_{vp}\,g_a] / [\lambda\,(s+\gamma)]$

**Table 4.10** The rate of evaporation and the boundary layer conductance of the canopy gap area in the logged plot. Air temperature, $T$, relative humidity, $R_h$, and windspeed, $u$, data were collected from the automatic weather station sited in the canopy gap of the logged plot. Interception loss, $I$, was calculated from field measurements of gross rainfall, throughfall and stemflow. Vapour pressure deficit, $D_{vp}$, boundary layer conductance, $g_a$, latent heat flux, $\lambda I$, and radiative and advective energies were all calculated using equations 4.8 and 4.11.

| Date | $T$ °C | $R_h$ % | $D_{vp}$[1] Pa | $R_n$[2] $J\ m^{-2}s^{-1}$ | $u$ $m\ s^{-1}$ | $g_a$[3] $m\ s^{-1}$ | $\lambda I$[4] $J\ m^{-2}s^{-1}$ | $I$ $mm\ h^{-1}$ | Rad.[5] $mm\ h^{-1}$ | Adv.[6] $mm\ h^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 28/06/94 | 24.8 | 94.3 | 180.5 | 48.9 | 0.20 | 0.05 | 77.9 | 0.12 | 0.05 | 0.06 |
| 05/07/94 | 24.8 | 92.9 | 224.8 | 56.9 | 0.10 | 0.05 | 97.4 | 0.14 | 0.06 | 0.08 |
| 07/07/94 | 25.5 | 89.1 | 366.3 | 90.9 | 0.20 | 0.03 | 121.7 | 0.18 | 0.10 | 0.08 |
| 25/12/94 | 25.6 | 94.0 | 201.6 | 41.4 | 0.20 | 0.38 | 365.2 | 0.54 | 0.05 | 0.49 |
| 05/01/95 | 24.3 | 97.0 | 89.4 | 38.4 | 0.15 | 0.50 | 243.7 | 0.36 | 0.04 | 0.32 |
| 11/01/95 | 24.7 | 95.2 | 152.0 | 58.9 | 0.20 | 0.42 | 341.0 | 0.50 | 0.06 | 0.44 |
| 16/01/95 | 25.4 | 92.0 | 253.3 | 46.9 | 0.20 | 0.18 | 243.6 | 0.36 | 0.05 | 0.31 |
| 17/01/95 | 25.5 | 94.1 | 198.3 | 49.4 | 0.20 | 0.23 | 236.2 | 0.35 | 0.05 | 0.29 |
| 23/01/95 | 24.9 | 94.3 | 180.5 | 47.9 | 0.20 | 0.07 | 97.4 | 0.14 | 0.05 | 0.09 |
| 26/01/95 | 25.1 | 90.7 | 294.8 | 62.9 | 0.20 | 0.04 | 97.4 | 0.14 | 0.07 | 0.08 |
| 01/02/95 | 25.6 | 93.5 | 218.4 | 67.4 | 0.20 | 0.12 | 170.4 | 0.25 | 0.07 | 0.18 |
| 02/02/95 | 24.6 | 96.0 | 126.8 | 30.4 | 0.10 | 0.34 | 219.2 | 0.32 | 0.03 | 0.29 |
| 04/02/95 | 23.7 | 94.0 | 168.5 | 27.4 | 0.20 | 0.41 | 365.7 | 0.54 | 0.03 | 0.51 |
| 16/02/95 | 25.6 | 93.5 | 218.4 | 67.4 | 0.20 | 0.00 | 48.7 | 0.07 | 0.07 | 0.00 |
| 23/02/95 | 25.5 | 92.0 | 268.8 | 68.9 | 0.20 | 0.41 | 535.7 | 0.79 | 0.08 | 0.72 |
| 25/02/95 | 24.6 | 96.4 | 114.1 | 33.4 | 0.13 | 0.14 | 97.4 | 0.14 | 0.04 | 0.11 |
| 02/03/95 | 25.3 | 93.2 | 215.3 | 49.9 | 0.10 | 0.04 | 73.0 | 0.11 | 0.05 | 0.05 |
| 13/03/95 | 25.2 | 92.3 | 244.0 | 74.4 | 0.20 | 0.45 | 560.2 | 0.83 | 0.08 | 0.75 |
| 14/03/95 | 24.2 | 95.0 | 149.0 | 37.4 | 0.10 | 0.40 | 316.8 | 0.47 | 0.04 | 0.43 |
| 20/03/95 | 24.8 | 94.2 | 183.6 | 62.4 | 0.20 | 0.23 | 243.6 | 0.36 | 0.07 | 0.29 |
| 23/03/95 | 24.3 | 96.4 | 107.2 | 35.4 | 0.10 | 0.65 | 365.5 | 0.54 | 0.04 | 0.50 |
| 27/03/95 | 25.1 | 93.4 | 209.0 | 77.9 | 0.20 | 0.12 | 170.5 | 0.25 | 0.09 | 0.17 |
| 15/04/95 | 24.4 | 95.0 | 149.0 | 38.4 | 0.10 | 0.16 | 146.2 | 0.22 | 0.04 | 0.17 |
| 19/05/95 | 25.8 | 90.4 | 322.6 | 108.4 | 0.20 | 0.23 | 413.9 | 0.61 | 0.12 | 0.49 |
| 31/05/95 | 25.0 | 92.2 | 247.0 | 93.4 | 0.20 | 0.11 | 194.8 | 0.29 | 0.10 | 0.19 |
| 03/06/95 | 25.6 | 95.9 | 137.8 | 55.4 | 0.14 | 0.13 | 121.7 | 0.18 | 0.06 | 0.12 |
| 14/06/95 | 24.2 | 98.1 | 56.6 | 30.0 | 0.10 | 0.10 | 48.7 | 0.07 | 0.03 | 0.04 |

(Table 4.10, continued)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 24.9 | 93.8 | 195.5 | 55.5 | 0.17 | 0.22 | 222.7 | 0.33 | 0.06 | 0.27 |
| SD | 0.55 | 2.08 | 71.2 | 20.7 | 0.04 | 0.17 | 143.2 | 0.21 | 0.02 | 0.21 |
| SE | 0.11 | 0.41 | 13.9 | 4.08 | 0.01 | 0.03 | 28.08 | 0.04 | 0.01 | 0.04 |

Note:

Lists of values for $s$, $e_s$, $e_a$, $\rho$, and $\gamma$ are included in Table IV.4 (Appendix IV)

1) $e_s(T_a) - e_a$

2) $R_n = 2.9 + 0.43\,Q$ ; $r^2 = 0.92$, $n = 233$ ($R_n$ and $Q$ were measured on top of the tower)

3) $[I\lambda\,(s+\gamma) - s\,R_n] \,/\, [\rho\, c_p\, \{e_s(T_a) - e_a\}]$

4) $[s\,R_n \,/\, (s+\gamma)] + [c_p\,\rho\, D_{vp}\, g_a \,/\, (s+\gamma)]$

5) $[s\,R_n\,] \,/\, [\lambda\,(s+\gamma)]$

6) $[\rho\, c_p\, D_{vp}\, g_a] \,/\, [\lambda\,(s+\gamma)]$

### 4.4.13. Boundary layer conductance

The boundary layer conductance, $g_a$, was calculated based on the modified Penman equation (Eq. 4.11). These calculations were based on micrometeorological data collected above the forest canopy of the unlogged plot and in the canopy gap of the logged plot. The values of $g_a$ in the logged plot were calculated for the areas of closed canopy, partial canopy and canopy gap. The average of $g_a$ were 0.40 m s$^{-1}$ (range 0.02 to 1.0 m s$^{-1}$), 0.28 m s$^{-1}$ (range 0.01 to 1.0 m s$^{-1}$) and 0.22 m s$^{-1}$ (range 0.03 to 0.6 m s$^{-1}$), respectively (Tables 4.8, 4.9 and 4.10).

## 4.5. Discussion

### Derived results

Table 4.11 shows the comparison of calculated stand and canopy structures in the unlogged and logged plots. In the logged plot, there are separate calculations of canopy and stand parameters for the different canopy covers resulting from logging activities.

**Table 4.11** The derived results of stand and canopy parameters in the unlogged and logged plots. The following parameters are compared: canopy storage capacity, $S$; free throughfall coefficient, $p$; trunk storage capacity, $S_t$; amount of rainfall diverted into the trunks, $p_t$; evaporation rate of intercepted water, $\lambda E_c$; and atmospheric boundary layer conductance, $g_a$. The second value for each parameter, where available, was calculated based on the method of Leyton *et al.* (1967).

| Parameters | Units | Unlogged plot | Logged plot | | | |
|---|---|---|---|---|---|---|
| | | | Closed canopy | Partial canopy | Canopy gap | Overall [1)] |
| $S$ | mm | 1.35<br>1.35 | 1.21 | 1.14 | 0.69 | 1.0 |
| $p$ | - | 0.20<br>0.03 | 0.31<br>0.13 | 0.47<br>0.15 | 0.73<br>0.64 | 0.50<br>0.30 |
| $S_t$ | mm | 0.01 | - | - | - | 0.001 |
| $p_t$ | - | 0.001 | - | - | - | 0.0001 |
| $\lambda E_c$ | $J m^{-2} s^{-1}$ | 468 | 676 | 423 | 222 | 440 |
| $g_a$ | $m s^{-1}$ | 0.47 | 0.40 | 0.28 | 0.22 | 0.30 |

Note: [1)] average of the three different canopy cover areas

### 4.5.1. Canopy storage capacity

In the unlogged plot, the values of the canopy storage capacity, $S$, determined using the method of Lloyd *et al.* (1988) and the method of Leyton *et al.* (1967), are in relatively good agreement with each other (Table 4.11). The value of $S$ in the unlogged plot was considerably larger ($S$ = 1.4 mm) than that in the logged plot (1.0 mm). This is to be expected, as there was a significant reduction in stand density in the logged plot, from 581 to 278 trees per hectare (52 %). The value of $S$ for the closed canopy in the logged plot ($S$ = 1.2 mm) was slightly smaller than that in the unlogged plot ($S$ = 1.4). This seems to be related to the condition of the canopy in the closed canopy sites of the logged plot where canopy cover was less, as a direct or indirect result of logging and its associated activities. The smaller value of $S$ in the closed canopy of the logged plot was in line with the smaller leaf area index and the larger gap fraction than in the unlogged plot (Tables 4.2 and 4.6).

Within the logged plot, the values of $S$ varied with canopy cover. The value of $S$ decreased as the canopy cover was reduced, from 1.2 mm for the closed canopy to 0.7 mm in the canopy gap (Table 4.11).

Most experimental studies of forest interception do not have simultaneous measurements of leaf area index (LAI). In this experiment, LAI values were estimated using the hemispherical photograph method and can therefore be related to water stored on forest canopies, *S*. Although some relation with the LAI is to be expected, many authors assume a proportional relation between these two. For example, in the temperate region, changing the LAI from zero in winter time to four in summer changes the water stored from about 0.3 mm to 0.8 mm (Shuttleworth, 1989). However, in my experiment, there are no distinctive relationships between *S* and LAI (slope = 0.1 and $r^2$ = 0.02). This applies to both the unlogged and logged plots. A possible explanation for this is that the hemispherical photograph method measures the canopy structure (i.e. LAI) on a larger scale than is pertinent to the throughfall measurements. For each hemispherical photograph, the LAI was obtained by image analysis, for the five annuli between 20 and 70° from zenith. The canopy storage capacity, on the other hand, was derived from a linear regression of throughfall on gross rainfall, where throughfall data were measured through a 18.3 cm diameter funnel and bottle gauge. It is apparent that there is no comparison between the way LAI and *S* were obtained, resulting in no relationship between these two variables. Another possibility is that not all leaf area is normally wetted, even by heavy storms because of the shedding effect associated with the waxy leaf surfaces, which is typical of tropical vegetation.

The mean value of *S* of the unlogged plot in this experiment was considerable larger than has been found in other tropical and temperate forest areas, for example, 0.7 mm in Amazonia rainforest (Lloyd *et al.*, 1988), 0.9 mm in tropical rainforest in East Africa (Jackson, 1975) and 0.6 mm in a tropical forest in Ivory Coast (Hutjes *et al.*, 1990). In temperate forest, reported values of *S* are also variable. Gash and Morton (1978) reported values of *S* varying from 0.8 to 2.8 mm in forest plantations in England, while values of *S* varying from 0.2 to 1.2 mm, depending on tree density, were reported by Teklehaimanot and Jarvis (1991) from a Sitka spruce plantation in Scotland. The value of *S* decreased as tree density decreased.

Even though the derivation of *S* using the method of Leyton *et al.* (1967) also seems to be quite reliable, for the purpose of modelling, the *S* value derived using the method of Lloyd *et al.* (1988) is to be preferred, because the Leyton method is subjective and prone to errors in recognizing the inflection point corresponding to the point of canopy saturation and in fitting the upper envelope to the scattered points.

### 4.5.2. Free throughfall coefficient

The free throughfall coefficient, $p$, in the unlogged and logged plots was calculated using two different methods. In the first method, $p$ was calculated by taking the ratio of net rainfall to gross rainfall for the smallest rainfall event (Navar and Bryan, 1994). This method was used because no rainfall events smaller than 1.5 mm were available for the conventional method of calculating $p$. To some extent, this method is open to criticism because very small rainfall events may not be detected as some very small storms were summed to give one rainfall event.

The mean value of $p$ was 0.2 in the unlogged plot and 0.5 in the logged plot (Table 4.11). The increase in $p$ was caused by canopy gaps resulting from logging and its associated activities. The values of $p$ for the unlogged plot and the closed canopy of the logged plot were not significantly different (Table 4.11). When canopy cover was reduced by logging, $p$ increased considerably, from 0.3 in the closed canopy area of the logged plot to 0.7 in the canopy gap. This increase of the $p$ values was presumably caused by the reduction of canopy cover resulting from logging and its associated activities. The larger the reduction, the larger the $p$ value that resulted, as shown in Fig. 4.7.

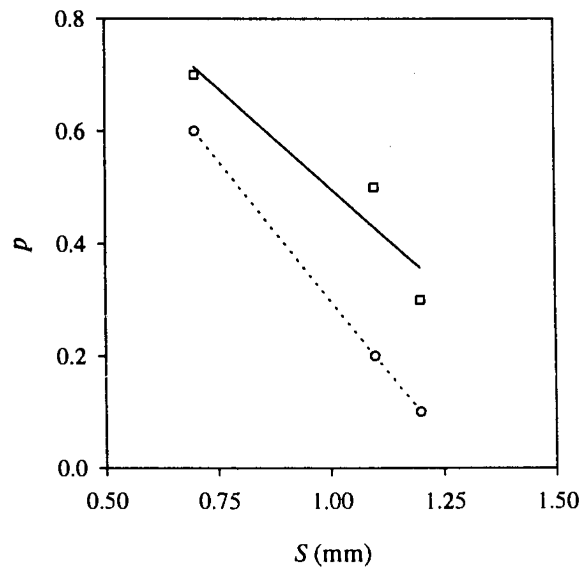



**Figure 4.7** The relationship between free throughfall coefficient, $p$, and canopy storage capacity, $S$, in the logged plot. Linear regression lines represent the relationships between $S$ and $p$ estimated by two different methods. The method of Navar and Bryan (1994) gives an equation of $y = 1.2 - 0.7\,x$, $r^2 = 0.89$ (———): the hemispherical photograph technique gives an equation of $y = 1.3 - 1.0\,x$, $r^2 = 0.99$ (·········).

The second method of calculating $p$ was based on the hemispherical photography technique. This technique is increasingly being used to estimate leaf area index and gap fraction of forest canopies. The gap fraction in the first five degrees from the zenith was used to represent the $p$ value because the gap fraction within these angles was most closely related to the values of throughfall obtained by each tipping bucket used in this experiment. The photographic estimate of $p$ of 0.03 for the unlogged plot is of the same order as the methodologically similar estimate of 0.03 of Hutjes *et al.*(1990) and Ubarana (1996), but somewhat smaller than the value of 0.08 obtained by Lloyd *et al.*(1988). It seems that photographic estimates might underestimate the $p$ value, as reported by Dolman (1987).

Table 4.11 indicates that the difference in mean $p$ between the unlogged and logged plots is surprisingly large, 0.03 in the unlogged plot as opposed to 0.3 in the logged plot. There was similarly large difference between the values of $p$ of the unlogged plot (0.03) and the closed canopy area of the logged plot (0.13). This large difference was expected, because of the large reduction of canopy cover following logging.

The values of $p$ calculated by the hemispherical photography method were far smaller than those calculated by the Navar and Bryan (1994) method. These large differences may be attributed to the lack of availability of the small rainfall events used for the analysis in the latter method, and by the tendency for the hemispherical photography technique to underestimate $p$. Because of the problems with the method of Navar and Bryan (1994), the hemispherical photography technique is likely to be the more reliable and, therefore, the $p$ values obtained by this method were used for modelling interception loss.

#### 4.5.3. Tree trunk parameters

As shown in Chapter 3, stemflow was much smaller than throughfall in both the unlogged and logged forest areas. As for stemflow, the mean values of trunk storage capacity, $S_t$, in the unlogged and logged plots were also very small and the value of $S_t$ decreased from 0.005 to 0.001 mm as a result of logging (Table 4.11). The amount of rainfall diverted to the trunks, $p_t$, was similarly very small and was reduced from 0.004 to 0.0001 mm by logging. These values are much lower than was found in the Amazonian forest (Lloyd *et al.*, 1988) where the trunk storage capacity, $S_t$, and the amount of rainfall diverted onto the trunk, $p_t$, were 0.15 and 0.04 mm, respectively.

#### 4.5.4. Canopy drainage parameters

The canopy and trunk drainage parameters will be discussed later in Section 5.7 of Chapter 5. These parameters are required specifically for the process-based model of Rutter *et al.* (1971, 1975), which uses an hourly time step.

#### 4.5.5. Evaporation rate

Evaporation from a vegetated surface is governed by radiant energy supply, atmospheric humidity deficit, atmospheric turbulence and stomatal control of transfer of water from the surface to the atmosphere. These governing factors provide the basic inputs to all models for vegetation-atmosphere energy exchange and evaporation (see, e.g., Kelliher *et al.*, 1995).

Evaporation rate is a combination of effects of net radiation, temperature, humidity, windspeed and the aerodynamic properties of the canopy/stand as shown in Eq. 4.8. The components of the surface energy balance used for evaporation in the unlogged and logged plots can be divided into radiative and advective energy (Tables 4.4, 4.8, 4.9 and 4.10). In the unlogged plot, the $R_n$ component of Eq. 4.8, i.e. $sR_n/\lambda(s + \gamma)$, allows for mean evaporation during and immediately after rain of about 0.13 mm $h^{-1}$ and varies from 0.07 to 0.2 mm $h^{-1}$ (Table 4.4). Table 4.4 also indicates that a major part of the energy required in evaporating intercepted water is advected, i.e. $c_p\, \rho\, D_{vp}\, g_a/\lambda(s + \gamma)$. The advected energy, especially the interaction of $D_{vp}$ and $g_a$ components, allows for mean evaporation rate during and immediately after rain of about 0.56 mm $h^{-1}$ and varies from 0.05 to 1.53 mm $h^{-1}$ (Table 4.4). This phenomenon is in line with the generally small value of aerodynamic resistance, $r_a$, in forests (e.g. Rutter and Morton, 1977) and this makes the right hand component of the numerator of Eq. 4.8 much larger than the left hand component. A similar relationship between the major driving factor for evaporation and the rate of interception loss was also found in the logged plot for all canopy cover areas. In general, the average evaporation rate accounted for by the advective energy component of evaporation was 0.53 mm $h^{-1}$, much larger than the evaporation rate accounted for by radiative energy of only 0.12 mm $h^{-1}$ (Tables 4.8, 4.9 and 4.10). These findings indicate that logging activities did not result in a great deal of change in the proportion of energy used for evaporation of intercepted rainfall.

Fig. 4.8 shows the proportion of radiative and advective energy used for evaporation of intercepted water in both the unlogged and logged plots. The figure indicates that at low interception loss, or at the beginning of rain, radiation supplied a large proportion of the energy used to evaporate water intercepted on the canopy surface because incoming solar radiation is still an effective supply of energy. However, as interception loss increased, the combination of small $r_a$ and the reduction of incoming solar radiation as a result of increasing cloud makes advective energy the dominant factor for evaporation.

The findings, that interception loss is largely influenced more by local advective energy from air passing over the forest canopy and not by radiation confirms previous similar studies (e.g. Stewart, 1977; Singh and Szeicz, 1979; Pearce *et al.*, 1980; Kelliher *et al.*, 1992). Additional evidence indicating that horizontal advective energy is an important driving factor for evaporation of intercepted rainfall in this study was that night-time rates of evaporation of intercepted water in the unlogged plot tended to be similar to day-time rates for 20 rainfall events. In the logged plot, the night-time rates were even higher than the day-time rates for 35 rainfall events, indicating that radiative energy is substantially less importance than advective energy in determining evaporation rate.

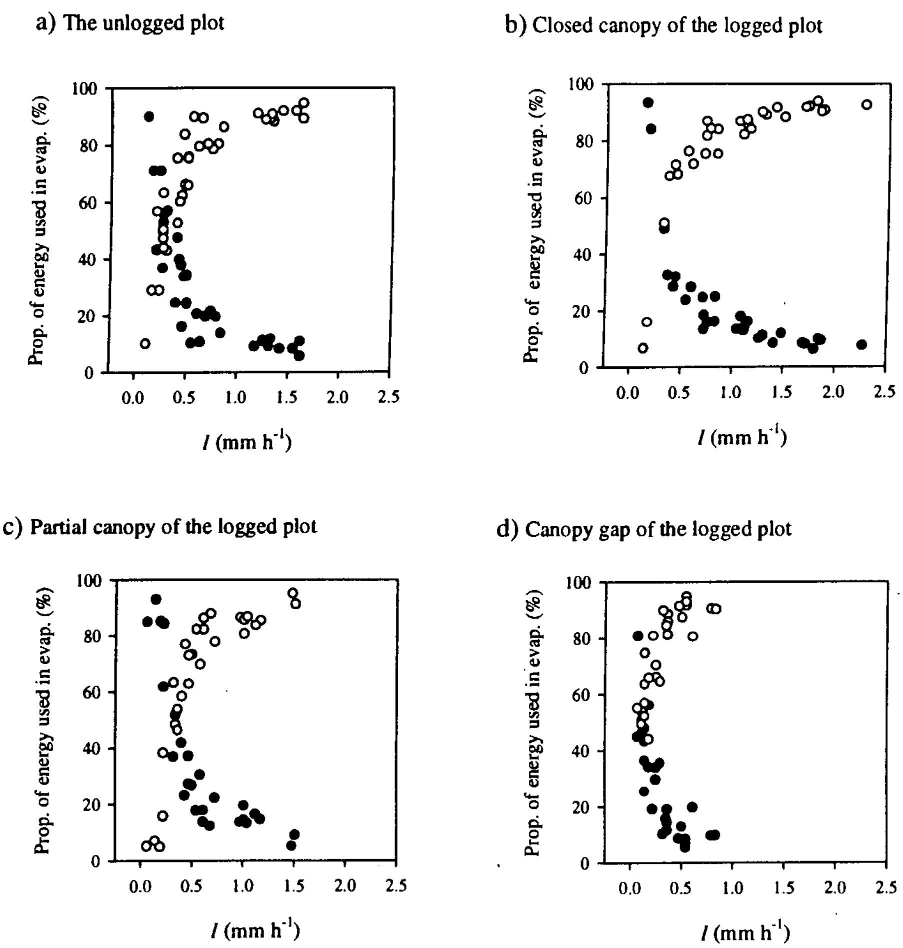



**Figure 4.8** The relationship between the proportion of radiative (● ) and advective energy (○ ) used for evaporation of intercepted rainfall against interception loss, *I*, in the unlogged and logged plots. The data used in these analyses were taken from Tables 4.4, 4.8, 4.9 and 4.10.

Table 4.11 shows that, on average, the mean latent heat flux used to evaporate intercepted water is slightly reduced from 468 J $m^{-2}$ $s^{-1}$ in the unlogged plot to 440 J $m^{-2}$ $s^{-1}$ in the logged plot following logging. This reduction can be largely attributed to the reduction of mean latent heat flux to 222 J $m^{-2}$ $s^{-1}$ in the canopy gap area of the logged plot (Table 4.10) and was mainly caused by the reduction of average $R_n$ from 119 to 55 J $m^{-2}$ $s^{-1}$ (Tables 4.8 and 4.10) and the reduction of average $g_a$ from 0.47 to 0.22 m $s^{-1}$ (Table 4.11) following logging. Table 4.11 also indicates that evaporation rate in terms of energy used in the closed canopy area of the logged plot was considerably larger than in the unlogged plot. This difference is probably related to the larger values of $R_n$ and $D_{vp}$ in the closed canopy area of the logged plot than in the unlogged plot. The smaller values of the latter probably result from the underestimation of $R_n$ and $D_{vp}$, which were calculated using the regression equations outlined in Section 4.3.6.

An example of the daily course of the water vapour transfer process as calculated for the unlogged plot is shown in Fig. 4.19. Since the canopy storage capacity, $S$, in the unlogged plot was 1.3 mm, it can be seen that almost all leaves were saturated by the rainfall in the early morning. The stored water began to evaporate in response to the increase in radiative energy before the cessation of rainfall and the increase in windspeed following the rainfall. The evaporation rate then immediately increased to the maximum of 0.3 mm $h^{-1}$, followed by a gradual decrease. The immediate increase in evaporation during the morning implies that a large amount of the available energy was first used to evaporate the stored water, so that the rate of heating of the atmosphere in the morning was consequently less than that for a dry day.

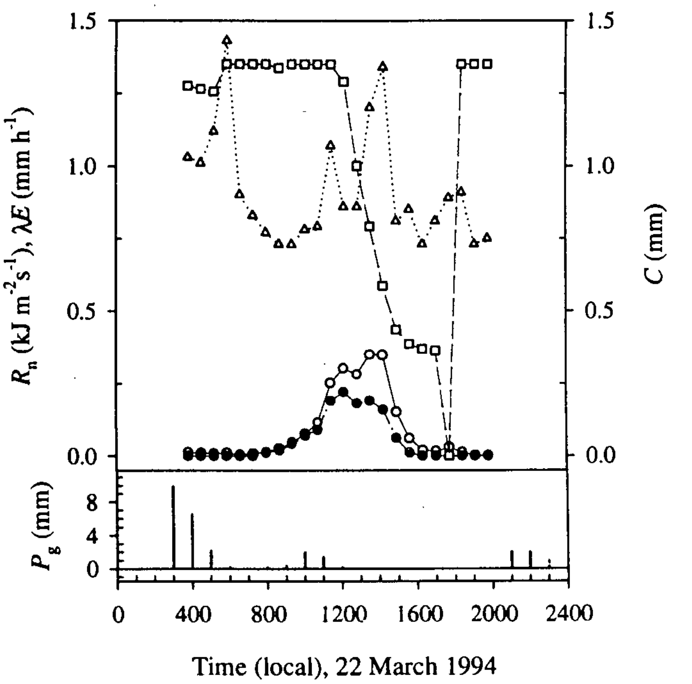



**Figure 4.9** Temporal distribution of the evaporation flux of intercepted water, $\lambda E_c$ (○), net radiation, $R_n$ (●), water stored on the canopy, $C$ (□), windspeed (△, left y-axis in m $s^{-1}$) and gross rainfall, $P_g$, calculated for 22 March 1994 in the unlogged plot.

### 4.5.6. Boundary layer conductance

Different methods of estimating boundary layer conductance, $g_a$, have been used by a number of research workers. In this experiment, $g_a$ was calculated indirectly by inverting the

Penman equation, given the values for evaporation of intercepted water and the micrometeorological variables. The environmental variables measured above and below the forest canopy were used for the derivation of $g_a$ after applying some corrections to the raw data.

Logging activities reduced $g_a$ from 0.5 m $s^{-1}$ in the unlogged plot to 0.3 m $s^{-1}$ in the logged plot: a reduction of $g_a$ of around 50 % (Table 4.11). This reduction of $g_a$ leads to the reduction of interception loss from 11 % of gross rainfall in the unlogged plot to 6 % in the logged plot (see Section 3.3). The reduction of $g_a$ seems to be attributable to the reduction of tree basal area per unit ground area, from 38.6 to 13.8 $m^2$ $ha^{-1}$ (Tables 2.1 and 2.2). A similar result was reported from the temperate region, by Teklehaimanot *et al.* (1991) who found that boundary layer conductance per unit area declined from 0.17 to 0.07 m $s^{-1}$ as the density of trees decreased from 2 to 8 m spacing. As often reported, the magnitude of $g_a$ is controlled by windspeed, $u$, and canopy characteristics such as plant density and height, which determine canopy roughness (e.g. Roberts *et al.*, 1993). In this experiment, boundary layer conductance was weakly related to windspeed in both the unlogged and logged plots. However, the physical environmental changes following logging were the variable heights and irregularities of the tree crowns and increase in canopy gaps. Reducing the height of some trees and creating more gaps in the logged forest could lead to local variations in foliage density which would allow more wind to penetrate the canopy and, hence, increase turbulent flow. These changes that might tend to increase $g_a$, and hence the evaporation of intercepted water, seem to be offset by the reduction of canopy storage capacity following logging, resulting in low interception loss, especially in areas where windspeed was also considered to be low.

Within the logged plot, $g_a$ was 0.4 m $s^{-1}$ in the closed canopy area, 0.3 in the partial canopy area and 0.2 m $s^{-1}$ in the canopy gap. These small reductions in $g_a$ seem to be associated with the reduction of tree density following logging, as would be expected. The direct proportional relationship between evaporation rate, $\lambda E_c$, and the product of $D_{vp}$ and $g_a$ can be seen in Fig. 4.10. Fig. 4.10 indicates that, for all canopy conditions, the relationship between $\lambda E_c$ and the product of $D_{vp}$ and $g_a$ in both the unlogged and logged plots shows a degree of consistency: $\lambda E_c$ increases similarly with the product of $D_{vp}$ and $g_a$.

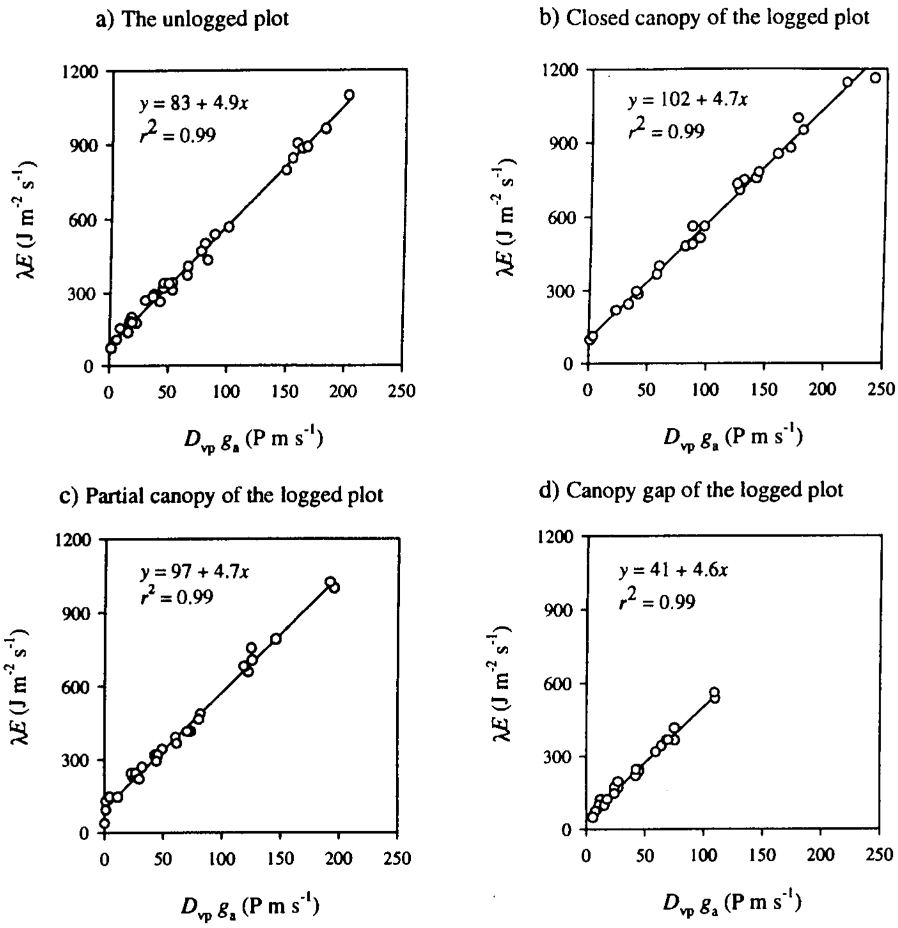



**Figure 4.10** The relationship between latent heat flux, $\lambda E_c$, and the product of vapour pressure deficit and boundary layer conductance, $D_{vp}\, g_a$, in the unlogged and logged plots. All regression equations were significant at $p = 0.05$. For the unlogged plot $n = 32$ and for the logged plot $n = 30$.

Fig. 4.11 shows that $\lambda E_c$ has a strong dependence on $g_a$ but it is clear that there is more scatter in the relationship between $\lambda E_c$ and $g_a$ than in the relationship between $\lambda E_c$ and the product $D_{vp} \cdot g_a$, shown in Fig. 4.10. This demonstrates clearly the significance of the interaction between $g_a$ and $D_{vp}$. This interaction is investigated in Fig. 4.12.

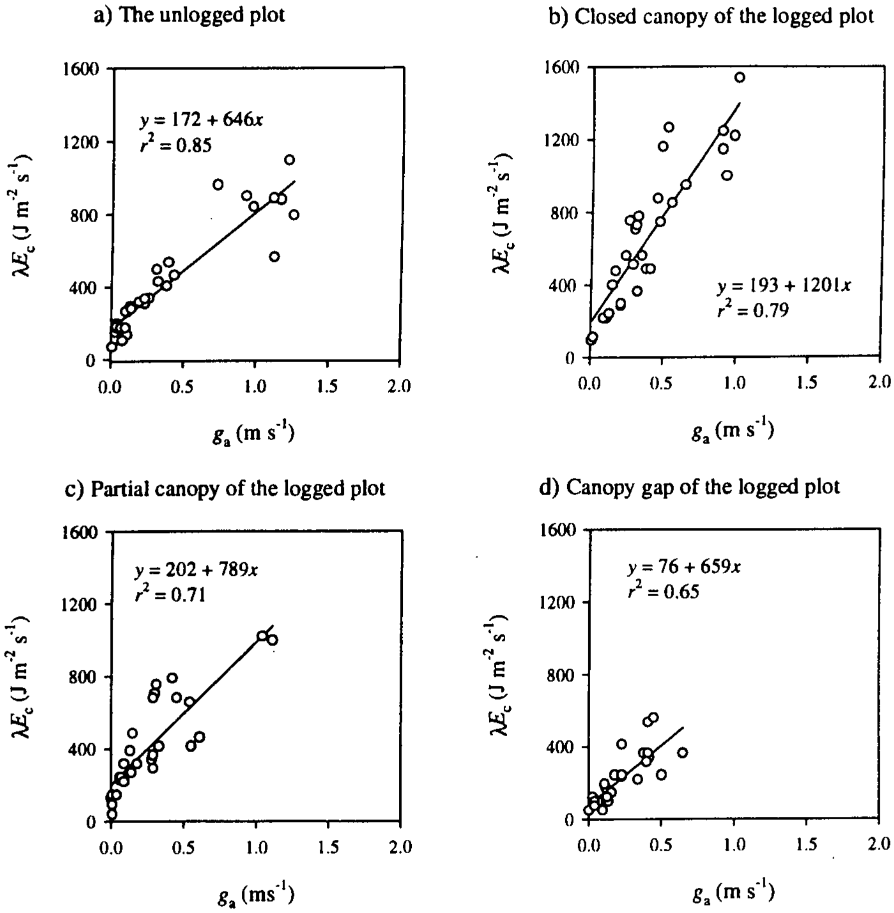



**Figure 4.11** The relationship between latent heat flux, $\lambda E_c$, and boundary layer conductance, $g_a$, in the unlogged and logged plots. The data were taken from Tables 4.4, 4.8, 4.9 and 4.10. All regression equations were significant at $p = 0.05$.

As in the temperate region, the increase of evaporation rate with increasing $g_a$ is checked by a decrease of $D_{vp}$, as shown in Fig. 4.13. In this situation, the value of $D_{vp}$ may become a consequence, rather than an independent cause, of the interaction between the vegetation and the atmosphere. At low $g_a$ and $\lambda E_c$, $D_{vp}$ is very small and highly variable. As $g_a$ increases, $D_{vp}$ tends to decrease as a result of the increase in evaporation rate and addition of water vapour to the atmosphere in the surface layer just above the canopy. These functional relationship analyses between $\lambda E_c$ and each component of the evaporation equation show that $g_a$ is a critical variable in determining the rate of evaporation of intercepted rainfall, as is generally expected for tall vegetation under low radiation conditions (Shuttleworth, 1989; Calder, 1990; Watanabe and Mizutani, 1996) but that interaction with $D_{vp}$ in the surface layer also feedback to influence $\lambda E_c$. The end result is the much closer relationship between $\lambda E_c$ and the product $D_{vp} \cdot g_a$ shown in Fig. 4.10.

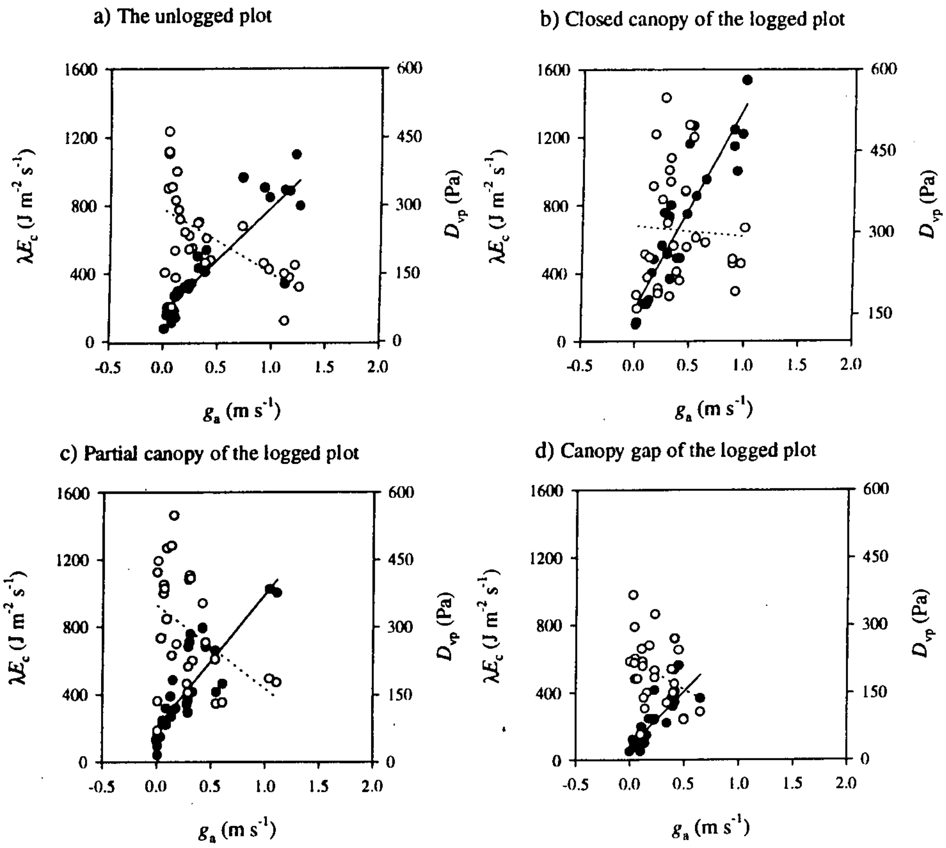



**Figure 4.12** The daily values of latent heat flux, $\lambda E_c$ (● ), and vapour pressure deficit, $D_{vp}$ (○ ), are shown as a function of boundary layer conductance, $g_a$. Solid lines are regression lines of $\lambda E_c$ on $g_a$ with coefficients of determination of a) $r^2 = 0.68$, b) $r^2 = 0.87$, c) $r^2 = 0.71$, and d) $r^2 = 0.65$ and dotted lines are regression lines of $D_{vp}$ on $g_a$: a) $r^2 = 0.37$, b) $r^2 = 0.05$, c) $r^2 = 0.17$, and d) $r^2 = 0.12$.

### 4.5.7. The Priestley-Taylor model

Several methods have been used to estimate evaporation from regions using standard climate data and are usually based on the theory of transport processes or energy exchanges in the surface layer a few meters above the canopy surface. The Priestley-Taylor (P-T) method is an exception to this rule because it is based on the physical processes in the whole of the turbulent planetary boundary layer, up to some thousands of meters and was originally developed for estimating evaporation from moist surfaces on a large scale (Priestley and Taylor, 1972; Bonell and Balek, 1993). The Priestley-Taylor hypothesis assumes that if the area is sufficiently large, advected energy will be negligible and evaporation must necessarily be proportional to the input of radiant energy. So far, the discussion has indicated that the calculation of evaporation rate using the Penman equation leads to the conclusion that advective energy is the major driving variable and so the boundary layer conductance, $g_a$, makes a significant contribution to determining the evaporation rate (Fig. 4.8). Fig. 4.13 suggests that the P-T model requires very large values of $\alpha$ to account for the evaporation rates; i.e. $R_n$ has to be several times larger to give values of evaporation rates that agree with those calculated using the Penman equation. This seems to be associated with the situation that evaporation from tall wetted vegetation, with large atmospheric exchange coefficients, is closely related to atmospheric vapour pressure deficit (e.g. Stewart and Thom, 1973) and this implies the presence of more sensible heat advection than the net radiation (Shuttleworth and Calder, 1979). Thus it may be concluded that the P-T model is a poor model for evaporation of intercepted water in tropical forests because advected energy is very important at the canopy scale. The reason for this is likely to be the highly sporadic occurrence of rainfall over tropical forest, so that the landscape is essentially a mosaic of wet and dry areas of forest on a scale of about 10 km (see below). Under such conditions interactive feedback between the air mass moving over a wet forest canopy and the evaporation flux is high. However, a similar comparison made in the Amazonian forest between forest evaporation and potential evaporation, as estimated by the Priestley-Taylor equation, led to a different result in which the average total evaporation was similar to a radiation-related estimate of potential evaporation (Shuttleworth, 1989). Thus the spatial pattern of rainfall may be markedly different in the two cases.

The evaporation of intercepted water from wet canopies over an extensive tropical forest at rapid and consistent rates is likely to be maintained by a combination of the horizontal transport of heat and moisture (local advection) and an entrainment processes. The entrainment process is the vertical movement of air from an external pressure gradient, and it involves a downwards heat flux across a stable region (Garratt, 1994). Strong local advection effects may arise in a situation where the surface energy balance is spatially variable (Rider *et al.*, 1963; McNaughton, 1976), as it was assumed to be the case in this experimental area.

The large spatial variability of the surface energy balance may be deduced from a comparison of gross rainfall measured in three different sites, as shown in Fig. 4.14. The first two sites, the Pondok and the logged plot, are close to each other (about 2 km apart), while the third site, Km 1, is about 50 km downstream. The results show that daily gross rainfall varied considerably between the three sites, even though the differences in the overall mean of gross rainfall between these sites were not significant at 0.05 level of probability. As would be expected, the variability in daily rainfall was greater for the Pondok and Km 1 site comparison than with the closer Pondok and logged plot site comparison (Fig. 4.14). Even though high spatial variability of precipitation in tropical rainforest has also been reported from Amazonian forest (Shuttleworth, 1988), the current available microclimate data at our research sites are not sufficient at present to justify the presumption that the landscape is essentially a mosaic of wet and dry areas of forest canopies. A more comprehensive large scale study with many more rainfall gauges and other relevant climatic variables is required to demonstrate the spatial scale of advective energy, the major driving factor for evaporation, and the effect of the dry and wet condition of forest canopies. An alternative approach would be to map the scale of wet and dry canopy areas using remote sensing. The most appropriate technique would be to overfly transects with a combination of C- and L-band Synthetic Aperture Radar (SAR); C-band carries information related to foliage and small branches, whereas L-band capable of penetrating through vegetation and the soil surface (Waring *et al.*, 1995).

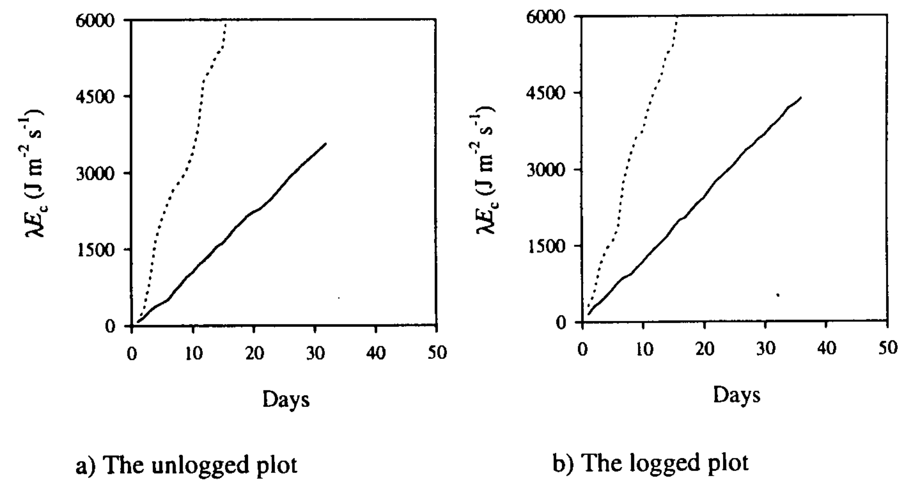



**Figure 4.13** Cumulative latent heat flux, $\lambda E_c$, calculated by the Priestley-Taylor equation, $\lambda E_c = 1.26 \times sR_n /(s + \gamma)$ (———) and the Penman equation, Eq. 4.8 (·········), in the unlogged and logged plots.

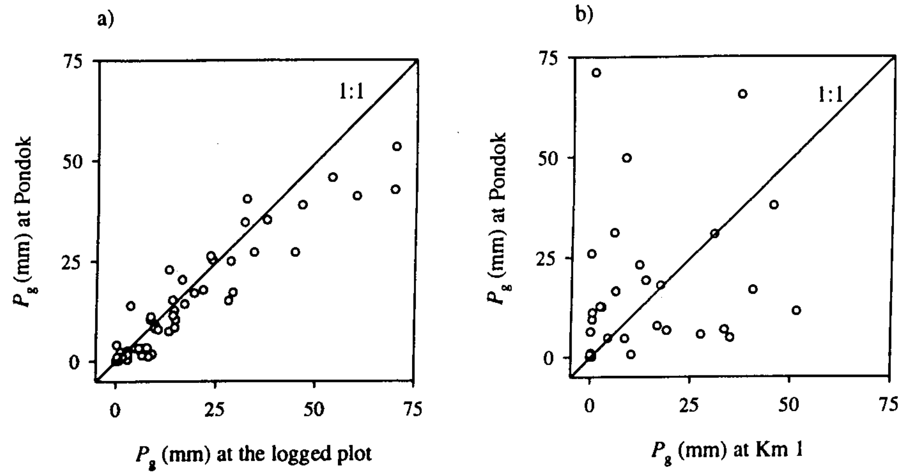



**Figure 4.14** The comparison of gross rainfall, $P_g$, collected at the Pondok site, the logged plot, and at Km 1, Camp 48, about 50 km downstream, for the period of a) January - February, 1995, and b) February - March, 1994 for individual rainfall events. The data are daily averages and taken at the same time for each graph.

# Chapter 5

## Modelling of rainfall interception loss

### 5.1. Introduction

The number of modelling studies concerned with rainfall interception loss in tropical rainforest is rather limited. In recent years, attempts have been made to apply modelling to the study of evaporation of intercepted water in the tropical rainforest (Calder *et al.*, 1986; Bruijnzeel and Wiersum, 1987; Rao, 1987; Lloyd *et al.*, 1988; Hutjes *et al.*, 1990; Ubarana, 1996). These modelling studies include empirical regression models, analytical and process-based approaches to the numerical simulation model.

Most investigations of rainfall interception loss studies have been confined to comparisons of the magnitude of interception loss from closed canopies of different species of trees, in temperate as well as tropical forests, usually with little variation in tree spacing or forest gaps resulting from forest logging. There have been a few studies aimed at finding out effects of different intensities of thinning and pruning on interception loss (e.g. Teklehaimanot *et al.*, 1991; Teklehaimanot and Jarvis, 1991; Whitehead and Kelliher, 1991) but there has been no investigation of the effects of logging practices on interception loss in tropical rainforest.

Many previous studies of the interception and evaporation of rainfall have been expressed in the form of empirical regression equations between interception loss ($I$) and gross rainfall ($P_g$) of the form (Gash, 1979):

$$I = a + b\,P_g \qquad (5.1)$$

Such an equation or model can be used either to describe sets of storm data or, if it is assumed that there is only one rainfall event per day, to describe daily interception loss as a function of daily gross rainfall (Gash, 1979). This assumption may contribute a large part of the error in the simulated interception loss (Lloyd *et al.*, 1988; Hutjes *et al.*, 1990). The empirical regression model has also been criticised for taking no account of such variables as rainfall intensity and duration, and the interval between storms (e.g. Jackson, 1975).

In contrast to the empirical regression approach, Rutter *et al.* (1971, 1975) developed a process-based model which uses inputs of rainfall and the meteorological variables controlling evaporation to calculate a running water balance of a forest canopy, including an estimate of the interception loss. This approach led to the development of an analytical model by Gash (1979), a numerical model by Mulder (1985) and by Whitehead and Kelliher (1991), and a stochastic model by Calder *et al.* (1986) and Calder (1990). One simplification of the Rutter model, known as WATMOD, was introduced by Whitehead *et al.* (1989). The modified Rutter model, as applied in WATMOD by Whitehead and Kelliher (1991) and Teklehaimanot and Jarvis (1991), has been used to investigate the effects of thinning and tree spacing on interception loss. In this study, WATMOD as in Whitehead and Kelliher (1991), with some modifications, and the revised version of the analytical model by Gash (1979) were tested and adapted to estimate interception loss in both the unlogged and logged-over forest areas in Central Kalimantan, Indonesia.

### 5.2. The Rutter model

The Rutter model (Rutter *et al.*, 1971, 1975) calculates a running balance of the amount of water on the canopy and tree trunks, with inputs of hourly rainfall and hourly meteorological variables controlling evaporation such as net radiation, windspeed, air temperature, relative humidity and water vapour pressure. These meteorological variables are used to calculate evaporation of intercepted rainfall using the Penman equation (Monteith, 1965) as presented in Section 4.4.1. The conceptual frame-work of the original Rutter model is shown diagramatically in Fig. 5.1.

The model requires the following parameters: canopy storage capacity, $S$, which is the depth of water left on the canopy in conditions of zero evaporation when rain and throughfall have ceased; free throughfall coefficient, $p$, the proportion of rain which falls to the ground without striking the canopy; trunk water storage capacity, $S_t$; and the proportion of rain diverted to the trunks, $p_t$. The results of calculations of these canopy and stand properties were presented in Section 4.4.

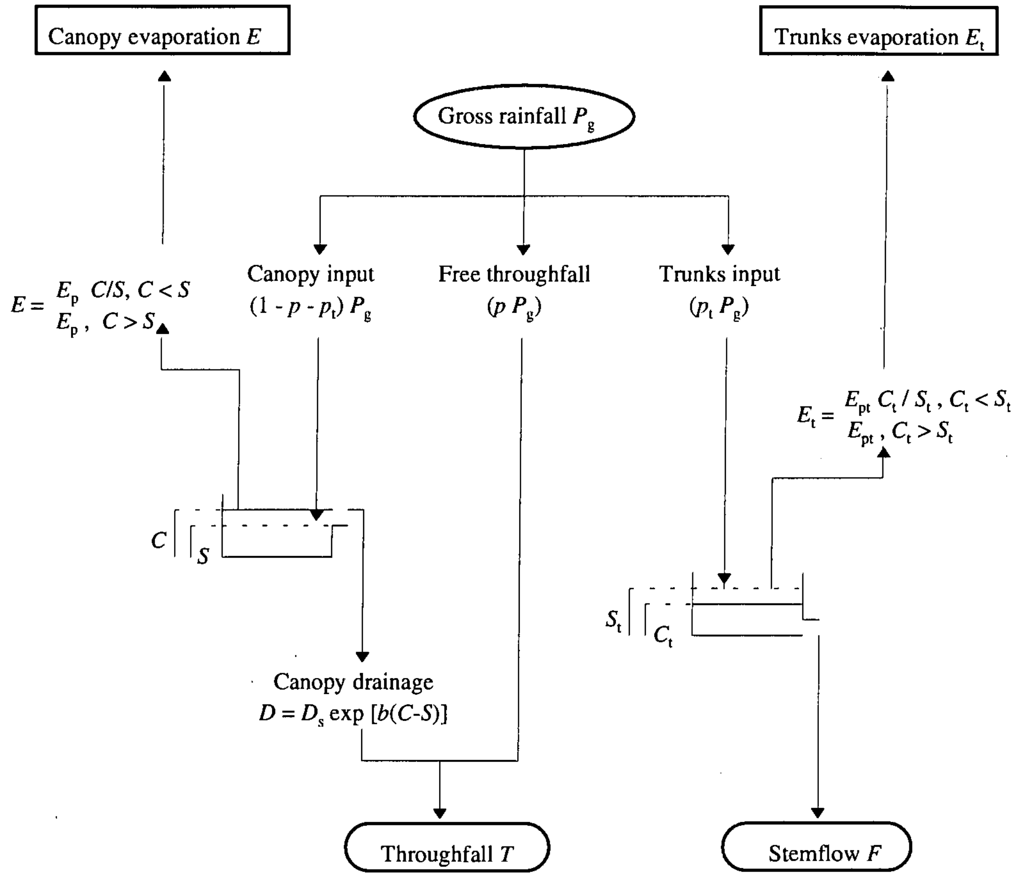



**Figure 5.1** The conceptual frame-work of the original Rutter model (adapted from Gash and Morton, 1978). $P_g$ is gross rainfall, $E$ is evaporation rate, $E_p$ is potential evaporation rate, $S$ is canopy storage capacity, $C$ is the depth of water on the canopy, $D$ is the drainage rate, $D_s$ is the drainage rate when $C = S$, $p_t$ is the amount of rain diverted to stemflow, $S_t$ is the stem water capacity, $C_t$ is the depth of water on the stems, and $b$ is a constant which describes the drip from the canopy.

Components of the water balance model are rainfall rate, $P_g$; throughfall rate, $T$; stemflow rate, $F$; and evaporation rates, $E$. $\Sigma P_g$, $\Sigma T$, $\Sigma F$ and $\Sigma E$ are the sums of each of these components at a given time. The interception loss, $\Sigma I$, in a storm, i.e., the water intercepted and evaporated between the time when rain begins to fall on a dry canopy and the end of the rainfall event when the canopy is again dry, is (Rutter *et al.*, 1971, 1975):

$$\Sigma I = \Sigma E = \Sigma P_g - \Sigma T - \Sigma F \tag{5.2}$$

The water balance of the canopy for any period within a storm may then be written as:

$$(1 - p - p_t)\ \Sigma P_g = \Sigma E + \Sigma D \pm \Delta C \tag{5.3}$$

and

$$p_t \Sigma P_g = \Sigma E_t + \Sigma F \pm \Delta C_t \tag{5.4}$$

where $\Sigma D$ is the amount of water draining or dripping from the canopy and $\Delta C$ is the change in the amount of water stored on the canopy, $C$.

It is assumed that there is a minimum quantity of water required to wet all the canopy surface. This corresponds to the canopy storage capacity, $S$, of Leyton *et al.* (1967). The amount of water stored on the canopy, $C$, may be larger or smaller than $S$. The rate of drainage, $D$, is calculated by Eq. 4.2. Another assumption applied in the Rutter model is that a potential evaporation rate, $E_{pot}$, is obtained when all canopy surfaces are wet, i.e., when $C>S$. The model also assume that when $C \leq S$ (indicating a partially wet canopy with no drainage), the rate of evaporation of any rainfall intercepted by the canopy is set equal to a proportion ($C/S$) of the wet canopy evaporation rate, $E_{pot}$ (Shuttleworth, 1988; Lloyd *et al.*, 1988), so that: $E_{ic} = E_{pot} \times C/S$. $E_{ic}$ is the evaporation rate from the wet tree canopy. These last two assumptions were verified by Teklehaimanot and Jarvis (1991). As the surface temperature of the canopy is not measured, the potential evaporation rate of intercepted rainfall, $E_{pot}$, is calculated from the Penman equation for saturated canopy. A parallel set of assumptions is made with respect to the water falling on the branches and trunks and channelled down the trunks in stemflow.

For the canopy, initially, the value of $C$ is set to zero, appropriate to dry canopy conditions. The change in canopy storage through time is obtained by rewriting Eq. 5.3 so that it operates as a running water balance (Rutter *et al.*, 1971, 1975):

$$\mathrm{d}C/\mathrm{d}t = \Sigma P_g\,(1 - p - p_t) - \Sigma E\,(C/S) - \Sigma D \tag{5.5}$$

Similarly for the trunks:

$$\mathrm{d}C_t/\mathrm{d}t = \Sigma P_g\, p_t - \Sigma E_t\,(C_t/S_t) - \Sigma F \tag{5.6}$$

As stated earlier, Whitehead and Kelliher (1991) modified the Rutter model and used the modified model for calculating interception loss before and after thinning of a *Pinus radiata* stand in New Zealand. Teklehaimanot and Jarvis (1991), using the modified WATMOD, have successfully predicted interception loss in an agroforestry systems with different tree spacings in Scotland. Two major modifications made by Teklehaimanot and Jarvis (1991) incorporated the boundary layer conductance, $g_a$, as a function of spacing and windspeed, in contrast to the original model in which it was assumed that $g_a$ is a constant value of $0.1u$, and related the drainage rate, *D*, to the difference between the amount of water stored in the canopy, *C*, and the canopy storage capacity, *S*, by a linear function in widely spaced stands. Other minor modifications included the elimination of some of the empiricisms in the original model such as the DRIP function used in conjunction with the exponential drainage function to calculate drainage when $C>S$.

### 5.3. The Gash model

An alternative to the Rutter model is the analytical model described by Gash (1979). The Gash model is a storm-based simplification of the Rutter model in which, if calibrated using hourly meteorological data, the mean evaporation rate, $\overline{E}$, and the mean rainfall rate, $\overline{R}$, can be run on daily rainfall values (Gash, 1979; Lloyd *et al.*, 1988). Consequently, daily records of meteorological data and the forest structure are sufficient to provide the inputs to the model, in contrast to hourly inputs required by the Rutter model. If one rainfall event per day is assumed, then $\overline{E}/\overline{R}$ ratios can be applied to other sites where only rainfall data are available. Lloyd *et al.*(1988) argued that such an assumption is reasonable in the humid tropics because of the short, intense storms, but it may not be acceptable in non-tropical areas, where the weather systems produce storms of long duration. A study in New Zealand indicated the inadequacy of this assumption when related to the long-duration storms typical of the temperate climatic regions (Pearce and Rowe, 1981).

The Gash model requires the same state variables of canopy and stand structures (*S*, *p*, $S_t$ and $p_t$) in addition to the predicted ratio of the mean evaporation rate to the mean rainfall rate, $\overline{E}/\overline{R}$, for hours when rain is falling on a saturated canopy. It is assumed that $\overline{E}/\overline{R}$ is constant during storms. The model considers rainfall to occur in a series of discrete storms each of which comprises a period of wetting-up, a period of saturation and a period of drying-out to empty the canopy storage. In previous applications of the Gash model in tropical rainforest areas (e.g. Rao, 1987; Lloyd *et al.*, 1988; Hutjes *et al.*, 1990), saturated conditions were arbitrarily defined as occurring when the hourly rainfall was greater than 0.50 mm. In this experimental site, the rainfall necessary to maintain saturation is 0.30 mm, following a widely accepted formula of $E/(1 - p - p_t)$ (Gash, 1979). As a compromise, an hourly rainfall value of 0.40 mm was used to indicate a saturated condition. The average evaporation rate and rainfall rate onto a saturated canopy were then used to estimate the total evaporation for each day and month. Evaporation from the wet canopy is assumed to occur at a fixed rate (Pearce and Rowe, 1981) equal to that calculated using the Penman equation (Eq. 5.7). It is also assumed that all rainfall on a day falls in a single storm, which may or may not be large enough to saturate the forest canopy.

This analytical model has been used satisfactorily in various different forests, including coniferous forest in the United Kingdom (e.g. Gash *et al,* 1980), evergreen mixed forest in New Zealand (e.g. Pearce and Rowe, 1981), tropical plantation forest in Indonesia (Bruijnzeel and Wiersum, 1987), and natural tropical rainforest in Amazonia (Lloyd *et al.*, 1988; Ubarana, 1996) and West Africa (e.g. Hutjes *et al.*, 1990). However, less success was obtained for sparse Sitka spruce (*Picea sitchensis*) stands in Scotland (Teklehaimanot and Jarvis, 1991) and thus led to a modification of the original model (Table 5.1), which requires an estimate of the evaporation per unit area of canopy rather than per unit ground area (Gash *et al.,* 1995). With the revised model, more open canopy structure can be taken into account, making it more suitable for calculating evaporation of intercepted water in a sparse forest stand. The stemflow sub-model has also been modified so that water is diverted to the trunks only after the canopy is saturated. Both the revised model and the original version (Gash, 1979), were applied in the unlogged and logged plots of this experiment.

**Table 5.1** Components of the rainfall interception loss of Gash's analytical model, revised version (Gash *et al.*, 1995).

| Component of interception | Gash's analytical formula |
|---|---|
| Amount of gross rainfall necessary to saturate the canopy ( $P_g'$ ) | $-(\overline{R}/\overline{E})\,S_c \ln[1-(\overline{E}_c/\overline{R})]$ |
| Amount of gross rainfall necessary to saturate the trunks ( $P_g''$ ) | $[\{\overline{R}/(\overline{R}-\overline{E}_c)\} \times S_t/p_t] + [P_g'']$ |
| Interception loss from the canopy: | |
| a. for $m$ small storms insufficient to saturate the canopy ( $P_g < P_g'$ ) | $c\sum_{j=1}^{m} P_{g,j}$ |
| b. for $n$ storms large enough to saturate the canopy ( $P_g \geq P_g'$ ) | $nc\,P_g' - nc\,S_c$ |
| c. for saturation until rainfall ceases | $(c\overline{E}_c/\overline{R})\sum_{j=1}^{n}(P_{g,j}-P_g')$ |
| d. evaporation after rainfall ceases | $ncS_c$ |
| Interception loss from the trunks: | |
| a. for $q$ storms that saturate the trunks ( $P_g \geq P_g''$ ) | $qS_t$ |
| b. for $n$-$q$ storms that do not ( $P_g < P_g''$ ) | $p_t\sum_{j=1}^{n-q} P_{g,j}$ |
| Stemflow | $p_t\sum_{j=1}^{q}(P_{g,j}-P_g'')$ |
| Throughfall | $[(1-c)\sum_{j=1}^{m+n} P_{g,j}] + c[1-(\overline{E}_c/\overline{R})]\sum_{j=1}^{n}(P_{g,j}-P_g')$ |

## 5.4. Determination of model parameters

### 5.4.1. Meteorological variables

Daily and hourly meteorological data of air temperature, relative humidity, net radiation, windspeed and precipitation were collected from three automatic weather stations located at different sites as outlined in Section 2.3. The mean evaporation rate, $\overline{E}$, during rainy hours when the canopy was saturated was calculated using the Penman equation. The canopy was presumed to be saturated when precipitation exceeded 0.40 mm, as discussed in Section 5.3. The mean rainfall rate, $\overline{R}$, was calculated from rainfall recorded in a large clearing area in the unlogged plot and in a canopy gap of the logged plot, 15 meters above the ground, again using rainfall events larger than 0.40 mm.

### 5.4.2. Canopy structure parameters

The canopy structure was represented by the canopy storage capacity, $S$, the free throughfall coefficient, $p$; the trunk storage capacity, $S_t$; and the stemflow partitioning coefficient, $p_t$. The boundary layer conductance, $g_a$ was also used as model input. All of these parameters were derived in Section 4.4.

## 5.5. Use of the Rutter model

### 5.5.1. Model assumptions

WATMOD as described in Whitehead and Kelliher (1991), was used to predict interception loss in the unlogged and logged plots. The original WATMOD uses the assumption that boundary layer conductance is unaffected by tree spacing and is always 0.1 times windspeed at tree top height in all tree spacings (Jarvis *et al.*, 1976). This assumption is based on the expectation that the air above a tall forest is well mixed by large scale turbulence in the convective boundary layer, such that small scale changes in stand architecture and, hence, energy balance, do not significantly affect the meteorological variables measured above the forest canopy or the transfer processes (McNaughton and Jarvis, 1983). The model combines the Penman-Monteith equation to estimate transpiration from the dry canopy and the Rutter model of interception to estimate evaporation from the canopy and trunks wetted by rainfall. Evaporation from the understorey and forest floor is also included in the canopy water balance model.

In this experiment, evaporation was limited to the canopy and trunks wetted by rainfall only. Evaporation from the dry canopy (i.e. transpiration) and evaporation from the understorey and forest floor was not included in the model. The assumptions used in the model indicate that when the tree canopy is partially wet, interception loss depends on the amount of water stored on the tree canopy. During and after rainfall, the amount of water stored on the tree canopy in the $j$th time period can be written as in Eq. 5.8.

Based on the Rutter model, when the canopy is partially wet, evaporation from the partially wet canopy is equal to the rate which would be obtained if all the canopy surfaces were wet, multiplied by the fraction of the canopy that was wet during the preceeding period ($C_{j-1}/S$). The fraction of the canopy that is completely wet in the *j*th period is $C_j/S$ (Rutter *et al.*, 1971, 1975; Shuttleworth, 1988). The average rate of canopy drainage, $D$, is assumed to be zero when $C_j \leq S$. When the amount of rainfall diverted to the canopy, $C$, during a period $\Delta t$ is greater than $S$, $D$ is equal to the amount of water on the canopy, $[(1-p-p_t)\,P_g - E_{ic}]\,\Delta t$, which exceeds the remaining water storage capacity ($S - C_{j-1}$) (Whitehead and Kelliher, 1991).

Eq. 5.9 describes the amount of water stored on the tree trunks, $C_{tj}$, in the *j*th period. If $S_t$ is the trunk water storage capacity, then the fraction of the trunks that is wet in the *j*th period is $C_{tj}/S_t$, and the average rate of drainage from wet trunks, $D_t$, is equal to the amount of rainfall diverted to the trunks, $(p_t\,P_g - E_{it})\,\Delta t$, which exceeds the remaining water storage capacity on the trunks ($S_t - C_{tj-1}$). $E_{it}$ is the evaporation rate from the trunks during the period.

### 5.5.2. Procedure for the application of the modified Rutter model

The procedure for the application of the model, WATMOD, is as follows:

1. The evaporation rate from the saturated canopy (when $C>S$) was calculated from the Penman equation (Eq. 5.7). When the canopy was partially wet (when $C = S$), the evaporation rate was calculated as $E_P \times C/S$ (Rutter *et al.*, 1971, 1975).

$$E_P = [sR_n + (\rho\, c_p\, D_{vp})\, g_a] \,/\, [\lambda\,(s+\gamma)] \tag{5.7}$$

   The boundary layer conductance, $g_a$, required for the solution of the Penman equation was calculated as in Sections 4.4.7 and 4.4.13 for both the unlogged and logged plots. In the logged plot, $g_a$ was calculated according to both, the three canopy cover areas and the canopy cover area taking no account of the canopy divisions.

2. During and after rainfall, the amount of water stored on the canopy, $C$, in the *j*th time period can be written as (Rutter *et al.*, 1971, 1975):

$$C_j = C_{j-1} + [(1-p-p_t)\,P_g - E_{ic} - D]\,\Delta t \tag{5.8}$$

Similarly for the trunk:

$$C_{tj} = C_{tj\text{-}1} + (\, p_t P_g - E_{it} - D_t)\, \Delta t \tag{5.9}$$

$E_{ic}$ and $E_{it}$ are evaporation rates from the wet tree canopy and trunks, respectively.

3. The model was run with an incremental time step of one hour to give throughfall and interception loss estimates for each rainfall event or day. These were then summed to provide the total throughfall and interception loss for the whole observation period.

4. The model predictions of throughfall and interception loss were compared with the two sets of measured data, as with the Gash model.

## 5.6. Use of the Gash model

### 5.6.1. Model assumptions

In the revised model of Gash (Gash *et al.*, 1995), two distinct sub-areas, open and covered areas, were considered, each having the same gross rainfall input. To comply with this revised conceptual framework for interception loss processes in a sparse forest stand, two new assumptions were introduced in the model: 1) the evaporation from a sparse forest should be predicted by reducing the evaporation calculated for a complete canopy in proportion to the canopy cover, and 2) rainfall is diverted to the trunks only after the canopy has become saturated. Therefore, the evaporation from the whole plot area is reduced in proprortion to the relative size of the covered area. Original canopy storage capacities $S$ and $S_t$ are redefined as $S_c$ (= $S/c$) and $S_{tc}$ (= $S_t/c$), where $c$ is the proportion of covered area relative to the total area. These new assumptions lead to the reformulation of the original equations as presented in Table 5.1.

### 5.6.2. Procedure for the application of the Gash model

The procedure followed in running the revised Gash model can be summarized as follows:

1. Canopy and stem parameter values ($S$, $S_t$, $p$, $p_t$) required for the model were derived from the field measurements using regression equations and the hemispherical photography technique (Section 4.3). In the unlogged plot, the canopy capacity per unit area of cover,

$S_c$, is assumed to be equal to $S$. In the logged plot, the values of $S_c$ were calculated according to the proportion of covered area relative to the total area, $c$. In the absence of detailed measurement for $c$, information on the basal area per canopy cover area has been used in this experiment to estimate $c$ values for different canopy cover conditions in the logged plot. In this experiment, the values of $c$ for the closed canopy, partial canopy and canopy gap areas were subjectively estimated to be 1.0, 0.5 and 0.2, respectively.

2. The rates of $\overline{E}$ in each treatment plot were calculated using the modified Penman equation, Eq. 5.7 (Monteith, 1965) from rainfall events larger than 0.40 mm. These mean evaporation rates were then averaged to give an estimate of $\overline{E}$. The rate of $\overline{E}$ for each canopy cover area in the logged plot was calculated from the mean evaporation rate in the whole plot weighted by the proportion of covered area relative to the total area.

3. Similarly, for the same hours, gross rainfall was extracted and averaged to give the mean rainfall rate, $\overline{R}$. These $\overline{E}$ and $\overline{R}$ values were then used to calculate the rainfall necessary to saturate the canopy, $P_g'$, and the trunks, $P_g''$, from the following equations (Gash *et al.*, 1995):

$$P_g' = -(\overline{R}/\overline{E}_c) \times S_c \ln [1-(\overline{E}_c/\overline{R})] \tag{5.10}$$

$$P_g'' = [(\overline{R}/\overline{R}-\overline{E}_c) \times (S_t/p_t)] + [P_g'] \tag{5.11}$$

   Both the rainfall necessary to saturate the canopy and the trunks for each canopy cover area in the logged plot were calculated using parameters estimated for each of these canopy cover areas.

4. The revised Gash model (Table 5.1) was used to predict throughfall and interception loss on a storm by storm basis. The original version of this Gash model is as outlined in Lloyd *et al.* (1988) and Gash *et al.* (1995). The model predictions were then summed to give total throughfall and interception for the whole measurement period. The model predictions were compared against the measured values for individual storms as well as for the totals.

## 5.7. Results

### The unlogged forest site

### 5.7.1. WATMOD

The predictions of throughfall and interception loss for each individual storm are shown in Appendix V (Table V.1). The number of storm events used in this study varied according to the availability of the micrometeorological data and other required model inputs. The regression equations between the model predictions and the measurements of throughfall and interception loss of individual storms are given in Table 5.2, which shows that there is close association between the predicted and measured throughfall in the unlogged plot (significant at $p$ = 0.01) but less close association between predicted and observed interception loss. The relationships between predicted and measured throughfall and interception loss in the unlogged plot are also shown graphically in Fig. 5.2. This figure indicates that the predicted interception loss for individual storms is slightly underpredicted. The sharp increase in the cumulative observed and predicted throughfall at the end of the curves of Fig. 5.2 is caused by two large and long-duration individual storms.

**Table 5.2** The relationship between hourly storm-based observed and predicted values in the unlogged plot. (WMODEL) indicates WATMOD output and (DATA) field data. $T_f$ = throughfall, $I$ = interception loss, $n$ = number of observations, $r^2$ = coefficient of determination of the regression equation.

| Parameters | $n$ | Regression equation | $r^2$ |
|---|---|---|---|
| $T_f$ | 19 | $T_f$ (WMODEL) = 0.1 + 1.0 $T_f$ (DATA) | 0.99 |
| $I$ | 19 | $I$ (WMODEL) = 1.2 + 0.6 $I$ (DATA) | 0.55 |

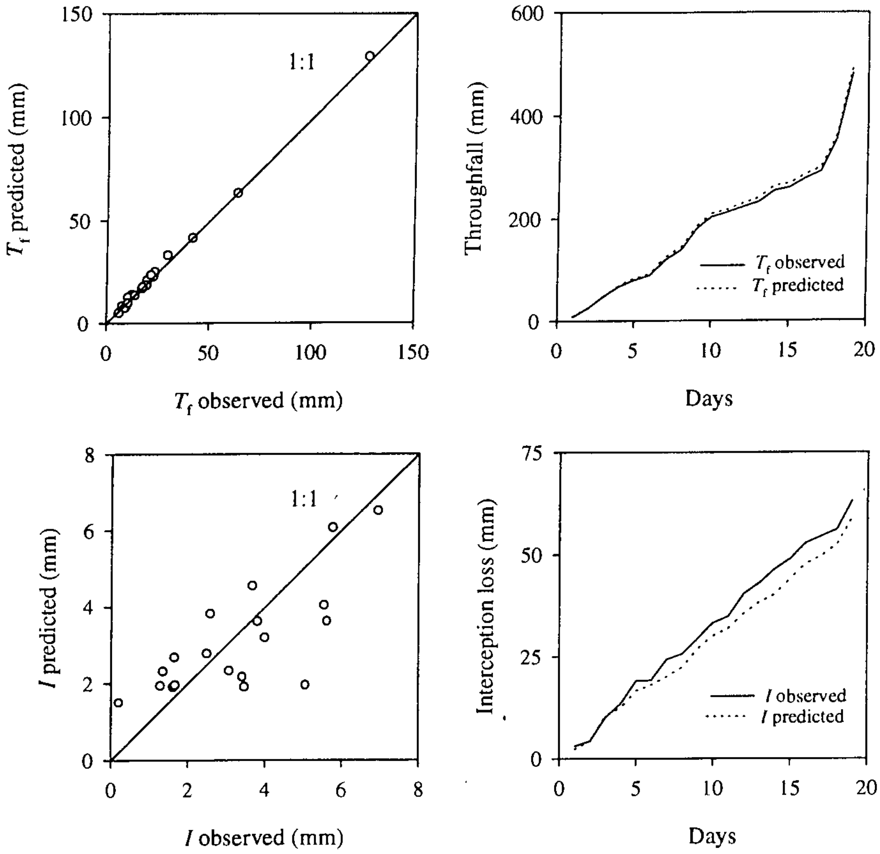



**Figure 5.2** The relationship between observed and WATMOD predicted throughfall, $T_f$, and interception loss, *I*, in the unlogged plot for individual storms.

## 5.7.2. The Gash model

The predicted values of throughfall and interception loss by the Gash model for each individual storm period in the unlogged plot are given in Appendix VI (Table VI.1). The mean evaporation rate, $\overline{E}$, was predicted to be 0.28 mm $h^{-1}$ and is comparable to similar estimates of 0.21 mm $h^{-1}$ (Lloyd *et al.*, 1988) and of 0.19 mm $h^{-1}$ (Hutjes *et al.*, 1990) in tropical rainforests of Brazil and Ivory Coast, respectively. The value of mean rainfall rate, $\overline{R}$, was calculated to be 5.7 mm $h^{-1}$, which is slightly larger than the 5.2 mm $h^{-1}$ of Lloyd *et al.* (1988). The predicted throughfall and interception loss output shows good agreement with the measured throughfall, as shown in Fig. 5.3. As shown in Table 5.3 and Fig. 5.3, there is a poor relationship between predicted and observed interception loss. Interception loss was underpredicted at values of interception loss larger than 3 mm (Fig. 5.3).

**Table 5.3** The relationship between storm by storm observed and predicted values of throughfall, $T_f$, and interception loss, $I$, in the unlogged plot. (GMODEL) indicates Gash model predicted and (DATA) field data. $n$ = number of observations, $r^2$ = coefficient of determination of the regression equation.

| Parameters | $n$ | Regression equation | $r^2$ |
|---|---|---|---|
| $T_f$ | 40 | $T_f$ (GMODEL) = 0.7 + 1.0 $T_f$ (DATA) | 0.99 |
| $I$ | 40 | $I$ (GMODEL) = 2.0 + 0.3 $I$ (DATA) | 0.27 |

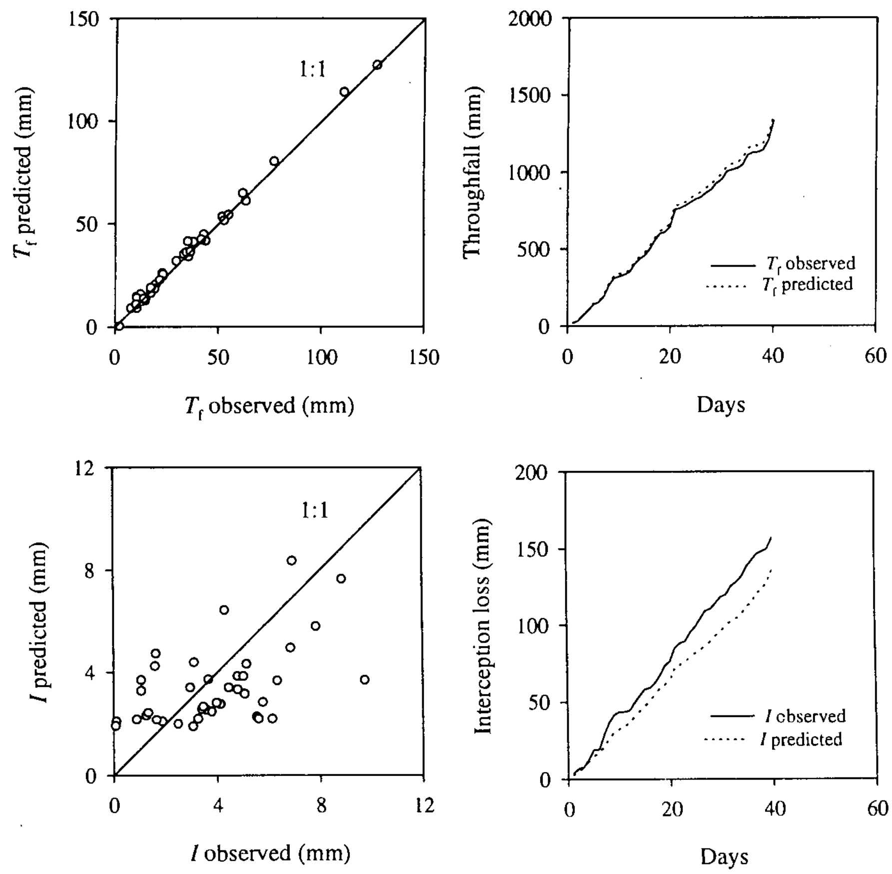



**Figure 5.3** The relationship between observed and the revised Gash model predicted throughfall, $T_f$, and interception loss, $I$, in the unlogged plot for individual storms.

Table 5.4 summarises the values of throughfall and interception loss predicted by the WATMOD and Gash models and observed in the unlogged plot. During the measurement period of 19 storms, WATMOD predicted a total interception loss of 5.8 ± 0.3 mm or 9.9 ±

0.5 % of the gross rainfall, while the Gash model predicted a total interception loss of 136.3 ± 0.2 mm (9.0 ± 0.01 %). The throughfall was calculated by WATMOD as 492.2 ± 6.5 mm (82.4 ± 1.0 %) and by the Gash model as 1370.7 ± 4.2 mm (90.8 ± 0.3 %). The difference of approximately 0.7 % of gross rainfall between WATMOD and the observed values of interception loss is considered to be acceptable. While the difference of approximately 1.4 % of gross rainfall between the Gash model and the observed values of interception loss is also acceptable, there is an indication that WATMOD performed better than the Gash model.

**Table 5.4** Observed and predicted results expressed as percentages of the gross rainfall in the unlogged plot for 19 storm events (WATMOD) and 40 (the Gash model). $I$ = interception loss, $T_f$ = throughfall, and $P_g$ = gross rainfall.

| Components | WATMOD | Gash model | Observed |
|---|---|---|---|
| Total $I$ | 9.9 | 9.0 | 10.6 (10.4)* |
| Total $T_f$ | 82.4 | 90.8 | 80.7 (88.3) |
| Total $P_g$ | 597.7 mm | 1508.5 mm | - |

* observed values for the Gash model

### 5.7.3. Sensitivity of the models

#### WATMOD

Sensitivity analysis is commonly used to test the relative influence of changes in the model parameters on the output of the model. To assess the poor results on interception loss, several simulation runs were performed on the available data in this experiment. To assess the sensitivity of the model to the most important parameters, the model was run using actual meteorological data with various combinations of values of canopy as well as aerodynamic roughness properties ($S$, $p$, and $g_a$) as demonstrated by Gash and Morton (1978), Mulder (1985), and Loustau *et al.* (1992). This analysis also provides some insight into the likely variation of interception loss which might be expected between different canopy structures in the same geographical location. For each run, one parameter was given an alternative value, in this experiment ± 30 % change, and the output compared with the output of the calibration runs as shown in Table 5.5. To examine the variation produced, the predicted interception loss using alternative values of the parameters was expressed as a ratio of the value predicted by the calibration run.

The model was very sensitive to variations in the canopy storage capacity, $S$, (Table 5.5). A change of 30 % in $S$ produced a change in interception loss of 17 %, while a change of 30 % in $p$ produced a change in interception loss of 1 %. Also noteworthy was the influence of a change in the canopy aerodynamic properties. A change of ± 30 % in $g_a$ at calibration values of $S$ and $p$ produced a change in interception loss of 6 to 8 %. Within the tested range, the model appeared to be fairly insensitive to changes in free throughfall coefficient. The result of this analysis indicates that the canopy storage capacity and the boundary layer conductance are the main stand and aerodynamic properties responsible for the variation of interception loss in the unlogged plot.

**Table 5.5** Comparison of outputs from the calibration runs ($I_{cal}$) with outputs from alternative runs ($I_{alt}$) for a range of parameter values in the unlogged plot. $S$ = canopy storage capacity, $p$ = free throughfall coefficient, $g_a$ = boundary layer conductance.

| | Parameter values | | | $I_{alt}$ / $I_{cal}$ |
|---|---|---|---|---|
| | $S$ | $p$ | $g_a$ | |
| Calibration values | 1.35 mm | 0.03 - | variable $m\ s^{-1}$ | - |
| Alternative values | 0.94 | | | 0.83 |
| | 1.75 | | | 1.17 |
| | | 0.02 | | 1.00 |
| | | 0.04 | | 1.01 |
| | | | + 30 % | 1.06 |
| | | | – 30 % | 0.92 |

Note: the standard error for the $I_{alt}$ / $I_{cal}$ values is ≤ ± 0.02

### The Gash model

The sensitivity test of the Gash model to uncertainty in model parameter values was done by running the model using the same meteorological data with different values of canopy storage capacity, $S$, free throughfall coefficient, $p$, mean rainfall rate, $\overline{R}$, and mean evaporation rate, $\overline{E}$. The value of each parameter was changed in turn by ± 30 %, which represents the error limits likely to be encountered in the measurement or derivation of the parameters. The results of these calculations are given in Table 5.6.

Table 5.6 shows that the model is sensitive to changes in mean rainfall and mean evaporation rates but insensitive to changes in canopy storage capacity, and free throughfall coefficient. A change of 30 % in $\overline{R}$ at $\overline{E} = 0.3$, $S = 1.35$, and $p = 0.03$ produced a variation in interception loss of 12 to 22 %, while a change of 30 % in either $S$ or $p$ at $\overline{E} = 0.3$, $\overline{R} = 5.8$ led to variation in interception loss of less than 1 %. When the mean evaporation rate was changed by ± 30 % and the other model parameters were held constant, the total predicted interception loss changed by 15 %. This analysis provides some insight into the likely source of variation of the observed interception loss and shows that the most important parameter in the Gash model is the mean rainfall rate, $\overline{R}$, and the mean evaporation rate, $\overline{E}$.

**Table 5.6** Comparison of outputs from the calibration runs ($I_{cal}$) with outputs from alternative runs ($I_{alt}$) for a range of parameter values in the unlogged plot. $S$ = canopy storage capacity, $p$ = free throughfall coefficient, $\overline{R}$ = mean rainfall rate, and $\overline{E}$ = mean evaporation rate.

| | Parameter values | | | | $I_{alt}$ / $I_{cal}$ |
|---|---|---|---|---|---|
| | $S$ | $p$ | $\overline{R}$ | $\overline{E}$ | |
| Calibration values | 1.35 mm | 0.03 - | 5.8 mm h$^{-1}$ | 0.30 mm h$^{-1}$ | - |
| Alternative values | 0.94 | | | | 1.00 |
| | 1.75 | | | | 1.00 |
| | | 0.02 | | | 1.01 |
| | | 0.04 | | | 0.99 |
| | | | 4.06 | | 1.22 |
| | | | 7.54 | | 0.88 |
| | | | | 0.21 | 0.85 |
| | | | | 0.39 | 1.15 |

Note: the standard error for the $I_{alt}$ / $I_{cal}$ values is ≤ ± 0.01

**The logged forest site**

### 5.8.4. WATMOD

In the logged plot, the forest canopy has a discontinuous canopy cover as a result of logging activities. The changes in forest canopy structure have led to changes in canopy and aerodynamic properties. Modelling of interception loss has been done in the same way as in the unlogged forest, except that changes were made in the canopy and aerodynamic properties. In this site, modelling was performed for the whole plot with no canopy cover division, and also according to the canopy cover area. The results can then be used to decide whether such division is required to model the logged-over area or other discontinuous areas with different vegetation cover.

The predictions of throughfall and interception loss from WATMOD for each individual storms are shown in Appendix V (Table V.2). The regression equations between the model predictions and the measurements of throughfall and interception loss of individual storms are given in Table 5.7, which shows that there is a strong association between the predicted and measured values of throughfall and interception loss (significant at $p = 0.05$), except for the canopy gap area, where the association is weak. Figs. 5.4 to 5.7 give further evidence of the closeness of the association between the predicted and observed throughfall and interception loss in the logged plot. Figs. 5.4 to 5.6 show the relationship between observed and predicted throughfall and interception loss from different canopy cover conditions, while Fig. 5.7 shows the same relationship, except that there is no canopy division. The figures indicate a tendency for the predicted interception loss for individual storms to be overpredicted as the canopy cover becomes sparser. The marked decrease in the cumulative interception loss observed in Fig. 5.7 was associated with large rainfall events. The rainfall event on the second day was derived from a long-duration storm that lasted for more than 24 hours.

**Table 5.7** The relationship between hourly storm-based observed and predicted values in the logged plot. (WMODEL) indicates WATMOD output and (DATA) field data. $T_f$ = throughfall, and $I$ = interception loss, $n$ = number of observations, $r^2$ = coefficient of determination of the regression equation.

| Parameters | $n$ | Regression equations | $r^2$ |
|---|---|---|---|
| Overall: | | | |
| $T_f$ | 50 | $T_f$ (WMODEL) = – 1.1 + 1.0 $T_f$ (DATA) | 0.99 |
| $I$ | 50 | $I$ (WMODEL) = 1.4 + 0.5 $I$ (DATA) | 0.73 |
| The closed canopy area: | | | |
| $T_f$ | 38 | $T_f$ (WMODEL) = – 0.2 + 1.0 $T_f$ (DATA) | 0.99 |
| $I$ | 38 | $I$ (WMODEL) = 1.2 + 0.6 $I$ (DATA) | 0.77 |
| The partial canopy area: | | | |
| $T_f$ | 32 | $T_f$ (WMODEL) = – 0.8 + 1.0 $T_f$ (DATA) | 0.99 |
| $I$ | 32 | $I$ (WMODEL) = 1.1 + 0.7 $I$ (DATA) | 0.90 |
| The canopy gap area: | | | |
| $T_f$ | 28 | $T_f$ (WMODEL) = – 0.5 + 1.0 $T_f$ (DATA) | 0.99 |
| $I$ | 28 | $I$ (WMODEL) = 1.1 + 0.5 $I$ (DATA) | 0.38 |

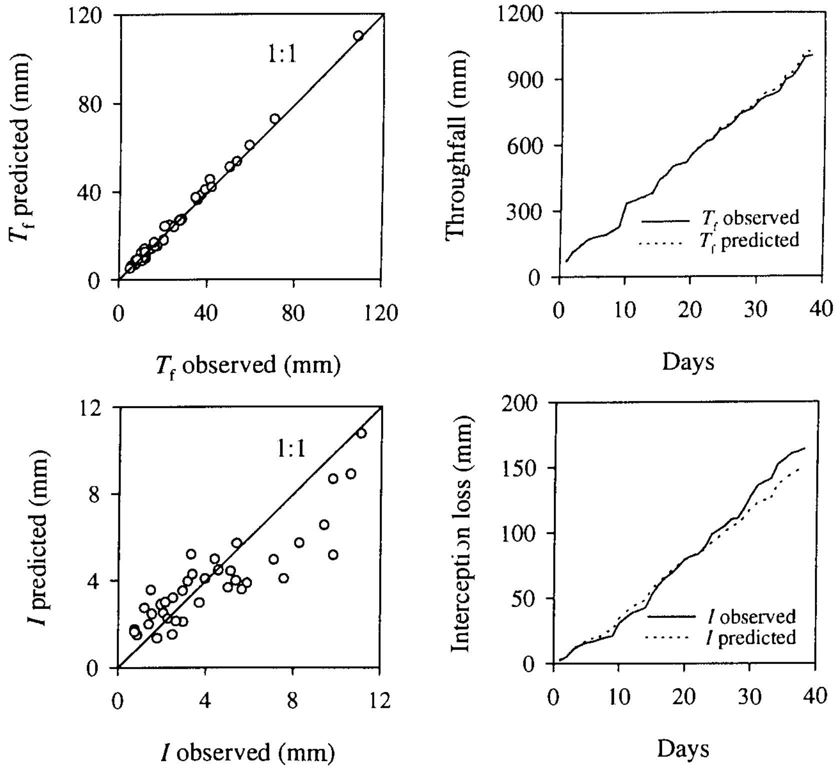



**Figure 5.4** The relationship between observed and WATMOD predicted throughfall, $T_f$, and interception loss, $I$, in the **closed canopy** area of the logged plot for individual storms.

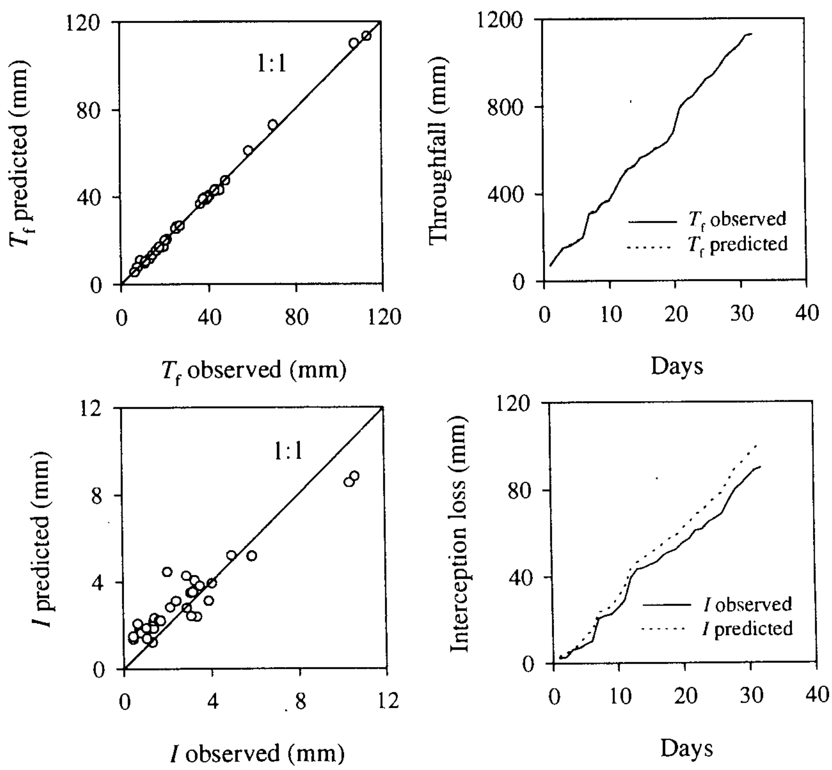



**Figure 5.5** The relationship between observed and WATMOD predicted throughfall, $T_f$, and interception loss, $I$, in the **partial canopy** area of the logged plot for individual storms.

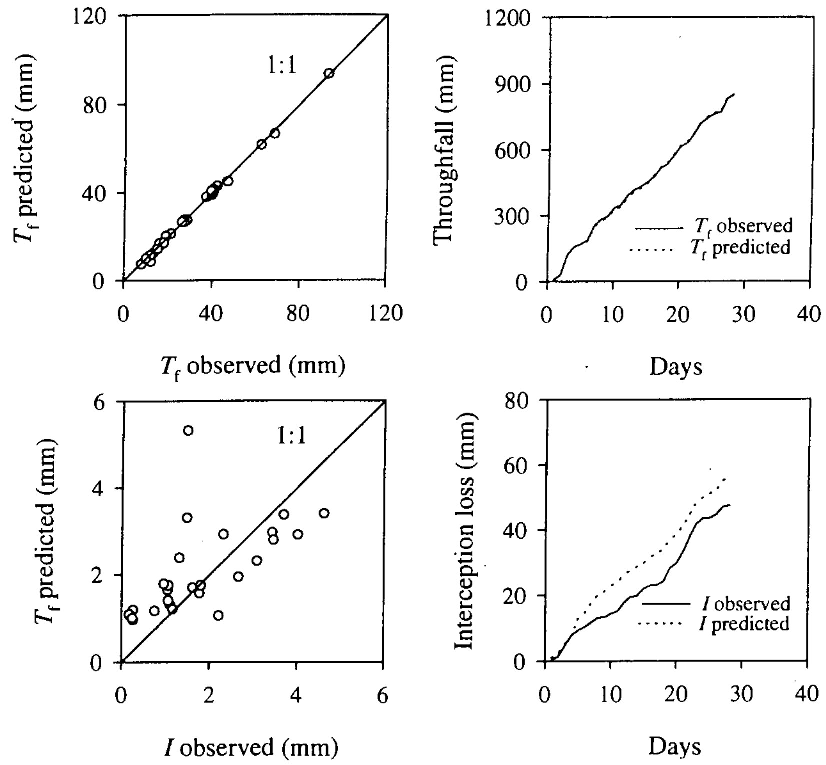



**Figure 5.6** The relationship between observed and WATMOD predicted throughfall, $T_f$, and interception loss, $I$, in the **canopy gap** area of the logged plot for individual storms.

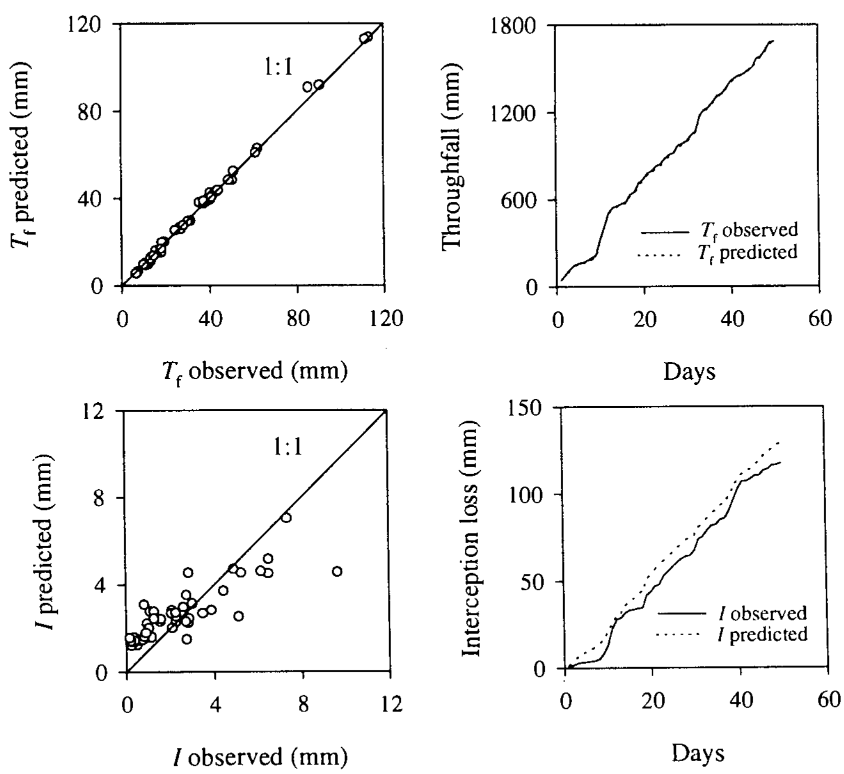



**Figure 5.7** The relationship between observed and WATMOD predicted throughfall, $T_f$, and interception loss, $I$, with no canopy cover division in the logged plot for individual storms.

### 5.8.5. The Gash model

The model predictions of throughfall, stemflow and interception loss by the Gash model for each individual storm in the logged plot are given in Appendix VI (Table VI.2). As shown in Table 5.8 and Fig. 5.8, there is a very strong association between predicted and observed throughfall. The predicted interception loss was poorly associated with the observed interception loss but there is a better in fit than the unlogged plot (Table 5.3). Fig. 5.9 shows the relationship between predicted and observed throughfall and interception loss using the original version of the Gash model (Gash, 1979). Figs. 5.8 and 5.9 indicate that for large values of interception loss, the revised Gash model tended to underestimate interception loss, while the original Gash model overestimates interception loss for both small and large values.

**Table 5.8** The relationship between storm by storm observed and predicted values of interception loss, $I$, and throughfall, $T_f$, in the logged plot. (GMODEL) indicates the revised Gash model estimates and (DATA) field data. $n$ = number of observations, $r^2$ = coefficient of determination of the regression equation.

| Parameters | $n$ | Regression equation | $r^2$ |
|---|---|---|---|
| $T_f$ | 70 | $T_f$ (GMODEL) = − 0.2 + 1.0 $T_f$ (DATA) | 0.99 |
| $I$ | 70 | $I$ (GMODEL) = 1.2 + 0.4 $I$ (DATA) | 0.40 |

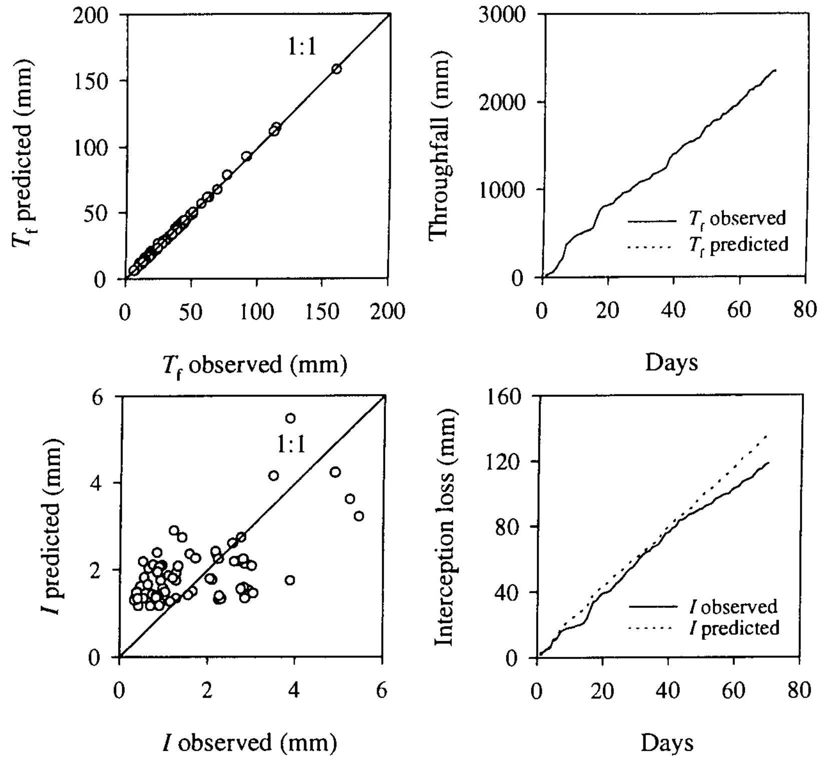



**Figure 5.8** The relationship between observed and the revised Gash model predicted throughfall, $T_f$, and interception loss, $I$, in the logged plot for individual storms.

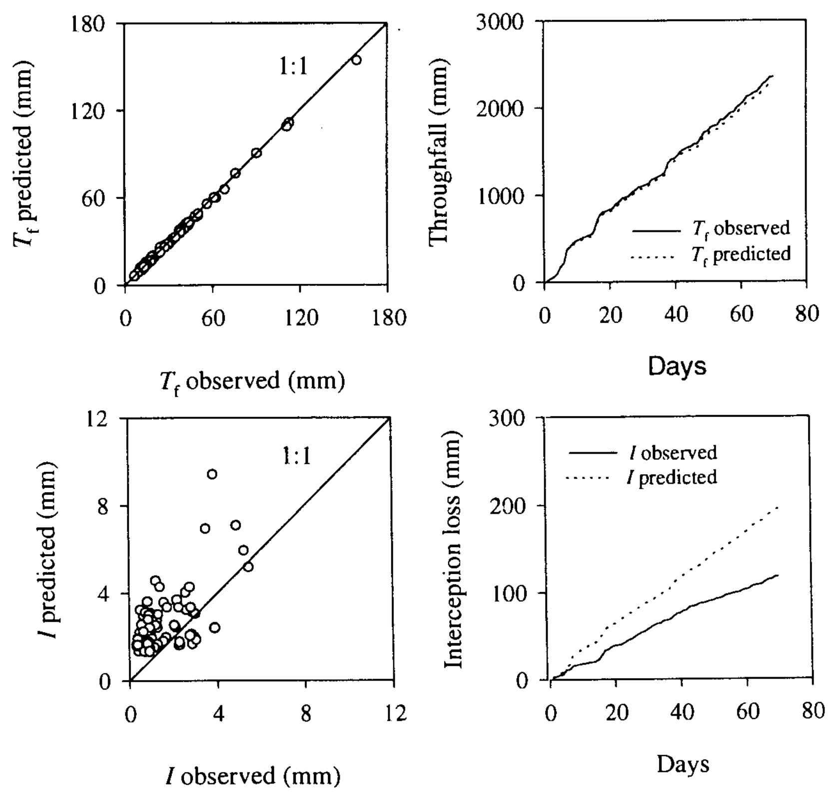



**Figure 5.9** The relationship between observed and the original Gash model predicted throughfall, $T_f$, and interception loss, $I$, in the logged plot for individual storms. The regression equations are: $T_f$ (MODEL)= – 0.2 + 0.9$T_f$ (DATA), $r^2 = 0.99$; $I$ (MODEL) = 1.5 + 0.7 $I$ (DATA), $r^2 = 0.37$.

Table 5.9 summarises the observed values of throughfall and interception loss and those predicted by the WATMOD and Gash models. During the measurement period ranging from 28 to 70 storms (Table 5.7), WATMOD predicted a total interception loss of 129.3 ± 0.2 mm or 7.2 ± 0.01 % of the gross rainfall for no canopy division. The revised Gash model predicted a total interception loss of 135.3 ± 0.1 mm (5.5 ± 0.004 %). The throughfall predicted by WATMOD was 1676.1 ± 3.6 mm (92.7 ± 0.2 %) and by the revised Gash model was 2336.2 ± 3.2 mm (94.5 ± 0.1 %). The difference of approximately 1 % of gross rainfall between either model prediction and the observed interception loss indicates that both models give an adequate prediction.

The predicted and observed results expressed as percentages of gross rainfall according to the canopy cover area are also presented in Table 5.9. The overall performances of these two models for each canopy cover area is that WATMOD performs much better than the revised Gash model. The difference between observed and WATMOD predicted interception loss was approximately 1 %, while the difference between observed and predicted interception loss by the revised Gash model ranged from 1.3 to 4.2 %.

**Table 5.9** Measured and modelled results expressed as percentages of the gross rainfall in the logged plot. $I$ = interception loss, $T_f$ = throughfall, and $P_g$ = gross rainfall.

| Components | WATMOD | Gash model | Observed |
|---|---|---|---|
| Overall: | | | |
| Total $I$ | 7.2 | 5.5 | 6.5 (4.8) * |
| Total $T_f$ | 92.7 | 94.5 | 93.2 (95.0) |
| Total $P_g$ | 1808.5 mm | 2471.7 mm | - |
| The closed canopy area: | | | |
| Total $I$ | 12.7 | 8.7 | 14.0 (12.9) |
| Total $T_f$ | 87.5 | 82.9 | 85.7 (78.6) |
| Total $P_g$ | 1172.9 mm | 900.7 mm | - |
| The partial canopy area: | | | |
| Total $I$ | 8.2 | 5.3 | 7.3 (6.9) |
| Total $T_f$ | 91.8 | 94.5 | 92.1 (92.8) |
| Total $P_g$ | 1225.4 mm | 850.7 mm | - |
| The canopy gap area: | | | |
| Total $I$ | 6.3 | 2.2 | 5.3 (4.5) |
| Total $T_f$ | 93.5 | 97.8 | 94.7 (95.5) |
| Total $P_g$ | 897.2 mm | 970.0 mm | - |

* observed values for the Gash model

### 5.8.6. Sensitivity of the models

#### WATMOD

The assessment of sensitivity of WATMOD to uncertainty in the model parameters has been simplified by considering only the most important parameters, which include canopy storage capacity, $S$, free throughfall coefficient, $p$, and boundary layer conductance, $g_a$. To assess the sensitivity of the model to these parameters, the model was run for various combinations of values of $S$, $p$, $g_a$, as summarised in Table 5.10.

Table 5.10 shows that WATMOD is sensitive to changes in the canopy storage capacity, $S$. A change of plus or minus 30 % in $S$ led to a change in interception loss of 15 %, while the same change in other model parameters led to a change of only 4 % or less.

**Table 5.10** Comparison of outputs from the calibration runs ($I_{cal}$) with outputs from alternative runs ($I_{alt}$) for a range of parameter values in the logged plot. $S$ = canopy storage capacity, $p$ = free throughfall coefficient, $g_a$ = boundary layer conductance.

| | Parameter values | | | $I_{alt}$ / $I_{cal}$ |
|---|---|---|---|---|
| | $S$ | $p$ | $g_a$ | |
| Calibration values | 1.0<br>mm | 0.3<br>- | variable<br>m s$^{-1}$ | - |
| Alternative values | 0.7 | | | 0.84 |
| | 1.3 | | | 1.15 |
| | | 0.2 | | 1.00 |
| | | 0.4 | | 1.02 |
| | | | + 30 % | 0.98 |
| | | | – 30 % | 0.96 |

Note: the standard error for the $I_{alt}$ / $I_{cal}$ values is ≤ ± 0.02

**The Gash model**

To assess the sensitivity of the Gash model a plus-minus change of 30 % was applied to the calibration model parameters as shown in Table 5.11. The Gash model parameters assessed in this study include canopy storage capacity, $S$, free throughfall coefficient, $p$, mean evaporation rate, $\overline{E}$, and mean rainfall rate, $\overline{R}$.

Table 5.11 shows that the Gash model is sensitive to changes $\overline{E}$ and $\overline{R}$ but insensitive to changes in $S$ and $p$. A change of 30 % in $\overline{R}$ at $\overline{E}$ = 0.3, $S$ = 1.0 and $p$ = 0.3, produced a change in interception loss of 13 to 24 %, while a change of 30 % in $S$ at $\overline{E}$ = 0.3 and $\overline{R}$= 5.8, led to no variation in interception loss. A change in 30 % of $p$ at the calibration values of $\overline{E}$ and $\overline{R}$ led to a change in interception loss of only 6 %. When the mean evaporation rate was changed by ± 30 % and the other model parameters were held constant, the total predicted interception loss was changed by 17 %.

**Table 5.11** Comparison of outputs from the calibration runs ($I_{cal}$) with outputs from alternative runs ($I_{alt}$) for a range of parameter values in the logged plot. $S$ = canopy storage capacity, $p$ = free throughfall coefficient, $\overline{R}$ = mean rainfall rate, and $\overline{E}$ = mean evaporation rate.

| | Parameter values | | | | $I_{alt}$ / $I_{cal}$ |
|---|---|---|---|---|---|
| | $S$ | $p$ | $\overline{R}$ | $\overline{E}$ | |
| Calibration values | 1.0 mm | 0.3 - | 5.8 mm h$^{-1}$ | 0.3 mm h$^{-1}$ | - |
| Alternative values | 0.70 | | | | 1.00 |
| | 1.30 | | | | 1.00 |
| | | 0.21 | | | 1.06 |
| | | 0.39 | | | 0.94 |
| | | | 4.06 | | 1.24 |
| | | | 7.54 | | 0.87 |
| | | | | 0.21 | 0.83 |
| | | | | 0.39 | 1.17 |

Note: the standard error for the $I_{alt}$ / $I_{cal}$ values is ≤± 0.01

## 5.9. Discussion

To assess the agreement between predicted and observed throughfall several statistical tests were performed (Table 5.12). First, the relationships between observed and predicted throughfall were tested by the regression. The coefficients of determination, $r^2$, are all 0.99. Observed and predicted means of throughfall were also compared using the standard errors of the estimates obtained from each regression equation. The differences were not significant at $p$ = 0.01. The agreements between observed and predicted totals were also assessed by calculating the ratio of predicted to observed losses and then testing the hypothesis that the mean value of that ratio did not differ from 1.0. The result indicated no significant differences of the mean ratios from 1.0 at $p$ = 0.01 (Table 5.12). These tests suggested that these models adequately simulated total throughfall over a long-period.

**Table 5.12** Tests on the agreement between predicted and observed throughfall, $T_f$, in the unlogged and logged plots. SE is the standard error of estimate of observed on predicted values; $n$ is the number of observation; $r^2$ is the coefficient of determination; $\overline{x / y}$ is the mean ratio of predicted to observed throughfall.

| Model | Mean $T_f$ obs. | Mean $T_f$ est. | $n$ | SE | $r^2$ | $\overline{x / y}$ |
|---|---|---|---|---|---|---|
| The unlogged plot | | | | | | |
| WATMOD | 25.4 | 25.9 | 19 | 0.5 | 0.99 | 0.98 |
| Gash | 33.3 | 34.3 | 40 | 0.6 | 0.99 | 0.99 |
| The logged plot | | | | | | |
| WATMOD | 33.7 | 33.5 | 50 | 0.14 | 0.99 | 0.97 |
| Gash | 33.5 | 33.4 | 70 | 0.12 | 0.99 | 0.99 |

The predicted interception losses found in both the unlogged and logged plots using both the models, the WATMOD and an analytical model of Gash, are of similar magnitude to those found in other tropical rainforests (e.g. Rao, 1987; Lloyd *et al.*, 1988; Hutjes *et al.*, 1990; Ubarana, 1996), i.e. they are a relatively small percentage of the gross rainfall with a considerable variation in model prediction. The discrepancy between predicted and measured interception loss, as some researchers have previously indicated, is often related to errors in measurement of model parameters and/or errors in the physical description of the stand in the model. It can also be attributed to large errors in the measurement of interception loss as the small difference between two large numbers, gross rainfall and throughfall. Table 5.13 shows the statistical tests on the agreement between predicted and observed interception loss in the unlogged and logged plots.

The regression relation between observed and predicted interception loss in the unlogged and logged plots as in Table 5.13 shows that model performances for interception loss are not as good as for throughfall. This can be observed from the coefficient of determination values, which varies from 0.27 to 0.72. The comparison of observed and predicted means of interception loss indicates that the differences were not significant at $p = 0.05$. The agreement between observed and predicted total interception losses was also assessed and the results indicated no significant differences of the mean ratios from 1.0 at $p = 0.05$. These results suggested that these models adequately simulated total interception loss over a long-period.

**Table 5.13** Tests on the agreement between predicted and observed interception loss, $I$, in the unlogged and logged plots. SE is the standard error of estimate of observed on predicted values; $n$ is the number of observation; $r^2$ is the coefficient of determination; $\overline{x / y}$ is the mean ratio of predicted to observed interception loss.

| Model | Mean $I$ obs. | Mean $I$ est. | $n$ | SE | $r^2$ | $\overline{x / y}$ |
|---|---|---|---|---|---|---|
| The unlogged plot | | | | | | |
| WATMOD | 3.3 | 3.0 | 19 | 0.36 | 0.55 | 0.96 |
| Gash | 3.9 | 3.4 | 40 | 0.65 | 0.27 | 0.79 |
| The logged plot | | | | | | |
| WATMOD | 2.3 | 2.5 | 50 | 0.18 | 0.72 | 1.04 |
| Gash | 1.6 | 1.9 | 70 | 0.11 | 0.38 | 0.96 |

The Gash model, as tested by Bruijnzeel and Wiersum (1987) in an Indonesian forest plantation, produced only minor differences between observed and predicted interception losses. In a tropical forest of Ivory Coast (Hutjes *et al.*, 1990), however, the discrepancy was much larger, i.e. 35 %. This large discrepancy was attributed to the error associated with either the measurement of model parameters or the description of model assumptions. Lloyd *et al.* (1988) suggested that the error in the simulated loss can largely be attributed to error in the estimation of $S$. However, Hutjes *et al.* (1990) argued that it is the single storm assumption which causes the discrepancy. The difference between cumulative observed and predicted interception loss by the Gash model, expressed as the percentage of the gross rainfall, in the present study is less than 1 % for both the unlogged and logged plots (Tables 5.4 and 5.9). This result seems to be much better than the results obtained by Hutjes *et al.* (1990), and better than in a similar study in a tropical forest in India, where modelled interception loss was 10 % less than the observed (Rao, 1987). The result of this study is also comparable with the result in a modelling interception loss study by Lloyd *et al.* (1988) in the Amazonian forest and in a study by Navar and Bryan (1994) in a semi-arid vegetation community in Mexico, in which the difference between modelled and observed interception loss were 2 % and 0.32 %, respectively.

The discrepancy between observed and predicted cumulative interception loss using the modified Rutter model, WATMOD, in both the unlogged and logged plots was also small (less than 1 % of gross rainfall, Tables 5.4 and 5.9). This is in a very good agreement with similar interception loss studies in the Amazonian forest by Lloyd *et al.* (1988) and by Ubarana (1996), where the difference between observed and predicted interception loss was less than 5 % of the gross rainfall. The discrepancy between observed and predicted cumulative interception loss was different in different canopy cover areas of the logged plot. The largest discrepancy (2.7 %) was found in the closed canopy area followed by the partial canopy and the canopy gap areas (0.9 and 1.0 % of gross rainfall, respectively) (Table 5.9). Nevertheless, these discrepancies are still comparable to the modelling of interception loss in the logged plot without taking into account the canopy cover divisions. The WATMOD performs better than the Gash model for modelling canopy cover area-based interception loss.

The sensitivity analyses showed that WATMOD is very sensitive to variations in the canopy storage capacity, $S$, whereas it is insensitive to the free throughfall coefficient, $p$, within the tested range. However, the change of $S$ from 1.3 to 1.0 mm as a result of logging activity gave a change of only 2 % in the model output. The model is relatively sensitive to changes in the boundary layer conductance, $g_a$, especially in the unlogged forest, where ± 30 % changes in $g_a$ led to changes of interception loss of 6 to 8 %. In the logged plot, the same changes in $g_a$ produced changes of interception loss of only 2-4 %. The significant influence of $S$ and, to a smaller extent, of $g_a$ indicates the predominant role of the canopy and aerodynamic properties in determining interception loss during and shortly after precipitation.

The total interception loss predicted by the Gash model, as can be seen from Tables 5.6 and 5.11, seems very sensitive to changes in mean rainfall rate, $\overline{R}$, and mean evaporation rate, $\overline{E}$, in both the unlogged and logged plots, where ± 30 % changes in $\overline{R}$ and $\overline{E}$ led to the changes of interception loss of about 12 to 24 %. A similar result of model sensitivity to changes in mean evaporation rate was reported by Navar and Bryan (1994) in their study on a semi-arid vegetation in Mexico, where a change of 35 % in $\overline{E}$ produced a change in total interception loss of 26 % of gross rainfall. The sensitivity of the predictions to changes in $\overline{E}$ and $\overline{R}$ may be associated with the interception loss calculated with the Gash model, where 55 % of total evaporation in the unlogged plot was lost during saturated conditions, 40 % during the drying-out phase, 2 % during the wetting-up phase, and the remaining 3 % the evaporation during small storms insufficient to saturate the canopy. For the logged plot, the corresponding figures are 47 % for saturated conditions, 51 % for the drying-out phase, 0.5 % for the wetting-up phase, and 1.5 % for small storms. It is clear that evaporation of intercepted water occurs mainly during the saturated conditions, for which the values of $\overline{E}$ and $\overline{R}$ are incorporated in the model. Similar studies using the Gash model in tropical regions also indicate that a large portion of intercepted rainfall was evaporated during saturated conditions, as shown in Table 5.14.

**Table 5.14** Components as percentages of total interception loss, as predicted by the Gash models in this study, and related studies using the Gash model.

| Interception components | The unlogged plot | The logged plot | Other related studies | | |
|---|---|---|---|---|---|
| | | | a | b | c |
| Small storms | 3 | 1.5 | 2 | 9 | 8 |
| Wetting-up phase, large storms | 2 | 0.5 | 1 | 1 | 1 |
| Saturation phase, large storms | 55 | 47 | 76 | 35 | 17 |
| Drying-out phase, large storms | 40 | 51 | 21 | 55 | 74 |

a. Bruijnzeel and Wiersum (1987): tropical plantation in Indonesia.
b. Lloyd *et al.* (1988): Amazonian tropical forest in Brazil.
c. Hutjes *et al.* (1990): humid tropical forest in Ivory Coast.

The following conclusions can be drawn from the results of the study:

- Both models used in this study, WATMOD and the Gash model, adequately predicted total interception loss over a long period (several months or on a seasonal basis). The difference between cumulative observed and predicted interception loss by these two models, expressed as the percentage of the gross rainfall, was less than 2 % for both the unlogged and logged plots. However, the models were not adequate in predicting interception loss on a storm by storm basis.

- In the unlogged plot, the revised Gash model's performance is as good as the original Gash model. In the logged plot, taking no account of canopy cover divisions, the revised Gash model is better than that of the original Gash model (the difference between observed and predicted interception loss, expressed as a percentage of gross rainfall are 0.7 and 3 %, respectively). When the one hectare plot was divided into three canopy cover areas, neither the revised Gash model nor the original one performed adequately.

- WATMOD performs better than the Gash model in both the unlogged and logged plots. In the logged plot, with or without canopy cover divisions, WATMOD simulated interception loss adequately. In general, modelling interception loss in the logged plot without dividing it into different canopy cover areas resulted in better predictions than when areas were divided by canopy cover.

- In both the unlogged and logged plots, WATMOD is sensitive to the canopy storage capacity, $S$, and to the boundary layer conductance, $g_a$, where the Gash model is sensitive to both mean evaporation rate, $\overline{E}$, and mean rainfall rate, $\overline{R}$. A change of ± 30 % in $S$ and $g_a$ led to a change of interception loss of 15 to 17 % and 4 to 8 %, respectively. A change of ± 30 % in $\overline{E}$ and $\overline{R}$ led to a change of interception loss of 15 and 17 %.

# Chapter 6

## Conclusions and recommendations

### 6.1. Introduction

Evaporation of intercepted rainfall by forests has been studied in various parts of the world for many years. Researchers in various fields, such as forestry, agriculture, hydrology, and meteorology have made a number of studies of interception loss for different purposes. The results that have been documented so far, especially those in temperate regions, have highlighted the role of interception loss in the water balance of a forested area or a catchment. So far only a few reliable studies on interception loss have been carried out in tropical rainforests. However, there has been no investigation of interception loss so far in logged forest conditions, despite the fact that forest logging has long been practised in many parts of the tropical regions. Therefore, the major question which this experiment was designed to answer is, "What effects do logging practices have on the interception loss of lowland tropical rainforest". The conclusions that can be drawn from this project fall into two parts. The first part is concerned with matters relating to the instrumentation and measurement problems involved in determining interception loss. The second part consists of the scientific conclusions and recommendations that can be drawn from the findings of the experiment.

### 6.2. Instrumentation and measurement problems

#### 6.2.1. The volume balance method

In the volume balance approach, evaporation of intercepted water is calculated by subtracting net rainfall (throughfall + stemflow) from gross rainfall. Since accurate estimation of evaporation rate of intercepted rainfall is determined by the net and gross rainfall, one should be critical of the measurements of these two variables. In an undisturbed natural rainforest, two alternatives are available for gross rainfall: measurement above the forest canopy or in a cleared forest area. Experiments done by Reynolds and Leyton (1963) and Mueller and Kidder (1972) showed that rainfall measurements made above the forest canopy are subject to large errors attributable to the disturbing effect of wind on raingauge catch. Errors are largest when windspeeds are high and raindrop size is small, resulting in underestimation of rainfall (Green, 1972; Ward and Robinson, 1990). For this reason, in many experiments in temperate regions, gross rainfall has been measured a few metres above the ground in a forest clearing rather than at or above canopy level. In tropical regions, storms are typically intense and accompanied by light winds and so aerodynamic-related errors are likely to be small. For this reason, gross rainfall in this experiment has been measured using a 0.2 mm tipping bucket sited on top of a post, 15 m above the ground (more than half the height of the forest canopy), and a few simple funnel + bottle gauges above the ground in a forest clearing, to minimise any possible disturbing effects of wind on raingauge catch. The data indicate that the position of the raingauges used and their arrangement in the field gives a good estimate of rainfall at the research sites as shown in Sections 3.1 and 3.5 of Chapter 3.

In the case of throughfall measurement, the most important consideration is the number of gauges used and the way they are operated, because throughfall is unevenly distributed under forest canopies, especially in undisturbed tropical rainforest. To achieve accurate measurements of throughfall, previous investigators have used either a large number of funnel gauges or sheet gauges to integrate the throughfall variation. In this experiment, throughfall was measured by a large number of gauges installed randomly along transect lines in the unlogged plot and according to stratum in the logged plot. The results given in Sections 3.2 and 3.6 clearly show the spatial variability of throughfall and, since this study was conducted in a relatively small area (within the same rainfall regime), this variability of throughfall can be attributed to stand structure. It can, therefore, be concluded that the random relocation of throughfall gauges beneath forest canopies is important if an accurate measurement of throughfall is to be made in tropical rainforest.

Stemflow was measured using half-sections of plastic tubes of different sizes, according to the sample tree diameter. The measurement of stemflow was done by two means: automatic measurement using a data logger and manual measurement using large plastic containers. The data were required for deriving model parameters and to estimate the total stemflow corresponding to total gross rainfall and throughfall over longer time intervals. The 1 $dm^3$ tipping bucket used for measuring stemflow automatically was also equipped with a mechanical counter which was very useful because the electrical mechanism in the data logger failed to operate on occasions, and also provided a check on the stemflow recorded by the data logger. The results presented in Sections 3.3 and 3.7 show that the method used in this experiment for measuring stemflow was satisfactory. In undisturbed rainforest with high variability in tree characteristics of size, shape and bark, more accurate results would be obtained if stemflow had been measured on a larger number of sample trees over a wider range of tree characteristics. However, this is not crucial as stemflow accounted for only a small proportion of the gross rainfall.

It was anticipated that the environment of a tropical rainforest would introduce experimental difficulties different from those encountered in temperate regions and this was found to be the case. These difficulties arose from the high frequency of electrical storms and lightning strikes which occasionally damaged the electrical devices in the logger, causing malfunctioning of the data logger and some loss of data. Minor difficulties were also experienced with insects eating the insulation of electrical cables, with blocking of the funnel and tipping bucket raingauges with leaf litter, and leakage from the half-section plastic tubes for stemflow measurement. Despite all these problems, a quantity of reliable data has been obtained for this rainfall interception study. Considering the nature of the problems encountered, reguler checking of the research devices and their support systems used in future experiments should be carried out to ensure that the devices are in good working condition.

### 6.2.2. The mass exchange method

The evaporation of intercepted rainfall was also estimated by an energy balance method, which relied on the modified Penman equation, using directly determined microclimatic and canopy structure variables as inputs. Measurements of microclimatic variables above the ground and above the forest canopy were satisfactorily made by light-weight, removable, automatic weather stations (AWS) as described in Section 4.2. Intercomparisons were made between the data from each AWS and manual observations before these data were used in the analysis. It took less than one hour to properly install or to one of these remove AWS in the field. One such AWS was even installed on top of a 56 m tall tower without any significant difficulties. The microclimatic data measured by this automatic weather station were considered reliable for calculating interception loss based on the energy balance method and for modelling interception loss, after some cross-checking and correction of the raw data.

## 6.3. Conclusions and recommendations drawn from the findings

The evaporation of intercepted water and the components of its derivation for the unlogged forest were compared with those in the literature for other tropical rainforests and found to be consistent. The estimates of throughfall, stemflow and interception loss obtained in the unlogged plot (87 %, 1 % and 11 % of gross rainfall, respectively) were in agreement with previous results reported in the literature for lowland tropical rainforests.

By contrast, in the logged plot, the estimates of throughfall, stemflow and interception loss (with no sub-divisions of canopy cover) were 93.5 %, 0.3 % and 6.2 % of gross rainfall, respectively. If canopy cover sub-divisions were considered, throughfall values varied from 85 % of gross rainfall in the closed canopy to 95 % and 99 % in the partial canopy and the canopy gap, respectively. This clearly shows that throughfall is a function of canopy cover, as would be expected. For interception loss, the figures are 15 %, 4.5 % and 0.7 % of gross rainfall for the closed canopy, partial canopy and canopy gap, respectively. These results were closely associated with the reduction in number of trees per hectare from 581 in the unlogged plot to 278 (52 %) in the logged plot or a reduction in terms of basal area from 38.6 to 13.8 $m^2$ $ha^{-1}$ (38 %). It seems likely that the reduction in interception loss is attributable to the logging practices, because these effect changes in canopy structure (in this case, increased free throughfall coefficient, $p$, and reduced canopy storage capacity, $S$, and boundary layer conductance, $g_a$) and allow more rainwater to reach the forest floor. The difference in throughfall between the closed canopy in the unlogged plot and the closed canopy area of the logged plot may be associated with variation between the sites and might be a function of edge effects in the logged forest. Further investigations need to be carried out to relate these last two factors, especially possible forest edge effects, to the differences in throughfall.

A further conclusion that can be drawn from this experiment is that the evaporation from wet canopies is driven more by advected energy than by radiative energy because of the highly sporadic occurrence of rainfall over tropical forest, so that the landscape is essentially a mosaic of wet and dry areas of forest canopies. In the unlogged plot advective energy accounted for 0.56 mm $h^{-1}$ of the 0.69 mm $h^{-1}$ of evaporation, whereas radiative energy accounted for only 0.13 mm $h^{-1}$. It can, therefore, be concluded that, unlike the "equilibrium" evaporation situation (McNaughton, 1976) where the local vapour pressure deficit is largely determined by surface wetness and net radiation, evaporation is driven by advection of dry air from the surrounding drier and warmer areas, as well as by entrainment of warmer, drier air from above. A similar relationship between the major driving variables and the rate of evaporation was found in both the unlogged and logged plots and this leads to the conclusion that logging activities did not change the proportion of energy used for interception loss.

As errors in the measurement of throughfall and stemflow were within acceptable limits (Sections 3.2 and 3.3), the derived model parameters, including the canopy storage capacity, $S$, trunk storage capacity, $S_t$, and proportion of rain diverted to stemflow, $p_t$, can be considered reliable. Using these parameters and others, including canopy drainage rate, $D$, boundary layer conductance, $g_a$, and mean evaporation and rainfall rates ($\bar{E}$ and $\bar{R}$), predictions of rainfall interception loss for individual storms and their total sum were made by the modified Rutter model, WATMOD, and the analytical model of Gash. The predictions of both models were compared with the observed rainfall interception loss of individual storms and their sum over the measurement periods. Both models, WATMOD and the Gash model slightly underestimated interception loss in the unlogged plot while, they both slightly overestimated interception loss in the logged plot.

The agreement between observed and estimated total interception losses were tested by statistical analysis and it can be concluded that, in general, both the WATMOD and the Gash models might be conceptually strong enough to be applicable in tropical rainforest. The model comparison with data also suggests that both models perform adequately over a long period, despite the potential for various errors in the measurement of throughfall and other parameters related to the forest structure. With both models, the difference between observed and predicted cumulative interception loss, expressed as percentage of the gross rainfall was less than 2 % for both the unlogged and logged plots. However, the models were not adequate in predicting interception loss on a storm by storm basis. These results suggest that before the models can be improved any further, it is necessary to increase the accuracy of the observations of gross and net rainfall in tropical rainforest environments.

In general, WATMOD performed better than the Gash model in both the unlogged and logged plots. In the unlogged plot, the original Gash model's performance was as good as the revised Gash model. In the logged plot, taking no account of canopy cover divisions, the revised Gash model was better than the original Gash model. The differences between total observed and predicted interception loss, expressed as percentage of gross rainfall, were 0.7 and 3 %, respectively. When the one hectare plot was divided into three canopy cover sub-areas, model performances of WATMOD, the revised Gash model and the original one were less adequate (Table 5.9). It can, therefore, be concluded that modelling interception loss in the logged plot is adequately done by treating the whole plot as a single unit for analysis, instead of dividing it into three different canopy cover sub-areas.

WATMOD showed a lack of sensitivity to ± 30 % changes in free throughfall coefficient, $p$, a moderate sensitivity to changes in boundary layer conductance, $g_a$, and a remarkable sensitivity to changes in canopy storage capacity, $S$ in both the unlogged and logged forest conditions. In the case of the Gash model, the model was not so sensitive to changes in $S$ and $p$, but very sensitive to changes in mean evaporation rate, $\overline{E}$, and mean rainfall rate, $\overline{R}$, for both the unlogged and logged plots. In general, this experiment has demonstrated that the most important parameters in the interception loss processes are the canopy storage capacity, the boundary layer conductance, the mean rainfall rate and the mean evaporation rate, as they dictate the rate of water loss from tropical rainforest canopies. It is, therefore, recommended that special attention is given to the derivation of $S$, $g_a$, $\overline{E}$, and $\overline{R}$ in any future similar studies.

The earlier interception loss modelling studies of tropical forests carried out by Lloyd *et al.* (1988) and Calder *et al.* (1986) showed an important but unresolved inconsistency; the Rutter model was found to work relatively well in Lloyd's case study in Amazonian forest but it did not do so in Calder's work in an Indonesian rainforest. This discrepancy was suspected to be associated with the sampling method: a large plastic-sheet gauge to measure throughfall in Calder's case study was discarded after trials in Lloyd's case, on the grounds that it was prone to overestimate interception loss in the tropical rainforest environment (Shuttleworth, 1989). The results of this experiment lead to two important points: 1) reliable sampling methods for throughfall measurement should be given more attention, for example, by using random relocation of throughfall gauges beneath forest canopies, and 2) aspects of micrometeorology of tropical rainforests merits further attention to resolve the inconsistency in modelling interception loss using Rutter-type models, particularly over the short time periods of individual storms.

The results from this experiment generally suggest that interception loss in an undisturbed tropical rainforest decreases following logging because logging practices create a discontinuous canopy. The discontinuous canopy affects total interception loss by influencing canopy structural properties, i.e. canopy storage capacity, $S$, free throughfall coefficient, $p$, and aerodynamic properties, including the boundary layer conductance, $g_a$. The difficulty with forests with a discontinuous canopy is how much effect the gaps have upon the overall turbulence. In general, as gaps appear in forest canopies, the canopy becomes rougher and turbulence increases thus increasing the rate of interception loss. At the same time, following logging activities, the total amount of interception loss is reduced as a result of the decrease in canopy storage capacity. The overall effect of logging on the interception loss will be determined by the magnitude of the gaps and the reduction of canopy storage capacity. These relationships have not been investigated very intensively and it can, therefore, be recommended that more attention should be given to these counteracting relationships in any future evaporation studies in tropical rainforests. However, in this experiment, the total amount of interception loss over a long period was reduced following logging.

A development of this experiment should be directed to study the total annual water balance of a forested catchment following logging. Rainfall interception loss is only one component of the water balance of a forested catchment. To enable a full assessment of the effects of logging activities on a catchment water balance, the evaporative loss of water in transpiration, together with streamflow estimates, should also be given equal attention in future research.

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# Appendix I

**Table I.1** Stemflow (m3) by rainfall event from sample tree in the unlogged plot

| Rainfall Event | Date | Gross Rainfall (mm) | Diameter class (cm) and tree number: > 80, 1 | > 80, 2 | > 80, 3 | 50 - 80, 4 | 50 - 80, 5 | 50 - 80, 6 | 30 - 50, 7 | 30 - 50, 8 | 30 - 50, 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 01/11/93 | 23.57 | 0.00036 | 0.00590 | 0.00057 | 0.00061 | 0.00350 | 0.00130 | 0.00855 | 0.00130 | 0.00134 |
| 2 | 03/11/93 | 16.14 | 0.00472 | 0.00342 | 0.00030 | 0.00037 | 0.00170 | 0.00066 | 0.00344 | 0.00130 | 0.00061 |
| 3 | 06/11/93 | 27.52 | 0.00666 | 0.00053 | 0.00200 | 0.00053 | 0.00400 | 0.00119 | 0.00851 | 0.00400 | 0.00113 |
| 4 | 08/11/93 | 51.40 | 0.04818 | 0.01373 | 0.03820 | 0.00346 | 0.04000 | 0.00749 | 0.04337 | 0.02360 | 0.01186 |
| 5 | 09/11/93 | 62.50 | 0.05596 | 0.08617 | 0.17530 | 0.02409 | 0.04824 | 0.01894 | 0.05293 | 0.03120 | 0.02354 |
| 6 | 12/11/93 | 37.26 | 0.03275 | 0.01256 | 0.07980 | 0.00179 | 0.01580 | 0.00467 | 0.03302 | 0.00750 | 0.00904 |
| 7 | 16/11/93 | 38.29 | 0.02614 | 0.01535 | 0.04180 | 0.00123 | 0.01070 | 0.00187 | 0.02613 | 0.00810 | 0.00337 |
| 8 | 17/11/93 | 44.86 | 0.04002 | 0.02102 | 0.07360 | 0.00497 | 0.02410 | 0.00169 | 0.03763 | 0.01430 | 0.00465 |
| 9 | 18/11/93 | 14.83 | 0.00859 | 0.00102 | 0.00697 | 0.00060 | 0.00406 | 0.00088 | 0.01047 | 0.00186 | 0.00144 |
| 10 | 25/11/93 | 45.57 | 0.01694 | 0.00184 | 0.01299 | 0.00242 | 0.01825 | 0.00236 | 0.03751 | 0.00650 | 0.00408 |
| 11 | 27/11/93 | 85.94 | 0.08742 | 0.04493 | 0.09332 | 0.01629 | 0.00717 | 0.01662 | 0.10127 | 0.03816 | 0.02416 |
| 12 | 28/11/93 | 78.03 | 0.10135 | 0.12059 | 0.29826 | 0.03626 | 0.00510 | 0.01327 | 0.10105 | 0.04004 | 0.02523 |
| 13 | 30/11/93 | 83.62 | 0.06305 | 0.07803 | 0.08940 | 0.02697 | 0.07760 | 0.01715 | 0.10603 | 0.04060 | 0.02529 |
| 14 | 03/12/93 | 48.34 | 0.03725 | 0.00622 | 0.00992 | 0.00169 | 0.00650 | 0.00265 | 0.04266 | 0.01137 | 0.00436 |
| 15 | 06/12/93 | 14.56 | 0.00403 | 0.00337 | 0.01649 | 0.00041 | 0.00310 | 0.00072 | 0.00722 | 0.00275 | 0.00092 |
| 16 | 09/12/93 | 79.09 | 0.12194 | 0.08340 | 0.14392 | 0.03444 | 0.09820 | 0.02042 | 0.02296 | 0.05670 | 0.02902 |
| 17 | 10/12/93 | 11.01 | 0.02460 | 0.00657 | 0.01930 | 0.00422 | 0.02630 | 0.00188 | 0.00503 | 0.01040 | 0.00520 |
| 18 | 12/12/93 | 15.99 | 0.02511 | 0.00352 | 0.00730 | 0.00353 | 0.01440 | 0.00057 | 0.00527 | 0.00570 | 0.00244 |
| 19 | 18/12/93 | 57.59 | 0.04479 | 0.00394 | 0.00910 | 0.00265 | 0.04540 | 0.00353 | 0.00853 | 0.02000 | 0.00684 |
| 20 | 21/12/93 | 48.79 | 0.01508 | 0.00168 | 0.00510 | 0.00097 | 0.01440 | 0.00148 | 0.02431 | 0.00535 | 0.00191 |
| 21 | 23/12/93 | 39.75 | 0.02860 | 0.00224 | 0.02110 | 0.00123 | 0.01690 | 0.00286 | 0.04017 | 0.00940 | 0.00410 |
| 22 | 06/01/94 | 37.83 | 0.00444 | 0.00210 | 0.00224 | 0.00076 | 0.00690 | 0.00113 | 0.00982 | 0.00243 | 0.00046 |
| 23 | 09/01/94 | 27.56 | 0.01141 | 0.00198 | 0.00213 | 0.00322 | 0.00590 | 0.00231 | 0.01965 | 0.00239 | 0.00249 |
| 24 | 12/01/94 | 45.43 | 0.04681 | 0.00771 | 0.01270 | 0.00644 | 0.00350 | 0.00344 | 0.05054 | 0.01582 | 0.00487 |
| 25 | 13/01/94 | 58.93 | 0.05357 | 0.01389 | 0.04016 | 0.00217 | 0.00590 | 0.00707 | 0.07424 | 0.02209 | 0.01059 |
| 26 | 17/01/94 | 48.66 | 0.03457 | 0.01694 | 0.05535 | 0.00156 | 0.00051 | 0.00598 | 0.03867 | 0.01376 | 0.00854 |
| 27 | 19/01/94 | 16.71 | 0.00242 | 0.00178 | 0.00275 | 0.00023 | 0.00140 | 0.00038 | 0.00189 | 0.00140 | 0.00041 |
| 28 | 23/01/94 | 39.55 | 0.02343 | 0.00205 | 0.00300 | 0.00119 | 0.01560 | 0.00322 | 0.03713 | 0.00960 | 0.00292 |
| 29 | 27/01/94 | 32.10 | 0.02931 | 0.00366 | 0.00880 | 0.00161 | 0.01780 | 0.00149 | 0.03360 | 0.01060 | 0.00115 |
| 30 | 05/02/94 | 121.82 | 0.04104 | 0.05080 | 0.07480 | 0.01765 | 0.11010 | 0.01747 | 0.12847 | 0.08590 | 0.02222 |
| 31 | 08/02/94 | 94.86 | 0.08075 | 0.07645 | 0.01968 | 0.01257 | 0.00083 | 0.01082 | 0.08493 | 0.03296 | 0.01519 |
| 32 | 10/02/94 | 10.84 | 0.00087 | 0.00185 | 0.00348 | 0.00020 | 0.00026 | 0.00033 | 0.00183 | 0.00029 | 0.00025 |
| 33 | 11/02/94 | 12.69 | 0.00511 | 0.00189 | 0.00140 | 0.00033 | 0.00290 | 0.00069 | 0.00992 | 0.00140 | 0.00043 |
| 34 | 12/02/94 | 18.81 | 0.01556 | 0.00182 | 0.00548 | 0.00073 | 0.00680 | 0.00530 | 0.00526 | 0.00528 | 0.00108 |
| 35 | 14/02/94 | 28.93 | 0.01586 | 0.00414 | 0.01470 | 0.00076 | 0.00660 | 0.00114 | 0.01488 | 0.00450 | 0.00112 |
| 36 | 15/02/94 | 23.37 | 0.01874 | 0.00963 | 0.00590 | 0.00115 | 0.01180 | 0.00304 | 0.00891 | 0.00784 | 0.00490 |
| 37 | 17/02/94 | 17.97 | 0.00460 | 0.00000 | 0.00160 | 0.00035 | 0.00380 | 0.00053 | 0.01472 | 0.00157 | 0.00056 |
| 38 | 19/02/94 | 9.69 | 0.00537 | 0.00186 | 0.00120 | 0.00036 | 0.00390 | 0.00048 | 0.00575 | 0.00270 | 0.00059 |
| 39 | 05/03/94 | 35.09 | 0.02019 | 0.00194 | 0.00270 | 0.00079 | 0.01150 | 0.00284 | 0.00097 | 0.00710 | 0.00267 |
| 40 | 07/03/94 | 20.93 | 0.01348 | 0.00159 | 0.00382 | 0.00054 | 0.00490 | 0.00128 | 0.05600 | 0.00345 | 0.00274 |
| 41 | 08/03/94 | 45.98 | 0.04014 | 0.00509 | 0.02880 | 0.00231 | 0.02600 | 0.00464 | 0.04993 | 0.01930 | 0.00441 |
| 42 | 21/03/94 | 11.98 | 0.00539 | 0.00970 | 0.01607 | 0.00095 | 0.00034 | 0.00165 | 0.00728 | 0.00365 | 0.00350 |
| 43 | 22/03/94 | 28.29 | 0.01730 | 0.00342 | 0.06030 | 0.00092 | 0.08260 | 0.00182 | 0.02297 | 0.05890 | 0.00322 |
| 44 | 24/03/94 | 55.89 | 0.06442 | 0.07501 | 0.01980 | 0.03526 | 0.06270 | 0.03032 | 0.08372 | 0.04729 | 0.03286 |
| 45 | 25/03/94 | 16.32 | 0.01655 | 0.02455 | 0.04680 | 0.01397 | 0.00740 | 0.00208 | 0.01306 | 0.00660 | 0.00316 |
| 46 | 27/03/94 | 12.82 | 0.00409 | 0.00189 | 0.00170 | 0.00041 | 0.00044 | 0.00060 | 0.00498 | 0.00090 | 0.00046 |
| 47 | 28/03/94 | 25.38 | 0.01839 | 0.00469 | 0.01467 | 0.00061 | 0.00830 | 0.00169 | 0.01951 | 0.00646 | 0.00389 |
| 48 | 29/03/94 | 8.69 | 0.00096 | 0.00039 | 0.00184 | 0.00018 | 0.00110 | 0.00023 | 0.00331 | 0.00100 | 0.00013 |
| 49 | 30/03/94 | 69.90 | 0.07159 | 0.06274 | 0.04870 | 0.02258 | 0.05380 | 0.01529 | 0.06810 | 0.04420 | 0.02022 |
| 50 | 04/04/94 | 51.66 | 0.03965 | 0.02481 | 0.06250 | 0.00039 | 0.02200 | 0.00180 | 0.01692 | 0.01500 | 0.00495 |
| 51 | 06/04/94 | 21.44 | 0.01351 | 0.00356 | 0.01350 | 0.00060 | 0.00061 | 0.00099 | 0.01282 | 0.00720 | 0.00056 |
| 52 | 09/04/94 | 6.65 | 0.00022 | 0.00052 | 0.00228 | 0.00009 | 0.00005 | 0.00010 | 0.00165 | 0.00007 | 0.00004 |
| 53 | 10/04/94 | 15.70 | 0.00720 | 0.00185 | 0.00150 | 0.00044 | 0.00270 | 0.00089 | 0.00859 | 0.00170 | 0.00033 |
| 54 | 11/04/94 | 65.81 | 0.05760 | 0.01287 | 0.01090 | 0.00931 | 0.04330 | 0.01150 | 0.01474 | 0.02211 | 0.01431 |
| 55 | 14/04/94 | 135.75 | * | 0.11948 | 0.02640 | * | 0.00006 | * | 0.01949 | 0.07626 | * |
| Mean | | 39.98 | 0.02922 | 0.01943 | 0.03204 | 0.00573 | 0.01850 | 0.00490 | 0.03037 | 0.01603 | 0.00677 |
| SD | | 28.42 | 0.02750 | 0.03103 | 0.05150 | 0.00969 | 0.02572 | 0.00654 | 0.03097 | 0.01973 | 0.00864 |
| SE | | 4.02 | 0.00389 | 0.00439 | 0.00728 | 0.00137 | 0.00364 | 0.00093 | 0.00438 | 0.00279 | 0.00122 |
| Total | | 2198.69 | 1.57808 | 1.06855 | 1.76234 | 0.30936 | 1.01771 | 0.26474 | 1.67031 | 0.88185 | 0.36575 |

| | | 15 - 30 | | | < 15 | | Mean | SD | SE | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 11 | 12 | 13 | 14 | 15 | 16 | | | | |
| 0.00182 | 0.00130 | 0.00183 | 0.00029 | 0.00171 | 0.00304 | 0.00310 | 0.00228 | 0.00221 | 0.00055 | 0.03652 |
| 0.00264 | 0.00070 | 0.00059 | 0.00015 | 0.00046 | 0.00006 | 0.00210 | 0.00145 | 0.00142 | 0.00035 | 0.02322 |
| 0.00224 | 0.00270 | 0.00182 | 0.00047 | 0.00174 | 0.00398 | 0.00490 | 0.00290 | 0.00231 | 0.00058 | 0.04640 |
| 0.02960 | 0.00870 | 0.01132 | 0.00327 | 0.01586 | 0.01465 | 0.02020 | 0.02084 | 0.01467 | 0.00367 | 0.33349 |
| 0.04357 | 0.01253 | 0.01212 | 0.00523 | 0.02045 | 0.01415 | 0.01340 | 0.03986 | 0.04202 | 0.01050 | 0.63782 |
| 0.01966 | 0.00370 | 0.00866 | 0.00109 | 0.00172 | 0.00398 | 0.01160 | 0.01546 | 0.01985 | 0.00496 | 0.24734 |
| 0.01268 | 0.00233 | 0.00472 | 0.00112 | 0.00197 | 0.00198 | 0.00690 | 0.01040 | 0.01172 | 0.00293 | 0.16639 |
| 0.02076 | 0.00880 | 0.00875 | 0.00224 | 0.00917 | 0.01054 | 0.00930 | 0.01822 | 0.01874 | 0.00469 | 0.29154 |
| 0.00537 | 0.00202 | 0.00195 | 0.00027 | 0.00039 | 0.00223 | 0.00311 | 0.00320 | 0.00310 | 0.00077 | 0.05123 |
| 0.01057 | 0.00030 | 0.00634 | 0.00099 | 0.00643 | 0.00485 | 0.00312 | 0.00847 | 0.00949 | 0.00237 | 0.13549 |
| 0.05357 | 0.01494 | 0.02530 | 0.00271 | 0.02111 | 0.01200 | 0.00293 | 0.03512 | 0.03252 | 0.00813 | 0.56189 |
| 0.06873 | 0.00305 | 0.02325 | 0.00462 | 0.02538 | 0.03807 | 0.00310 | 0.05671 | 0.07469 | 0.01867 | 0.90734 |
| 0.06581 | 0.01670 | 0.02430 | 0.00660 | 0.02575 | 0.02041 | 0.02170 | 0.04409 | 0.03090 | 0.00773 | 0.70539 |
| 0.02276 | 0.01061 | 0.00761 | 0.00182 | 0.00560 | 0.00850 | 0.01510 | 0.01216 | 0.01211 | 0.00303 | 0.19462 |
| 0.00435 | 0.00063 | 0.00066 | 0.00042 | 0.00041 | 0.00067 | 0.00393 | 0.00313 | 0.00408 | 0.00102 | 0.05008 |
| 0.05538 | 0.01900 | 0.03144 | 0.01041 | 0.01929 | 0.03177 | 0.02320 | 0.05009 | 0.04055 | 0.01014 | 0.80149 |
| 0.01215 | 0.00418 | 0.00532 | 0.00131 | 0.00394 | 0.00629 | 0.00480 | 0.00884 | 0.00782 | 0.00195 | 0.14149 |
| 0.00705 | 0.00382 | 0.00374 | 0.00236 | 0.00444 | 0.00463 | 0.00530 | 0.00620 | 0.00589 | 0.00147 | 0.09918 |
| 0.00188 | 0.00732 | 0.00815 | 0.00273 | 0.00670 | 0.01236 | 0.01270 | 0.01229 | 0.01361 | 0.00340 | 0.19662 |
| * | 0.00470 | 0.00360 | 0.00097 | 0.00227 | 0.00115 | 0.00840 | 0.00609 | 0.00680 | 0.00170 | 0.09137 |
| * | 0.00603 | 0.00513 | 0.00104 | 0.00340 | 0.00448 | 0.01180 | 0.01056 | 0.01147 | 0.00287 | 0.15847 |
| 0.00166 | 0.00406 | 0.00165 | 0.00102 | 0.00076 | 0.00297 | 0.00740 | 0.00311 | 0.00275 | 0.00069 | 0.04979 |
| 0.00810 | 0.00217 | 0.00414 | 0.00087 | 0.00282 | 0.00454 | 0.00210 | 0.00476 | 0.00480 | 0.00120 | 0.07621 |
| 0.03383 | 0.00584 | 0.00616 | 0.00367 | 0.00834 | 0.00499 | 0.00310 | 0.01361 | 0.01565 | 0.00391 | 0.21776 |
| 0.04053 | 0.00934 | 0.00842 | 0.00321 | 0.01146 | 0.01201 | 0.00290 | 0.01985 | 0.02109 | 0.00527 | 0.31755 |
| 0.02173 | 0.00510 | 0.00412 | 0.00218 | 0.00489 | 0.00645 | 0.01570 | 0.01475 | 0.01569 | 0.00392 | 0.23605 |
| 0.00039 | 0.00110 | 0.00013 | 0.00021 | 0.00012 | 0.00244 | 0.00240 | 0.00122 | 0.00096 | 0.00024 | 0.01944 |
| 0.01034 | 0.00548 | 0.00478 | 0.00143 | 0.00327 | 0.00638 | 0.01210 | 0.00887 | 0.00965 | 0.00241 | 0.14192 |
| 0.01741 | 0.00470 | 0.00395 | 0.00183 | 0.00472 | 0.00615 | 0.00860 | 0.00971 | 0.00994 | 0.00249 | 0.15538 |
| 0.05660 | 0.02580 | 0.01825 | 0.00703 | 0.03780 | 0.02492 | 0.05590 | 0.04842 | 0.03548 | 0.00887 | 0.77475 |
| 0.06086 | 0.01239 | 0.01649 | 0.02675 | 0.00343 | 0.01457 | 0.02300 | 0.03073 | 0.02834 | 0.00709 | 0.49167 |
| 0.00016 | 0.00010 | 0.00011 | 0.00008 | 0.00009 | 0.00229 | 0.00680 | 0.00119 | 0.00181 | 0.00045 | 0.01899 |
| 0.00325 | 0.00257 | 0.00035 | 0.00016 | 0.00028 | 0.00124 | 0.00420 | 0.00226 | 0.00253 | 0.00063 | 0.03612 |
| 0.00837 | 0.00201 | 0.00215 | 0.00081 | 0.00187 | 0.00320 | 0.00460 | 0.00439 | 0.00376 | 0.00094 | 0.07031 |
| 0.00873 | 0.00190 | 0.00253 | 0.00063 | 0.00172 | 0.00405 | 0.00620 | 0.00559 | 0.00527 | 0.00132 | 0.08946 |
| 0.01171 | 0.00203 | 0.00302 | 0.00085 | 0.00370 | 0.00683 | 0.00450 | 0.00653 | 0.00477 | 0.00119 | 0.10455 |
| 0.00092 | 0.00130 | 0.00041 | 0.00029 | 0.00043 | 0.00000 | 0.00340 | 0.00215 | 0.00364 | 0.00091 | 0.03448 |
| 0.00121 | 0.00130 | 0.00073 | 0.00041 | 0.00056 | 0.00214 | 0.00250 | 0.00194 | 0.00173 | 0.00043 | 0.03106 |
| 0.00420 | 0.00426 | 0.00401 | 0.00069 | 0.00117 | 0.00713 | 0.01150 | 0.00523 | 0.00528 | 0.00132 | 0.08366 |
| 0.00530 | 0.00177 | 0.00089 | 0.00035 | 0.00031 | 0.00302 | 0.00540 | 0.00655 | 0.01357 | 0.00339 | 0.10483 |
| 0.02716 | 0.00630 | 0.00810 | 0.00195 | 0.00719 | 0.00666 | 0.01420 | 0.01576 | 0.01466 | 0.00367 | 0.25218 |
| 0.00322 | 0.00241 | 0.00078 | 0.00022 | 0.00132 | 0.00230 | 0.00580 | 0.00404 | 0.00417 | 0.00104 | 0.06458 |
| 0.01158 | 0.03160 | 0.00032 | 0.00053 | 0.00098 | 0.00259 | 0.04530 | 0.02152 | 0.02654 | 0.00663 | 0.34435 |
| 0.05514 | 0.01547 | 0.01243 | 0.00573 | 0.02465 | 0.01856 | 0.01470 | 0.03738 | 0.02431 | 0.00608 | 0.59806 |
| 0.01093 | 0.00310 | 0.00125 | 0.00124 | 0.00463 | 0.00260 | 0.00450 | 0.01015 | 0.01177 | 0.00294 | 0.16242 |
| 0.00058 | 0.00021 | 0.00014 | 0.00016 | 0.00010 | 0.00244 | 0.00130 | 0.00127 | 0.00146 | 0.00036 | 0.02040 |
| 0.01026 | 0.00320 | 0.00229 | 0.00076 | 0.00162 | 0.00443 | 0.00760 | 0.00677 | 0.00607 | 0.00152 | 0.10836 |
| 0.00021 | 0.00090 | 0.00009 | 0.00007 | 0.00005 | 0.00018 | 0.00180 | 0.00078 | 0.00090 | 0.00023 | 0.01244 |
| 0.05711 | 0.01386 | 0.01425 | 0.00465 | 0.02420 | 0.02229 | 0.01750 | 0.03507 | 0.02230 | 0.00558 | 0.56108 |
| 0.01990 | 0.00685 | 0.00675 | 0.00225 | 0.00892 | 0.00858 | 0.00730 | 0.01554 | 0.01624 | 0.00406 | 0.24857 |
| 0.00570 | 0.00280 | 0.00190 | 0.00083 | 0.00177 | 0.00268 | 0.00360 | 0.00454 | 0.00472 | 0.00118 | 0.07263 |
| 0.00014 | 0.00172 | 0.00006 | 0.00002 | 0.00004 | * | 0.00000 | 0.00047 | 0.00076 | 0.00019 | 0.00700 |
| 0.00154 | 0.00130 | 0.00069 | 0.00042 | 0.00017 | 0.00255 | 0.00400 | 0.00224 | 0.00244 | 0.00061 | 0.03587 |
| 0.04290 | 0.00927 | 0.01357 | 0.00331 | 0.00713 | 0.00849 | 0.01780 | 0.01869 | 0.01544 | 0.00386 | 0.29911 |
| * | 0.03476 | * | * | * | 0.04950 | 0.00450 | 0.04131 | 0.04000 | 0.01000 | 0.33045 |
| 0.01889 | 0.00656 | 0.00632 | 0.00231 | 0.00646 | 0.00831 | 0.00951 | 0.01409 | | | |
| 0.02065 | 0.00750 | 0.00727 | 0.00398 | 0.00863 | 0.00975 | 0.01007 | 0.01470 | | | |
| 0.00292 | 0.00106 | 0.00103 | 0.00056 | 0.00122 | 0.00138 | 0.00142 | 0.00208 | | | |
| 0.98226 | 0.36103 | 0.34151 | 0.12472 | 0.34870 | 0.44896 | 0.52289 | 0.77477 | 0.54108 | 0.13527 | 12.04875 |

**Table I.2** Stemflow (m3) by rainfall event per ha based on basal area in the unlogged plot

| Rainfall event | Date | Gross Rainfall (mm) | Sum of Class I *) | Vol Class I 1) | Sum of Class II *) | Vol Class II 2) | Sum of Class III *) | Vol Class III 3) | Sum of Class IV *) | Vol Class IV 4) | Sum of Class V *) | Vol Class V 5) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 01/11/93 | 23.57 | 0.0068 | 0.0319 | 0.0054 | 0.0594 | 0.0130 | 0.2863 | 0.0034 | 0.2074 | 0.0079 | 0.6879 |
| 2 | 03/11/93 | 16.14 | 0.0084 | 0.0394 | 0.0027 | 0.0300 | 0.0080 | 0.1758 | 0.0014 | 0.0873 | 0.0026 | 0.2296 |
| 3 | 06/11/93 | 27.52 | 0.0092 | 0.0429 | 0.0057 | 0.0628 | 0.0159 | 0.3494 | 0.0050 | 0.3027 | 0.0106 | 0.9306 |
| 4 | 08/11/93 | 51.40 | 0.1001 | 0.4671 | 0.0510 | 0.5595 | 0.1084 | 2.3860 | 0.0233 | 1.4127 | 0.0507 | 4.4438 |
| 5 | 09/11/93 | 62.50 | 0.3174 | 1.4811 | 0.0913 | 1.0022 | 0.1512 | 3.3280 | 0.0299 | 1.8124 | 0.0480 | 4.2063 |
| 6 | 12/11/93 | 37.26 | 0.1251 | 0.5838 | 0.0223 | 0.2444 | 0.0692 | 1.5232 | 0.0135 | 0.8158 | 0.0173 | 1.5160 |
| 7 | 16/11/93 | 38.29 | 0.0833 | 0.3886 | 0.0138 | 0.1515 | 0.0503 | 1.1064 | 0.0082 | 0.4956 | 0.0109 | 0.9508 |
| 8 | 17/11/93 | 44.86 | 0.1346 | 0.6282 | 0.0308 | 0.3378 | 0.0773 | 1.7018 | 0.0198 | 1.2004 | 0.0290 | 2.5422 |
| 9 | 18/11/93 | 14.83 | 0.0166 | 0.0774 | 0.0055 | 0.0608 | 0.0191 | 0.4211 | 0.0042 | 0.2572 | 0.0057 | 0.5021 |
| 10 | 25/11/93 | 45.57 | 0.0318 | 0.1482 | 0.0230 | 0.2529 | 0.0587 | 1.2908 | 0.0076 | 0.4628 | 0.0144 | 1.2619 |
| 11 | 27/11/93 | 85.94 | 0.2257 | 1.0529 | 0.0401 | 0.4401 | 0.2172 | 4.7786 | 0.0430 | 2.6052 | 0.0360 | 3.1582 |
| 12 | 28/11/93 | 78.03 | 0.5202 | 2.4272 | 0.0546 | 0.5999 | 0.2351 | 5.1722 | 0.0309 | 1.8755 | 0.0666 | 5.8319 |
| 13 | 30/11/93 | 83.62 | 0.2305 | 1.0754 | 0.1217 | 1.3366 | 0.2377 | 5.2312 | 0.0476 | 2.8872 | 0.0679 | 5.9467 |
| 14 | 03/12/93 | 48.34 | 0.0534 | 0.2491 | 0.0108 | 0.1190 | 0.0811 | 1.7856 | 0.0200 | 1.2155 | 0.0292 | 2.5588 |
| 15 | 06/12/93 | 14.56 | 0.0239 | 0.1115 | 0.0042 | 0.0464 | 0.0152 | 0.3353 | 0.0017 | 0.1037 | 0.0050 | 0.4390 |
| 16 | 09/12/93 | 79.09 | 0.3493 | 1.6296 | 0.1531 | 1.6807 | 0.1641 | 3.6101 | 0.0609 | 3.6909 | 0.0743 | 6.5075 |
| 17 | 10/12/93 | 11.01 | 0.0505 | 0.2355 | 0.0324 | 0.3558 | 0.0328 | 0.7213 | 0.0108 | 0.6557 | 0.0150 | 1.3171 |
| 18 | 12/12/93 | 15.99 | 0.0359 | 0.1676 | 0.0185 | 0.2031 | 0.0205 | 0.4502 | 0.0099 | 0.6017 | 0.0144 | 1.2593 |
| 19 | 18/12/93 | 57.59 | 0.0578 | 0.2698 | 0.0516 | 0.5664 | 0.0373 | 0.8197 | 0.0182 | 1.1039 | 0.0318 | 2.7832 |
| 20 | 21/12/93 | 48.79 | 0.0219 | 0.1020 | 0.0169 | 0.1850 | 0.0316 | 0.8687 | 0.0093 | 0.5623 | 0.0118 | 1.0358 |
| 21 | 23/12/93 | 39.75 | 0.0519 | 0.2423 | 0.0210 | 0.2305 | 0.0537 | 1.4771 | 0.0122 | 0.7400 | 0.0197 | 1.7246 |
| 22 | 06/01/94 | 37.83 | 0.0088 | 0.0409 | 0.0088 | 0.0965 | 0.0144 | 0.3162 | 0.0067 | 0.4082 | 0.0111 | 0.9753 |
| 23 | 09/01/94 | 27.56 | 0.0155 | 0.0724 | 0.0114 | 0.1255 | 0.0326 | 0.7180 | 0.0072 | 0.4355 | 0.0095 | 0.8290 |
| 24 | 12/01/94 | 45.43 | 0.0672 | 0.3136 | 0.0134 | 0.1469 | 0.1051 | 2.3118 | 0.0157 | 0.9505 | 0.0164 | 1.4398 |
| 25 | 13/01/94 | 58.93 | 0.1076 | 0.5022 | 0.0151 | 0.1663 | 0.1475 | 3.2446 | 0.0210 | 1.2719 | 0.0264 | 2.3109 |
| 26 | 17/01/94 | 48.66 | 0.1068 | 0.4986 | 0.0081 | 0.0884 | 0.0827 | 1.8198 | 0.0114 | 0.6915 | 0.0270 | 2.3696 |
| 27 | 19/01/94 | 16.71 | 0.0069 | 0.0324 | 0.0020 | 0.0221 | 0.0041 | 0.0900 | 0.0014 | 0.0873 | 0.0050 | 0.4347 |
| 28 | 23/01/94 | 39.55 | 0.0285 | 0.1329 | 0.0200 | 0.2197 | 0.0600 | 1.3201 | 0.0117 | 0.7091 | 0.0218 | 1.9060 |
| 29 | 27/01/94 | 32.10 | 0.0418 | 0.1949 | 0.0209 | 0.2295 | 0.0628 | 1.3810 | 0.0105 | 0.6357 | 0.0195 | 1.7062 |
| 30 | 05/02/94 | 121.82 | 0.1666 | 0.7775 | 0.1452 | 1.5946 | 0.2932 | 6.4516 | 0.0511 | 3.0983 | 0.1186 | 10.3949 |
| 31 | 08/02/94 | 94.86 | 0.1769 | 0.8253 | 0.0242 | 0.2660 | 0.1939 | 4.2675 | 0.0556 | 3.3742 | 0.0410 | 3.5929 |
| 32 | 10/02/94 | 10.84 | 0.0062 | 0.0289 | 0.0008 | 0.0087 | 0.0025 | 0.0557 | 0.0003 | 0.0176 | 0.0092 | 0.8045 |
| 33 | 11/02/94 | 12.69 | 0.0084 | 0.0392 | 0.0039 | 0.0430 | 0.0150 | 0.3301 | 0.0031 | 0.1868 | 0.0057 | 0.5013 |
| 34 | 12/02/94 | 18.81 | 0.0229 | 0.1066 | 0.0128 | 0.1409 | 0.0200 | 0.4400 | 0.0050 | 0.3015 | 0.0097 | 0.8474 |
| 35 | 14/02/94 | 28.93 | 0.0347 | 0.1619 | 0.0085 | 0.0933 | 0.0292 | 0.6432 | 0.0051 | 0.3069 | 0.0120 | 1.0490 |
| 36 | 15/02/94 | 23.37 | 0.0343 | 0.1599 | 0.0160 | 0.1756 | 0.0334 | 0.7341 | 0.0059 | 0.3579 | 0.0150 | 1.3171 |
| 37 | 17/02/94 | 17.97 | 0.0062 | 0.0289 | 0.0047 | 0.0514 | 0.0178 | 0.3910 | 0.0020 | 0.1213 | 0.0038 | 0.3356 |
| 38 | 19/02/94 | 9.69 | 0.0084 | 0.0393 | 0.0047 | 0.0520 | 0.0103 | 0.2255 | 0.0024 | 0.1480 | 0.0052 | 0.4557 |
| 39 | 05/03/94 | 35.09 | 0.0248 | 0.1158 | 0.0151 | 0.1661 | 0.0149 | 0.3288 | 0.0090 | 0.5435 | 0.0198 | 1.7351 |
| 40 | 07/03/94 | 20.93 | 0.0189 | 0.0881 | 0.0067 | 0.0738 | 0.0675 | 1.4850 | 0.0030 | 0.1826 | 0.0087 | 0.7650 |
| 41 | 08/03/94 | 45.98 | 0.0740 | 0.3454 | 0.0330 | 0.3618 | 0.1008 | 2.2181 | 0.0164 | 0.9917 | 0.0281 | 2.4581 |
| 42 | 21/03/94 | 11.98 | 0.0312 | 0.1454 | 0.0029 | 0.0323 | 0.0176 | 0.3883 | 0.0034 | 0.2068 | 0.0094 | 0.8255 |
| 43 | 22/03/94 | 28.29 | 0.0810 | 0.3780 | 0.0853 | 0.9371 | 0.0967 | 2.1272 | 0.0325 | 1.9683 | 0.0489 | 4.2826 |
| 44 | 24/03/94 | 55.89 | 0.1592 | 0.7429 | 0.1283 | 1.4086 | 0.2190 | 4.8192 | 0.0336 | 2.0399 | 0.0579 | 5.0747 |
| 45 | 25/03/94 | 16.32 | 0.0879 | 0.4101 | 0.0235 | 0.2575 | 0.0338 | 0.7427 | 0.0056 | 0.3391 | 0.0117 | 1.0279 |
| 46 | 27/03/94 | 12.82 | 0.0077 | 0.0358 | 0.0015 | 0.0159 | 0.0069 | 0.1523 | 0.0005 | 0.0309 | 0.0038 | 0.3365 |
| 47 | 28/03/94 | 25.38 | 0.0377 | 0.1761 | 0.0106 | 0.1164 | 0.0401 | 0.8829 | 0.0063 | 0.3791 | 0.0137 | 1.1962 |
| 48 | 29/03/94 | 8.69 | 0.0032 | 0.0149 | 0.0015 | 0.0166 | 0.0047 | 0.1023 | 0.0011 | 0.0643 | 0.0020 | 0.1779 |
| 49 | 30/03/94 | 69.90 | 0.1830 | 0.8540 | 0.0917 | 1.0066 | 0.1896 | 4.1728 | 0.0328 | 1.9871 | 0.0640 | 5.6075 |
| 50 | 04/04/94 | 51.66 | 0.1270 | 0.5924 | 0.0242 | 0.2656 | 0.0568 | 1.2492 | 0.0159 | 0.9614 | 0.0248 | 2.1733 |
| 51 | 06/04/94 | 21.44 | 0.0306 | 0.1426 | 0.0022 | 0.0242 | 0.0263 | 0.5783 | 0.0055 | 0.3354 | 0.0081 | 0.7054 |
| 52 | 09/04/94 | 6.65 | 0.0030 | 0.0141 | 0.0002 | 0.0026 | 0.0019 | 0.0418 | 0.0018 | 0.1092 | 0.0001 | 0.0061 |
| 53 | 10/04/94 | 15.70 | 0.0105 | 0.0492 | 0.0040 | 0.0443 | 0.0122 | 0.2676 | 0.0024 | 0.1462 | 0.0067 | 0.5889 |
| 54 | 11/04/94 | 65.81 | 0.0814 | 0.3797 | 0.0641 | 0.7040 | 0.0941 | 2.0698 | 0.0262 | 1.5861 | 0.0334 | 2.9286 |
| 55 | 14/04/94 | 135.75 | 0.1459 | 0.6807 | * | * | 0.0958 | 2.1070 | * | * | 0.0540 | 4.7321 |

*) Calculated from Table I.1 (Appendix I)

1) Sum of class I * 4.66; [4.66 = BA per size class/total BA within the class]

2) Sum of class II * 10.98; [10.98 = ditto]

3) Sum of class III * 22.00; [22.00 = ditto]

4) Sum of class IV * 60.65; [60.65 = ditto]

5) Sum of class V * 87.63; [87.63 = ditto]

**Table I.3** Stemflow volume (mm) per ha in the unlogged plot

| Rainfall event | Date | Gross Rainfall (mm) | Vol. of Class I ($m^3$) [1)] | Vol. of Class II ($m^3$) | Vol. of Class III ($m^3$) | Vol. of Class IV ($m^3$) | Vol. of Class V ($m^3$) | Total Volume ($m^3$) | Total Volume (mm) [2)] |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 01/11/93 | 23.57 | 0.0319 | 0.0594 | 0.2863 | 0.2074 | 0.6879 | 1.2729 | 0.1273 |
| 2 | 03/11/93 | 16.14 | 0.0394 | 0.0300 | 0.1758 | 0.0873 | 0.2296 | 0.5621 | 0.0562 |
| 3 | 06/11/93 | 27.52 | 0.0429 | 0.0628 | 0.3494 | 0.3027 | 0.9306 | 1.6884 | 0.1688 |
| 4 | 08/11/93 | 51.40 | 0.4671 | 0.5595 | 2.3860 | 1.4127 | 4.4438 | 9.2690 | 0.9269 |
| 5 | 09/11/93 | 62.50 | 1.4811 | 1.0022 | 3.3280 | 1.8124 | 4.2063 | 11.8300 | 1.1830 |
| 6 | 12/11/93 | 37.26 | 0.5838 | 0.2444 | 1.5232 | 0.8158 | 1.5160 | 4.6832 | 0.4683 |
| 7 | 16/11/93 | 38.29 | 0.3886 | 0.1515 | 1.1064 | 0.4956 | 0.9508 | 3.0929 | 0.3093 |
| 8 | 17/11/93 | 44.86 | 0.6282 | 0.3378 | 1.7018 | 1.2004 | 2.5422 | 6.4104 | 0.6410 |
| 9 | 18/11/93 | 14.83 | 0.0774 | 0.0608 | 0.4211 | 0.2572 | 0.5021 | 1.3186 | 0.1319 |
| 10 | 25/11/93 | 45.57 | 0.1482 | 0.2529 | 1.2908 | 0.4628 | 1.2619 | 3.4166 | 0.3417 |
| 11 | 27/11/93 | 85.94 | 1.0529 | 0.4401 | 4.7786 | 2.6052 | 3.1582 | 12.0350 | 1.2035 |
| 12 | 28/11/93 | 78.03 | 2.4272 | 0.5999 | 5.1722 | 1.8755 | 5.8319 | 15.9067 | 1.5907 |
| 13 | 30/11/93 | 83.62 | 1.0754 | 1.3366 | 5.2312 | 2.8872 | 5.9467 | 16.4771 | 1.6477 |
| 14 | 03/12/93 | 48.34 | 0.2491 | 0.1190 | 1.7856 | 1.2155 | 2.5588 | 5.9281 | 0.5928 |
| 15 | 06/12/93 | 14.56 | 0.1115 | 0.0464 | 0.3353 | 0.1037 | 0.4390 | 1.0360 | 0.1036 |
| 16 | 09/12/93 | 79.09 | 1.6296 | 1.6807 | 3.6101 | 3.6909 | 6.5075 | 17.1189 | 1.7119 |
| 17 | 10/12/93 | 11.01 | 0.2355 | 0.3558 | 0.7213 | 0.6557 | 1.3171 | 3.2854 | 0.3285 |
| 18 | 12/12/93 | 15.99 | 0.1676 | 0.2031 | 0.4502 | 0.6017 | 1.2593 | 2.6820 | 0.2682 |
| 19 | 18/12/93 | 57.59 | 0.2698 | 0.5664 | 0.8197 | 1.1039 | 2.7832 | 5.5430 | 0.5543 |
| 20 | 21/12/93 | 48.79 | 0.1020 | 0.1850 | 0.8687 | 0.5623 | 1.0358 | 2.7538 | 0.2754 |
| 21 | 23/12/93 | 39.75 | 0.2423 | 0.2305 | 1.4771 | 0.7400 | 1.7246 | 4.4145 | 0.4414 |
| 22 | 06/01/94 | 37.83 | 0.0409 | 0.0965 | 0.3162 | 0.4082 | 0.9753 | 1.8372 | 0.1837 |
| 23 | 09/01/94 | 27.56 | 0.0724 | 0.1255 | 0.7180 | 0.4355 | 0.8290 | 2.1804 | 0.2180 |
| 24 | 12/01/94 | 45.43 | 0.3136 | 0.1469 | 2.3118 | 0.9505 | 1.4398 | 5.1626 | 0.5163 |
| 25 | 13/01/94 | 58.93 | 0.0502 | 0.1663 | 3.2446 | 1.2720 | 2.3109 | 7.0439 | 0.7044 |
| 26 | 17/01/94 | 48.66 | 0.4986 | 0.0884 | 1.8198 | 0.6915 | 2.3696 | 5.4678 | 0.5468 |
| 27 | 19/01/94 | 16.71 | 0.0324 | 0.0221 | 0.0900 | 0.0873 | 0.4347 | 0.6664 | 0.0666 |
| 28 | 23/01/94 | 39.55 | 0.1329 | 0.2197 | 1.3201 | 0.7091 | 1.9060 | 4.2877 | 0.4288 |
| 29 | 27/01/94 | 32.10 | 0.1949 | 0.2295 | 1.3810 | 0.6357 | 1.7062 | 4.1473 | 0.4147 |
| 30 | 05/02/94 | 121.82 | 0.7775 | 1.5946 | 6.4516 | 3.0983 | 10.3949 | 22.3169 | 2.2317 |
| 31 | 08/02/94 | 94.86 | 0.8253 | 0.2660 | 4.2676 | 3.3743 | 3.5929 | 12.3261 | 1.2326 |
| 32 | 10/02/94 | 10.84 | 0.0289 | 0.0087 | 0.0557 | 0.0176 | 0.8045 | 0.9153 | 0.0915 |
| 33 | 11/02/94 | 12.69 | 0.0392 | 0.0430 | 0.3301 | 0.1868 | 0.5013 | 1.1004 | 0.1100 |
| 34 | 12/02/94 | 18.81 | 0.1066 | 0.1409 | 0.4400 | 0.3015 | 0.8474 | 1.8363 | 0.1836 |
| 35 | 14/02/94 | 28.93 | 0.1619 | 0.0933 | 0.6432 | 0.3069 | 1.0490 | 2.2543 | 0.2254 |
| 36 | 15/02/94 | 23.37 | 0.1599 | 0.1756 | 0.7341 | 0.3579 | 1.3171 | 2.7445 | 0.2745 |
| 37 | 17/02/94 | 17.97 | 0.0289 | 0.0514 | 0.3910 | 0.1213 | 0.3356 | 0.9282 | 0.0928 |
| 38 | 19/02/94 | 9.69 | 0.0393 | 0.0520 | 0.2255 | 0.1480 | 0.4557 | 0.9206 | 0.0921 |
| 39 | 05/03/94 | 35.09 | 0.1158 | 0.1661 | 0.3288 | 0.5435 | 1.7351 | 2.8893 | 0.2889 |
| 40 | 07/03/94 | 20.93 | 0.0881 | 0.0738 | 1.4850 | 0.1826 | 0.7650 | 2.5945 | 0.2595 |
| 41 | 08/03/94 | 45.98 | 0.3454 | 0.3618 | 2.2181 | 0.9917 | 2.4581 | 6.3751 | 0.6375 |
| 42 | 21/03/94 | 11.98 | 0.1454 | 0.0323 | 0.3883 | 0.2068 | 0.8255 | 1.5983 | 0.1598 |
| 43 | 22/03/94 | 28.29 | 0.3780 | 0.9371 | 2.1272 | 1.9683 | 4.2826 | 9.6932 | 0.9693 |
| 44 | 24/03/94 | 55.89 | 0.7429 | 1.4086 | 4.8192 | 2.0399 | 5.0747 | 14.0854 | 1.4085 |
| 45 | 25/03/94 | 16.32 | 0.4101 | 0.2575 | 0.7427 | 0.3391 | 1.0279 | 2.7773 | 0.2777 |
| 46 | 27/03/94 | 12.82 | 0.0358 | 0.0159 | 0.1523 | 0.0309 | 0.3365 | 0.5714 | 0.0571 |
| 47 | 28/03/94 | 25.38 | 0.1761 | 0.1164 | 0.8829 | 0.3791 | 1.1962 | 2.7506 | 0.2751 |
| 48 | 29/03/94 | 8.69 | 0.0149 | 0.0166 | 0.1023 | 0.0643 | 0.1779 | 0.3760 | 0.0376 |
| 49 | 30/03/94 | 69.90 | 0.8540 | 1.0066 | 4.1728 | 1.9871 | 5.6075 | 13.6281 | 1.3628 |
| 50 | 04/04/94 | 51.66 | 0.5924 | 0.2656 | 1.2492 | 0.9614 | 2.1733 | 5.2419 | 0.5242 |
| 51 | 06/04/94 | 21.44 | 0.1426 | 0.0242 | 0.5783 | 0.3354 | 0.7054 | 1.7859 | 0.1786 |
| 52 | 09/04/94 | 6.65 | 0.0141 | 0.0026 | 0.0418 | 0.1092 | 0.0061 | 0.1739 | 0.0174 |
| 53 | 10/04/94 | 15.70 | 0.0492 | 0.0443 | 0.2676 | 0.1462 | 0.5889 | 1.0961 | 0.1096 |
| 54 | 11/04/94 | 65.81 | 0.3797 | 0.7040 | 2.0698 | 1.5861 | 2.9286 | 7.6683 | 0.7668 |
| 55 | 14/04/94 | 135.75 | 1.0212 | 0.0020 | 4.2609 | 6.3958 | 7.0470 | 18.7269 | 1.8727 |

1) Volume of class I, II...V were taken from Table I.2 (Appendix I)

2) Conversion of a total stemflow volume ($m^3$) per hectare to the unit of depht (mm) per hectare

**Table I.4** Stemflow ($m^3$) by rainfall event from sample trees in the logged plot

| Rainfall event | Date | Gross rainfall (mm) | Diameter class (cm) and tree number: >50 | | | 30-50 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 6 | 9 | 5 | 8 | 10 | 18 | 2 | 4 | 11 |
| 1 | 25/06/94 | 20.70 | 0.0002 | 0.0009 | 0.0002 | 0.0008 | 0.0004 | 0.0003 | 0.0005 | 0.0000 | 0.0009 | 0.0001 |
| 2 | 26/06/94 | 23.67 | 0.0003 | 0.0044 | 0.0027 | 0.0022 | 0.0013 | 0.0014 | 0.0033 | 0.0004 | 0.0013 | 0.0008 |
| 3 | 28/06/94 | 19.60 | 0.0003 | 0.0056 | 0.0014 | 0.0015 | 0.0007 | 0.0012 | 0.0007 | 0.0004 | 0.0002 | 0.0002 |
| 4 | 30/06/94 | 38.57 | 0.0005 | 0.0108 | 0.0029 | 0.0022 | 0.0019 | 0.0032 | 0.0008 | 0.0005 | 0.0018 | 0.0005 |
| 5 | 05/07/94 | 81.77 | 0.0089 | 0.0248 | 0.0090 | 0.0043 | 0.0057 | 0.0058 | 0.0177 | 0.0020 | 0.0055 | 0.0044 |
| 6 | 07/07/94 | 23.10 | 0.0004 | 0.0015 | 0.0010 | 0.0019 | 0.0011 | 0.0009 | 0.0018 | 0.0004 | 0.0016 | 0.0009 |
| 7 | 18/11/94 | 72.70 | 0.0055 | 0.0199 | 0.0017 | 0.0128 | 0.0049 | 0.0121 | 0.0078 | 0.0026 | 0.0042 | 0.0050 |
| 8 | 19/11/94 | 44.20 | 0.0077 | 0.0100 | 0.0021 | 0.0067 | 0.0059 | 0.0049 | 0.0049 | 0.0011 | 0.0023 | 0.0025 |
| 9 | 29/11/94 | 163.60 | 0.0112 | 0.0091 | 0.0178 | 0.0168 | 0.0155 | 0.0126 | 0.0118 | 0.0045 | 0.0150 | 0.0075 |
| 10 | 01/12/94 | 32.53 | 0.0064 | 0.0092 | 0.0048 | 0.0037 | 0.0053 | 0.0132 | 0.0016 | 0.0016 | 0.0031 | 0.0009 |
| 11 | 02/12/94 | 41.53 | 0.0059 | 0.0039 | 0.0048 | 0.0016 | 0.0032 | 0.0223 | 0.0019 | 0.0027 | 0.0028 | 0.0016 |
| 12 | 04/12/94 | 30.90 | 0.0022 | 0.0027 | 0.0029 | 0.0056 | 0.0041 | 0.0094 | 0.0017 | 0.0013 | 0.0021 | 0.0004 |
| 13 | 08/12/94 | 13.30 | 0.0001 | 0.0001 | 0.0003 | 0.0004 | 0.0010 | 0.0002 | 0.0002 | 0.0000 | 0.0003 | 0.0001 |
| 14 | 18/12/94 | 8.27 | 0.0010 | 0.0009 | 0.0011 | 0.0002 | 0.0039 | 0.0000 | 0.0002 | 0.0010 | 0.0011 | 0.0000 |
| 15 | 19/12/94 | 7.60 | 0.0010 | 0.0010 | 0.0012 | 0.0012 | 0.0010 | 0.0010 | 0.0000 | 0.0010 | 0.0011 | 0.0000 |
| 16 | 20/12/94 | 21.57 | 0.0012 | 0.0012 | 0.0019 | 0.0008 | 0.0018 | 0.0007 | 0.0010 | 0.0002 | 0.0010 | 0.0005 |
| 17 | 21/12/94 | 11.23 | 0.0001 | 0.0015 | 0.0011 | 0.0004 | 0.0004 | 0.0019 | 0.0003 | 0.0001 | 0.0016 | 0.0003 |
| 18 | 23/12/94 | 18.03 | 0.0011 | 0.0004 | * | 0.0014 | 0.0014 | 0.0015 | 0.0006 | 0.0011 | 0.0013 | 0.0001 |
| 19 | 25/12/94 | 22.37 | 0.0001 | 0.0009 | 0.0009 | 0.0019 | 0.0010 | 0.0020 | 0.0013 | 0.0001 | 0.0010 | 0.0002 |
| 20 | 27/12/94 | 118.47 | 0.0328 | 0.0229 | 0.0010 | 0.0040 | 0.0177 | 0.0365 | 0.0232 | 0.0038 | 0.0106 | 0.0097 |
| 21 | 30/12/94 | 95.43 | 0.0242 | 0.0084 | 0.0011 | 0.0014 | 0.0125 | 0.0269 | 0.0200 | 0.0026 | 0.0087 | 0.0061 |
| 22 | 05/01/95 | 96.33 | 0.0145 | 0.0146 | 0.0014 | 0.0071 | 0.0100 | 0.0211 | 0.0156 | 0.0017 | 0.0067 | 0.0055 |
| 23 | 09/01/95 | 8.83 | 0.0001 | 0.0007 | 0.0005 | 0.0002 | 0.0010 | 0.0001 | 0.0002 | 0.0000 | 0.0004 | 0.0002 |
| 24 | 11/01/95 | 40.23 | 0.0013 | 0.0044 | 0.0062 | 0.0056 | 0.0038 | 0.0050 | 0.0028 | 0.0013 | 0.0006 | 0.0008 |
| 25 | 16/01/95 | 13.80 | 0.0001 | 0.0010 | 0.0001 | 0.0002 | 0.0001 | 0.0001 | 0.0004 | 0.0000 | 0.0010 | 0.0001 |
| 26 | 17/01/95 | 16.33 | 0.0002 | 0.0010 | 0.0022 | 0.0020 | 0.0015 | 0.0014 | 0.0027 | 0.0011 | 0.0004 | 0.0002 |
| 27 | 18/01/95 | 9.80 | 0.0001 | 0.0010 | 0.0005 | 0.0007 | 0.0002 | 0.0001 | 0.0006 | 0.0001 | 0.0007 | 0.0001 |
| 28 | 19/01/95 | 13.57 | 0.0011 | 0.0010 | 0.0029 | 0.0012 | 0.0010 | 0.0007 | 0.0006 | 0.0000 | 0.0012 | 0.0001 |
| 29 | 20/01/95 | 51.40 | 0.0103 | 0.0106 | 0.0184 | 0.0037 | 0.0067 | 0.0137 | 0.0120 | 0.0017 | 0.0046 | 0.0022 |
| 30 | 21/01/95 | 16.60 | 0.0002 | 0.0010 | 0.0032 | 0.0012 | 0.0012 | 0.0020 | 0.0008 | 0.0001 | 0.0020 | 0.0002 |
| 31 | 23/01/95 | 69.70 | 0.0217 | 0.0217 | 0.0231 | 0.0045 | 0.0107 | 0.0196 | 0.0122 | 0.0029 | 0.0063 | 0.0041 |
| 32 | 26/01/95 | 29.77 | 0.0012 | 0.0013 | 0.0049 | 0.0015 | 0.0012 | 0.0028 | 0.0008 | 0.0001 | 0.0017 | 0.0002 |
| 33 | 27/01/95 | 42.45 | 0.0019 | 0.0062 | 0.0119 | 0.0038 | 0.0029 | 0.0075 | 0.0032 | 0.0012 | 0.0030 | 0.0004 |
| 34 | 28/01/95 | 13.70 | 0.0002 | 0.0005 | 0.0012 | 0.0012 | 0.0004 | 0.0006 | 0.0003 | 0.0000 | 0.0005 | 0.0001 |
| 35 | 01/02/95 | 40.60 | 0.0029 | 0.0028 | 0.0080 | 0.0033 | 0.0050 | 0.0059 | 0.0071 | 0.0007 | 0.0038 | 0.0004 |
| 36 | 02/02/95 | 12.63 | 0.0001 | 0.0001 | 0.0007 | 0.0005 | 0.0002 | 0.0002 | 0.0003 | 0.0001 | 0.0009 | 0.0000 |
| 37 | 04/02/95 | 44.70 | 0.0019 | 0.0065 | 0.0144 | 0.0075 | 0.0039 | 0.0084 | 0.0080 | 0.0013 | 0.0033 | 0.0006 |
| 38 | 06/02/95 | 30.53 | 0.0004 | 0.0065 | 0.0059 | 0.0033 | 0.0020 | 0.0043 | 0.0024 | 0.0004 | 0.0022 | 0.0003 |
| 39 | 07/02/95 | 28.85 | 0.0004 | 0.0054 | 0.0037 | 0.0018 | 0.0019 | 0.0049 | 0.0027 | 0.0003 | 0.0013 | 0.0002 |
| 40 | 09/02/95 | 34.60 | 0.0005 | 0.0078 | 0.0019 | 0.0026 | 0.0042 | 0.0031 | 0.0034 | 0.0007 | 0.0035 | 0.0003 |
| 41 | 10/02/95 | 13.30 | 0.0001 | 0.0005 | 0.0011 | 0.0000 | 0.0001 | 0.0005 | 0.0002 | 0.0001 | 0.0007 | 0.0001 |
| 42 | 11/02/95 | 5.00 | 0.0001 | 0.0003 | 0.0001 | 0.0001 | 0.0000 | 0.0001 | 0.0001 | 0.0000 | 0.0002 | 0.0000 |
| 43 | 14/02/95 | 17.70 | 0.0002 | 0.0001 | 0.0007 | 0.0005 | 0.0004 | 0.0002 | 0.0003 | 0.0001 | 0.0009 | 0.0001 |
| 44 | 16/02/95 | 15.75 | 0.0001 | 0.0001 | 0.0004 | 0.0004 | 0.0002 | 0.0001 | 0.0004 | 0.0001 | 0.0005 | 0.0001 |
| 45 | 17/02/95 | 50.63 | 0.0023 | 0.0070 | 0.0087 | 0.0063 | 0.0065 | 0.0127 | 0.0044 | 0.0013 | 0.0036 | 0.0016 |
| 46 | 18/02/95 | 13.70 | 0.0002 | 0.0013 | 0.0012 | 0.0017 | 0.0007 | 0.0011 | 0.0004 | 0.0001 | 0.0002 | 0.0001 |
| 47 | 19/02/95 | 21.25 | 0.0003 | 0.0019 | 0.0034 | 0.0028 | 0.0015 | 0.0048 | 0.0008 | 0.0014 | 0.0011 | 0.0003 |
| 48 | 23/02/95 | 46.85 | 0.0005 | 0.0047 | 0.0071 | 0.0034 | 0.0045 | 0.0050 | 0.0029 | 0.0004 | 0.0036 | 0.0004 |
| 49 | 24/02/95 | 19.03 | 0.0003 | 0.0018 | 0.0034 | 0.0035 | 0.0024 | 0.0023 | 0.0018 | 0.0003 | 0.0014 | 0.0001 |
| 50 | 25/02/95 | 28.25 | 0.0012 | 0.0040 | 0.0077 | 0.0033 | 0.0029 | 0.0045 | 0.0022 | 0.0002 | 0.0032 | 0.0003 |
| 51 | 26/02/95 | 115.47 | 0.0439 | 0.0228 | 0.0460 | 0.0148 | 0.0242 | 0.0445 | 0.0154 | 0.0044 | 0.0101 | 0.0063 |
| 52 | 02/03/95 | 114.70 | 0.0283 | 0.0182 | 0.0396 | 0.0168 | 0.0193 | 0.0328 | 0.0160 | 0.0043 | 0.0080 | 0.0047 |
| 53 | 09/03/95 | 40.55 | 0.0011 | 0.0012 | 0.0049 | 0.0026 | 0.0016 | 0.0023 | 0.0030 | 0.0005 | 0.0019 | 0.0004 |
| 54 | 13/03/95 | 16.77 | 0.0001 | 0.0005 | 0.0040 | 0.0023 | 0.0013 | 0.0016 | 0.0006 | 0.0004 | 0.0011 | 0.0002 |
| 55 | 14/03/95 | 44.30 | 0.0018 | 0.0069 | 0.0125 | 0.0068 | 0.0040 | 0.0089 | 0.0036 | 0.0005 | 0.0037 | 0.0006 |
| 56 | 16/03/95 | 41.80 | 0.0029 | 0.0026 | 0.0109 | 0.0045 | 0.0038 | 0.0082 | 0.0035 | 0.0006 | 0.0030 | 0.0006 |
| 57 | 20/03/95 | 19.75 | 0.0011 | 0.0001 | 0.0012 | 0.0005 | 0.0005 | 0.0006 | 0.0003 | 0.0000 | 0.0012 | 0.0000 |
| 58 | 23/03/95 | 43.90 | 0.0002 | 0.0003 | 0.0010 | 0.0005 | 0.0018 | 0.0007 | 0.0003 | 0.0001 | 0.0013 | 0.0000 |
| 59 | 24/03/95 | 50.45 | 0.0059 | 0.0084 | 0.0164 | 0.0017 | 0.0060 | 0.0174 | 0.0051 | 0.0013 | 0.0037 | 0.0016 |
| 60 | 27/03/95 | 28.20 | 0.0011 | 0.0013 | 0.0036 | 0.0008 | 0.0023 | 0.0039 | 0.0006 | 0.0003 | 0.0019 | 0.0002 |
| 61 | 28/03/95 | 18.23 | 0.0002 | 0.0004 | 0.0042 | 0.0003 | 0.0009 | 0.0048 | 0.0005 | 0.0001 | 0.0019 | 0.0002 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 62 | 29/03/95 | 11.10 | 0.0001 | 0.0010 | 0.0001 | 0.0004 | 0.0012 | 0.0011 | 0.0002 | 0.0000 | 0.0005 | 0.0001 |
| 63 | 01/04/95 | 43.15 | 0.0025 | 0.0053 | 0.0134 | 0.0016 | 0.0044 | 0.0122 | 0.0048 | 0.0010 | 0.0039 | 0.0010 |
| 64 | 03/04/95 | 30.27 | 0.0010 | 0.0014 | 0.0053 | 0.0021 | 0.0019 | 0.0063 | 0.0017 | 0.0003 | 0.0019 | 0.0004 |
| 65 | 04/04/95 | 7.47 | 0.0001 | 0.0001 | 0.0002 | 0.0002 | 0.0001 | 0.0003 | 0.0002 | 0.0000 | 0.0003 | 0.0001 |
| 66 | 06/04/95 | 70.17 | 0.0117 | 0.0091 | 0.0170 | 0.0060 | 0.0077 | 0.0260 | 0.0077 | 0.0026 | 0.0038 | 0.0030 |
| 67 | 07/04/95 | 64.27 | 0.0229 | 0.0139 | 0.0278 | 0.0079 | 0.0086 | 0.0296 | 0.0081 | 0.0022 | 0.0046 | 0.0036 |
| 68 | 08/04/95 | 12.00 | 0.0001 | 0.0005 | 0.0020 | 0.0007 | 0.0008 | 0.0041 | 0.0003 | 0.0001 | 0.0002 | 0.0001 |
| 69 | 10/04/95 | 46.65 | 0.0025 | 0.0085 | 0.0107 | 0.0099 | 0.0037 | 0.0143 | 0.0040 | 0.0017 | 0.0022 | 0.0010 |
| 70 | 12/04/95 | 15.90 | 0.0001 | 0.0006 | 0.0024 | 0.0008 | 0.0010 | 0.0020 | 0.0004 | 0.0001 | 0.0012 | 0.0001 |
| 71 | 14/04/95 | 10.10 | 0.0001 | 0.0009 | 0.0004 | 0.0006 | 0.0003 | 0.0004 | 0.0003 | 0.0000 | 0.0006 | 0.0000 |
| 72 | 15/04/95 | 59.50 | 0.0084 | 0.0098 | 0.0161 | 0.0142 | 0.0074 | 0.0241 | 0.0077 | 0.0022 | 0.0044 | 0.0029 |
| 73 | 18/04/95 | 7.25 | 0.0000 | 0.0001 | 0.0001 | 0.0002 | 0.0000 | 0.0001 | 0.0001 | 0.0000 | 0.0001 | 0.0000 |
| 74 | 22/04/95 | 40.20 | 0.0003 | 0.0018 | 0.0058 | 0.0055 | 0.0016 | 0.0066 | 0.0018 | 0.0011 | 0.0018 | 0.0007 |
| 75 | 23/04/95 | 39.20 | 0.0033 | 0.0056 | 0.0109 | 0.0095 | 0.0043 | 0.0137 | 0.0040 | 0.0018 | 0.0027 | 0.0014 |
| 76 | 26/04/95 | 48.55 | 0.0041 | 0.0062 | 0.0147 | 0.0107 | 0.0051 | 0.0146 | 0.0062 | 0.0014 | 0.0031 | 0.0019 |
| 77 | 04/05/95 | 43.23 | 0.0005 | 0.0028 | 0.0058 | 0.0075 | 0.0027 | 0.0084 | 0.0056 | 0.0028 | 0.0031 | 0.0011 |
| 78 | 05/05/95 | 13.40 | 0.0012 | 0.0018 | 0.0015 | 0.0010 | 0.0016 | 0.0017 | 0.0004 | 0.0001 | 0.0007 | 0.0001 |
| 79 | 13/05/95 | 177.53 | 0.0484 | 0.0343 | 0.0110 | 0.0410 | 0.0184 | 0.0602 | 0.0274 | 0.0045 | 0.0148 | 0.0099 |
| 80 | 15/05/95 | 50.87 | 0.0070 | 0.0108 | 0.0031 | 0.0111 | 0.0034 | 0.0157 | 0.0074 | 0.0014 | 0.0054 | 0.0025 |
| 81 | 19/05/95 | 30.60 | 0.0004 | 0.0012 | 0.0013 | 0.0029 | 0.0015 | 0.0024 | 0.0011 | 0.0006 | 0.0018 | 0.0004 |
| 82 | 25/05/95 | 35.67 | 0.0015 | 0.0032 | 0.0091 | 0.0024 | 0.0016 | 0.0056 | 0.0031 | 0.0011 | 0.0029 | 0.0007 |
| 83 | 26/05/95 | 18.40 | 0.0003 | 0.0017 | 0.0020 | 0.0022 | 0.0015 | 0.0023 | 0.0017 | 0.0005 | 0.0010 | 0.0003 |
| 84 | 31/05/95 | 64.23 | 0.0089 | 0.0108 | 0.0207 | 0.0157 | 0.0058 | 0.0160 | 0.0095 | 0.0021 | 0.0054 | 0.0029 |
| 85 | 01/06/95 | 32.13 | 0.0013 | 0.0044 | 0.0092 | 0.0049 | 0.0037 | 0.0088 | 0.0031 | 0.0016 | 0.0019 | 0.0012 |
| 86 | 03/06/95 | 15.43 | 0.0004 | 0.0002 | 0.0071 | 0.0008 | 0.0003 | 0.0013 | 0.0016 | 0.0001 | 0.0007 | 0.0001 |
| 87 | 06/06/95 | 28.50 | 0.0004 | 0.0013 | 0.0050 | 0.0023 | 0.0017 | 0.0038 | 0.0014 | 0.0003 | 0.0013 | 0.0004 |
| 88 | 09/06/95 | 14.10 | 0.0001 | 0.0002 | 0.0007 | 0.0010 | 0.0001 | 0.0003 | 0.0004 | 0.0001 | 0.0008 | 0.0002 |
| 89 | 14/06/95 | 46.30 | 0.0060 | 0.0110 | 0.0097 | 0.0086 | 0.0042 | 0.0110 | 0.0055 | 0.0012 | 0.0036 | 0.0019 |
| 90 | 19/06/95 | 52.77 | 0.0020 | 0.0131 | 0.0087 | 0.0090 | 0.0042 | 0.0103 | 0.0069 | 0.0018 | 0.0038 | 0.0024 |
| 91 | 20/06/95 | 24.90 | 0.0003 | 0.0066 | 0.0059 | 0.0028 | 0.0018 | 0.0062 | 0.0009 | 0.0005 | 0.0011 | 0.0006 |
| 92 | 22/06/95 | 46.37 | 0.0060 | 0.0057 | 0.0068 | 0.0084 | 0.0043 | 0.0060 | 0.0064 | 0.0011 | 0.0022 | 0.0023 |
| 93 | 24/06/95 | 51.17 | 0.0102 | 0.0159 | 0.0035 | 0.0101 | 0.0032 | 0.0020 | 0.0073 | 0.0022 | 0.0022 | 0.0056 |
| 94 | 30/06/95 | 7.37 | 0.0001 | 0.0000 | 0.0002 | 0.0002 | 0.0001 | 0.0001 | 0.0002 | 0.0000 | 0.0002 | 0.0001 |
| 95 | 02/07/95 | 13.10 | 0.0001 | 0.0002 | 0.0003 | 0.0005 | 0.0003 | 0.0012 | 0.0007 | 0.0001 | 0.0004 | 0.0001 |
| Mean | | 37.48 | 0.0044 | 0.0054 | 0.0062 | 0.0042 | 0.0036 | 0.0077 | 0.0040 | 0.0010 | 0.0026 | 0.0013 |
| SD | | 31.49 | 0.0088 | 0.0066 | 0.0080 | 0.0056 | 0.0045 | 0.0104 | 0.0054 | 0.0011 | 0.0028 | 0.0021 |
| SE | | 3.25 | 0.0009 | 0.0007 | 0.0008 | 0.0006 | 0.0005 | 0.0011 | 0.0006 | 0.0001 | 0.0003 | 0.0002 |
| Total | | 3561.0 | 0.4150 | 0.5086 | 0.5875 | 0.3997 | 0.3416 | 0.7350 | 0.3781 | 0.0937 | 0.2496 | 0.1243 |

# Appendix I

| 15-30 | | | | | | <15 | | | | Mean | SD | SE | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12 | 13 | 16 | 17 | 3 | 7 | 14 | 15 | 19 | 20 | | | | |
| 0.0002 | 0.0005 | 0.0002 | 0.0022 | 0.0005 | 0.0013 | 0.0003 | 0.0002 | 0.0005 | 0.0005 | 0.0005 | 0.0005 | 0.0001 | 0.0108 |
| 0.0015 | 0.0017 | 0.0015 | 0.0090 | 0.0005 | 0.0022 | 0.0016 | 0.0008 | 0.0008 | 0.0010 | 0.0019 | 0.0019 | 0.0004 | 0.0388 |
| 0.0004 | 0.0013 | 0.0007 | 0.0098 | 0.0004 | 0.0011 | 0.0009 | 0.0009 | 0.0005 | 0.0010 | 0.0015 | 0.0023 | 0.0005 | 0.0293 |
| 0.0011 | 0.0034 | 0.0014 | 0.0087 | 0.0010 | 0.0023 | 0.0015 | 0.0012 | 0.0015 | 0.0014 | 0.0024 | 0.0027 | 0.0006 | 0.0487 |
| 0.0056 | 0.0138 | 0.0057 | 0.0338 | 0.0029 | 0.0022 | 0.0054 | 0.0046 | 0.0033 | 0.0041 | 0.0085 | 0.0082 | 0.0018 | 0.1694 |
| 0.0009 | 0.0011 | 0.0009 | 0.0069 | 0.0010 | 0.0012 | 0.0014 | 0.0005 | 0.0006 | 0.0010 | 0.0013 | 0.0014 | 0.0003 | 0.0268 |
| 0.0065 | 0.0085 | 0.0045 | 0.0108 | 0.0011 | 0.0022 | 0.0038 | 0.0029 | 0.0026 | 0.0014 | 0.0060 | 0.0048 | 0.0011 | 0.1208 |
| 0.0022 | 0.0041 | 0.0031 | 0.0154 | 0.0021 | 0.0022 | 0.0028 | 0.0024 | 0.0014 | 0.0009 | 0.0042 | 0.0036 | 0.0008 | 0.0847 |
| 0.0119 | 0.0179 | 0.0104 | 0.0650 | 0.0040 | 0.0024 | 0.0112 | 0.0090 | 0.0072 | 0.0039 | 0.0132 | 0.013 | 0.0029 | 0.2647 |
| 0.0015 | 0.0064 | 0.0013 | 0.0224 | 0.0017 | 0.0044 | 0.0016 | 0.0019 | 0.0013 | 0.0009 | 0.0047 | 0.0052 | 0.0012 | 0.0932 |
| 0.0032 | 0.0039 | 0.0219 | 0.0215 | 0.0020 | 0.0014 | 0.0016 | 0.0022 | 0.0014 | 0.0018 | 0.0056 | 0.0071 | 0.0016 | 0.1116 |
| 0.0010 | 0.0030 | 0.0014 | 0.0250 | 0.0021 | 0.0020 | 0.0011 | 0.0009 | 0.0010 | 0.0005 | 0.0035 | 0.0055 | 0.0012 | 0.0706 |
| 0.0002 | 0.0004 | 0.0001 | 0.0052 | 0.0003 | 0.0013 | 0.0001 | 0.0001 | 0.0003 | 0.0001 | 0.0006 | 0.0011 | 0.0003 | 0.0110 |
| 0.0001 | 0.0001 | 0.0001 | 0.0008 | 0.0001 | 0.0001 | 0.0001 | 0.0000 | 0.0001 | 0.0002 | 0.0006 | 0.0009 | 0.0002 | 0.0111 |
| 0.0002 | 0.0001 | 0.0001 | 0.0021 | 0.0011 | 0.0011 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0007 | 0.0006 | 0.0001 | 0.0133 |
| 0.0015 | 0.0020 | 0.0005 | 0.0068 | 0.0014 | 0.0015 | 0.0015 | 0.0004 | 0.0006 | 0.0011 | 0.0014 | 0.0014 | 0.0003 | 0.0278 |
| 0.0002 | 0.0012 | 0.0001 | 0.0021 | 0.0005 | 0.0003 | 0.0006 | 0.0001 | 0.0003 | 0.0006 | 0.0007 | 0.0006 | 0.0001 | 0.0138 |
| 0.0006 | 0.0015 | 0.0003 | 0.0035 | 0.0015 | 0.0015 | 0.0010 | 0.0004 | 0.0003 | 0.0013 | 0.0011 | 0.0008 | 0.0002 | 0.0209 |
| 0.0005 | 0.0015 | 0.0004 | 0.0045 | 0.0010 | 0.0012 | 0.0012 | 0.0004 | 0.0004 | 0.0009 | 0.0011 | 0.001 | 0.0002 | 0.0215 |
| 0.0093 | 0.0175 | 0.0119 | 0.0650 | 0.0045 | 0.0055 | 0.0123 | 0.0076 | 0.0051 | 0.0076 | 0.0154 | 0.0152 | 0.0034 | 0.3083 |
| 0.0087 | 0.0118 | 0.0091 | 0.0650 | 0.0033 | 0.0056 | 0.0065 | 0.0053 | 0.0038 | 0.0048 | 0.0118 | 0.0144 | 0.0032 | 0.2358 |
| 0.0053 | 0.0123 | 0.0068 | 0.0650 | 0.0034 | 0.0042 | 0.0062 | 0.0034 | 0.0037 | 0.0059 | 0.0107 | 0.0138 | 0.0031 | 0.2145 |
| 0.0004 | 0.0001 | 0.0001 | 0.0017 | 0.0002 | 0.0000 | 0.0001 | 0.0001 | 0.0006 | 0.0003 | 0.0003 | 0.0004 | 9E-05 | 0.0068 |
| 0.0011 | 0.0046 | 0.0016 | 0.0236 | 0.0014 | 0.0015 | 0.0024 | 0.0011 | 0.0013 | 0.0021 | 0.0036 | 0.005 | 0.0011 | 0.0726 |
| 0.0001 | 0.0003 | 0.0001 | 0.0019 | 0.0000 | 0.0000 | 0.0001 | 0.0001 | 0.0001 | 0.0003 | 0.0003 | 0.0005 | 0.0001 | 0.0060 |
| 0.0006 | 0.0015 | 0.0004 | 0.0098 | 0.0005 | 0.0014 | 0.0008 | 0.0001 | 0.0003 | 0.0005 | 0.0014 | 0.0021 | 0.0005 | 0.0287 |
| 0.0003 | 0.0003 | 0.0002 | 0.0039 | 0.0002 | 0.0001 | 0.0004 | 0.0001 | 0.0002 | 0.0002 | 0.0005 | 0.0008 | 0.0002 | 0.0097 |
| 0.0003 | 0.0008 | 0.0002 | 0.0068 | 0.0001 | 0.0015 | 0.0010 | 0.0002 | 0.0002 | 0.0004 | 0.0011 | 0.0015 | 0.0003 | 0.0213 |
| 0.0036 | 0.0052 | 0.0048 | 0.0288 | 0.0019 | 0.0016 | 0.0058 | 0.0030 | 0.0024 | 0.0024 | 0.0072 | 0.0069 | 0.0015 | 0.1434 |
| 0.0004 | 0.0014 | 0.0004 | 0.0107 | 0.0010 | 0.0011 | 0.0004 | 0.0004 | 0.0004 | 0.0006 | 0.0014 | 0.0023 | 0.0005 | 0.0286 |
| 0.0055 | 0.0090 | 0.0071 | 0.0159 | 0.0022 | 0.0020 | 0.0056 | 0.0043 | 0.0028 | 0.0021 | 0.0092 | 0.0073 | 0.0016 | 0.1832 |
| 0.0005 | 0.0025 | 0.0008 | 0.0016 | 0.0011 | 0.0011 | 0.0013 | 0.0005 | 0.0004 | 0.0008 | 0.0013 | 0.0011 | 0.0002 | 0.0261 |
| 0.0017 | 0.0049 | 0.0022 | 0.0321 | 0.0015 | 0.0013 | 0.0031 | 0.0014 | 0.0018 | 0.0015 | 0.0047 | 0.007 | 0.0016 | 0.0936 |
| 0.0003 | 0.0011 | 0.0002 | 0.0031 | 0.0008 | 0.0000 | 0.0007 | 0.0001 | 0.0002 | 0.0006 | 0.0006 | 0.0007 | 0.0002 | 0.0119 |
| 0.0015 | 0.0031 | 0.0024 | 0.0151 | 0.0018 | 0.0026 | 0.0020 | 0.0007 | 0.0012 | 0.0013 | 0.0036 | 0.0034 | 0.0008 | 0.0716 |
| 0.0003 | 0.0006 | 0.0002 | 0.0009 | 0.0003 | 0.0004 | 0.0004 | 0.0001 | 0.0002 | 0.0002 | 0.0003 | 0.0003 | 6E-05 | 0.0066 |
| 0.0027 | 0.0051 | 0.0030 | 0.0111 | 0.0004 | 0.0023 | 0.0023 | 0.0014 | 0.0012 | 0.0029 | 0.0044 | 0.0038 | 0.0008 | 0.0881 |
| 0.0013 | 0.0058 | 0.0015 | 0.0064 | 0.0013 | 0.0006 | 0.0022 | 0.0007 | 0.0010 | 0.0015 | 0.0025 | 0.0021 | 0.0005 | 0.0499 |
| 0.0016 | 0.0035 | 0.0016 | 0.0058 | 0.0011 | 0.0012 | 0.0028 | 0.0011 | 0.0012 | 0.0018 | 0.0022 | 0.0017 | 0.0004 | 0.0444 |
| 0.0013 | 0.0031 | 0.0021 | 0.0074 | 0.0013 | 0.0020 | 0.0030 | 0.0013 | 0.0013 | 0.0022 | 0.0026 | 0.002 | 0.0004 | 0.0529 |
| 0.0003 | 0.0015 | 0.0002 | 0.0009 | 0.0005 | 0.0010 | 0.0014 | 0.0001 | 0.0002 | 0.0003 | 0.0005 | 0.0005 | 0.0001 | 0.0099 |
| 0.0001 | 0.0002 | 0.0001 | 0.0004 | 0.0001 | 0.0002 | 0.0001 | 0.0001 | 0.0001 | 0.0002 | 0.0001 | 9E-05 | 2E-05 | 0.0025 |
| 0.0004 | 0.0013 | 0.0002 | 0.0007 | 0.0005 | 0.0000 | 0.0008 | 0.0001 | 0.0002 | 0.0006 | 0.0004 | 0.0003 | 7E-05 | 0.0079 |
| 0.0003 | 0.0007 | 0.0002 | 0.0004 | 0.0002 | 0.0010 | 0.0005 | 0.0001 | 0.0002 | 0.0005 | 0.0003 | 0.0002 | 5E-05 | 0.0063 |
| 0.0046 | 0.0083 | 0.0037 | 0.0101 | 0.0038 | 0.0020 | 0.0058 | 0.0026 | 0.0011 | 0.0021 | 0.0049 | 0.0032 | 0.0007 | 0.0984 |
| 0.0005 | 0.0023 | 0.0002 | 0.0010 | 0.0010 | 0.0002 | 0.0011 | 0.0002 | 0.0002 | 0.0008 | 0.0007 | 0.0006 | 0.0001 | 0.0144 |
| 0.0013 | 0.0027 | 0.0005 | 0.0016 | 0.0005 | 0.0029 | 0.0017 | 0.0007 | 0.0007 | 0.0008 | 0.0016 | 0.0012 | 0.0003 | 0.0316 |
| 0.0013 | 0.0046 | 0.0017 | 0.0063 | 0.0012 | 0.0018 | 0.0033 | 0.0010 | 0.0008 | 0.0015 | 0.0028 | 0.0021 | 0.0005 | 0.0559 |
| 0.0006 | 0.0024 | 0.0008 | 0.0034 | 0.0015 | 0.0004 | 0.0017 | 0.0006 | 0.0004 | 0.0001 | 0.0015 | 0.0011 | 0.0003 | 0.0294 |
| 0.0010 | 0.0048 | 0.0012 | 0.0074 | 0.0017 | 0.0018 | 0.0025 | 0.0009 | 0.0006 | 0.0018 | 0.0027 | 0.0021 | 0.0005 | 0.0533 |
| 0.0146 | 0.0231 | 0.0107 | 0.0210 | 0.0042 | 0.0070 | 0.0146 | 0.0097 | 0.0049 | 0.0056 | 0.0174 | 0.0134 | 0.003 | 0.3481 |
| 0.0054 | 0.0179 | 0.0100 | 0.0180 | 0.0029 | 0.0050 | 0.0124 | 0.0060 | 0.0035 | 0.0046 | 0.0137 | 0.0105 | 0.0023 | 0.2738 |
| 0.0018 | 0.0045 | 0.0005 | 0.0049 | 0.0013 | 0.0028 | 0.0034 | 0.0008 | 0.0009 | 0.0019 | 0.0021 | 0.0014 | 0.0003 | 0.0420 |
| 0.0004 | 0.0013 | 0.0002 | 0.0042 | 0.0005 | 0.0002 | 0.0006 | 0.0003 | 0.0005 | 0.0004 | 0.0010 | 0.0012 | 0.0003 | 0.0205 |
| 0.0018 | 0.0059 | 0.0024 | 0.0333 | 0.0013 | 0.0040 | 0.0030 | 0.0010 | 0.0006 | 0.0021 | 0.0052 | 0.0073 | 0.0016 | 0.1048 |
| 0.0014 | 0.0049 | 0.0023 | 0.0299 | 0.0015 | 0.0010 | 0.0030 | 0.0014 | 0.0006 | 0.0018 | 0.0044 | 0.0065 | 0.0015 | 0.0884 |
| 0.0002 | 0.0008 | 0.0002 | 0.0078 | 0.0003 | 0.0011 | 0.0006 | 0.0001 | 0.0001 | 0.0004 | 0.0009 | 0.0017 | 0.0004 | 0.0170 |
| 0.0005 | 0.0013 | 0.0002 | 0.0098 | 0.0010 | 0.0003 | 0.0010 | 0.0002 | 0.0001 | 0.0006 | 0.0011 | 0.0021 | 0.0005 | 0.0213 |
| 0.0031 | 0.0075 | 0.0042 | 0.0342 | 0.0020 | 0.0049 | 0.0045 | 0.0021 | 0.0015 | 0.0025 | 0.0067 | 0.0079 | 0.0017 | 0.1340 |
| 0.0011 | 0.0031 | 0.0005 | 0.0144 | 0.0017 | 0.0020 | 0.0015 | 0.0003 | 0.0005 | 0.0012 | 0.0021 | 0.0031 | 0.0007 | 0.0425 |
| 0.0005 | 0.0029 | 0.0003 | 0.0139 | 0.0004 | 0.0015 | 0.0010 | 0.0003 | 0.0003 | 0.0008 | 0.0018 | 0.0032 | 0.0007 | 0.0352 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0002 | 0.0008 | 0.0001 | 0.0063 | 0.0003 | 0.0001 | 0.0004 | 0.0001 | 0.0002 | 0.0002 | 0.0007 | 0.0014 | 0.0003 | 0.0131 |
| 0.0026 | 0.0056 | 0.0022 | 0.0246 | 0.0022 | 0.0020 | 0.0004 | 0.0011 | 0.0012 | 0.0011 | 0.0046 | 0.0059 | 0.0013 | 0.0928 |
| 0.0020 | 0.0056 | 0.0008 | 0.0296 | 0.0010 | 0.0021 | 0.0017 | 0.0006 | 0.0010 | 0.0013 | 0.0034 | 0.0064 | 0.0014 | 0.0680 |
| 0.0002 | 0.0004 | 0.0001 | 0.0032 | 0.0002 | 0.0000 | 0.0002 | 0.0000 | 0.0001 | 0.0002 | 0.0003 | 0.0007 | 0.0002 | 0.0062 |
| 0.0055 | 0.0112 | 0.0057 | 0.0650 | 0.0039 | 0.0059 | 0.0062 | 0.0034 | 0.0020 | 0.0036 | 0.0104 | 0.0141 | 0.0031 | 0.2071 |
| 0.0042 | 0.0115 | 0.0070 | 0.0650 | 0.0039 | 0.0052 | 0.0062 | 0.0039 | 0.0020 | 0.0035 | 0.0121 | 0.0149 | 0.0033 | 0.2416 |
| 0.0002 | 0.0018 | 0.0002 | 0.0085 | 0.0009 | 0.0006 | 0.0008 | 0.0002 | 0.0002 | 0.0005 | 0.0011 | 0.002 | 0.0004 | 0.0227 |
| 0.0019 | 0.0068 | 0.0021 | 0.0388 | 0.0012 | 0.0022 | 0.0036 | 0.0015 | 0.0011 | 0.0020 | 0.0060 | 0.0086 | 0.0019 | 0.1197 |
| 0.0004 | 0.0016 | 0.0003 | 0.0134 | 0.0024 | 0.0012 | 0.0008 | 0.0002 | 0.0002 | 0.0007 | 0.0015 | 0.0029 | 0.0006 | 0.0299 |
| 0.0001 | 0.0006 | 0.0002 | 0.0092 | 0.0002 | 0.0002 | 0.0004 | 0.0001 | 0.0001 | 0.0003 | 0.0008 | 0.002 | 0.0004 | 0.0150 |
| 0.0050 | 0.0100 | 0.0045 | 0.0650 | 0.0022 | 0.0061 | 0.0064 | 0.0035 | 0.0020 | 0.0025 | 0.0102 | 0.014 | 0.0031 | 0.2046 |
| 0.0002 | 0.0001 | 0.0001 | 0.0032 | 0.0000 | 0.0000 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0002 | 0.0007 | 0.0002 | 0.0045 |
| 0.0022 | 0.0009 | 0.0023 | 0.0443 | 0.0036 | 0.0014 | 0.0019 | 0.0007 | 0.0001 | 0.0001 | 0.0042 | 0.0096 | 0.0021 | 0.0846 |
| 0.0033 | 0.0065 | 0.0033 | 0.0314 | 0.0014 | 0.0026 | 0.0039 | 0.0018 | 0.0015 | 0.0021 | 0.0057 | 0.0069 | 0.0015 | 0.1149 |
| 0.0031 | 0.0067 | 0.0032 | 0.0454 | 0.0038 | 0.0023 | 0.0041 | 0.0023 | 0.0014 | 0.0032 | 0.0072 | 0.0098 | 0.0022 | 0.1433 |
| 0.0015 | 0.0046 | 0.0021 | 0.0424 | 0.0012 | 0.0032 | 0.0025 | 0.0016 | 0.0009 | 0.0021 | 0.0051 | 0.009 | 0.002 | 0.1022 |
| 0.0005 | 0.0011 | 0.0003 | 0.0138 | 0.0006 | 0.0010 | 0.0007 | 0.0002 | 0.0002 | 0.0013 | 0.0015 | 0.0029 | 0.0007 | 0.0296 |
| 0.0114 | 0.0302 | 0.0090 | 0.0650 | 0.0059 | 0.0143 | 0.0137 | 0.0079 | 0.0062 | 0.0106 | 0.0222 | 0.0185 | 0.0041 | 0.4441 |
| 0.0030 | 0.0101 | 0.0031 | 0.0582 | 0.0022 | 0.0049 | 0.0031 | 0.0028 | 0.0019 | 0.0032 | 0.0080 | 0.0124 | 0.0028 | 0.1603 |
| 0.0012 | 0.0025 | 0.0008 | 0.0245 | 0.0006 | 0.0010 | 0.0010 | 0.0007 | 0.0004 | 0.0014 | 0.0024 | 0.0053 | 0.0012 | 0.0477 |
| 0.0015 | 0.0032 | 0.0006 | 0.0251 | 0.0013 | 0.0016 | 0.0016 | 0.0008 | 0.0007 | 0.0012 | 0.0034 | 0.0055 | 0.0012 | 0.0689 |
| 0.0008 | 0.0020 | 0.0010 | 0.0193 | 0.0054 | 0.0013 | 0.0010 | 0.0003 | 0.0006 | 0.0008 | 0.0023 | 0.0042 | 0.0009 | 0.0462 |
| 0.0037 | 0.0093 | 0.0054 | 0.0650 | 0.0019 | 0.0057 | 0.0044 | 0.0028 | 0.0016 | 0.0036 | 0.0101 | 0.014 | 0.0031 | 0.2011 |
| 0.0032 | 0.0046 | 0.0021 | 0.0250 | 0.0015 | 0.0025 | 0.0016 | 0.0015 | 0.0011 | 0.0014 | 0.0042 | 0.0054 | 0.0012 | 0.0845 |
| 0.0006 | 0.0010 | 0.0004 | 0.0084 | 0.0002 | 0.0002 | 0.0004 | 0.0001 | 0.0001 | 0.0005 | 0.0012 | 0.0023 | 0.0005 | 0.0244 |
| 0.0007 | 0.0033 | 0.0004 | 0.0196 | 0.0013 | 0.0010 | 0.0016 | 0.0004 | 0.0004 | 0.0012 | 0.0024 | 0.0042 | 0.0009 | 0.0476 |
| 0.0003 | 0.0009 | 0.0001 | 0.0121 | 0.0004 | 0.0001 | 0.0005 | 0.0002 | 0.0001 | 0.0002 | 0.0009 | 0.0026 | 0.0006 | 0.0187 |
| 0.0016 | 0.0073 | 0.0033 | 0.0491 | 0.0031 | 0.0015 | 0.0036 | 0.0026 | 0.0010 | 0.0023 | 0.0069 | 0.0104 | 0.0023 | 0.1381 |
| 0.0043 | 0.0083 | 0.0032 | 0.0527 | 0.0031 | 0.0026 | 0.0024 | 0.0020 | 0.0013 | 0.0023 | 0.0072 | 0.0112 | 0.0025 | 0.1444 |
| 0.0009 | 0.0009 | 0.0008 | 0.0277 | 0.0016 | 0.0017 | 0.0012 | 0.0006 | 0.0010 | 0.0010 | 0.0032 | 0.0061 | 0.0014 | 0.0640 |
| 0.0024 | 0.0074 | 0.0038 | 0.0538 | 0.0029 | 0.0028 | 0.0026 | 0.0023 | 0.0010 | 0.0021 | 0.0065 | 0.0114 | 0.0025 | 0.1303 |
| 0.0032 | 0.0088 | 0.0048 | 0.0556 | 0.0034 | 0.0025 | 0.0016 | 0.0029 | 0.0014 | 0.0025 | 0.0074 | 0.0119 | 0.0027 | 0.1489 |
| 0.0001 | 0.0001 | 0.0001 | 0.0018 | 0.0000 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0002 | 0.0004 | 8E-05 | 0.0035 |
| 0.0002 | 0.0007 | 0.0001 | 0.0099 | 0.0004 | 0.0003 | 0.0003 | 0.0001 | 0.0001 | 0.0005 | 0.0008 | 0.0021 | 0.0005 | 0.0164 |
| 0.0021 | 0.0047 | 0.0024 | 0.0204 | 0.0015 | 0.0020 | 0.0026 | 0.0015 | 0.0011 | 0.0016 | 0.0040 | | | |
| 0.0027 | 0.0053 | 0.0034 | 0.0203 | 0.0013 | 0.0021 | 0.0030 | 0.0020 | 0.0013 | 0.0017 | 0.0043 | | | |
| 0.0003 | 0.0005 | 0.0004 | 0.0021 | 0.0001 | 0.0002 | 0.0003 | 0.0002 | 0.0001 | 0.0002 | 0.0004 | | | |
| 0.1990 | 0.4451 | 0.2249 | 1.9418 | 0.1462 | 0.1894 | 0.2428 | 0.1396 | 0.1044 | 0.1526 | 0.3810 | 0.4071 | 0.0905 | 7.6187 |

# Appendix I

**Table I.5** Stemflow (m3) by rainfall event based on the basal area per hectare in the logged plot

| Rainfall Event | Date | Gross Rainfall (mm) | Sum of Class I *) | Vol. of Class I 1) | Sum of Class II *) | Vol. of Class II 2) | Sum of Class III *) | Vol. of Class III 3) | Sum of Class IV *) | Vol. of Class IV 4) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 25/06/94 | 20.70 | 0.0013 | 0.0064 | 0.0019 | 0.0223 | 0.0042 | 0.0619 | 0.0034 | 0.0635 |
| 2 | 26/06/94 | 23.67 | 0.0075 | 0.0356 | 0.0082 | 0.0976 | 0.0162 | 0.2403 | 0.0069 | 0.1289 |
| 3 | 28/06/94 | 19.60 | 0.0073 | 0.0349 | 0.0041 | 0.0489 | 0.0130 | 0.1920 | 0.0049 | 0.0910 |
| 4 | 30/06/94 | 38.57 | 0.0142 | 0.0680 | 0.0081 | 0.0957 | 0.0174 | 0.2577 | 0.0090 | 0.1691 |
| 5 | 05/07/94 | 81.77 | 0.0427 | 0.2039 | 0.0336 | 0.3981 | 0.0706 | 1.0464 | 0.0225 | 0.4218 |
| 6 | 07/07/95 | 23.10 | 0.0028 | 0.0135 | 0.0056 | 0.0670 | 0.0127 | 0.1877 | 0.0057 | 0.1060 |
| 7 | 18/11/94 | 72.70 | 0.0272 | 0.1297 | 0.0375 | 0.4450 | 0.0420 | 0.6224 | 0.0141 | 0.2639 |
| 8 | 19/11/94 | 44.20 | 0.0198 | 0.0945 | 0.0225 | 0.2666 | 0.0307 | 0.4542 | 0.0118 | 0.2203 |
| 9 | 29/11/94 | 163.60 | 0.0381 | 0.1817 | 0.0567 | 0.6724 | 0.1322 | 1.9588 | 0.0377 | 0.7068 |
| 10 | 01/12/94 | 32.53 | 0.0204 | 0.0974 | 0.0238 | 0.2823 | 0.0372 | 0.5512 | 0.0118 | 0.2204 |
| 11 | 02/12/94 | 41.53 | 0.0147 | 0.0701 | 0.0290 | 0.3443 | 0.0576 | 0.8527 | 0.0104 | 0.1944 |
| 12 | 04/12/94 | 30.90 | 0.0079 | 0.0375 | 0.0208 | 0.2472 | 0.0343 | 0.5076 | 0.0076 | 0.1422 |
| 13 | 08/12/94 | 13.30 | 0.0005 | 0.0026 | 0.0019 | 0.0221 | 0.0064 | 0.0942 | 0.0023 | 0.0424 |
| 14 | 18/12/94 | 8.27 | 0.0031 | 0.0146 | 0.0043 | 0.0508 | 0.0032 | 0.0473 | 0.0006 | 0.0113 |
| 15 | 19/12/94 | 7.60 | 0.0031 | 0.0150 | 0.0033 | 0.0387 | 0.0045 | 0.0670 | 0.0024 | 0.0450 |
| 16 | 20/12/94 | 21.57 | 0.0044 | 0.0208 | 0.0043 | 0.0509 | 0.0125 | 0.1848 | 0.0067 | 0.1250 |
| 17 | 21/12/94 | 11.23 | 0.0027 | 0.0131 | 0.0030 | 0.0360 | 0.0056 | 0.0825 | 0.0024 | 0.0451 |
| 18 | 23/12/94 | 18.03 | 0.0016 | 0.0075 | 0.0049 | 0.0583 | 0.0084 | 0.1248 | 0.0060 | 0.1132 |
| 19 | 25/12/94 | 22.37 | 0.0019 | 0.0091 | 0.0062 | 0.0739 | 0.0082 | 0.1216 | 0.0051 | 0.0963 |
| 20 | 27/12/94 | 118.47 | 0.0568 | 0.2708 | 0.0813 | 0.9647 | 0.1277 | 1.8921 | 0.0425 | 0.7967 |
| 21 | 30/12/94 | 95.43 | 0.0337 | 0.1609 | 0.0608 | 0.7209 | 0.1120 | 1.6595 | 0.0293 | 0.5484 |
| 22 | 01/05/95 | 96.33 | 0.0305 | 0.1456 | 0.0539 | 0.6387 | 0.1033 | 1.5308 | 0.0269 | 0.5028 |
| 23 | 01/09/95 | 8.83 | 0.0013 | 0.0060 | 0.0014 | 0.0166 | 0.0029 | 0.0427 | 0.0013 | 0.0238 |
| 24 | 01/11/95 | 40.23 | 0.0120 | 0.0571 | 0.0172 | 0.2040 | 0.0337 | 0.4991 | 0.0097 | 0.1823 |
| 25 | 16/01/95 | 13.80 | 0.0012 | 0.0057 | 0.0008 | 0.0090 | 0.0035 | 0.0519 | 0.0005 | 0.0095 |
| 26 | 17/01/95 | 16.33 | 0.0034 | 0.0163 | 0.0077 | 0.0912 | 0.0139 | 0.2056 | 0.0037 | 0.0693 |
| 27 | 18/01/95 | 9.80 | 0.0016 | 0.0076 | 0.0015 | 0.0178 | 0.0054 | 0.0803 | 0.0012 | 0.0225 |
| 28 | 19/01/95 | 13.57 | 0.0050 | 0.0238 | 0.0035 | 0.0410 | 0.0094 | 0.1392 | 0.0034 | 0.0644 |
| 29 | 20/01/95 | 51.40 | 0.0393 | 0.1876 | 0.0361 | 0.4283 | 0.0509 | 0.7535 | 0.0171 | 0.3205 |
| 30 | 21/01/95 | 16.60 | 0.0044 | 0.0210 | 0.0052 | 0.0614 | 0.0152 | 0.2251 | 0.0038 | 0.0712 |
| 31 | 23/01/95 | 69.70 | 0.0665 | 0.3173 | 0.0469 | 0.5564 | 0.0508 | 0.7522 | 0.0190 | 0.3555 |
| 32 | 26/01/95 | 29.77 | 0.0073 | 0.0350 | 0.0062 | 0.0738 | 0.0074 | 0.1100 | 0.0051 | 0.0962 |
| 33 | 27/01/95 | 42.45 | 0.0200 | 0.0953 | 0.0174 | 0.2069 | 0.0455 | 0.6734 | 0.0107 | 0.2007 |
| 34 | 28/01/95 | 13.70 | 0.0018 | 0.0087 | 0.0025 | 0.0293 | 0.0052 | 0.0766 | 0.0024 | 0.0453 |
| 35 | 01/02/94 | 40.60 | 0.0137 | 0.0654 | 0.0212 | 0.2519 | 0.0270 | 0.3998 | 0.0096 | 0.1806 |
| 36 | 02/02/95 | 12.63 | 0.0009 | 0.0042 | 0.0012 | 0.0139 | 0.0030 | 0.0439 | 0.0016 | 0.0290 |
| 37 | 02/04/95 | 44.70 | 0.0229 | 0.1092 | 0.0277 | 0.3287 | 0.0271 | 0.4014 | 0.0104 | 0.1952 |
| 38 | 02/06/95 | 30.53 | 0.0128 | 0.0612 | 0.0120 | 0.1422 | 0.0179 | 0.2654 | 0.0072 | 0.1352 |
| 39 | 02/07/95 | 28.85 | 0.0095 | 0.0455 | 0.0113 | 0.1340 | 0.0144 | 0.2129 | 0.0092 | 0.1727 |
| 40 | 02/09/95 | 34.60 | 0.0102 | 0.0489 | 0.0134 | 0.1587 | 0.0183 | 0.2716 | 0.0110 | 0.2058 |
| 41 | 02/10/95 | 13.30 | 0.0017 | 0.0081 | 0.0009 | 0.0105 | 0.0038 | 0.0562 | 0.0035 | 0.0659 |
| 42 | 02/11/95 | 5.00 | 0.0004 | 0.0018 | 0.0004 | 0.0044 | 0.0010 | 0.0151 | 0.0007 | 0.0132 |
| 43 | 14/02/95 | 17.70 | 0.0010 | 0.0048 | 0.0013 | 0.0157 | 0.0034 | 0.0507 | 0.0022 | 0.0407 |
| 44 | 16/02/95 | 15.75 | 0.0006 | 0.0028 | 0.0011 | 0.0130 | 0.0022 | 0.0320 | 0.0025 | 0.0460 |
| 45 | 17/02/95 | 50.63 | 0.0180 | 0.0861 | 0.0299 | 0.3552 | 0.0331 | 0.4910 | 0.0173 | 0.3232 |
| 46 | 18/02/95 | 13.70 | 0.0027 | 0.0128 | 0.0038 | 0.0454 | 0.0044 | 0.0647 | 0.0035 | 0.0650 |
| 47 | 19/02/95 | 21.25 | 0.0056 | 0.0266 | 0.0098 | 0.1167 | 0.0088 | 0.1310 | 0.0073 | 0.1370 |
| 48 | 23/02/95 | 46.85 | 0.0123 | 0.0587 | 0.0159 | 0.1880 | 0.0182 | 0.2704 | 0.0095 | 0.1770 |
| 49 | 24/02/95 | 19.03 | 0.0056 | 0.0265 | 0.0100 | 0.1184 | 0.0090 | 0.1337 | 0.0048 | 0.0905 |
| 50 | 25/02/95 | 28.25 | 0.0130 | 0.0618 | 0.0129 | 0.1530 | 0.0181 | 0.2689 | 0.0093 | 0.1742 |
| 51 | 26/02/95 | 115.47 | 0.1127 | 0.5380 | 0.0989 | 1.1734 | 0.0903 | 1.3381 | 0.0461 | 0.8629 |
| 52 | 02/03/95 | 114.70 | 0.0862 | 0.4112 | 0.0849 | 1.0064 | 0.0683 | 1.0118 | 0.0345 | 0.6459 |
| 53 | 09/03/95 | 40.55 | 0.0072 | 0.0343 | 0.0095 | 0.1123 | 0.0144 | 0.2136 | 0.0110 | 0.2052 |
| 54 | 13/03/95 | 16.77 | 0.0045 | 0.0217 | 0.0058 | 0.0689 | 0.0076 | 0.1133 | 0.0025 | 0.0470 |
| 55 | 14/03/95 | 44.30 | 0.0213 | 0.1015 | 0.0233 | 0.2766 | 0.0482 | 0.7135 | 0.0121 | 0.2259 |
| 56 | 16/03/95 | 41.80 | 0.0164 | 0.0785 | 0.0199 | 0.2364 | 0.0428 | 0.6335 | 0.0092 | 0.1727 |
| 57 | 20/03/95 | 19.75 | 0.0024 | 0.0113 | 0.0018 | 0.0213 | 0.0102 | 0.1517 | 0.0026 | 0.0494 |
| 58 | 23/03/95 | 43.90 | 0.0014 | 0.0068 | 0.0034 | 0.0398 | 0.0133 | 0.1967 | 0.0032 | 0.0601 |
| 59 | 24/03/95 | 50.45 | 0.0307 | 0.1465 | 0.0302 | 0.3576 | 0.0556 | 0.8236 | 0.0175 | 0.3284 |
| 60 | 27/03/95 | 28.20 | 0.0061 | 0.0289 | 0.0076 | 0.0900 | 0.0216 | 0.3201 | 0.0072 | 0.1351 |
| 61 | 28/03/95 | 18.23 | 0.0047 | 0.0225 | 0.0066 | 0.0780 | 0.0197 | 0.2915 | 0.0043 | 0.0797 |
| 62 | 29/03/95 | 11.10 | 0.0011 | 0.0053 | 0.0029 | 0.0342 | 0.0080 | 0.1178 | 0.0012 | 0.0219 |
| 63 | 01/04/95 | 43.15 | 0.0212 | 0.1012 | 0.0230 | 0.2728 | 0.0408 | 0.6039 | 0.0079 | 0.1477 |
| 64 | 03/04/95 | 30.27 | 0.0078 | 0.0371 | 0.0121 | 0.1430 | 0.0405 | 0.6007 | 0.0076 | 0.1432 |
| 65 | 04/04/95 | 7.47 | 0.0003 | 0.0016 | 0.0008 | 0.0096 | 0.0043 | 0.0638 | 0.0007 | 0.0132 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 66 | 06/04/95 | 70.17 | 0.0378 | 0.1805 | 0.0474 | 0.5616 | 0.0968 | 1.4345 | 0.0251 | 0.4704 |
| 67 | 07/04/95 | 64.27 | 0.0646 | 0.3083 | 0.0542 | 0.6423 | 0.0981 | 1.4538 | 0.0247 | 0.4623 |
| 68 | 08/04/95 | 12.00 | 0.0026 | 0.0124 | 0.0058 | 0.0691 | 0.0111 | 0.1650 | 0.0031 | 0.0581 |
| 69 | 10/04/95 | 46.65 | 0.0216 | 0.1033 | 0.0319 | 0.3787 | 0.0545 | 0.8070 | 0.0117 | 0.2183 |
| 70 | 12/04/95 | 15.90 | 0.0031 | 0.0148 | 0.0042 | 0.0501 | 0.0171 | 0.2527 | 0.0055 | 0.1038 |
| 71 | 14/04/95 | 10.10 | 0.0014 | 0.0067 | 0.0016 | 0.0192 | 0.0107 | 0.1587 | 0.0013 | 0.0243 |
| 72 | 15/04/95 | 59.50 | 0.0343 | 0.1637 | 0.0535 | 0.6341 | 0.0941 | 1.3936 | 0.0228 | 0.4264 |
| 73 | 18/04/95 | 7.25 | 0.0003 | 0.0012 | 0.0004 | 0.0046 | 0.0036 | 0.0539 | 0.0003 | 0.0047 |
| 74 | 22/04/95 | 40.20 | 0.0080 | 0.0380 | 0.0156 | 0.1846 | 0.0533 | 0.7900 | 0.0077 | 0.1447 |
| 75 | 23/04/95 | 39.20 | 0.0198 | 0.0946 | 0.0315 | 0.3732 | 0.0503 | 0.7458 | 0.0133 | 0.2488 |
| 76 | 26/04/95 | 48.55 | 0.0250 | 0.1193 | 0.0366 | 0.4344 | 0.0647 | 0.9580 | 0.0170 | 0.3185 |
| 77 | 04/05/95 | 43.23 | 0.0091 | 0.0434 | 0.0241 | 0.2862 | 0.0575 | 0.8517 | 0.0115 | 0.2144 |
| 78 | 05/05/95 | 13.40 | 0.0045 | 0.0212 | 0.0046 | 0.0549 | 0.0166 | 0.2453 | 0.0040 | 0.0745 |
| 79 | 13/05/95 | 177.53 | 0.0938 | 0.4477 | 0.1470 | 1.7433 | 0.1447 | 2.1441 | 0.0586 | 1.0971 |
| 80 | 15/05/95 | 50.87 | 0.0209 | 0.0995 | 0.0376 | 0.4465 | 0.0837 | 1.2400 | 0.0181 | 0.3396 |
| 81 | 19/05/95 | 30.60 | 0.0028 | 0.0135 | 0.0079 | 0.0940 | 0.0318 | 0.4711 | 0.0052 | 0.0964 |
| 82 | 25/05/95 | 35.67 | 0.0138 | 0.0660 | 0.0128 | 0.1515 | 0.0351 | 0.5202 | 0.0072 | 0.1349 |
| 83 | 26/05/95 | 18.40 | 0.0040 | 0.0193 | 0.0076 | 0.0906 | 0.0249 | 0.3695 | 0.0095 | 0.1786 |
| 84 | 31/05/95 | 64.23 | 0.0405 | 0.1932 | 0.0469 | 0.5558 | 0.0939 | 1.3907 | 0.0199 | 0.3722 |
| 85 | 01/06/95 | 32.13 | 0.0149 | 0.0712 | 0.0205 | 0.2433 | 0.0395 | 0.5857 | 0.0095 | 0.1788 |
| 86 | 03/06/95 | 15.43 | 0.0077 | 0.0366 | 0.0040 | 0.0472 | 0.0112 | 0.1665 | 0.0015 | 0.0277 |
| 87 | 06/06/95 | 28.50 | 0.0067 | 0.0320 | 0.0092 | 0.1087 | 0.0259 | 0.3838 | 0.0058 | 0.1095 |
| 88 | 09/06/95 | 14.10 | 0.0010 | 0.0049 | 0.0019 | 0.0219 | 0.0143 | 0.2122 | 0.0015 | 0.0275 |
| 89 | 14/06/95 | 46.30 | 0.0267 | 0.1273 | 0.0292 | 0.3468 | 0.0681 | 1.0083 | 0.0141 | 0.2648 |
| 90 | 19/06/95 | 52.77 | 0.0238 | 0.1136 | 0.0304 | 0.3605 | 0.0765 | 1.1338 | 0.0137 | 0.2557 |
| 91 | 20/06/95 | 24.90 | 0.0128 | 0.0613 | 0.0116 | 0.1380 | 0.0324 | 0.4795 | 0.0072 | 0.1342 |
| 92 | 22/06/95 | 46.37 | 0.0185 | 0.0883 | 0.0251 | 0.2974 | 0.0730 | 1.0819 | 0.0137 | 0.2560 |
| 93 | 24/06/95 | 51.17 | 0.0295 | 0.1407 | 0.0226 | 0.2683 | 0.0824 | 1.2212 | 0.0143 | 0.2683 |
| 94 | 30/06/95 | 7.37 | 0.0002 | 0.0011 | 0.0005 | 0.0058 | 0.0023 | 0.0343 | 0.0004 | 0.0081 |
| 95 | 02/07/95 | 13.10 | 0.0006 | 0.0030 | 0.0026 | 0.0313 | 0.0115 | 0.1698 | 0.0017 | 0.0309 |

[*] Calculated from Table II.1 (Appendix II)

[1] Sum of class I * 4.77; [4.77 = *BA* per size class / total *BA* within the class]

[2] Sum of class * 11.85; [ 11.85 = *BA* per size class / total *BA* within the class]

[3] Sum of class * 14.82; [14.82 = *BA* per size class / total *BA* within the class]

[4] Sum of class * 18.72; [18.72 = *BA* per size class / total *BA* within the class]

**Table I.6** Stemflow volume (mm) per hectare in the logged plot

| Rainfall event | Date | Gross Rainfall (mm) | Vol. of Class I ($m^3$) 1) | Vol. of Class II ($m^3$) | Vol. of Class III ($m^3$) | Vol. of Class IV ($m^3$) | Total volume ($m^3$) | Total volume (mm) 2) |
|---|---|---|---|---|---|---|---|---|
| 1 | 25/06/94 | 20.70 | 0.0064 | 0.0223 | 0.0619 | 0.0635 | 0.1540 | 0.0154 |
| 2 | 26/06/94 | 23.67 | 0.0356 | 0.0976 | 0.2403 | 0.1289 | 0.5024 | 0.0502 |
| 3 | 28/06/94 | 19.60 | 0.0349 | 0.0489 | 0.1920 | 0.0910 | 0.3668 | 0.0367 |
| 4 | 30/06/94 | 38.57 | 0.0680 | 0.0957 | 0.2577 | 0.1691 | 0.5905 | 0.0590 |
| 5 | 05/07/94 | 81.77 | 0.2039 | 0.3981 | 1.0464 | 0.4218 | 2.0701 | 0.2070 |
| 6 | 07/07/94 | 23.10 | 0.0135 | 0.0670 | 0.1877 | 0.1060 | 0.3741 | 0.0374 |
| 7 | 18/11/94 | 72.70 | 0.1297 | 0.4450 | 0.6224 | 0.2639 | 1.4609 | 0.1461 |
| 8 | 19/11/94 | 44.20 | 0.0945 | 0.2666 | 0.4542 | 0.2203 | 1.0356 | 0.1036 |
| 9 | 29/11/94 | 163.60 | 0.1817 | 0.6724 | 1.9588 | 0.7068 | 3.5196 | 0.3520 |
| 10 | 01/12/94 | 32.53 | 0.0974 | 0.2823 | 0.5512 | 0.2204 | 1.1513 | 0.1151 |
| 11 | 02/12/94 | 41.53 | 0.0701 | 0.3443 | 0.8527 | 0.1944 | 1.4614 | 0.1461 |
| 12 | 04/12/94 | 30.90 | 0.0375 | 0.2472 | 0.5076 | 0.1422 | 0.9345 | 0.0935 |
| 13 | 08/12/94 | 13.30 | 0.0026 | 0.0221 | 0.0942 | 0.0424 | 0.1612 | 0.0161 |
| 14 | 18/12/94 | 8.27 | 0.0146 | 0.0508 | 0.0473 | 0.0113 | 0.1240 | 0.0124 |
| 15 | 19/12/94 | 7.60 | 0.0150 | 0.0387 | 0.0670 | 0.0450 | 0.1658 | 0.0166 |
| 16 | 20/12/94 | 21.57 | 0.0208 | 0.0509 | 0.1848 | 0.1250 | 0.3815 | 0.0382 |
| 17 | 21/12/94 | 11.23 | 0.0131 | 0.0360 | 0.0825 | 0.0451 | 0.1767 | 0.0177 |
| 18 | 23/12/94 | 18.03 | 0.0075 | 0.0583 | 0.1248 | 0.1132 | 0.3037 | 0.0304 |
| 19 | 25/12/94 | 22.37 | 0.0091 | 0.0739 | 0.1216 | 0.0963 | 0.3009 | 0.0301 |
| 20 | 27/12/94 | 118.47 | 0.2708 | 0.9647 | 1.8921 | 0.7967 | 3.9243 | 0.3924 |
| 21 | 30/12/94 | 95.43 | 0.1609 | 0.7209 | 1.6595 | 0.5484 | 3.0897 | 0.3090 |
| 22 | 05/01/95 | 96.33 | 0.1456 | 0.6387 | 1.5308 | 0.5028 | 2.8179 | 0.2818 |
| 23 | 09/01/95 | 8.83 | 0.0060 | 0.0166 | 0.0427 | 0.0238 | 0.0890 | 0.0089 |
| 24 | 11/01/95 | 40.23 | 0.0571 | 0.2040 | 0.4991 | 0.1823 | 0.9424 | 0.0942 |
| 25 | 16/01/95 | 13.80 | 0.0057 | 0.0090 | 0.0519 | 0.0095 | 0.0762 | 0.0076 |
| 26 | 17/01/95 | 16.33 | 0.0163 | 0.0912 | 0.2056 | 0.0693 | 0.3825 | 0.0382 |
| 27 | 18/01/95 | 9.80 | 0.0076 | 0.0178 | 0.0803 | 0.0225 | 0.1282 | 0.0128 |
| 28 | 19/01/95 | 13.57 | 0.0238 | 0.0410 | 0.1392 | 0.0644 | 0.2683 | 0.0268 |
| 29 | 20/01/95 | 51.40 | 0.1876 | 0.4283 | 0.7535 | 0.3205 | 1.6899 | 0.1690 |
| 30 | 21/01/95 | 16.60 | 0.0210 | 0.0614 | 0.2251 | 0.0712 | 0.3786 | 0.0379 |
| 31 | 23/01/95 | 69.70 | 0.3173 | 0.5564 | 0.7522 | 0.3555 | 1.9813 | 0.1981 |
| 32 | 26/01/95 | 29.77 | 0.0350 | 0.0738 | 0.1100 | 0.0962 | 0.3150 | 0.0315 |
| 33 | 27/01/95 | 42.45 | 0.0953 | 0.2069 | 0.6734 | 0.2007 | 1.1763 | 0.1176 |
| 34 | 28/01/95 | 13.70 | 0.0087 | 0.0293 | 0.0766 | 0.0453 | 0.1599 | 0.0160 |
| 35 | 01/02/95 | 40.60 | 0.0654 | 0.2519 | 0.3998 | 0.1806 | 0.8977 | 0.0898 |
| 36 | 02/02/95 | 12.63 | 0.0042 | 0.0139 | 0.0439 | 0.0290 | 0.0911 | 0.0091 |
| 37 | 04/02/95 | 44.70 | 0.1092 | 0.3287 | 0.4014 | 0.1952 | 1.0346 | 0.1035 |
| 38 | 06/02/95 | 30.53 | 0.0612 | 0.1422 | 0.2654 | 0.1352 | 0.6040 | 0.0604 |
| 39 | 07/02/95 | 28.85 | 0.0455 | 0.1340 | 0.2129 | 0.1727 | 0.5651 | 0.0565 |
| 40 | 09/02/95 | 34.60 | 0.0489 | 0.1587 | 0.2716 | 0.2058 | 0.6849 | 0.0685 |
| 41 | 10/02/95 | 13.30 | 0.0081 | 0.0105 | 0.0562 | 0.0659 | 0.1406 | 0.0141 |
| 42 | 11/02/95 | 5.00 | 0.0018 | 0.0044 | 0.0151 | 0.0132 | 0.0345 | 0.0034 |
| 43 | 14/02/95 | 17.70 | 0.0048 | 0.0157 | 0.0507 | 0.0407 | 0.1119 | 0.0112 |
| 44 | 16/02/95 | 15.75 | 0.0028 | 0.0130 | 0.0320 | 0.0460 | 0.0939 | 0.0094 |
| 45 | 17/02/95 | 50.63 | 0.0861 | 0.3552 | 0.4910 | 0.3232 | 1.2555 | 0.1255 |
| 46 | 18/02/95 | 13.70 | 0.0128 | 0.0454 | 0.0647 | 0.0650 | 0.1880 | 0.0188 |
| 47 | 19/02/95 | 21.25 | 0.0266 | 0.1167 | 0.1310 | 0.1370 | 0.4113 | 0.0411 |
| 48 | 23/02/95 | 46.85 | 0.0587 | 0.1880 | 0.2704 | 0.1770 | 0.6941 | 0.0694 |
| 49 | 24/02/95 | 19.03 | 0.0265 | 0.1184 | 0.1337 | 0.0905 | 0.3691 | 0.0369 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 50 | 25/02/95 | 28.25 | 0.0618 | 0.1530 | 0.2689 | 0.1742 | 0.6579 | 0.0658 |
| 51 | 26/02/95 | 115.47 | 0.5380 | 1.1734 | 1.3381 | 0.8629 | 3.9123 | 0.3912 |
| 52 | 02/03/95 | 114.70 | 0.4112 | 1.0064 | 1.0118 | 0.6459 | 3.0753 | 0.3075 |
| 53 | 09/03/95 | 40.55 | 0.0343 | 0.1123 | 0.2136 | 0.2052 | 0.5653 | 0.0565 |
| 54 | 13/03/95 | 16.77 | 0.0217 | 0.0689 | 0.1133 | 0.0470 | 0.2509 | 0.0251 |
| 55 | 14/03/95 | 44.30 | 0.1015 | 0.2766 | 0.7135 | 0.2259 | 1.3175 | 0.1317 |
| 56 | 16/03/95 | 41.80 | 0.0785 | 0.2364 | 0.6335 | 0.1727 | 1.1211 | 0.1121 |
| 57 | 20/03/95 | 19.75 | 0.0113 | 0.0213 | 0.1517 | 0.0494 | 0.2337 | 0.0234 |
| 58 | 23/03/95 | 43.90 | 0.0068 | 0.0398 | 0.1967 | 0.0601 | 0.3034 | 0.0303 |
| 59 | 24/03/95 | 50.45 | 0.1465 | 0.3576 | 0.8236 | 0.3284 | 1.6561 | 0.1656 |
| 60 | 27/03/95 | 28.20 | 0.0289 | 0.0900 | 0.3201 | 0.1351 | 0.5741 | 0.0574 |
| 61 | 28/03/95 | 18.23 | 0.0225 | 0.0780 | 0.2915 | 0.0797 | 0.4717 | 0.0472 |
| 62 | 29/03/95 | 11.10 | 0.0053 | 0.0342 | 0.1178 | 0.0219 | 0.1792 | 0.0179 |
| 63 | 01/04/95 | 43.15 | 0.1012 | 0.2728 | 0.6039 | 0.1477 | 1.1256 | 0.1126 |
| 64 | 03/04/95 | 30.27 | 0.0371 | 0.1430 | 0.6007 | 0.1432 | 0.9239 | 0.0924 |
| 65 | 04/04/95 | 7.47 | 0.0016 | 0.0096 | 0.0638 | 0.0132 | 0.0882 | 0.0088 |
| 66 | 06/04/95 | 70.17 | 0.1805 | 0.5616 | 1.4345 | 0.4704 | 2.6470 | 0.2647 |
| 67 | 07/04/95 | 64.27 | 0.3083 | 0.6423 | 1.4538 | 0.4623 | 2.8667 | 0.2867 |
| 68 | 08/04/95 | 12.00 | 0.0124 | 0.0691 | 0.1650 | 0.0581 | 0.3046 | 0.0305 |
| 69 | 10/04/95 | 46.65 | 0.1033 | 0.3787 | 0.8070 | 0.2183 | 1.5073 | 0.1507 |
| 70 | 12/04/95 | 15.90 | 0.0148 | 0.0501 | 0.2527 | 0.1038 | 0.4214 | 0.0421 |
| 71 | 14/04/95 | 10.10 | 0.0067 | 0.0192 | 0.1587 | 0.0243 | 0.2089 | 0.0209 |
| 72 | 15/04/95 | 59.50 | 0.1637 | 0.6341 | 1.3936 | 0.4264 | 2.6178 | 0.2618 |
| 73 | 18/04/95 | 7.25 | 0.0012 | 0.0046 | 0.0539 | 0.0047 | 0.0644 | 0.0064 |
| 74 | 22/04/95 | 40.20 | 0.0380 | 0.1846 | 0.7900 | 0.1447 | 1.1573 | 0.1157 |
| 75 | 23/04/95 | 39.20 | 0.0946 | 0.3732 | 0.7458 | 0.2488 | 1.4624 | 0.1462 |
| 76 | 26/04/95 | 48.55 | 0.1193 | 0.4344 | 0.9580 | 0.3185 | 1.8302 | 0.1830 |
| 77 | 04/05/95 | 43.23 | 0.0434 | 0.2862 | 0.8517 | 0.2144 | 1.3956 | 0.1396 |
| 78 | 05/05/95 | 13.40 | 0.0212 | 0.0549 | 0.2453 | 0.0745 | 0.3959 | 0.0396 |
| 79 | 13/05/95 | 177.53 | 0.4477 | 1.7433 | 2.1441 | 1.0971 | 5.4320 | 0.5432 |
| 80 | 15/05/95 | 50.87 | 0.0995 | 0.4465 | 1.2400 | 0.3396 | 2.1256 | 0.2126 |
| 81 | 19/05/95 | 30.60 | 0.0135 | 0.0940 | 0.4711 | 0.0964 | 0.6750 | 0.0675 |
| 82 | 25/05/95 | 35.67 | 0.0660 | 0.1515 | 0.5202 | 0.1349 | 0.8725 | 0.0873 |
| 83 | 26/05/95 | 18.40 | 0.0193 | 0.0906 | 0.3695 | 0.1786 | 0.6580 | 0.0658 |
| 84 | 31/05/95 | 64.23 | 0.1932 | 0.5558 | 1.3907 | 0.3722 | 2.5118 | 0.2512 |
| 85 | 01/06/95 | 32.13 | 0.0712 | 0.2433 | 0.5857 | 0.1788 | 1.0788 | 0.1079 |
| 86 | 03/06/95 | 15.43 | 0.0366 | 0.0472 | 0.1665 | 0.0277 | 0.2781 | 0.0278 |
| 87 | 06/06/95 | 28.50 | 0.0320 | 0.1087 | 0.3838 | 0.1095 | 0.6340 | 0.0634 |
| 88 | 09/06/95 | 14.10 | 0.0049 | 0.0219 | 0.2122 | 0.0275 | 0.2665 | 0.0266 |
| 89 | 14/06/95 | 46.30 | 0.1273 | 0.3468 | 1.0083 | 0.2648 | 1.7472 | 0.1747 |
| 90 | 19/06/95 | 52.77 | 0.1136 | 0.3605 | 1.1338 | 0.2557 | 1.8637 | 0.1864 |
| 91 | 20/06/95 | 24.90 | 0.0613 | 0.1380 | 0.4795 | 0.1342 | 0.8130 | 0.0813 |
| 92 | 22/06/95 | 46.37 | 0.0883 | 0.2974 | 1.0819 | 0.2560 | 1.7237 | 0.1724 |
| 93 | 24/06/95 | 51.17 | 0.1407 | 0.2683 | 1.2212 | 0.2683 | 1.8985 | 0.1899 |
| 94 | 30/06/95 | 7.37 | 0.0011 | 0.0058 | 0.0343 | 0.0081 | 0.0493 | 0.0049 |
| 95 | 02/07/95 | 13.10 | 0.0030 | 0.0313 | 0.1698 | 0.0309 | 0.2350 | 0.0235 |

[1)] Volume of class I, II, ...IV were taken from Table II.2 (Appendix II)

[2)] Conversion of a total stemflow volume ($m^3$) per ha to the unit of depth (mm) per ha

# Appendix II

**Table II.1** Gross rainfall (mm) variation between gauges in the unlogged plot

| Rainfall Event | Date | Container Rain Gauge Gauge 1 (mm) | Container Rain Gauge Gauge 2 (mm) | Tipping Bucket (mm) | Mean | SD | SE |
|---|---|---|---|---|---|---|---|
| 1 | 06/11/93 | 26.99 | 27.37 | 28.20 | 27.52 | 0.62 | 0.36 |
| 2 | 08/11/93 | 49.05 | 48.28 | 56.87 | 51.40 | 4.75 | 2.75 |
| 3 | 09/11/93 | 61.97 | 62.73 | 63.40 | 62.70 | 0.71 | 0.41 |
| 4 | 12/11/93 | 37.26 | 37.26 | 36.40 | 37.26 | 0.50 | 0.29 |
| 5 | 16/11/93 | 38.02 | 37.26 | 40.40 | 38.56 | 1.64 | 0.95 |
| 6 | 17/11/93 | 44.86 | 44.86 | 44.20 | 44.86 | 0.38 | 0.22 |
| 7 | 18/11/93 | 14.45 | 14.83 | 16.00 | 14.83 | 0.81 | 0.47 |
| 8 | 20/11/93 | 60.45 | 61.21 | 60.60 | 60.75 | 0.40 | 0.23 |
| 9 | 25/11/93 | 45.24 | 44.86 | 45.80 | 45.30 | 0.47 | 0.27 |
| 10 | 27/11/93 | 86.30 | 86.30 | 85.40 | 86.00 | 0.52 | 0.30 |
| 11 | 28/11/93 | 77.94 | 77.56 | 78.60 | 78.03 | 0.53 | 0.30 |
| 12 | 30/11/93 | 83.64 | 84.40 | 83.00 | 83.68 | 0.70 | 0.41 |
| 13 | 03/12/93 | 47.90 | 47.52 | 49.80 | 48.41 | 1.22 | 0.70 |
| 14 | 06/12/93 | 14.83 | 14.07 | 14.80 | 14.56 | 0.43 | 0.25 |
| 15 | 09/12/93 | 79.84 | 80.22 | 77.20 | 79.09 | 1.65 | 0.95 |
| 16 | 10/12/93 | 11.03 | 11.41 | 10.60 | 11.01 | 0.40 | 0.23 |
| 17 | 12/12/93 | 15.97 | 15.59 | 16.40 | 15.99 | 0.41 | 0.23 |
| 18 | 18/12/93 | 57.79 | 57.79 | 57.60 | 57.73 | 0.11 | 0.06 |
| 19 | 21/12/93 | 57.79 | 57.79 | 32.00 | 49.19 | 14.89 | 8.61 |
| 20 | 23/12/93 | 39.16 | 40.30 | 39.40 | 39.62 | 0.60 | 0.35 |
| 21 | 19/01/94 | 15.97 | 16.35 | 17.80 | 16.71 | 0.97 | 0.56 |
| 22 | 23/01/94 | 40.30 | 39.16 | 40.20 | 39.89 | 0.63 | 0.37 |
| 23 | 27/01/94 | 31.94 | 31.56 | 31.80 | 31.76 | 0.19 | 0.11 |
| 24 | 05/02/94 | 125.84 | 126.22 | 113.40 | 121.82 | 7.30 | 4.22 |
| 25 | 11/02/94 | 12.55 | 12.93 | 12.60 | 12.69 | 0.21 | 0.12 |
| 26 | 12/02/94 | 19.01 | 18.63 | 18.80 | 18.81 | 0.19 | 0.11 |
| 27 | 14/02/94 | 28.51 | 29.28 | 29.00 | 28.93 | 0.39 | 0.22 |
| 28 | 15/02/94 | 23.95 | 23.95 | 22.20 | 23.37 | 1.01 | 0.58 |
| 29 | 17/02/94 | 18.25 | 17.87 | 17.80 | 17.97 | 0.24 | 0.14 |
| 30 | 19/02/94 | 9.50 | 9.89 | 9.68 | 9.69 | 0.19 | 0.11 |
| 31 | 05/03/94 | 35.74 | 35.74 | 33.80 | 35.09 | 1.12 | 0.65 |
| 32 | 07/03/94 | 20.91 | 21.29 | 20.60 | 20.93 | 0.35 | 0.20 |
| 33 | 08/03/94 | 46.38 | 46.76 | 44.80 | 45.98 | 1.04 | 0.60 |
| 34 | 22/03/94 | 28.51 | 27.75 | 28.60 | 28.29 | 0.47 | 0.27 |
| 35 | 24/03/94 | 55.89 | 55.89 | 55.89 | 55.89 | 0.00 | 0.00 |
| 36 | 25/03/94 | 15.97 | 15.59 | 17.40 | 16.32 | 0.96 | 0.55 |
| 37 | 27/03/94 | 12.93 | 12.93 | 12.60 | 12.82 | 0.19 | 0.11 |
| 38 | 28/03/94 | 25.09 | 25.85 | 25.20 | 25.38 | 0.41 | 0.24 |
| 39 | 29/03/94 | 8.74 | 9.12 | 8.20 | 8.69 | 0.46 | 0.27 |
| 40 | 30/03/94 | 74.90 | 73.00 | 61.80 | 69.90 | 7.08 | 4.09 |
| 41 | 04/04/94 | 52.47 | 51.71 | 50.80 | 51.66 | 0.83 | 0.48 |
| 42 | 06/04/94 | 22.05 | 21.67 | 20.60 | 21.44 | 0.75 | 0.44 |
| 43 | 10/04/94 | 16.35 | 16.35 | 14.40 | 15.70 | 1.12 | 0.65 |
| 44 | 11/04/94 | 66.91 | 66.91 | 63.60 | 65.81 | 1.91 | 1.11 |
| 45 | 14/04/94 | 134.97 | 133.07 | 139.20 | 135.75 | 3.14 | 1.81 |
| Mean | | 42.09 | 42.02 | 41.05 | 41.73 | | |
| SD | | 29.31 | 29.18 | 28.46 | | | |
| SE | | 4.32 | 4.32 | 4.32 | | | |
| Total | | 1894.13 | 1891.09 | 1847.44 | 1877.80 | 26.12 | 15.37 |

**Table II.2** Gross rainfall (mm) between gauges in the logged plot

| Rainfall event | Date | Rainfall gauges Gauge 1 | Gauge 2 | Gauge 3 | Mean | SD | SE |
|---|---|---|---|---|---|---|---|
| 1 | 25/06/94 | 20.90 | 20.20 | 21.00 | 20.70 | 0.44 | 0.26 |
| 2 | 26/06/94 | 25.00 | 23.60 | 22.40 | 23.67 | 1.30 | 0.77 |
| 3 | 28/06/94 | 20.60 | 18.80 | 19.40 | 19.60 | 0.92 | 0.54 |
| 4 | 30/06/94 | 40.10 | 38.20 | 37.40 | 38.57 | 1.39 | 0.82 |
| 5 | 05/07/94 | 86.70 | 82.40 | 76.20 | 81.77 | 5.28 | 3.11 |
| 6 | 07/07/94 | 26.50 | 22.20 | 20.60 | 23.10 | 3.05 | 1.79 |
| 7 | 12/08/94 | 33.90 | 35.80 | 37.80 | 35.83 | 1.95 | 1.15 |
| 8 | 01/12/94 | 32.60 | 32.60 | 32.40 | 32.53 | 0.12 | 0.07 |
| 9 | 02/12/94 | 42.60 | 41.60 | 40.40 | 41.53 | 1.10 | 0.65 |
| 10 | 04/12/94 | 30.90 | 32.00 | 29.80 | 30.90 | 1.10 | 0.65 |
| 11 | 08/12/94 | 13.60 | 13.60 | 14.60 | 13.93 | 0.58 | 0.34 |
| 12 | 10/12/94 | 86.10 | 81.40 | 77.60 | 81.70 | 4.26 | 2.50 |
| 13 | 18/12/94 | 7.60 | 8.20 | 9.00 | 8.27 | 0.70 | 0.41 |
| 14 | 19/12/94 | 7.40 | 7.80 | 7.60 | 7.60 | 0.20 | 0.12 |
| 15 | 20/12/94 | 22.70 | 21.00 | 21.00 | 21.57 | 0.98 | 0.58 |
| 16 | 21/12/94 | 12.10 | 11.00 | 10.60 | 11.23 | 0.78 | 0.46 |
| 17 | 23/12/94 | 18.50 | 18.90 | 18.60 | 18.03 | 0.21 | 0.12 |
| 18 | 25/12/94 | 24.50 | 21.80 | 20.80 | 22.37 | 1.91 | 1.13 |
| 19 | 27/12/94 | 120.40 | 118.00 | 117.00 | 118.47 | 1.75 | 1.03 |
| 20 | 30/12/94 | 96.90 | 95.80 | 93.60 | 95.43 | 1.68 | 0.99 |
| 21 | 05/01/95 | 97.20 | 96.20 | 95.60 | 96.33 | 0.81 | 0.48 |
| 22 | 09/01/95 | 10.50 | 7.40 | 8.60 | 8.83 | 1.56 | 0.92 |
| 23 | 11/01/95 | 42.10 | 40.20 | 38.40 | 40.23 | 1.85 | 1.09 |
| 24 | 16/01/95 | 14.60 | 14.20 | 12.60 | 13.80 | 1.06 | 0.62 |
| 25 | 17/01/95 | 17.10 | 16.40 | 15.50 | 16.33 | 0.80 | 0.47 |
| 26 | 18/01/95 | 9.60 | 10.00 | 9.80 | 9.80 | 0.20 | 0.12 |
| 27 | 19/01/95 | 14.50 | 14.00 | 12.20 | 13.57 | 1.21 | 0.71 |
| 28 | 26/01/95 | 31.10 | 30.60 | 27.60 | 29.77 | 1.89 | 1.11 |
| 29 | 27/01/95 | 44.80 | 43.00 | 39.60 | 42.45 | 2.64 | 1.55 |
| 30 | 28/01/95 | 15.10 | 13.60 | 12.40 | 13.70 | 1.35 | 0.80 |
| 31 | 01/02/95 | 42.60 | 42.00 | 37.20 | 40.60 | 2.96 | 1.74 |
| 32 | 02/02/95 | 13.70 | 12.80 | 11.40 | 12.63 | 1.16 | 0.68 |
| 33 | 04/02/95 | 46.80 | 44.80 | 40.40 | 44.70 | 3.27 | 1.93 |
| 34 | 06/02/95 | 30.20 | 31.00 | 30.40 | 30.53 | 0.42 | 0.24 |
| 35 | 07/02/95 | 31.80 | 27.20 | 24.60 | 28.85 | 3.65 | 2.14 |
| 36 | 16/02/95 | 16.40 | 16.00 | 14.20 | 15.75 | 1.17 | 0.69 |
| 37 | 17/02/95 | 53.90 | 50.40 | 47.60 | 50.63 | 3.16 | 1.86 |
| 38 | 18/02/95 | 14.10 | 14.20 | 12.40 | 13.70 | 1.01 | 0.60 |
| 39 | 19/02/95 | 23.90 | 19.80 | 17.40 | 21.25 | 3.29 | 1.93 |
| 40 | 23/02/95 | 40.20 | 56.80 | 50.20 | 46.85 | 8.36 | 4.92 |
| 41 | 24/02/95 | 18.50 | 19.20 | 19.40 | 19.03 | 0.47 | 0.28 |
| 42 | 25/02/95 | 28.10 | 30.00 | 26.80 | 28.25 | 1.61 | 0.95 |
| 43 | 26/02/95 | 115.20 | 118.00 | 113.20 | 115.47 | 2.41 | 1.42 |
| 44 | 02/03/95 | 115.60 | 118.60 | 109.00 | 114.70 | 4.91 | 2.89 |
| 45 | 09/03/95 | 40.10 | 42.00 | 40.00 | 40.55 | 1.13 | 0.66 |
| 46 | 13/03/95 | 17.50 | 16.60 | 16.20 | 16.77 | 0.67 | 0.39 |
| 47 | 14/03/95 | 45.80 | 44.60 | 41.00 | 44.30 | 2.50 | 1.47 |
| 48 | 16/03/95 | 41.20 | 42.20 | 42.00 | 41.80 | 0.53 | 0.31 |
| 49 | 20/03/95 | 21.50 | 18.80 | 17.20 | 19.75 | 2.17 | 1.28 |
| 50 | 23/03/95 | 42.20 | 54.40 | 36.80 | 43.90 | 9.02 | 5.30 |
| 51 | 24/03/95 | 56.90 | 47.40 | 40.60 | 50.45 | 8.19 | 4.82 |
| 52 | 27/03/95 | 30.80 | 29.00 | 24.80 | 28.20 | 3.08 | 1.81 |
| 53 | 28/03/95 | 17.50 | 20.00 | 17.20 | 18.23 | 1.54 | 0.90 |
| 54 | 29/03/95 | 12.50 | 10.20 | 9.20 | 11.10 | 1.69 | 1.00 |
| 55 | 01/04/95 | 44.80 | 43.80 | 15.60 | 43.15 | 16.58 | 9.75 |
| 56 | 03/04/95 | 30.20 | 32.80 | 27.80 | 30.27 | 2.50 | 1.47 |
| 57 | 04/04/95 | 7.80 | 7.80 | 6.80 | 7.47 | 0.58 | 0.34 |
| 58 | 06/04/95 | 71.70 | 70.00 | 68.80 | 70.17 | 1.46 | 0.86 |
| 59 | 07/04/95 | 61.80 | 65.80 | 65.20 | 64.27 | 2.16 | 1.27 |
| 60 | 08/04/95 | 12.10 | 13.00 | 10.80 | 12.00 | 1.11 | 0.65 |
| 61 | 10/04/95 | 46.70 | 50.00 | 43.20 | 46.65 | 3.40 | 2.00 |
| 62 | 12/04/95 | 16.50 | 16.60 | 14.00 | 15.90 | 1.47 | 0.87 |
| 63 | 14/04/95 | 10.90 | 10.00 | 8.60 | 10.10 | 1.16 | 0.68 |
| 64 | 15/04/95 | 59.50 | 64.40 | 54.60 | 59.50 | 4.90 | 2.88 |
| 65 | 18/04/95 | 7.60 | 7.60 | 6.20 | 7.25 | 0.81 | 0.48 |
| 66 | 22/04/95 | 41.80 | 41.00 | 36.20 | 40.20 | 3.03 | 1.78 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 67 | 23/04/95 | 39.80 | 41.60 | 35.60 | 39.20 | 3.08 | 1.81 |
| 68 | 26/04/95 | 50.10 | 50.20 | 43.80 | 48.55 | 3.67 | 2.16 |
| 69 | 02/05/95 | 12.10 | 10.40 | 9.60 | 10.70 | 1.28 | 0.75 |
| 70 | 04/05/95 | 43.70 | 46.20 | 39.80 | 43.23 | 3.23 | 1.90 |
| 71 | 13/05/95 | 190.00 | 185.80 | 156.80 | 177.53 | 18.08 | 10.63 |
| 72 | 15/05/95 | 54.80 | 52.20 | 45.60 | 50.87 | 4.74 | 2.79 |
| 73 | 25/05/95 | 34.60 | 37.20 | 35.20 | 35.67 | 1.36 | 0.80 |
| 74 | 31/05/95 | 64.10 | 65.20 | 63.40 | 64.23 | 0.91 | 0.53 |
| 75 | 01/06/95 | 32.20 | 34.80 | 29.40 | 32.13 | 2.70 | 1.59 |
| 76 | 03/06/95 | 16.50 | 15.00 | 14.80 | 15.43 | 0.93 | 0.55 |
| 77 | 09/06/95 | 14.50 | 14.00 | 13.80 | 14.10 | 0.36 | 0.21 |
| 78 | 12/06/95 | 8.50 | 8.20 | 7.60 | 8.10 | 0.46 | 0.27 |
| 79 | 14/06/95 | 48.50 | 48.20 | 42.20 | 46.30 | 3.55 | 2.09 |
| 80 | 19/06/95 | 55.50 | 54.60 | 48.20 | 52.77 | 3.98 | 2.34 |
| 81 | 20/06/95 | 26.90 | 25.40 | 22.40 | 24.90 | 2.29 | 1.35 |
| 82 | 22/06/95 | 49.10 | 47.80 | 42.20 | 46.37 | 3.67 | 2.16 |
| 83 | 24/06/95 | 53.90 | 50.60 | 49.00 | 51.17 | 2.50 | 1.47 |
| 84 | 30/06/95 | 7.50 | 7.80 | 6.80 | 7.37 | 0.51 | 0.30 |
| Mean | | 38.06 | 37.79 | 34.56 | 36.97 | | |
| SD | | 30.83 | 30.78 | 28.34 | | | |
| SE | | 3.35 | 3.35 | 3.08 | | | |
| Total | | 3196.90 | 3174.50 | 2903.30 | 3105.15 | 163.43 | 96.13 |

Gauge 1 = AWS (1 m above the ground); Gauges 2 & 3 = Tipping buckets at 15 m above the ground.

# Appendix III

**Table III.1** Throughfall variation (mm) in the unlogged plot

| Date | Gross Rainfall (mm) | Throughfall gauges Line 1 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 01/11/93 | 23.57 | 12.55 | 19.77 | 24.71 | 17.87 | 19.77 | 22.43 | 17.11 | 17.49 | 12.93 | 28.52 |
| 03/11/93 | 16.14 | 12.17 | 8.36 | 11.03 | 9.51 | 11.03 | 15.59 | 12.55 | 7.98 | 11.41 | 11.79 |
| 06/11/93 | 27.52 | 18.25 | 22.81 | 19.39 | 21.29 | 22.05 | 12.55 | 17.87 | 12.17 | 15.97 | 15.21 |
| 08/11/93 | 51.40 | 48.67 | 45.62 | 52.09 | 47.53 | 59.69 | 37.64 | 50.19 | 47:53 | 57.79 | 55.51 |
| 09/11/93 | 62.50 | 59.69 | 42.58 | 39.16 | 55.51 | 56.65 | 57.79 | 49.81 | 53.61 | 64.63 | 43.72 |
| 12/11/93 | 37.26 | 28.52 | 36.50 | 17.49 | 39.92 | 41.06 | 35.36 | 36.12 | 46.77 | 26.99 | 35.36 |
| 16/11/93 | 38.29 | 15.97 | 19.01 | 33.46 | 42.20 | 33.84 | 34.98 | 31.56 | 26.99 | 25.09 | 27.75 |
| 17/11/93 | 44.86 | 16.35 | 58.17 | 34.98 | 60.07 | 63.87 | 42.20 | 27.37 | 37.26 | 42.20 | 44.48 |
| 18/11/93 | 14.83 | 16.35 | 14.83 | 14.07 | 15.59 | 8.74 | 15.97 | 14.45 | 15.21 | 15.49 | 16.35 |
| 25/11/93 | 45.57 | 33.84 | 48.67 | 41.82 | 41.06 | 31.94 | 30.80 | 32.32 | 26.99 | 18.63 | 37.26 |
| 27/11/93 | 85.94 | 79.08 | 85.93 | 54.37 | 85.17 | 64.63 | 81.36 | 76.42 | 73.00 | 66.54 | 72.62 |
| 28/11/93 | 78.03 | 81.74 | 98.47 | 83.26 | 72.24 | 84.03 | 74.52 | 64.63 | 80.60 | 71.10 | 80.98 |
| 30/11/93 | 83.62 | 96.19 | 80.22 | 79.84 | 100.75 | 61.21 | 78.70 | 91.25 | 88.21 | 57.41 | 90.49 |
| 03/12/93 | 48.34 | 36.12 | 41.06 | 39.92 | 49.43 | 49.81 | 49.43 | 26.99 | 45.62 | 46.77 | 44.86 |
| 06/12/93 | 14.56 | 10.27 | 14.83 | 12.93 | 16.35 | 12.55 | 11.03 | 7.98 | 9.89 | 19.39 | 5.32 |
| 09/12/93 | 79.09 | 81.74 | 79.84 | 82.50 | 62.35 | 85.17 | 83.64 | 81.36 | 77.94 | 77.56 | 58.55 |
| 10/12/93 | 11.01 | 11.10 | 11.03 | 10.96 | 11.79 | 10.93 | 12.55 | 11.05 | 12.54 | 11.05 | 9.45 |
| 12/12/93 | 15.99 | 16.20 | 14.29 | 15.59 | 16.20 | 11.59 | 16.28 | 14.65 | 15.97 | 14.30 | 15.20 |
| 18/12/93 | 57.59 | 52.47 | 62.73 | 46.77 | 47.53 | 53.99 | 51.71 | 53.23 | 46.00 | 57.41 | 56.65 |
| 21/12/93 | 48.79 | 27.37 | 23.19 | 27.37 | 30.80 | 32.32 | 22.81 | 25.85 | 26.61 | 34.98 | 26.61 |
| 23/12/93 | 39.75 | 33.08 | 42.58 | 42.20 | 31.56 | 33.46 | 27.37 | 40.68 | 22.05 | 40.68 | 39.92 |
| 06/01/94 | 37.83 | 27.37 | 19.77 | 25.09 | 29.28 | 36.50 | 23.57 | 30.04 | 29.28 | 24.71 | 32.32 |
| 09/01/94 | 27.56 | 23.95 | 25.47 | 23.19 | 35.36 | 22.43 | 26.99 | 19.39 | 26.23 | 20.53 | 17.11 |
| 12/01/94 | 45.43 | 42.58 | 33.46 | 35.74 | 49.43 | 44.48 | 44.86 | 42.20 | 47.15 | 30.80 | 38.02 |
| 13/01/94 | 57.79 | 54.75 | 46.38 | 62.73 | 54.37 | 49.81 | 45.24 | 53.61 | 60.45 | 46.00 | 50.95 |
| 17/01/94 | 48.66 | 36.88 | 52.47 | 39.16 | 38.40 | 36.50 | 48.28 | 52.47 | 50.95 | 39.16 | 31.94 |
| 19/01/94 | 16.71 | 11.41 | 7.98 | 11.41 | 11.79 | 10.27 | 8.36 | 6.46 | 8.74 | 12.93 | 8.36 |
| 23/01/94 | 39.55 | 34.60 | 41.82 | 33.84 | 41.06 | 46.00 | 37.26 | 31.18 | 38.78 | 43.72 | 32.32 |
| 27/01/94 | 32.10 | 26.23 | 33.08 | 29.66 | 33.46 | 36.12 | 31.94 | 40.68 | 33.08 | 30.04 | 29.28 |
| 05/02/94 | 121.82 | 104.56 | 63.11 | 129.27 | 109.12 | 146.38 | 123.57 | 125.47 | 95.05 | 99.99 | 150.18 |
| 08/02/94 | 94.86 | 88.21 | 74.52 | 91.63 | 74.90 | 57.41 | 99.23 | 87.44 | 60.83 | 88.97 | 80.22 |
| 10/02/94 | 10.84 | 5.70 | 4.56 | 7.98 | 6.08 | 6.84 | 5.32 | 6.84 | 6.46 | 3.80 | 7.22 |
| 11/02/94 | 12.69 | 12.17 | 12.87 | 15.11 | 14.45 | 15.21 | 14.45 | 12.55 | 13.43 | 9.89 | 9.12 |
| 12/02/94 | 18.81 | 12.17 | 16.35 | 18.25 | 19.01 | 25.47 | 14.07 | 15.97 | 18.63 | 17.11 | 18.25 |
| 14/02/94 | 28.93 | 29.28 | 18.25 | 22.43 | 14.45 | 22.81 | 34.60 | 23.57 | 19.77 | 18.63 | 18.25 |
| 15/02/94 | 23.37 | 12.93 | 14.07 | 15.21 | 22.43 | 25.09 | 14.83 | 12.17 | 23.19 | 26.61 | 27.75 |
| 17/02/94 | 17.97 | 11.41 | 14.45 | 12.55 | 12.93 | 9.51 | 12.17 | 11.41 | 9.12 | 14.07 | 12.17 |
| 19/02/94 | 9.69 | 10.27 | 8.36 | 5.70 | 10.79 | 11.31 | 10.17 | 9.12 | 8.36 | 10.17 | 9.89 |
| 05/03/94 | 35.09 | 25.09 | 17.49 | 25.09 | 30.42 | 39.92 | 30.80 | 27.37 | 30.04 | 34.98 | 21.67 |
| 07/03/94 | 20.93 | 20.15 | 14.83 | 20.53 | 21.29 | 15.59 | 23.57 | 18.63 | 20.91 | 12.93 | 15.97 |
| 08/03/94 | 45.98 | 31.18 | 51.33 | 27.75 | 33.84 | 51.33 | 36.50 | 37.26 | 60.07 | 29.66 | 42.58 |
| 21/03/94 | 11.98 | 12.93 | 12.93 | 8.74 | 7.22 | 8.74 | 14.07 | 8.74 | 8.36 | 12.93 | 7.98 |
| 22/03/94 | 28.29 | 27.75 | 15.97 | 23.57 | 23.57 | 29.66 | 32.32 | 20.15 | 27.75 | 22.43 | 28.52 |
| 24/03/94 | 55.89 | 60.07 | 55.89 | 54.25 | 53.61 | 53.40 | 60.00 | 52.35 | 53.23 | 46.38 | 55.49 |
| 25/03/94 | 16.32 | 11.79 | 14.45 | 9.12 | 10.27 | 9.12 | 10.65 | 10.27 | 11.79 | 7.22 | 9.51 |
| 27/03/94 | 12.82 | 7.98 | 11.79 | 7.22 | 8.74 | 13.31 | 8.74 | 10.27 | 9.51 | 12.55 | 7.98 |
| 28/03/94 | 25.38 | 15.59 | 16.73 | 26.23 | 19.39 | 15.97 | 28.90 | 16.35 | 22.05 | 26.61 | 18.63 |
| 29/03/94 | 8.69 | 3.80 | 4.94 | 5.70 | 6.46 | 7.98 | 6.46 | 5.70 | 6.46 | 6.84 | 5.70 |
| 30/03/94 | 69.90 | 110.26 | 51.71 | 43.72 | 78.70 | 63.11 | 57.79 | 70.34 | 60.45 | 87.83 | 59.69 |
| 04/04/94 | 51.66 | 38.02 | 45.24 | 41.82 | 40.30 | 41.44 | 38.02 | 38.78 | 42.58 | 34.22 | 45.62 |
| 06/04/94 | 21.44 | 21.67 | 20.15 | 16.35 | 17.87 | 16.35 | 15.59 | 17.49 | 17.49 | 22.81 | 15.59 |
| 09/04/94 | 6.65 | 1.90 | 0.76 | 0.76 | 2.28 | 1.90 | 2.28 | 2.28 | 1.52 | 1.90 | 2.28 |
| 10/04/94 | 15.70 | 12.93 | 20.15 | 15.21 | 9.89 | 27.75 | 18.63 | 9.12 | 15.59 | 15.59 | 15.59 |
| 11/04/94 | 65.81 | 54.37 | 54.75 | 71.86 | 68.82 | 59.69 | 67.30 | 59.69 | 58.55 | 63.11 | 71.10 |
| 14/04/94 | 135.75 | 101.51 | 85.55 | 142.58 | 128.13 | 146.38 | 112.16 | 128.51 | 114.06 | 140.68 | 53.23 |
| Mean | 39.96 | 34.35 | 33.68 | 34.61 | 36.60 | 37.31 | 35.88 | 34.50 | 34.55 | 34.62 | 33.95 |
| SD | 28.41 | 28.55 | 24.55 | 29.38 | 28.00 | 29.87 | 27.63 | 28.91 | 25.73 | 27.72 | 27.22 |
| SE | 3.80 | 3.82 | 3.28 | 3.93 | 3.74 | 3.99 | 3.69 | 3.86 | 3.44 | 3.71 | 3.64 |
| Total | 2197.5 | 1889.2 | 1852.1 | 1903.4 | 2012.8 | 2052.1 | 1973.4 | 1897.3 | 1900.4 | 1904.1 | 1867.1 |

| Throughfall gauges | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Line 2 | | | | | | | |
| 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
| 14.07 | 17.11 | 25.47 | 14.83 | 27.37 | 18.25 | 17.11 | 12.93 | 15.59 | 19.39 | 17.87 | 20.15 |
| 16.35 | 6.84 | 11.79 | 20.91 | 12.55 | 15.59 | 12.55 | 11.03 | 11.03 | 12.93 | 12.17 | 10.27 |
| 21.29 | 21.29 | 24.71 | 19.01 | 15.97 | 20.15 | 21.67 | 14.83 | 19.77 | 15.97 | 13.31 | 21.29 |
| 45.62 | 60.07 | 42.20 | 62.73 | 39.16 | 57.03 | 53.61 | 41.44 | 61.59 | 55.13 | 49.81 | 46.77 |
| 60.07 | 47.91 | 33.84 | 47.15 | 57.41 | 36.50 | 42.20 | 53.61 | 37.64 | 52.85 | 49.43 | 34.98 |
| 26.23 | 42.58 | 35.74 | 37.64 | 42.96 | 22.81 | 34.98 | 42.58 | 36.12 | 15.97 | 38.40 | 57.03 |
| 35.74 | 31.56 | 30.04 | 13.69 | 31.18 | 32.32 | 28.90 | 36.50 | 23.19 | 33.08 | 42.96 | 44.86 |
| 36.12 | 37.64 | 28.90 | 16.35 | 26.23 | 36.88 | 41.06 | 50.95 | 52.47 | 49.05 | 32.70 | 37.26 |
| 12.93 | 16.73 | 12.93 | 13.69 | 16.83 | 9.12 | 12.55 | 8.36 | 17.49 | 17.49 | 12.17 | 10.65 |
| 37.64 | 31.18 | 36.88 | 30.80 | 28.52 | 35.36 | 34.98 | 38.40 | 31.56 | 30.04 | 31.18 | 33.84 |
| 88.97 | 63.11 | 57.41 | 111.02 | 41.44 | 70.72 | 49.81 | 66.54 | 79.08 | 98.85 | 80.60 | 70.34 |
| 65.40 | 83.26 | 66.16 | 56.27 | 68.06 | 66.92 | 79.84 | 83.26 | 53.61 | 88.21 | 56.27 | 100.37 |
| 62.73 | 60.07 | 74.90 | 74.52 | 83.26 | 93.15 | 75.66 | 81.74 | 57.41 | 74.52 | 70.72 | 94.67 |
| 46.77 | 26.99 | 48.29 | 21.67 | 21.29 | 51.33 | 54.75 | 44.10 | 47.91 | 53.23 | 50.95 | 50.19 |
| 13.69 | 12.17 | 14.07 | 7.98 | 15.59 | 14.83 | 6.46 | 14.07 | 9.89 | 14.83 | 10.27 | 14.07 |
| 71.86 | 78.70 | 70.34 | 68.06 | 76.42 | 69.20 | 82.88 | 66.54 | 71.10 | 56.65 | 84.03 | 56.65 |
| 9.89 | 12.17 | 10.65 | 12.60 | 10.27 | 11.10 | 10.27 | 11.50 | 11.20 | 9.26 | 10.15 | 12.00 |
| 13.06 | 15.59 | 14.55 | 15.39 | 13.96 | 10.29 | 15.97 | 15.59 | 15.05 | 14.92 | 12.68 | 15.45 |
| 49.43 | 32.32 | 53.23 | 49.81 | 45.62 | 57.79 | 65.40 | 62.35 | 68.82 | 52.47 | 46.38 | 34.22 |
| 18.63 | 27.75 | 22.05 | 27.37 | 23.95 | 21.67 | 14.07 | 22.05 | 29.66 | 32.70 | 26.23 | 21.29 |
| 30.42 | 30.80 | 50.57 | 45.24 | 42.20 | 36.50 | 35.74 | 37.26 | 27.37 | 34.22 | 40.30 | 47.91 |
| 24.33 | 25.85 | 29.28 | 31.94 | 42.20 | 24.33 | 27.37 | 42.58 | 28.14 | 31.94 | 32.32 | 27.75 |
| 22.05 | 24.71 | 27.37 | 16.35 | 22.43 | 21.29 | 22.43 | 19.39 | 23.19 | 27.75 | 22.05 | 20.91 |
| 47.53 | 30.80 | 44.10 | 43.72 | 55.51 | 49.05 | 54.75 | 40.30 | 31.56 | 46.38 | 38.78 | 40.68 |
| 68.82 | 45.24 | 63.11 | 52.85 | 46.00 | 50.95 | 51.33 | 61.21 | 44.86 | 55.51 | 52.09 | 55.89 |
| 34.22 | 39.92 | 44.86 | 40.68 | 37.26 | 38.78 | 39.54 | 46.00 | 32.32 | 50.19 | 64.63 | 49.05 |
| 6.46 | 9.89 | 11.41 | 9.51 | 10.65 | 11.41 | 12.55 | 12.17 | 13.31 | 13.69 | 10.27 | 9.89 |
| 8.36 | 33.84 | 37.26 | 11.41 | 36.88 | 28.90 | 36.12 | 44.86 | 33.08 | 36.50 | 36.12 | 50.19 |
| 28.90 | 50.19 | 20.91 | 31.18 | 22.81 | 43.34 | 27.37 | 23.19 | 25.85 | 29.66 | 30.04 | 43.72 |
| 97.71 | 122.81 | 147.14 | 97.33 | 110.26 | 71.10 | 123.19 | 116.34 | 92.39 | 110.26 | 110.26 | 117.86 |
| 58.17 | 87.44 | 56.65 | 92.39 | 58.17 | 96.19 | 63.49 | 93.91 | 82.88 | 22.43 | 42.58 | 79.84 |
| 5.70 | 8.36 | 7.98 | 7.60 | 12.93 | 7.22 | 5.32 | 11.03 | 8.36 | 7.98 | 7.22 | 7.60 |
| 10.65 | 14.07 | 14.45 | 15.59 | 16.73 | 15.21 | 11.41 | 14.07 | 14.83 | 15.21 | 8.36 | 14.07 |
| 21.67 | 22.43 | 14.83 | 17.49 | 19.01 | 17.87 | 17.87 | 14.83 | 15.97 | 13.69 | 16.35 | 15.21 |
| 23.57 | 23.95 | 27.37 | 20.91 | 16.73 | 23.57 | 20.91 | 24.71 | 23.57 | 24.71 | 22.05 | 23.19 |
| 15.97 | 15.59 | 17.87 | 13.69 | 19.01 | 20.91 | 23.19 | 20.91 | 19.77 | 20.15 | 20.91 | 25.85 |
| 11.79 | 14.83 | 11.41 | 10.27 | 14.45 | 12.55 | 12.17 | 13.31 | 15.97 | 12.93 | 13.69 | 11.79 |
| 7.98 | 9.03 | 9.51 | 9.12 | 10.69 | 8.89 | 10.45 | 8.36 | 10.27 | 10.93 | 7.98 | 8.74 |
| 30.80 | 20.53 | 35.36 | 37.64 | 34.22 | 30.80 | 41.06 | 32.32 | 37.26 | 30.80 | 28.14 | 21.29 |
| 11.03 | 22.81 | 15.59 | 12.17 | 21.67 | 16.35 | 23.19 | 23.57 | 16.73 | 21.29 | 21.29 | 25.47 |
| 43.34 | 37.26 | 44.86 | 56.27 | 29.66 | 42.58 | 49.05 | 43.72 | 35.36 | 40.30 | 43.34 | 44.48 |
| 12.17 | 9.51 | 16.73 | 12.93 | 7.60 | 7.22 | 6.08 | 7.22 | 13.69 | 9.12 | 9.51 | 12.93 |
| 21.29 | 21.29 | 15.97 | 25.09 | 25.47 | 15.97 | 22.05 | 26.61 | 24.33 | 49.81 | 23.19 | 23.95 |
| 58.55 | 26.61 | 52.66 | 53.64 | 47.15 | 49.43 | 54.30 | 55.35 | 60.10 | 49.81 | 58.55 | 47.91 |
| 14.45 | 7.22 | 11.41 | 9.12 | 10.65 | 9.51 | 9.89 | 7.98 | 11.79 | 7.60 | 13.69 | 12.93 |
| 7.22 | 11.03 | 7.60 | 8.74 | 14.07 | 8.74 | 11.79 | 11.03 | 10.27 | 13.69 | 14.45 | 14.07 |
| 24.71 | 19.01 | 24.71 | 29.66 | 23.95 | 22.81 | 18.25 | 17.11 | 16.73 | 27.75 | 25.47 | 19.01 |
| 6.08 | 3.80 | 4.56 | 4.56 | 7.60 | 6.08 | 7.60 | 6.46 | 6.84 | 4.94 | 7.22 | 8.74 |
| 55.13 | 40.68 | 56.27 | 43.72 | 71.48 | 44.10 | 57.03 | 69.58 | 69.96 | 66.92 | 71.48 | 72.24 |
| 34.98 | 28.52 | 30.42 | 30.04 | 36.12 | 34.22 | 28.52 | 22.05 | 34.98 | 38.02 | 36.50 | 28.90 |
| 17.87 | 11.03 | 19.39 | 15.59 | 19.39 | 14.45 | 13.69 | 7.60 | 18.25 | 19.39 | 20.15 | 13.31 |
| 2.66 | 1.90 | 3.04 | 1.90 | 2.28 | 2.28 | 1.90 | 3.42 | 2.66 | 2.66 | 2.66 | 2.66 |
| 12.17 | 15.59 | 11.41 | 12.93 | 9.51 | 15.97 | 20.91 | 11.41 | 12.17 | 11.03 | 7.98 | 12.17 |
| 42.20 | 45.24 | 60.07 | 60.45 | 67.30 | 61.21 | 63.11 | 68.82 | 68.44 | 67.68 | 59.69 | 28.90 |
| 169.19 | 72.24 | 104.56 | 133.07 | 95.05 | 113.30 | 122.43 | 139.53 | 134.97 | 159.69 | 136.49 | 159.69 |
| 33.36 | 31.44 | 33.91 | 33.39 | 33.00 | 33.17 | 34.56 | 35.94 | 33.97 | 36.04 | 34.62 | 36.09 |
| 29.09 | 23.98 | 26.36 | 28.25 | 23.67 | 24.98 | 27.07 | 29.27 | 26.16 | 29.45 | 27.04 | 30.30 |
| 3.89 | 3.21 | 3.52 | 3.78 | 3.16 | 3.34 | 3.62 | 3.91 | 3.50 | 3.94 | 3.61 | 4.05 |
| 1834.6 | 1729.1 | 1864.8 | 1836.3 | 1815.1 | 1824.1 | 1900.8 | 1976.6 | 1868.4 | 1982.1 | 1904.1 | 1985.1 |

| Throughfall gauges | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Line 3 | | | | | | | | Line 4 | | | |
| 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 |
| 19.39 | 20.91 | 20.15 | 21.67 | 19.77 | 19.01 | 20.91 | 21.67 | 14.45 | 19.77 | 15.97 | 17.87 |
| 13.69 | 9.51 | 11.79 | 13.31 | 13.69 | 20.15 | 12.17 | 8.36 | 12.17 | 17.87 | 11.41 | 13.69 |
| 15.59 | 19.01 | 19.39 | 18.63 | 18.25 | 20.15 | 14.83 | 12.17 | 11.41 | 11.79 | 21.29 | 20.15 |
| 55.89 | 52.85 | 41.06 | 50.19 | 57.79 | 43.72 | 42.58 | 51.33 | 44.10 | 50.19 | 46.77 | 58.55 |
| 35.36 | 53.99 | 63.49 | 52.09 | 51.33 | 50.95 | 48.29 | 36.12 | 57.41 | 51.33 | 57.03 | 49.05 |
| 36.50 | 36.88 | 37.26 | 19.77 | 20.15 | 30.42 | 27.37 | 30.80 | 40.30 | 28.14 | 45.24 | 43.34 |
| 31.18 | 33.08 | 38.02 | 44.86 | 39.54 | 40.68 | 23.95 | 38.78 | 23.19 | 35.36 | 37.26 | 41.44 |
| 40.30 | 39.16 | 37.26 | 17.87 | 33.46 | 41.82 | 37.64 | 17.87 | 38.78 | 30.04 | 40.68 | 42.58 |
| 14.07 | 14.45 | 11.79 | 14.07 | 17.49 | 18.71 | 14.77 | 13.66 | 15.59 | 16.73 | 14.77 | 7.98 |
| 28.52 | 33.08 | 20.53 | 33.84 | 47.53 | 37.64 | 49.05 | 34.98 | 19.77 | 38.78 | 41.82 | 39.92 |
| 93.15 | 77.18 | 70.34 | 57.41 | 80.22 | 65.78 | 76.42 | 67.30 | 80.60 | 84.79 | 91.63 | 69.58 |
| 23.57 | 56.27 | 79.46 | 72.62 | 103.04 | 42.20 | 87.07 | 90.11 | 84.79 | 57.03 | 95.43 | 69.58 |
| 84.41 | 89.73 | 63.49 | 82.88 | 76.04 | 84.03 | 53.23 | 72.62 | 96.57 | 82.12 | 81.74 | 129.27 |
| 35.36 | 29.28 | 47.53 | 30.80 | 43.34 | 41.82 | 40.68 | 26.99 | 39.92 | 48.67 | 50.95 | 47.15 |
| 11.79 | 14.83 | 12.17 | 12.55 | 10.27 | 12.17 | 17.11 | 11.03 | 14.07 | 10.65 | 11.79 | 12.17 |
| 83.26 | 70.72 | 76.80 | 75.66 | 51.71 | 94.67 | 79.84 | 76.04 | 78.32 | 74.90 | 88.21 | 92.01 |
| 10.65 | 11.00 | 9.89 | 10.50 | 8.74 | 10.89 | 11.75 | 11.26 | 10.15 | 12.93 | 8.65 | 12.93 |
| 13.69 | 14.98 | 13.78 | 16.00 | 16.35 | 15.78 | 14.83 | 13.78 | 15.97 | 14.98 | 15.25 | 14.05 |
| 58.55 | 51.71 | 52.09 | 66.92 | 39.92 | 58.17 | 43.72 | 49.81 | 41.82 | 63.49 | 44.10 | 57.41 |
| 27.75 | 23.19 | 31.18 | 25.47 | 38.78 | 28.52 | 29.28 | 27.75 | 20.91 | 27.37 | 12.55 | 25.47 |
| 35.74 | 49.43 | 28.52 | 34.60 | 15.21 | 24.71 | 40.30 | 31.94 | 28.14 | 30.42 | 45.24 | 40.68 |
| 31.56 | 34.98 | 26.99 | 31.56 | 31.94 | 42.58 | 24.33 | 28.90 | 15.59 | 29.28 | 25.85 | 45.24 |
| 23.95 | 28.14 | 24.33 | 20.15 | 20.53 | 20.15 | 23.19 | 23.57 | 23.95 | 26.99 | 22.43 | 19.39 |
| 43.34 | 29.28 | 43.72 | 42.96 | 36.50 | 41.82 | 46.38 | 37.64 | 47.15 | 55.51 | 28.14 | 40.30 |
| 43.72 | 59.31 | 51.33 | 61.21 | 50.57 | 59.31 | 48.28 | 61.59 | 65.77 | 63.11 | 68.82 | 54.75 |
| 47.52 | 34.98 | 40.30 | 39.16 | 51.33 | 65.39 | 54.75 | 44.10 | 41.06 | 44.48 | 37.64 | 30.80 |
| 8.36 | 11.03 | 9.89 | 8.36 | 14.45 | 10.27 | 12.17 | 10.65 | 12.93 | 15.21 | 10.27 | 5.70 |
| 44.48 | 15.97 | 35.74 | 42.58 | 25.85 | 34.22 | 23.19 | 45.62 | 44.48 | 58.17 | 31.18 | 61.21 |
| 35.36 | 32.32 | 34.22 | 23.57 | 29.28 | 22.05 | 25.47 | 38.02 | 36.12 | 42.58 | 34.22 | 22.43 |
| 103.80 | 152.08 | 99.99 | 72.24 | 83.26 | 110.26 | 144.48 | 99.23 | 118.24 | 103.80 | 106.46 | 103.42 |
| 78.70 | 87.83 | 49.81 | 42.58 | 75.28 | 57.79 | 80.60 | 85.92 | 58.55 | 63.87 | 84.40 | 69.58 |
| 33.46 | 9.89 | 9.51 | 6.08 | 6.46 | 7.98 | 7.22 | 8.36 | 3.80 | 6.84 | 7.60 | 3.80 |
| 13.53 | 13.31 | 11.03 | 11.79 | 9.89 | 12.17 | 10.65 | 12.17 | 10.27 | 14.45 | 13.31 | 4.18 |
| 13.31 | 15.97 | 14.07 | 10.27 | 16.35 | 17.87 | 20.91 | 16.35 | 17.11 | 22.81 | 20.53 | 16.73 |
| 29.66 | 23.95 | 27.37 | 24.71 | 21.67 | 21.67 | 18.63 | 24.71 | 17.11 | 25.09 | 17.11 | 23.57 |
| 22.05 | 18.63 | 15.59 | 23.95 | 14.83 | 15.21 | 10.65 | 17.11 | 14.83 | 13.69 | 19.01 | 21.29 |
| 14.07 | 11.79 | 12.17 | 9.12 | 7.98 | 16.35 | 14.83 | 13.69 | 6.84 | 10.27 | 12.17 | 17.11 |
| 10.65 | 10.65 | 11.17 | 10.65 | 11.45 | 7.98 | 12.93 | 7.60 | 9.89 | 10.27 | 10.17 | 7.60 |
| 20.15 | 36.50 | 17.49 | 30.80 | 56.65 | 35.74 | 28.14 | 26.99 | 23.57 | 31.18 | 27.37 | 23.95 |
| 16.35 | 23.57 | 19.77 | 11.79 | 20.15 | 23.95 | 15.97 | 19.77 | 20.53 | 19.77 | 33.46 | 19.77 |
| 44.48 | * | 44.86 | 43.34 | 44.10 | 43.34 | 53.99 | 41.82 | 33.46 | 37.26 | 41.06 | 43.72 |
| 11.03 | 13.31 | 9.12 | 15.21 | 13.69 | 8.74 | 8.36 | 16.35 | 7.22 | 10.27 | 16.35 | 7.98 |
| 15.21 | 23.57 | 17.87 | 27.75 | 20.53 | 20.53 | 24.71 | 24.71 | 17.49 | 18.63 | 22.81 | 25.47 |
| 53.90 | 55.60 | 54.64 | 55.05 | 51.95 | 52.04 | 65.50 | 40.30 | 37.64 | 51.92 | 58.17 | 58.90 |
| 11.03 | 8.36 | 10.27 | 11.03 | 10.65 | 11.03 | 9.89 | 12.17 | 11.03 | 10.27 | 9.51 | 7.22 |
| 10.65 | 4.18 | 14.07 | 0.00 | 8.74 | 16.35 | 7.60 | 6.08 | 9.12 | 13.69 | 16.35 | 13.31 |
| 19.39 | 25.85 | 17.87 | 8.36 | 14.07 | 25.09 | 17.87 | 22.81 | 23.19 | 31.94 | 41.44 | 23.19 |
| 6.46 | 7.60 | 7.60 | 4.56 | 6.46 | 6.46 | 5.32 | 3.42 | 6.08 | 5.32 | 6.08 | 6.84 |
| 67.68 | 65.40 | 42.58 | 61.97 | 31.18 | 28.52 | 40.30 | 38.02 | 58.93 | 64.63 | 57.79 | 58.55 |
| 36.50 | 3.80 | 18.63 | 36.12 | 40.30 | 43.34 | 35.74 | 42.20 | 43.72 | 35.74 | 25.09 | 36.12 |
| 21.29 | 20.15 | 9.12 | 16.73 | 20.15 | 16.73 | 16.73 | 19.01 | 19.77 | 14.07 | 14.07 | 19.77 |
| 3.04 | 2.66 | 1.90 | 1.52 | 1.90 | 2.66 | 2.28 | 2.28 | 3.80 | 2.66 | 2.28 | 2.66 |
| 11.03 | 7.98 | 17.11 | 12.93 | 15.21 | 15.97 | 13.69 | 6.08 | 13.31 | 15.21 | 13.69 | 12.55 |
| 63.49 | 50.57 | 58.17 | 60.83 | 93.15 | 54.75 | 68.06 | 67.68 | 46.77 | 103.42 | 91.63 | 59.69 |
| 167.29 | 123.57 | 127.37 | 131.17 | 127.37 | 134.97 | 126.23 | 103.42 | 124.33 | 149.04 | 133.07 | 124.33 |
| 35.36 | 34.52 | 32.58 | 32.40 | 34.30 | 34.64 | 34.63 | 32.96 | 33.31 | 36.89 | 37.04 | 36.29 |
| 29.79 | 29.94 | 25.30 | 25.42 | 27.22 | 26.53 | 29.13 | 25.18 | 28.06 | 29.19 | 29.72 | 29.26 |
| 3.98 | 4.00 | 3.38 | 3.40 | 3.64 | 3.55 | 3.89 | 3.37 | 3.75 | 3.90 | 3.97 | 3.91 |
| 1944.9 | 1864.0 | 1791.6 | 1781.8 | 1886.5 | 1905.3 | 1904.8 | 1812.7 | 1832.1 | 2028.7 | 2037.3 | 1996.0 |

| 35 | 36 | 37 | 38 | 39 | 40 | Mean | SD | SE | Total |
|---|---|---|---|---|---|---|---|---|---|
| 23.57 | 26.99 | 18.25 | 23.95 | 19.01 | 18.63 | 19.38 | 3.90 | 0.62 | 775.24 |
| 20.91 | 15.59 | 7.98 | 12.55 | 15.59 | 25.09 | 13.02 | 3.85 | 0.61 | 520.88 |
| 22.81 | 16.35 | 16.35 | 20.91 | 22.43 | 19.39 | 18.19 | 3.51 | 0.56 | 727.71 |
| 39.92 | 57.79 | 53.99 | 49.05 | 39.54 | 55.13 | 50.20 | 6.90 | 1.09 | 2007.86 |
| 42.58 | 42.96 | 30.80 | 59.31 | 46.38 | 64.25 | 49.24 | 9.08 | 1.44 | 1969.46 |
| 38.02 | 41.44 | 42.58 | 47.53 | 42.58 | 43.34 | 35.72 | 8.87 | 1.40 | 1428.81 |
| 50.19 | 40.68 | 31.56 | 51.33 | 30.04 | 31.56 | 33.44 | 8.38 | 1.33 | 1337.56 |
| 41.82 | 41.44 | 30.04 | 29.28 | 32.70 | 49.81 | 37.88 | 11.03 | 1.74 | 1515.11 |
| 14.87 | 15.77 | 18.63 | 18.63 | 17.87 | 15.77 | 14.59 | 2.78 | 0.44 | 583.58 |
| 38.40 | 46.00 | 38.40 | 43.72 | 46.38 | 26.23 | 35.21 | 7.43 | 1.18 | 1408.28 |
| 77.94 | 118.24 | 68.82 | 119.00 | 71.10 | 90.49 | 76.92 | 16.46 | 2.60 | 3076.99 |
| 55.13 | 83.26 | 90.11 | 92.77 | 90.11 | 100.37 | 75.80 | 17.05 | 2.70 | 3032.13 |
| 66.54 | 70.72 | 72.62 | 76.04 | 96.95 | 77.56 | 79.61 | 14.49 | 2.29 | 3184.21 |
| 57.41 | 60.07 | 45.62 | 35.36 | 49.05 | 42.96 | 43.01 | 9.54 | 1.51 | 1720.42 |
| 18.63 | 12.17 | 15.97 | 11.79 | 14.07 | 11.03 | 12.57 | 2.98 | 0.47 | 502.63 |
| 92.39 | 91.63 | 85.93 | 94.67 | 75.28 | 80.98 | 77.15 | 10.47 | 1.66 | 3086.12 |
| 12.40 | 10.27 | 11.62 | 6.84 | 12.55 | 9.50 | 10.90 | 1.29 | 0.20 | 435.98 |
| 15.00 | 12.78 | 14.70 | 14.60 | 16.54 | 17.54 | 14.83 | 1.40 | 0.22 | 593.36 |
| 17.87 | 53.99 | 43.34 | 50.57 | 72.62 | 69.58 | 52.05 | 10.71 | 1.70 | 2082.00 |
| 19.39 | 21.67 | 23.57 | 36.88 | 29.66 | 22.05 | 25.92 | 5.43 | 0.86 | 1036.82 |
| 39.54 | 24.33 | 25.09 | 30.42 | 23.19 | 29.66 | 34.73 | 8.09 | 1.28 | 1389.27 |
| 25.47 | 31.56 | 30.80 | 21.67 | 28.14 | 29.28 | 29.54 | 6.10 | 0.97 | 1181.67 |
| 26.23 | 23.57 | 24.33 | 23.19 | 17.87 | 25.85 | 23.21 | 3.51 | 0.55 | 928.46 |
| 46.00 | 53.61 | 42.20 | 54.75 | 55.13 | 77.56 | 43.85 | 9.21 | 1.46 | 1753.88 |
| 46.76 | 73.38 | 53.99 | 50.95 | 57.03 | 61.97 | 55.10 | 7.47 | 1.18 | 2203.99 |
| 32.32 | 44.48 | 52.09 | 28.13 | 49.05 | 42.96 | 43.10 | 8.50 | 1.34 | 1724.18 |
| 8.74 | 8.36 | 9.51 | 12.55 | 15.59 | 7.60 | 10.51 | 2.35 | 0.37 | 420.51 |
| 34.98 | 30.42 | 44.10 | 50.19 | 36.12 | 27.75 | 36.51 | 10.68 | 1.69 | 1460.36 |
| 18.25 | 17.11 | 38.02 | 37.64 | 44.48 | 26.23 | 31.45 | 7.61 | 1.20 | 1258.09 |
| 145.62 | 133.83 | 99.61 | 115.58 | 77.56 | 96.19 | 110.72 | 22.05 | 3.49 | 4429.00 |
| 65.01 | 68.44 | 72.62 | 111.02 | 74.14 | 87.83 | 73.79 | 17.90 | 2.83 | 2951.45 |
| 6.84 | 6.84 | 6.46 | 6.08 | 3.42 | 8.36 | 7.68 | 4.59 | 0.73 | 307.20 |
| 10.27 | 12.43 | 12.49 | 9.12 | 11.79 | 10.65 | 12.43 | 2.46 | 0.39 | 497.32 |
| 19.77 | 14.45 | 16.35 | 17.11 | 22.81 | 18.63 | 17.35 | 3.10 | 0.49 | 693.87 |
| 25.85 | 25.47 | 21.67 | 15.97 | 25.85 | 30.42 | 22.95 | 4.22 | 0.67 | 917.81 |
| 23.57 | 33.46 | 27.37 | 23.57 | 19.77 | 24.71 | 19.69 | 5.08 | 0.80 | 787.40 |
| 9.51 | 11.03 | 13.31 | 6.46 | 14.45 | 17.87 | 12.35 | 2.56 | 0.40 | 493.88 |
| 9.12 | 6.84 | 3.80 | 22.43 | 7.22 | 7.60 | 9.60 | 2.70 | 0.43 | 384.14 |
| 34.98 | 23.95 | 31.94 | 22.43 | 23.57 | 31.18 | 29.74 | 7.45 | 1.18 | 1189.66 |
| 17.87 | 18.25 | 10.65 | 25.09 | 23.95 | 16.73 | 19.32 | 4.58 | 0.72 | 772.95 |
| 31.94 | 39.16 | 32.70 | 52.09 | 49.05 | 37.26 | 41.68 | 7.64 | 1.21 | 1625.37 |
| 17.11 | 12.55 | 16.73 | 13.31 | 12.55 | 11.41 | 11.22 | 3.17 | 0.50 | 448.64 |
| 19.39 | 25.47 | 17.49 | 30.42 | 15.97 | 18.25 | 23.33 | 6.14 | 0.97 | 933.02 |
| 47.15 | 47.53 | 62.30 | 57.41 | 60.20 | 45.24 | 52.85 | 7.11 | 1.13 | 2114.16 |
| 11.41 | 9.51 | 13.31 | 11.03 | 11.41 | 7.60 | 10.43 | 1.87 | 0.30 | 417.08 |
| 7.98 | 11.41 | 11.41 | 11.03 | 9.89 | 8.74 | 10.28 | 3.26 | 0.52 | 411.38 |
| 15.59 | 26.61 | 19.77 | 20.15 | 25.47 | 11.03 | 21.63 | 6.08 | 0.96 | 865.34 |
| 6.08 | 7.98 | 5.70 | 6.46 | 5.32 | 4.94 | 6.08 | 1.22 | 0.19 | 243.33 |
| 55.13 | 50.19 | 111.02 | 79.46 | 84.41 | 69.96 | 61.70 | 17.90 | 2.83 | 2467.90 |
| 55.51 | 40.68 | 30.80 | 57.03 | 36.88 | 40.68 | 36.20 | 9.17 | 1.45 | 1448.20 |
| 29.66 | 11.41 | 15.97 | 28.90 | 12.55 | 20.91 | 17.46 | 4.40 | 0.70 | 698.43 |
| 2.28 | 2.28 | 2.28 | 2.28 | 3.42 | 2.66 | 2.32 | 0.61 | 0.10 | 92.77 |
| 11.41 | 15.59 | 17.87 | 9.89 | 15.21 | 19.01 | 13.93 | 4.05 | 0.64 | 557.38 |
| 56.65 | 50.95 | 70.72 | 103.42 | 58.55 | 55.13 | 63.40 | 14.60 | 2.31 | 2535.96 |
| 112.92 | 133.07 | 119.76 | 150.56 | 150.18 | 146.00 | 126.94 | 24.05 | 3.81 | 5077.62 |
| 34.41 | 36.84 | 35.37 | 40.23 | 36.77 | 37.26 | 34.89 | | | |
| 27.31 | 30.71 | 28.10 | 33.84 | 28.82 | 30.18 | | | | |
| 3.65 | 4.11 | 3.76 | 4.52 | 3.85 | 4.03 | | | | |
| 1892.7 | 2026.0 | 1945.1 | 2212.6 | 2022.6 | 2049.1 | 1917.7 | 93.9 | 14.9 | 76706.8 |

**Table III.2** Mean throughfall, $T_f$, (mm) per rainfall event from 40 gauges in the unlogged plot

| Rainfall Event | Date | Gross rainfall (mm) | Mean $T_f$ | SD | SE of mean | CV (%) |
|---|---|---|---|---|---|---|
| 1 | 01/11/93 | 23.57 | 19.38 | 3.90 | 0.62 | 20.14 |
| 2 | 03/11/93 | 16.14 | 13.02 | 3.85 | 0.61 | 29.55 |
| 3 | 06/11/93 | 27.52 | 18.19 | 3.51 | 0.56 | 19.30 |
| 4 | 08/11/93 | 51.40 | 50.20 | 6.90 | 1.09 | 13.74 |
| 5 | 09/11/93 | 62.50 | 49.24 | 9.08 | 1.44 | 18.44 |
| 6 | 12/11/93 | 37.26 | 35.72 | 8.87 | 1.40 | 24.83 |
| 7 | 16/11/93 | 38.29 | 33.44 | 8.38 | 1.33 | 25.05 |
| 8 | 17/11/93 | 44.86 | 37.88 | 11.03 | 1.74 | 29.11 |
| 9 | 18/11/93 | 14.83 | 15.08 | 4.09 | 0.65 | 27.13 |
| 10 | 25/11/93 | 45.57 | 35.21 | 7.43 | 1.18 | 21.10 |
| 11 | 27/11/93 | 85.94 | 76.92 | 16.46 | 2.60 | 21.39 |
| 12 | 28/11/93 | 78.03 | 75.80 | 17.05 | 2.70 | 22.50 |
| 13 | 30/11/93 | 83.62 | 79.61 | 14.49 | 2.29 | 18.21 |
| 14 | 03/12/93 | 48.34 | 43.01 | 9.54 | 1.51 | 22.18 |
| 15 | 06/12/93 | 14.56 | 12.57 | 2.98 | 0.47 | 23.75 |
| 16 | 09/12/93 | 79.09 | 77.15 | 10.47 | 1.66 | 13.57 |
| 17 | 10/12/93 | 11.01 | 10.90 | 1.29 | 0.20 | 11.81 |
| 18 | 12/12/93 | 15.99 | 14.83 | 1.40 | 0.22 | 9.42 |
| 19 | 18/12/93 | 57.59 | 52.05 | 10.71 | 1.70 | 20.58 |
| 20 | 21/12/93 | 48.79 | 25.92 | 5.43 | 0.86 | 20.93 |
| 21 | 23/12/93 | 39.75 | 34.73 | 8.09 | 1.28 | 23.29 |
| 22 | 06/01/94 | 37.83 | 29.54 | 6.10 | 0.97 | 20.65 |
| 23 | 09/01/94 | 27.56 | 23.21 | 3.51 | 0.55 | 15.10 |
| 24 | 12/01/94 | 45.43 | 43.85 | 9.21 | 1.46 | 21.00 |
| 25 | 19/01/94 | 16.71 | 10.51 | 2.35 | 0.37 | 22.35 |
| 26 | 23/01/94 | 39.55 | 36.51 | 10.68 | 1.69 | 29.24 |
| 27 | 27/01/94 | 32.10 | 31.45 | 7.61 | 1.20 | 24.21 |
| 28 | 05/02/94 | 121.82 | 110.72 | 22.05 | 3.49 | 19.91 |
| 29 | 10/02/94 | 10.84 | 7.68 | 4.59 | 0.73 | 59.78 |
| 30 | 11/02/94 | 12.69 | 13.38 | 3.69 | 0.58 | 27.60 |
| 31 | 12/02/94 | 18.81 | 17.35 | 3.10 | 0.49 | 17.89 |
| 32 | 14/02/94 | 28.93 | 22.95 | 4.22 | 0.67 | 18.38 |
| 33 | 15/02/94 | 23.37 | 19.69 | 5.08 | 0.80 | 25.80 |
| 34 | 17/02/94 | 17.97 | 12.35 | 2.56 | 0.40 | 20.71 |
| 35 | 19/02/94 | 9.69 | 9.60 | 2.70 | 0.43 | 28.10 |
| 36 | 05/03/94 | 35.09 | 29.74 | 7.45 | 1.18 | 25.03 |
| 37 | 07/03/94 | 20.93 | 19.32 | 4.58 | 0.72 | 23.71 |
| 38 | 08/03/94 | 45.98 | 41.68 | 7.64 | 1.21 | 18.34 |
| 39 | 21/03/94 | 11.98 | 11.22 | 3.17 | 0.50 | 28.29 |
| 40 | 22/03/94 | 28.29 | 23.33 | 6.14 | 0.97 | 26.34 |
| 41 | 24/03/94 | 55.89 | 52.85 | 7.11 | 1.13 | 13.46 |
| 42 | 25/03/94 | 16.32 | 10.43 | 1.87 | 0.30 | 17.98 |
| 43 | 27/03/94 | 12.82 | 10.28 | 3.26 | 0.52 | 31.72 |
| 44 | 28/03/94 | 25.38 | 21.63 | 6.08 | 0.96 | 28.10 |
| 45 | 29/03/94 | 8.69 | 6.08 | 1.22 | 0.19 | 20.12 |
| 46 | 30/03/94 | 69.90 | 61.70 | 17.90 | 2.83 | 29.01 |
| 47 | 04/04/94 | 51.66 | 36.20 | 9.17 | 1.45 | 25.32 |
| 48 | 06/04/94 | 21.44 | 17.46 | 4.40 | 0.70 | 25.21 |
| 49 | 10/04/94 | 15.70 | 13.93 | 4.05 | 0.64 | 29.05 |
| 50 | 11/04/94 | 65.81 | 63.40 | 14.60 | 2.31 | 23.03 |

## Appendix III

**Table III.3** Throughfall variation (mm) in the logged plot

| Date | Rainfall | Closed canopy cover | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (mm) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Mean |
| 11/06/94 | 4.10 | 4.18 | 4.56 | 6.46 | 7.22 | 3.80 | 4.56 | 6.46 | 4.18 | 9.12 | 3.80 | 4.56 | 3.61 | 5.21 |
| 12/06/94 | 50.50 | 34.98 | 47.52 | 61.59 | 49.43 | 51.71 | 47.52 | 55.13 | 40.30 | 45.62 | 70.34 | 74.14 | 50.95 | 52.44 |
| 16/06/94 | 37.00 | 34.98 | 42.96 | 28.51 | 38.02 | 16.73 | 27.37 | 42.58 | 20.91 | 12.93 | 38.02 | 29.28 | 28.51 | 30.07 |
| 25/06/94 | 20.70 | 7.98 | 12.17 | 9.89 | 17.11 | 13.69 | 12.93 | 21.29 | 13.31 | 16.73 | 12.17 | 12.93 | 12.17 | 13.53 |
| 26/06/94 | 23.67 | 20.60 | 21.29 | 19.77 | 21.29 | 20.89 | 19.39 | 23.19 | 16.73 | 25.85 | 23.95 | 18.25 | 17.49 | 20.72 |
| 28/06/94 | 19.60 | 14.45 | 16.35 | 11.03 | 14.83 | 20.80 | 11.03 | 21.29 | 9.12 | 20.70 | 22.43 | 9.89 | 20.72 | 16.05 |
| 30/06/94 | 38.57 | 46.90 | 49.99 | 21.29 | 28.89 | 36.12 | 25.47 | 36.88 | 28.51 | 45.24 | 45.00 | 49.43 | 35.74 | 37.46 |
| 05/07/94 | 81.77 | 90.65 | 75.66 | 68.28 | 67.29 | 80.22 | 81.74 | 101.51 | 66.15 | 101.51 | 90.11 | 63.49 | 82.96 | 80.80 |
| 07/07/94 | 23.10 | 25.85 | 16.73 | 18.63 | 19.39 | 27.37 | 27.75 | 29.28 | 30.04 | 25.47 | 23.95 | 17.11 | 22.05 | 23.64 |
| 12/08/94 | 35.83 | 60.83 | 83.64 | 55.51 | 60.83 | 38.02 | 52.09 | 51.33 | 68.44 | 70.34 | 53.23 | 52.47 | 47.90 | 57.88 |
| 18/11/94 | 72.70 | 57.41 | 80.22 | 67.29 | 50.19 | 75.28 | 55.51 | 93.53 | 65.39 | 99.61 | 77.18 | 64.63 | 54.37 | 70.05 |
| 19/11/94 | 44.20 | 38.55 | 42.47 | 47.14 | 45.62 | 45.62 | 40.30 | 34.98 | 34.60 | 40.95 | 44.10 | 46.38 | 32.70 | 41.12 |
| 29/11/94 | 163.60 | 135.00 | 152.08 | 157.02 | 145.65 | 125.46 | 138.39 | 123.94 | 179.45 | 184.01 | 147.52 | 161.96 | 174.89 | 152.12 |
| 01/12/94 | 32.53 | 31.48 | 32.70 | 34.98 | 34.98 | 24.33 | 30.49 | 22.81 | 19.01 | 31.94 | 18.25 | 11.41 | 31.94 | 27.03 |
| 02/12/94 | 41.53 | 41.82 | 61.59 | 47.90 | 41.06 | 31.94 | 53.23 | 31.94 | 40.30 | 31.94 | 40.30 | 31.18 | 40.30 | 41.12 |
| 04/12/94 | 30.90 | 31.94 | 19.01 | 26.61 | 34.22 | 19.77 | 30.42 | 36.50 | 21.29 | 38.02 | 41.82 | 12.93 | 19.01 | 27.63 |
| 08/12/94 | 13.93 | 12.17 | 11.41 | 9.12 | 13.25 | 11.41 | 10.65 | 14.45 | 14.21 | 9.12 | 14.21 | 14.45 | 9.12 | 11.96 |
| 10/12/94 | 81.70 | 84.02 | 76.42 | 76.42 | 68.44 | 60.07 | 76.04 | 98.09 | 60.83 | 93.53 | 80.22 | 83.64 | 76.04 | 77.81 |
| 18/12/94 | 8.27 | 8.36 | 6.08 | 8.36 | 8.36 | 6.08 | 6.08 | 14.45 | 4.94 | 7.98 | 8.36 | 4.18 | 5.32 | 7.38 |
| 19/12/94 | 7.60 | 4.56 | 3.80 | 10.65 | 6.84 | 4.18 | 6.08 | 7.98 | 4.56 | 4.18 | 4.94 | 4.56 | 7.22 | 5.80 |
| 20/12/94 | 21.57 | 15.21 | 16.35 | 17.87 | 25.47 | 21.67 | 22.05 | 19.01 | 24.33 | 13.69 | 16.73 | 23.19 | 25.09 | 20.06 |
| 21/12/94 | 11.23 | 11.41 | 7.98 | 14.83 | 11.49 | 11.49 | 11.87 | 10.65 | 5.32 | 7.22 | 15.59 | 11.79 | 12.93 | 11.05 |
| 23/12/94 | 18.03 | 15.21 | 19.77 | 19.39 | 20.61 | 21.29 | 15.21 | 16.73 | 9.88 | 11.79 | 21.18 | 19.77 | 15.97 | 17.23 |
| 25/12/94 | 22.37 | 15.21 | 4.56 | 12.55 | 20.15 | 15.21 | 15.21 | 16.73 | 21.29 | 14.45 | 19.77 | 16.73 | 15.59 | 15.62 |
| 27/12/94 | 118.47 | 122.04 | 87.06 | 93.53 | 92.39 | 89.35 | 126.99 | 115.58 | 106.83 | 124.32 | 114.44 | 109.88 | 117.10 | 108.29 |
| 30/12/94 | 95.43 | 45.24 | 85.66 | 61.59 | 90.87 | 46.76 | 46.38 | 99.61 | 65.53 | 68.05 | 90.60 | 32.70 | 85.93 | 68.24 |
| 05/01/95 | 96.33 | 115.96 | 83.64 | 83.64 | 76.04 | 85.16 | 93.53 | 85.92 | 84.02 | 61.21 | 61.21 | 38.02 | 84.21 | 79.38 |
| 09/01/95 | 8.83 | 10.27 | 7.98 | 7.98 | 13.69 | 4.94 | 7.60 | 8.36 | 32.70 | 5.32 | 4.94 | 6.84 | 4.94 | 9.63 |
| 11/01/95 | 40.23 | 38.02 | 46.00 | 29.28 | 38.40 | 53.99 | 42.20 | 46.00 | 42.20 | 32.51 | 30.80 | 36.69 | 61.59 | 41.47 |
| 16/01/95 | 13.80 | 7.79 | 17.11 | 5.70 | 5.70 | 13.31 | 6.08 | 12.17 | 7.60 | 8.36 | 6.84 | 9.89 | 12.17 | 9.39 |
| 17/01/95 | 16.33 | 11.98 | 8.74 | 12.93 | 12.55 | 13.31 | 11.79 | 13.31 | 7.22 | 10.27 | 13.31 | 13.69 | 19.20 | 12.36 |
| 18/01/95 | 9.80 | 14.83 | 7.60 | 7.98 | 9.12 | 11.79 | 10.27 | 4.18 | 7.60 | 6.84 | 17.11 | 8.17 | 3.99 | 9.12 |
| 19/01/95 | 13.57 | 17.11 | 9.89 | 8.55 | 12.17 | 8.93 | 17.49 | 5.32 | 12.93 | 12.36 | 24.71 | 5.70 | 8.93 | 12.01 |
| 20/01/95 | 51.40 | 57.79 | 88.21 | 77.94 | 47.14 | 47.14 | 42.96 | 46.38 | 23.57 | 46.00 | 55.13 | 34.03 | 46.19 | 51.04 |
| 21/01/95 | 16.60 | 5.32 | 13.69 | 15.97 | 8.17 | 20.72 | 13.69 | 12.17 | 15.97 | 21.67 | 13.69 | 15.59 | 17.30 | 14.49 |
| 23/01/95 | 69.70 | 17.11 | 66.91 | 73.38 | 38.02 | 66.15 | 63.11 | 80.22 | 46.38 | 60.83 | 57.79 | 60.83 | 76.04 | 58.90 |
| 26/01/95 | 29.77 | 31.18 | 20.91 | 5.32 | 17.11 | 22.81 | 22.81 | 27.75 | 26.99 | 32.32 | 13.69 | 24.33 | 26.61 | 22.65 |
| 27/01/95 | 42.45 | 36.50 | 41.82 | 21.29 | 38.02 | 25.47 | 57.79 | 29.66 | 26.61 | 28.89 | 46.00 | 46.00 | 45.62 | 36.97 |
| 28/01/95 | 13.70 | 5.70 | 11.41 | 6.65 | 10.65 | 7.60 | 13.69 | 7.60 | 6.08 | 8.36 | 17.87 | 12.93 | 15.97 | 10.38 |
| 02/01/95 | 40.60 | 38.02 | 15.97 | 12.93 | 7.60 | 15.59 | 46.00 | 26.23 | 21.67 | 36.50 | 36.12 | 34.22 | 23.57 | 26.20 |
| 02/02/95 | 12.63 | 6.46 | 4.56 | 4.18 | 3.99 | 6.08 | 15.59 | 5.32 | 7.60 | 11.98 | 11.79 | 6.08 | 7.79 | 7.62 |
| 04/02/95 | 44.70 | 30.42 | 32.32 | 17.49 | 51.52 | 34.60 | 53.23 | 29.66 | 34.98 | 51.52 | 61.97 | 19.01 | 47.90 | 38.72 |
| 06/02/95 | 30.53 | 41.82 | 29.28 | 31.18 | 17.87 | 23.19 | 32.70 | 15.21 | 27.37 | 25.09 | 28.13 | 27.37 | 40.68 | 28.32 |
| 07/02/95 | 28.85 | 51.71 | 24.52 | 30.42 | 19.01 | 23.95 | 27.18 | 8.36 | 30.42 | 20.91 | 23.57 | 30.80 | 38.02 | 27.41 |
| 09/02/95 | 34.60 | 35.50 | 39.92 | 30.61 | 22.81 | 24.71 | 34.98 | 19.77 | 20.72 | 40.30 | 40.11 | 30.41 | 42.20 | 31.84 |
| 10/02/95 | 13.30 | 16.35 | 9.89 | 11.79 | 19.01 | 5.70 | 9.89 | 6.08 | 6.08 | 11.41 | 17.49 | 10.27 | 12.55 | 11.38 |
| 11/02/95 | 5.00 | 3.99 | 1.90 | 3.61 | 3.80 | 3.80 | 4.94 | 2.28 | 2.66 | 4.56 | 6.16 | 4.18 | 6.84 | 4.06 |
| 14/02/95 | 17.70 | 17.49 | 7.60 | 15.21 | 13.31 | 11.41 | 9.89 | 9.31 | 3.80 | 12.55 | 22.81 | 12.93 | 9.12 | 12.12 |
| 16/02/95 | 15.75 | 13.31 | 11.60 | 9.12 | 15.21 | 9.50 | 8.74 | 8.74 | 6.08 | 3.04 | 13.88 | 9.89 | 12.17 | 10.11 |
| 17/02/95 | 50.63 | 53.23 | 36.12 | 42.58 | 60.07 | 31.18 | 48.28 | 32.70 | 22.81 | 31.18 | 49.05 | 30.42 | 50.57 | 40.68 |
| 18/02/95 | 13.70 | 13.31 | 10.27 | 9.12 | 14.45 | 11.41 | 13.69 | 9.12 | 6.08 | 3.80 | 14.83 | 11.41 | 11.41 | 10.74 |
| 19/02/95 | 21.25 | 20.91 | 13.69 | 15.21 | 19.01 | 17.49 | 15.97 | 12.93 | 11.41 | 9.12 | 20.53 | 12.17 | 20.91 | 15.78 |
| 23/02/95 | 46.85 | 54.75 | 38.78 | 39.92 | 29.28 | 34.41 | 34.22 | 29.28 | 32.70 | 53.61 | 29.28 | 30.42 | 38.02 | 37.05 |
| 24/02/95 | 19.03 | 26.61 | 21.67 | 20.53 | 15.21 | 15.21 | 17.49 | 12.93 | 7.60 | 24.71 | 15.97 | 15.21 | 16.73 | 17.49 |
| 25/02/95 | 28.25 | 32.32 | 28.51 | 28.89 | 23.95 | 19.77 | 30.42 | 21.67 | 9.89 | 38.02 | 22.81 | 18.63 | 22.81 | 24.81 |
| 26/02/95 | 115.47 | 96.19 | 108.36 | 100.56 | 96.95 | 110.84 | 93.53 | 103.41 | 70.34 | 104.55 | 105.46 | 102.65 | 111.02 | 100.32 |
| 02/03/95 | 114.70 | 117.86 | 76.04 | 76.04 | 91.25 | 76.04 | 91.25 | 83.64 | 76.04 | 102.65 | 51.71 | 106.45 | 79.84 | 85.73 |
| 09/03/95 | 40.55 | 38.78 | 36.50 | 11.41 | 44.10 | 18.25 | 32.32 | 30.42 | 42.20 | 42.39 | 63.49 | 41.06 | 23.57 | 35.37 |
| 13/03/95 | 16.77 | 14.07 | 13.69 | 15.97 | 17.11 | 15.21 | 26.61 | 17.87 | 15.21 | 12.17 | 15.21 | 13.69 | 15.21 | 16.00 |
| 14/03/95 | 44.30 | 24.71 | 25.09 | 49.43 | 26.99 | 28.89 | 92.39 | 47.14 | 45.62 | 45.24 | 64.63 | 41.82 | 37.26 | 44.10 |
| 16/03/95 | 41.80 | * | 25.09 | 68.82 | 45.24 | 28.51 | 42.96 | 42.01 | 52.47 | 46.38 | 53.23 | 36.50 | 32.70 | 43.08 |
| 20/03/95 | 19.75 | 8.74 | 7.22 | 10.65 | 13.31 | 9.50 | 6.46 | 12.17 | 20.15 | 17.11 | 15.21 | 7.60 | 9.50 | 11.47 |
| 23/03/95 | 43.90 | 31.18 | 38.59 | 34.98 | 26.99 | 39.54 | 47.90 | 38.02 | 36.50 | 25.85 | 25.47 | 42.58 | 25.85 | 34.46 |
| 24/03/95 | 50.45 | 44.10 | 34.22 | 46.38 | 50.19 | 41.44 | 40.87 | 30.42 | 53.23 | 22.81 | 20.91 | 43.72 | 47.14 | 39.62 |
| 27/03/95 | 28.20 | 22.43 | 13.31 | 31.94 | 19.01 | 20.91 | 28.51 | 15.21 | 29.28 | 15.21 | 8.36 | 26.99 | 15.97 | 20.59 |
| 28/03/95 | 18.23 | 12.55 | 15.02 | 9.89 | 9.89 | 26.61 | 19.01 | 16.73 | 16.54 | 12.36 | 23.19 | 17.68 | 32.70 | 17.68 |
| 29/03/95 | 11.10 | 10.45 | 4.56 | 7.60 | 5.99 | 8.36 | 10.27 | 9.12 | 8.17 | 5.70 | 9.50 | 7.60 | 13.88 | 8.44 |
| 01/04/95 | 43.15 | 46.74 | * | 19.01 | 45.62 | 30.80 | 47.14 | 46.38 | 31.18 | 19.01 | 24.33 | 32.70 | 24.71 | 33.42 |

# Appendix III

| SD | SE | Partial canopy cover | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| 1.72 | 0.49 | 4.56 | 5.70 | 3.42 | 4.18 | 4.37 | 5.32 | 3.61 | 2.66 | 8.36 | 3.42 | 4.56 | 6.46 |
| 11.45 | 3.27 | 70.72 | 46.38 | 68.44 | 46.76 | 47.52 | 46.76 | 55.89 | 63.11 | 59.31 | 45.62 | 36.12 | 47.52 |
| 9.73 | 2.78 | 38.02 | 27.37 | 42.58 | 20.91 | 38.02 | 33.46 | 58.93 | 17.11 | 43.72 | 34.98 | 16.35 | 43.72 |
| 3.49 | 1.00 | 19.77 | 23.57 | 14.07 | 8.74 | 28.51 | 16.35 | 24.33 | 17.49 | 9.89 | 26.23 | 17.49 | 15.97 |
| 2.68 | 0.76 | 29.28 | 24.71 | 27.37 | 19.77 | 25.47 | 25.85 | 27.37 | 26.23 | 26.23 | 29.64 | 27.80 | 14.83 |
| 5.00 | 1.43 | 14.83 | 21.29 | 16.35 | 15.97 | 21.27 | 20.66 | 24.67 | 19.77 | 8.36 | 15.97 | 25.09 | 21.29 |
| 9.86 | 2.82 | 39.92 | 38.78 | 39.16 | 32.70 | 42.58 | 45.62 | 46.38 | 33.84 | 21.67 | 34.98 | 40.68 | 44.10 |
| 13.24 | 3.78 | 82.12 | 59.31 | 89.73 | 53.61 | 112.92 | 88.59 | 63.87 | 65.39 | 19.77 | 88.21 | 9.01 | 96.95 |
| 4.75 | 1.36 | 17.49 | 25.47 | 22.43 | 23.57 | 33.08 | 17.87 | 15.97 | 25.09 | 22.43 | 23.19 | 18.25 | 27.37 |
| 11.96 | 3.42 | 64.63 | 50.19 | 60.83 | 45.62 | 60.83 | 67.29 | 68.44 | 53.23 | 41.82 | 55.13 | 50.19 | 57.03 |
| 15.60 | 4.46 | 69.20 | 65.77 | 61.97 | 52.09 | 69.20 | 84.40 | 72.24 | 36.50 | 69.20 | 69.96 | 107.21 | 74.90 |
| 4.99 | 1.43 | 44.10 | 49.43 | 41.71 | 47.14 | 47.03 | 40.19 | 47.14 | 38.78 | 45.62 | 41.82 | 40.95 | 38.44 |
| 20.12 | 5.75 | 162.72 | 147.90 | 154.36 | 174.89 | 165.00 | 107.98 | 167.29 | 163.48 | 152.08 | 155.88 | 160.00 | 178.69 |
| 7.68 | 2.19 | 32.70 | 30.42 | 31.18 | 31.71 | 29.54 | 34.86 | 27.37 | 28.89 | 35.74 | 38.66 | 35.74 | 38.02 |
| 9.37 | 2.68 | 32.70 | 38.78 | 31.18 | 40.30 | 50.95 | 40.30 | 34.98 | 12.93 | 37.26 | 45.62 | 38.78 | 46.38 |
| 9.17 | 2.62 | 61.97 | 34.22 | 21.29 | 34.22 | 51.71 | 30.42 | 12.93 | 22.81 | 34.22 | 16.73 | 41.82 | 30.42 |
| 2.15 | 0.61 | 10.65 | 10.65 | 10.65 | 13.69 | 10.65 | 13.69 | 15.97 | 15.21 | 12.17 | 14.45 | 9.89 | 15.97 |
| 11.43 | 3.27 | 95.05 | 108.74 | 85.92 | 84.02 | 103.41 | 92.77 | 75.66 | 101.13 | 76.04 | 69.20 | 131.55 | 79.84 |
| 2.69 | 0.77 | 7.22 | 7.60 | 12.93 | 5.70 | 10.27 | 7.60 | 10.27 | 7.60 | 10.27 | 15.21 | 4.56 | 7.98 |
| 2.05 | 0.58 | 7.60 | 8.36 | 8.36 | 8.36 | 6.84 | 6.84 | 9.89 | 6.08 | 6.46 | 9.89 | 7.98 | 9.89 |
| 4.09 | 1.17 | 23.19 | 20.91 | 22.43 | 15.97 | 16.35 | 22.81 | 15.97 | 11.79 | 24.33 | 17.87 | 17.49 | 16.73 |
| 2.97 | 0.85 | 13.69 | 12.93 | 15.59 | 9.89 | 4.94 | 11.41 | 13.69 | 7.22 | 14.45 | 15.59 | 11.06 | 13.69 |
| 3.75 | 1.07 | 22.81 | 17.49 | 19.99 | 21.29 | 15.97 | 17.49 | 19.77 | 11.79 | 20.53 | 17.49 | 18.25 | 20.15 |
| 4.33 | 1.24 | 21.67 | 24.33 | 29.66 | 25.85 | 15.97 | 19.77 | 19.77 | 15.59 | 25.85 | 15.21 | 16.35 | 24.33 |
| 14.30 | 4.09 | 131.55 | 99.61 | 133.83 | 53.61 | 67.67 | 61.97 | 121.28 | 122.42 | 125.08 | 154.74 | 136.11 | 101.51 |
| 22.15 | 6.33 | 75.12 | 64.25 | 84.02 | 69.96 | 68.56 | 99.68 | 99.23 | 95.65 | 97.71 | 99.61 | 100.37 | 100.24 |
| 19.25 | 5.50 | 91.25 | 47.52 | 66.15 | 84.02 | 106.45 | 121.66 | 121.66 | 91.25 | 76.04 | 85.54 | 87.06 | 122.04 |
| 7.70 | 2.20 | 8.55 | 4.37 | 4.18 | 7.22 | 6.46 | 7.60 | 9.89 | 7.60 | 7.98 | 8.74 | 7.79 | 6.08 |
| 9.49 | 2.71 | 53.99 | 34.98 | 27.37 | 47.90 | 46.00 | 46.00 | 34.60 | 17.49 | 31.56 | 31.56 | 55.51 | 34.22 |
| 3.59 | 1.03 | 7.98 | 9.12 | 8.74 | 17.49 | 11.79 | 15.21 | 11.03 | 14.83 | 6.84 | 7.60 | 11.79 | 11.41 |
| 2.95 | 0.84 | 14.45 | 12.93 | 15.21 | 27.37 | 15.59 | 17.49 | 13.31 | 13.31 | 15.78 | 14.07 | 12.17 | 22.81 |
| 3.90 | 1.11 | 8.55 | 8.93 | 9.89 | 8.93 | 14.45 | 9.12 | 8.17 | 11.03 | 8.74 | 7.98 | 8.36 | 14.07 |
| 5.55 | 1.58 | 13.31 | 12.55 | 15.59 | 10.84 | 19.77 | 11.79 | 11.98 | 14.07 | 15.59 | 9.12 | 10.27 | 20.72 |
| 17.52 | 5.01 | 45.24 | 53.61 | 50.19 | 51.33 | 19.77 | 60.83 | 89.73 | 44.48 | 58.93 | 38.40 | 38.40 | 41.63 |
| 4.62 | 1.32 | 10.65 | 16.73 | 8.36 | 17.30 | 17.11 | 17.49 | 20.91 | 20.53 | 9.12 | 22.81 | 17.49 | 15.21 |
| 17.69 | 5.05 | 65.39 | 65.39 | 33.46 | 69.96 | 59.69 | 63.30 | 75.09 | 52.47 | 55.32 | 66.15 | 65.01 | 58.55 |
| 7.65 | 2.19 | 16.73 | 16.73 | 57.41 | 30.80 | 39.54 | 22.81 | 26.61 | 31.94 | 24.71 | 29.66 | 46.76 | 32.70 |
| 10.87 | 3.11 | 17.49 | 41.06 | 39.54 | 37.26 | 38.02 | 53.99 | 47.52 | 35.36 | 40.68 | 53.61 | 44.10 | 17.11 |
| 4.04 | 1.15 | 7.98 | 12.17 | 13.69 | 13.69 | 11.41 | 21.29 | 17.11 | 10.27 | 13.69 | 15.21 | 13.69 | 6.08 |
| 11.94 | 3.41 | 27.75 | 42.77 | 36.50 | 44.10 | 44.10 | 37.64 | 31.94 | 44.29 | 34.60 | 34.98 | 37.26 | 46.00 |
| 3.64 | 1.04 | 7.60 | 13.69 | 11.60 | 10.27 | 10.65 | 11.41 | 9.50 | 14.83 | 12.17 | 8.36 | 9.12 | 12.55 |
| 14.22 | 4.06 | 34.22 | 38.02 | 48.28 | 46.00 | 51.71 | 38.40 | 33.08 | 53.23 | 26.61 | 62.92 | 43.72 | 47.90 |
| 7.88 | 2.25 | 26.61 | 28.89 | 23.76 | 31.56 | 23.95 | 39.54 | 34.98 | 26.23 | 42.58 | 38.02 | 29.85 | 28.89 |
| 10.63 | 3.04 | 25.09 | 26.61 | 24.14 | 22.81 | 19.39 | 33.08 | 27.94 | 22.81 | 22.05 | 34.22 | 31.18 | 24.33 |
| 8.21 | 2.35 | 30.42 | 39.16 | 39.52 | 39.67 | 28.51 | 28.13 | 34.98 | 30.80 | 34.98 | 31.94 | 30.42 | 30.79 |
| 4.43 | 1.27 | 9.50 | 13.31 | 12.17 | 11.60 | 9.12 | 7.60 | 10.65 | 9.50 | 10.27 | 11.41 | 9.89 | 8.74 |
| 1.46 | 0.42 | 4.56 | 5.32 | 6.84 | 6.08 | 3.42 | 5.70 | 4.94 | 3.80 | 4.37 | 3.80 | 3.42 | 4.94 |
| 4.93 | 1.41 | 12.93 | 17.11 | 15.21 | 15.78 | 11.79 | 11.41 | 10.27 | 12.93 | 16.35 | 19.77 | 15.97 | 12.17 |
| 3.41 | 0.98 | 16.35 | 13.31 | 9.50 | 12.20 | 19.01 | 14.45 | 12.55 | 9.89 | 14.07 | 15.97 | 15.21 | 18.25 |
| 11.49 | 3.28 | 70.72 | 46.38 | 45.62 | 55.51 | 39.16 | 31.37 | 70.72 | 47.52 | 53.99 | 63.11 | 55.51 | 58.93 |
| 3.33 | 0.95 | 14.83 | 11.41 | 7.60 | 14.45 | 15.59 | 11.41 | 19.01 | 8.36 | 15.21 | 15.21 | 13.69 | 16.73 |
| 4.02 | 1.15 | 22.81 | 15.21 | 15.97 | 19.01 | 21.67 | 17.87 | 26.61 | 17.11 | 19.77 | 19.01 | 23.38 | 19.77 |
| 8.84 | 2.52 | 37.26 | 47.90 | 38.02 | 38.02 | 52.09 | 39.54 | 36.12 | 45.81 | 59.31 | 41.44 | 44.10 | 34.22 |
| 5.22 | 1.49 | 18.25 | 19.20 | 17.49 | 19.01 | 21.29 | 19.01 | 15.21 | 25.47 | 22.81 | 20.91 | 17.49 | 17.11 |
| 7.37 | 2.11 | 26.99 | 30.42 | 25.09 | 24.71 | 33.46 | 26.61 | 22.81 | 34.22 | 36.12 | 31.94 | 24.71 | 23.95 |
| 10.97 | 3.13 | 100.37 | 118.62 | 118.62 | 96.95 | * | 115.96 | 102.65 | 120.07 | 125.50 | * | 131.17 | 112.48 |
| 17.53 | 5.01 | 76.04 | 121.66 | 114.06 | 114.06 | 110.26 | 129.27 | 110.26 | 152.08 | 102.65 | * | 102.65 | 83.64 |
| 13.65 | 3.90 | 38.02 | 38.78 | 24.71 | 38.78 | 32.70 | 39.92 | 38.78 | 38.78 | 40.30 | 38.78 | 32.32 | 32.70 |
| 3.68 | 1.05 | 14.45 | 8.36 | 14.07 | 17.87 | 15.21 | 23.57 | 13.69 | 19.39 | 15.21 | 19.77 | 13.69 | 13.69 |
| 19.32 | 5.52 | 43.34 | 38.02 | 43.34 | 43.34 | 25.09 | 33.84 | 53.23 | 53.99 | 44.48 | 31.94 | 20.91 | 62.35 |
| 12.48 | 3.57 | 31.94 | 38.78 | 38.78 | 38.02 | 28.13 | 36.50 | 62.35 | 65.39 | 38.78 | 31.94 | 19.01 | 51.71 |
| 4.25 | 1.21 | 23.57 | 12.17 | 16.73 | 15.59 | 12.17 | 15.21 | 16.92 | 25.85 | 11.79 | 20.91 | 17.49 | 20.15 |
| 7.40 | 2.11 | 45.62 | 36.50 | 47.71 | 24.71 | 27.75 | 35.36 | 40.68 | 42.58 | 38.40 | 35.36 | 49.43 | 27.37 |
| 10.39 | 2.97 | 39.92 | 45.62 | 55.13 | 42.58 | 43.34 | 42.58 | 45.62 | 51.71 | 42.01 | 44.10 | 39.92 | 53.23 |
| 7.36 | 2.10 | 27.37 | 25.09 | 38.02 | 23.00 | 27.37 | 15.21 | 27.37 | 31.18 | 25.09 | 23.57 | 25.66 | 17.11 |
| 6.90 | 1.97 | 15.97 | 13.31 | 22.05 | 21.29 | 28.89 | 19.01 | 17.49 | 13.31 | 12.17 | 17.49 | 16.16 | 17.49 |
| 2.50 | 0.71 | 8.36 | 10.65 | 12.17 | 11.79 | 32.70 | 8.36 | 8.36 | 12.17 | 7.60 | 9.12 | 7.60 | 9.12 |
| 11.26 | 3.22 | 44.86 | 38.02 | 15.21 | 32.32 | 39.92 | 25.85 | 33.84 | 32.70 | 33.84 | 42.96 | 46.76 | 33.08 |

# Appendix III

| | | | | | | | | | | | Canopy gap | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25 | 26 | Mean | SD | SE | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 |
| 4.56 | 3.80 | 4.64 | 4.64 | 1.29 | 4.56 | 8.36 | 3.42 | 4.18 | 4.94 | 5.32 | 4.56 | 4.56 | 6.46 |
| 68.05 | 55.13 | 54.10 | 54.10 | 15.03 | 50.19 | 63.11 | 55.13 | 59.31 | 56.27 | 59.31 | 47.52 | 17.49 | 63.30 |
| 53.99 | 37.64 | 36.20 | 36.20 | 10.06 | 43.72 | 42.58 | 37.64 | 19.77 | 35.36 | 47.52 | 52.47 | 34.98 | 38.02 |
| 23.57 | 13.31 | 18.52 | 18.52 | 5.14 | 15.97 | 12.93 | 22.43 | 24.33 | 27.75 | 25.09 | 17.87 | 15.97 | 20.72 |
| 23.19 | 20.15 | 24.85 | 24.85 | 6.90 | 23.57 | 20.15 | 23.19 | 21.67 | 22.43 | 23.95 | 27.37 | 25.09 | 22.43 |
| 17.11 | 19.77 | 18.74 | 18.74 | 5.21 | 19.39 | 15.97 | 19.77 | 20.15 | 19.77 | 21.67 | 17.11 | 9.12 | 25.85 |
| 28.89 | 39.16 | 37.75 | 37.75 | 10.49 | 36.88 | 39.54 | 38.59 | 44.48 | 23.95 | 38.78 | 39.54 | 38.27 | 56.65 |
| 28.51 | 90.11 | 67.72 | 67.72 | 18.81 | 85.54 | 76.42 | 87.83 | 85.54 | 63.11 | 73.76 | 89.73 | 84.78 | 80.98 |
| 19.77 | 27.37 | 22.81 | 22.81 | 6.34 | 23.57 | 17.11 | 21.67 | 20.91 | 23.57 | 20.53 | 24.33 | 22.43 | 23.19 |
| 72.24 | 45.62 | 56.65 | 56.65 | 15.74 | 49.43 | 60.83 | 45.24 | 50.57 | 39.92 | 42.20 | 68.44 | 51.33 | 49.43 |
| 76.04 | 73.38 | 70.15 | 70.15 | 19.48 | 39.54 | 74.90 | 83.64 | 76.04 | 73.76 | 61.59 | 107.21 | 60.83 | 68.44 |
| 42.47 | 46.38 | 43.66 | 43.66 | 12.13 | 48.66 | 47.90 | 46.38 | 47.23 | 44.10 | 50.95 | 50.23 | 45.47 | 50.23 |
| 177.87 | 167.67 | 159.70 | 159.70 | 44.36 | 152.08 | 175.65 | 168.81 | 164.24 | 155.88 | 158.92 | 178.69 | 155.12 | 159.68 |
| 37.90 | 34.40 | 33.37 | 33.37 | 9.27 | 37.79 | 35.74 | 25.09 | 31.94 | 35.74 | 36.50 | 35.74 | 33.46 | 34.98 |
| 39.54 | 42.58 | 38.02 | 38.02 | 10.56 | 40.30 | 67.67 | 31.18 | 40.30 | 38.02 | 40.30 | 40.30 | 41.82 | 45.62 |
| 26.61 | 38.02 | 32.67 | 32.67 | 9.08 | 31.18 | 38.02 | 30.42 | 19.01 | 34.22 | 34.22 | 34.22 | 34.22 | 13.69 |
| 15.53 | 15.21 | 13.17 | 13.17 | 3.66 | 9.89 | 10.65 | 15.97 | 15.97 | 15.21 | 14.45 | 15.29 | 9.89 | 14.45 |
| 97.71 | 92.39 | 92.39 | 92.39 | 25.66 | 88.59 | 117.86 | 108.74 | 84.78 | 82.50 | 88.97 | 84.78 | 66.91 | 64.63 |
| 8.36 | 9.89 | 8.96 | 8.96 | 2.49 | 8.36 | 9.12 | 7.98 | 6.84 | 5.32 | 9.89 | 4.18 | 8.36 | 8.36 |
| 6.08 | 4.56 | 7.66 | 7.66 | 2.13 | 9.12 | 7.98 | 5.70 | 7.60 | 8.36 | 7.22 | 9.12 | 7.60 | 8.36 |
| 18.25 | 29.28 | 19.53 | 19.53 | 5.42 | 22.81 | 23.57 | 22.81 | 16.35 | 28.13 | 22.81 | 22.81 | 22.05 | 19.39 |
| 10.65 | 7.98 | 11.63 | 11.63 | 3.23 | 14.45 | 12.93 | 11.41 | 9.89 | 12.17 | 12.93 | 12.93 | 12.93 | 12.93 |
| 16.73 | 13.69 | 18.10 | 18.10 | 5.03 | 19.01 | 8.36 | 19.01 | 15.97 | 19.01 | 19.01 | 19.01 | 21.29 | 17.49 |
| 20.15 | 21.29 | 21.13 | 21.13 | 5.87 | 21.67 | 20.15 | 20.15 | 19.77 | 22.43 | 23.19 | 28.13 | 23.19 | 18.63 |
| 65.39 | 132.69 | 107.68 | 107.68 | 29.91 | 107.21 | 127.37 | 127.37 | 127.37 | 114.82 | 127.37 | 127.37 | 126.22 | 127.37 |
| 95.35 | 93.91 | 88.83 | 88.83 | 24.68 | 96.73 | 99.23 | 101.51 | 99.23 | 99.23 | 99.23 | 99.23 | 99.23 | 99.23 |
| 110.64 | 167.67 | 98.50 | 98.50 | 27.36 | 102.65 | 42.58 | 98.85 | 95.05 | 92.01 | 92.01 | 102.65 | 92.77 | 91.25 |
| 9.50 | 9.12 | 7.51 | 7.51 | 2.09 | 11.79 | 9.12 | 10.08 | 7.79 | 12.93 | 9.50 | 8.36 | 10.27 | 10.65 |
| 57.41 | 32.32 | 39.35 | 39.35 | 10.93 | 33.84 | 37.26 | 33.46 | 39.16 | 31.18 | 34.98 | 38.02 | 34.98 | 38.40 |
| 12.55 | 6.08 | 10.89 | 10.89 | 3.02 | 8.74 | 14.07 | 12.17 | 12.17 | 13.69 | 13.69 | 14.45 | 13.31 | 11.41 |
| 15.78 | 17.11 | 16.24 | 16.24 | 4.51 | 15.97 | 16.35 | 14.07 | 12.93 | 12.17 | 16.54 | 13.69 | 20.53 | 15.21 |
| 8.36 | 9.12 | 9.69 | 9.69 | 2.69 | 10.65 | 8.36 | 11.41 | 9.50 | 9.50 | 11.03 | 9.50 | 10.65 | 9.89 |
| 11.79 | 9.89 | 13.37 | 13.37 | 3.72 | 13.31 | 11.41 | 13.69 | 13.69 | 14.45 | 14.45 | 13.69 | 14.45 | 14.45 |
| 32.89 | 46.00 | 47.96 | 47.96 | 13.32 | 49.43 | 39.54 | 52.85 | 53.99 | 53.23 | 52.47 | 50.95 | 50.57 | 50.19 |
| 12.17 | 19.39 | 16.09 | 16.09 | 4.47 | 16.73 | 17.49 | 19.77 | 17.30 | 17.49 | 17.49 | 21.67 | 17.49 | 17.11 |
| 34.60 | 59.69 | 58.86 | 58.86 | 16.35 | 72.05 | 72.05 | 63.30 | 66.91 | 64.63 | 63.11 | 79.84 | 62.92 | 63.87 |
| 33.08 | 26.99 | 31.18 | 31.18 | 8.66 | 28.51 | 28.51 | 28.32 | 28.89 | 29.66 | 28.89 | 26.61 | 28.89 | 28.51 |
| 34.22 | 38.02 | 38.43 | 38.43 | 10.67 | 42.58 | 41.82 | 42.96 | 46.00 | 42.96 | 41.06 | 42.96 | 43.72 | 38.02 |
| 12.93 | 13.31 | 13.04 | 13.04 | 3.62 | 13.69 | 13.31 | 13.31 | 13.12 | 13.12 | 13.31 | 13.31 | 13.69 | 13.69 |
| 39.92 | 46.00 | 39.13 | 39.13 | 10.87 | 42.96 | 39.16 | 33.46 | 39.16 | 38.02 | 38.02 | 38.02 | 38.78 | 39.92 |
| 11.41 | 14.07 | 11.23 | 11.23 | 3.12 | 11.79 | 11.79 | 11.79 | 12.17 | 11.79 | 11.41 | 11.79 | 11.60 | 12.17 |
| 42.20 | 55.51 | 44.41 | 44.41 | 12.34 | 44.10 | 40.30 | 38.78 | 42.96 | 42.58 | 40.68 | 41.82 | 47.52 | 43.34 |
| 26.23 | 27.37 | 30.61 | 30.61 | 8.50 | 32.70 | 34.22 | 31.18 | 28.13 | 32.32 | 34.22 | 32.70 | 31.18 | 35.36 |
| 19.58 | 26.61 | 25.70 | 25.70 | 7.14 | 26.99 | 28.13 | 28.13 | 27.37 | 26.61 | 28.89 | 26.99 | 26.61 | 29.28 |
| 38.42 | 35.63 | 33.81 | 33.81 | 9.39 | 36.88 | 35.73 | 32.70 | 34.98 | 35.93 | 32.32 | 33.46 | 30.79 | 34.98 |
| 8.74 | 25.09 | 11.26 | 11.26 | 3.13 | 12.93 | 11.41 | 11.03 | 12.17 | 12.17 | 7.60 | 7.98 | 10.65 | 8.36 |
| 3.80 | 9.12 | 5.01 | 5.01 | 1.39 | 5.32 | 6.84 | 5.32 | 6.46 | 5.89 | 5.32 | 6.08 | 4.56 | 4.94 |
| 17.11 | 27.75 | 15.47 | 15.47 | 4.30 | 15.97 | 13.69 | 15.97 | 16.73 | 16.73 | 15.97 | 15.97 | 15.97 | 17.30 |
| 14.83 | 15.21 | 14.34 | 14.34 | 3.98 | 15.59 | 15.21 | 15.59 | 16.73 | 15.21 | 15.59 | 15.21 | 15.97 | 15.97 |
| 54.75 | 54.75 | 53.43 | 53.43 | 14.84 | 50.95 | 51.71 | 55.51 | 53.23 | 47.52 | 50.57 | 50.19 | 50.19 | 52.47 |
| 15.97 | 14.45 | 13.85 | 13.85 | 3.85 | 13.69 | 13.69 | 13.69 | 15.21 | 14.07 | 14.07 | 15.21 | 14.07 | 15.21 |
| 22.81 | 20.91 | 20.14 | 20.14 | 5.59 | 18.25 | 19.01 | 21.67 | 20.53 | 19.01 | 16.73 | 19.77 | 18.25 | 19.01 |
| 42.58 | 53.61 | 43.57 | 43.57 | 12.10 | 39.54 | 38.78 | 40.30 | 38.78 | 40.30 | 39.54 | 38.97 | 39.92 | 43.34 |
| 17.87 | 17.11 | 19.16 | 19.16 | 5.32 | 19.01 | 19.01 | 19.01 | 17.49 | 19.01 | 19.01 | 20.91 | 19.01 | 19.01 |
| 28.89 | 26.61 | 28.32 | 28.32 | 7.87 | 27.37 | 27.37 | 27.75 | 24.71 | 27.37 | 26.61 | 26.61 | 28.51 | 30.42 |
| 108.74 | 110.38 | 113.46 | 113.46 | 31.52 | 116.34 | 118.62 | 116.34 | 117.86 | 122.04 | 118.62 | 123.37 | 125.46 | 126.60 |
| 106.45 | 98.85 | 109.38 | 109.38 | 30.38 | 114.06 | 129.27 | 106.45 | 114.06 | 114.06 | 114.06 | 106.45 | 76.04 | 121.66 |
| 31.94 | 43.72 | 36.44 | 36.44 | 10.12 | 40.68 | 38.78 | 38.02 | 38.02 | 40.68 | 40.30 | 44.48 | 44.10 | 41.06 |
| 21.67 | 17.49 | 16.29 | 16.29 | 4.53 | 16.35 | 15.97 | 14.07 | 15.97 | 16.73 | 17.11 | 15.21 | 15.97 | 15.97 |
| 39.54 | 36.12 | 40.68 | 40.68 | 11.30 | 38.78 | 39.54 | 36.31 | 39.54 | 43.15 | 40.30 | 39.54 | 38.40 | 43.15 |
| 48.09 | 30.42 | 39.99 | 39.99 | 11.11 | 39.54 | 38.40 | 38.40 | 39.16 | 51.33 | 40.30 | 38.40 | 41.82 | 43.34 |
| 14.07 | 23.57 | 17.58 | 17.58 | 4.88 | 16.73 | 17.49 | 12.93 | 15.59 | 19.01 | 17.11 | 15.59 | 15.97 | 17.49 |
| 39.92 | 40.30 | 37.98 | 37.98 | 10.55 | 39.54 | 41.82 | 44.10 | 39.16 | 43.72 | 36.88 | 36.88 | 38.02 | 38.02 |
| 39.54 | 49.43 | 45.34 | 45.34 | 12.59 | 44.10 | 44.48 | 47.90 | 44.48 | 44.10 | 49.43 | 45.62 | 49.43 | 49.43 |
| 22.81 | 24.71 | 25.26 | 25.26 | 7.02 | 25.09 | 25.47 | 24.71 | 26.61 | 25.85 | 28.51 | 26.61 | 25.47 | 28.13 |
| 13.50 | 19.01 | 17.65 | 17.65 | 4.90 | 17.11 | 19.01 | 19.01 | 19.01 | 17.49 | 17.87 | 19.01 | 19.01 | 15.97 |
| 8.36 | 10.65 | 11.22 | 11.22 | 3.12 | 9.89 | 10.27 | 8.36 | 11.41 | 9.12 | 10.27 | 10.27 | 10.27 | 11.41 |
| 39.92 | 47.52 | 36.20 | 36.20 | 10.06 | 43.72 | 39.54 | 39.92 | 38.78 | * | 42.96 | 76.42 | 39.16 | 40.30 |

| 36 | 37 | 38 | 39 | 40 | Mean | SD | SE |
|---|---|---|---|---|---|---|---|
| 4.75 | 4.94 | 4.94 | 4.18 | 7.98 | 5.23 | 1.42 | 0.39 |
| 72.24 | 58.93 | 63.11 | 55.13 | 55.51 | 55.47 | 12.51 | 3.48 |
| 41.82 | 38.02 | 43.72 | 35.74 | 38.02 | 39.24 | 7.51 | 2.09 |
| 17.11 | 24.33 | 16.73 | 20.15 | 26.99 | 20.60 | 4.64 | 1.29 |
| 27.37 | 24.33 | 25.09 | 23.57 | 24.33 | 23.90 | 1.99 | 0.55 |
| 20.15 | 19.77 | 19.58 | 18.63 | 17.87 | 18.91 | 3.62 | 1.01 |
| 37.45 | 33.84 | 34.79 | 38.78 | 35.74 | 38.38 | 6.94 | 1.93 |
| 76.42 | 96.95 | 71.86 | 76.99 | 76.42 | 80.45 | 8.61 | 2.39 |
| 21.29 | 27.37 | 24.33 | 23.57 | 24.33 | 22.73 | 2.40 | 0.67 |
| 45.62 | 57.03 | 49.43 | 59.69 | 53.23 | 51.60 | 7.76 | 2.15 |
| 99.99 | 73.38 | 84.40 | 97.33 | 77.94 | 77.07 | 17.45 | 4.85 |
| 26.61 | 46.38 | 45.62 | 46.76 | 47.14 | 45.98 | 5.91 | 1.64 |
| 159.68 | 161.58 | 184.77 | 174.13 | 165.38 | 165.33 | 9.77 | 2.72 |
| 21.29 | 34.22 | 34.98 | 37.26 | 34.86 | 33.54 | 4.69 | 1.30 |
| 60.83 | 40.30 | 38.78 | 23.57 | 42.58 | 42.26 | 10.83 | 3.01 |
| 34.22 | 38.02 | 34.22 | 22.81 | 22.81 | 30.09 | 7.48 | 2.08 |
| 9.12 | 15.97 | 12.17 | 15.97 | 16.73 | 13.69 | 2.74 | 0.76 |
| 91.25 | 82.12 | 66.15 | 95.43 | 72.24 | 85.35 | 15.42 | 4.28 |
| 13.69 | 6.08 | 9.12 | 6.46 | 8.36 | 8.01 | 2.29 | 0.64 |
| 7.60 | 9.89 | 10.65 | 8.36 | 8.36 | 8.28 | 1.20 | 0.33 |
| 23.57 | 22.81 | 19.01 | 18.25 | 23.57 | 22.00 | 2.91 | 0.81 |
| 12.93 | 12.93 | 14.45 | 14.45 | 12.93 | 12.88 | 1.21 | 0.34 |
| 19.77 | 18.25 | 19.01 | 15.21 | 21.67 | 18.01 | 3.27 | 0.91 |
| 19.77 | 21.67 | 19.01 | 19.77 | 20.15 | 21.26 | 2.46 | 0.68 |
| 112.54 | 114.06 | 127.37 | 127.37 | 126.22 | 122.86 | 7.22 | 2.01 |
| 101.51 | 99.23 | 101.51 | 99.23 | 95.73 | 99.29 | 1.62 | 0.45 |
| 98.85 | 91.25 | 99.23 | 102.65 | 98.85 | 92.90 | 15.13 | 4.20 |
| 7.98 | 6.46 | 10.65 | 6.08 | 9.12 | 9.34 | 1.92 | 0.53 |
| 39.54 | 38.40 | 45.62 | 38.78 | 36.50 | 37.15 | 3.49 | 0.97 |
| 15.21 | 10.65 | 11.98 | 11.79 | 9.12 | 12.32 | 1.92 | 0.53 |
| 16.35 | 15.59 | 15.21 | 16.73 | 12.55 | 15.28 | 2.16 | 0.60 |
| 10.27 | 10.65 | 9.50 | 11.03 | 11.41 | 10.24 | 0.89 | 0.25 |
| 14.45 | 14.83 | 14.45 | 14.45 | 13.69 | 13.96 | 0.86 | 0.24 |
| 53.23 | 68.44 | 52.09 | 50.76 | 53.99 | 52.26 | 5.89 | 1.64 |
| 16.73 | 17.87 | 19.77 | 17.68 | 17.49 | 18.00 | 1.41 | 0.39 |
| 69.96 | 66.91 | 71.86 | 72.24 | 65.39 | 68.22 | 4.95 | 1.37 |
| 26.99 | 28.51 | 28.51 | 29.28 | 28.13 | 28.45 | 0.80 | 0.22 |
| 42.58 | 42.20 | 44.48 | 42.96 | 43.34 | 42.69 | 1.79 | 0.50 |
| 13.69 | 13.31 | 13.69 | 14.83 | 13.31 | 13.52 | 0.43 | 0.12 |
| 41.82 | 42.58 | 39.54 | 41.06 | 41.06 | 39.54 | 2.41 | 0.67 |
| 12.17 | 12.17 | 12.17 | 12.17 | 11.41 | 11.88 | 0.29 | 0.08 |
| 42.58 | 41.82 | 41.06 | 42.96 | 38.02 | 42.04 | 2.34 | 0.65 |
| 32.70 | 27.37 | 31.18 | 30.42 | 33.65 | 31.95 | 2.26 | 0.63 |
| 23.19 | 24.33 | 26.99 | 28.13 | 27.37 | 27.08 | 1.63 | 0.45 |
| 33.08 | 31.94 | 35.74 | 33.46 | 35.93 | 34.14 | 1.84 | 0.51 |
| 8.74 | 10.65 | 11.41 | 8.36 | 11.79 | 10.38 | 1.80 | 0.50 |
| 4.56 | 4.56 | 6.84 | 5.32 | 4.56 | 5.47 | 0.83 | 0.23 |
| 15.21 | 14.45 | 17.49 | 15.97 | 16.73 | 16.01 | 1.03 | 0.29 |
| 15.21 | 15.21 | 15.21 | 15.02 | 15.21 | 15.49 | 0.46 | 0.13 |
| 49.43 | 50.19 | 51.33 | 53.61 | 53.99 | 51.49 | 2.10 | 0.58 |
| 14.45 | 14.07 | 18.25 | 13.69 | 14.07 | 14.53 | 1.21 | 0.34 |
| 16.73 | 19.01 | 19.77 | 19.01 | 19.77 | 19.04 | 1.32 | 0.37 |
| 39.92 | 39.54 | 39.54 | 39.54 | 39.54 | 39.83 | 1.12 | 0.31 |
| 19.01 | 19.01 | 19.01 | 19.01 | 19.01 | 19.04 | 0.67 | 0.19 |
| 26.61 | 27.37 | 26.61 | 27.75 | 26.99 | 27.29 | 1.25 | 0.35 |
| 126.87 | 120.14 | 122.04 | 117.86 | 121.66 | 120.99 | 3.61 | 1.00 |
| 117.86 | 116.34 | 117.86 | 117.86 | 121.66 | 113.41 | 12.25 | 3.40 |
| 39.54 | 40.30 | 38.78 | 40.30 | 39.54 | 40.33 | 1.94 | 0.54 |
| 15.40 | 15.21 | 15.21 | 15.97 | 14.83 | 15.71 | 0.79 | 0.22 |
| 39.54 | 49.43 | 39.92 | 38.40 | 38.02 | 40.29 | 3.19 | 0.89 |
| 36.50 | 42.58 | 38.02 | 35.74 | 39.16 | 40.19 | 3.85 | 1.07 |
| 15.97 | 15.97 | 15.21 | 15.97 | 17.11 | 16.29 | 1.41 | 0.39 |
| 36.88 | 39.92 | 41.63 | 36.88 | 36.50 | 39.28 | 2.62 | 0.73 |
| 55.51 | 48.66 | 44.86 | 42.96 | 43.72 | 46.76 | 3.46 | 0.96 |
| 25.85 | 30.42 | 26.61 | 25.09 | 25.09 | 26.40 | 1.62 | 0.45 |
| 16.73 | 19.20 | 17.49 | 18.25 | 17.49 | 18.05 | 1.03 | 0.29 |
| 8.36 | 10.27 | 9.89 | 9.12 | 10.27 | 9.94 | 0.93 | 0.26 |
| 38.40 | 55.13 | 39.16 | 39.16 | 40.30 | 44.07 | 10.68 | 2.97 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 03/04/95 | 30.27 | 13.31 | * | 19.77 | 36.50 | 25.09 | 32.70 | 38.02 | 30.42 | 19.77 | 23.19 | 17.87 | 15.21 | 24.71 |
| 04/04/95 | 7.47 | 4.56 | 5.70 | 6.08 | 5.70 | 11.41 | 7.22 | 2.66 | 8.36 | 9.50 | 7.60 | 1.14 | 7.22 | 6.43 |
| 06/04/95 | 70.17 | 73.38 | 64.63 | 83.26 | 63.11 | 67.29 | 47.52 | 79.46 | 80.22 | 76.42 | 81.74 | 60.83 | 68.44 | 70.53 |
| 07/04/95 | 64.27 | 76.04 | 47.52 | 101.13 | 49.43 | 47.90 | 42.20 | 64.63 | 79.84 | 44.48 | 48.28 | 58.17 | 69.20 | 60.74 |
| 08/04/95 | 12.00 | 11.79 | 16.92 | 12.17 | 15.97 | 5.70 | 7.60 | 10.27 | 14.45 | 7.22 | 4.56 | 11.41 | 9.50 | 10.63 |
| 10/04/95 | 46.65 | 69.96 | 62.35 | 47.90 | 49.81 | 32.70 | 26.61 | 25.09 | 44.48 | 31.18 | 32.70 | 39.16 | 43.72 | 42.14 |
| 12/04/95 | 15.90 | 24.33 | 22.81 | 15.97 | 10.65 | 8.36 | 8.74 | 15.21 | 15.21 | 9.89 | 11.03 | 11.79 | 12.17 | 13.85 |
| 14/04/95 | 10.10 | 10.65 | 11.79 | 10.65 | 9.12 | 6.84 | 9.89 | 10.27 | 9.89 | 7.22 | 5.32 | 5.70 | 6.46 | 8.65 |
| 15/04/95 | 59.50 | 54.18 | 50.57 | 64.63 | 52.47 | 49.81 | 53.61 | 39.16 | 84.02 | 26.99 | 38.02 | 31.18 | 74.52 | 51.60 |
| 18/04/95 | 7.25 | 4.56 | 4.56 | 6.46 | 3.80 | 5.70 | 4.94 | 5.32 | 9.50 | 6.84 | 5.70 | 3.80 | 4.18 | 5.45 |
| 22/04/95 | 40.20 | 24.33 | 25.85 | 49.43 | 45.62 | 49.43 | 31.94 | 28.13 | 37.03 | 29.85 | 15.21 | 23.19 | 33.27 | 32.77 |
| 23/04/95 | 39.20 | 32.89 | 34.22 | 45.24 | 34.41 | 34.22 | 31.94 | 28.89 | 38.02 | 26.61 | 32.32 | 23.57 | 32.32 | 32.89 |
| 26/04/95 | 48.55 | 23.57 | 25.85 | 38.40 | 76.80 | 47.90 | 23.57 | 38.02 | 47.52 | 46.57 | 51.33 | 40.30 | 47.52 | 42.28 |
| 02/05/95 | 10.70 | 12.17 | 15.21 | 12.55 | 26.61 | 4.18 | 15.21 | 9.50 | 14.64 | 15.21 | 9.50 | 9.50 | 9.50 | 12.82 |
| 04/05/95 | 43.23 | 26.61 | 13.69 | 11.41 | 40.30 | 19.01 | 28.89 | 34.98 | 36.50 | 25.85 | 17.49 | 38.02 | 28.13 | 26.74 |
| 05/05/95 | 13.40 | 9.12 | 6.46 | 3.61 | 5.70 | 6.84 | 11.41 | 12.93 | 15.21 | 13.69 | 11.98 | 14.26 | 7.98 | 9.93 |
| 13/05/95 | 177.53 | 167.29 | 104.93 | 121.28 | 104.93 | 132.69 | 70.72 | 113.11 | 134.02 | 85.54 | 89.35 | 139.15 | 141.62 | 117.05 |
| 15/05/95 | 50.87 | 50.23 | 30.42 | 45.62 | 39.92 | 35.74 | 27.37 | 55.13 | 50.79 | 51.71 | 19.77 | 50.19 | 50.19 | 42.26 |
| 19/05/95 | 30.60 | 32.70 | 25.09 | 54.75 | 19.77 | 26.61 | 22.81 | 23.95 | 15.21 | 25.09 | 42.20 | 38.02 | 12.93 | 28.26 |
| 25/05/95 | 35.67 | 30.42 | * | 65.39 | 24.71 | 34.98 | 34.98 | 28.51 | 24.71 | 27.37 | 51.33 | 39.92 | 15.21 | 34.32 |
| 26/05/95 | 18.40 | 15.97 | 15.97 | 19.20 | 11.60 | 11.41 | 12.93 | 7.60 | 15.21 | 8.36 | 20.91 | 21.29 | 29.66 | 15.84 |
| 31/05/95 | 64.23 | 63.11 | * | 45.62 | 57.79 | 49.43 | 41.06 | 68.44 | 61.21 | 51.71 | 51.71 | 25.09 | 66.91 | 52.92 |
| 01/06/95 | 32.13 | 25.85 | 28.13 | 17.49 | 38.02 | 31.94 | 31.75 | 25.47 | 28.89 | 26.61 | 42.58 | 23.95 | 23.57 | 28.69 |
| 03/06/95 | 15.43 | 7.60 | 12.17 | 22.81 | 11.03 | 9.50 | 7.60 | 10.65 | 19.01 | 9.50 | 8.36 | 12.55 | 9.50 | 11.69 |
| 06/06/95 | 28.50 | 16.73 | 24.90 | 27.94 | 18.63 | 20.53 | 15.21 | 20.15 | 19.77 | 20.91 | 21.67 | 21.29 | 19.20 | 20.58 |
| 09/06/95 | 14.10 | 12.93 | 7.98 | 15.78 | 9.12 | 12.93 | 7.22 | 8.36 | 11.79 | 7.22 | 7.22 | 7.98 | 9.5 | 9.84 |
| 12/06/95 | 8.10 | 9.50 | 15.21 | 20.15 | 12.93 | 7.60 | 9.89 | 11.41 | 9.50 | 21.67 | 19.01 | 13.31 | 14.07 | 13.69 |
| 14/06/95 | 46.30 | 28.13 | 30.42 | 57.03 | 22.81 | 32.70 | 31.18 | 20.91 | 30.42 | 45.62 | 47.14 | 34.98 | 24.33 | 33.81 |
| 19/06/95 | 52.77 | 42.58 | 42.58 | 46.53 | 38.02 | 41.82 | 37.26 | 30.80 | 38.78 | 44.63 | 59.31 | 41.82 | 57.03 | 43.43 |
| 20/06/95 | 24.90 | 19.01 | 26.61 | 24.46 | 20.91 | 12.55 | 16.73 | 18.25 | 29.66 | 28.51 | 17.11 | 15.97 | 32.70 | 21.87 |
| 22/06/95 | 46.37 | 37.26 | 45.39 | 35.54 | 36.88 | 43.61 | 46.38 | 34.98 | 53.23 | 47.90 | 33.08 | 38.02 | 47.41 | 41.64 |
| 24/06/95 | 51.17 | 39.92 | 59.84 | 43.34 | 58.93 | 60.83 | 45.62 | 53.99 | 53.91 | 46.38 | 39.54 | 38.02 | 57.03 | 49.78 |
| 30/06/95 | 7.37 | 1.90 | 1.90 | 10.27 | 1.14 | 3.80 | 7.22 | 5.70 | 10.65 | 6.46 | 3.04 | 3.80 | 5.32 | 5.10 |
| 02/07/95 | 13.10 | 7.60 | 5.70 | 22.81 | 9.50 | 8.36 | 13.31 | 11.41 | 13.31 | 17.49 | 8.36 | 8.36 | 11.41 | 11.47 |
| Mean | 37.15 | 33.51 | 31.75 | 33.26 | 31.88 | 29.83 | 31.80 | 31.95 | 31.86 | 32.44 | 33.08 | 30.21 | 33.69 | 32.13 |
| SD | 31.15 | 30.62 | 28.28 | 28.75 | 26.00 | 25.74 | 25.87 | 28.56 | 28.58 | 29.84 | 26.93 | 27.88 | 30.18 | 26.48 |
| SE | 3.08 | 3.03 | 2.80 | 2.85 | 2.57 | 2.55 | 2.56 | 2.83 | 2.83 | 2.95 | 2.67 | 2.76 | 2.99 | 2.62 |
| Total | 3789.6 | 3384.8 | 3111.6 | 3393.0 | 3252.0 | 3042.9 | 3243.4 | 3258.5 | 3249.5 | 3309.0 | 3374.2 | 3081.7 | 3436.0 | 3277.1 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8.55 | 2.44 | 30.42 | 23.19 | 15.59 | 14.45 | 30.80 | 19.77 | 30.04 | 24.71 | 26.99 | 35.74 | 32.70 | 31.18 |
| 2.82 | 0.81 | 6.08 | 9.50 | 6.84 | 8.36 | 6.08 | 6.46 | 7.60 | 4.94 | 7.03 | 8.36 | 7.60 | 7.98 |
| 10.58 | 3.02 | 87.83 | 63.11 | 61.59 | 73.38 | 63.49 | 70.72 | 76.04 | 58.55 | 76.04 | 89.35 | 79.46 | 38.40 |
| 17.98 | 5.14 | 70.34 | 47.90 | 60.83 | 65.01 | 61.78 | 59.69 | 71.48 | 61.59 | 75.28 | 82.12 | 65.01 | 75.28 |
| 3.93 | 1.12 | 12.17 | 15.97 | 11.98 | 7.60 | 10.65 | 16.73 | 12.17 | 11.41 | 15.21 | 8.36 | 12.93 | 10.27 |
| 13.89 | 3.97 | 51.33 | 47.52 | 46.76 | 47.52 | 37.26 | 44.10 | 45.62 | 47.52 | 49.43 | 32.32 | 44.10 | 36.12 |
| 5.18 | 1.48 | 15.21 | 18.25 | 15.97 | 12.93 | 12.93 | 21.67 | 17.49 | 15.97 | 14.83 | 9.89 | 15.59 | 16.73 |
| 2.21 | 0.63 | 9.12 | 7.60 | 7.60 | 11.41 | 8.74 | 8.74 | 11.03 | 9.12 | 7.60 | 6.08 | 10.65 | 7.60 |
| 16.85 | 4.81 | 46.38 | 45.62 | 55.51 | 76.04 | 54.37 | 79.84 | 87.44 | 50.95 | 61.59 | 60.83 | 56.27 | 41.82 |
| 1.61 | 0.46 | 5.32 | 4.37 | 6.08 | 6.46 | 6.46 | 4.56 | 7.60 | 3.80 | 6.46 | 8.36 | 6.46 | 2.28 |
| 10.82 | 3.09 | 34.60 | 51.71 | 41.06 | 40.83 | 34.60 | 30.42 | 40.83 | 28.32 | 53.42 | 29.08 | 41.63 | 26.61 |
| 5.46 | 1.56 | 30.42 | 51.71 | 34.60 | 47.14 | 36.12 | 29.28 | 50.19 | 34.98 | 42.58 | 38.40 | 38.40 | 30.42 |
| 14.73 | 4.21 | 49.81 | 47.52 | 51.14 | 83.64 | 46.00 | 51.71 | 55.13 | 53.61 | 49.43 | 42.20 | 42.96 | 40.30 |
| 5.48 | 1.56 | 15.97 | 15.59 | 17.11 | 27.37 | 20.53 | 12.17 | 12.17 | 17.49 | 28.51 | 19.01 | 19.01 | 14.07 |
| 9.69 | 2.77 | 28.89 | 31.94 | 29.66 | 55.51 | 30.42 | 30.42 | 22.81 | 38.02 | 33.46 | 29.66 | 34.98 | 34.22 |
| 3.81 | 1.09 | 11.79 | 12.93 | 12.17 | 21.29 | 12.55 | 13.69 | 15.21 | 16.92 | 16.54 | 12.55 | 14.26 | 13.69 |
| 27.61 | 7.89 | 172.99 | 79.84 | 175.46 | 146.56 | 156.64 | 181.73 | 142.57 | 160.06 | 120.14 | 123.18 | 190.86 | 180.02 |
| 11.46 | 3.27 | 53.42 | 53.23 | 46.38 | 52.54 | 53.23 | 50.95 | 50.83 | 53.23 | 38.78 | 53.99 | 49.43 | 45.62 |
| 11.91 | 3.40 | 38.02 | 34.98 | 17.49 | 33.08 | 28.13 | 28.89 | 30.04 | 34.60 | 34.22 | 19.01 | 33.65 | 27.37 |
| 13.91 | 3.97 | 53.23 | 33.08 | 22.81 | 34.98 | 37.26 | 39.92 | 34.22 | 42.58 | 39.54 | 19.77 | 30.42 | 31.18 |
| 6.24 | 1.78 | 20.15 | 19.01 | 15.97 | 19.01 | 19.01 | 10.65 | 19.77 | 17.49 | 19.39 | 12.17 | 23.57 | 25.47 |
| 12.71 | 3.63 | 72.24 | 65.39 | 54.75 | 63.49 | 92.77 | 63.11 | 72.24 | 72.24 | 72.24 | 49.43 | 68.44 | 57.03 |
| 6.72 | 1.92 | 32.70 | 29.28 | 36.50 | 32.70 | 44.86 | 29.85 | 38.78 | 34.98 | 20.53 | 27.37 | 38.02 | 27.37 |
| 4.66 | 1.33 | 17.49 | 17.49 | 13.50 | 19.01 | 12.55 | 15.21 | 32.32 | 20.91 | 19.58 | 15.21 | 4.56 | 15.21 |
| 3.37 | 0.96 | 37.26 | 38.02 | 27.56 | 34.22 | 28.89 | 32.70 | 49.43 | 29.47 | 36.12 | 22.81 | 17.49 | 25.28 |
| 2.84 | 0.81 | 20.91 | 16.73 | 14.45 | 16.35 | 13.69 | 17.49 | 27.37 | 15.97 | 18.63 | 8.74 | 8.74 | 8.36 |
| 4.56 | 1.30 | 19.58 | 26.61 | 13.31 | 20.91 | 23.95 | 14.07 | 47.14 | 25.09 | 9.89 | 18.25 | 15.21 | 20.53 |
| 10.86 | 3.10 | 62.73 | 45.62 | 47.52 | 47.90 | 63.49 | 33.46 | 108.74 | 38.02 | 39.54 | 49.43 | 19.01 | 49.43 |
| 8.00 | 2.28 | 57.03 | 68.44 | 51.33 | 64.42 | 53.61 | 66.42 | 56.45 | 66.04 | 35.74 | 46.76 | 26.61 | 58.44 |
| 6.36 | 1.82 | 29.22 | 29.22 | 29.37 | 27.16 | 28.50 | 29.28 | 19.01 | 29.18 | 28.13 | 26.08 | 20.53 | 16.35 |
| 6.45 | 1.84 | 39.92 | 49.43 | 39.54 | 51.71 | 49.43 | 49.43 | 42.20 | 34.60 | 26.61 | 57.03 | 44.10 | 61.21 |
| 8.55 | 2.44 | 54.90 | 57.79 | 46.00 | 64.82 | 60.45 | 60.83 | 54.75 | 38.78 | 38.02 | 60.83 | 44.10 | 59.31 |
| 3.13 | 0.90 | 6.46 | 7.98 | 7.22 | 6.84 | 4.56 | 7.60 | 7.60 | 4.18 | 5.70 | 9.12 | 7.98 | 5.32 |
| 4.79 | 1.37 | 15.21 | 12.55 | 13.69 | 4.56 | 19.01 | 17.11 | 15.21 | 11.79 | 9.12 | 9.12 | 15.97 | 15.21 |
| | | 36.86 | 34.64 | 35.14 | 35.83 | 36.10 | 36.19 | 39.46 | 35.88 | 34.83 | 34.55 | 35.79 | 35.98 |
| | | 31.28 | 26.45 | 31.04 | 28.85 | 29.73 | 30.78 | 32.26 | 32.21 | 28.55 | 28.91 | 34.18 | 32.10 |
| | | 3.10 | 2.62 | 3.07 | 2.86 | 2.94 | 3.05 | 3.19 | 3.19 | 2.83 | 2.86 | 3.38 | 3.18 |
| 128.3 | 36.7 | 3759.7 | 3533.7 | 3584.5 | 3654.9 | 3645.9 | 3691.0 | 4024.6 | 3659.5 | 3553.0 | 3455.3 | 3650.4 | 3670.1 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 31.18 | 32.70 | 27.10 | 27.10 | 7.53 | 33.84 | 26.61 | 31.94 | 30.80 | * | 31.18 | 35.74 | 31.94 | 31.94 |
| 8.36 | 4.94 | 7.16 | 7.16 | 1.99 | 7.60 | 7.22 | 7.22 | 7.98 | 7.22 | 7.60 | 6.84 | 7.60 | 7.60 |
| 61.59 | 61.21 | 68.63 | 68.63 | 19.06 | 72.62 | 62.35 | 62.73 | 63.87 | 60.64 | 74.52 | 66.53 | 64.63 | 77.18 |
| 60.07 | 63.49 | 65.71 | 65.71 | 18.25 | 66.15 | 53.23 | 57.03 | 60.07 | 58.55 | 60.83 | 61.97 | 58.93 | 65.77 |
| 12.55 | 9.89 | 11.99 | 11.99 | 3.33 | 12.17 | 11.41 | 13.31 | 13.31 | 11.79 | 11.41 | 11.79 | 12.17 | 13.69 |
| 42.58 | 55.13 | 44.81 | 44.81 | 12.45 | 47.14 | 47.14 | 49.43 | 47.52 | 46.38 | 43.34 | 47.14 | 43.72 | 58.93 |
| 15.21 | 15.21 | 15.56 | 15.56 | 4.32 | 15.97 | 15.59 | 14.83 | 15.21 | 15.59 | 15.21 | 15.97 | 13.69 | 15.97 |
| 9.50 | 7.60 | 8.74 | 8.74 | 2.43 | 10.27 | 10.65 | 11.03 | 8.36 | 10.65 | 11.41 | 8.74 | 10.27 | 9.12 |
| 65.01 | 47.52 | 59.23 | 59.23 | 16.45 | 57.03 | 53.23 | 57.41 | 55.13 | 55.51 | 62.73 | 61.59 | 58.93 | 41.06 |
| 7.60 | 4.18 | 5.72 | 5.72 | 1.59 | 8.74 | 7.60 | 6.84 | 8.74 | 7.98 | 8.74 | 8.36 | 9.50 | 12.93 |
| 47.03 | 45.09 | 38.95 | 38.95 | 10.82 | 34.79 | 38.40 | 45.24 | 47.03 | 48.44 | 43.23 | 43.23 | 46.00 | 48.44 |
| 51.71 | 39.54 | 39.68 | 39.68 | 11.02 | 39.92 | 44.10 | 37.64 | 44.10 | 34.98 | 44.10 | 40.30 | 42.58 | 46.38 |
| 53.23 | 50.76 | 51.24 | 51.24 | 14.23 | 47.90 | 47.52 | 46.00 | 49.43 | 51.71 | 47.14 | 53.23 | 50.19 | 55.13 |
| 32.32 | 26.61 | 19.85 | 19.85 | 5.51 | 21.29 | 20.53 | 19.77 | 20.91 | 20.91 | 20.53 | 21.29 | 20.91 | 22.05 |
| 48.66 | 36.50 | 34.65 | 34.65 | 9.63 | 34.22 | 31.94 | 33.84 | 32.70 | 34.98 | 34.22 | 39.16 | 33.84 | 37.26 |
| 22.81 | 12.17 | 14.90 | 14.90 | 4.14 | 13.69 | 14.07 | 12.55 | 13.31 | 14.07 | 13.31 | 13.31 | 14.07 | 15.02 |
| 120.90 | 122.61 | 148.11 | 148.11 | 41.14 | 173.37 | 171.47 | 174.13 | 178.69 | 182.87 | 184.39 | 182.30 | 182.87 | 184.39 |
| 50.51 | 48.44 | 50.04 | 50.04 | 13.90 | 50.19 | 50.19 | 53.23 | 53.99 | 53.42 | 53.23 | 56.27 | 53.23 | 55.51 |
| 27.37 | 30.42 | 29.80 | 29.80 | 8.28 | 30.42 | 30.42 | 30.42 | 28.51 | 30.04 | 30.42 | 29.28 | 31.18 | 27.37 |
| 25.09 | 34.22 | 34.16 | 34.16 | 9.49 | 33.46 | 35.74 | 37.64 | 32.70 | 38.02 | 38.02 | 34.22 | 34.98 | 34.98 |
| 17.68 | 22.81 | 18.72 | 18.72 | 5.20 | 20.15 | 19.77 | 19.39 | 19.39 | 19.01 | 19.01 | 19.77 | 20.15 | 19.77 |
| 66.15 | 69.20 | 67.05 | 67.05 | 18.63 | 59.31 | 67.67 | 63.11 | 59.69 | 60.07 | 60.07 | 58.55 | 67.67 | 65.39 |
| 38.02 | 38.02 | 33.50 | 33.50 | 9.30 | 31.94 | 32.70 | 34.22 | 33.46 | 32.70 | 33.46 | 29.66 | 38.02 | 36.12 |
| 14.83 | 12.55 | 16.46 | 16.46 | 4.57 | 12.93 | 15.97 | 15.21 | 19.01 | 15.21 | 13.69 | 17.11 | 15.97 | 15.21 |
| 28.89 | 27.37 | 31.11 | 31.11 | 8.64 | 30.42 | 30.42 | 29.66 | 33.84 | 29.66 | 29.66 | 29.66 | 28.51 | 28.89 |
| 14.83 | 11.79 | 15.29 | 15.29 | 4.25 | 14.83 | 14.07 | 14.83 | 15.59 | 15.21 | 14.45 | 13.69 | 15.02 | 14.07 |
| 19.01 | 18.63 | 20.87 | 20.87 | 5.80 | 20.15 | 20.53 | 17.11 | 25.09 | 18.25 | 17.87 | 17.11 | 21.29 | 15.21 |
| 45.62 | 34.60 | 48.94 | 48.94 | 13.59 | 46.00 | 47.90 | 51.33 | 47.90 | 46.00 | 45.62 | 39.54 | 43.72 | 44.86 |
| 60.83 | 38.02 | 53.58 | 53.58 | 14.88 | 53.23 | 55.89 | 57.03 | 60.83 | 52.47 | 52.09 | 53.23 | 53.23 | 50.95 |
| 25.47 | 27.37 | 26.06 | 26.06 | 7.24 | 23.57 | 25.85 | 26.61 | 28.13 | 23.57 | 23.57 | 24.33 | 25.09 | 24.71 |
| 38.97 | 18.25 | 43.03 | 43.03 | 11.95 | 46.38 | 47.90 | 47.90 | 51.71 | 46.38 | 45.62 | 45.62 | 45.62 | 50.57 |
| 51.71 | 19.39 | 50.83 | 50.83 | 14.12 | 54.51 | 53.88 | 54.03 | 51.78 | 52.74 | 53.23 | 53.13 | 47.14 | 53.03 |
| 6.08 | 1.90 | 6.33 | 6.33 | 1.76 | 7.60 | 7.22 | 7.98 | 8.36 | 7.60 | 7.60 | 7.98 | 7.60 | 8.36 |
| 14.45 | 9.12 | 13.01 | 13.01 | 3.61 | 14.07 | 15.21 | 15.21 | 12.93 | 13.69 | 14.45 | 14.07 | 13.69 | 15.59 |
| 35.84 | 36.76 | 36.15 | | | 36.69 | 37.30 | 37.25 | 37.22 | 36.81 | 37.36 | 38.77 | 36.21 | 37.94 |
| 29.03 | 31.73 | 29.16 | | | 30.28 | 32.48 | 32.05 | 31.70 | 30.91 | 31.33 | 33.46 | 30.40 | 31.90 |
| 2.87 | 3.14 | 2.89 | | | 3.00 | 3.22 | 3.17 | 3.14 | 3.06 | 3.10 | 3.31 | 3.01 | 3.16 |
| 3655.9 | 3749.3 | 3687.4 | 132.2 | 36.7 | 3742.0 | 3805.1 | 3799.5 | 3796.5 | 3681.1 | 3810.4 | 3954.1 | 3693.5 | 3870.2 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 31.18 | 41.82 | * | 30.42 | 31.94 | 32.44 | 3.64 | 1.01 |
| 6.08 | 6.84 | 8.36 | 7.60 | 8.36 | 7.44 | 0.61 | 0.17 |
| 65.39 | 65.39 | 69.96 | 66.15 | 68.44 | 67.17 | 4.83 | 1.34 |
| 60.83 | 60.83 | 65.39 | 63.11 | 61.59 | 61.02 | 3.53 | 0.98 |
| 12.17 | 11.41 | 11.79 | 12.55 | 11.41 | 12.17 | 0.77 | 0.22 |
| 45.62 | 45.62 | 45.62 | 46.38 | 44.10 | 47.01 | 3.80 | 1.05 |
| 15.97 | 15.21 | 15.21 | 15.21 | 15.97 | 15.40 | 0.63 | 0.17 |
| 7.98 | 11.79 | 10.27 | 9.89 | 9.50 | 9.99 | 1.13 | 0.31 |
| 61.97 | 59.31 | 57.79 | 76.04 | 61.21 | 58.50 | 7.40 | 2.05 |
| 7.98 | 7.60 | 7.60 | 7.98 | 6.08 | 8.34 | 1.57 | 0.44 |
| 48.44 | 41.44 | 53.30 | 44.48 | 41.44 | 44.56 | 4.70 | 1.30 |
| 43.34 | 39.92 | 37.26 | 44.10 | 37.83 | 41.18 | 3.39 | 0.94 |
| 53.42 | 41.82 | 53.99 | 52.09 | 58.93 | 50.61 | 4.37 | 1.21 |
| 20.91 | 21.48 | 22.05 | 20.91 | 20.91 | 21.03 | 0.59 | 0.17 |
| 34.22 | 34.22 | 36.88 | 34.22 | 34.22 | 34.71 | 1.88 | 0.52 |
| 13.31 | 13.31 | 13.69 | 13.69 | 13.31 | 13.62 | 0.58 | 0.16 |
| 180.97 | 180.40 | 168.81 | 179.45 | 182.87 | 179.07 | 5.09 | 1.41 |
| 53.99 | 54.75 | 51.71 | 50.19 | 53.99 | 53.13 | 1.93 | 0.54 |
| 27.37 | 30.80 | 30.42 | 30.80 | 29.66 | 29.79 | 1.23 | 0.34 |
| 37.64 | 34.98 | 38.02 | 34.22 | 34.22 | 35.63 | 1.88 | 0.52 |
| 19.77 | 18.63 | 19.01 | 19.39 | 19.01 | 19.44 | 0.47 | 0.13 |
| 60.83 | 60.07 | 64.63 | 59.69 | 60.07 | 61.92 | 3.16 | 0.88 |
| 32.70 | 32.70 | 32.32 | 31.94 | 31.94 | 33.13 | 2.00 | 0.56 |
| 13.31 | 16.35 | 11.79 | 15.59 | 15.21 | 15.18 | 1.83 | 0.51 |
| 28.89 | 28.89 | 31.18 | 29.66 | 28.51 | 29.85 | 1.38 | 0.38 |
| 14.45 | 11.41 | 12.17 | 15.21 | 12.93 | 14.14 | 1.22 | 0.34 |
| 19.01 | 15.21 | 17.49 | 19.77 | 15.97 | 18.58 | 2.68 | 0.74 |
| 45.62 | 47.52 | 45.62 | 45.43 | 44.86 | 45.85 | 2.60 | 0.72 |
| 53.23 | 57.03 | 53.23 | 52.85 | 53.99 | 54.23 | 2.59 | 0.72 |
| 23.19 | 25.09 | 22.81 | 23.57 | 24.71 | 24.63 | 1.47 | 0.41 |
| 46.00 | 49.05 | 45.62 | 45.62 | 47.14 | 47.23 | 1.98 | 0.55 |
| 52.13 | 54.03 | 53.23 | 53.20 | 53.75 | 52.84 | 1.80 | 0.50 |
| 7.60 | 7.60 | 7.98 | 7.60 | 7.60 | 7.77 | 0.32 | 0.09 |
| 14.45 | 15.21 | 13.69 | 13.31 | 13.69 | 14.23 | 0.81 | 0.23 |
| 37.58 | 37.87 | 37.82 | 37.64 | 37.25 | 37.41 | | |
| 32.34 | 31.59 | 32.38 | 32.96 | 31.87 | 31.48 | | |
| 3.20 | 3.13 | 3.21 | 3.26 | 3.16 | 3.12 | | |
| 3833.2 | 3863.0 | 3819.5 | 3839.4 | 3799.8 | 3815.5 | 70.09 | 19.47 |

# Appendix IV

**Table IV.1** The boundary layer conductance and the rate of evaporation in the unlogged plot

| Date | $T$ [1)] °C | $e_s(T_a)$ Pa | $s(T_a)$ Pa °C$^{-1}$ | ρ kg m$^{-3}$ | λ J kg$^{-1}$ | γ Pa °C$^{-1}$ | $R_h$ [2)] % | $e_a$ [3)] Pa | $D_{vp}$ [4)] Pa |
|---|---|---|---|---|---|---|---|---|---|
| 01/11/93 | 24.3 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 94.50 | 2819 | 164.1 |
| 03/11/93 | 25.1 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 89.40 | 2831 | 335.7 |
| 12/11/93 | 24.7 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 95.20 | 3015 | 152.0 |
| 16/11/93 | 24.5 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 88.20 | 2793 | 373.7 |
| 17/11/93 | 24.2 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 92.40 | 2756 | 226.7 |
| 25/11/93 | 23.8 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 96.00 | 2864 | 119.3 |
| 27/11/93 | 24.5 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 91.70 | 2904 | 262.9 |
| 30/11/93 | 24.4 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 92.20 | 2750 | 232.7 |
| 03/12/93 | 24.9 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 90.20 | 2857 | 310.4 |
| 06/12/93 | 24.2 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 88.70 | 2646 | 337.1 |
| 12/12/93 | 25.4 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 85.40 | 2705 | 462.4 |
| 18/12/93 | 24.0 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 93.10 | 2777 | 205.8 |
| 23/12/93 | 24.4 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 91.30 | 2723 | 259.5 |
| 19/01/94 | 24.4 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 91.50 | 2729 | 253.6 |
| 23/01/94 | 23.9 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 86.10 | 2568 | 414.6 |
| 05/02/94 | 23.9 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 90.30 | 2694 | 289.4 |
| 12/02/94 | 23.9 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 95.30 | 2843 | 140.2 |
| 14/02/94 | 23.4 | 2809 | 170 | 1.18 | 2438000 | 66.29 | 93.90 | 2638 | 171.3 |
| 15/02/94 | 24.1 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 94.40 | 2816 | 167.0 |
| 17/02/94 | 24.2 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 94.00 | 2804 | 179.0 |
| 07/03/94 | 24.7 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 86.80 | 2749 | 418.0 |
| 08/03/94 | 24.1 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 88.60 | 2643 | 340.1 |
| 22/03/94 | 23.4 | 2809 | 170 | 1.18 | 2438000 | 66.29 | 97.50 | 2739 | 70.2 |
| 24/03/94 | 22.8 | 2809 | 170 | 1.18 | 2438000 | 66.29 | 97.30 | 2733 | 75.8 |
| 25/03/94 | 23.7 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 95.30 | 2843 | 140.2 |
| 27/03/94 | 24.5 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 92.40 | 2926 | 240.7 |
| 28/03/94 | 24.7 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 91.50 | 2898 | 269.2 |
| 29/03/94 | 24.2 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 93.20 | 2780 | 202.8 |
| 30/03/94 | 24.0 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 95.00 | 2834 | 149.2 |
| 04/04/94 | 23.7 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 94.70 | 2825 | 158.1 |
| 06/04/94 | 24.2 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 94.20 | 2810 | 173.0 |
| 10/04/94 | 25.1 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 93.70 | 2967 | 199.5 |
| 11/04/94 | 23.4 | 2809 | 170 | 1.18 | 2438000 | 66.29 | 98.40 | 2764 | 44.9 |
| 14/04/94 | 23.8 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 97.00 | 2894 | 89.5 |
| Mean | 24.19 | 3016.6 | 180.88 | 1.18 | 2436824 | 66.33 | 92.63 | 2792.27 | 224.37 |
| SD | 0.54 | 113.0 | 6.04 | 0.00 | 626.22 | 0.02 | 3.31 | 96.74 | 104.63 |
| SE | 0.09 | 19.5 | 1.04 | 0.00 | 107.97 | 0.00 | 0.57 | 16.68 | 18.04 |

[1)] $T = -0.1 + 1.0\,T_{bc}$ [Eq. 4.12]

[2)] $R_h = -1.9 + 0.9\,R_h$ [Eq. 4.13]

[3)] $e_s(T) * R_h$

[4)] $e_s(T) - e_a$

[5)] $R_n = 2.9 + 0.43\,Q_*$ [Eq. 4.15]

[6)] $[I\,\lambda\,(s + \gamma) - s\,R_n] / [\rho C_p\{e_s(T) - e_a\}]$

$Cp = 1010$ J kg$^{-1}$ °C$^{-1}$

[7)] $(s\,R_n) / \lambda\,(s + \gamma)$

[8)] $C_p\,\rho\,D_{vp}\,g_a / \lambda\,(s + \gamma)$

| $u$ | $R_n$ [5] | $I$ | $g_a$ [6] | $\lambda$ $I$ | Rad [7] | Advec[8] |
|---|---|---|---|---|---|---|
| m $s^{-1}$ | J $m^{-2}$ $s^{-1}$ | mm $s^{-1}$ | m $s^{-1}$ | J $m^{-2}$ $s^{-1}$ | mm $h^{-1}$ | mm $h^{-1}$ |
| 1.93 | 117.1 | 0.00043 | 1.21 | 1047.91 | 0.13 | 1.42 |
| 2.32 | 81.4 | 0.00045 | 0.67 | 1096.20 | 0.09 | 1.53 |
| 1.55 | 87.9 | 0.00003 | 0.01 | 72.35 | 0.10 | 0.01 |
| 2.32 | 87.4 | 0.00011 | 0.11 | 263.09 | 0.10 | 0.29 |
| 1.93 | 144.2 | 0.00022 | 0.39 | 536.14 | 0.16 | 0.64 |
| 1.93 | 99.6 | 0.00033 | 1.25 | 794.46 | 0.11 | 1.07 |
| 2.32 | 62.4 | 0.00018 | 0.32 | 431.17 | 0.07 | 0.57 |
| 2.32 | 68.7 | 0.00013 | 0.23 | 309.50 | 0.07 | 0.38 |
| 2.10 | 171.5 | 0.00011 | 0.10 | 267.96 | 0.19 | 0.21 |
| 2.50 | 149.4 | 0.00006 | 0.03 | 153.53 | 0.16 | 0.07 |
| * | 153.8 | 0.00008 | 0.04 | 199.75 | 0.17 | 0.13 |
| 1.60 | 113.2 | 0.00014 | 0.26 | 341.18 | 0.12 | 0.38 |
| 2.30 | 147.1 | 0.00021 | 0.31 | 499.59 | 0.16 | 0.58 |
| * | 108.4 | 0.00040 | 0.72 | 962.62 | 0.12 | 1.31 |
| * | 128.9 | 0.00007 | 0.04 | 177.90 | 0.14 | 0.12 |
| * | 152.4 | 0.00012 | 0.13 | 294.88 | 0.16 | 0.27 |
| 1.08 | 81.4 | 0.00006 | 0.11 | 137.45 | 0.09 | 0.12 |
| 1.08 | 146.9 | 0.00037 | 0.92 | 902.06 | 0.16 | 1.18 |
| 1.24 | 162.4 | 0.00045 | 1.21 | 1096.65 | 0.18 | 1.44 |
| 1.04 | 126.4 | 0.00019 | 0.43 | 467.90 | 0.14 | 0.55 |
| * | 138.4 | 0.00008 | 0.04 | 182.70 | 0.15 | 0.12 |
| * | 88.4 | 0.00007 | 0.07 | 175.46 | 0.10 | 0.16 |
| 1.04 | 52.9 | 0.00015 | 0.94 | 370.58 | 0.06 | 0.49 |
| 1.16 | 105.9 | 0.00004 | 0.08 | 107.27 | 0.11 | 0.05 |
| 1.08 | 129.4 | 0.00036 | 1.16 | 882.19 | 0.14 | 1.16 |
| 1.08 | 145.9 | 0.00013 | 0.19 | 319.12 | 0.16 | 0.31 |
| 1.47 | 151.9 | 0.00012 | 0.14 | 282.58 | 0.17 | 0.25 |
| 1.31 | 158.9 | 0.00014 | 0.23 | 338.74 | 0.17 | 0.33 |
| 1.16 | 112.4 | 0.00037 | 1.11 | 889.51 | 0.12 | 1.19 |
| 1.12 | 129.9 | 0.00035 | 0.97 | 843.20 | 0.14 | 1.11 |
| 1.12 | 114.9 | 0.00017 | 0.38 | 406.98 | 0.12 | 0.48 |
| 1.20 | 119.4 | 0.00007 | 0.10 | 177.83 | 0.13 | 0.13 |
| 1.08 | 115.0 | 0.00014 | 1.12 | 336.44 | 0.12 | 0.37 |
| 1.28 | 106.4 | 0.00023 | 1.12 | 565.38 | 0.11 | 0.72 |
| 1.56 | 119.41 | 0.00019 | 0.47 | 468.54 | 0.13 | 0.56 |
| 0.52 | 30.65 | 0.00013 | 0.44 | 317.72 | 0.03 | 0.47 |
| 0.09 | 5.28 | 0.00002 | 0.08 | 54.78 | 0.01 | 0.08 |

**Table IV.2** The boundary layer conductance and the rate of evaporation of the **closed canopy** of the logged plot

| Day | $T$ | $e_s(T_a)$ | $s$ | ρ | λ | γ | $R_h$ | $e_a$ [1)] | $D_{vp}$ [2)] |
|---|---|---|---|---|---|---|---|---|---|
| | °C | Pa | Pa °C$^{-1}$ | kg m$^{-3}$ | J kg$^{-1}$ | Pa °C$^{-1}$ | % | Pa | Pa |
| 01/12/94 | 24.7 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 90.3 | 2859.80 | 307.20 |
| 04/12/94 | 24.0 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 92.7 | 2765.24 | 217.76 |
| 20/12/94 | 24.5 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 92.8 | 2938.98 | 228.02 |
| 23/12/94 | 24.4 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 91.3 | 2723.48 | 259.52 |
| 05/01/95 | 23.7 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 91.9 | 2741.38 | 241.62 |
| 16/01/95 | 25.4 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 82.7 | 2619.11 | 547.89 |
| 17/01/95 | 25.0 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 88.1 | 2790.13 | 376.87 |
| 19/01/95 | 24.4 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 91.5 | 2729.45 | 253.56 |
| 20/01/95 | 23.8 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 93.8 | 2798.05 | 184.95 |
| 21/01/95 | 23.5 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 93.4 | 2786.12 | 196.88 |
| 23/01/95 | 23.9 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 86.1 | 2568.36 | 414.64 |
| 26/01/95 | 24.1 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 87.9 | 2622.06 | 360.94 |
| 06/02/95 | 22.5 | 2809 | 170 | 1.18 | 2438000 | 66.29 | 93.3 | 2620.80 | 188.20 |
| 07/02/95 | 23.4 | 2809 | 170 | 1.18 | 2438000 | 66.29 | 90.3 | 2536.53 | 272.47 |
| 16/02/95 | 25.2 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 85 | 2691.95 | 475.05 |
| 18/02/95 | 23.5 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 90.3 | 2693.65 | 289.35 |
| 23/02/95 | 24.8 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 86.8 | 2589.24 | 393.76 |
| 24/02/95 | 25.0 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 86.2 | 2729.95 | 437.05 |
| 25/02/95 | 23.5 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 93.9 | 2801.04 | 181.96 |
| 09/03/95 | 25.6 | 3361 | 199 | 1.17 | 2435000 | 66.38 | 85.7 | 2880.38 | 480.62 |
| 13/03/95 | 24.3 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 87.1 | 2598.19 | 384.81 |
| 20/03/95 | 23.8 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 90.8 | 2708.56 | 274.44 |
| 01/06/95 | 25.9 | 3361 | 199 | 1.17 | 2435000 | 66.38 | 85.2 | 2863.57 | 497.43 |
| 06/06/95 | 23.1 | 2809 | 170 | 1.18 | 2438000 | 66.29 | 93.2 | 2617.99 | 191.01 |
| 09/06/95 | 23.5 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 90.6 | 2702.60 | 280.40 |
| 14/06/95 | 23.9 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 91.9 | 2741.38 | 241.62 |
| 19/06/95 | 23.2 | 2809 | 170 | 1.18 | 2438000 | 66.29 | 91.1 | 2559.00 | 250.00 |
| 22/06/95 | 23.6 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 92.9 | 2771.21 | 211.79 |
| 24/06/95 | 23.4 | 2809 | 170 | 1.18 | 2438000 | 66.29 | 94.3 | 2648.89 | 160.11 |
| 30/06/95 | 25.0 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 90 | 2850.30 | 316.70 |
| Mean | 24.15 | 3022.1 | 181.17 | 1.18 | 2436800 | 66.33 | 90.04 | 2718.25 | 303.89 |
| SD | 0.82 | 147.18 | 7.80 | 0.00 | 805.16 | 0.02 | 3.18 | 105.04 | 107.89 |
| SE | 0.15 | 27.26 | 1.44 | 0.00 | 149.10 | 0.00 | 0.59 | 19.45 | 19.98 |

Note:

$T$, $R_h$ and $R_n$ were measured above the forest canopy (station 3, tower)

* $I$cc is the interception loss from the closed canopy of the logged plot

1) $e_s(T_a) * R_h$

2) $e_s(T_a) - e_a$

3) $[I\,\lambda\,(s+\gamma) - s\,R\mathrm{n}] / [\rho C_p\,\{e_s(T_a) - e_a\}]$

$C_p = 1010$ J kg$^{-1}$ °C$^{-1}$

4) $[s\,R_n] / [\lambda\,(s+\gamma)]$

5) $[\rho\,C_p\,D_{vp}\,g_a] / [\lambda\,(s+\gamma)]$

| $u$ | $R_n$ | $I$ cc | $g_a$[3)] | $\lambda\ I$ | Rad[4)] | Advec[5)] |
|---|---|---|---|---|---|---|
| m $s^{-1}$ | J $m^{-2}$ $s^{-1}$ | mm $s^{-1}$ | m $s^{-1}$ | J $m^{-2}$ $s^{-1}$ | mm $h^{-1}$ | mm $h^{-1}$ |
| 2.66 | 155.60 | 0.00063 | 1.00 | 1534.68 | 0.17 | 2.10 |
| 2.90 | 147.90 | 0.00009 | 0.11 | 219.33 | 0.16 | 0.16 |
| 2.00 | 120.90 | 0.00020 | 0.38 | 487.20 | 0.13 | 0.59 |
| 2.30 | 147.10 | 0.00009 | 0.09 | 219.33 | 0.16 | 0.17 |
| 0.56 | 104.30 | 0.00050 | 0.97 | 1218.50 | 0.11 | 1.69 |
| 0.10 | 146.30 | 0.00031 | 0.26 | 755.16 | 0.16 | 0.96 |
| 0.10 | 130.90 | 0.00036 | 0.45 | 876.96 | 0.14 | 1.15 |
| 0.10 | 108.40 | 0.00010 | 0.13 | 243.70 | 0.12 | 0.24 |
| 0.10 | 124.80 | 0.00004 | 0.01 | 97.48 | 0.13 | 0.01 |
| 0.10 | 111.50 | 0.00012 | 0.21 | 285.13 | 0.12 | 0.30 |
| 0.10 | 128.90 | 0.00029 | 0.30 | 706.73 | 0.14 | 0.91 |
| 0.10 | 190.30 | 0.00023 | 0.24 | 560.51 | 0.21 | 0.62 |
| 0.10 | 132.00 | 0.00012 | 0.21 | 297.44 | 0.14 | 0.30 |
| 0.10 | 133.00 | 0.00031 | 0.47 | 748.47 | 0.14 | 0.96 |
| 0.10 | 158.60 | 0.00052 | 0.52 | 1266.72 | 0.17 | 1.70 |
| 0.10 | 117.60 | 0.00035 | 0.55 | 852.95 | 0.13 | 1.13 |
| 0.10 | 179.00 | 0.00030 | 0.31 | 731.10 | 0.19 | 0.89 |
| 0.10 | 168.80 | 0.00032 | 0.32 | 779.52 | 0.18 | 0.97 |
| 0.10 | 118.70 | 0.00015 | 0.32 | 365.55 | 0.13 | 0.41 |
| 0.10 | 157.50 | 0.00020 | 0.17 | 479.70 | 0.17 | 0.53 |
| 0.10 | 154.50 | 0.00016 | 0.15 | 399.67 | 0.17 | 0.42 |
| 0.10 | 123.80 | 0.00023 | 0.35 | 560.51 | 0.13 | 0.69 |
| 0.10 | 125.00 | 0.00048 | 0.48 | 1161.50 | 0.14 | 1.58 |
| 0.10 | 164.00 | 0.00041 | 0.92 | 999.58 | 0.17 | 1.30 |
| 0.10 | 109.00 | 0.00039 | 0.64 | 950.43 | 0.12 | 1.29 |
| 0.10 | 131.00 | 0.00047 | 0.89 | 1145.39 | 0.14 | 1.55 |
| 0.10 | 170.00 | 0.00051 | 0.89 | 1243.38 | 0.18 | 1.66 |
| 0.10 | 89.00 | 0.00020 | 0.41 | 487.40 | 0.10 | 0.62 |
| 0.10 | 131.00 | 0.00005 | 0.02 | 112.15 | 0.14 | 0.03 |
| 0.10 | 109.00 | 0.00021 | 0.29 | 511.56 | 0.12 | 0.64 |
| 0.43 | 136.28 | 0.00028 | 0.40 | 676.59 | 0.15 | 0.85 |
| 0.83 | 24.44 | 0.00016 | 0.29 | 386.20 | 0.03 | 0.57 |
| 0.15 | 4.53 | 0.00003 | 0.05 | 71.52 | 0.00 | 0.10 |

**Table IV.3** The boundary layer conductance and the rate of evaporation of **partial canopy** in the logged plot

| Date | $T$ | $e_s(T_a)$ | $s$ | $\rho$ | $\lambda$ | $\gamma$ | $R_h$ | $e_a$ 1) | $D_{vp}$ 2) | $u$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | °C | Pa | Pa °C$^{-1}$ | kg m$^{-3}$ | J kg$^{-1}$ | Pa °C$^{-1}$ | % | Pa | Pa | m s$^{-1}$ |
| 02/12/94 | 24.9 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 88.90 | 2815.46 | 351.54 | 3.10 |
| 08/12/94 | 24.9 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 86.70 | 2745.79 | 421.21 | 3.00 |
| 20/12/94 | 24.5 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 92.80 | 2938.98 | 228.02 | 2.00 |
| 25/12/94 | 24.7 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 92.90 | 2942.14 | 224.86 | 1.60 |
| 30/12/94 | 23.8 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 94.10 | 2807.00 | 176.00 | 1.97 |
| 09/01/95 | 24.2 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 91.10 | 2717.51 | 265.49 | 0.10 |
| 11/01/95 | 23.1 | 2809 | 170 | 1.18 | 2438000 | 66.29 | 95.20 | 2674.17 | 134.83 | 0.10 |
| 16/01/95 | 25.4 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 82.70 | 2619.11 | 547.89 | 0.10 |
| 20/01/95 | 23.8 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 93.80 | 2798.05 | 184.95 | 0.10 |
| 23/01/95 | 23.9 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 86.10 | 2568.36 | 414.64 | 0.10 |
| 27/01/95 | 24.7 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 87.20 | 2761.62 | 405.38 | 0.10 |
| 01/02/95 | 24.9 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 88.20 | 2793.29 | 373.71 | 0.10 |
| 02/02/95 | 23.3 | 2809 | 170 | 1.18 | 2438000 | 66.29 | 95.40 | 2679.79 | 129.21 | 0.10 |
| 04/02/95 | 22.2 | 2643 | 162 | 1.19 | 2440000 | 66.26 | 97.40 | 2574.28 | 68.72 | 0.10 |
| 16/02/95 | 25.2 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 85.00 | 2691.95 | 475.05 | 0.10 |
| 19/02/95 | 24.9 | 2809 | 170 | 1.18 | 2438000 | 66.29 | 85.50 | 2401.70 | 407.31 | 0.10 |
| 23/02/95 | 24.8 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 86.80 | 2589.24 | 393.76 | 0.10 |
| 26/02/95 | 22.9 | 2809 | 170 | 1.18 | 2438000 | 66.29 | 93.80 | 2634.84 | 174.16 | 0.10 |
| 02/03/95 | 24.0 | 2809 | 170 | 1.18 | 2438000 | 66.29 | 90.70 | 2547.76 | 261.24 | 0.10 |
| 09/03/95 | 25.6 | 3361 | 199 | 1.17 | 2435000 | 66.38 | 85.70 | 2880.38 | 480.62 | 0.10 |
| 13/03/95 | 24.3 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 87.10 | 2598.19 | 384.81 | 0.10 |
| 14/03/95 | 22.8 | 2809 | 170 | 1.18 | 2438000 | 66.29 | 94.50 | 2654.51 | 154.50 | 0.10 |
| 16/03/95 | 24.1 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 85.00 | 2535.55 | 447.45 | 0.10 |
| 20/03/95 | 23.8 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 90.80 | 2708.56 | 274.44 | 0.10 |
| 23/03/95 | 23.0 | 2809 | 170 | 1.18 | 2438000 | 66.29 | 95.30 | 2676.98 | 132.02 | 0.10 |
| 27/03/95 | 24.1 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 92.10 | 2747.34 | 235.66 | 0.10 |
| 22/06/95 | 23.6 | 2983 | 179 | 1.18 | 2437000 | 66.32 | 92.90 | 2771.21 | 211.79 | 0.10 |
| 30/06/95 | 25.0 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 90.00 | 2850.30 | 316.70 | 0.10 |
| Mean | 24.16 | 3000.00 | 180.07 | 1.18 | 2436964 | 66.32 | 90.28 | 2704.43 | 295.57 | 0.50 |
| SD | 0.86 | 168.55 | 8.87 | 0.01 | 1035.74 | 0.03 | 4.01 | 127.15 | 129.18 | 0.91 |
| SE | 0.16 | 31.80 | 1.67 | 0.00 | 195.42 | 0.01 | 0.76 | 23.99 | 24.37 | 0.17 |

Note:

$T$, $R_h$ and $R_n$ were measured above the forest canopy (station 3, tower)

* $I$pc is the interception loss from the partial canopy area of the logged plot

1) $e_s(T_a) * R_h$

2) $e_s(T_a) - e_a$

3) $[I\ \lambda\ (s+\gamma) - s\ R\text{n}] / [\rho C_p \{e_s(T_a) - e_a\}]$

$C_p = 1010$ J kg$^{-1}$ °C$^{-1}$

4) $[s\ R_n] / [\lambda\ (s+\gamma)]$

5) $[\rho\ C_p\ D_{vp}\ g_a] / [\lambda\ (s+\gamma)]$

| $R_n$ | $I$ pc* | $g_a$[3] mc | $\lambda\ I$ | $I$ mc | Rad[4] | Adv[5] |
|---|---|---|---|---|---|---|
| $J\ m^{-2}\ s^{-1}$ | $mm\ s^{-1}$ | $m\ s^{-1}$ | $J\ m^{-2}\ s^{-1}$ | $mm\ h^{-1}$ | $mm\ h^{-1}$ | $mm\ h^{-1}$ |
| 156.3 | 0.00033 | 0.42 | 791.70 | 1.17 | 0.17 | 1.00 |
| 166.0 | 0.00005 | 0.00 | 129.11 | 0.19 | 0.18 | 0.01 |
| 120.9 | 0.00027 | 0.54 | 657.72 | 0.97 | 0.13 | 0.84 |
| 99.6 | 0.00017 | 0.33 | 414.12 | 0.61 | 0.11 | 0.50 |
| 68.7 | 0.00041 | 1.11 | 999.17 | 1.48 | 0.07 | 1.40 |
| 135.0 | 0.00028 | 0.45 | 682.36 | 1.01 | 0.15 | 0.86 |
| 119.7 | 0.00004 | 0.01 | 92.64 | 0.14 | 0.13 | 0.01 |
| 146.3 | 0.00020 | 0.15 | 487.20 | 0.72 | 0.16 | 0.56 |
| 124.8 | 0.00042 | 1.04 | 1023.54 | 1.51 | 0.13 | 1.38 |
| 128.9 | 0.00029 | 0.30 | 706.73 | 1.04 | 0.14 | 0.91 |
| 179.0 | 0.00028 | 0.29 | 682.08 | 1.01 | 0.20 | 0.81 |
| 161.6 | 0.00010 | 0.06 | 231.42 | 0.34 | 0.18 | 0.17 |
| 78.8 | 0.00017 | 0.55 | 414.46 | 0.61 | 0.08 | 0.53 |
| 52.2 | 0.00002 | 0.01 | 39.04 | 0.06 | 0.05 | 0.00 |
| 158.6 | 0.00013 | 0.09 | 316.68 | 0.47 | 0.17 | 0.29 |
| 171.9 | 0.00031 | 0.31 | 755.78 | 1.12 | 0.18 | 0.93 |
| 179.0 | 0.00010 | 0.06 | 243.70 | 0.36 | 0.19 | 0.17 |
| 126.9 | 0.00014 | 0.28 | 341.32 | 0.50 | 0.13 | 0.37 |
| 119.7 | 0.00013 | 0.18 | 316.94 | 0.47 | 0.13 | 0.34 |
| 157.5 | 0.00016 | 0.13 | 389.60 | 0.58 | 0.17 | 0.40 |
| 154.5 | 0.00010 | 0.07 | 243.70 | 0.36 | 0.17 | 0.19 |
| 94.1 | 0.00012 | 0.29 | 292.56 | 0.43 | 0.10 | 0.33 |
| 168.8 | 0.00006 | 0.01 | 146.22 | 0.22 | 0.18 | 0.03 |
| 123.8 | 0.00006 | 0.04 | 146.22 | 0.22 | 0.13 | 0.08 |
| 78.8 | 0.00019 | 0.61 | 463.22 | 0.68 | 0.08 | 0.60 |
| 153.5 | 0.00011 | 0.14 | 268.07 | 0.40 | 0.17 | 0.23 |
| 89.0 | 0.00015 | 0.29 | 365.55 | 0.54 | 0.10 | 0.44 |
| 109.0 | 0.00009 | 0.09 | 219.24 | 0.32 | 0.12 | 0.20 |
| 129.39 | 0.00017 | 0.28 | 423.57 | 0.63 | 0.14 | 0.49 |
| 35.39 | 0.00011 | 0.29 | 267.26 | 0.39 | 0.04 | 0.40 |
| 6.68 | 0.00002 | 0.05 | 50.43 | 0.07 | 0.01 | 0.07 |

**Table IV.4** The boundary layer conductance and the rate of evaporation of the **canopy gap** of the logged plot (data from Stations 2 and 3)

| Date | $T$ | $e_s(T_a)$ | $s$ | ρ | λ | γ | $R_h$ | $e_a$ [1)] | $D_{vp}$ [2)] |
|---|---|---|---|---|---|---|---|---|---|
| | °C | Pa | Pa °C$^{-1}$ | kg m$^{-3}$ | J kg$^{-1}$ | Pa °C$^{-1}$ | % | Pa | Pa |
| 28/06/94 | 24.8 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 94.3 | 2986 | 180.52 |
| 05/07/94 | 24.8 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 92.9 | 2942 | 224.86 |
| 07/07/94 | 25.5 | 3361 | 199 | 1.16 | 2435000 | 66.38 | 89.1 | 2995 | 366.35 |
| 25/12/94 | 25.6 | 3361 | 199 | 1.16 | 2435000 | 66.38 | 94.0 | 3159 | 201.66 |
| 05/01/95 | 24.3 | 2980 | 179 | 1.18 | 2437000 | 66.32 | 97.0 | 2891 | 89.40 |
| 11/01/95 | 24.7 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 95.2 | 3015 | 152.02 |
| 16/01/95 | 25.4 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 92.0 | 2914 | 253.36 |
| 17/01/95 | 25.5 | 3361 | 199 | 1.16 | 2435000 | 66.38 | 94.1 | 3163 | 198.30 |
| 23/01/95 | 24.9 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 94.3 | 2986 | 180.52 |
| 26/01/95 | 25.1 | 3170 | 189 | 1.17 | 2436000 | 66.35 | 90.7 | 2875 | 294.81 |
| 01/02/95 | 25.6 | 3361 | 199 | 1.16 | 2435000 | 66.38 | 93.5 | 3143 | 218.47 |
| 02/02/95 | 24.6 | 3170 | 189 | 1.17 | 2436000 | 66.35 | 96.0 | 3043 | 126.80 |
| 04/02/95 | 23.7 | 2809 | 170 | 1.18 | 2438000 | 66.29 | 94.0 | 2640 | 168.54 |
| 16/02/95 | 25.6 | 3361 | 199 | 1.17 | 2435000 | 66.38 | 93.5 | 3143 | 218.47 |
| 23/02/95 | 25.5 | 3361 | 199 | 1.16 | 2435000 | 66.38 | 92.0 | 3092 | 268.88 |
| 25/02/95 | 24.6 | 3170 | 189 | 1.17 | 2436000 | 66.35 | 96.4 | 3056 | 114.12 |
| 02/03/95 | 25.3 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 93.2 | 2952 | 215.36 |
| 13/03/95 | 25.2 | 3170 | 189 | 1.17 | 2436000 | 66.35 | 92.3 | 2926 | 244.09 |
| 14/03/95 | 24.2 | 2980 | 179 | 1.18 | 2437000 | 66.32 | 95.0 | 2831 | 149.00 |
| 20/03/95 | 24.8 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 94.2 | 2983 | 183.69 |
| 23/03/95 | 24.3 | 2980 | 179 | 1.18 | 2437000 | 66.32 | 96.4 | 2873 | 107.28 |
| 27/03/95 | 25.1 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 93.4 | 2958 | 209.02 |
| 15/04/95 | 24.4 | 2980 | 179 | 1.18 | 2437000 | 66.32 | 95.0 | 2831 | 149.00 |
| 19/05/95 | 25.8 | 3361 | 199 | 1.16 | 2435000 | 66.38 | 90.4 | 3038 | 322.66 |
| 31/05/95 | 25.0 | 3167 | 189 | 1.17 | 2436000 | 66.35 | 92.2 | 2920 | 247.03 |
| 03/06/95 | 25.6 | 3361 | 199 | 1.16 | 2435000 | 66.38 | 95.9 | 3223 | 137.80 |
| 14/06/95 | 24.2 | 2980 | 179 | 1.18 | 2437000 | 66.32 | 98.1 | 2923 | 56.62 |
| Mean | 24.97 | 3177.04 | 189.41 | 1.17 | 2435963 | 66.35 | 93.89 | 2981.53 | 195.50 |
| SD | 0.55 | 152.09 | 7.98 | 0.01 | 807.73 | 0.02 | 2.08 | 125.84 | 71.26 |
| SE | 0.11 | 29.82 | 1.57 | 0.00 | 158.38 | 0.00 | 0.41 | 24.68 | 13.97 |

Note:

$T$ and $R_h$ were measured in the canopy gap (2-m above the ground)

* $I$ cg is the interception loss from the canopy gap of logged plot

1) $e_s(T_a) * R_h$

2) $e_s(T_a) - e_a$

3) $R_n = 2.9 + 0.43\,Q$ ; $r^2 = 0.92$ , n = 233 ($R_n$ and $Q$ were measured above the forest canopy) $Q$'s for measuring $R_n$ were taken from Station 2 at the canopy gap of the logged plot

4) $P_g - T_f$ (Gross rainfall - Throughfall in the canopy gap)

5) $[I\,\lambda\,(s+\gamma) - s\,R\text{n}] / [\rho C_p \{e_s(T_a) - e_a\}]$

6) $[s\,R_n] / [\lambda\,(s+\gamma)]$

7) $[\rho\,C_p\,D_{vp}\,g_a] / [\lambda\,(s+\gamma)]$

| $u$ | $R_n$ [3] | $I$ [4] cg* | $g_a$ [5] | λ $I$ | Rad[6] | Adv.[7] |
|---|---|---|---|---|---|---|
| m s$^{-1}$ | J m$^{-2}$ s$^{-1}$ | mm s$^{-1}$ | m s$^{-1}$ | J m$^{-2}$ s$^{-1}$ | mm h$^{-1}$ | mm h$^{-1}$ |
| 0.20 | 48.65 | 0.00003 | 0.05 | 77.95 | 0.05 | 0.0000 |
| 0.10 | 56.61 | 0.00004 | 0.05 | 97.44 | 0.06 | 0.0000 |
| 0.20 | 90.45 | 0.00005 | 0.03 | 121.75 | 0.10 | 0.0000 |
| 0.20 | 41.21 | 0.00015 | 0.38 | 365.25 | 0.05 | 0.0001 |
| 0.15 | 38.22 | 0.00010 | 0.50 | 243.70 | 0.04 | 0.0001 |
| 0.20 | 58.62 | 0.00014 | 0.42 | 341.04 | 0.06 | 0.0001 |
| 0.20 | 46.68 | 0.00010 | 0.18 | 243.60 | 0.05 | 0.0001 |
| 0.20 | 49.17 | 0.00010 | 0.23 | 236.20 | 0.05 | 0.0001 |
| 0.20 | 47.68 | 0.00004 | 0.07 | 97.44 | 0.05 | 0.0000 |
| 0.20 | 62.60 | 0.00004 | 0.04 | 97.44 | 0.07 | 0.0000 |
| 0.20 | 67.08 | 0.00007 | 0.12 | 170.45 | 0.07 | 0.0000 |
| 0.10 | 30.26 | 0.00009 | 0.34 | 219.24 | 0.03 | 0.0001 |
| 0.20 | 27.78 | 0.00015 | 0.41 | 365.70 | 0.03 | 0.0001 |
| 0.20 | 67.08 | 0.00002 | 0.00 | 48.70 | 0.07 | 0.0000 |
| 0.20 | 68.57 | 0.00022 | 0.41 | 535.70 | 0.08 | 0.0002 |
| 0.13 | 33.25 | 0.00004 | 0.14 | 97.44 | 0.04 | 0.0000 |
| 0.10 | 49.66 | 0.00003 | 0.04 | 73.08 | 0.05 | 0.0000 |
| 0.20 | 74.04 | 0.00023 | 0.45 | 560.28 | 0.08 | 0.0002 |
| 0.10 | 37.23 | 0.00013 | 0.40 | 316.81 | 0.04 | 0.0001 |
| 0.20 | 62.10 | 0.00010 | 0.23 | 243.60 | 0.07 | 0.0001 |
| 0.10 | 35.24 | 0.00015 | 0.65 | 365.55 | 0.04 | 0.0001 |
| 0.20 | 79.02 | 0.00007 | 0.12 | 170.52 | 0.09 | 0.0000 |
| 0.10 | 38.22 | 0.00006 | 0.16 | 146.22 | 0.04 | 0.0000 |
| 0.20 | 107.87 | 0.00017 | 0.23 | 413.95 | 0.12 | 0.0001 |
| 0.20 | 92.95 | 0.00008 | 0.11 | 194.88 | 0.10 | 0.0001 |
| 0.14 | 55.14 | 0.00005 | 0.13 | 121.75 | 0.06 | 0.0000 |
| 0.10 | 29.76 | 0.00002 | 0.10 | 48.74 | 0.03 | 0.0000 |
| 0.17 | 55.37 | 0.00009 | 0.22 | 222.76 | 0.06 | 0.0001 |
| 0.04 | 20.73 | 0.00006 | 0.17 | 143.20 | 0.02 | 0.0001 |
| 0.01 | 4.07 | 0.00001 | 0.03 | 28.08 | 0.00 | 0.0000 |

**Table V.1** The observed and predicted interception loss using WATMOD in the unlogged plot

| Date | $P_g$ mm | $T_f$ obs. mm | $T_f$ pred.* mm | $S_f$ obs. mm | $S_f$ pred.* mm | $I$ obs. mm | $I$ pred.* mm |
|---|---|---|---|---|---|---|---|
| 10/02/94 | 10.84 | 7.68 | 8.51 | 0.09 | 0.00 | 3.07 | 2.33 |
| 12/02/94 | 18.81 | 17.35 | 16.87 | 0.18 | 0.00 | 1.28 | 1.94 |
| 14/02/94 | 28.93 | 22.95 | 22.86 | 0.23 | 0.00 | 5.76 | 6.07 |
| 15/02/94 | 23.37 | 19.69 | 21.20 | 0.27 | 0.01 | 3.41 | 2.16 |
| 17/02/94 | 17.97 | 12.35 | 13.93 | 0.09 | 0.00 | 5.53 | 4.04 |
| 19/02/94 | 9.69 | 9.40 | 8.19 | 0.09 | 0.00 | 0.20 | 1.50 |
| 05/03/94 | 35.09 | 29.74 | 33.14 | 0.29 | 0.02 | 5.06 | 1.93 |
| 07/03/94 | 20.93 | 19.32 | 18.61 | 0.26 | 0.00 | 1.35 | 2.32 |
| 08/03/94 | 45.98 | 41.68 | 41.43 | 0.64 | 0.01 | 3.66 | 4.54 |
| 22/03/94 | 28.29 | 23.33 | 25.09 | 0.97 | 0.00 | 3.99 | 3.19 |
| 24/03/94 | 55.89 | 8.85 | 7.46 | 1.41 | 0.00 | 1.62 | 1.91 |
| 25/03/94 | 16.32 | 10.43 | 12.69 | 0.28 | 0.00 | 5.61 | 3.62 |
| 27/03/94 | 12.83 | 10.28 | 10.05 | 0.06 | 0.00 | 2.49 | 2.78 |
| 28/03/94 | 25.38 | 21.63 | 23.48 | 0.28 | 0.00 | 3.47 | 1.90 |
| 29/03/94 | 8.69 | 6.08 | 4.86 | 0.04 | 0.00 | 2.57 | 3.83 |
| 06/04/94 | 21.44 | 17.46 | 17.82 | 0.18 | 0.00 | 3.80 | 3.62 |
| 10/04/94 | 15.70 | 13.93 | 13.77 | 0.11 | 0.00 | 1.66 | 1.95 |
| 11/04/94 | 65.81 | 63.40 | 63.12 | 0.77 | 0.04 | 1.64 | 2.65 |
| 14/04/94 | 135.75 | 126.94 | 129.25 | 1.87 | 0.06 | 6.94 | 6.45 |
| Mean | 31.46 | 25.39 | 25.91 | 0.43 | 0.01 | 3.32 | 3.09 |
| SD | 29.62 | 28.12 | 28.59 | 0.50 | 0.02 | 1.83 | 1.41 |
| SE | 6.81 | 6.46 | 6.57 | 0.12 | 0.00 | 0.42 | 0.32 |
| Total | 597.71 | 482.49 | 492.33 | 8.11 | 0.14 | 63.11 | 58.73 |
| % | | 80.72 | 82.37 | 1.36 | 0.02 | 10.56 | 9.83 |

* predicted as outlined in Section 5.5.2.

**Table V.2** The observed and predicted interception loss in the logged plot using WATMOD for no canopy cover divisions

| Date | $P_g$ mm | $T_f$ obs. mm | $T_f$ pred.* mm | $S_f$ obs. mm | $S_f$ pred.* mm | $I$ obs. mm | $I$ pred.* mm |
|---|---|---|---|---|---|---|---|
| 19/11/94 | 44.20 | 43.58 | 42.97 | 0.10 | 0.0014 | 0.52 | 1.23 |
| 01/12/94 | 32.53 | 31.31 | 29.78 | 0.12 | 0.0004 | 1.10 | 2.75 |
| 02/12/94 | 41.53 | 40.43 | 39.32 | 0.15 | 0.0020 | 0.95 | 2.21 |
| 04/12/94 | 30.90 | 30.26 | 29.43 | 0.09 | 0.0000 | 0.55 | 1.47 |
| 08/12/94 | 13.30 | 12.94 | 11.20 | 0.02 | 0.0000 | 0.34 | 1.46 |
| 19/12/94 | 7.60 | 7.32 | 6.39 | 0.02 | 0.0000 | 0.26 | 1.20 |
| 21/12/94 | 12.23 | 11.85 | 9.67 | 0.02 | 0.0000 | 0.36 | 1.57 |
| 23/12/94 | 18.83 | 17.78 | 15.12 | 0.03 | 0.0001 | 1.02 | 1.99 |
| 25/12/94 | 22.37 | 19.52 | 20.14 | 0.03 | 0.0002 | 2.82 | 2.23 |
| 27/12/94 | 118.47 | 113.17 | 113.75 | 0.39 | 0.0061 | 4.90 | 4.72 |
| 30/12/94 | 95.43 | 85.45 | 90.88 | 0.31 | 0.0057 | 9.67 | 4.55 |
| 05/01/95 | 96.33 | 90.80 | 91.80 | 0.28 | 0.0018 | 5.24 | 4.53 |
| 11/01/95 | 40.23 | 39.22 | 38.66 | 0.09 | 0.0005 | 0.92 | 1.57 |
| 16/01/95 | 13.80 | 10.94 | 9.28 | 0.01 | 0.0000 | 2.85 | 4.53 |
| 17/01/95 | 16.33 | 14.74 | 14.03 | 0.04 | 0.0002 | 1.55 | 2.30 |
| 19/01/95 | 13.57 | 13.17 | 12.20 | 0.03 | 0.0000 | 0.37 | 1.38 |
| 20/01/95 | 51.40 | 50.39 | 48.31 | 0.17 | 0.0025 | 0.84 | 3.09 |
| 21/01/95 | 16.60 | 16.28 | 15.22 | 0.04 | 0.0000 | 0.28 | 1.37 |
| 23/01/95 | 69.70 | 62.15 | 62.66 | 0.20 | 0.0023 | 7.35 | 7.04 |
| 26/01/95 | 29.77 | 27.66 | 26.97 | 0.03 | 0.0000 | 2.07 | 2.81 |
| 27/01/95 | 42.45 | 39.48 | 40.00 | 0.12 | 0.0021 | 2.85 | 2.44 |
| 28/01/95 | 13.70 | 12.41 | 10.94 | 0.02 | 0.0000 | 1.28 | 2.75 |
| 01/02/95 | 40.60 | 35.40 | 38.09 | 0.09 | 0.0023 | 5.11 | 2.51 |
| 02/02/95 | 12.63 | 10.37 | 10.36 | 0.01 | 0.0000 | 2.25 | 2.27 |
| 04/02/95 | 44.70 | 41.87 | 42.40 | 0.10 | 0.0018 | 2.72 | 2.30 |
| 07/02/95 | 28.85 | 26.69 | 26.84 | 0.06 | 0.0011 | 2.10 | 2.01 |
| 16/02/95 | 15.75 | 13.47 | 13.22 | 0.01 | 0.0000 | 2.27 | 2.53 |
| 17/02/95 | 50.63 | 48.93 | 48.23 | 0.13 | 0.0020 | 1.58 | 2.41 |
| 18/02/95 | 13.70 | 13.15 | 12.27 | 0.02 | 0.0000 | 0.53 | 1.43 |
| 19/02/95 | 21.25 | 18.44 | 19.78 | 0.04 | 0.0011 | 2.76 | 1.47 |
| 23/02/95 | 46.85 | 40.31 | 42.34 | 0.07 | 0.0000 | 6.48 | 4.51 |
| 25/02/95 | 28.25 | 26.91 | 25.82 | 0.07 | 0.0000 | 1.28 | 2.43 |
| 26/02/95 | 115.47 | 111.59 | 112.81 | 0.39 | 0.0077 | 3.49 | 2.66 |
| 09/03/95 | 40.55 | 37.48 | 37.43 | 0.06 | 0.0000 | 3.01 | 3.12 |
| 13/03/95 | 16.77 | 16.00 | 15.28 | 0.03 | 0.0003 | 0.74 | 1.49 |
| 14/03/95 | 44.30 | 41.57 | 41.32 | 0.13 | 0.0000 | 2.60 | 2.98 |
| 16/03/95 | 41.80 | 40.93 | 40.35 | 0.11 | 0.0004 | 0.75 | 1.46 |
| 20/03/95 | 19.75 | 15.30 | 16.04 | 0.02 | 0.0000 | 4.43 | 3.71 |
| 23/03/95 | 43.90 | 37.38 | 38.72 | 0.03 | 0.0012 | 6.49 | 5.18 |
| 24/03/95 | 50.45 | 44.12 | 43.62 | 0.17 | 0.0017 | 6.16 | 4.61 |
| 27/03/95 | 28.20 | 24.26 | 25.38 | 0.06 | 0.0000 | 3.89 | 2.82 |
| 28/03/95 | 18.23 | 17.80 | 16.80 | 0.05 | 0.0000 | 0.38 | 1.43 |
| 29/03/95 | 11.10 | 9.93 | 9.52 | 0.02 | 0.0000 | 1.15 | 1.58 |
| 03/04/95 | 30.27 | 28.12 | 27.59 | 0.09 | 0.0000 | 2.05 | 2.68 |
| 26/05/95 | 18.40 | 18.11 | 16.99 | 0.07 | 0.0007 | 0.22 | 1.41 |
| 31/05/95 | 64.23 | 61.22 | 60.71 | 0.25 | 0.0012 | 2.76 | 3.52 |
| 03/06/95 | 15.43 | 14.58 | 13.84 | 0.03 | 0.0003 | 0.82 | 1.59 |
| 22/06/95 | 46.37 | 43.96 | 43.66 | 0.17 | 0.0009 | 2.24 | 2.71 |
| 24/06/95 | 51.50 | 51.15 | 52.33 | 0.19 | 0.0021 | 0.16 | 1.53 |
| 30/06/95 | 7.37 | 6.46 | 5.60 | 0.00 | 0.0000 | 0.90 | 1.77 |
| Mean | 36.17 | 33.73 | 33.52 | 0.10 | 0.0010 | 2.35 | 2.59 |
| SD | 26.14 | 24.82 | 25.52 | 0.09 | 0.0016 | 2.16 | 1.26 |
| SE | 3.73 | 3.55 | 3.65 | 0.01 | 0.0002 | 0.31 | 0.18 |
| Total | 1808.57 | 1686.39 | 1676.06 | 4.78 | 0.0501 | 117.44 | 129.31 |
| Percentage (%) | | 93.24 | 92.67 | 0.26 | 0.00 | 6.49 | 7.15 |

* predicted as outlined in Section 5.5.2

# Appendix VI

**Table VI.1** The observed and predicted rainfall interception loss (mm) in the unlogged plot using the revised Gash model (1995)

| Date | Gross rainfall (mm) | Wetting-up phase (mm) [1] | Saturation phase (mm) [2] | Drying-up phase (mm) [3] | Evap. from the trunks (mm) [4] | $S_f$ pred. (mm) [5] | $T_f$ pred. (mm) | $I$ pred. (mm) [6] | $S_f$ obs. (mm) | $T_f$ obs. (mm) | $I$ obs. (mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 01/11/93 | 23.09 | 0.05 | 1.12 | 1.35 | 0.01 | 0.01 | 20.55 | 2.53 | 0.13 | 19.38 | 3.58 |
| 03/11/93 | 16.35 | 0.05 | 0.77 | 1.35 | 0.01 | 0.00 | 14.16 | 2.18 | 0.06 | 13.02 | 3.27 |
| 12/11/93 | 37.26 | 0.05 | 1.85 | 1.35 | 0.01 | 0.03 | 33.97 | 3.26 | 0.47 | 35.72 | 1.07 |
| 16/11/93 | 38.56 | 0.05 | 1.92 | 1.35 | 0.01 | 0.03 | 35.20 | 3.33 | 0.31 | 33.44 | 4.81 |
| 17/11/93 | 44.86 | 0.05 | 2.25 | 1.35 | 0.01 | 0.03 | 41.17 | 3.66 | 0.64 | 37.88 | 6.34 |
| 18/11/93 | 14.83 | 0.05 | 0.69 | 1.35 | 0.01 | 0.00 | 12.72 | 2.10 | 0.13 | 14.59 | 0.11 |
| 25/11/93 | 45.30 | 0.05 | 2.27 | 1.35 | 0.01 | 0.03 | 41.59 | 3.68 | 0.34 | 35.21 | 9.75 |
| 27/11/93 | 86.00 | 0.05 | 4.38 | 1.35 | 0.01 | 0.07 | 80.14 | 5.79 | 1.21 | 76.92 | 7.87 |
| 03/12/93 | 48.41 | 0.05 | 2.43 | 1.35 | 0.01 | 0.04 | 44.53 | 3.84 | 0.59 | 43.01 | 4.81 |
| 06/12/93 | 14.56 | 0.05 | 0.68 | 1.35 | 0.01 | 0.00 | 12.47 | 2.09 | 0.10 | 12.57 | 1.89 |
| 10/12/93 | 11.01 | 0.05 | 0.50 | 1.35 | 0.01 | 0.00 | 9.10 | 1.91 | 0.33 | 10.60 | 0.08 |
| 12/12/93 | 15.99 | 0.05 | 0.75 | 1.35 | 0.01 | 0.00 | 13.82 | 2.16 | 0.27 | 14.83 | 0.89 |
| 18/12/93 | 57.73 | 0.05 | 2.91 | 1.35 | 0.01 | 0.05 | 53.36 | 4.32 | 0.55 | 52.05 | 5.13 |
| 23/12/93 | 39.62 | 0.05 | 1.98 | 1.35 | 0.01 | 0.03 | 36.21 | 3.39 | 0.45 | 34.73 | 4.44 |
| 09/01/94 | 27.56 | 0.05 | 1.35 | 1.35 | 0.01 | 0.02 | 24.78 | 2.76 | 0.22 | 23.21 | 4.13 |
| 12/01/94 | 45.43 | 0.05 | 2.28 | 1.35 | 0.01 | 0.03 | 41.71 | 3.69 | 0.52 | 43.85 | 1.06 |
| 13/01/94 | 58.93 | 0.05 | 2.98 | 1.35 | 0.01 | 0.05 | 54.50 | 4.39 | 0.70 | 55.10 | 3.13 |
| 17/01/94 | 48.66 | 0.05 | 2.44 | 1.35 | 0.01 | 0.04 | 44.77 | 3.85 | 0.55 | 43.10 | 5.01 |
| 19/01/94 | 16.71 | 0.05 | 0.79 | 1.35 | 0.01 | 0.00 | 14.50 | 2.20 | 0.07 | 10.51 | 6.13 |
| 23/01/94 | 39.89 | 0.05 | 1.99 | 1.35 | 0.01 | 0.03 | 36.46 | 3.40 | 0.43 | 36.51 | 2.95 |
| 05/02/94 | 121.82 | 0.05 | 6.23 | 1.35 | 0.01 | 0.11 | 114.07 | 7.64 | 2.24 | 110.72 | 8.86 |
| 10/02/94 | 10.84 | 0.05 | 0.49 | 1.35 | 0.01 | 0.00 | 8.94 | 1.90 | 0.09 | 7.68 | 3.07 |
| 12/02/94 | 18.81 | 0.05 | 0.90 | 1.35 | 0.01 | 0.01 | 16.49 | 2.31 | 0.18 | 17.35 | 1.28 |
| 14/02/94 | 28.93 | 0.05 | 1.42 | 1.35 | 0.01 | 0.02 | 26.08 | 2.83 | 0.23 | 22.95 | 5.76 |
| 15/02/94 | 23.37 | 0.05 | 1.14 | 1.35 | 0.01 | 0.01 | 20.81 | 2.55 | 0.27 | 19.69 | 3.41 |
| 17/02/94 | 17.97 | 0.05 | 0.86 | 1.35 | 0.01 | 0.01 | 15.70 | 2.27 | 0.09 | 12.35 | 5.53 |
| 05/03/94 | 35.09 | 0.05 | 1.74 | 1.35 | 0.01 | 0.02 | 31.91 | 3.15 | 0.29 | 29.74 | 5.06 |
| 07/03/94 | 20.93 | 0.05 | 1.01 | 1.35 | 0.01 | 0.01 | 18.50 | 2.42 | 0.26 | 19.32 | 1.35 |
| 08/03/94 | 45.98 | 0.05 | 2.31 | 1.35 | 0.01 | 0.03 | 42.23 | 3.72 | 0.64 | 41.68 | 3.66 |
| 22/03/94 | 28.29 | 0.05 | 1.39 | 1.35 | 0.01 | 0.02 | 25.47 | 2.80 | 0.97 | 23.33 | 3.99 |
| 24/03/94 | 55.89 | 0.05 | 2.82 | 1.35 | 0.01 | 0.04 | 51.62 | 4.23 | 1.41 | 52.85 | 1.62 |
| 25/03/94 | 16.32 | 0.05 | 0.77 | 1.35 | 0.01 | 0.00 | 14.13 | 2.18 | 0.28 | 10.43 | 5.61 |
| 27/03/94 | 12.83 | 0.05 | 0.59 | 1.35 | 0.01 | 0.00 | 10.83 | 2.00 | 0.06 | 10.28 | 2.49 |
| 28/03/94 | 25.38 | 0.05 | 1.24 | 1.35 | 0.01 | 0.01 | 22.72 | 2.65 | 0.28 | 21.63 | 3.47 |
| 30/03/94 | 69.90 | 0.05 | 3.54 | 1.35 | 0.01 | 0.06 | 64.89 | 4.95 | 1.37 | 61.70 | 6.84 |
| 06/04/94 | 21.44 | 0.05 | 1.04 | 1.35 | 0.01 | 0.01 | 18.98 | 2.45 | 0.18 | 17.46 | 3.80 |
| 09/04/94 | 6.65 | 0.05 | 0.27 | 1.35 | 0.01 | 0.00 | 0.21 | 6.44 | 0.02 | 2.32 | 4.31 |
| 10/04/94 | 15.70 | 0.05 | 0.74 | 1.35 | 0.01 | 0.00 | 13.55 | 2.15 | 0.11 | 13.93 | 1.66 |
| 11/04/94 | 65.81 | 0.05 | 3.33 | 1.35 | 0.01 | 0.05 | 61.01 | 4.74 | 0.77 | 63.40 | 1.64 |
| 14/04/94 | 135.75 | 0.05 | 6.95 | 1.35 | 0.01 | 0.12 | 127.27 | 8.36 | 1.87 | 126.94 | 6.94 |
| Mean | 37.71 | 0.05 | 1.88 | 1.35 | 0.01 | 0.03 | 34.28 | 3.41 | 0.49 | 33.30 | 3.92 |
| SD | 28.21 | 0.00 | 1.46 | 0.00 | 0.00 | 0.03 | 26.87 | 1.52 | 0.50 | 26.60 | 2.32 |
| SE | 4.48 | 0.00 | 0.23 | 0.00 | 0.00 | 0.00 | 4.26 | 0.24 | 0.08 | 4.22 | 0.37 |
| Total | 1508.45 | 2.00 | 75.13 | 54.00 | 0.40 | 1.03 | 1371.1 | 136.29 | 19.68 | 1332.0 | 156.78 |
| Percentage (%) | | 1.47 | 55.12 | 39.62 | 0.29 | | | | | | |

For storms > rainfall required to saturate the canopy, $P'_g$:

[1] $I_w = c\,[P'_g - S_c]$

[2] $I_s = c\,(E_c/R\ [P_g - P'_g]$

[3] $I_a = c\,S_c$

[4] $I_t = S_t$

[5] $S_f = p_t\,(P_g - P''_g)$

[6] $I = I_w + I_s + I_a + I_t$

$I$ = interception loss; $I_w$ = interception loss at wetting-up phase; $I_s$ = interception loss at saturation phase

$I_a$ = interception loss at drying-up phase; $I_t$ = trunk interception loss

$P_g$ = gross rainfall; $S_f$ = stemflow; $T_f$ = throughfall; $P''_g$ = rainfall required to saturate the trunks

$S_c$ = canopy capacity per unit area of cover; $S_t$ = trunk storage capacity; $p_t$ = proportion of rain diverted onto the trunks

$c$ = proportion of covered area relative to the total area

**Table VI.2** The observed and predicted interception loss (mm) in the logged plot using the revised Gash model (1995) for no canopy cover divisions

| Date | Gross rainfall (mm) | Wetting-up phase (mm) [1)] | Saturation phase (mm) [2)] | Drying-up phase (mm) [3)] | Evap.from the trunks (mm) [4)] | $S_f$ pred. (mm) [5)] | $T_t$ pred. (mm) | $I$ pred. (mm) [6)] | $S_f$ obs. (mm) | $T_f$ obs. (mm) | $I$ obs. (mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 25/06/94 | 20.70 | 0.011 | 0.519 | 1.001 | 0.001 | 0.001 | 19.17 | 1.53 | 0.02 | 17.75 | 2.93 |
| 26/06/94 | 23.67 | 0.011 | 0.600 | 1.001 | 0.001 | 0.001 | 22.06 | 1.61 | 0.05 | 23.15 | 0.47 |
| 28/06/94 | 19.60 | 0.011 | 0.488 | 1.001 | 0.001 | 0.001 | 18.10 | 1.50 | 0.04 | 17.90 | 1.66 |
| 30/06/94 | 38.57 | 0.011 | 1.010 | 1.001 | 0.001 | 0.003 | 36.54 | 2.02 | 0.06 | 37.86 | 0.65 |
| 05/07/94 | 81.77 | 0.011 | 2.198 | 1.001 | 0.001 | 0.007 | 78.55 | 3.21 | 0.21 | 76.10 | 5.46 |
| 19/11/94 | 44.20 | 0.011 | 1.165 | 1.001 | 0.001 | 0.003 | 42.02 | 2.18 | 0.10 | 43.58 | 0.52 |
| 29/11/94 | 163.60 | 0.011 | 4.448 | 1.001 | 0.001 | 0.015 | 158.12 | 5.46 | 0.35 | 159.40 | 3.85 |
| 01/12/94 | 32.53 | 0.011 | 0.844 | 1.001 | 0.001 | 0.002 | 30.67 | 1.86 | 0.12 | 31.31 | 1.10 |
| 02/12/94 | 41.53 | 0.011 | 1.091 | 1.001 | 0.001 | 0.003 | 39.42 | 2.10 | 0.15 | 40.43 | 0.95 |
| 04/12/94 | 30.90 | 0.011 | 0.799 | 1.001 | 0.001 | 0.002 | 29.09 | 1.81 | 0.09 | 30.26 | 0.55 |
| 08/12/94 | 13.30 | 0.011 | 0.315 | 1.001 | 0.001 | 0.000 | 11.97 | 1.33 | 0.02 | 12.94 | 0.34 |
| 20/12/94 | 21.57 | 0.011 | 0.543 | 1.001 | 0.001 | 0.001 | 20.01 | 1.56 | 0.04 | 20.55 | 0.98 |
| 21/12/94 | 12.23 | 0.011 | 0.286 | 1.001 | 0.001 | 0.000 | 10.93 | 1.30 | 0.02 | 11.85 | 0.36 |
| 23/12/94 | 18.83 | 0.011 | 0.467 | 1.001 | 0.001 | 0.001 | 17.35 | 1.48 | 0.03 | 17.78 | 1.02 |
| 25/12/94 | 22.37 | 0.011 | 0.565 | 1.001 | 0.001 | 0.001 | 20.79 | 1.58 | 0.03 | 19.52 | 2.82 |
| 27/12/94 | 118.47 | 0.011 | 3.207 | 1.001 | 0.001 | 0.011 | 114.24 | 4.22 | 0.39 | 113.17 | 4.90 |
| 05/01/95 | 96.33 | 0.011 | 2.598 | 1.001 | 0.001 | 0.008 | 92.71 | 3.61 | 0.28 | 90.80 | 5.24 |
| 11/01/95 | 40.23 | 0.011 | 1.056 | 1.001 | 0.001 | 0.003 | 38.16 | 2.07 | 0.09 | 39.22 | 0.92 |
| 16/01/95 | 13.80 | 0.011 | 0.329 | 1.001 | 0.001 | 0.000 | 12.46 | 1.34 | 0.01 | 10.94 | 2.85 |
| 17/01/95 | 16.33 | 0.011 | 0.398 | 1.001 | 0.001 | 0.000 | 14.92 | 1.41 | 0.04 | 14.74 | 1.55 |
| 19/01/95 | 13.57 | 0.011 | 0.323 | 1.001 | 0.001 | 0.000 | 12.23 | 1.34 | 0.03 | 13.17 | 0.37 |
| 20/01/95 | 51.40 | 0.011 | 1.363 | 1.001 | 0.001 | 0.004 | 49.02 | 2.38 | 0.17 | 50.39 | 0.84 |
| 26/01/95 | 29.77 | 0.011 | 0.768 | 1.001 | 0.001 | 0.002 | 27.99 | 1.78 | 0.03 | 27.66 | 2.07 |
| 27/01/95 | 42.45 | 0.011 | 1.117 | 1.001 | 0.001 | 0.003 | 40.32 | 2.13 | 0.12 | 39.48 | 2.85 |
| 28/01/95 | 13.70 | 0.011 | 0.326 | 1.001 | 0.001 | 0.000 | 12.36 | 1.34 | 0.02 | 12.41 | 1.28 |
| 02/02/95 | 12.63 | 0.011 | 0.297 | 1.001 | 0.001 | 0.000 | 11.32 | 1.31 | 0.01 | 10.37 | 2.25 |
| 04/02/95 | 44.70 | 0.011 | 1.179 | 1.001 | 0.001 | 0.003 | 42.51 | 2.19 | 0.10 | 41.87 | 2.72 |
| 07/02/95 | 28.85 | 0.011 | 0.743 | 1.001 | 0.001 | 0.002 | 27.09 | 1.76 | 0.06 | 26.69 | 2.10 |
| 09/02/95 | 34.60 | 0.011 | 0.901 | 1.001 | 0.001 | 0.002 | 32.68 | 1.91 | 0.07 | 33.26 | 1.27 |
| 10/02/95 | 13.30 | 0.011 | 0.315 | 1.001 | 0.001 | 0.000 | 11.97 | 1.33 | 0.01 | 10.98 | 2.30 |
| 14/02/95 | 17.70 | 0.011 | 0.436 | 1.001 | 0.001 | 0.001 | 16.25 | 1.45 | 0.01 | 14.65 | 3.04 |
| 16/02/95 | 15.75 | 0.011 | 0.383 | 1.001 | 0.001 | 0.000 | 14.35 | 1.40 | 0.01 | 13.47 | 2.27 |
| 17/02/95 | 50.63 | 0.011 | 1.342 | 1.001 | 0.001 | 0.004 | 48.27 | 2.35 | 0.13 | 48.93 | 1.58 |
| 18/02/95 | 13.70 | 0.011 | 0.326 | 1.001 | 0.001 | 0.000 | 12.36 | 1.34 | 0.02 | 13.15 | 0.53 |
| 19/02/95 | 21.25 | 0.011 | 0.534 | 1.001 | 0.001 | 0.001 | 19.70 | 1.55 | 0.04 | 18.44 | 2.76 |
| 24/02/95 | 19.03 | 0.011 | 0.473 | 1.001 | 0.001 | 0.001 | 17.54 | 1.49 | 0.04 | 18.62 | 0.38 |
| 25/02/95 | 28.25 | 0.011 | 0.726 | 1.001 | 0.001 | 0.002 | 26.51 | 1.74 | 0.07 | 26.91 | 1.28 |
| 26/02/95 | 115.47 | 0.011 | 3.125 | 1.001 | 0.001 | 0.010 | 111.32 | 4.14 | 0.39 | 111.59 | 3.49 |
| 09/03/95 | 40.55 | 0.011 | 1.065 | 1.001 | 0.001 | 0.003 | 38.47 | 2.08 | 0.06 | 37.48 | 3.01 |
| 13/03/95 | 16.77 | 0.011 | 0.411 | 1.001 | 0.001 | 0.000 | 15.35 | 1.42 | 0.03 | 16.00 | 0.74 |
| 14/03/95 | 44.30 | 0.011 | 1.168 | 1.001 | 0.001 | 0.003 | 42.12 | 2.18 | 0.13 | 41.57 | 2.60 |
| 16/03/95 | 41.80 | 0.011 | 1.099 | 1.001 | 0.001 | 0.003 | 39.69 | 2.11 | 0.11 | 40.93 | 0.75 |
| 27/03/95 | 28.20 | 0.011 | 0.725 | 1.001 | 0.001 | 0.002 | 26.46 | 1.74 | 0.06 | 24.26 | 3.89 |
| 28/03/95 | 18.23 | 0.011 | 0.451 | 1.001 | 0.001 | 0.001 | 16.77 | 1.46 | 0.05 | 17.80 | 0.38 |
| 29/03/95 | 11.10 | 0.011 | 0.255 | 1.001 | 0.001 | 0.000 | 9.83 | 1.27 | 0.02 | 9.93 | 1.15 |
| 03/04/95 | 30.27 | 0.011 | 0.782 | 1.001 | 0.001 | 0.002 | 28.47 | 1.79 | 0.09 | 28.12 | 2.05 |
| 04/04/95 | 7.47 | 0.011 | 0.155 | 1.001 | 0.001 | 0.000 | 6.30 | 1.17 | 0.01 | 7.04 | 0.42 |
| 06/04/95 | 70.17 | 0.011 | 1.879 | 1.001 | 0.001 | 0.006 | 67.27 | 2.89 | 0.26 | 68.69 | 1.22 |
| 07/04/95 | 64.27 | 0.011 | 1.717 | 1.001 | 0.001 | 0.005 | 61.53 | 2.73 | 0.29 | 62.58 | 1.41 |
| 08/04/95 | 12.00 | 0.011 | 0.279 | 1.001 | 0.001 | 0.000 | 10.71 | 1.29 | 0.03 | 11.64 | 0.33 |
| 10/04/95 | 46.65 | 0.011 | 1.232 | 1.001 | 0.001 | 0.003 | 44.40 | 2.25 | 0.15 | 44.78 | 1.72 |
| 12/04/95 | 15.90 | 0.011 | 0.387 | 1.001 | 0.001 | 0.000 | 14.50 | 1.40 | 0.04 | 14.99 | 0.87 |
| 14/04/95 | 10.10 | 0.011 | 0.227 | 1.001 | 0.001 | 0.000 | 8.86 | 1.24 | 0.02 | 9.15 | 0.93 |
| 15/04/95 | 59.50 | 0.011 | 1.586 | 1.001 | 0.001 | 0.005 | 56.90 | 2.60 | 0.26 | 56.68 | 2.56 |
| 18/04/95 | 7.25 | 0.011 | 0.149 | 1.001 | 0.001 | 0.000 | 6.09 | 1.16 | 0.01 | 6.55 | 0.69 |
| 22/04/95 | 40.20 | 0.011 | 1.055 | 1.001 | 0.001 | 0.003 | 38.13 | 2.07 | 0.12 | 38.76 | 1.32 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 23/04/95 | 39.20 | 0.011 | 1.027 | 1.001 | 0.001 | 0.003 | 37.16 | 2.04 | 0.15 | 38.17 | 0.89 |
| 05/05/95 | 13.40 | 0.011 | 0.318 | 1.001 | 0.001 | 0.000 | 12.07 | 1.33 | 0.04 | 12.96 | 0.40 |
| 15/05/95 | 50.87 | 0.011 | 1.348 | 1.001 | 0.001 | 0.004 | 48.50 | 2.36 | 0.21 | 48.47 | 2.19 |
| 19/05/95 | 30.60 | 0.011 | 0.791 | 1.001 | 0.001 | 0.002 | 28.79 | 1.80 | 0.07 | 29.34 | 1.20 |
| 25/05/95 | 35.67 | 0.011 | 0.930 | 1.001 | 0.001 | 0.002 | 33.72 | 1.94 | 0.09 | 34.73 | 0.85 |
| 31/05/95 | 64.23 | 0.011 | 1.716 | 1.001 | 0.001 | 0.005 | 61.50 | 2.73 | 0.25 | 61.22 | 2.76 |
| 03/06/95 | 15.43 | 0.011 | 0.374 | 1.001 | 0.001 | 0.000 | 14.04 | 1.39 | 0.03 | 14.58 | 0.82 |
| 06/06/95 | 28.50 | 0.011 | 0.733 | 1.001 | 0.001 | 0.002 | 26.75 | 1.75 | 0.06 | 27.51 | 0.93 |
| 09/06/95 | 14.10 | 0.011 | 0.337 | 1.001 | 0.001 | 0.000 | 12.75 | 1.35 | 0.03 | 13.25 | 0.82 |
| 14/06/95 | 46.30 | 0.011 | 1.223 | 1.001 | 0.001 | 0.003 | 44.06 | 2.24 | 0.17 | 43.32 | 2.81 |
| 19/06/95 | 52.77 | 0.011 | 1.401 | 1.001 | 0.001 | 0.004 | 50.35 | 2.41 | 0.19 | 50.41 | 2.17 |
| 20/06/95 | 24.90 | 0.011 | 0.634 | 1.001 | 0.001 | 0.001 | 23.25 | 1.65 | 0.08 | 24.18 | 0.64 |
| 22/06/95 | 46.37 | 0.011 | 1.225 | 1.001 | 0.001 | 0.003 | 44.13 | 2.24 | 0.17 | 43.96 | 2.24 |
| 30/06/95 | 7.37 | 0.011 | 0.152 | 1.001 | 0.001 | 0.000 | 6.21 | 1.17 | 0.00 | 6.46 | 0.90 |
| Mean | 35.31 | 0.01 | 0.92 | 1.00 | 0.00 | 0.00 | 33.37 | 1.93 | 0.10 | 33.53 | 1.69 |
| SD | 28.11 | 0.00 | 0.77 | 0.00 | 0.00 | 0.00 | 27.33 | 0.77 | 0.10 | 27.29 | 1.21 |
| SE | 3.35 | 0.00 | 0.09 | 0.00 | 0.00 | 0.00 | 3.25 | 0.09 | 0.01 | 3.25 | 0.14 |
| Total | 2471.72 | 0.77 | 64.43 | 70.07 | 0.07 | 0.16 | 2336.22 | 135.34 | 6.71 | 2346.84 | 118.17 |
| % | | 0.57 | 47.61 | 51.77 | 0.05 | 0.12 | 1726.18 | 100.00 | 4.96 | 1734.03 | 87.32 |

For storms > rainfall required to saturate the canopy, $P'_g$:

1) $I_w = c\,[P'_g - S_c]$; $c = 0.55$, $S_c = 1.82$ mm, $P'_g = 1.84$ mm

2) $I_s = c\,(E_c/R\ [P_g - P_g']$; $E_c = 0.30$ mm h$^{-1}$, $R = 5.7$ mm h$^{-1}$

3) $I_a = c\,S_c$

4) $I_t = S_t$; $S_t = 0.001$ mm

5) $S_f = p_t\,(P_g - P''_g)$; $p_t = 0.0001$, $P''_g = 12.12$ mm

6) $I = I_w + I_s + I_a + I_t$

$I$ = interception loss; $I_w$ = interception loss at wetting-up phase; $I_s$ = interception loss at saturation phase

$I_a$ = interception loss at drying-up phase; $I_t$ = trunk interception loss

$P_g$ = gross rainfall; $S_f$ = stemflow; $T_f$ = throughfall; $P''_g$ = rainfall required to saturate the trunks

$S_c$ = canopy capacity per unit area of cover; $S_t$ = trunk storage capacity; $p_t$ = proportion of rain diverted onto the trunks

$c$ = proportion of covered area relative to the total area

## Appendix VII

**Table VII.1** Calibration values of tipping bucket gauges used in this experiment

| No. of gauges | 0.2 mm tipping bucket (mm) | 1 $dm^3$ tipping bucket (ml) | |
|---|---|---|---|
| 1 | 0.19 | 787 [1)] | 924 [2)] |
| 2 | 0.19 | 892 | 987 |
| 3 | 0.20 | 784 | 921 |
| 4 | 0.19 | 800 | 866 |
| 5 | 0.20 | 855 | 1053 |
| 6 | 0.20 | 763 | 862 |
| 7 | 0.20 | 850 | 983 |
| 8 | 0.19 | 990 | 943 |
| 9 | 0.19 | 855 | 959 |
| 10 | 0.20 | 900 | 909 |

[1)] Calibrated values after being used in the unlogged plot
[2)] Calibrated values after being used in the logged plot

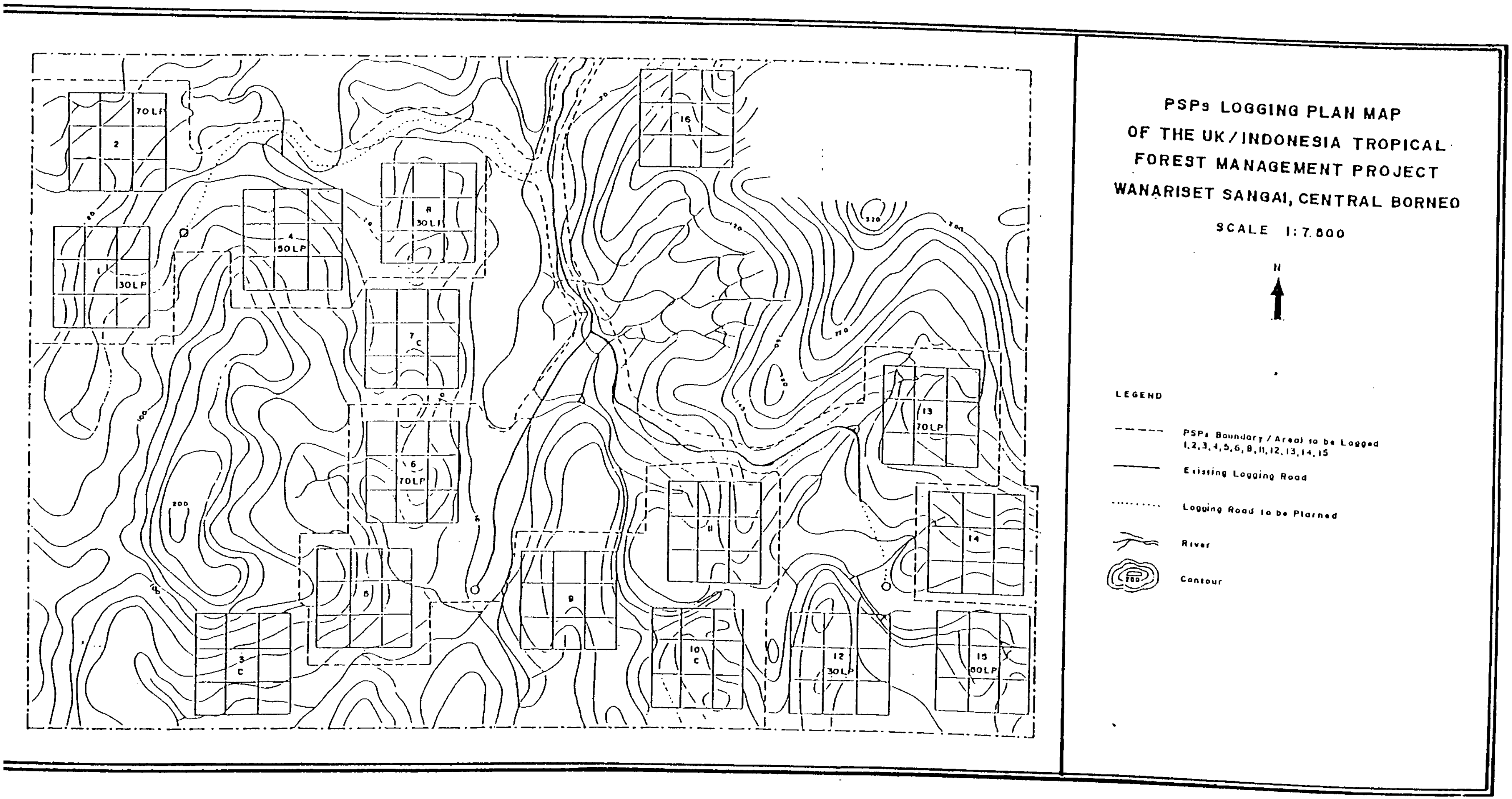


**Figure 1.1b** Contour map showing the unlogged plot (Permanent Sample Plot No. 9)