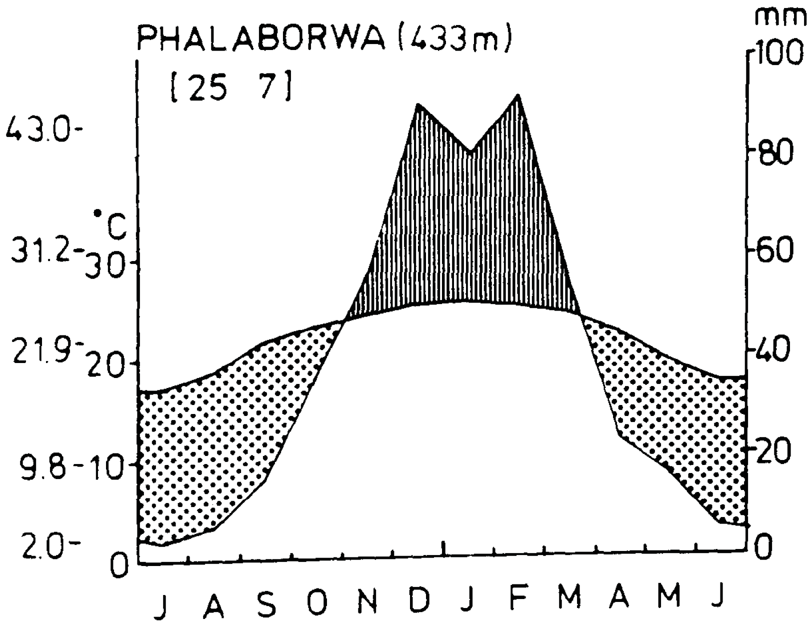


Figure 9. Climate diagram for Phalaborwa: Follows the conventions of Walter (1975). The stippled areas represent periods of water deficiency and the striped areas water sufficiency.

The regional rainfall isohyets reveal a trend towards lower rainfall in the north-east. In the context of the Klaserie Private Nature Reserve, this translates into a mean annual precipitation in the south-west of 500 to 550 mm, and 450 to 500 mm in the north-east. As is characteristic of semi-arid savanna regions, the annual precipitation is highly variable in both time and space. There is some evidence to suggest that the temporal variation is periodic (Tyson & Dyer 1975 , Gertenbach 1980). The mid- and late-1970s were characterised by above average rainfalls in the region, while the project coincided with a period of exceptionally low rainfall. A diagram showing monthly rainfall and mean monthly temperature over the course of the project appears as Figure 10 on page 49.

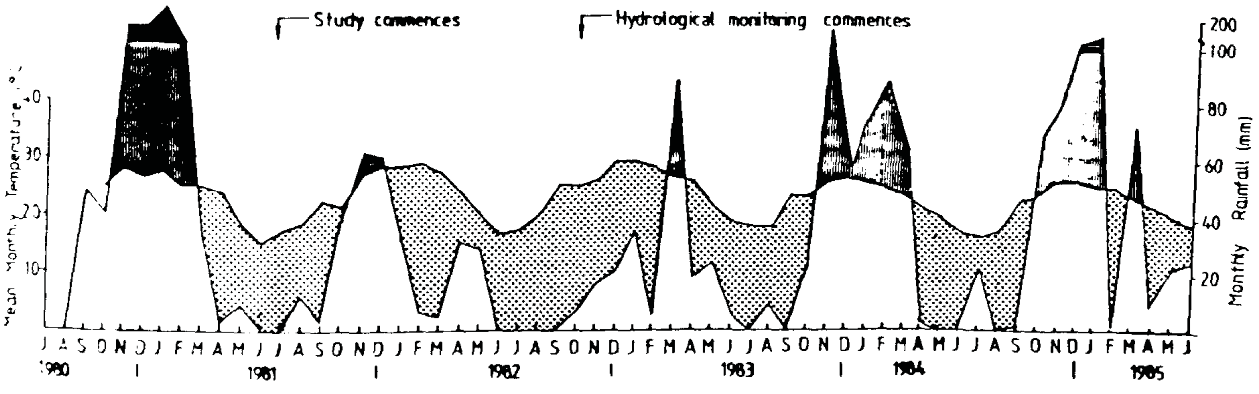


Figure 10. Monthly rainfall and mean monthly temperature recorded at Klaserie P.N.R.: Diagram follows the conventions of Walter (1975)

### 2.1.3 GEOLOGY, GEOMORPHOLOGY AND SOILS

The parent materials throughout the reserve are predominantly Archaean granites and gneisses (Cleverley & Bristow 1979). Considerable local variation of the mineral composition occurs, which influences the topography and soils, and therefore the vegetation. The southern area is gently undulating to flat, with frequent narrow doleritic intrusions. The characteristic catenary sequence that develops on granite-derived soils in the Lowveld, as described by Coetzee (1983) and Gertenbach (1983) is conspicuous here (Figure 12 on page 51), but the conditions for the formation of hydromorphic grasslands within the catena (known as seeplines) are seldom met (Olbrich 1984). Marginally hydromorphic soils are widespread, but of limited extent. A tendency towards sodicity and duplex soils in the bottomlands (for a description of this phenomenon see Dye & Walker (1980)) is also widespread. The soils of the uplands tend to be coarse sand and stony with orthic A horizons and yellow-brown

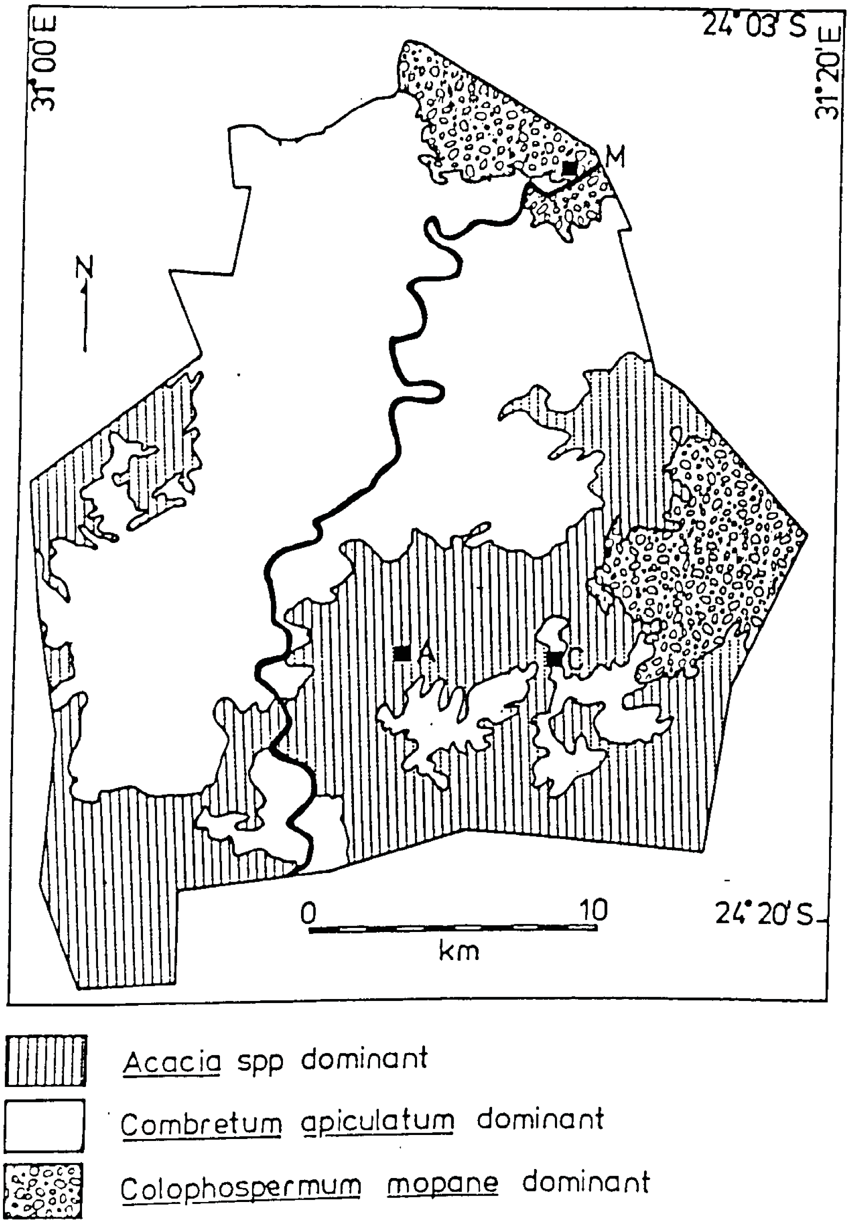


Figure 11. Simplified map of the vegetation of Klaserie P.N.R.: location of the study plots is indicated.

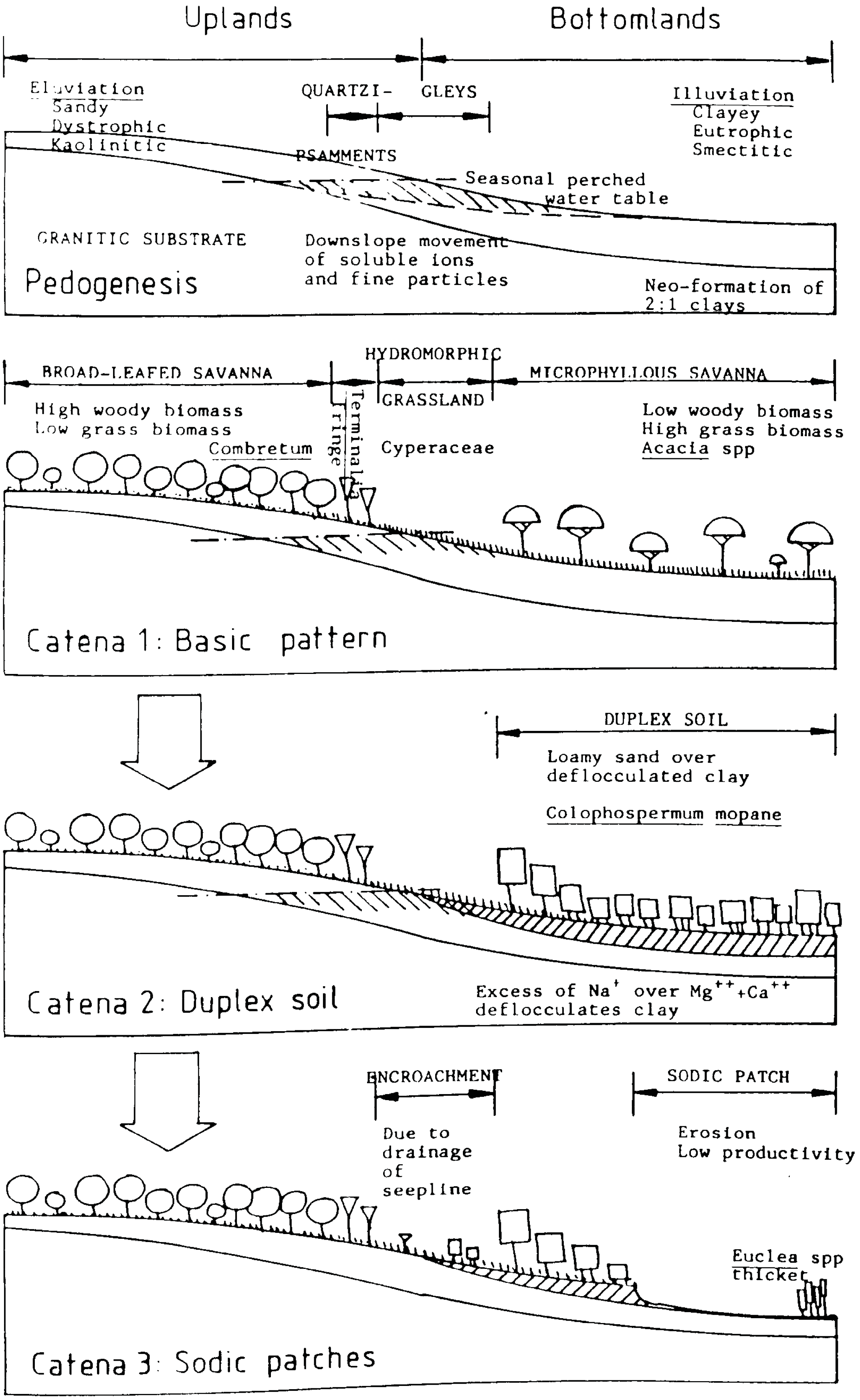


Figure 12. Catena development on granites in the lowveld

apedal B horizons, i.e. Clovelly or Hutton forms or, where shallower, Glenrosa (MacVicar *et al* 1977). The footslopes and bottomlands have more clayey soils, and thus more structure. Valsrivier form is typical, but on or near doleritic intrusions a melanic A horizon (such as Mayo form) is common.

The northern portion is steeply hilly with amphibolite, quartzite and quartz-schist predominating. The soils tend to be very shallow and therefore less differentiated than in the south. Glenrosa form is typical. On level areas Valsrivier form (Zuiderzee series) can be found. These soils do not fit into the catenary sequence outlined above, and the presence of water-rounded pebbles within the profile further suggests an independent ontogeny. Alluvial soils of the Dundee and Oakleaf forms occur near the major rivers.

### 2.1.4 CATENAS ON GRANITE IN SEMI-ARID REGIONS

The soil and vegetation associations in Klaserie mostly follow a distinctive topographical sequence which is widespread in the Eastern Transvaal lowveld and other areas of semi-arid Africa. The pattern can be explained in terms of the catena concept of Milne (1935), and is illustrated in Figure 12 on page 51.

The eluviation of fine particles and soluble salts from the soil profile not only results in the increasing clay content and base saturation with depth that is characteristic of many soils, but is also responsible for a similar pattern at a landscape level. Ridgetop soils tend to be shallow, sandy and dystrophic, while bottomland soils tend to be deeper, clayey and eutrophic. The dominant clay minerology of the uplands is kaolinitic, with a Silicon : Aluminium ratio of 1:1. The Si : Al ratio in the soil solution of the bottomlands is higher due to the Si which leaches down from the uplands, and 2:1 clays (smectites and illites) develop by neoformation. Where doleritic dykes are present, smectites can also be the primary clay minerals formed. The 2:1 clays have a much higher surface charge density than the 1:1 clays, and their high capacity to retain cations contributes to the high nutrient status of the bottomlands relative to the uplands.

The soils of the uplands and bottomlands are both alfisols (soils with a marked increase in clay content with depth in the profile). In a particularly well developed catena the bottomlands may contain sufficient 2:1 clays to qualify as vertisols. Following sodification the bottomland soils are natrustalfs (alfisols, strongly duplex and dominated by sodium).

The water holding capacity of the coarse uplands soils is much lower than that of the finer bottomland soils, and their hydraulic conductivity is much higher. The granite which underlies the soil at a depth of 500-1500 mm is poorly permeable to water. Thus when the profile water content exceeds the water holding capacity in the upland soils, the excess water drains downhill along the soil-granite interface. When it encounters the low permeability clays in the bottomland, a seasonal perched water table is formed. (The main water table is tens of meters deeper.) If sufficient water is present it appears at the soil surface as a seepline. The width of the seepline is a function of the available water, which is in turn determined by the length of the upslope catchment and the annual rainfall (Olbrich 1984).

This type of catena appears to form under a semi-arid seasonal climate on a gently undulating topography. Classically it is underlain by granites or gneisses, but a very similar sequence has been described on Karoo sediments by Purves & Blyth (1969). The Combretum and Acacia sites in the present study are representative of upland and bottomland catenal positions respectively (Table 2.1 & 2.2, Figure 14 on page 63). Comparable catenas have been described by Berry & Ruxton (1959), Calton (1963) in Tanzania and Watson (1964) in Zimbabwe.

The fidelity of the soil-vegetation complexes and the abruptness of the transitions between them makes the catenal pattern very obvious in the field. The uplands support a broad-leafed savanna dominated in Klaserie by *Combretum apiculatum*, while the bottomlands support a microphyllous savanna dominated by *Acacia nigrescens*. This pattern parallels, at a local scale, the moist/dystrophic (upland) *versus* arid/eutrophic (bottomland) categories of Huntley (1982).

The seepline, where present, supports a treeless hydromorphic grassland rich in sedges. Above its upslope edge is a fringe of *Terminalia sericea* and *Dalbergia melanoxylon*. *T. sericea* is a shallow-rooted tree apparently able to tolerate occassional waterlogging in the subsoil. *T. sericea* is widely distributed on sandy soils, and is not an infallible indicator of seeplines.

Ions leach down the catena in order of their solubility. The granite parent material is a good source of sodium, and in time the monovalent $Na^+$ comes to predominate over the polyvalent ions such as $Ca^{++}$ and $Mg^{++}$ in the bottomland soil solution. When a certain critical threshold is exceeded (Bresler, McNeal & Carter 1982) the clay particles in the soil deflocculate, which causes the soil to become much less permeable to water and roots. The soil is said to be sodic and this process is probably responsible for the abruptness of the vegetation boundaries on the catena. The vegetation of sodic soils is described by Dye & Walker (1980). In Klaserie they characteristically support *Colophospermum mopane* or *Euclea* spp. thicket. The soil usually has a duplex structure, with loamy sands overlying the deflocculated clays. In this condition they are fairly productive, but highly prone to erosion. Game tends to concentrate on these soils, possibly attracted by the high sodium content of the vegetation or the frequent presence of wallows. Exposure of the soil by overgrazing or tracks leads to the rapid loss of the A horison by erosion. The exposed deflocculated clays form a hostile substrate for most grasses and grass production declines drastically. Once such sodic or "saline" patches have formed it is very difficult to return them to a productive state (Dye & Stead 1978).

### 2.1.5 VEGETATION

The vegetation of the Klaserie has been described by Witkowski (1983) and mapped by Zambatis (1983). It is included in Acocks's (1953) broad category of Arid Lowveld. Under the system of landscape units developed for the Kruger National Park by Coetzee (1983) and Gertenbach (1983), the vegetation/soil complexes found in the Klaserie are mixed *Combretum/Terminalia* Woodland in the south with Olifants River Rugged Veld in the north and *Combretum/Colophospermum* Woodland in the east. The classifications of Witkowski and Zambatis are based on the plant associations alone. Although they differ slightly from each other in detail, the broad classification and distribution of vegetation types is similar. A simplified version of the Zambatis map is given in Figure 11 on page 50.

Sandy upland soils in the south of the reserve are dominated in the woody layer by *Combretum apiculatum*, in association with *Sclerocarya birrea* and *Lannea schweinfurthii*. The dominant trees are deciduous, broadleafed and non-spinescent. The herbaceous layer is variable, but usually includes *Schmidtia pappophoroides*, *Pogonarthria squarrosa*, *Aristida congesta*, *Digitaria eriantha*
and a large proportion of forbs.

Bottomlands in the same region have *Acacia nigrescens* as the woody dominant, in association with *Sclerocarya birrea*, *Albizia harveyi* and *Ormocarpum trichocarpum*. The trees are generally deciduous with microphyllous compound leaves and thorns. The major grasses are *Panicum coloratum*, *Sporobolus nitens*, *Bothriochloa radicans* and *Urochloa mosambicensis*.

A narrow seepline (5 m) is occasionally present between the uplands and bottomlands, but usually it is represented only by a few scattered *Terminalia sericea* and an increased proportion of sedges in the herbaceous layer.

The vegetation pattern is less obvious on the rocky, shallow soils of the hills of the northern portions of Klaserie which support *Combretum apiculatum* with *Sclerocarya birrea*, *Commiphora mollis*, *Acacia nigrescens*, *Boscia albitrunca* and *Terminalia prunioides*. The herbaceous layer is sparse, but is otherwise similar to that of the southern *Combretum* types.

In the north-east of the reserve *Colophospermum mopane* is overwhelmingly dominant in the tree layer on red sandy clay loam soils. The herbaceous layer has *Digitaria eriantha* and *Panicum maximum* under the canopies and *Schmidtia pappophoroides* in the open. Where *C. mopane* is extensive within the reserve it has a stunted, multi-stemmed growth form, but only locally (in the south) is it associated with a hardpan layer in the soil as is common elsewhere in Southern Africa (Cole, 1982). On better watered sites such as river banks the growth form is single-stemmed and tall.

*Grewia* spp. and *Cissus cornifolia* are the most prevalent shrubs throughout the reserve.

Various other vegetation types such as Riverine Woodland, Alluvial Savanna, Reedbeds, Old Lands and Riparian Thicket make a small contribution to the vegetation of the reserve.

*Combretum apiculatum* Woodland, *Colophospermum mopane* Woodland and *Acacia nigrescens* Woodland were selected as being not only representative of the vegetation of the Klaserie, but also of the continuum which exists between dystrophic savannas on sandy soils and eutrophic savannas on clayey soils. An experimental site was established in each of these types and will be refered to as the Combretum Site, the Mopane Site and the Acacia Site.

### 2.1.6 BUSH ENCROACHMENT IN KLASERIE PRIVATE NATURE RESERVE

A comparison of aerial photographs taken of the whole of Klaserie in 1940 and 1974 revealed very few areas which could unequivocally be identified as having undergone bush encroachment during this period. A ground check of these areas revealed them to be marginally hydromorphic alluvia, and the main encroaching species to be *A. nigrescens.* No bottomland areas as typified by the Acacia site had become discernibly encroached, and the population age structure there is thought to reflect good seedling establishment by *A. nigrescens* but a strong selection for middle-sized (accessible) individuals by browsers. Given a reduction in browsing, the potential exists for encroachment by this species.

Stem diameter distributions per species were recorded at the three main experimental study sites. The stem diameter distributions are illustrated in Figure 13 on page 58. A species which is actively encroaching would be expected to have a size class distribution heavily weighted towards small individuals. This is the case for *Acacia nigrescens* at the Acacia site and *Sclerocarya birrea* at the Combretum site, but in both cases the rest of the population was fairly mature and the distribution probably reflects sporadic germination success and high seedling mortality.

The size structure for *Colophospermum mopane* is fairly even but this species also has a coppice growth form, so the diameter of the above-ground stems may bear little relationship to the age of the ligno-tuber. If encroachment by *C.Mopane* has occurred it is unlikely to have been a recent event, since there is no trace of pre-existing woody vegetation in the almost monodominant *C. mopane stands.* These stands appear identical on the 1940 and 1974 images.

The stem diameter structure of *Grewia bicolor* shows a weighting towards middle-sized individuals which may reveal encroachment during some period in the past. Interpretation of the stem size-distribution is complicated by the multi-stemmed growth habit of this species. The *Grewia* bush is below the threshold of resolution of large-scale aerial photography and so encroachment by this species is unconfirmed.

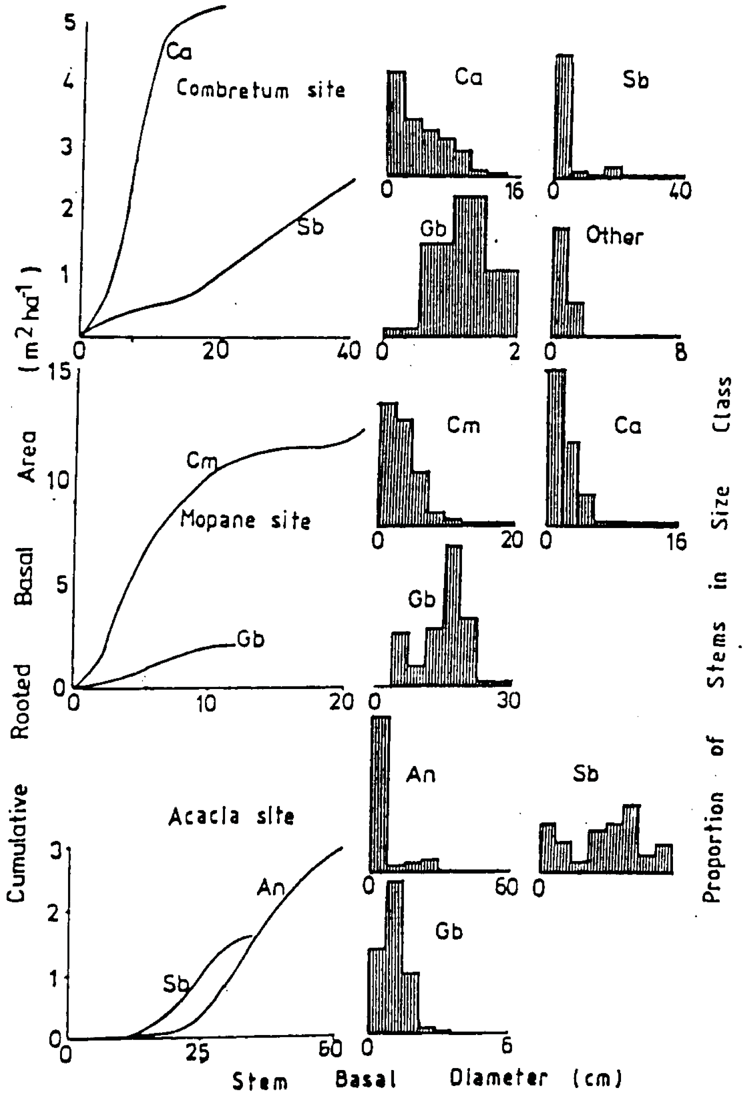


Figure 13. Stem diameter distributions for dominant woody plants: graphs on the left show the cumulative basal area of stems with a diameter smaller than the value on the x-axis. The approximate contribution to the total biomass by any size class can be read off them. Histograms on the right are the proportions of stems in each size class. These are an approximate indication of the age structure of the populations. *Ca-Combretum apiculatum, Sb-Sclerocarya birrea, Gb-Grewia bicolor, Cm-Colophospermum mopane and An-Acacia nigrescens.*

The presentation in Figure 13 of cumulative basal area of stems below a given diameter gives an indication of the contribution of each size class to the total woody basal area and, by implication, to the total woody biomass. The stem size threshold relating to a desired percentage of woody plant removal can be directly interpolated from these graphs.

## 2.2 THE EXPERIMENTAL SITES

### 2.2.1 SITE LAYOUT

The experiment was designed to determine the consequences of bush clearing on the hydrology, primary production and herbaceous species composition of the system. Each of the three study sites therefore consisted of a manipulation plot one hectare in extent in which all woody vegetation was removed, and an adjacent one hectare unmodified control plot. Replication of study sites within soil types was not feasible. The sites were selected with the aid of aerial photographs and ground surveys to satisfy the following criteria.

1. Representative of the species composition and density of one of the three major vegetation types identified above.
2. Soil hydrological characteristics distinct from the other two sites, so that in conjunction the sites should represent as broad a sample as possible of the range of savanna soil conditions.
3. Slope of 2 - 4%.
4. Relatively well developed soil without excessive stoniness.
5. Internally homogeneous as far as possible with respect to soil and vegetation.

6. Not excessively disturbed by proximity to water points.

The layout of the experimental plots at each site was identical in concept, although the positioning of the instruments varied slightly. The layout of the Acacia site was typical, and is illustrated in Figure 15 on page 64.

## 2.2.2 A COMMENT ON PSEUDOREPLICATION

Hurlbert (1984) criticises the design of many ecological studies on the basis that inferential statistical tests are applied to designs in which the replicates are not statistically independent, usually because they are clumped together in one plot rather than interspersed between the replicates of other treatments. The criticism is well founded, and applies to aspects of this study. The ecosystem-level researcher, however, is faced with a difficult choice. Should he concentrate his limited number of plots at one site, thereby strengthening the statistical inference but sacrificing generality, or should he spread the plots over the range of sites and abandon statistical tests?

This study has chosen to spread the plots; therefore all tests between the (unreplicated) treatment plots at a given site are, strictly speaking, invalid. However, it is still necessary to know the degree of error associated with sampling. Therefore replicate samples were taken in each plot. The magnitude of this error can only be assessed relative to the size of the treatment difference. The paired t-test (or similar) is a familiar and instructive vehicle for this comparison. The between-treatment tests should be interpreted in this light.

### 2.2.3 SOILS OF THE EXPERIMENTAL SITES

The soil hydrological characteristics were the dominant factor in the selection of the sites and are detailed in chapter 3. Table 2.1 and 2.2 describe the physical and chemical characteristics of the three soils prior to the experiment. The profiles are illustrated in Figure 14 on page 63. Although the Mopane site is intermediate between the Combretum and Acacia sites with regard to clay content, it is not necessarily intermediate on the eutrophy-dystrophy continuum. The first two sites represent elements of the same catenary sequence (but not the same catena), while the Mopane soils have a different pedogenic history.

Soil analyses were according to standard procedures (Black 1965, FSSA 1980). Cations were extracted in 1 N Ammonium bicarbonate at pH 7. Conductivity was determined in a saturated paste extract and texture by the hydrometer method. The values in Tables 2.1 & 2.2 are the means of two representative samples from separate pits (one located beneath a tree canopy and one in the open) in each treatment plot, thus four samples per horizon per site. Variation of the chemical properties within and between plots was high, which is a reflection of both the variability of nutrient availability typical of arid savannas and of the poor resolution of the analysis techniques.

### 2.2.4 VEGETATION OF THE EXPERIMENTAL SITES

The rooted basal area of the herbaceous layer in each treatment was scored by the systematic placement of 2000 points per plot (10 lines of 200) using a Bruce-Levy bridge with 10 points of 1.5 mm diameter and point separation of 150 mm. The points were scored for contact with live plant material at ground level, plant litter and soil capping. The results are presented in Table 2.3. A significant pre-treatment difference ($p<0.05$) between total grass basal area of the control and manipulation plot at the Acacia site was detected by a Wilcoxon rank-sum test and is

Table 2.1 Physical properties of the soil at each study site before clearing. Each value is the mean of four samples.

| Site & Horizon | | Depth<br>cm | Bulk Density<br>kg.m$^{3}$ | Stoniness (%>2mm)<br>% | Particle size distribution<br>Sand<br>% | Silt<br>% | Clay<br>% |
|---|---|---|---|---|---|---|---|
| Combretum | A | 0-20 | 1.66 | 32 | 83 | 9 | 8 |
| | B1 | 20-40 | | 75 | 80 | 9 | 11 |
| | B2 | 40-70 | | 75 | 81 | 9 | 10 |
| Mopane | A | 0-25 | 1.79 | 12 | 79 | 4 | 17 |
| | B1 | 25-40 | | 62 | 74 | 3 | 23 |
| | B2 | 40-80 | | 56 | 68 | 6 | 26 |
| Acacia | A | 0-30 | 1.87 | 13 | 64 | 11 | 25 |
| | B1 | 30-50 | | 58 | 63 | 9 | 28 |
| | B2 | 50-90 | | 68 | 61 | 8 | 31 |

Table 2.2 Chemical properties of the soil at each study site before clearing. Each value is the mean of four samples.

| Site & Horizon | | Depth<br>cm | pH 1M KCl | Nitrogen Total<br>mg.kg$^{-1}$ | Avail NO<br>mg.kg$^{-1}$ | NH<br>mg.kg$^{-1}$ | P Bray 1<br>mg.kg$^{-1}$ | K<br>cmol(+).kg$^{-1}$ | Major cations Na<br>cmol(+).kg$^{-1}$ | Mg<br>cmol(+).kg$^{-1}$ | Ca<br>cmol(+).kg$^{-1}$ | EC<br>mS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Combretum | A | 0-20 | 7.7 | 332 | 4 | 15 | 13 | 0.49 | 0.60 | 1.40 | 3.34 | 686 |
| | B1 | 20-40 | 4.9 | 350 | 8 | 11 | 9 | 0.45 | 0.85 | 1.85 | 3.41 | 585 |
| | B2 | 40-80 | 4.7 | 387 | 0 | 9 | 6 | 0.47 | 0.83 | 2.14 | 3.90 | 629 |
| Mopane | A | 0-25 | 5.5 | 1070 | 0 | 12 | 15 | 0.78 | 0.09 | 2.12 | 9.09 | 326 |
| | B1 | 25-40 | 5.7 | 730 | 0 | 18 | 5 | 0.36 | 0.07 | 2.91 | 12.58 | 298 |
| | B2 | 40-80 | 5.8 | 730 | 25 | 22 | 15 | 0.35 | 0.14 | 3.35 | 23.34 | 300 |
| Acacia | A | 0-30 | 5.5 | 571 | 2 | 23 | 2 | 0.84 | 0.24 | 3.75 | 10.01 | 618 |
| | B1 | 30-50 | 5.4 | 534 | 0 | 22 | 3 | 0.56 | 0.20 | 4.77 | 10.63 | 558 |
| | B2 | 50-80 | 5.9 | 368 | 0 | 17 | 6 | 0.68 | 0.23 | 6.27 | 14.21 | 599 |

Combretum site

Series Glenrosa
Form Glenrosa

A$_1$ 0-250 Orthic, brown 7.5YR 4/4 (moist) coarse loamy sand; loose; apedal; many medium and coarse angular quartz fragments; gradual transition.

B$_{21}$ 250-700 Lithocutanic; bright brown 7.5YR (moist) coarse loamy sand; loose; many medium and coarse quartz fragments; gradual transition.

700-900 Bright brown 7.5YR 5/6 (moist) coarse sand; loose; apedal.

R 900+ Weathered gneiss.

Acacia site

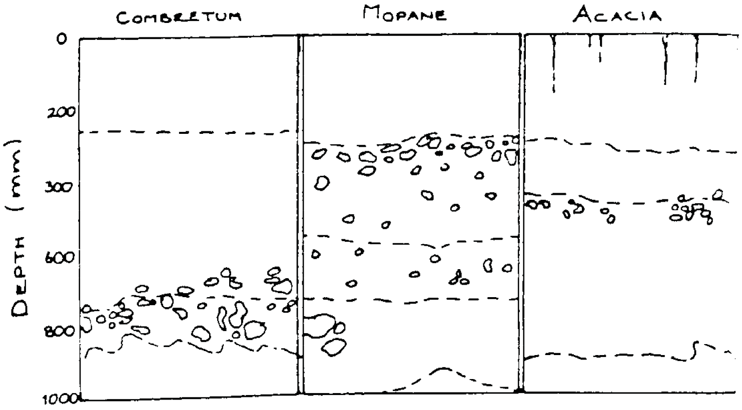
Series Mayo
Form Mayo

A1 0-300 Melanic; very dark brown 10YR 2/2 (moist) medium sandy clay loam; hard; weak prismatic structure; many fine roots; clear transition.

B$_{21}$ 300-560 Pedocutanic; dark brown 7.5YR 3/2 (moist) sandy clay loam; extremely hard; medium blocky structure; many fine and medium roots; gradual transition.

B$_{22}$ 560-900 Pedocutanic; dark brown 7.5YR 3/2 (moist) clay loam; extremely hard; medium blocky structure; many small half-rounded quartz inclusions; gradual transition.

C 900+ Lithocutanic, bright brown 7.5YR 5/8 (moist)



Mopane site

Series Zuiderzee
Form Valsrivier

A$_1$ 0-280 Orthic, reddish brown 5YR 4/6 (moist) medium sandy loam; loose; apedal; many fine to coarse angular and half-round quartz fragments; few fine and medium roots; clear transition.

B$_{21}$ 280-560 Pedocutanic, bright reddish brown 5YR 5/8 (moist) coarse sandy clay loam; hard; strong coarse blocky structure; few medium soft $CaCO_3$ concretions; many fine and medium angular quartz fragments; gradual transition.

B$_{22}$ 560-720 Orange 5YR 6/8 (moist) medium sandy clay loam; slightly hard; strong medium blocky structure; common fine diffuse red mottles; many medium and coarse soft and hardened $CaCO_3$ concretions; common medium roots; gradual transition.

C 700+ Orange 5YR 6/8 (moist). Unconsolidated material.

Figure 14. Soil profiles at the three study sites

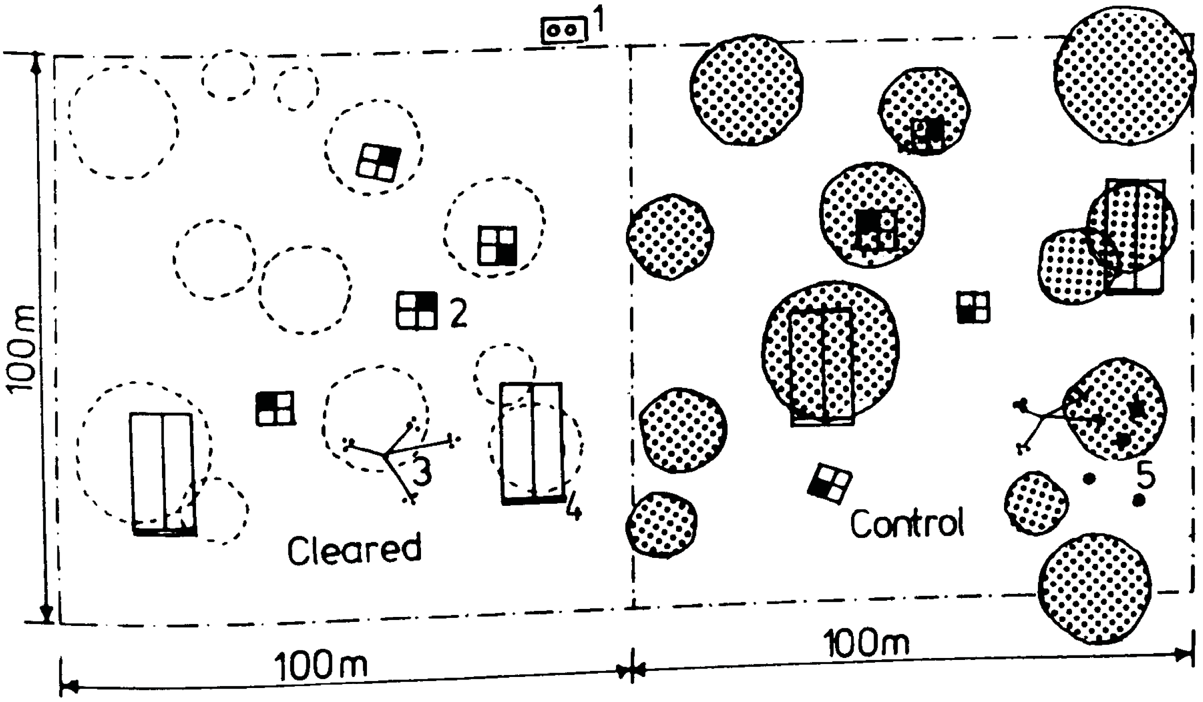


Figure 15. Layout of a study site: Based on the Acacia site, not to scale. 1) Recording raingauges 2) Marked tillers and herbivore exclusion frames 3) Array of soil moisture sensors 4) Paired runoff plot 5) Lysimeters.

attributed to a patch of *Bothriochloa radicans* in one corner of the cleared plot.

The percentage bulk contribution by species was estimated by ranking the contributions in 100 0.5x0.5 m quadrats per plot according to the method of t'Mannetje and Heydock (1963), as modified by Barnes, Odendaal & Beukes (1982). The results appear in Table 4.1. The herbaceous layer composition was markedly different between the sites, but was not markedly different between the control and treatment plots within the sites prior to the experiment. The dry-weight-ranking method does not lend itself to statistical comparisons. The composition subse-

Table 2.3 Percentage rooted basal cover by grasses, November 1981.

| Site | Acacia | | Combretum | | Mopane | |
|---|---|---|---|---|---|---|
| Species | Cleared | Control | Cleared | Control | Cleared | Control |
| *Digitaria eriantha* | 0.36 | 0.69 | 0.24 | 0.36 | 2.80 | 2.20 |
| *Panicum maximum* | 0.27 | 0.21 | 0.12 | 0.33 | 0.50 | 0.50 |
| *Schmidtia pappophoroides* | 0.06 | - | - | - | 0.75 | 0.30 |
| *Aristida congesta* | 0.15 | 0.15 | 0.06 | 0.12 | 0.20 | 0.30 |
| *Bothriochloa radicans* | 1.47 | 0.27 | - | 0.06 | - | - |
| *Panicum coloratum* | 0.81 | 0.84 | 0.30 | 0.09 | - | - |
| Other grasses | - | - | - | - | 0.35 | 0.30 |
| Cyperaceae | - | - | 0.21 | 0.09 | 0.30 | 0.15 |
| Forbs | 0.06 | 0.06 | 0.09 | 0.27 | - | - |
| Total | 3.24 | 2.22 | 1.00 | 1.42 | 4.90 | 3.75 |
| Standard error | 0.95 | 0.78 | 0.67 | 0.62 | 1.06 | 0.15 |

quently changed as a combined consequence of the treatment and the drought.

Woody vegetation was characterised by recording the species, height, diameter above the basal swelling of each stem and the long and short canopy diameters of every woody plant occurring within eight 5x50 m systematically located belt transects per treatment. A woody plant was defined as having secondary lignification and the potential to grow above the herbaceous layer (i.e. exceed 1 m in height). Stems growing further than 0.5 m away from their nearest neighbour of the same species were considered to be individual plants. Plants with more than 50% of their rooted basal area within the transect were considered to be totally included, otherwise totally excluded. The plant density, basal area and canopy cover per species and site is presented in Table 2.4. The application of t-tests to the data revealed no significant differences at the 95% confidence level between control and manipulation plots at each site.

Table 2.4 Density, basal area and canopy cover of woody plants at each study site prior to the experiment. Each value is the mean of eight replicate 5x50 m belt transects.

| *Species* | *Density* ($plants.ha^{-1}$) | | *Basal area* ($m^2.ha^{-1}$) | | *Canopy cover* (%) | |
|---|---|---|---|---|---|---|
| | *Clear* | *Control* | *Clear* | *Control* | *Clear* | *Control* |
| 1.Combretum site | | | | | | |
| *Combretum apiculatum* | 312 | 336 | 2.87 | 3.54 | 29.0 | 31.0 |
| *Sclerocarya birrea* | 84 | 164 | 0.97 | 2.20 | 4.1 | 10.2 |
| *Grewia bicolor* | 124 | 140 | 0.25 | 0.45 | 5.8 | 7.6 |
| *Cissus cornifolia* | 124 | 136 | 0.23 | 0.11 | 4.1 | 2.2 |
| *Others combined* | 164 | 116 | 0.18 | 0.58 | 2.6 | 7.6 |
| *Totals* | 808 | 892 | 4.50 | 6.88 | 45.6 | 58.6 |
| *Standard error* | 269 | 183 | 2.79 | 2.65 | 13.9 | 20.5 |
| 2.Mopane site | | | | | | |
| *Colophospermum mopane* | 872 | 731 | 6.40 | 9.50 | 35.7 | 36.3 |
| *Combretum apiculatum* | 72 | 200 | 0.40 | 1.10 | 4.4 | 8.3 |
| *Grewia bicolor* | 40 | 72 | 0.10 | 0.10 | 2.4 | 2.8 |
| *Others combined* | - | 77 | - | 0.24 | - | 2.6 |
| *Totals* | 984 | 1080 | 6.90 | 10.94 | 41.6 | 50.0 |
| *Standard error* | 420 | 127 | 3.00 | 2.74 | 11.3 | 9.1 |
| 3.Acacia site | | | | | | |
| *Acacia nigrescens* | 36 | 148 | 1.50 | 3.67 | 4.6 | 19.9 |
| *Sclerocarya birrea* | 24 | 16 | 0.70 | 1.20 | 3.8 | 3.5 |
| *Grewia bicolor* | 240 | 72 | 0.67 | 0.12 | 11.8 | 3.0 |
| *Cissus cornifolia* | 76 | 20 | 0.08 | 0.02 | 1.8 | 0.2 |
| *Others combined* | 148 | 432 | 0.27 | 0.42 | 7.1 | 4.3 |
| *Totals* | 524 | 688 | 3.22 | 5.43 | 39.1 | 30.9 |
| *Standard error* | 266 | 345 | 3.29 | 5.91 | 17.9 | 34.4 |

# 3.0 HYDROLOGY

The soil moisture regime, an expression of the integrated effect of all the hydrological processes operating at a site, is one of the primary determinants of savanna structure and function (Frost *et al* 1986). It is therefore logical to focus a study of structural/functional change in savannas on alterations in hydrological processes. Furthermore, soil moisture controls the soil nutrient status (the other primary determinant of savanna structure), both in the long term (through the rates of pedogenic processes) and the short term (by limiting nutrient availability).

There is much circumstantial evidence to suggest that primary production is directly linked to soil moisture availability in semi-arid savannas (Rutherford 1980). Several workers have sought to relate the bush clearing response to changes in soil moisture content (Strang 1969a, Pratchett 1978). Aspects of the water relations of savanna plants have been studied in detail, but the overall knowledge of the hydrology of semi-arid savannas is fragmentary. Bate, Furniss and Pendle (1982) present that which is available for southern Africa.

Hydrological changes as a consequence of savanna clearing are of interest for their own sake as well. Small changes in the proportion of water providing runoff or recharging the ground water could have major consequences in a semi-arid region. Runoff is also very closely linked to erosion (Morgan, 1979). Leaching influences the nutrient balance of the system and most pedogenic processes.

A schematic hydrological flow diagram for a generalised semi-arid savanna is given in Figure 16 on page 68. The conceptual model has only one spatial dimension (the vertical) and thus does not apply to situations which receive a significant proportion of their water input from sources other than precipitation, for example run-on from adjacent areas or lateral

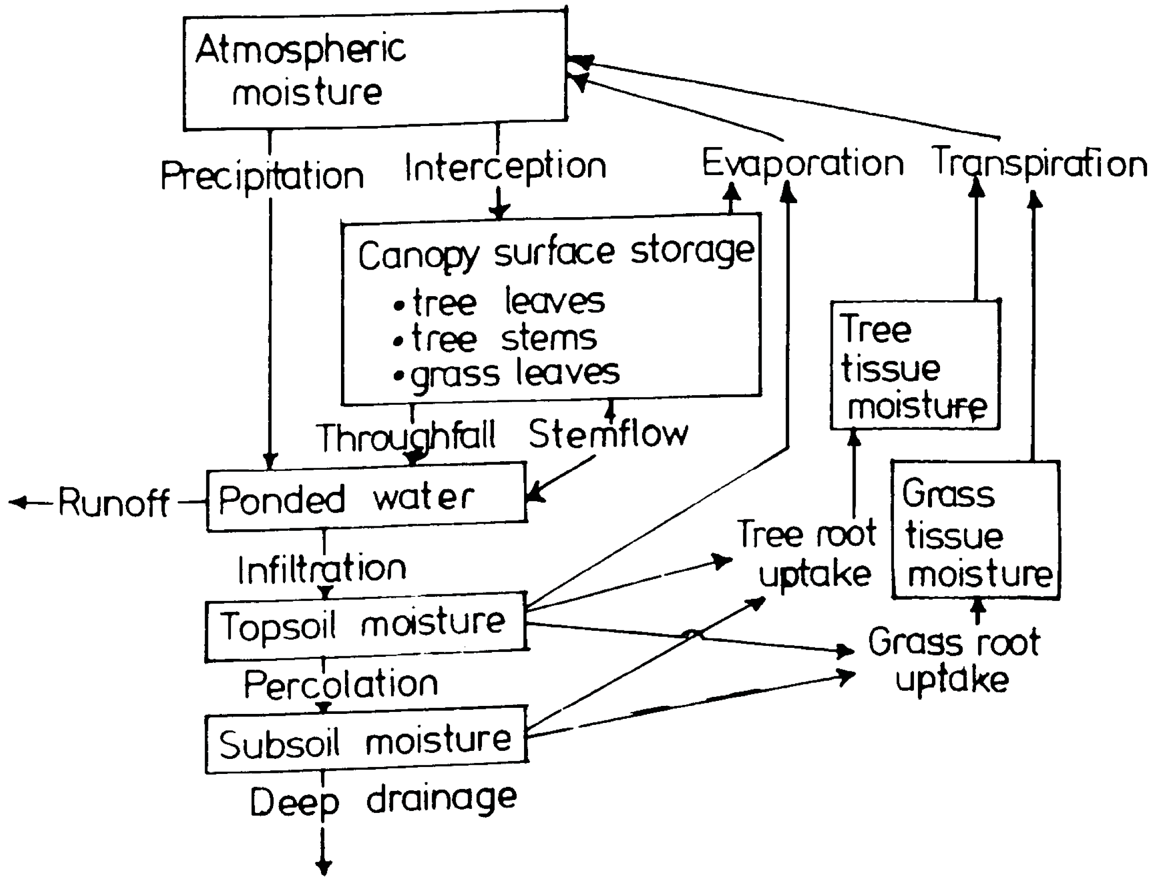


Figure 16. Generalised hydrological cycle for a savanna

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subsurface flow. Thus riparian fringes and hydromorphic seeplines are excluded. These areas constitute a very small proportion of the Klaserie Private Nature Reserve, which is not to belittle their importance as wildlife habitats or areas of bush-clearing potential. The grass and woody dynamics of such areas differ qualitatively, however, from the generalised savanna scheme. Riparian fringes generally support dense thicket or tall gallery forest, permitted by the reliable supply of deep ground water. Seepline zones are generally treeless due to the alternating extremes of saturation and dehydration.

The simplifying assumptions that have been made in the general savanna hydrological model are as follows.

The atmospheric water pool is so large and mobile that it is independent of local terrestrial hydrological events. In other words, limited bush clearing does not alter the macroclimate.

2. Rainfall is the predominant form of precipitation and is the sole input of water into the system.

3. The savanna soil and vegetation are spatially homogeneous in a horizontal plane. The upper and lower scale limits of the model are defined by significant soil differences (at a scale of hundreds of meters) and the pattern imposed by tree canopies (ten meters) respectively. Some of the implications of these large and small scale variations are explored in the study.

4. Trees and grasses are the only vegetation forms considered.

5. Hydrological cycling through higher trophic levels is insignificantly small. The internal plant water pool is relatively small.

## 3.1 PRECIPITATION

Rainfall at Klaserie is concentrated into the months of September to April, and occurs as convective storms of variable (but often high) intensity, usually in the late afternoon or evening, or as long-duration low-intensity drizzle associated with cyclonic systems. Rainfall statistics for the region are presented by Gertenbach (1980) and Green (1969a & b). Monthly rainfall recorded over the period of this study is given in Table 3.1., and daily rainfall in appendix 1.

From a plant production viewpoint, the important parameters of rainfall are its depth (quantity) and temporal pattern. The hydrologically important rainfall parameters are rainfall depth and intensity. The data used to simulate long-term rainfall patterns were those from the weather station at Skukuza, 150 km southeast of Klaserie. Although Skukuza

Table 3.1 Rainfall by month and site during the study period. Daily rainfall data for each site is recorded in Appendix 1.

| Month | 1982/3 | | | 1983/4 | | | 1984/5 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Combret | Mopane | Acacia | Combret | Mopane | Acacia | Combret | Mopane | Acacia |
| July | | | (2.5) | | | | | | |
| August | | | | | | | | | |
| September | | | | | | | | | |
| October | 8 | | (8) | | | | 150 | 105 | 149 |
| November | 13 | 20 | 27 | 164 | 87 | 162 | 99 | 145 | 87 |
| December | 12 | 13 | 10 | 85 | 60 | 116 | 44 | 104 | 90 |
| January | 63 | 68 | 56 | 120 | 56 | 83 | 195 | 228 | 188 |
| February | 4 | 6 | 3 | 38 | 73 | 58 | 100 | 91 | 101 |
| March | 102 | 83 | 127 | 127 | 96 | 74 | 102 | 114 | 92 |
| April | 13 | 15 | 15 | | | | | | |
| May | | (22) | (12) | | | | 40 | 25 | 33 |
| June | | (6) | (6) | | | | | | |
| Total | 215 | 233 | 266 | 534 | 372 | 493 | 730 | 812 | 740 |

Values in parentheses are from the closest permanent raingauge.
(Combretum- Xanatseni gate; Mopane- Ntoma lodge; Acacia: Wardens HQ)

receives 10% more rainfall on average than Klaserie, the distribution of event probabilities is assumed to be similar, since both stations occur in the same climatic zone. A long record, such as is obtainable from Skukuza (since 1910), was held to be more important than an exactly equal mean annual rainfall. Where the Skukuza data were used for modelling purposes, the depths per storm were reduced to reflect the lower mean rainfall at Klaserie.

If the "Walter hypothesis" is correct in suggesting that the balance between trees and grasses is a reflection of topsoil to subsoil moisture distribution (Knoop & Walker 1984), then the storm depth distribution, along with a knowledge of the water holding capacity of the soil, should provide an indication of the frequency with which moisture penetrates to the subsoil. This analysis is presented in Figure 17 on page 72. It indicates that when individual storms are considered in isolation, only 10% of the annual rainfall moistens the soil to depths exceeding 300mm in the Acacia site, 20% in the Mopane site and 28% in the Combretum site. These are underestimates of the true moisture inputs into the subsoil, (especially on sandy soils) since rain frequently falls on soil already wet by previous storms, and the influence of unsaturated soil moisture movement is not included. The episodic nature of savanna rainfall, however, allows these distributions to be used as a crude index of the relative moisture status of the top- and subsoil.

Rainfall depths and intensities were recorded at each study site for the duration of the study by plastic rain gauges (100mm orifice) and tipping bucket recording rain gauges (200mm) respectively. The gauges were installed in a pit with their orifices at ground level. The minimum resolution was 0.5 mm in both cases. Bucket tips were recorded to the nearest second on paper tape by a printing calculator (Casio Fp-10). The times were then analysed to produce a storm hydrograph.

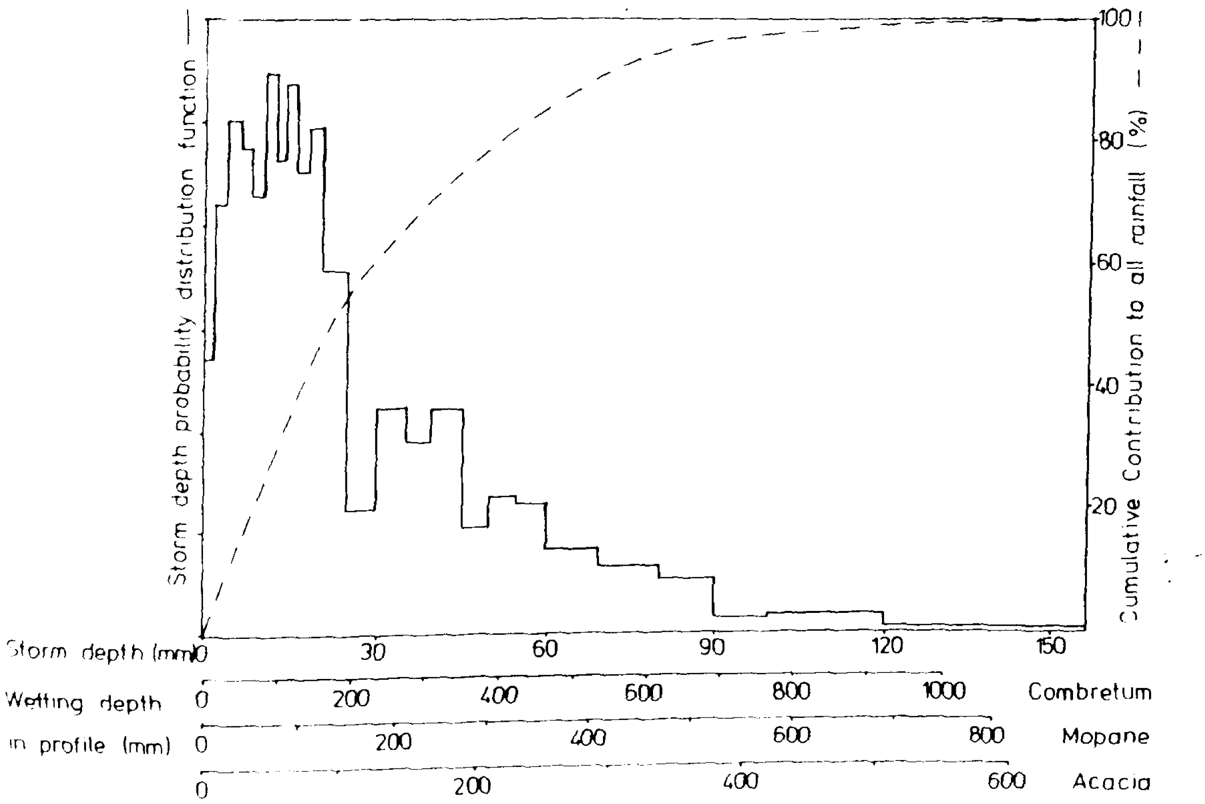

Figure 17. The distribution of storm depths: the histogram is the proportion of all storms in each depth class and the broken line is the cumulative contribution by each depth class to the total long-term rainfall. The wetting-depth equivalents to a storm of given depth are plotted for each study site, taking into account the water-holding capacity of the soil. The proportion of the rainfall penetrating beyond a given depth can be estimated by projecting a line vertically from the appropriate site axis to the broken line, and subtracting the corresponding value on the right-hand y-axis from 100%.

## 3.2 INTERCEPTION AND STEMFLOW

Interception is that portion of the incoming precipitation which initially strikes vegetation rather than the ground. Some of this intercepted rainfall drips off the canopy to the ground (throughfall). Provided the canopy is low (<6 m) these drops have a lower kinetic energy than incoming rainfall and thus result in higher infiltration, less splash erosion and less soil clay capping than direct rainfall. For modelling purposes, however, the throughfall was treated as direct precipitation, since the gain in precision is disproportionate to the increase in complexity (and uncertainty) which results from its inclusion as a separate variable.

A further portion of the intercepted rainfall runs down the plant stems to the ground (stemflow). While this constitutes a relatively minor portion of the total system water input, it has, like throughfall, an altered kinetic energy. Infiltration of this component of precipitation is further assisted by the presence of a crack between the bark and the soil, caused by the shrinkage and swelling of the stem and soil. Several workers have noted increased rainfall penetration beneath tree canopies (Pressland 1973), which is usually ascribed to stemflow. In its passage down the bark, the stemflow also picks up dust and plant exudates which result in it being nutrient enriched and dark brown in colour. For these reasons stemflow was regarded as an important contributor to the formation of the sub-canopy habitat and was recorded despite its small contribution to the overall water budget. Since the focus was on the sub-canopy habitat, only stemflow of trees and shrubs was measured.

Various methods of gauging stemflow have been applied (Slatyer 1961, and de Villiers & de Jager 1981). All involve attaching a collar or gutter to the stem near ground level, which channels the flow into a container. In this study a spiral gutter made of 25mm diameter plastic hose was tacked to the tree stem and bonded to the bark with silicone sealant. The spiral was kept shallow to prevent the flow from rushing out of the gutter, and consisted of at least one and a half turns around the stem (Figure 18 on page 74). The collecting containers were limited by practical considerations to twenty litres, and were sufficient for small

Figure 18. Stemflow collector

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trees, but were frequently overtopped by large storms on large trees. The stemflow volume was measured by weighing the containers after each storm to the nearest 0.1 kg with a spring balance.

Five specimens of each of the two species with the highest basal area in each site were fitted with stemflow gauges. The five stems were selected to represent the range of diameters found in the site. In the Mopane site, all ten stems were allocated to *Colophospermum mopane*.

Regression analysis was used to relate stemflow yield to storm depth, duration and stem size. Storm duration accounted for little variation in

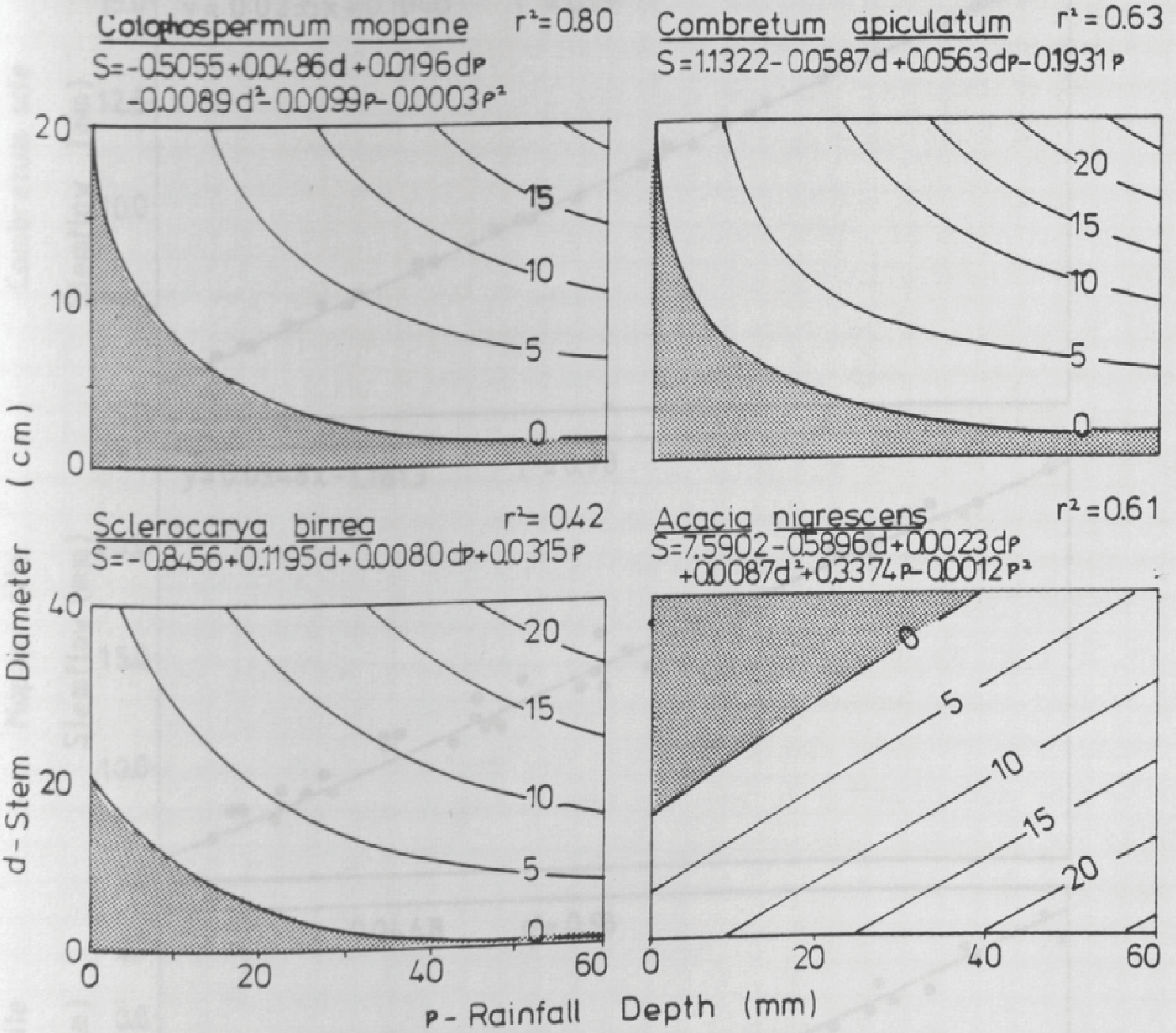

Figure 19. Stemflow per trunk as a function of stem size and storm depth.

any of the models so it was excluded. Models including storm depth and stem basal diameter provided the best fits to the stemflow yield data, and are presented in Figure 19 on page 75. One third of the stemflow data were randomly excluded before the regressions were calculated, and were used for calculating the predictive power of the models, expressed as the $r^2$ values in the diagrams. The yields from *Grewia bicolor* were very variable and no plausible model could be fitted.

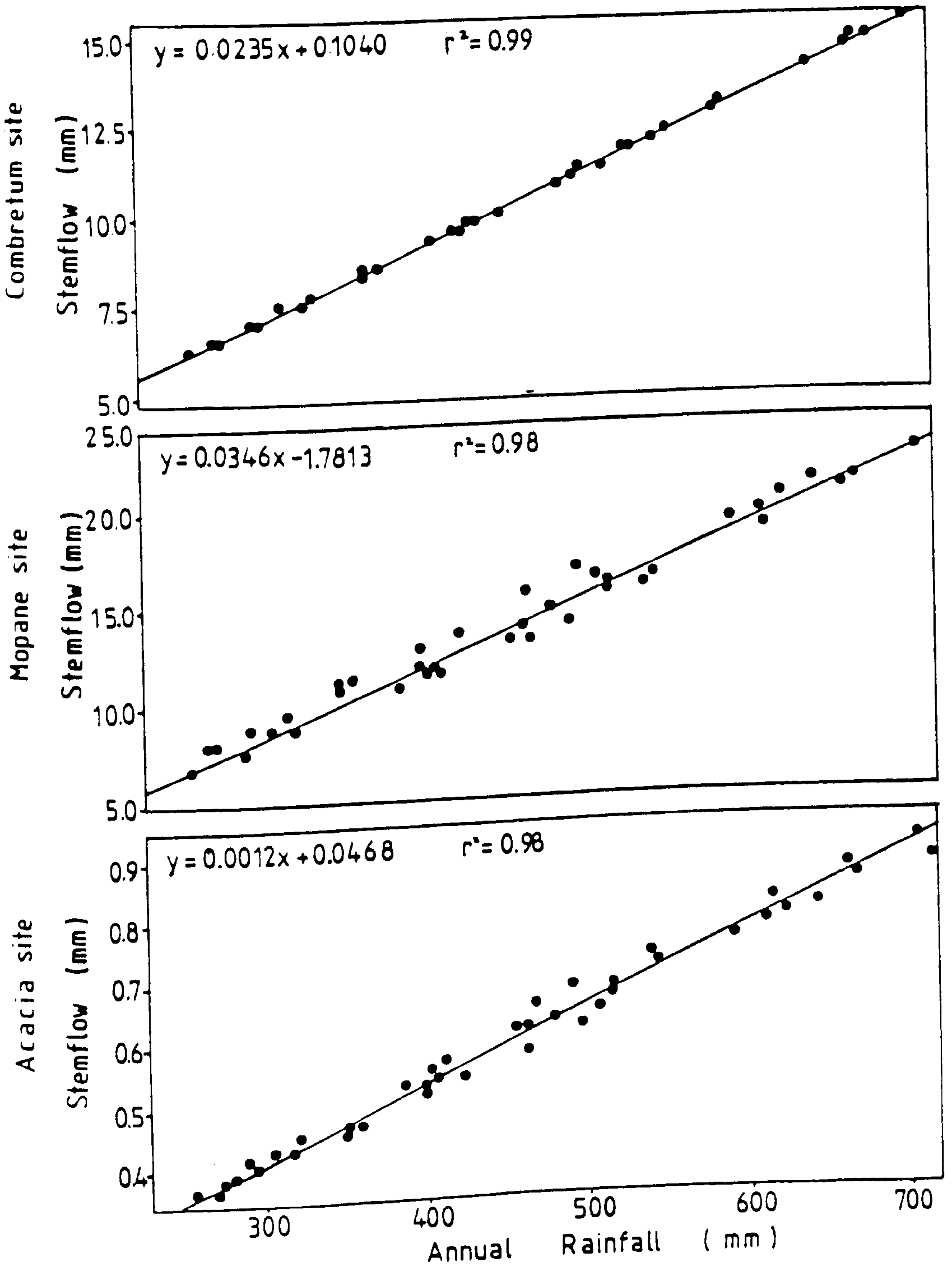

Figure 20. Stemflow per hectare per annum as a function of annual rainfall: n=40, some points are coincident

The atypical form of the stemflow-rainfall-stem diameter relation for *Acacia nigrescens* is thought to be due to the high trunk storage capacity and horizontal canopy architecture of this species. The spreading branches of large trees limit the stemflow reaching the trunk to an amount less than the storage capacity. Therefore large trees yield less stemflow than small.

Stemflow per unit ground area per year cannot be estimated by simple multiplication of the estimates per stem per storm by the number of stems per hectare and the number of storms per year, due to the strong non-linearities in the prediction equations. The probability distributions of storm sizes and stem diameters must be taken into account. The former were obtained from forty years of rainfall records at Skukuza, and the latter from the initial site survey data. These distributions, when substituted into the equations for estimating stemflow per stem, yielded the long-term stemflow predictions presented in Figure 20 on page 76. While stemflow contributes a minor component to the annual water budget (3% Mopane site, 2% Combretum site and 0.2% Acacia site), if this supply is considered to be concentrated into an area of 0.25m radius around the stem, the local contribution can be considerable. Assuming an annual rainfall of 500mm, this area receives an additional 300, 250 and 500mm of moisture as stemflow (over and above the throughfall it receives) on each site respectively.

The third possible fate of intercepted precipitation is to be evaporated from the wet plant surfaces. Water leaving the system in this fashion is known as interception loss. Whether it is a true loss, or whether by the cooling and humidifying effect of its evaporation it partially replaces transpiration losses (McNaughton 1981) is an unanswered question. Since it occurs at a time when transpirational demand on the plant is low (due to low temperatures and high humidities following a storm) it seems conservative to treat it as a loss.

The magnitude of interception losses in semi-arid savannas is largely unknown, but has been estimated as up to 15% of the annual rainfall by de Villiers (1982). Estimates for grasslands, which have a much higher leaf area index than savannas, are considerably lower (Burgy & Pomeroy