WATER BALANCE STUDY OF KARUVANNUR RIVER BASIN

By

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THESIS

Submitted in partial fulfilment of
the requirement for the degree

Master of Science in Agricultural Engineering

Faculty of Agricultural Engineering
Kerala Agricultural University

Department of Irrigation and Drainage Engineering
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Tavanur - Malappuram

1988

DECLARATION

I hereby declare that this thesis entitled "Water Balance Study of the Karuvannur River Basin" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship, or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis, entitled " Water Balance Study of the Karuvannur River Basin " is a record of research work done independently by Sri. Santosh. G. Thampi under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship, or associateship to him.

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We, the undersigned, members of the Advisory Committee of Shri. Santosh. G. Thampi, a candidate for the degree of Master of Science in Agricultural Engineering with major in Soil and Water Engineering, agree that the thesis entitled "Water Balance Study of the Karuvannur River Basin" may be submitted by Shri. Santosh. G. Thampi in partial fulfilment of the requirements for the degree.

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SYMBOLS AND ABBREVIATIONS

&	And
α	Relection co-efficient
A_L	Water surface area of the reservoir
°C	Degree centigrade
cm	Centimetre (s)
C	Adjustment factor
Δ	Delta
Dept.	Department
e	Unadjusted Potential Evapotranspiration in cm/month
et al	And other people
ed	Saturation vapour pressure at the dew point temperature of atmosphere in mm. of mercury
es	Saturation vapour pressure at the temperature of the evaporating surface in mm. of mercury
eg	Example
E	Evaporation from the basin or water body
E_o	Evaporation from open water surface in mm/day
ETa	Actual evapotranspiration in mm/day
ET crop	Crop evapotranspiration in mm/day
ETo	Mean monthly reference crop evapotranspirat-ion in mm/day
Epan	Pan evaporation in mm/day

E_1	Evaporation under the canopy
E_2	Evaporation of precipitation intercepted by the canopy
E_3	Transpiration of trees
E_1'	Evaporation from the soil
E_2'	Evaporation of precipitation intercepted by the groundwater, moss, low bushes, grass etc.
E_3'	Ground cover transpiration
E_L	Evaporation from the lake surface
η	Discrepancy term
η'	Unassigned balance discrepancy
F	Sum of mean monthly consumptive use factors for the growing season
f(u)	A function of wind velocity
γ	Psychrometric constant
ΔG	Change of water storage in aquifers
ha.	Hectare
ht.	Height
hrs.	Hours
i	Monthly heat index
I	Annual or seasonal heat index
I_1	Water flow due to filtration from arterial canals
I_2	Water flow due to filtration from irrigation canals
I_3	Inflow of irrigation water on the field surface

I_4	Outflow of irrigation water from the field
I_5	Irrigation water removed from canals
IHD	International Hydrological Decade
ISI	Indian Standards Institution
°K	Degree Kelvin
K	Empirical seasonal consumptive use co-efficient for the growing season
k	Empirical consumptive use crop-coefficient for the month
kc	Crop factor
K_p	Pan co-efficient
K_u	Co-efficient of river flow due to ground water
K_E	Evaporation co-efficient
mm.	Millimetre (s)
m.	Metre (s)
m^3/S	Cubic metre per second
Mm^3	Million cubic metre
ΔM	Change in water storage in the upper 1m. of soil
$\Delta M'$	Variation of water storage in the soil mantle beneath the upper 1m. layer
n	Actual sunshine hours
N	Maximum possible sunshine hours
No.	Number

p	Mean daily percentage of total annual day time hours OR
	Monthly day light hours expressed as percentage day light hours of the year
/	Per
%	Percentage
P	Precipitation over the basin or water body
	OR
	Annual rainfall
P_1	Rainfall in the year OR
	Precipitation over the forest terrain penetrating through the canopy
P_2	Rainfall in the previous year OR
	Precipitation intercepted by the canopy
P_3	Precipitation flowing down the stem of trees
PET	Potential Evapotranspiration
PWD	Public Works Department
P_L	Precipitation on the lake surface
Q	Discharge in the river or stream flow
Q_a	Angot's value of mean monthly extra terrestrial radiation in mm of water/day
Q_β	Return water
Q_α	Water removed for economic purposes
Q_m	Inflow from the main stream
Q_n	Net radiation in mm of water/day
Q_l	Lateral inflow
Q_s	Surface runoff

Q_b	Under ground runoff
Q_{SI}	Surface inflow into the basin or water body
Q_{UI}	Sub surface inflow into the basin or water body
Q_{SO}	Surface outflow from the basin or water body
Q_{UO}	Sub surface outflow from the basin or water body
Q_{up}	Percolation beyond the zone of saturation
Q_{MI}	Inflow of soil water in the unsaturated zone
Q_{MO}	Outflow of soil water in the unsaturated zone
Q_{U1}	Inflow of ground water from lower aquifers
Q_{U2}	Outflow of ground water from lower aquifers
Q_{U3}	Ground water outflow through springs
Q_{u1}	Inflow of ground water from other aquifers
$Q_{u\alpha}$	Ground water withdrawn from artesian aquifers
$Q_{u\beta}$	Artificial recharge volume
$Q_{u\gamma}$	Ground water outflow along the channel
$Q_{u\mu}$	Inflow of surface water along the design stretch of the aquifer
Q_{uc}	Outflow of underground water into the zone of aeration for moisture recovery lost by evapotranspiration
$Q_o V_o$	Overland flow input to the stream channel
R	Annual runoff

R_a	Extra terrestrial radiation expressed in equivalent evaporation in mm/day
R_e	Recharge due to canal seepage or effective precipitation in mm.
RH	Relative humidity in percentage
Rn	Net radiation in mm/day
Rs	Solar radiation in equivalent evaporation in mm/day
Rns	Net shortwave solar radiation in mm/day
Rnl	Net long wave solar radiation in mm/day
Rr	Recharge due to rainfall
Ri	Recharge due to return flow of irrigation water
R_T	Total precipitation in mm.
r	Reflection co-efficient
ΔS	Change of water storage in the basin or water body
ΔS_{ch}	Change of water storage in river channels
ΔS_{gl}	Change of water storage in glaciers
ΔS_L	Change of water storage in lakes and reservoirs
ΔS_n	Error of mean level estimation
ΔS_s	Water storage variation on the forest terrain surface
ΔS_{sn}	Change of water storage in snow cover

ΔS_y	Mean square deviation of soil moisture storage
S_i	Recharge due to influent seepage from rivers, streams, reservoirs, lakes, ponds etc.
S_e	Loss of ground water due to effluent seepage in rivers and streams
σ	Stefan Boltzman constant
sq.km.	Square kilometre (s)
t	Mean air temperature in °C
T	Mean daily temperature in °C over the month considered
Ta	Mean air temperature in °K
T_p	Pumpage of groundwater in the basin for irrigation and other uses
temp.	Temperature
u	Wind speed in km/day
u_1	Wind speed in miles/day at any height
u_2	Wind speed in miles/day at 2m. height
U	Seasonal consumptive use of water by the crop for a given period in inches
UNESCO	United Nations Educational Scientific and Cultural Organisation
U.P.	Uttar Pradesh
USWB	United States Weather Bureau
Univ.	University
vs	versus

W	Weighting factor which depends on temperature and altitude
WMO	World Meteorological Organisation

Introduction

INTRODUCTION

Kerala is a land rich in water resources. A rough assessment of her water resources was made in the year 1958 at the instance of the Central Water and Power Commission. Since the publication of this report, the State has been striving hard to utilise her water wealth to the maximum extent possible. But fiscal constraints had prevented her from achieving the desired levels of development. At the same time some of the water scarce neighbouring States started laying claims for a share of our waters, on the plea of national interest. Hence a reappraisal of the State's water resources was considered necessary.

Detailed computations showed that the total runoff in the rivers from Kerala's catchment was about 70,323 Mm^3 (2484 TMC) and the utilisable water resources was about 42,722 Mm^3.(1510 TMC). As against the State's surface water resources of 1510 TMC, the ultimate utilisation of water under various heads was estimated to be as follows:

Irrigation	1020 TMC
Domestic and Industrial use	265 TMC
Salinity control and navigation	254 TMC
Removal of Toxicity from Karilands	177 TMC
	1716 TMC

In addition, under an agreement entered into with the Tamilnadu Government, about 70 TMC of water from the Periyar catchment was being diverted to Tamilnadu in 1971. The study clearly showed that Kerala had defenite plans to utilise her water wealth and that she required it to the last drop. Also, it was clearly established that this demand could be met only by the conjunctive use of ground and surface waters.

The scarcity of water, experienced in the summer months, over large areas of the State, during the last five or six years has made studies on water resources very important.

Water balance techniques are a way of solving important theoretical and practical hydrological problems. By using the water - balance approach it is possible to make a quantitative evaluation of water resources and to assess any changes that might occur through the influence of man's activities. The study of the water - balance structure of regulated river basins permits the rational use, control and redistribution of water resources in time and space. Knowledge of water balance assists the prediction of the consequences of artificial changes in the regime of streams, lakes and ground water.

An understanding of the water - balance is also extremely important for studies of the hydrological cycle. With water - balance data it is possible to compare individual sources of water in a system, over different periods of time, and to establish the extent of their effect on variations in the water regime.

The initial analysis used to compute the individual water - balance components, and their co-ordination in the balance equation, make it possible to identify deficiencies in the distribution of hydrometric observation stations and to discover systematic errors of measurements.

Water balance studies can also provide an indirect evaluation of any unknown water - balance component by providing the difference between the known components.

The broad objective of this project was to make a quantitative evaluation of the water resources of the Karuvannur River Basin.

The specific objectives of this project were:

i) To estimate the average monthly rainfall in the basin for the period 1976 to 1985.

ii) To conduct frequency analysis of rainfall for various durations.

iii) To determine the total runoff from the basin for the period 1976 to 1985 and to develop an equation connecting rainfall with runoff.

iv) To estimate the evapotranspiration from the basin during the period 1976 to 1985.

v) To study the monthly water balance for the basin in order to estimate the balance for groundwater recharge or depletion during the period 1976 to 1985.

Review of Literature

REVIEW OF LITERATURE

2.1. General form of the water balance equation.

The study of the water balance could be regarded as an application in hydrology of the principle of conservation of mass, often referred to as the continuity equation. According to this equation, for any arbitrary volume and during any period of time, the difference between total input and output would be balanced by the change of water storage within the volume. In general, therefore, use of water balance technique would imply measurement of both storages and fluxes or rates of flow of water. However, by appropriate selection of the volume and period of time for which the balance would be applied, some measurements might be eliminated.

The water balance equation for any natural area or water body would indicate the relative values of inflow, outflow and change in water storage for the area or body. In general, the inflow part of the equation would consist of precipitation and surface and subsurface water inflow into the basin or water body from outside and the outflow part would consist of evaporation from the surface and subsurface outflow from the basin or water body. The total water storage in the body would increase when the inflow is greater than the outflow and viceversa. As all the water balance components are

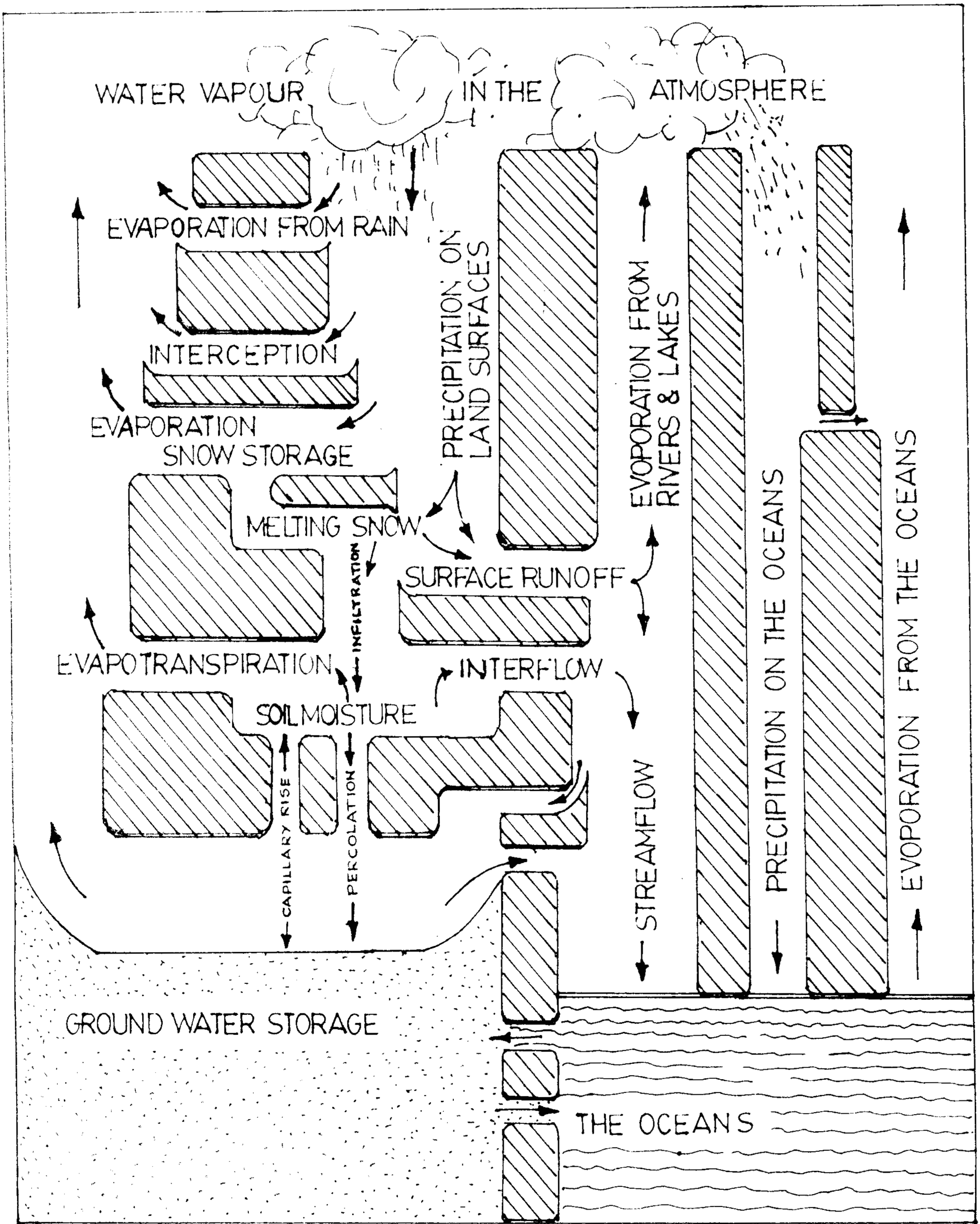


FIG. 2.1. THE HYDROLOGIC CYCLE

subject to errors of measurement or estimation the water balance equation would also include a discrepancy term. Consequently the water balance for any water body and any time interval in its general form could be represented by the following equation.

$$P + Q_{SI} + Q_{UI} - E - Q_{SO} - Q_{UO} - \Delta S - \eta = 0. \quad - (2.1)$$

where P is the precipitation over the basin or the water body, Q_{SI} and Q_{UI} are the surface and subsurface inflow into the basin or water body, Q_{SO} and Q_{UO} are the surface and subsurface outflow from the basin or water body, E is the evaporation from the basin or water body, ΔS is the change in water storage in the basin or water body and η is the discrepancy term. (UNESCO, 1974)

For application to a variety of water balance computations the above equation could be simplified or made more complex, depending on the available initial data, the purpose of computation, the type of body-river basin or artificially seperated administrative district, lake or reservoir etc. - and the dimensions of the water body, its hydrographic and hydrologic features, the duration of the balance time interval, and the phase of the hydrological regime - flood, low flow - for which the water balance is computed.

In large river basins, Q_{UI} and Q_{UO} are found to be small when compared with other terms and hence could be ignored. Also, there would be no surface inflow into a river basin with a distinct water-shed divide - assuming no artificial diversions from other basins - and hence the term Q_{SI} could be neglected. Thus, for a river basin the simplified equation would be

$$P - E - Q - \Delta S - \eta = 0 \quad \text{--} \qquad (2.2)$$

2.2. Special features of the water balance equation for different time intervals.

The water balance could be computed for any time interval. However distinction should be made between mean water balances and balances for specific periods such as season, months, days etc., sometimes called current or operational water balances.

In the computation of mean annual water balance (for an annual cycle, calendar year, or hydrological year and sometimes for a season or month), the change in water storage in the basin ΔS, which are difficult to measure and compute, could be disregarded. This becomes possible because over a long period, positive and negative water storage variations for individual years would balance and their net value at the end of a long period would tend to zero.

The shorter the time intervals, the more precise would be the requirements for measurement or computation of the water balance components and the more subdivided should be the values of ΔS and other elements. This would result is a complex water balance equation too difficult to close with acceptable errors. For eg:- for short time intervals, the change in total water storage ΔS in a small river basin might be subdivided into changes of moisture storage in the upper 1m. of soil (ΔM), in aquifers (ΔG), in lakes and reservoirs (ΔS_L), in river channels (ΔS_{ch}), in glaciers (ΔS_{gl}) and in snow cover (ΔS_{sn}). The water balance equation would then take the form.

$$P + Q_{SI} + Q_{UI} - E - Q_{SO} - Q_{UO} - \Delta M - \Delta G - \Delta S_L - \Delta S_{ch} - \Delta S_{gl} - \Delta S_{sn} - \eta = 0 \quad \text{--} \quad (2.3)$$

2.3. Special features of the water balance equation for water bodies of different dimensions.

The water balance could be computed for water bodies of any size, but the complexity of computation would depend on the extent of area under study. It has been found that the accuracy of computation would increase with an increase in the area of the river basin. This is so because in the case of small basins, the estimation of secondary components of the balance such as ground - water exchange with adjacent

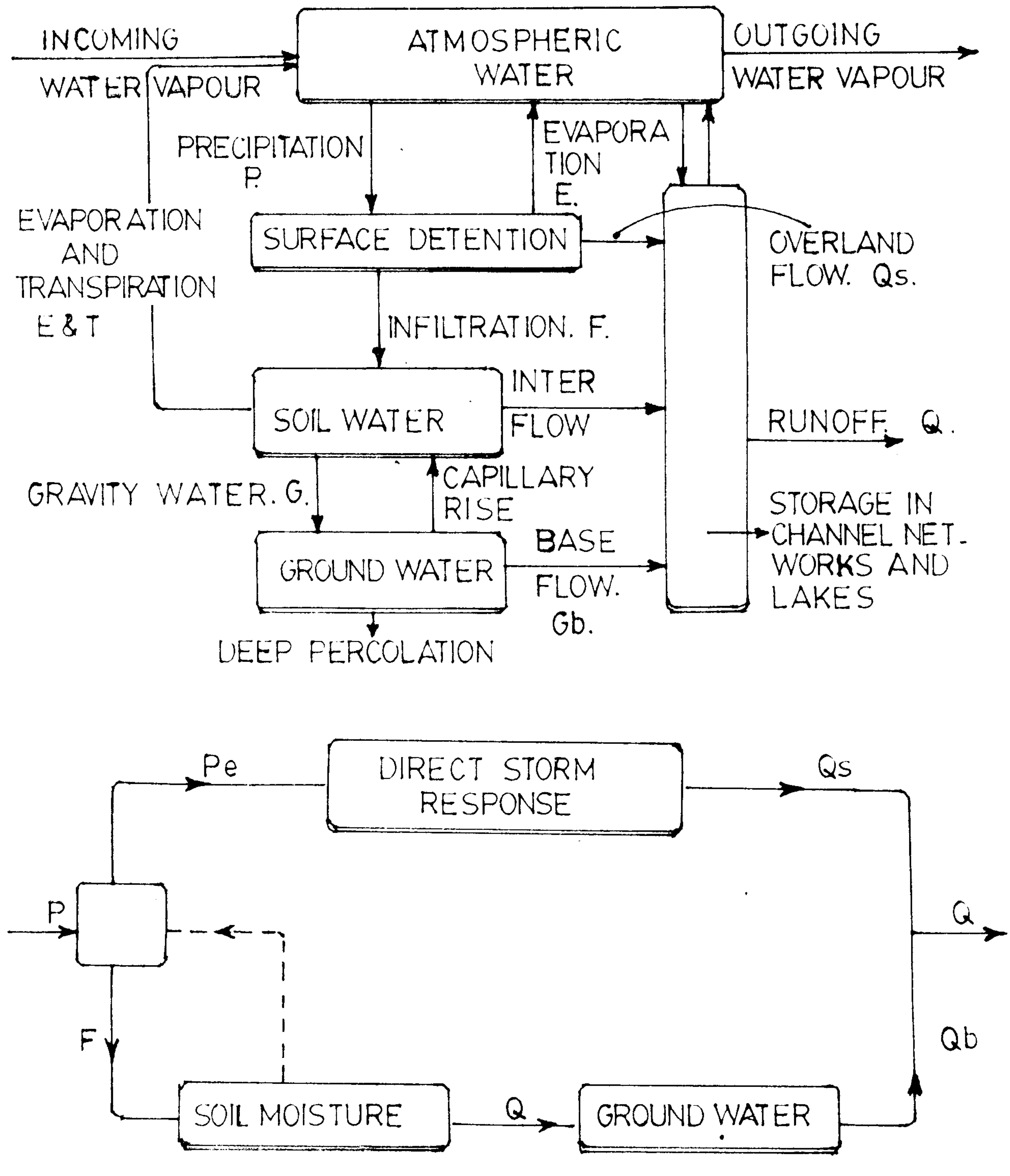


FIG.2.2.A SYSTEMS REPRESENTATION OF A BASIN WATER BALANCE (after Dooge)

basins, water storage in lakes, reservoirs, swamps and glaciers and the dynamics of the water balance of forests and irrigated and draned land would be difficult. In the case of lakes, reservoirs, swamps, ground water basins and mountain glacier basins the complexity of the computation would dependon the ease or difficulty of accurately measuring and computing components such as lateral inflow, variation in water storage, precipitation on the water surface etc.

2.4. Main components of the water balance equation.

2.4.1.1. Precipitation

General

Precipitation from the atmosphere to the ground surface would occur in different forms such as drizzle, rain, glaze, sleet, snow and snow flakes, hail, dew, frost, fog, mist etc.

2.4.1.2. Measurement of rainfall

Rainfall in a catchment would be measured by a net work of rain gauges and recorded on a daily basis. Non recording rain gauges (Standard rain gauge of IMD), recording rain gauges (tipping bucket, weighing or float type), automatic radio reporting rain gauges or radar could be used for measurement of rainfall at a station.

WMO (1975) recommended that the minimum rain gauge density required for flat regions of temperate mediterranean and tropical zones would be one station per 600-900 sq.km., relaxable to one station per 600-3000 sq.km. for countries with limited funds, population or other factors such as lack of communication. For mountainous regions of temperate mediterranean and tropical zones the corresponding figures would be 1 per 100-250 sq.km. and 1 per 250-1000 sq.km. respectively. For arid or polar zones, a minimum density of 1 per 1500-10000 sq.km. has been recommended.

Linsley _et al_ (1969) recommended the following minimum rain gauge densities. (Table 2.1)

Table 2.1 Recommended minimum rain gauge densities.

Area (sq.km.)	No.of rain gauging Stations
0-75	1
75-150	2
150-300	3
300-550	4
500-800	5
800-1200	6

ISI (1968) recommended a statistical method for determining the optimum number of rain gauges in order to facilitate determination of average catchment rainfall within a certain percentage of error. Kagan (1966) introduced a spatial correlation function approach to design a rain gauge net work. Sreedharan & James (1978) used this approach for the design of a rain gauge net work for the Chaliyar river basin in Kerala.

Kaur & Upadhyay (1987) observed that the precipitation in mountainous regions had higher spatial variability and that the correlation between precipitation series recorded at two stations distant 's' apart decreases with 's' at a faster rate than in plain region. A procedure for the evaluation of net work density for mountainous catchments was developed and then illustrated for the Beas catchment.

2.4.1.3. Estimation of Areal Rainfall

Hall (1972) has reviewed 15 different methods used for estimating areal rainfall and a selection of these with comments has been presented by Pierre humbert (1975).

Table 2.2. Different methods used for estimating areal rainfall.

Method	Comment
Isohyetal average	Most accurate method available. Time consuming. Can be computerised with some loss of accuracy.

Arithmetical average	Simple & easy. Requires fairly dense & relatively even geographical distribution of stations to produce reliable results.
Thiessen Polygon average	Allows for variation in station density, but cannot make allowance for ungaged areas of maximum rainfall which occur frequently. Time consuming. Weighting factors must be recomputed for every combination of reporting stations. Can be readily computerised without loss of accuracy.
Abbreviated Isopercentual average	The Thiessen weight for each station is modified by the ratio of the main catchment average rainfall to the mean rainfall over the Thiessen Polygons. Allows a standard adjustment for orographic and other effects which do not change greatly from storm to storm.
Orographic Thiessen Polygon average	Thiessen polygons are determined by elevation rather than by distance between stations.

Multiple regression Analysis average	Weighting factors are based on multiple regression co-efficients which are obtained from a multiple regression equation using the least squares method. Areal rainfall in the Isohyetal method is the dependent variable and station rainfalls are the independent variables. Simple to use particularly in a computerised model.
Percent to mean annual catchment average	Isopercentuals of mean annual rainfall are constructed and the storm rainfall is calculated as a percentage average.
Variation of the abbreviated isopercentual average	Similar to the Thiessen method except that the weighting factors are calculated from the contribution to the mean annual rainfall over the catchment from each Thiessen polygon.
Inclined Plane average	Uses the centroid height of planes formed by erecting verticals corresponding to the rainfall at each gage at the apex of the triangle.

as a polynominal function of its location vector.

2.4.2. Infiltration.

This would include movement of water into the soil through the surface of the ground. The rate of infiltration would depend on a number of factors including type and state of soil, ground cover etc.

2.4.3. Evaporation, Transpiration and Evapotranspiration.

2.4.3.1. Evaporation.

Evaporation could be defined as the process by which a liquid is changed to a vapour or a gas. The fundamental principle of evaporation from a free water surface was enunciated by Dalton in 1882. According to him,

$$E = (es-ed)\ f(u) \qquad \text{---} \qquad (2.4)$$

Where E = evaporation, es = saturation vapour pressure at the temperature of the evaporating surface in mm. of Hg., ed = Saturation vapour pressure at the dew point temp. of atmosphere is mm. of Hg, and f(u) = a function of wind-velocity.

A number of empirical formulae have been developed based on Dalton's Law to estimate evaporation. (Chow, 1964).

Evaporation could be measured using evaporation pans (USWB Class A Land pan, US Bureau of Plant Industry Sunken

Centre of Gravity average	Uses the inverse of the distance of a station from the centroid of the catchment of the appropriate weighting factor. Falls down when there is a station at or near the centroid as this station has a weighting factor approaching infinity.
Correlation Thiessen Polygon average	Uses polygons constructed to points where the correlation co-efficients between stations are equal.
Correlation influence function analysis average.	Similar to the Correlation Thiessen Polygon method but uses the assumption that interstation correlation declines with the distance from the station.
Trend surface analysis average.	Involves the fitting of a polynominal surface to the rainfalls at the observation points. Surface is used to estimate the average catchment rainfall.

Upadhyay & Adhikari (1986) developed a polynominal method for estimation of catchment rainfall. This was based on the presumption that point rainfall could be expressed pan, GGI 3000 pan, Colorado Sunken pan or US Geological Survey Floating pan), or atmometers (Livingston, Bellari or Piche Atmometer). Energy balance, water balance and mass transfer methods could also be used. When pans are used, the observed evaporation should be multiplied by appropriate co-efficients to get the evaporation from land or water surfaces.

2.4.3.2. Transpiration

Transpiration could be defined as the process by which water vapour leaves the plant body and enters the atmosphere. For measuring transpiration, phytometers could be used.

2.4.3.3. Evapotranspiration

Evapotranspiration could be defined as the combined amount of water evaporated from the soil surface and transpired from the soil moisture storage through vegetation. Evapotranspiration could be estimated by using lysimeters, or by field experimental plots, soil moisture depletion studies and water balance method. Empirical formulae could also be used.

2.4.3.3.1. Potential evapotranspiration (PET)

Thornthwaite (1948) defined Potential Evapotranspiration as the evapotranspiration from a large vegetation covered land surface with adequate moisture at all times. He assumed an exponential relationship between mean monthly temperature and mean monthly consumptive use, based on experience in the central and eastern United States. The formula developed was

$$e = 1.6 \left(\frac{10t}{I}\right)^{a} \qquad - \qquad (2.5)$$

where e = unadjusted PET in cm/month for months of 30 days each and 12 hrs. day time., t = mean air temp. in °C, I = annual or seasonal heat index, the summation of 12 values of monthly heat indices (i) where $i = \left(\frac{t}{5}\right)^{1.514}$ and a = empirical exponent computed by $a = 0.000000675\, I^3 - 0.0000771\, I^2 + 0.017923\, I + 0.49239$. The unadjusted values of PET would be corrected for actual day light hrs. and days in a month.

2.4.3.3.2 Crop Evapotranspiration.

Penman (1948) proposed an equation for evaporation from open water surface based on a combination of energy balance and sink strength.

$$E_o = \frac{Qn \cdot \Delta + \gamma\, Ea}{\Delta + \gamma} \qquad - \qquad (2.6)$$

where E_o = evaporation from open water suffece in mm/day.

Δ = Slope of saturation vapour pressure vs temperature curve $\left(\frac{dea}{dT}\right)$ at the mean air temperature Ta in mm of Hg per °C., ea = saturation vapour pressure of the evaporating surface in mm of Hg at mean air temperature Ta, Ta = mean air temperature in °K = 273 + °C, Qn = net radiation (mm. of water) $= Qa \cdot (1-r) \cdot \left(0.18 + 0.55 \frac{n}{N}\right) - \sigma Ta^4 \left(0.55 - 0.092\sqrt{ed}\right) \cdot \left(0.10 + 0.90 \frac{n}{N}\right)$ where r = reflection co-efficient of evaporating surface (0.06 for open water surface), Qa = Angot's value of mean monthly extra terrestrial radiation mm of

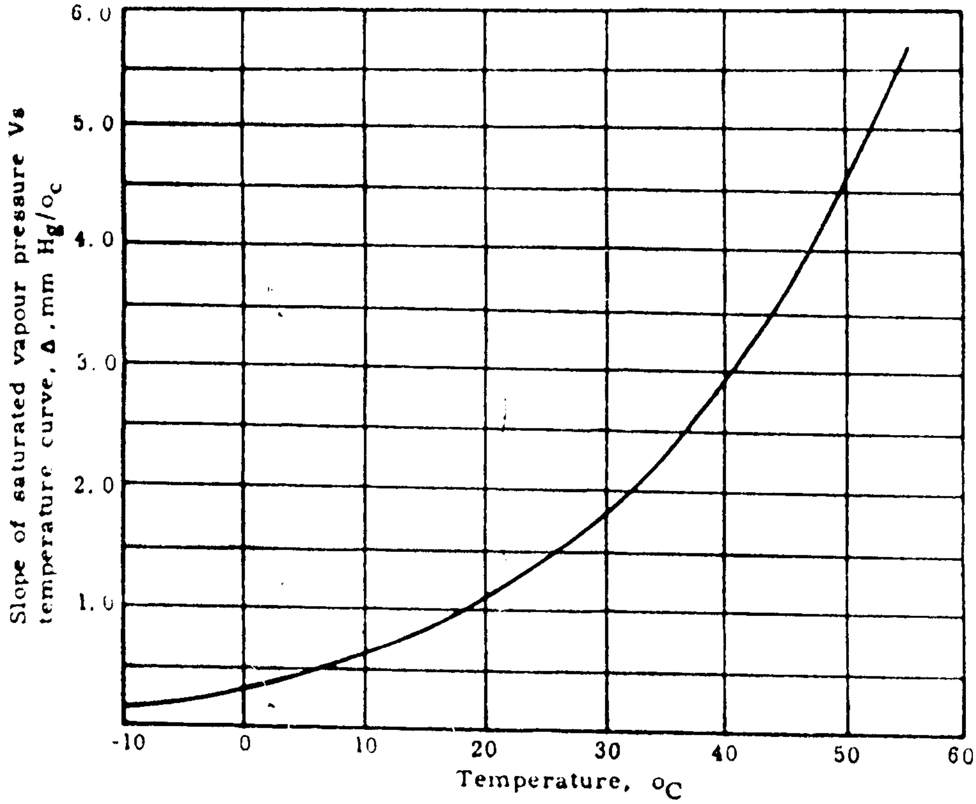
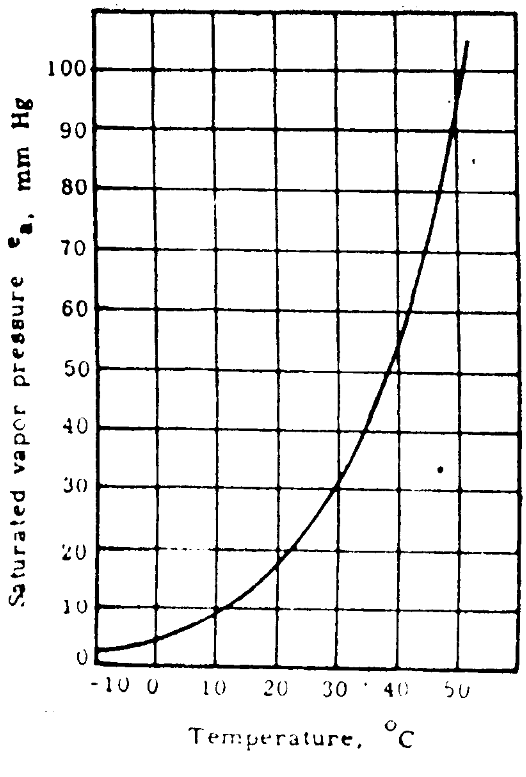


Fig. 2.3 Slope of saturated vapour pressure vs. temperature curve.

Fig. 2.4 Saturated vapour pressure versus temperature.



water/day, $\frac{n}{N}$ = ratio between actual and possible hrs. of bright sunshine, σ = Stefan Boltzman constant, ed = Saturation vapour pressure of the atmosphere in mm Hg at dew point temperature = $\frac{RH\ mean}{100}$ X ea where RH mean = mean relative humidity, γ = Psychrometric constant or the ratio of specific heat of air to the latent heat of evaporation of water, Ea = an aerodynamic component = 0.35 (ea - ed) (1 + 0.0098 u_2) and u_2 = wind speed in miles/ day at 2m. ht. = u_1 $\left(\frac{\log 6.6}{\log h}\right)$, where u_1 = wind speed in miles/day at any other height h in ft.

ET crop = K.ET, where K = crop co-efficient.

Blaney and Criddle (1950) observed that the amount of water consumptively used by crops during their growing seasons closely correlated with mean monthly temperatures and day light hours. The relationship could be stated as

$$U = KF = \sum kf = \sum u = \sum \frac{ktp}{100} \quad - \quad (2.7)$$

where U = seasonal consumptive use of water by the crop for a given period in inches, u = monthly consumptive use in inches, K = emprical seasonal consumptive use co-efficient for the growing season, F = sum of mean monthly consumptive use factors (f) for the growing season, k = empirical consumptive use crop co-efficient for the month, t = mean monthly temp. °F and p = monthly day light hrs.

expressed as percentage of day light hrs. of the year.

The relationship between USWB Class A pan evaporation and crop evapotranspiration could be expressed as

Crop Evapotranspiration = Panevaporation X Crop factor — (2.8)

Sharma and Dastane (1968) developed a Sunken screen evaporimeter which gave evaporation values close to the crop evapotranspiration.

Doorenbos & Pruitt (1975) rejected the use of crop co-efficients (K) in the original equations. They introduced the concept of reference crop evapotranspiration (ETo), which was defined as the rate of evapotranspiration from an extensive surface of 8 cm. to 15 cm. tall green grass cover of uniform height, actively growing, completely shading the ground and not short of water. After ETo was computed by any of the four methods presented, one set of crop factors (kc) could be used to determine crop evapotranspiration ET crop.

$$ET_{crop} = kc \times ETo \quad - \quad (2.9)$$

The recommended relationship, modifying the original Blaney Criddle equation, could be expressed as

$$ETo = C \left[p\ (0.46T + 8) \right] \text{ mm/day} \quad — \quad (2.10)$$

where T = mean daily temp. in °C over the month considered, P = mean daily percentage of total annual day time hrs. obtained from Appendix 1 for a given month and latitude, c = adjustment factor which depends on minimum relative humidity, sunshine hours and day time wind estimate. Fig. 2.5 could be used to estimate ETo graphically.

According to the Radiation Method,

$$ETo = C\ (WRs)\ \text{mm/day} \qquad \text{--} \qquad (2.11)$$

where Rs = Solar radiation in equivalent evaporation in mm/day = Ra $(0.25 + 0.50\ \frac{n}{N})$, W = weighting factor which depends on temperature and altitude (Appendix 7) and C = adjustment factor which depends on mean humidity and day time wind conditions, $\frac{n}{N}$ = ratio of actual measured bright sunshine hours to maximum possible sunshine hrs. and Ra = extra terrestrial radiation expressed in equivalent evaporation in mm/day. Values of N and Ra for different months and latitudes could be determined from Appendix 2 and 3 respectively and ETo could be determined graphically from Fig. 2.6.

The modified Penman equation suggested to determine ETo involves a revised wind function term.

$$ETo = C\ \left[WRn + (1-W)\ f\ (u)\ (ea - ed)\right]\ \text{mm/day} - (2.12)$$

Radiation term Aerodynamic term

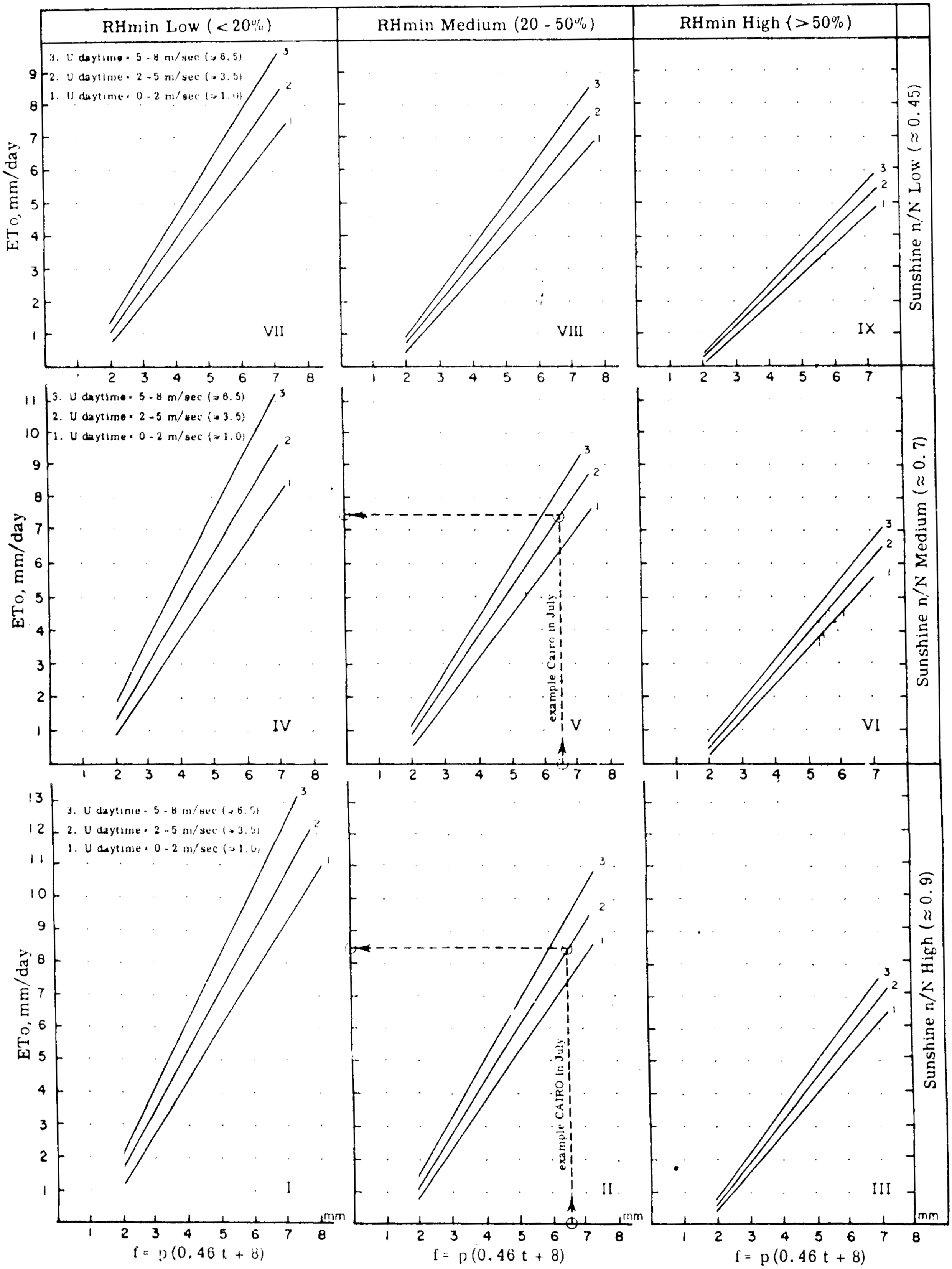


Fig. 2.5 Prediction of ETo from Blaney-Criddle f factor for different conditions of minimum relative humidity, sunshine duration and day time wind.

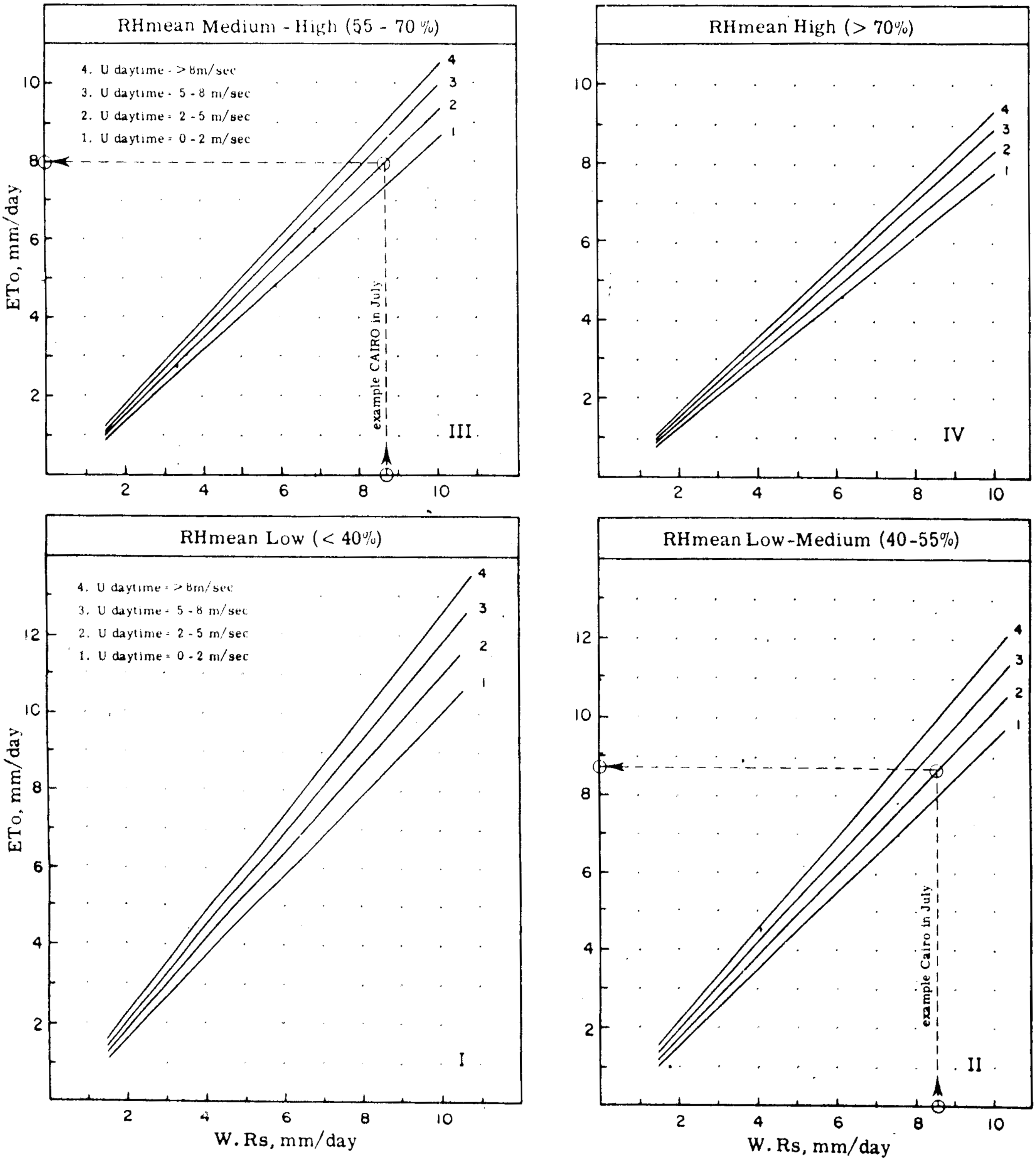


Fig. 2.6 Prediction of ETo from W. RS for different conditions of mean relative humidity and day time wind.

where, ea = saturation vapour pressure in m. bar at mean air temperature in °C (Appendix 4), ed = mean actual vapour pressure of air in m. bar = ea x $\frac{RH\ mean}{100}$, where RH = relative humidity, f(u) = a wind related function (Appendix 5), (I-W) = weighting factor which depends on wind and humidity (Appendix 6), and Rn = net radiation = the net incoming shortwave solar radiation (Rns) - the net long wave radiation (Rnl) Rns = Rs (1- α) (0.25 + 0.5 $\frac{n}{N}$) where α = reflection co-efficient = 0.25 for most crops, Rnl = f(t). f(ed). f($\frac{n}{N}$) the values of which have been given in Appendices 9, 10 and 11 respectively, and C = adjustment factor to compensate for the effect of day and night weather conditions (Appendix 12).

The last of the four recommended methods was the modified Pan Evaporation Method. USWB Class A pans or Sunken colorado pans could be used.

$$ETo = K_p \times Epan \ \ mm/day \qquad - \qquad (2.13)$$

where Epan = pan evaporation in mm/day (mean daily value of the period considered) and Kp = pan Co-efficient.

Doorenbos & Pruitt (1975) also said that the prediction of evapotranspiration from non-cropped or bare soils closely followed the method shown for field crops initial stage.

(Fig. 2.7). For light and heavy textured soils kc values might need a downward adjustment by about 30% and an upward adjustment by 15% respectively. kc values for aquatic weeds and co-efficients relating open water evaporation (Eo) to ETo were also presented. (Appendix 16). For reservoirs and lakes with depth greater than 25 m., k values might be 20% to 30% lower in spring and early summer and 20% to 30% higher during late summer.

2.4.3.3.3. Studies on suitability of equations to estimate evapotranspiration.

Brut saert (1965) revealed that the evapotranspiration measured in the lysimeter correlated better with the evapotranspiration computed by the Penman or Blaney Morin equations.

In summarising various studies, Hernandez (1970) concluded that to produce satisfactory results water balance models in tropical regions should have a humidity/wind term to serve as an index of the mass transfer component and an advected energy term for the effect of warm dry winds which prevail during the dry season. None of the empirical equations could be considered entirely satisfactory in this respect.

Hossein (1969) has suggested that empirical equations like the Thornthwaite, Blaney - Criddle and Lorry - Johnson

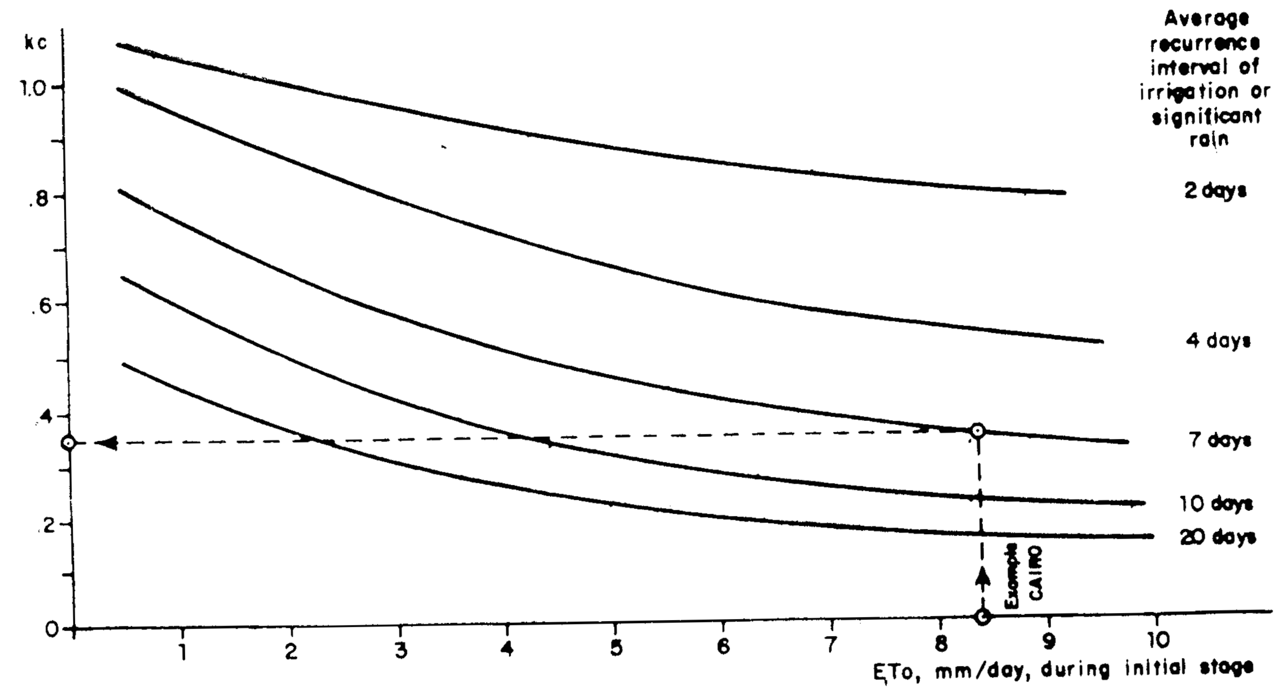


Fig. 2.7 Average kc value for initial crop development stage as related to level of ETo and frequency of irrigation and/or significant rain

would give a higher figure for the evapotranspiration which in turn would lead to under utilising the available water resources.

Schulz and Hossain (1970) made a study of monthly rainfall and runoff over a 1,05,000 sq.km. watershed in Nortern Thailand. Comparison of the computed runoff with the observed runoff from the watershed showed that the model most nearly predicted the observed runoff when the Penman or Blaney - Morin methods were used to estimate evapotranspiration.

Doorenbos and Pruitt (1975) concluded that the modified Penman method would offer the best results with minimum possible error of ± 10% in summer and upto 20% under low evaporative conditions. The pan method was graded next followed by Radiation and modified Blaney - Criddle methods in that order.

Rao and Vamadevan (1986) studied the relative evaporation rates from class A open pan, GGI 3000 and Colorado Sunken pans under humid tropical conditions and compared the observed evaporation values with that estimated by the modified Penman equation. The seasonal variation of evaporation was found to be between 4 mm and 10 mm/day and variation in evaporation due to the type of pan used was upto 3 mm/day. The estimated evaporation values were within 2 mm/day from the measured values.

2.4.4. Stream flow or Runoff

2.4.4.1. General

Runoff could be defined as that part of the precipitation, as well as any other flow contributions, which appear in surface streams of either perennial or intermittent form. This flow collected from the drainage basin or watershed would appear at an outlet of the basin. From total precipation to total runoff the different terms could be related as shown in Fig. 2.8.

2.4.4.2. Measurement of stream flow.

Stream flow could be determined by the following methods.

1. Measurement of river stage using various types of stage recorders and then employing stage discharge curves.

2. Measurement of mean velocity of flow at a cross section of the river using current meters, floats, pitot tube etc. and then computing discharge by mid section, mean section etc. methods.

3. By salt dilution and radio active tracer methods.
4. By using oxygen polarography, wire anemometer, electro-magnetic or ultrasonic flow meters.

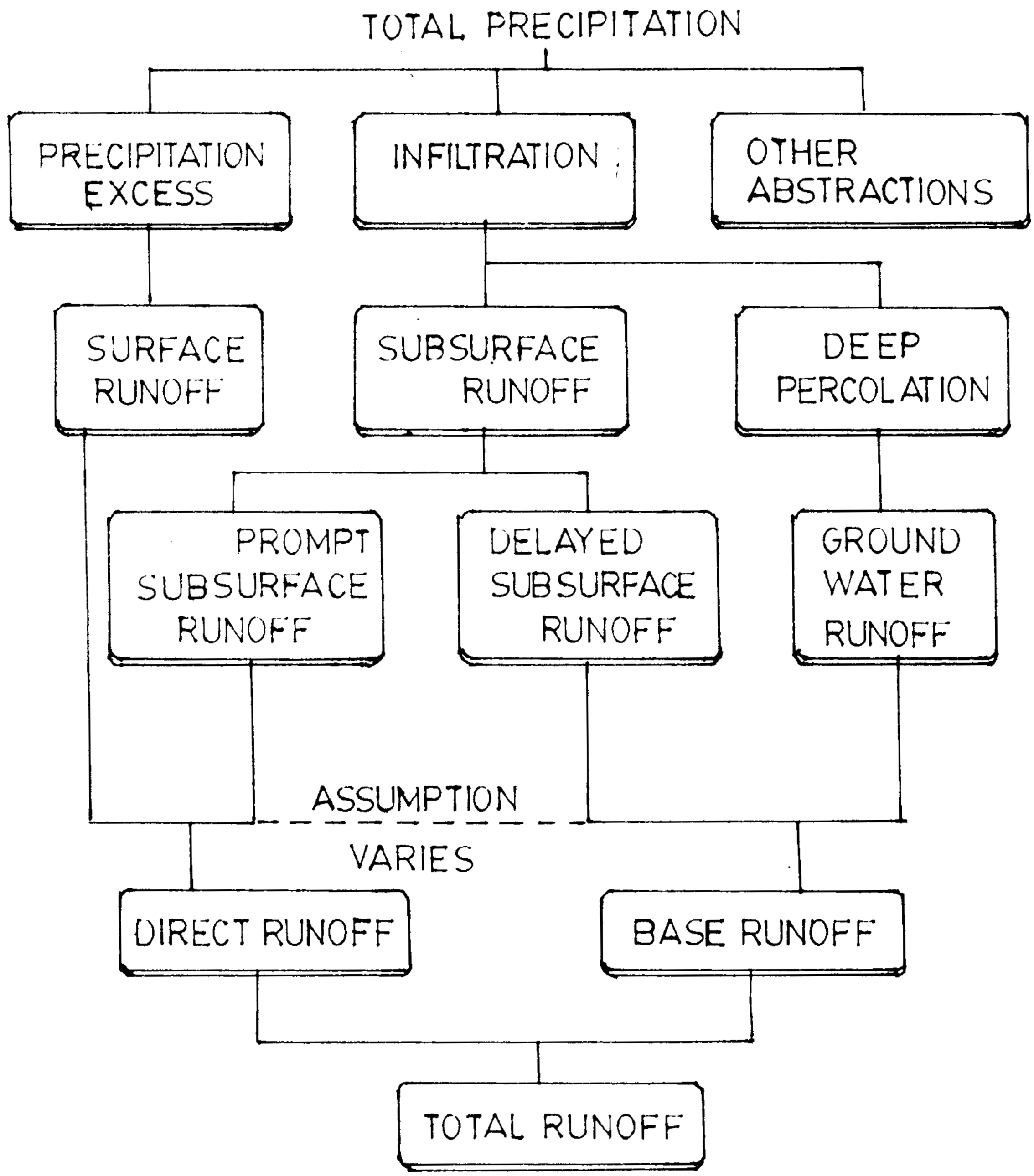


FIG. 2.8. RAINFALL - RUNOFF SYSTEM

5. By employing empirical formulae.

6. By unit hydrograph method.

Inglis & De' Souza (1930) made a critical study of rainfall and runoff of the Bombay - Deccan area which is criss - crossed by Tapi, Godavari, Bhima, Nira, Krishna, Ghata prabha & Wardha rivers. For basins in the Western Ghats, having large catchments with rainfall varying from 30 inches to 200 inches it was found that,

$$\text{Runoff} = 0.85 \times \text{rainfall} - 12 \text{ inches} \qquad - (2.14)$$

For non Ghat areas,

$$\text{Runoff} = \frac{\text{Rainfall} - 7 \text{ inches}}{100} \times \text{Rainfall} \qquad - (2.15)$$

Khosla (1949) derived a rainfall runoff formula based on the rational concept for the Bhakra Project. Runoff was taken as the residual of rainfall after deduction of losses due to evapotranspiration. According to him,

Mean monthly runoff Rm = Mean monthly rainfall

Pm - Mean monthly ET Loss Lm - (2.16)

$$\text{where } L_m = \frac{(T_m - 32)}{9.5}$$

Tm = mean monthly temp. in °F (Tm 40°F).

Taking mean annual rainfall as 119 cm, the estimated the total water potential of the country as $1.7 \times 10^6 Mm^3$.

Dhar & Rakecha (1975) reported that studies conducted in the Mahanadi, Koyna, Damodar & the Mayurakshi River basins

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Dhar & Rakecha (1975) reported that studies conducted in the Mahanadi, Koyna, Damodar & the Mayurakshi River basins gave the following relationship.

Runoff is inches at Koyna = 0.7145 (Mahandi Rainfall) – 6.7461 – (2.17)

Empirical formulae developed for certain other drainage basins are given below:

Ganga Basin, $R = 2.14\ P^{0.64}$ – (2.18)

Yamuna Basin (Delhi) $R = 0.14\ P^{0.11}$ – (2.19)

Rihand Basin (UP) $R = P - 1.17\ P^{0.86}$ – (2.20)

Chambal Basin (Rajasthan) $R = 120\ P - 4945$ – (2.21)

Tawa Basin (MP) $R = 90.5\ P - 4800$ – (2.22)

Tapti Basin (Gujarat) $R = 435\ P - 17200$ – (2.23)

A.N. Khosla's formula for North India;

$$R = P - \frac{T}{3.74} \qquad - (2.24)$$

Lacey's formula for

Indo-Gangetic plains, $$R = \frac{P}{\left(1 + \frac{304.8}{P}\left(\frac{F}{S}\right)\right)} \qquad - (2.25)$$

where R = average annual runoff in cm; P = average annual rainfall in cm. and T = mean annual temp. in °C for the entire drainage basin, F = monsoon duration factor varying between 0.5 to 1.5 and S = catchment factor depending on slope and varying from 0.25 for flat areas to 3.45 for hilly areas.

Several investigators have presented rainfall runoff relationships in the form of curves and tables such as

(1) Binnies' percentages (Tables) for catchments in Madhya Pradesh.

(2) Strange's curves and tables for Bombay - Deccan catchments.

(3) Barlows' tables for runoff co-efficient in U.P.

Kerala PWD (1974) have presented empirical formulae for estimating annual runoff for some river basins in Kerala.

Manjeshwar - Uppala Basin
Shiriya Basin : $R = 0.63\ P_1 + 0.37\ P_2 - 51.65$ - (2.26)

Chandragiri Basin -
Ramapuram Basin
Valapattanam Basin : $R = 0.68\ P_1 + 0.32\ P_2 - 42.08$ - (2.27)

Kuttiadi Basin : $R = 0.6\ P_1 + 0.4 P_2 - 33.40$ - (2.28)

The Greater Chaliyar Basin : $R = 0.72\ P_1 + 0.28\ P_2 - 53.50$ (2.29)

Periyar Basin : $R = 0.76\ P_1 + 0.24\ P_2 - 27.76$ (2.30)

Muvattupusha Basin : $R = 0.79\ P_1 + 0.21\ P_2 - 41.66$ (2.31)

Meenachil Basin : $R = 0.78\ P_1 + 0.22\ P_2 - 32.71$ (2.32)

Manimala Basin : $R = 0.73\ P_1 + 0.27\ P_2 - 33.37$ (2.33)

Pamba Basin : $R = 0.67\ P_1 + 0.33\ P_2 - 47.89$ - (2.34)

Achenkoil Basin : $R = 0.67\ P_1 + 0.33\ P_2 - 45.00$ - (2.35)

Kallada Basin : $R = 0.97 P_1 + 0.03 P_2 - 53.90$ - (2.36)

R = Annual runoff in Mm^3, P_1 = Rainfall in the year in Mm^3 and P_2 = previous Year's rainfall in Mm^3.

2.4.5. Soil Moisture

To obtain data for the detailed computation of water balance of river basins, measurement of soil moisture should be done. The changes of water storage in the aeration zone should be determined from observations of data on the moisture content in the upper layer of soil at such period of time as a season, a month or a ten day period.

UNESCO (1984) published guidelines regarding observation of soil moisture. Observations should be made from a net of points well distributed over the observed area in order to obtain mean values of soil moisture storage in the basin with a given accuracy. Soil moisture surveys would be made in order to establish the frequency of observations that are necessary, to determine the criteria for their accuracy and to assess how representative the points are. Multiple moisture measurements should be carried out in a short period of time (one to two days) to define the natural variation in a given area. This would determine the mean square deviation of water storage values for an observed soil layer. The mean square deviation of soil moisture storage (ΔSy) would depend on the variability of soil, the vegetation conditions and relief. The approximate values of ΔSy for basins of different complexity would be as follows.

1. Simple basin; relief, soil and vegetation are of the same type over the whole basin;

   ΔSy = 10 mm to 25 mm.

2. Complex basin; various parts differ in relief, soil and vegetation type (gentle and steep slopes, field with virgin soil and with agricultural plants, afforested or bushed in some places.

   ΔSy = 25 mm to 50 mm.

3. Very complex basin, its different parts are characterised by a wide variety of relief, soil and vegetation. (broken country, soils of loamy to sandy types, forest, shrubbery, field, virgin lands, common pasture)

   ΔSy = 50 mm to 90 mm.

The number of observation points needed for the determination of the mean moisture content in the upper soil layer for basins of different complexity would be as given in Table 2.3.

Table 2.3 - No. of observation points necessary for determination of mean moisture storage.

Basin complexity	Mean moisture storage determinational error (80% probability)		
	± 5 mm	± 10 mm	± 15 mm
Simple	10 - 40	4 - 12	3 - 7
Compex	60 - 70	17 - 44	10 - 20
Very Complex	80 - 240	62 - 135	30 - 60

2.4.6 Ground water

The water located in the sub surface strata of the earth would be called Ground Water. Sources of replenishment of ground water include precipitation, snowmelt and runoff. Occurence of outflow of water from aquifers could be due to concentrated spring flow, diffused seepage flow, or evapotranspiration. Man induced outflow might be due to (1) further development of natural outlets and (2) the construction of wells, boreholes or tunnels.

Ground water and surface water are inter related although their watershed bounderies do not necessarily coincide.

2.5. Water balance of water bodies.

UNESCO (1974) published guidelines regarding methods that might be used for water balance studies of various water bodies. This has been summarised in this section.

2.5.1. River basins.

2.5.1.1. General

River basins form the main subject of water balance research and computation.

In the water balance equation of river basins all the balance elements are mean values for the basin. For computing the water balance of large river basins (hundreds of thousand km^2) with different physiographic features, the basin should be divided into an appropriate number of areas (sub basins) for which water balance computations should be made individually. The water balance of the whole basin is computed from weighted average values of main water balance components of sub basins. In the case of small river basins (1000 km^2 - 1200 km^2) characterised by balance regime, grass land, forest, irrigated or drained lands, swamps, glaciers etc. the components of the water balance should be determined taking into account the specific water balances of these areas, provided these land types cover more than 20% to 30% of the total basin area. For mountainous river basins, the effect of altitudinal zones on the distribution of water balance components should be considered.

2.5.1.2. Mean water balance of a river basin.

The mean water balance equation of a closed river basin for a longterm period (Calendar or hydrologic year) would be of the form.

$$P - Q - E = 0 \qquad - (2.37)$$

In the absence of significant ground water exchange with adjoining basins or the sea, the value of mean annual evaporation from the basin could be computed as

$$\bar{E} = \bar{P} - \bar{Q}$$

If the river water is used on a large scale for primary or secondary industry, the term Q_{α} for water removal for economic purposes and the term Q_{β} for return water should be introduced in equation 2.37.

Nauka (1969) and Lvovitch (1973) used a differentiated water balance equation for a long term period, in which the total runoff Q was seperated into surface runoff (Q_s) and underground runoff (Q_u). Equation (2.37) was modified as

$$P - Q_s - Q_u - E = 0 \qquad - (2.38)$$

Hence, $W = P - Q_s = Q_u + E$; $K_u = \frac{Q_u}{W}$; $K_E = \frac{E}{W}$ - (2.39) where N is the total infiltration (gross moistening); K_u is the co-efficient of river flow due to ground water, indicating the proportion of annual infiltration forming underground runoff into rivers and K_E the evaporation co-efficient. The total infiltration of an area, with the exception of losses of rainfall and snow melt water by infiltration, would include evaporation from the water surface and evaporation of water wetting the drainage basin surface and accumulating in micro & meso depressions. These two sources of precipitation losses would be quite high in regions with a high percentage of lakes and forests particularly in flat drainage basins with a great number of depressions.

The mean monthly or seasonal water balance equation of a closed river basin would be

$$P - Q - E - \Delta S_L - \Delta S_{ch} - \Delta S_{sn} - \Delta M - \Delta G - Q_\alpha + Q_\beta - \eta = 0 \quad - \qquad (2.40)$$

When solving this equation the mean variation of moisture storage in the basin should be considered.

For an unclosed river basin, the surface inflow Q_{SI} and underground inflow Q_{UI} from adjacent areas should be added in equations (2.37) to (2.40). The balance discrepancy $\eta = \Delta M' + \eta'$ where $\Delta M'$ = variation of water storage in the soil mantle beneath the upper 1m. layer and η' = unassigned balance discrepancy.

2.5.1.3. Forests and Forested basins.

Smith et al (1974) outlined the scientific and practical importance of water balance studies and computations relating to forest plots.

(1) Necessity of determining the hydroclimatic role of the forest and of assessing the effect of forest cutting, reforestation and forest development measures on the water regime and water resources of forested river basins.

(2) Estimation of possible changes in the transport of water in the atmosphere due to deforestation of large areas.

Water balance studies of forests and forested river basins should be carried out on water - balance plots, with an area ranging from several hundred to several thousand sq. m. located within the forest. The plots should be artificially isolated from the surrounding area by a water shed divide wall from the surface down to the aquiclude. Depending on the type of vegetation & soil, one or several plots, representative of the surrounding forest terrain should be used.

The general water balance equation for a closed forest terrain would be

$$P_1 + P_2 + P_3 - Q_{so} - Q_{uo} - E_1 - E_2 - E_3 - S_s - M - G - = 0 \quad - \quad (2.41)$$

where P_1 = precipitation over the forst terrain penetrating through the canopy, P_2 = precipitation flowing down the stems of trees, Q_{so} and Q_{uo} the surface and underground outflow respectively from the forest terrain, E_1 = evaporation under the canopy, E_2 = evaporation of precipitation intercepted by the canopy, E_3 = transpiration of trees, S_s = water storage variation on the forest terrain surface and = $M' + Q_{up} +$ ' where Q_{up} = percolation beyond the zone of saturation.

Precipitation penetrating through the canopy P_1 and precipitation flowing down the tree stems P_2 could be determined by special methods. (Sopper and Lull, 1967., Luchshev, 1970).

$$P_2 = P - P_1 - P_3 \quad - \quad (2.42)$$

Kitson <u>et al</u> (1984) recommended that precipitation gauges should be installed in the centre of forest clearings, where the elevation above the horizontal line from the gauge orifice to the top of the nearest trees is 30° to 50° for coniferous forest & 78° for decidious forest.

Penman (1967) proposed that evaporation from forest terrain could be determined by methods of water balance, heat balance and turbulent diffusion.

Evaporation from forest terrain could be expressed as

$$E = E_1 + E_2 + E_3 \qquad - \qquad (2.43)$$

Evaporation under the canopy

$$E_1 = E_1' + E_2' + E_3' \qquad - \qquad (2.44)$$

where E_1' = Evaporation from the soil, E_2' = evaporation of precipitation intercepted by the ground water, moss, low bushes, grass and E_3' = ground cover transpiration.

Fedorov (1969) found that depending on the type of forest and the taxonomic characteristics of the forest stands, composition, age, density etc. the ratio between the evaporation components would vary. However transpiration and evaporation of precipitation intercepted by the canopy constituted a major part of the total evaporation.

To determine evaporation under the canopy, weighing evaperimeters should be installed according to the geobotanic map of the forest plot, and the evaporation should be computed as a weighted mean.

$$E_2 = P - P_1 - P_3 - P_2 \qquad - \quad (2.45)$$

Tree stand transpiration on the forest plot could be determined by the equation.

$$E_3 = P_1 + P_3 - Q_{so} - Q_{uo} - U_{up} - E_1 - \Delta S_s - \Delta M - \Delta M' - \Delta G \qquad - \quad (2.46)$$

For the computation of evaporation from forest terrains using the heat balance method, initial data may be obtained by means of gradient masts installed in the forest and equipped with meteorological and actinometric instruments. The masts should be located in the forest at a distance from the forest edge equal to 50 to 60 times the tree height.

For forested basins, the principal aspects of water balance study would be the same as that for forest plots.

2.5.1.4. Irrigated and drained land.

Irrigated areas could be subdivided hydrologically into well drained lands with underground runoff predominating among outflow components of the balance and poorly drained lands without underground runoff. On the basis of climatic factors it would be possible to distinguish between the arid irrigation areas, where irrigation water is the predominant water balance component and the zone of approximate water balance, where precipiation may be as important as irrigation water.

The water balance equation for an irrigated field from the soil surface down to the aquiclude, for any time interval could be expressed as

$$P + / I_3 - I_4 - I_5 / + / I_1 + I_2 / + / Q_{SI} - Q_{SO} / + / Q_{MI} - Q_{MO} / + / Q_{UI} - Q_{UO} / + / Q_{U1} - Q_{U2} / - / E + E_1 / - \Delta S - \eta = 0 \qquad - (2.47)$$

where I_1 and I_2 indicate water flow due to filtration from arterial and irrigation canals, I_3 = the inflow of irrigation water on the field surface, I_4 = outflow of irrigation water from the field, I_5 = irrigation water removed from canals, Q_{SI} and Q_{SO} indicate natural inflow and outflow of surface water, Q_{MI} and Q_{MO} indicate the inflow and outflow of soil water in the unsaturated zone, Q_{UI} and Q_{UO} indicate the inflow and outflow of shallow ground water, Q_{U1} and Q_{U2} indicate the inflow and outflow of ground water from lower aquifers, E = evaporation from the land surface, E_1 = evaporation from the water surface in canals and ΔS = water storage variation on the surface and underground.

$$\Delta S = \Delta S_{sn} + \Delta S_s + \Delta M + \Delta G \qquad - (2.48)$$

where S_{sn} and S_s are the water storage variation on the soil surface due to snow accumulation and water accumulation in the depressions respectively. ΔS_{sn}, ΔS_s and ΔM could be computed as the difference between the values of the respective water balance elements at the end and at the beginning of the balance period and ΔG could be computed by applying the water balance equation for ground water.

Evaporation, ground water discharge into the unsaturated zone and ground water recharge due to infiltration of precipitation and irrigation water would be determined using lysimeters. Where the depth to the water table is about 3 m to 5 m weighing evaporimeters should be used. Evaporation could also be computed by the heat balance method. Phenological observations would aid in the evaluation of lysimetric observations and in the application of the results to agricultural fields, taking into account the state and density of crops in the monoliths and the field.

Ground water inflow and outflow could be estimated by hydrogeological methods. In the case of ground water recharge under pressure, a net work of observation wells and piezometers should be set up over the plot, taking into account the topography, hydrogeological conditions, distribution of water collecting under drainage canals and irrigation net works etc. and the seperation of drainage runoff into infiltration and pressure components could be done by studying the hydraulics of ground water flow.

Soil water inflow and outflow could be disregarded. Moisture storage variations ΔM in the unsaturated zone should be determined by gravimetric method, using neutron probe or soil moisture meters.

For irrigation farming purposes the equation is usually solved for the term ΔS or its component ΔM.

For a reclaimed basin, the water balance equation for any period of time could be expressed as

$$P + Q_{SI} - Q_{SO} + Q_{UI} - Q_{UO} + Q_{U1} - Q_{U2} - E - \Delta S = 0 \qquad - (2.49)$$

2.5.2. Lakes and Reservoirs.

According to the nature of water balance, lakes could be classified into three main categories. Open (exorheic) lakes with outflow, closed (endorheic) lakes without outflow and lakes with intermittent (ephemeral) outflow during high water stages.

The water balance equation for any time interval could be written as

$$Q_{SI} + Q_{UI} + P_L - E_L - Q_{SO} - Q_{UO} - \Delta S_L - \eta = 0 \quad - (2.50)$$

where Q_{SI} = surface inflow into the lake or reservoir Q_{UI} = ground water inflow, P_L = precipitation on the lake surface, E_L = evaporation from the lake surface, Q_{SO} = surface outflow from the lake or reservoir, Q_{UO} = underground outflow including percolation through the dam and ΔS_L = variation of water storage in the lake for the balance period.

For large lakes and reservoirs the surface inflow would be subdivided into inflow Q_m from the main stream and lateral inflow Q_1

$$Q_{SI} = Q_m + Q_1 \quad - (2.51)$$

For lakes and reservoirs with considerable variation in surface area due to water level fluctuations, the components of the water balance equation would be expressed in volumetric units. For lakes with constant surface area, this could be expressed as a depth of water layer relative to the mean surface area of the lake. The mean surface area would be equal to the arithmetic mean for the balance period.

The mean water balance equation for open (exorheic) lakes and reservoirs would be

$$Q_{SI} + Q_{UI} + P_L = Q_{SO} + Q_{UO} + E_L \quad - (2.52)$$

For closed (endorheic) lakes the corresponding equation could be expressed as

$$Q_{SI} + P_L = E_L \quad - (2.53)$$

For an approximate computation of the water balance for the purpose of routine control of water inflow and outflow, the water balance equation would be

$$\Sigma I = Q + \Delta S_L \quad - (2.54)$$

where ΣI = sum of input components of the equation. Q = sum of discharge through turbines, spillways, locks and infiltration through the dam, and ΔS_L = variation of water volume in the reservoir during the balance period. Eq. 2.60 should be used only for small reservoirs with intensive inflow and outflow and for which discharge through hydroelectric plants and surface water inflow constitute the most important components of the balance. In the case of large lakes, its physiographic peculiarities should be taken into account.

The accuracy of computation of balance and the minimum allowable balance period, would depend on the accuracy of estimation of surface inflow and water storage in the reservoir.

The relative error of water storage changes compared to the inflow could be expressed as

$$C_L = \frac{10^4 A_L S_n}{V_L} = \frac{10^4 A_L S_n}{86400\ Q_1 T} \quad - \quad (2.55)$$

where A_L = water surface area of the reservoir, S_n = error of mean level estimation, Q_1 = inflow in m^3/sec and T = duration of the balance period in days.

Equation (2.55) could be used to determine the length of the balance period such that C_L is not more than ± 5%.

Kitson et al (1984) reported that the amount of precipitation falling on water surfaces, including islands and beaches, is less than that on the land and littoral area. To take this into account, they recommended that gages should be installed not only around the periphery of the lake, but also at some distance from the coast on islands and light ships.

2.5.3. Ground water basins

The computation of the water balance of ground water basins is considered important for substantiation of projects on ground water as a source of water supply.

The general form of the water balance equation for a ground water basin or one of its parts for any time interval could be given by

$$/Q_{UI} + Q_{u1} - Q_{UO} + Q_{u2}/ + /Q_{up} - Q_{uc}/ + / Q_{u\mu} - Q_{u\gamma} -$$

$$Q_{u3}/ + / Q_{u\beta} - Q_{u\alpha}/ - \Delta G - \eta = 0 \qquad (2.56)$$

where Q_{up} = inflow (infiltration) of precipitation to the upper surface of ground water, $Q_{u\mu}$ = inflow of surface water along the design stretch of the aquifer, $Q_{u\gamma}$ = ground water outflow along the channel, Q_{UI} = inflow of ground water through the given aquifer to the design basin, Q_{u1} = inflow of ground water from other aquifers, $Q_{u\beta}$ = artificial recharge volume, Q_{uc} = outflow of underground water into the zone of aeration for moisture recovery lost by evapotranspiration, Q_{UO} = ground water outflow from the basin through the given aquifer, Q_{u2} = ground water outflow to other aquifers, Q_{u3} = ground water outflow through springs, $Q_{u\alpha}$ = ground water withdrawn from artesian aquifers, ΔG = change in ground water storage and η = discrepancy term.

For longterm periods such as the water year, G could be taken as zero. For aquifers on hard dense aquicludes $Q_{u2} = 0$.

The first term in equation 2.56, representing under ground water exchange across the boundary of the design basin could be estimated by means of hydrodynamic computation of groundwater flow according to the appropriate equation of ground water motion. The third term could be estimated on the basis of discharge measurements for springs and ground water flow calculations for $Q_{u\gamma}$ and $Q_{u\mu}$. The net value of ground water recharge by infiltration / $Q_{up} - Q_{uc}$/ could be estimated using the soil moisture balance equation.

$$Q_{up} - Q_{uc} = P - Q_o V_o - E - \Delta M - \eta_3 \qquad - (2.57)$$

where P = precipitation, E = Evaporation, $Q_o V_o$ is the over land flow input to the stream channel and ΔM = change in soil moisture storage. Data on artesian aquifers and recharge wells could be used to estimate the fourth term in equation 2.56.

Chaturvedi (1936) developed an empirical formula at Roorkee, which gave recharge as a function of annual precipitation.

$$R = 2 (P-15)^{0.4} \qquad - (2.58)$$

where R = net recharge to ground water in inches & P = annual rainfall in inches. Later this formula was modified as

$$R = 1.35 (P-14)^{0.5} \qquad - (2.59)$$

Sehgal (1973) developed the following formula at Amritsar.

$$R = 2.5 (P-16)^{0.5} \qquad - (2.60)$$

Bouwer (1969) defined the following three basic conditions to which the multitude of natural profiles of soil hydraulic conductivity could be reduced for theoretical treatment of seepage flow systems.

Condition A: The soil in which the channel is embedded is uniform and underlain by more permeable material. Seepage flow in this case is generally amenable to exact analytical solution. The problem was solved by Kozney using Zhukovsky's function and later by Pavlovsky (Harr, 1962).assuming an infinite water table depth. The solution did not incorporate any specific channel shape but assumed it to be described by the equation of the equipotential line. Exact solution for trapezoidal channels with finite as well as infinite water table depth were obtained by Muskat (1946), Harr (1962). Poluborinova Kochina (1962) used hodograph and conformal mapping techniques.

Condition B: The soil in which the channel is embedded is uniform andis underlain by less permeable material. Linear models for solving this problem assume a linear relationship between flowrate and head difference between channel and aquifer and is based on Dupuit - Forchheimer assumptions. Non linear models could also be used.

Condition C: The soil in which the channel is embedded is of much lower hydraulic conductivity than the original soil for a relatively short distance normal to the channel perimeter. This could occur if a relatively thin layer of low hydraulic conductivity occured along the wetted perimeter of the channel. Bouwer (1969) gave analytical solution for estimation of seepage in such conditions.

For estimating seepage from channels embedded in non homogeneous soils one would have to resort to numerical solution of Laplace equation with appropriate boundary conditions using finite difference or finite element techniques.

In alluvial tracts, the general practice has been to take 6 to 8 cusec per million sq. ft. of wetted area as seepage losses from canals. The following formulae have also been used.

Uttar Pradesh: $$\text{Losses in cumec/km.} = \frac{C\ (B+D)}{200} \quad - \quad (2.61)$$

where C = constant taken as 1 for intermittent running channels and 0.75 for continiously running channels.

Davis & Wilson: $$q = 8.64 \times 10^{-3}\ CpH^{1/3} \quad - \quad (2.62)$$

where q = Seepage rate in m^3/day/m. length of canal, p = wetted perimeter in m., H = water depth in canal in m. and C = soil co-efficient ranging from 12 for loams to 70 for sandy gravels.

A.N Kostyakov: $q = 2.94\ Q^{0.5}$ — (2.63)

(for highly permeable soils) and

$$q = 1.64\ Q^{0.6} \qquad - (2.64)$$

(for medium permeable soils), where Q = canal discharge in m^3 per second.

Chandra and Saksena (1975) proposed a method whereby reliability of water balance computations could be cross checked. Water balance study for monsoon and non-monsoon periods were carried out seperately. The former would yield an estimate of recharge co-efficient and the latter would determine the degree of accuracy with which the components of the water balance equation have been estimated.

Methods for estimating recharge from rainfall based on soil moisture data include lumped and distributed model methods. (Chandra, 1979).

Chandra (1979) reported that estimation of recharge from water table data would require an accurate assessment of the net effect of pumping, seepage from irrigation, leakage from adjoining aquifers, seepage from canals, rivers and other water bodies and geohydrological characteristics of the aquifer.

According to him,

$$R_r + R_e + R_i + I + S_i = S_e + O + E_t + T_p + S \qquad - (2.65)$$

where R_r, R_c, and R_i represent recharge due to rainfall, canal seepage and return flow of irrigation water applied in the field respectively, I = inflow from areas outside the basin, S_i = recharge due to influent seepage from rivers, streams, reservoirs, lakes, ponds etc., S_e = loss of ground water due to effluent seepage in rivers and streams, O = outflow to areas outside the basin, E_t = losses due to evapotranspiration from water logged areas, big trees, etc., T_p = pumpage of ground water in the basin for irrigation and other uses and S = change in ground water storage. All the components of equation (2.65) other than rainfall recharge would be estimated using the relevant hydrological and meteorological information. Rainfall recharge could then be calculated. Table 2.4 shows the values of recharge co-efficients ie., recharge per unit of rainfall for some catchments in Uttarpradesh estimated using this method.

Table 2.4 Recharge co-efficients for some river basins in Uttarpradesh

Name of Inter basin/basin	Recharge co-efficient
Ganga Ramganga	0.232
Gomti - Sai	0.252
Upper Ganga Canal command	0.264
Varuna	0.318
Gomti - Kalyani	0.354
Krishna - Hindon	0.18

Rushton (1979) carried out experimental studies for determing the recharge mechanism for chalk aquifers in North Linconshire and developed the formula

$$\text{Recharge} = 0.15\ R_e + 0.15\ (R_T - 5) \text{ if } R_T \geq 5\text{mm} \quad - \quad (2.66)$$

$$= 0.15\ R_e \text{ if } R_T < 5\text{mm} \quad - \quad (2.67)$$

where R_e & R_T are effective and total precipitations in mm.

Naney (1979) carried out investigations to develop an equation for estimating the amount of seepage lost from a reservoir in relation to the hydraulic head behind the dam.

Recharge from applied irrigation would depend on factors such as pattern of water availability, mode of irrigation management practices, literacy level among cultivators, mode of water charges etc. As human factors are involved, estimation by analytical methods would be difficult. In the case of a project in Haryana proposed for World Bank assistance the following figures were adopted.

Canal irrigation with unlined water courses	:	37%
Canal irrigation with lined water courses	:	20%
Tube well irrigation	:	20%

However, these figures were considered low for flooding irrigation. (Chandra, 1979).

2.6. Case Studies

UNESCO (1974) published a report of the initial survey on water balance of the major lakes and reservoirs of the earth conducted by the secretariat of the IHD co-ordinating council. The water balance of 137 lakes and reservoirs, situated all over the world, were studied. Complete data satisfying the required accuracy were received for only 63 lakes and 43 reservoirs; the information on the remainder of the water bodies either characterises only certain water-balance elements or reveals the discrepancies between the loss and gain elements of water balance equations. The figures as calculated from this survey were tabulated as given in Table 2.5.

Table 2.5 Water Balance of Lakes & Reservoirs of the World.

Country	Volume of water involved	Water Gains		Water losses	
		Surface inflow	Precipitation	Surface outflow	Evaporation
	cu.km.	cu.km.	cu.km.	cu.km.	cu.km.
North America	440	241	194	273	167
Europe	126	100	24	108	18
Asia	172	140	30	66	104
Africa	154	25	100	26	99

It was found that other components such as underground inflow, draw down of accumulated storage etc. amounted to only about 1% to 2% of the total inflow into lakes. Surface inflow accounted for the following proportions of the total inflow. 55% in North America, 80% in Europe, 83% in Asia and 20% in Africa. The proportion of outflow accounted for by runoff was found to be 62% in North America, 86% in Europe 39% in Asia and 21% in Africa. In areas of intensive economic development the total water exchange was high due to large reservoirs.

Peixoto (1981) reported details of the Mediterranean water balance (Table 2.6).

Table 2.6 Water Balance of the Mediterranean Basin.
(10^3 m/s)

	Carter (1956) Revised by Mac Gill (1969)	Tixeront (1970)	Ouchinnikov (1974)	Present Study (1978)
Evaporation ($\bar{E}$)	92	95	100	
Precipitation ($\bar{P}$)	33	28	42	
$\bar{E} - \bar{P}$	59	67	58	54.4
River runoff	14	16	14	
Black Sea runoff	6	6	6	
Atlantic	40	45	49	

According to Lacambe and Tchernia (1972) the net inflow of water into the Mediterranean sea from the Atlantic would be 1740 cu.km/year and from the Black sea, the corresponding figure would be 189 cu.km./yr. The exchange of water with the Red Sea was found to be negligible. The contribution of underground water discharge to the sea, which is not negligible quantity, was ignored in all studies on the Mediterranean water balance.

Chandra and Pande (1975) developed a mathematical model for the Varuna Basin in Uttarpradesh to determine the average annual recharge and water balance available for the year 1972 - 1973. The recharge due to rainfall was estimated as 65,567 ha.m. and the recharge co-efficient was found to be 0.32. This closely agreed with the value of recharge co-efficient (0.312) given by the empirical Amritsar formula.

Chandra and Saksena (1975) conducted a detailed water balance study of the Ganga - Ramganga Doab in the alluvial plains of the State of Uttarpradesh. The principle of multiple correlation was applied to develop a linear regression equation, summarising the relationships of the past hydrologic events as evidenced in records of natural regeneration and base flow in a river and of factors contributing to the same. Complete water balance and a separate inventory of the ground water regime for the hydrologic year 1971 - 1972 was done. This revealed that the distribution of total precipitation falling on the doab area would be surface runoff 44%, recharge to ground water 23% and evapotranspiration 33%. The safe yield and utilisable yield of the doab were estimated to be 4,01,200 ha. m and 2,81,000 ha. m respectively.

Venugopal *et al* (1979) computed the ground water recharge from rainfall in the hard rock areas of Karanja Basin in Karnataka State by observing water table fluctuations and by water balance analysis. It was recommended that for the Karanja basin recharge values of 15% to 20% in laterites and 5% to 12% in basalts could be adopted.

Raghunath (1982) reported the results of the water balance studies for the Noyyil river basin in Coimbatore district for the period 1970 - 1972. A uniform evapotranspiration of 81Mm^3 was taken for the months January to May and November - December. For the remaining months evapotranspiration was taken as 162Mm^3. Subsurface inflow and outflow were not taken into account. Ground water recharge for different months during this period were estimated using water balance method.

Anjos (1984) studied the water balance of the Sao Francisco River basin located in the eastern regions of Brazil. A preliminary water-balance of the basin, considering only its annual average resources, indicated a 1410 mm precipitation, a 1,185 mm (84%) evapotranspiration and a 155 mm (11%) runoff. The usable ground water reservoirs were estimated at 4970 x 10^{6}m^3. A secondary water balance, considering the demands of water was also performed. This indicated that by the end of the century domestic consumption would reach 35m^3/s with a return of effluent of 20m^3/s.

Industrial demand would be $35m^3/s$ returning $25m^3/s$; animal needs would be $15m^3/s$ with a return of $5m^3/s$ and the irrigation demand would be $530m^3/s$ returning $236m^3/s$. The total use of $387m^3/s$ was found to be compatible with the hydrological availability within the Sao Francisco.

Szlavik (1984) demonstrated the human impact in the water balance of the Hungarian section of the Koros River System. Monthly water balances for the year 1978 were presented.

Ivanov (1984) used the water balance technique to compare the change of water storage in the Kairakum and Chardara Reservoirs (Volga and Syrdarja basins) computed according to the balance, with the values obtained from the storage curve, for the period March - December, 1969.

George <u>et al</u> (1987) made a water balance study of the Maruthur Thodu sub basin of the Neyyar River to estimate ground water recharge.

A detailed water balance study of the Betwa basin in Madhyapradesh by Sutcliffe (1987) showed that annual soil moisture recharge could be estimated by comparing seasonal net rainfall with runoff. Detailed investigation of the Nion tributary showed that the net rainfall was divided in sequence between soil moisture replenishment, ground water recharge and runoff.

Materials and Methods

MATERIALS AND METHODS

3.1. Objectives

The broad objective of this project was to make a quantitative evaluation of the water resources of the Karuvannur River Basin.

The specific objectives of this project were the following:

i) To estimate the average monthly rainfall in the basin for the period 1976 to 1985.

ii) To conduct frequency analysis of rainfall for various durations.

iii) To determine the total runoff from the basin for the period 1976 to 1985 and to develop an equation connecting rainfall with runoff.

iv) To estimate the evapotranspiration from the basin during the period 1976 to 1985.

v) To study the monthly water balance for the basin in order to estimate the ground water recharge or depletion for the period 1976 to 1985.

3.2. The Karuvannur River Basin.

The Karuvannur river basin lies on the South of the Keechari river basin and on the north of the Chalakudy river basin, between 76° 23'E and 76° 26'E longitudes and 10° 13'N and 10° 31'N latitudes. It has an area of 1054 sq.km.

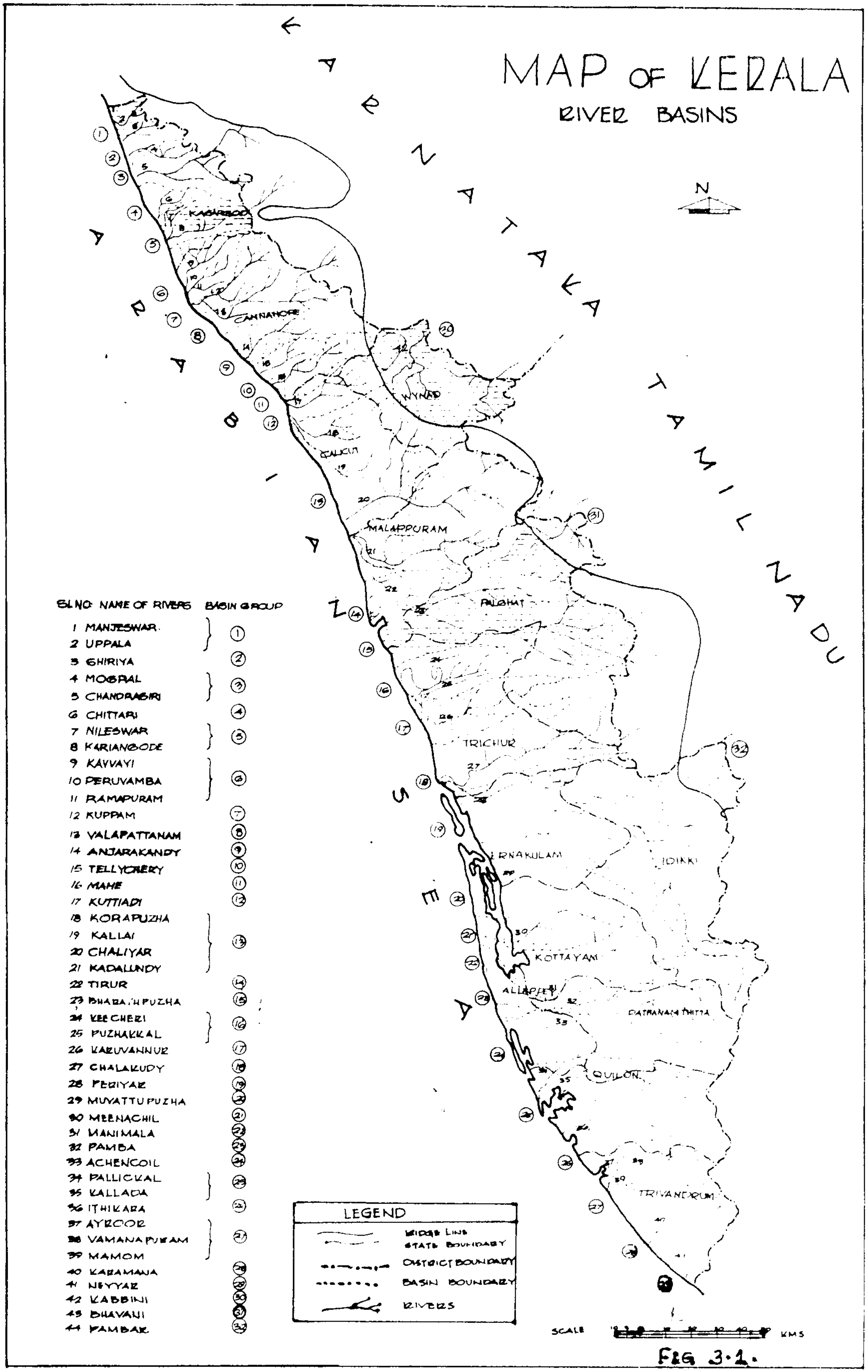

MAP OF KERALA
RIVER BASINS
N
KARNATAKA
TAMIL NADU
ARABIAN SEA
KASARGOD
CANNANORE
WYNAD
CALICUT
MALAPPURAM
PALGHAT
TRICHUR
ERNAKULAM
IDIKKI
KOTTAYAM
ALLEPPEY
PATHANAMTHITTA
QUILON
TRIVANDRUM
SL.NO. NAME OF RIVERS BASIN GROUP
1 MANJESWAR (1)
2 UPPALA (1)
3 SHIRIYA (2)
4 MOGRAL (3)
5 CHANDRAGIRI (3)
6 CHITTARI (4)
7 NILESWAR (5)
8 KARIANGODE (5)
9 KAVVAYI (6)
10 PERUVAMBA (6)
11 RAMAPURAM (6)
12 KUPPAM (7)
13 VALAPATTANAM (8)
14 ANJARAKANDY (9)
15 TELLYCHERY (10)
16 MAHE (11)
17 KUTTIADI (12)
18 KORAPUZHA (13)
19 KALLAI (13)
20 CHALIYAR (13)
21 KADALUNDY (13)
22 TIRUR (14)
23 BHARATHPUZHA (15)
24 KEECHERI (16)
25 PUZHAKKAL (16)
26 KARUVANNUR (17)
27 CHALAKUDY (18)
28 PERIYAR (19)
29 MUVATTUPUZHA (20)
30 MEENACHIL (21)
31 MANIMALA (22)
32 PAMBA (23)
33 ACHENCOIL (24)
34 PALLICKAL (25)
35 KALLADA (25)
36 ITHIKARA (26)
37 AYROOR (27)
38 VAMANAPURAM (27)
39 MAMOM (27)
40 KARAMANA (28)
41 NEYYAR (29)
42 KABBINI (30)
43 BHAVANI (31)
44 PAMBAR (32)
LEGEND
RIDGE LINE
STATE BOUNDARY
DISTRICT BOUNDARY
BASIN BOUNDARY
RIVERS
SCALE
KMS

FIG 3.1.

spreading over Trichur, Mukundapuram and Chavakkad Taluks of Trichur District.

The river originates from the Western Ghats and is fed by its two main tributaries namely the Manali and the Kurumali. The Manali originates from the Vaniampara Hills at an elevation of + 365m. The Chimoni and the Muply, the two sub-tributaries of the Kurumali originate from Pumalai at an elevation of + 1100m. The Pillathodu joins the Kurumali just downstream of the confluence of the Chimony with the Muply. The Manali river flows westwards upto Mundanchira and then soutwards upto Nemmenikkara before turning towards the west and subsequently to the south and joining the Kurumali at Palakadavu near Aratupuzha. The Chimony & the Muply flow westwards through dense forest and these join together at Elikode to form the Kurumali river. The Kurumali river then flows in a westerly direction till it joins the Manali to form the Karuvannur river. The Karuvannur river then takes a South westerly direction and then a westerly course. Just before joining the backwaters, it bifurcates and one branch flows towards south to join the Periyar at Cranganore while the other branch flows northwards and enters the Arabian sea at Chettuvai.

No rainfall-runoff correlation studies have so far been made for this basin. Using the Inglis formula the annual yield was assessed. This comes to $1887 Mm^3$ and the utilisable yield works out to 963Mm^3. The total water requirement for irrigation is estimated to be 970Mm^3.

The Peechi Irrigation project, the only major irrigation project at present located in this basin is built across the Manali river at Peechi. Commissioned in 1957, the scheme consists of a masonry dam of the straight gravity type 225m long and 39m high and a distribution system comprising the left and right bank canals. The reservoir has a total capacity of 113.227Mm^3 and serves an area of about 17,555 ha. for the Ist and 2nd crops including 8100 ha. of kole lands for the Puncha crop. The water spread area at full reservoir level is 5 sq.km.

In addition there are 3 minor irrigation (Class I) schemes, 77 minor irrigation schemes (Class II) and 6 lift irrigation schemes which serve about 4000 ha. of lands mainly for two crops.

For providing irrigation facilities to all the wet lands of the basin for three crops and for meeting the irrigation needs of the garden lands an integrated project called Chimoni - Mupli - Kole Project has been formulated.

The Chimoni - Mupli - Kole Project involves

1. the construction of two storage reservoirs, one each on the Mupli & Chimoni tributaries of the Karuvannur river, for irrigation.

2. the construction of two regulators one at Chettuvai and other at Valliattom for preventing the ingress of salt water.

3. the diversion of a part of the Mupli storage through a tunnel and canal system to the Vellikkulangara valley to irrigate 3 crops in 100 ha. of high level lands and

4. the reclamation of 1100 ha. of low lying kolelands together with the construction of a direct flood outlet to the sea at Kuttamangalam. Ultimately, the project is estimated to benefit a cropped area of 60,600 ha. The kole project envisages five flood outlets - Enamakkal, Puthenthodu - Chirakkal thodu, Herbert canal and Shanmugham canal regulators in addition to the existing one in the Enamakkal - Muriyad Moorkanad canal. Work on the Chimoni project is progressing.

3.3. Water Balance Study.

3.3.1. Estimation of average areal rainfall.

Fig. 3.2. shows the map of the Karuvannur river basin along with the location of raingauge stations in the basin. Data regarding monthly rainfall at the various raingauge stations in the basin for the period 1976 to 1985 were collected from the Water Resources Divisional Office, Kerala P.W.D., Trichur. Rainfall data at Pottimada, Irumpupalam and Trichur I.C.C. compound were not taken into account as they do not

extend over the entire period of study. Rainfall data at Triprayar for the period 1976 to 1985 was not available and hence this station was also not included in the computation of monthly mean areal rainfall. Rainfall data at Irinjalakuda for the years 1981 and 1985 and at Thanipadam for the years 1984 and 1985 were also not available. This was however estimated using the following equations.

$$P_x = \frac{P_1 + P_2 + P_3}{3} \qquad - \quad (3.1)$$

(Provided N_1, N_2, and N_3 differs within 10% of N_x)

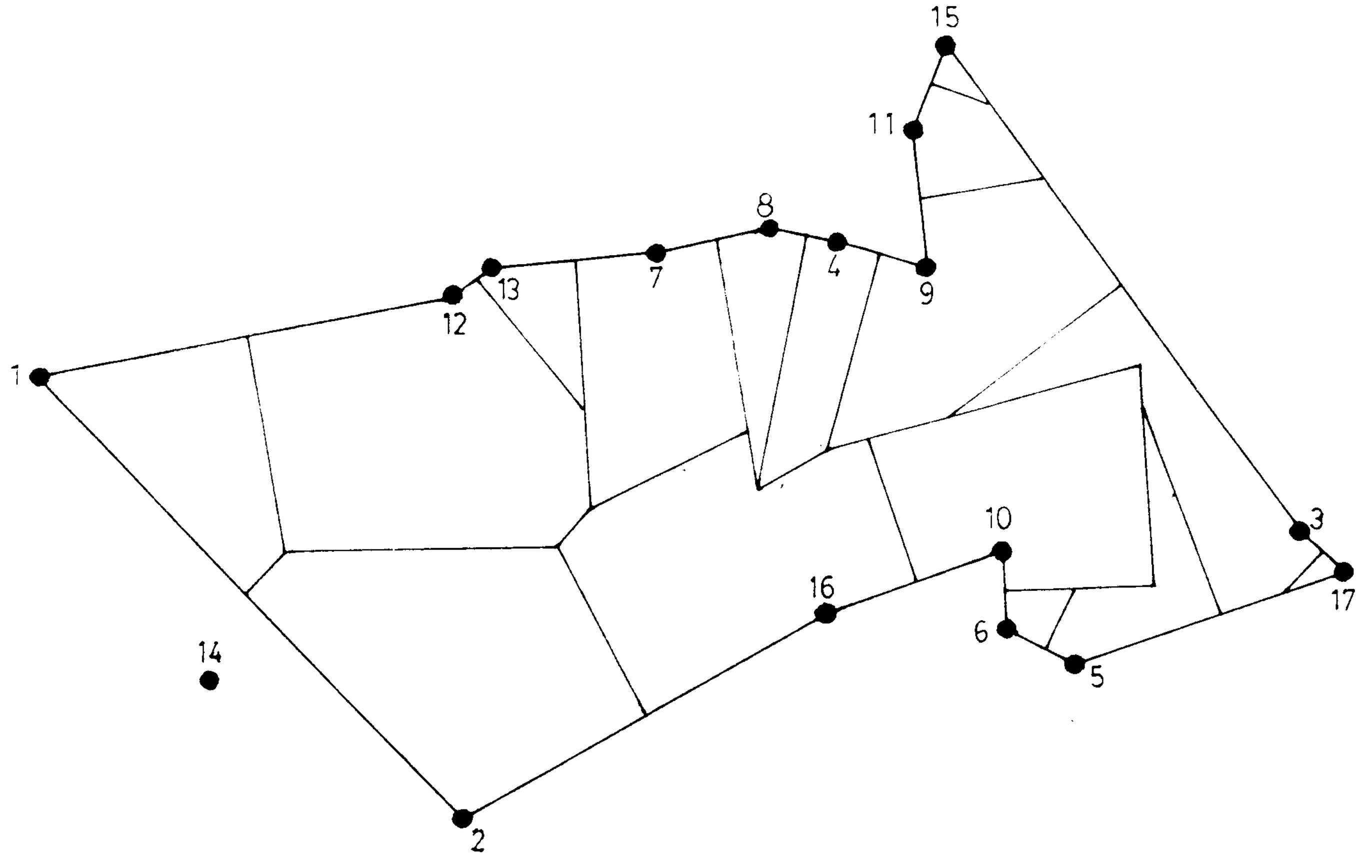
and

$$P_x = 1/3 \left(P_1 \frac{N_x}{N_1} + P_2 \frac{N_x}{N_2} + P_3 \frac{N_x}{N_3} \right) \qquad - \quad (3.2)$$

(Provided any of N_1, N_2 and N_3 differs from N_x by more than 10%)

where P_1, P_2, P_3 and P_x represent the rainfall of the month at stations 1, 2, 3 and X, N_1, N_2, N_3 and N_x represent the average annual rainfall at stations, 1, 2, 3 and X, X represents the station with missing record and 1, 2 and 3 represents three nearby raingauge stations.

For the computation of the average areal rainfall Thiessen polygon method was used. Fig. 3.3. shows the Thiessen polygon constructed for this purpose. The area coming under the influence of each station was measured. (Table 3.1)



Note: Notation of raingauge stations as in Fig. 3.2

FIG. 3.3. THIESSEN POLYGON FOR ESTIMATING MEAN AREAL RAINFALL

Table 3.1. Area coming under the influence of each raingauge station in the Karuvannur Basin.

Raingauge Station	Area (sq.km.)
Enamakkal	22.76
Irinjalakuda	44.76
Kallichithra	21.74
Kannara CPCRI	11.7
Karikadavu	9.14
Mupli Estate	1.88
Ollukkara	23.12
Pananchery	8.52
Peechi	29.5
Puducad Estate	32.54
Thanipadam	6.56
Trichur Railway Station	50.96
Trichur Taluk Office	5.30
Vaniampara	0.92
Varandarappilly	40.42
Echipara	0.56

Mean monthly rainfall was calculated using the equation

$$P = \frac{P_1 A_1 + P_2 A_2 + \text{---} + P_n A_n}{A_1 + A_2 + \text{---} + A_n} \quad - \quad (3.3)$$

where P_1, P_2, - - - - - P_n denote monthly rainfall at stations 1, 2, --- --- n and A_1, A_2, ---- A_n denote the area coming under the influence of respective raingauge stations.

3.3.2. Estimation of runoff

Data regarding runoff from the basin, measured at the seven river guage stations shown in Fig. 3.2, were collected from the Water Resources Divisional Office, Kerala P.W.D., Trichur. To calculate the total runoff, the inflow into the Peechi reservoir would also have to be taken into account. This data was obtained from the Water Resources Divisional Office, Trichur and the Instrumentation Division, KERI, Peechi.

The total runoff from the basin would be the sum of the runoff values measured at Karuvannur and Naduthodu and the inflow into the Peechi Reservoir.

A number of bunds are being constructed in the river at various locations following the north east monsoon. Hence, during the months from January to May discharge in the river is not being measured. Hence for this period appropriate values of stream flow have been assumed.

RIVER GAUGE AT KARUVANNUR BRIDGE

Computer analysis was done in order to determine the correlation between annual rainfall and annual runoff and to develop equations for predicting the runoff from rainfall data using the theory of multiple regression.

3.3.3. Estimation of Evapotranspiration.

3.3.3.1. Estimation of reference crop evapotranspiration.

Evapotranspiration from the basin was calculated using the modified Penman formula. The climatological data required for this purpose was obtained from the District Agricultural Farm at Mannuthy and the Agromet Observatory at Vellanikkara. It was assumed that the climatic conditions would remain the same at all other parts of the basin.

As discussed in section 2.4.3.3.2., the unadjusted reference crop evapotranspiration in mm/day is given by

$$ETo^{*} = W.Rn + (1-W).\ f(u)\ (ea - ed). \qquad - \quad (3.4)$$

The adjusted reference crop evapotranspiration ETo in mm/day was calculated using the Table 12 presented in Appendix.

Mean air temperature for each month (t) was taken as the average of the mean monthly maximum and minimum temperatures. For calculating mean monthly relative humidity (RH mean) the average of the mean monthly maximum and minimum relative humidities was determined. Wind speed (u) measurements were being made at 3m. height. As wind speeds at 2m. height were required for calculation, the observed wind speeds were multiplied by a co-efficient equal to 0.93. Saturation vapour pressure ea in m. bar was calculated using Table 4 of the Appendix and the mean actual vapour pressure of air ed in m. bar was calculated using the expression,

$$ed = ea \times \frac{RH\ mean}{100}.$$

The values of the wind related function f(u), the weighting factor for the effect of wind and humidity on reference crop evapotranspiration (1-W) and the weighting factor for the effect of radiation on reference crop evapotranspiration (W) were determined from Tables 5, 6 and 7 of the Appendix respectively.

For determining the mean daily maximum duration of bright sunshine hours (N) and the extra terrestrial radiation (Ra) expressed in equivalent evaporation in mm/day for different months of the year, Table 2 and Table 3 of the Appendix were used respectively. For this calculation, the mean latitude of the basin was taken as 10° 22' N. The actual hours of bright sunshine (n) for each month of the period 1976 - 1985 was obtained from the records at the observatory. The reflection co-efficient (α) was taken as 0.25. The net incoming short wave solar radiation Rns was calculated using the equation

$$Rns = Ra\ (1-\alpha)\ (0.25 + 0.5\ \frac{n}{N})$$

The net long wave radiation $Rnl = f(t) . f(ed) . f(\frac{n}{N})$.
The values of $f(t)$, $f(ed)$ and $f(\frac{n}{N})$ were obtained from tables A.9, A.10 and A.11 respectively. The net radiation $Rn = Rns - Rnl$.

3.3.3.2. Estimation of Actual Evapotranspiration.

For calculating actual evapotranspiration (ETa), the level of the available soil water should be considered. The maximum evapotranspiration (ETm) in mm/day for the period considered could be obtained using the equation.

$$ETm = kc \ ETo \qquad - \qquad (3.4)$$

where kc = crop factor. Actual evapotranspiration would be equal to the maximum evapotranspiration only when there is adequate soil water available to the crop. However, ETa would be less than ETm when available soil water is limited. The available soil water could be defined as the fraction (p) to which the total available soil water could be depleted without causing ETa to become less than ETm and the total available soil water (Sa) could be defined as the depth of water in mm/m soil depth between the soil water content at field capacity and the soil water content at wilting point. As a general indication, Sa mm/m for different soil textures could be taken as follows:

Heavy textured soils	200mm/m.
Medium textured soils	140mm/m.
Coarse textured soils	60mm/m.

According to Rijtema and Aboukhaled (1975), actual evapotranspiration (ETa) in mm/day could be calculated using the equation,

$$ETa = \left[\frac{Sa.D}{t} \quad 1 - (1-p)e^{-\frac{ETm\ t}{(1-p)\ Sa.D} + \frac{p}{1-p}} \right] \qquad - (3.5)$$

when $t \geq t'$ where $t' = \frac{p.Sa.D}{ETm}$ = time in days during which ETa is equal to ETm.

ETa could be quantified for the interval between irrigation or heavy rain (Table A.17) and for monthly periods (Table A.18).

Mean monthly actual evapotranspiration (ETa) for a given crop could be obtained using the available soil water index (ASI). The ASI would give an indication of the part of the month when adequate soil water would be available for meeting full crop water requirements. (ETa = ETm). A combination of ASI value, maximum Evapotranspiration (ETm) and remaining available soil water $\left[(1-p)\ Sa.D\right]$ would give an estimate of the mean monthly ETa.

$$ASI = \frac{In + Pe + Wb - (1-p)\ Sa.D}{ETm \text{ in mm/month.}} \qquad - (3.6)$$

where In = net monthly irrigation application in mm/month, Pe = effective rainfall in mm/month, Wb = actual depth of available soil water at begining of the month in mm/root depth and $[(1-p)\ Sa.\ D]$ = depth of remaining available soil water when ETa ETm in mm/root depth.

For the ASI it has been assumed that In + Pe when smaller than or equal to 30 ETm would fully contribute to the evapotranspiration and no deep percolation or runoff would occur. It has also been assumed that mean monthly ETa would be affected only by the total of In, Pe and Wb and not by their distribution over the month.

When ASI > 1, ETa = ETm and when ASI 0, crop growth is hardly possible except when ETm is low and the remaining available soil water is high.

Due to lack of data, the concept of available soil water index could not be used for estimating the mean monthly actual evapotranspiration. Instead, it was assumed that actual evapotranspiration would remain the same during all irrigation intervals and hence Table 17 of the Appendix along with equation 3.5 was used for estimating actual evapotranspiration. The various crop combinations in the basin were determined and the area under each of these combinations was estimated. For the computation of ETa, the value of the fraction 'p' was taken as 0.5. Total available soil water (Sa) was assumed to be equal to 200 mm/m. for heavy textured soils and 60 mm/m. for coarse textured soils.

In the case of irrigated crops, the irrigation interval was assumed to be 8 days for the months of January to May and for November and December. The recurrence interval of significant rain was taken as 2 days for the months of June, July and August. The corresponding figures for September and October were assumed to be 6 days and 4 days respectively.

In the case of non irrigated crops, the calculation of actual evapotranspiration during the rainy months (viz. May to November) was done in the same way as for irrigated crops. For calculating the actual evapotranspiration during the dry months (viz. December, January, February, March and April), a constant value was taken for the available soil water (DSa) for all the months (for eg:- 72 mm in the case of coconut, 60 mm. in the case of rubber etc.) initially. The value of 't' in equation 3.5 was taken as 31 days for December, 62 days for days for January, 90 days for February and 121 days for March etc. The values of mean monthly actual evapotranspiration (ETa) in mm/day obtained using this method was found to be reasonable. However, the total evapotranspiration during the dry spell exceeded the amount of available water in the soil. Hence this method could not be adopted.

Since no other method was available for estimating actual evapotranspiration, a mean value of ETa in mm/day was calculated using equation 3.5 for the entire dry spell preceding the first rain. The value of 't' in equation 3.5 was taken as the number of days since the cessation of rain (at the end of the rainy season) to the beginning of the month in which the sum of the soil moisture balance and the effective rainfall exceeds the available soil water. (D.Sa). Once this was calculated, actual evapotranspiration during each month could be determined. If considerable rain occured during a dry month, (for eg:- April 1981) the effective portion of it was determined and added along with the value obtained using the above method to get the total evapotranspiration from the basin.

kc values for calculating the evaporation from bare soils and water surface were taken from Fig. 2.6 and Table 16 of the Appendix respectively.

3.3.4. Inflow into the basin from irrigation.

Data regarding the amount of water released for irrigation from Peechi Reservoir was collected from the Water Resources Divisional Office, Trichur and the Instrumentation Division, KERI, Peechi. However for other small irrigation schemes, this data was not available. Irrigation water along with rainfall would form the input into the basin.

3.3.5. Ground water accretion or depletion.

This was taken as the balance obtained, after deducting the sum of the runoff and the actual evapotranspiration from the input into the basin.

3.4. Frequency Analysis of Rainfall for Various Durations.

Frequency analysis of rainfall for various durations was done for the Ollukkara raingauge station. Daily rainfall data for a period of 20 years was collected. The sum of successive one day, two day, three day, four day and five day rainfalls were determined for the entire period. In each case the highest twenty values so obtained were ranked in the descending order. Rank was assigned to each value and the recurrence interval of each rainfall was determined.

Results and Discussion

RESULTS AND DISCUSSION

The results of the water balance study of the Karuvannur river basin have been discussed in the following sections.

4.1. Rainfall.

Table 4.1 gives the values of mean monthly and mean annual rainfall in the Karuvannur basin for the period 1976 to 1985. The table clearly shows that a major portion of the rainfall in the basin (about 65%) occurs during the months from June to August. December, January, February and March are found to be dry months.

The average annual rainfall in the basin, estimated from longterm records, is 3033.50m. From the point of view of total rainfall received in a year, five years are found to be bad years viz. 1976, 1982, 1983, 1984 and 1985. The rainfall deficiency in 1976 may be termed "large". In the remaining years, annual rainfall has been more or less equal to or greater than the average annual rainfall in the basin. Eventhough low rainfall has been recorded during the years 1982 to 1985, it is too early to say that this is an indication of a 'decreasing trend' in rainfall.

Fig. 4.1 shows the variation of annual areal rainfall from the average annual rainfall in the basin and Fig. 4.2 gives an indication of the distribution of rainfall among the

Table 4.1 Mean monthly rainfall in the Karuvannur Basin (mm.)

Year / Month	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
January	0	0	0	0	0.14	0	0	0	1.09	34.44
February	0	8.17	11.71	25.97	0.65	0.09	0	0	11.76	0.42
March	5.76	11.65	11.61	4.28	11.61	8.51	4.87	0	18.78	0.55
April	107.48	68.02	42.25	39.31	137.88	43.59	61.69	9.36	141.20	33.57
May	74.93	304.56	292.47	112.08	149.38	243.10	140.34	57.01	50.36	192.93
June	218.66	589.51	870.26	793.94	959.40	1155.04	802.82	403.91	876.61	974.37
July	730.98	756.62	752.82	889.99	1180.08	471.93	604.23	766.15	756.94	519.16
August	401.44	270.13	659.69	481.63	554.42	516.30	581.95	757.50	279.11	427.85
September	127.88	164.22	96.98	271.69	180.69	684.81	86.22	594.78	136.51	129.70
October	21[illegible].70	382.59	163.19	182.75	404.28	268.05	237.28	129.05	377.21	263.23
November	226.33	447.19	302.33	284.28	183.17	127.94	107.14	108.94	18.95	27.94
December	15.16	0.05	74.14	0	8.13	7.63	3.60	41.70	16.92	47.31
Mean Annual Rainfall	2123.16	3002.68	3277.16	3085.93	3769.16	3526.99	2630.17	2868.40	2685.43	2651.47

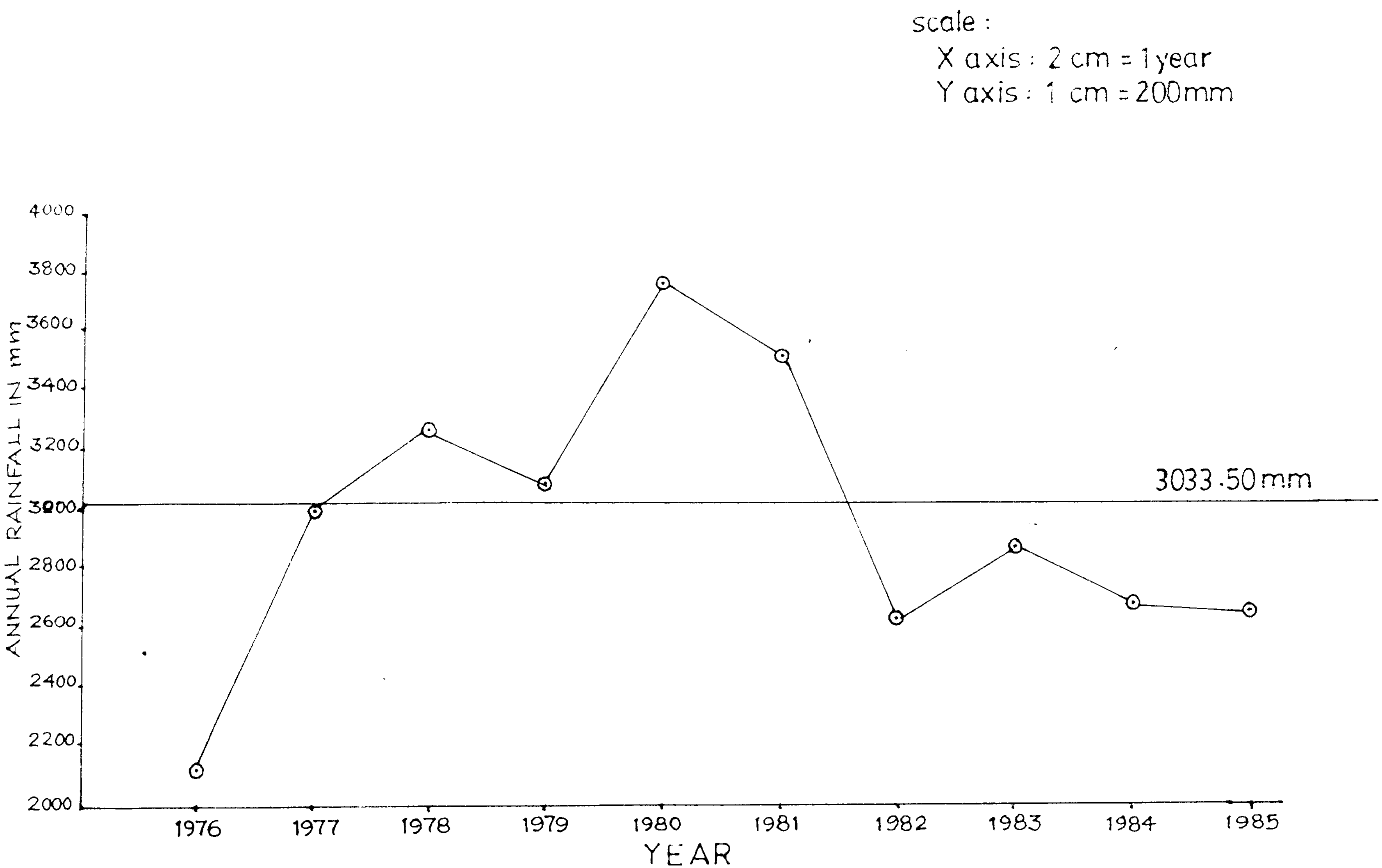


FIG. 4.1. VARIATION OF ANNUAL AREAL RAINFALL FROM THE AVERAGE ANNUAL RAINFALL OVER KARUVANNUR RIVER BASIN

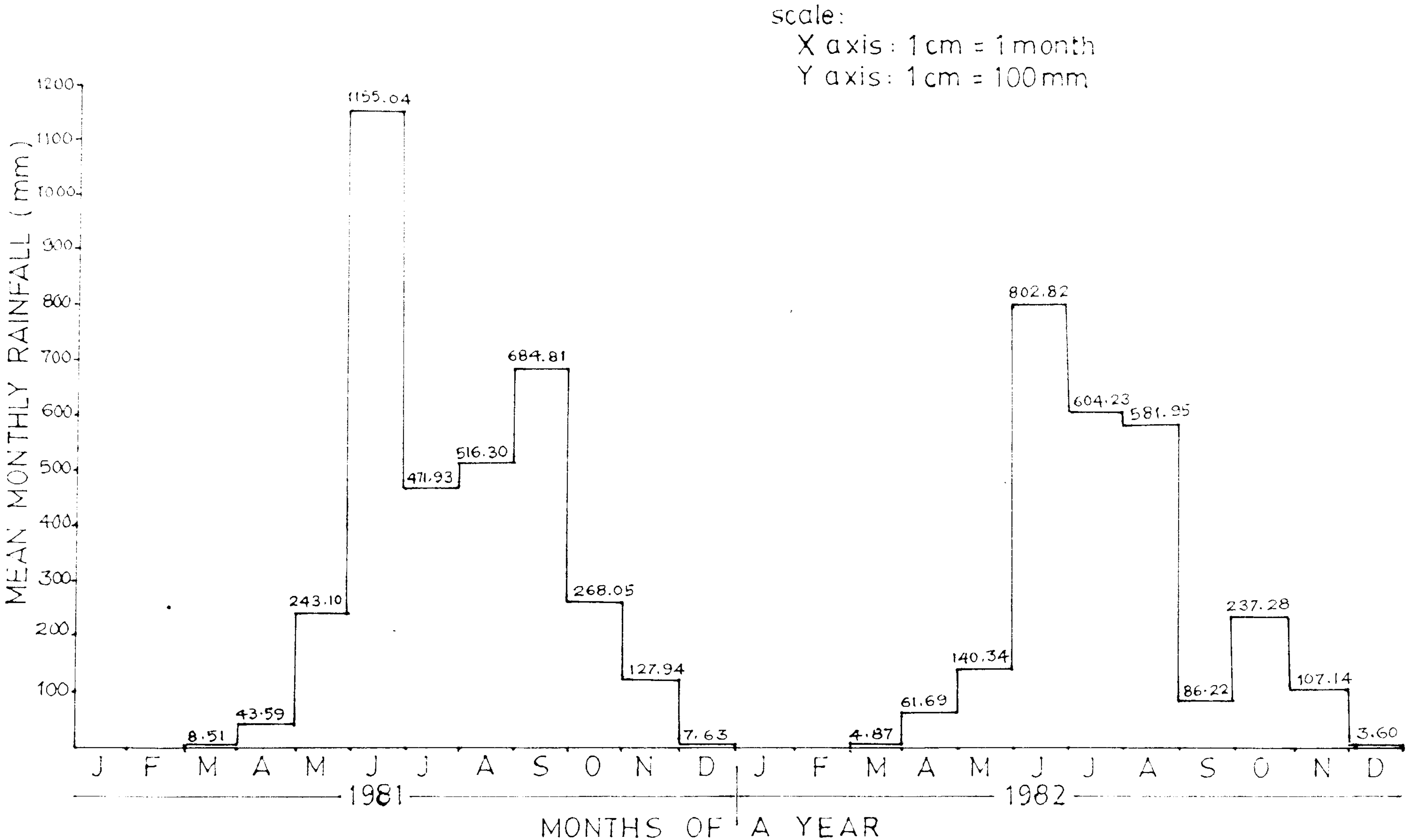


FIG. 4.2. GRAPH SHOWING DISTRIBUTION OF RAINFALL DURING DIFFERENT MONTHS (1981-1982)

Table 4.2 Frequency Analysis of Rainfall at Ollukkara for various Durations.

Rank Number	Rainfall in mm					Recurrence interval (years).
	1 day	2 day	3 day	4 day	5 day	
1	196	277.7	382.0	430.5	472.1	20
2	183	263.2	350.6	415	459.2	10
3	182.6	262.2	350.0	413.5	455.3	6.67
4	177.8	261.8	347.4	398	454.5	5
5	173.4	241.1	318.6	376.1	434.3	4
6	153	238.1	313.4	360.2	433.4	3.33
7	146.6	236.3	304.0	359.5	429.5	2.86
8	142.2	235.5	302.9	358.2	426.9	2.5
9	135	234	297.3	353.6	405.9	2.22
10	129.6	232.4	282.6	343.4	399.2	2

Table 4.2 (contd.) Frequency Analysis of Rainfall at Ollukkara for various Durations.

Rank Number	Rainfall in mm					Recurrence interval (years).
	1 day	2 day	3 day	4 day	5 day	
11	129.4	224.2	279.3	328.6	397.7	1.818
12	120.7	217.5	276.2	321.3	388.2	1.667
13	120.	217.2	259.6	316.7	380.3	1.53
14	118.3	209.4	259.4	314.7	379.9	1.43
15	116.3	208.4	256.7	314.2	377.5	1.33
16	116.7	201.9	256.6	308.6	377.4	1.25
17	115.2	201.1	250.2	304.3	376.6	1.18
18	113	200.8	248.1	301.8	375.2	1.111
19	112.4	199	245	300.2	367.3	1.05
20	112.3	198.2	244.2	297	366.3	1

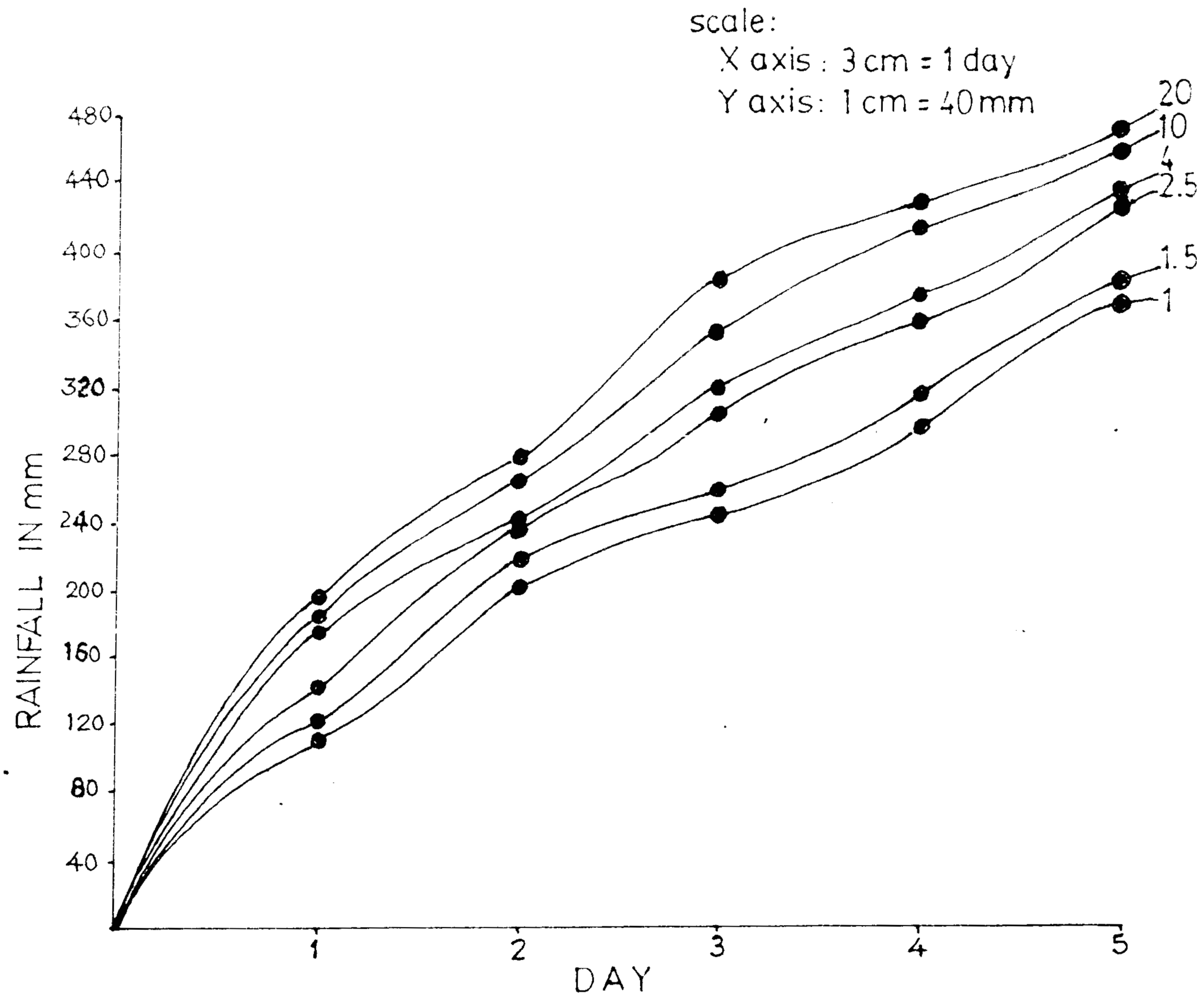


FIG. 4.3. FREQUENCY ANALYSIS OF RAINFALL AT OLLUKKARA FOR VARIOUS DURATIONS

different months during the years 1981 and 1982. During the period of study, maximum annual areal rainfall occured in 1980 (3769.16mm) and minimum rainfall occured in 1976. (2123.16mm). The results of the frequency analysis of rainfall at Ollukkara for various durations have also been presented. (Table 4.2 and Fig.4.3).

4.2. Runoff

Table 4.3 gives the total runoff from the Karuvannur basin during each month of the period 1976 to 1985. In general, it is found that during the months of heavy rainfall, runoff in the river is high and viceversa.

The runoff co-efficient for the basin, on the basis of the 10 years of record, shows considerable variation. (from 0.62 to about 0.74). On an average, the runoff Co-efficient for the basin works out to 0.667.

Using the principle of simple and multiple regression, equations have been developed connecting rainfall and runoff. These equations are

$$R = 0.606\,P + 188.675 \qquad - \qquad (4.1)$$

$$R = 0.629\,P_1 + 0.021\,P_2 + 54.602 \qquad - \qquad (4.2)$$

$$R = 0.92\,P^{.96} \qquad - \qquad (4.3)$$

where R = annual runoff in Mm^3, P = annual rainfall in Mm^3, P_1 = rainfall in the year in Mm^3 and P_2 = rainfall in the previous year in Mm^3.

Table 4.3 Total Runoff from Karuvannur River Basin (Mm^3)

Month \ Year	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
January	40.96	38.79	88.19	53.73	71.04	89.28	72.29	53.25	70.28	42.81
February	32.74	33.67	64.76	50.29	49.11	67.11	52.07	39.67	44.19	29.96
March	27.26	29.47	42.09	38.41	30.97	47.08	41.99	26.17	31.72	18.47
April	62.39	50.93	43.24	49.93	68.70	69.73	63.78	15.45	60.40	16.29
May	57.47	128.17	121.19	79.43	85.21	110.20	89.92	30.45	50.32	36.80
June	83.34	181.10	325.34	252.21	256.15	528.43	244.15	51.28	288.06	435.40
July	284.21	612.21	535.38	557.49	860.44	288.70	339.88	418.48	658.05	610.52
August	305.45	211.42	536.52	455.76	479.57	347.44	418.05	581.71	248.71	384.99
September	153.06	147.77	162.69	168.43	132.07	405.88	89.04	419.07	113.64	133.50
October	144.90	285.18	88.84	229.81	318.28	124.58	109.20	123.30	310.04	168.90
November	148.47	309.79	182.47	139.57	146.00	121.68	111.91	105.08	150.20	140.00
December	61.19	134.66	76.64	95.10	137.12	94.41	79.69	90.79	50.19	50.71
Total	1401.44	2163.16	2267.35	2160.16	2634.66	2294.52	1771.97	1954.70	2075.80	2068.35

It is found that high correlation exists between the values of rainfall and runoff during the period 1976 to 1985. The correlation co-efficient is equal to 0.935 in all the three cases. Fig. 4.4 shows the graphical representation of equations (4.1) and (4.3). The observed values have also been plotted. Fig 4.4 clearly shows that the simple linear equation (equation 4.17) represents satisfactorily the relationship between rainfall and runoff.

It has to be noted that the stream flow in the Karuvannur river, taken for water balance computations, is not measured at the outfall of the river into the sea but a few kms. upstream of it, due to various practical limitations. Also, the quantity of water that is taken from the river for various purposes including irrigation is not known. Moreover, stream flow in the dry months have been assumed. All these factors are expected to effect the accuracy of stream flow values to some extent.

4.3. Evapotranspiration

Table 4.4 gives a detailed account of the computation of reference crop evapotranspiration for each month of the year 1977. The values of mean monthly reference crop evapotranspiration (ETo) for the period 1976 to 1985 have also been tabulated. (Table 4.5).

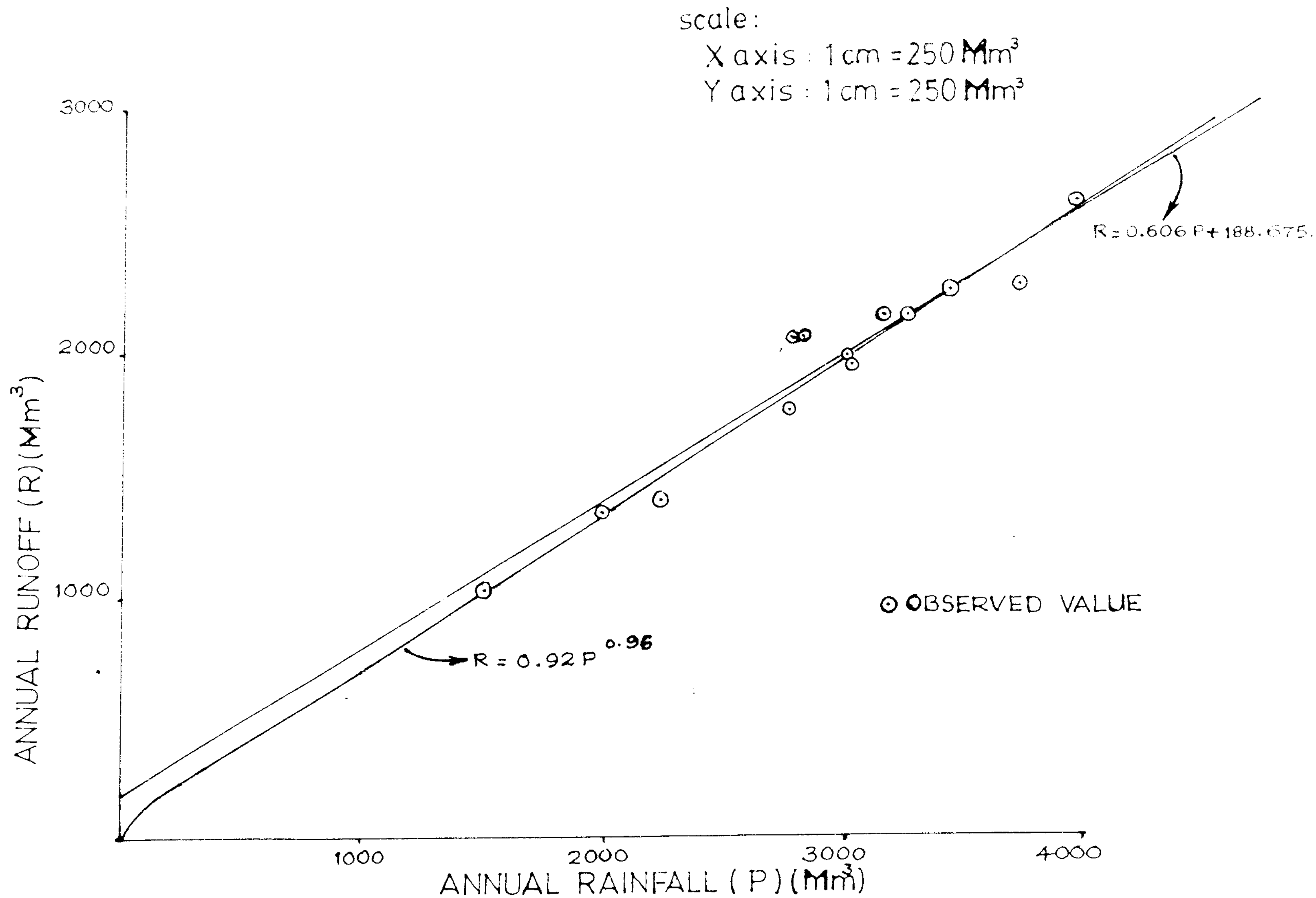


FIG. 4.4. GRAPHICAL REPRESENTATION OF EQUATION 4.1 AND EQUATION 4.3 CONNECTING RAINFALL AND RUNOFF

Table 4.4 Computation of reference crop evapotranspiration for the year 1977

1977	t(°C)	RH mean %	uat 3m (km/day)	uat 2m (km/day)	ea in m.bar	ed in m.bar	W	1-W	n (hrs)	N (hrs)	$\frac{n}{N}$
January	26.1	63	204.2	189.9	33.81	21.30	0.76	0.24	8.98	11.58	0.776
February	28.4	58	176.6	164.3	38.72	22.46	0.78	0.22	7.64	11.785	0.648
March	30.3	64	135.4	125.9	43.15	27.62	0.79	0.21	7.23	12.000	0.603
April	30.5	70	109.4	101.8	43.65	30.56	0.78	0.20	6.20	12.315	0.504
May	28.1	80	80.6	75.0	38.03	30.42	0.77	0.22	3.23	12.615	0.256
June	26.6	86	71.8	66.7	34.86	29.98	0.76	0.23	1.73	12.720	0.136
July	25.7	87	84.2	78.3	33.03	28.74	0.77	0.24	1.34	12.620	0.106
August	26.9	82	84.7	78.8	35.49	29.10	0.77	0.23	2.05	12.415	0.165
September	27.1	81	89.8	83.5	35.91	29.09	0.77	0.23	3.24	12.107	0.268
October	27.4	80	80.0	74.4	36.54	29.23	0.77	0.23	4.54	11.800	0.385
November	26.7	82	88.3	82.1	35.07	28.76	0.76	0.23	4.35	11.585	0.376
December	26.3	63	256.8	238.8	34.23	21.57	0.76	0.24	7.95	11.480	0.693

Table 4.4 (contd.) Computation of reference crop evapotranspiration for the year 1977

1977	Ra (mm/day)	Rns (mm/day)	f(t)	f(ed)	f(n/N)	Rnl (mm/day)	Rn (mm/day)	f(u)	(ea-ed) m.bar	ETo* (mm/day)	ETo (mm/day)
January	13.13	6.28	15.92	0.134	0.801	1.71	4.57	0.780	12.51	5.82	5.82
February	14.15	6.09	16.38	0.128	0.688	1.44	4.65	0.713	16.26	6.18	6.18
March	15.26	6.31	16.78	0.112	0.643	1.21	5.10	0.608	15.53	6.01	6.01
April	15.54	5.91	16.83	0.097	0.554	0.90	5.01	0.540	13.09	5.43	5.43
May	15.34	4.41	16.32	0.098	0.335	0.54	3.87	0.475	7.61	3.81	4.13
June	15.34	3.66	16.02	0.100	0.226	0.36	3.30	0.450	4.88	3.05	3.25
July	15.52	3.49	15.83	0.106	0.196	0.33	3.16	0.485	4.29	2.90	3.15
August	15.28	3.87	16.08	0.105	0.252	0.43	3.44	0.486	6.39	3.36	3.70
September	14.65	4.40	16.12	0.105	0.344	0.58	3.82	0.497	6.82	3.72	4.05
October	13.55	4.86	16.18	0.104	0.448	0.75	4.11	0.473	7.31	3.96	4.27
November	15.70	4.45	16.04	0.106	0.441	0.75	3.70	0.494	6.31	3.57	3.57
December	12.83	5.74	15.96	0.132	0.724	1.53	4.21	0.916	12.66	5.98	5.98

Table - 4.5 Values of reference crop evapotranspiration ETo (mm/day) for each month during the years 1976 - 1985

Month/Year	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
January	6.75	5.82	5.77	6.08	6.11	5.68	6.19	7.14	6.89	6.46
February	6.58	6.18	6.15	5.00	6.63	5.96	5.89	5.82	7.66	6.48
March	5.68	6.01	5.59	5.57	5.80	6.12	5.82	6.38	6.30	6.72
April	5.35	5.43	5.45	5.16	5.86	5.64	5.14	6.40	5.76	6.33
May	5.50	4.13	4.53	4.74	5.38	5.13	5.21	5.78	6.03	5.46
June	4.30	3.25	2.96	3.41	3.29	3.05	3.41	4.44	3.28	3.31
July	3.30	3.15	3.05	2.68	3.28	3.51	3.29	3.56	3.63	3.63
August	3.48	3.70	2.96	2.94	4.22	4.33	4.30	3.36	4.59	3.79
September	4.68	4.05	4.47	3.40	4.87	4.60	5.19	3.88	5.61	4.86
October	4.22	4.27	4.21	3.75	4.43	4.59	5.02	5.38	4.77	5.01
November	3.68	3.57	4.15	2.82	4.46	4.26	4.84	5.08	5.30	5.01
December	5.69	5.98	5.65	4.16	4.51	5.55	6.27	4.57	6.03	5.75

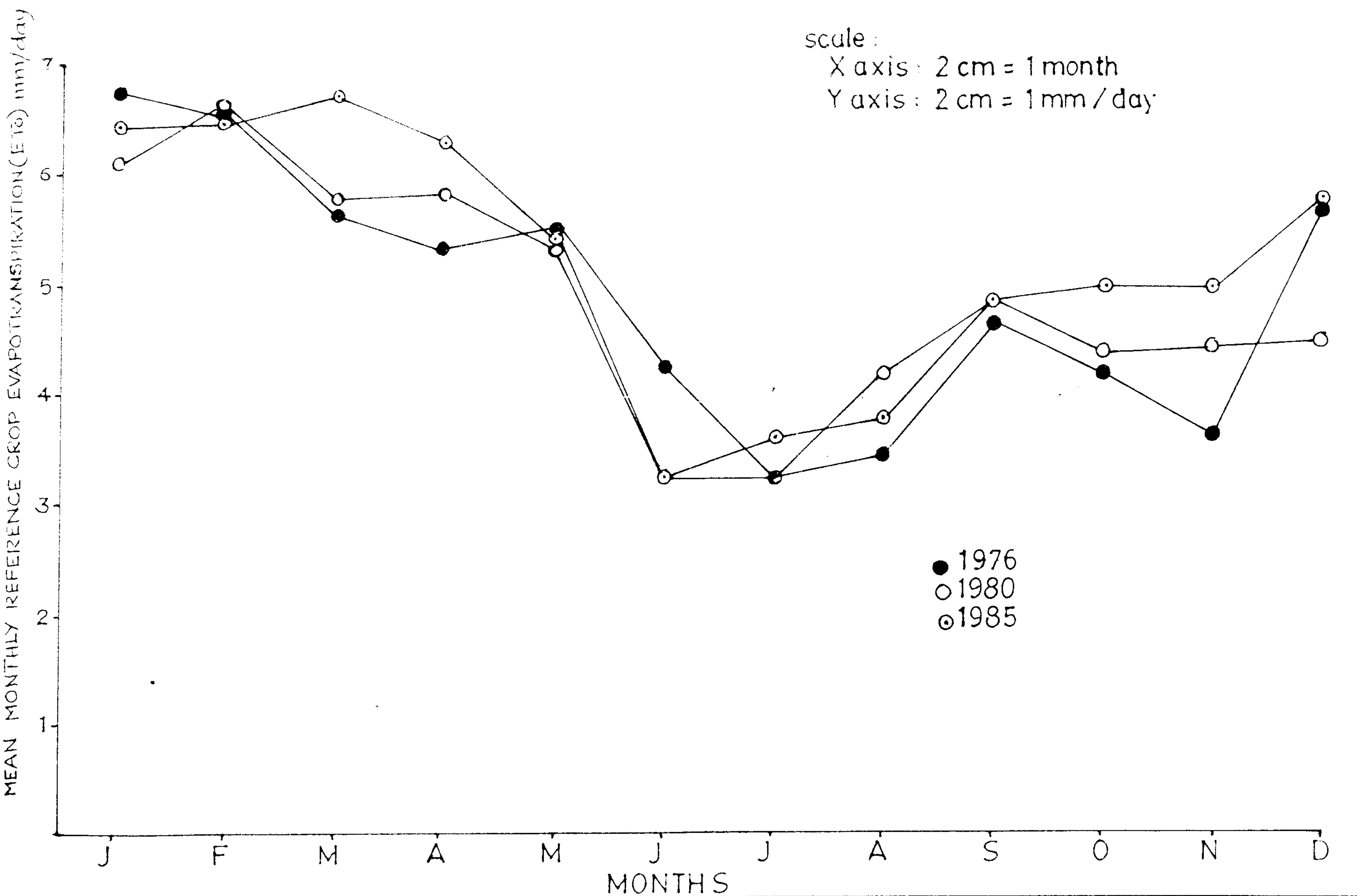


FIG. 4.5. GRAPH SHOWING VARIATION OF MEAN MONTHLY REFERENCE CROP EVAPOTRANSPIRATION (ETo) VALUES FOR DIFFERENT MONTHS DURING 1976, 1980 & 1985.

Reference crop evapotranspiration (ETo) values are high during the months of December, January, February, March and April. This may be because of the low relative humidity and the greater number of bright sunshine hours during these months. In December and January, the strong winds experienced in the basin is also considered to be a major factor producing higher evapotranspiration. During the months of June, July and August, ETo values are found to be low.

Table 4.6 (i) to 4.6 (xii) gives an account of the calculation of actual evapotranspiration from the basin for the year 1977 and Table 4.7 gives the actual evapotranspiration from the basin during each month of the period 1976 to 1985.

While calculating actual evapotranspiration, the variation in the area under different crops or crop combinations from year to year have been ignored for the sake of simplicity. Also, it is assumed that in the case of non irrigated crops, evapotranspiration would occur at a uniform rate during the dry months until the onset of rain. In fact, during the dry months, the rate of evapotranspiration would be maximum in early December. Therefore it will continiously decrease until the rains arrive. The exact pattern of decay in the rate of evapotranspiration is not known. The assumption of a uniform rate of evapotranspiration will affect the accuracy of monthly actual evapotranspiration

Table 4.6 (i) COMPUTATION OF ACTUAL EVAPOTRANSPIRATION FOR JANUARY 1977

Particulars of Crop/surface	D (m)	Sa (mm/m)	DSa (mm)	kc	ETo (mm/day)	ETm (mm/day)	ETa (mm/day)	No. of days in the month	Total ET (mm)	Area (sq.km.)	Total ET (Mm^3)
Coconut	1.2	60	72	0.85	5.82	4.95	0.476	31	14.756	50.40	0.74
Coconut with Cocoa/ tapioca/banana	1.2	60	72	1.10	5.82	6.40	5.72	31	177.32	40.20	7.13
Coconut with Cocoa/ young coconut under planted with tapioca/ banana etc.	1.2	60	72	1.20	5.82	6.98	6.07	31	188.17	42.70	8.03
Coconut with misc. tree crops	1.2	60	72	0.75	5.82	4.37	0.476	31	14.756	56.50	0.83
Cashew	1.2	60	72	0.60	5.82	3.49	0.476	31	14.756	18.70	0.28
Banana	1.0	60	60	0.95	5.82	5.53	4.88	31	151.28	6.00	0.91
Tapioca	0.5	60	30	0.60	5.82	3.49	2.75	31	85.25	6.00	0.51
Fodder	1.0	60	60	1.05	5.82	6.11	5.24	31	162.44	0.39	0.06
Rubber	1.0	60	60	0.60	5.82	3.49	0.397	31	12.30	46.56	0.57
Pulses/Vegetables	0.5	200	100	0.50	5.82	2.91	2.91	10	29.10	6.37	0.19
Sesamum	0.6	200	120	0.50	5.82	2.91	2.91	10	29.10	4.26	0.12
Rice				1.10	5.82	6.40	6.40	21	134.40	128.00	
				1.12	5.82	6.51	6.51	10	65.10	128.00	27.57
				1.10	5.82	6.40	6.40	3	19.20	106.00	
Forest	1.2	60	72	0.75	5.82	4.37	0.476	31	14.756	345.00	5.090
Bare Soil				0.125	5.82	0.73	0.73	31	22.63	98.55	
								28	20.44	95.37	5.15
								18	13.14	10.63	
Water				1.15	5.82	6.69	6.69	31	207.39	4.00	
Total ET (Mm^3)											57.18

Table 4.6 (ii) COMPUTATION OF ACTUAL EVAPOTRANSPIRATION FOR FEBRUARY 1977

Particulars of crop/surface	D (m)	Sa (mm/m)	DSa (mm)	kc	ETo (mm/day)	ETm (mm/day)	ETa (mm/day)	No. of days in the month	Total ET (mm)	Area (sq.km.)	Total ET (Mm^3)
Coconut	1.2	60	72	0.85	6.18	5.25	0.476	28	13.3	50.40	0.67
Coconut with Cocoa/ tapioca/banana (2 tier)	1.2	60	72	1.10	6.18	6.80	5.96	28	166.88	40.20	6.71
Coconut with Cocoa/ young coconut underplanted with tapioca/banana etc.	1.2	60	72	1.20	6.18	7.42	6.33	28	177.24	42.70	7.57
Coconut with misc.tree crops like jack, mango etc. (intensity of coconut about 50%)	1.2	60	72	0.75	6.18	4.64	0.476	28	13.33	56.50	0.75
Cashew	1.2	60	72	0.60	6.18	3.71	0.476	28	13.33	18.70	0.25
Banana	1.0	60	60	1.00	6.18	6.18	5.27	28	147.56	6.00	0.89
Tapioca	0.5	60	30	0.60	6.18	3.71	2.90	28	81.20	6.00	0.49
Fodder	1.0	60	60	1.05	6.18	6.49	5.40	28	151.20	0.39	0.06
Ginger and Turmeric	0.3	60	18								
Rubber	1.0	60	60	0.60	6.18	3.71	0.397	28	11.12	46.56	0.52
Pulses/Vegetables	0.5	200	100	0.63	6.18	3.89	3.89	28	108.92	6.36	0.69
Sesamum	0.6	200	120	0.63	6.18	3.89	3.89	28	108.92	4.26	0.47
Rice				1.19	6.18	7.35	7.35	28	205.80	128.00	26.34
Forest	1.2	60	72	0.75	6.18	4.64	0.476	28	13.33	345.00	4.60
Bare Soil				0.03	6.18	0.19	0.19	28	5.32	195.93	1.64
Water				0.15	6.18	7.11	7.11	28	199.08	3.00	
Total ET (Mm^3)											51.65

Table 4.6 (iii) COMPUTATION OF ACTUAL EVAPOTRANSPIRATION FOR MARCH 1977

Particulars of Crop/surface	D (m)	Sa (mm/m)	DSa (mm)	kc	ETo (mm/day)	ETm (mm/day)	ETa (mm/day)	No.of days in the month	Total ET (mm)	Area (sq.km.	Total ET (Mm^3)
Coconut	1.2	60	72	0.85	6.01	5.11	0.476	31	14.756	50.40	0.74
Coconut with Cocoa/ tapioca/banana (2 tier)	1.2	60	72	1.10	6.01	6.61	5.85	31	181.35	40.20	7.29
Coconut with Cocoa/young coconut underplanted with tapioca/banana etc.	1.2	60	72	1.20	6.01	7.21	6.21	31	192.51	42.70	8.22
Coconut with misc.tree crops like jack,mango etc. (intensity of coconut about 50%)	1.2	60	72	0.75	6.01	4.51	0.476	31	14.756	56.50	0.83
Cashew	1.2	60	72	0.60	6.01	3.61	0.476	31	14.756	18.70	0.28
Banana	1.0	60	60	1.00	6.01	6.01	5.19	31	160.89	6.00	0.97
Tapioca	0.5	60	30	0.60	6.01	3.61	2.81	31	87.11	6.00	0.52
Fodder	1.0	60	60	1.05	6.01	6.31	5.32	31	164.92	0.39	0.06
Ginger and Turmeric	0.3	60	18								
Rubber	1.0	60	60	0.60	6.01	3.61	0.397	31	12.307	46.56	0.57
Pulses/Vegetables	0.5	200	100	1.033	6.01	6.21	6.21	31	192.51	6.36	1.22
Sesamum	0.6	200	120	0.95	6.01	5.71	5.71	31	177.01	4.26	0.75
Rice				1.25	6.01	7.51	7.51	31	232.81	128.00	29.80
Forest	1.2	60	72	0.75	6.01	4.51	0.476	31	14.756	345.00	5.090
Bare Soil				0.405	6.01	2.43					
Water				1.15	6.01	6.91	6.91	31	214.21	2.00	0.43
Total ET (Mm^3)											56.770

Table 4.6 (iv) Computation of actual evapotransporation for April 1977

Particulars of crop surface	D (m)	Sa (mm/m)	DSa (mm)	kc	ETo (mm/day)	ETm (mm/day)	ETa (mm/day)	No.of days in the month	Total ET (mm)	Area (sq.km.)	Total ET (Mm^3)
Coconnt	1.2	60	72	0.85	5.43	4.62	-	30	65.40	50.40	3.30
Coconut with Cocoa/tapioca/ bababa (2 tier)	1.2	60	72	1.10	5.43	5.97	5.48	30	164.40	40.20	6.61
Coconut with Cocoa/young coconut under planted with tapioca, banana etc.	1.2	60	72	1.20	5.43	6.52	5.79	30	173.70	42.70	7.42
Coconut with misc.tree crops like jack, mango etc.(intensity of coconut about 50%)	1.2	60	72	0.75	5.43	4.07	-	30	63.50	56.50	3.59
Cashew	1.2	60	72	0.60	5.43	3.26	-	30	60.99	18.70	1.14
Banana	1.0	60	60	1.00	5.43	5.43	4.82	30	144.60	6.00	0.87
Tapioca	0.5	60	30	0.60	5.43	3.26	2.62	30	78.60	6.00	0.47
Fodder	1.0	60	60	1.05	5.43	5.70	4.71	30	141.30	00.39	0.06
Ginger and Turmeric	0.3	60	18	-	-	-	-	-	-	-	-
Rubber	1.0	60	60	0.60	5.43	3.26	-	30	58.62	46.56	2.73
Pulses/Vegetables	0.5	200	100	0.99	5.43	5.38	5.38	25	134.50	6.36	0.86
Sesamum	0.6	200	120	0.64	5.43	3.48	3.48	21	73.08	4.26	0.31
Rice	-	-	-	1.13	5.43	6.14	6.14	21	128.94	128.00	16.50
Forest	1.2	60	72	0.75	5.43	3.93	-	30	63.50	345.00	21.91
Bare Soil	-	-	-	0.43	5.43	2.31	2.31	30 5 9	69.30 11.55 20.79	103.55 6.36 132.26	- 10.19
Water	-	-	-	1.15	5.43	6.25	6.25	30	187.50	1.00	-
Total ET(Mm^3)											75.[illegible]

Table 4.6(v)

COMPUTATION OF ACTUAL EVAPOTRANSPIRATION FOR MAY 1977

Particulars of crop/surface	D (m)	Sa (mm/m)	DSa (mm)	kc	ETo (mm/day)	ETm (mm/day)	ETa (mm/day)	No.of days in the month.	Total ET(mm)	Area (Sq.km.)	Total ET (Mm^3)
Coconut	1.20	60	72	0.85	4.13	3.51	3.46	31	107.26	50.4	5.41
Coconut with cocoa/ tapioca/banana(2 tier)	1.20	60	72	1.10	4.13	4.54	4.35	31	134.85	40.2	5.42
Coconut with cocoa/young coconut under planted with tapioca, banana etc.	1.20	60	72	1.20	4.13	4.96	4.67	31	144.77	42.7	6.18
Coconut with misc. tree crops like jack, mango etc. (intensity of coconut about 50%)	1.20	60	72	0.75	4.13	3.10	3.06	31	94.86	56.5	5.36
Cashew	1.20	60	72	0.60	4.13	2.48	2.46	31	76.26	18.7	1.43
Banana	1.00	60	60	1.00	4.13	4.13	3.97	31	123.07	6.0	0.74
Tapioca	0.50	60	30	0.60	4.13	2.48	2.46	31	68.51	6.0	0.41
Fodder	1.00	60	60	1.05	4.13	4.34	4.10	31	127.10	0.39	0.05
Ginger and Turmeric	0.30	60	18	0.50	4.13	2.07	1.95	31	60.45	0.55	0.03
Rubber	1.00	60	60	0.60	4.13	2.48	2.45	31	75.95	46.56	3.54
Pulses and Vegetables	0.50	200	100								
Sesamum	0.60	200	120								
Rice				1.10	4.13	4.54	4.54	15	68.10	150	10.22
Forest	1.20	60	72	0.75	4.13	3.10	3.06	31	94.86	345	32.73
Bare soil				0.49	4.13	2.02	2.02	31	62.62	102	
								16	32.32	234	16.64
								15	30.30	84	
Water				1.15	4.13	4.75	4.75	31	147.25	1	
Total ET (Mm^3)											88.16

Table 4.6(vi) COMPUTATION OF ACTUAL EVAPOTRANSPIRATION FOR JUNE 1977

Particulars of crop/surface	D (m)	Sa (mm/m)	DSa (mm)	kc	ETo (mm/day)	ETm (mm/day)	ETa (mm/day)	No. of days in the month	Total ET (mm)	Area (Sq.km.)	Total ET (Mm^3)
Coconut	1.2	60	72	0.85	3.25	2.76	2.76	30	82.8	50.4	4.17
Coconut with cocoa/ tapioca/banana (2 tier)	1.2	60	72	1.10	3.25	3.58	3.58	30	107.4	40.2	4.32
Coconut with cocoa/young coconut under planted with tapioca, banana etc.	1.2	60	72	1.20	3.25	3.90	3.90	30	117.0	42.7	5.00
Coconut with misc. tree crops like jack, mango etc. (intensity of coconut about 50%)	1.2	60	72	0.75	3.25	2.44	2.44	30	73.2	56.5	4.14
Cashew	1.2	60	72	0.60	3.25	1.95	1.95	30	58.5	18.7	1.09
Banana	1.0	60	60	1.00	3.25	3.25	3.25	30	97.5	6.0	0.59
Tapioca	0.5	60	30	0.54	3.25	1.76	1.76	30	52.8	6.0	0.32
Fodder	1.0	60	60	1.00	3.25	3.25	3.25	30	97.5	0.39	0.04
Ginger and Turmeric	0.3	60	18	0.64	3.25	2.08	2.08	30	62.4	0.55	0.03
Rubber	1.0	60	60	0.60	3.25	1.95	1.95	30	58.5	46.56	2.72
Pulses and Vegetables	0.5	200	100	0.54	3.25	1.76	1.76	30	52.8	6.00	0.32
Sesamum	0.6	200	120								
Rice				1.10 1.094	3.25 3.25	3.58 3.56	3.58 3.56	10 20	35.8 71.2	150.00	16.05
Forest	1.2	60	72	0.75	3.25	3.56	3.56	30	73.2	345.00	25.25
Soil				0.935	3.25	3.04	3.04	30	91.2	97.00	17.76
Water				1.10	3.25	3.58	3.58	30	107.4	83.00	
Total ET (Mm^3)											81.80

Table 4.6(vii) COMPUTATION OF ACTUAL EVAPOTRANSPIRATION FOR JULY 1977

Particulars of crop/surface	D (m)	Sa (mm/m)	DSa (mm)	kc	ETo (mm/day)	ETm' (mm/day)	ETa (mm/day)	No.of days in the month	Total ET(mm)	Area (Sq.km.)	Total ET (Mm^3)
Coconut	1.2	60	72	0.85	3.15	2.68	2.68	31	83.08	50.4	4.19
Coconut with cocoa/ tapioca/banana (2 tier)	1.2	60	72	1.10	3.15	3.47	3.47	31	107.57	40.2	4.32
Coconut with cocoa/young coconut under planted with tapioca/banana etc.	1.2	60	72	1.20	3.15	3.78	3.78	31	117.18	42.7	5.00
Coconut with misc. tree crops like jack, mango etc.(intensity of coconut about 50%)	1.2	60	72	0.75	3.15	2.36	2.36	31	73.16	56.5	4.15
Cashew	1.2	60	72	0.60	3.15	1.89	1.89	31	58.59	18.7	1.10
Banana	1.0	60	60	1.00	3.15	3.15	3.15	31	97.65	6.0	0.59
Tapioca	0.5	60	30	0.41	3.15	1.29	1.29	31	39.99	6.0	0.24
Fodder	1.0	60	60	1.00	3.15	3.15	3.15	31	97.65	0.39	0.04
Ginger and turmeric	0.3	60	18	0.91	3.15	2.87	2.87	31	88.97	0.55	0.05
Rubber	1.0	60	60	0.60	3.15	1.89	1.89	31	58.59	46.56	2.33
Pulses and Vegetables	0.5	200	100	0.97	3.15	3.06	3.06	31	94.86	6.00	0.57
Sesamum	0.6	200	100								
Rice				1.06	3.15	3.34	3.34	31	103.54	150.00	15.53
Forest	1.2	60	72	0.75	3.15	2.36	2.36	31	73.16	345.00	25.24
Bare Soil				0.94	3.15	2.96	2.96	31	91.76	97.00	17.83
Water				1.10	3.15	3.47	3.47	31	107.57	83.00	
Total ET (Mm^3)											81.56

Table 4.6(viii) COMPUTATION OF ACTUAL EVAPOTRANSPIRATION FOR AUGUST 1977

Particulars of crop/surface	D (m)	Sa (mm/m)	DSa (mm)	kc	ETo (mm/day)	ETm (mm/day)	ETa (mm/day)	No.of days in the month	Total ET (mm)	Area (sq.km)	Total ET (Mm^3)
Coconut	1.2	60	72	0.85	3.7	3.15	3.15	31	97.65	50.4	4.92
Coconut with Cocoa/ tapioca/banana (2 tier)	1.2	60	72	1.10	3.7	4.07	4.07	31	126.17	40.2	5.07
Coconut with Cocoa/young coconut under planted with tapioca/banana etc.	1.2	60	72	1.20	3.7	4.44	4.44	31	137.64	42.7	5.88
Coconut with misc.tree crops like jack,mango etc.(intensity of coconut about 50%)	1.2	60	72	0.60	3.7	2.78	2.78	31	86.18	56.5	4.87
Cashew	1.2	60	72	0.60	3.7	2.22	2.22	31	68.82	18.7	1.29
Banana	1.0	60	60								
Tapioca	0.5	60	30								
Fodder	1.0	60	60	1.00	3.70	3.70	3.70	31	114.70	0.39	0.05
Ginger and Turmeric	0.3	60	18	1.05	3.70	3.89	3.89	31	120.59	0.55	0.07
Rubber	1.0	60	60	0.60	3.70	2.22	2.22	31	68.82	46.56	3.20
Pulses/Vegetables	0.5	200	100	1.015	3.70	3.76	3.76	31	116.56	6.0	0.70
Sasamum	0.6	200	120								
Rice	0.6	200	120	1.041	3.70	3.85	3.85	31	119.35	150.00	17.90
Forest	1.2	60	72	0.75	3.70	2.78	2.78	31	86.18	345.00	29.73
Bare Soil				0.92	3.70	3.40	3.40	31	105.40	109.00	21.96
Water				1.10	3.70	4.07	4.07	31	126.17	83.00	
Total ET (Mm^3)											95.64

Table 4.6(ix) **COMPUTATION OF ACTUAL EVAPOTRANSPIRATION FOR SEPTEMBER 1977**

Particulars of crop/surface	D (m)	Sa (mm/m)	DSa (mm)	kc	ETo (mm/day)	ETm (mm/day)	ETa (mm/day)	No. of days in the month	Total ET (mm)	Area (sq.km)	Total ET (Mm^3)
Coconut	1.2	60	72	0.85	4.05	3.44	3.44	30	103.2	50.4	5.20
Coconut with Cocoa/ tapioca/banana (2 tier)	1.2	60	72	1.10	4.05	4.46	4.42	30	132.6	40.2	5.33
Coconut with Cocoa/ young coconut under planted with tapioca/ banana etc.	1.2	60	72	1.20	4.05	4.86	4.79	30	143.7	42.7	6.14
Coconut with misc.tree crops	1.2	60	72	0.75	4.05	3.04	3.04	30	91.2	56.5	5.15
Cashew	1.2	60	72	0.60	4.05	2.43	2.43	30	72.9	18.7	1.36
Banana	1.0	60	60	0.70	4.05	2.84	2.84	30	85.2	6.0	0.51
Tapioca	0.5	60	30	0.35	4.05	1.42	1.42	30	42.6	6.0	0.26
Fodder	1.0	60	60	1.00	4.05	4.05	4.05	30	121.5	0.39	0.05
Ginger and Turmeric	0.3	60	18	1.05	4.05	4.25	3.41	30	102.3	0.55	0.06
Rubber	1.0	60	60	0.60	4.05	2.43	2.43	30	72.9	46.56	3.39
Pulses/Vegetables	0.5	200	100	0.91 0.50	4.05 4.05	3.69 2.03	3.69 2.03	3 20	11.07 40.6	6.00 1.00	0.11
Sesamum	0.6	200	120								
Rice	0.6	200	120	0.976 1.10 1.10	4.05 4.05 4.05	3.95 4.46 4.46	3.95 4.46 4.46	13 25 25	51.35 111.5 111.5	150.00 11.7 117	22.05
Forest	1.2	60	72	0.75	4.05	3.04	3.04	30	91.2	345	31.46
Bare Soil				0.56	4.05	2.27	2.27	30	68.1	96	7.21
Water				1.10	4.05	4.46	4.46	30	133.8	5	
Total ET (Mm^3)											88.28

Table 4.6(x) COMPUTATION OF ACTUAL EVAPOTRANSPIRATION FOR OCTOBER 1977

Particulars of crop/surface	D (m)	Sa (mm/m)	DSa (mm)	kc	ETo (mm/day)	ETm (mm/day)	ETa (mm/day)	No.of days in the month	Total ET (mm)	Area (sq.km)	Total ET (Mm^3)
Coconut	1.2	60	72	0.85	4.27	3.63	3.63	31	112.53	50.4	5.67
Coconut with Cocoa/ tapioca banana (2 tier)	1.2	60	72	1.10	4.27	4.70	4.70	31	145.70	40.2	5.86
Coconut with Cocoa/ young coconut under planted with tapioca/ banana etc.	1.2	60	72	1.20	4.27	5.12	5.12	31	158.72	42.7	6.78
Coconut with misc.tree crops	1.2	60	72	0.75	4.27	3.20	3.20	31	99.20	56.5	5.61
Cashew	1.2	60	72	0.60	4.27	2.56	2.56	31	79.36	18.7	1.48
Banana	1.0	60	60	0.70	4.27	2.99	2.99	31	92.69	6.0	0.56
Tapioca	0.5	60	30	0.41	4.27	1.75	1.75	31	54.25	6.0	0.33
Fodder	1.0	60	60	1.00	4.27	4.27	4.27	31	132.37	0.39	0.05
Ginger and Turmeric	0.3	60	18	1.05	4.27	4.48	4.13	31	128.03	0.55	0.07
Rubber	1.0	60	60	0.60	4.27	2.56	2.56	31	79.36	46.56	3.70
Pulses/Vegetables	0.5	200	100	0.83	4.27	3.54	3.54	31	109.74	1.0	0.11
Sesamum	0.6	200	120								
Rice	0.6	200	120	1.081	4.27	4.62	4.62	31	143.22	234.0	33.51
Forest	1.2	60	72	0.75	4.27	3.20	3.20	31	99.20	345.0	34.22
Bare Soil				0.70	4.27	2.99	2.99	31	92.69	96.0	9.63
Water				1.10	4.27	4.70	4.70	31	145.70	5.0	
Total ET (Mm^3)											107.58

Table 4.6 (xi) **COMPUTATION OF ACTUAL AVAPOTRANSPIRATION FOR NOVEMBER 1977**

Particulars of crop/surface	D (m)	Sa (mm/m)	DSa (mm)	kc	ETo (mm/day)	ETm (mm/day)	ETa (mm/day)	No.of days in the month	Total ET (mm)	Area (sq.km)	Total ET (Mm^3)
Coconut	1.2	60	72	0.85	3.57	3.04	3.00	30	90.00	50.4	4.54
Coconut with Cocoa/ tapioca banana (2 tier)	1.2	60	72	1.10	3.57	3.93	3.86	30	115.80	40.2	4.66
Coconut with cocoa/ young coconut under planted with tapioca/ banana etc.	1.2	60	72	1.20	3.57	4.28	4.15	30	124.50	42.7	5.32
Coconut with misc.tree crops.	1.2	60	72	0.75	3.57	2.68	2.66	30	79.80	56.5	4.51
Cashew	1.2	60	72	0.60	3.57	2.14	2.14	30	64.20	18.7	1.20
Banana	1.0	60	60	0.75	3.57	2.68	2.64	30	7.92	6.0	0.48
Tapioca	0.5	60	30	0.54	3.57	1.93	1.93	30	57.90	6.0	0.35
Fodder	1.0	60	60	1.00	3.57	3.57	3.48	30	104.40	0.39	0.04
Ginger and Turmeric	0.3	60	18	1.05	3.57	3.75	2.69	30	80.70	0.55	0.04
Rubber	1.0	60	60	0.60	3.57	2.14	2.13	30	63.90	46.56	2.98
Pulses/Vegetables	0.5	200	100	1.046	3.57	3.73	3.73	30	111.90	1.0	0.11
Sesamum	0.6	200	120								
Rice	0.6	200	120	1.052	3.57	3.76	3.76	30	112.8	234.0	26.40
Forest	1.2	60	72	0.75	3.57	2.68	2.66	30	79.8	345.0	27.53
Bare Soil				0.50	3.57	1.79	1.79	30	53.7	96.0	5.74
Water				1.10	3.57	3.93	3.93	30	117.9	5.0	
Total ET (Mm^3)											83.90

Table 4.6 (xii) COMPUTATION OF ACTUAL EVAPOTRANSPIRATION FOR DECEMBER 1977

Particulars of Crop/surface	D (m)	Sa (mm/m)	DSa (mm)	kc	ETo (mm/day)	ETm (mm/day)	ETa (mm/day)	No.of days in the month	Total ET (mm)	Area (sq.km.	Total ET (Mm^3)
Coconut	1.2	60	72	0.85	5.98	5.98	0.476	31	14.756	50.4	0.74
Coconut with Cocoa/ tapioca banana (2 tier)	1.2	60	72	1.10	5.98	6.58	5.83	31	180.73	40.2	7.27
Coconut with cocoa/young coconut under planted with tapioca/banana etc.	1.2	60	72	1.20	5.98	7.18	6.19	31	191.89	42.7	8.19
Coconut with misc. tree crops	1.2	60	72	0.75	5.98	4.49	0.476	31	14.756	56.5	0.83
Cashew	1.2	60	72	0.60	5.98	3.59	0.476	31	14.756	18.7	0.28
Banana	1.0	60	60	0.90	5.98	5.38	4.78	31	148.18	6.0	0.89
Tapioca	0.5	60	30	0.60	5.98	3.59	2.80	31	86.80	6.0	0.52
Fodder	1.0	60	60	1.05	5.98	6.28	5.31	31	164.61	0.39	0.06
Gigner and Turmeric	0.3	60	18	0.98	5.98	5.86	3.03	26	78.78	0.55	0.04
Rubber	1.0	60	60	0.06	5.98	3.59	0.397	31	12.307	46.56	0.57
Pulses/Vegetables	0.5	200	100	0.953	5.98	5.70	5.70	14	79.80	1.00	0.08
Sesamum	0.6	200	120								
Rice	0.6	200	120	1.019	5.98	6.09	6.09	31	188.79	234.00	44.18
Forest	1.2	60	72	0.75	5.98	4.49	0.476	31	14.756	345.00	5.090
Bare Soil				0.19	5.98	2.42	1.14	31	35.34	96.00	
								17	19.38	1.00	4.49
								5	5.70	0.55	
Water				1.15	5.98	6.88	6.88	31	213.28	5.00	
Total ET (Mm^3)											73.23.

Table 4.7 Actual Evapotranspiration from the basin (Mm^3)

Year / Month	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
January	65.41	57.18	56.86	61.31	63.91	56.31	59.89	64.24	66.04	84.93
February	58.53	51.65	54.88	61.92	58.37	50.54	55.25	48.18	70.68	58.04
March	56.18	56.77	53.74	60.40	57.05	55.67	57.20	59.01	75.44	67.16
April	79.03	75.96	64.21	61.01	112.19	69.01	80.93	30.30	87.48	68.45
May	76.43	88.16	94.92	99.17	125.18	107.32	107.26	78.07	120.33	111.01
June	107.75	81.80	74.59	85.85	82.82	76.92	85.74	111.25	82.56	83.22
July	85.48	81.56	79.12	69.68	89.97	90.69	85.23	92.08	93.76	93.70
August	90.02	95.64	76.76	76.39	108.13	111.82	110.90	87.65	118.24	96.73
September	101.30	88.28	97.11	74.57	105.40	99.65	112.15	94.96	119.47	105.24
October	106.49	107.58	106.17	93.21	111.64	115.30	126.13	134.79	119.94	125.83
November	86.56	83.90	96.49	66.60	103.15	99.09	111.43	116.72	75.38	74.98
December	61.50	73.23	98.37	70.78	61.49	73.00	78.45	79.96	83.08	91.99

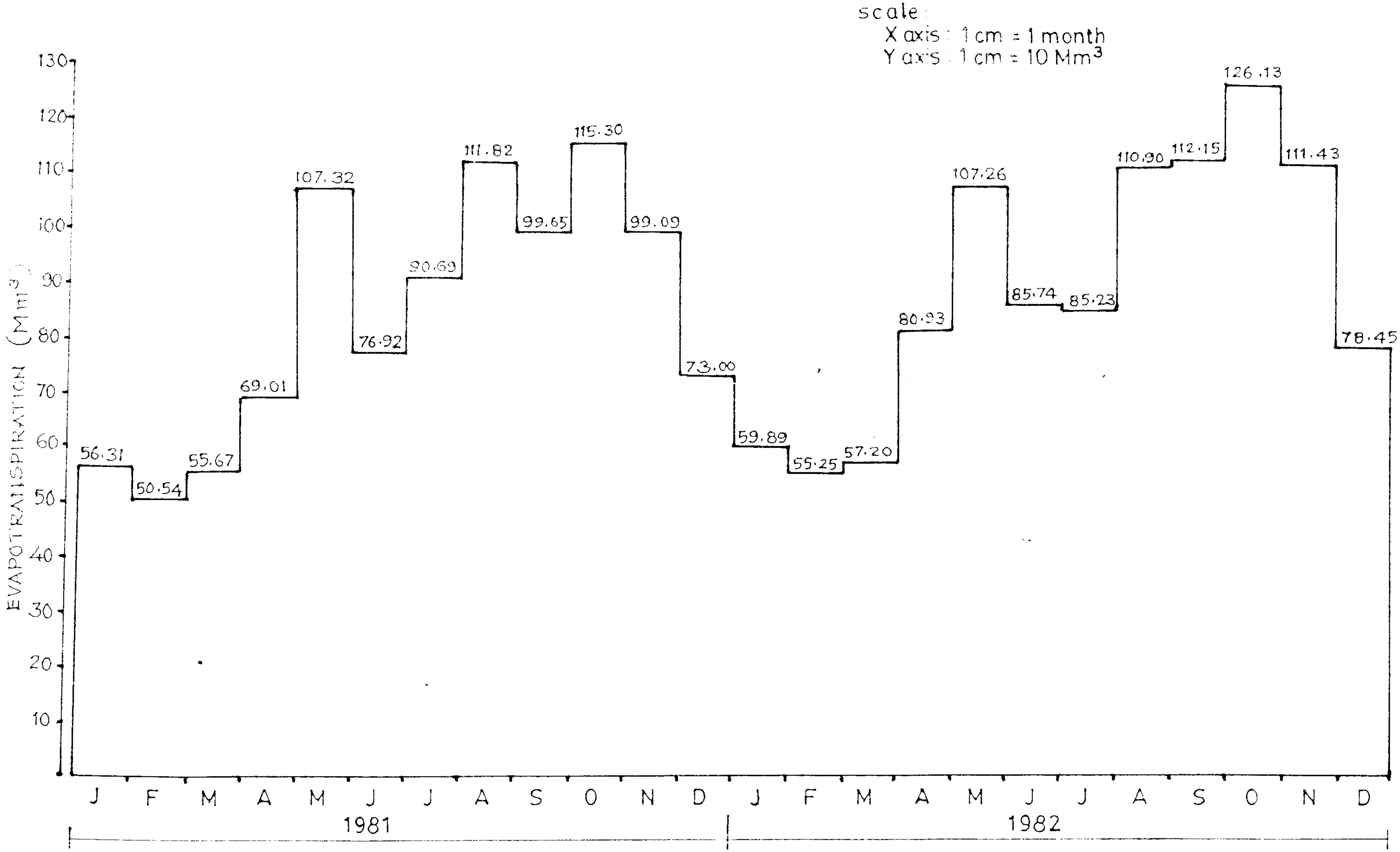


FIG. 4.6. DISTRIBUTION OF EVAPOTRANSPIRATION DURING DIFFERENT MONTHS IN 1981 & 1982

estimates during this period. However, when the dry period is considered as a whole, the actual evapotranspiration estimates will be correct.

4.4. Input from other sources

The input of water into the basin due to domestic consumption, industrial and commercial activities, public use, wastages in the distribution system etc. has been ignored because preliminary analysis showed that this quantity would be very small in comparison with the other quantities involved in the water balance equation.

Irrigation water is the other source of input into the basin. The quantity of irrigation water released from the Peechi Reservoir has been measured and recommend. But data regarding the irrigation water released from other schemes are not available and hence it has not been taken into account. Ignoring the quantity of water diverted for irrigation from other sources is likely to reduce the balance available for ground water recharge or depletion. However, as the stream flow values used in the water balance computation are estimated to be less than the actual values, the error introduced by ignoring this part of the irrigation input may not be considerable.

4.5. Water Balance Study

Table 4.8 gives the monthly water balance statement of the Karuvannur river basin for the period 1976 to 1985.

The abstract of the water balance statement on an yearly basis has also been presented. (Table 4.9).

Recharge to the ground water reservoir occurs mainly in the months of June, July and August. In some years, recharge occurs during the months of May, September, October and November also. The balance available for ground water accretion, (unaccounted water) is maximum either in June or July. During the remaining months, the balance works out to be negative. This indicates that water is withdrawn from the ground water reservoir.

When the water balance of the basin is calculated on an annual basis, it is found that the balance available for ground water accretion (unaccounted water) is negative in 1976, 1984 and 1985. It may be noted that low rainfall has been recorded in these three years. Although low rainfall was recorded in 1982, the balance works out be positive. (+ 58.086Mm^3) Maximum annual rainfall (3972.70Mm^3) was recorded in 1980. However the balance for ground water accretion was maximum in 1981 (+ 581.127 Mm^3), the year in which the next highest rainfall occured. This is because of the comparatively lower values of evapotranspiration and stream flow in 1981.

When the values of the balance water available for ground water accretion or depletion (unaccounted water) are

Table 4.8 Monthly Water Balance Statement (1976-1985)

Month	Inflow			Evapotranspiration	Stream flow	Balance available for ground water depletion or accretion (unaccounted water)	Cumulative Balance
	Rainfall	Irrigation water released from Peechi Reservoir	Total inflow				
		Mm^3	Mm^3	Mm^3	Mm^3	Mm^3	Mm^3
<u>1976</u>							
January	0	6.032	6.032	65.41	40.96	-100.338	-100.338
February	0	10.915	10.915	58.53	32.74	- 80.355	-180.693
March	6.073	13.357	19.430	56.18	27.26	- 64.010	-244.703
April	113.284	1.971	115.255	79.03	62.39	- 26.165	-270.868
May	78.971	-	78.971	76.43	57.47	- 54.929	-325.797
June	230.470	-	230.470	107.75	83.34	+ 39.380	-286.417
July	770.449	-	770.449	85.48	284.21	+400.759	+114.342
August	423.116	-	423.116	90.02	305.45	+ 27.646	+141.988
September	134.787	11.056	145.843	101.30	153.06	-108.517	+ 33.471
October	226.297	17.698	243.995	106.49	144.90	- 7.395	+ 26.076
November	238.547	4.883	253.430	86.56	148.47	+ 18.400	+ 44.476
December	15.983	17.342	33.325	61.50	61.19	- 89.365	- 44.889

Table 4.8 (Contd.). Monthly Water Balance Statement (1976-1985)

Month	Inflow			Evapotranspiration	Stream flow	Balance available for ground water depletion or accretion (unaccounted water)	Cumulative Balance
	Rainfall	Irrigation water released from Peechi Reservoir Mm^3	Total inflow Mm^3	Mm^3	Mm^3	Mm^3	Mm^3
<u>1977</u>							
January	0	2.789	2.789	57.18	38.19	-92.581	-137.470
February	8.612	0.998	9.610	51.65	33.67	-75.710	-213.180
March	12.282	14.358	26.640	56.77	29.47	-59.600	-272.780
April	71.691	3.062	74.753	75.96	50.93	-52.137	-324.917
May	321.003	-	321.003	88.16	128.17	+104.673	-220.244
June	621.344	-	621.344	81.80	181.10	+358.444	+138.200
July	797.475	-	797.475	81.56	612.21	+103.705	+241.905
August	284.718	-	284.718	95.64	211.42	- 22.342	+219.563
September	173.084	13.300	186.384	88.28	147.77	- 49.666	+169.897
October	403.248	17.100	420.348	107.58	285.18	+ 27.588	+197.485
November	471.339	11.500	482.837	83.90	309.79	+ 89.147	+286.632
December	0.047	25.339	25.386	73.23	134.66	-182.504	+104.128

Table 4.8 (Contd.) Monthly Water Balance Statement (1976-1985)

Month	Inflow			Evapotranspiration	Stream flow	Balance available for ground water depletion or accretion (unaccounted water)	Cumulative Balance
	Rainfall	Irrigation water released from Peechi Reservoir	Total inflow				
		Mm^3	Mm^3	Mm^3	Mm^3	Mm^3	Mm^3
1978							
January	0	5.621	5.621	56.86	88.19	-139.429	-35.301
February	12.347	13.671	26.018	54.88	64.76	- 93.622	-128.923
March	12.232	17.947	30.178	53.74	42.09	- 65.652	-194.575
April	44.529	8.052	52.581	64.21	43.24	- 54.869	-249.444
May	308.267	0.058	308.325	94.92	121.19	+ 92.215	-157.229
June	917.258	-	917.258	74.59	325.34	+517.328	+360.099
July	793.469	-	793.469	79.12	535.38	+178.969	+539.068
August	695.312	-	695.312	76.76	536.52	+ 82.032	+621.100
September	102.212	9.070	111.222	97.11	162.69	-148.576	+47[illegible]
October	172.007	28.338	200.345	106.17	88.84	+ 5.335	+477.857
November	318.654	20.925	339.579	96.49	182.47	+ 60.619	+538.476
December	78.148	26.106	104.254	98.37	76.64	- 70.756	+467.720

Table 4.8 (Contd.). Monthly Water Balance Statement (1976-1985)

Month	Inflow			Evapotranspiration	Stream flow	Balance available for ground water depletion or accretion (unaccounted water)	Cumulative Balance
	Rainfall	Irrigation water released from Peechi Reservoir	Total inflow				
		Mm3	Mm3	Mm3	Mm3	Mm3	Mm3
1979							
January	0	7.496	7.496	61.31	53.73	-107.544	+360.176
February	27.377	4.736	32.113	61.92	50.29	- 80.097	+280.079
March	4.515	24.321	28.836	60.40	38.41	- 69.974	+210.105
April	41.437	10.076	51.513	61.01	49.93	- 59.427	+150.678
May	118.132	-	118.132	99.17	79.43	- 60.468	+ 90.210
June	836.809	-	836.809	85.85	252.21	+498.749	+588.959
July	938.052	-	938.052	69.68	557.49	+310.882	+899.841
August	507.638	-	507.638	76.39	455.76	- 24.512	+875.329
September	286.359	21.994	308.353	74.57	168.43	+ 65.353	+940.682
October	192.619	25.292	217.911	93.21	219.81	- 95.109	+845.573
November	299.635	22.481	322.116	66.60	139.57	+115.946	+961.519
December	0	23.005	23.005	70.78	95.10	-142.875	+818.644

Table 4.8 (Contd.) Monthly Water Balance Statement (1976-1985)

Month	Inflow			Evapotranspiration	Stream flow	Balance available for ground water depletion or accretion (unaccounted water)	Cumulative Balance
	Rainfall	Irrigation water released from Peechi Reservoir	Total inflow				
		Mm^3	Mm^3	Mm^3	Mm^3	Mm^3	Mm^3
<u>1980</u>							
January	0.152	5.496	5.648	63.91	71.04	-129.302	+689.342
February	0.681	14.793	15.474	58.37	49.11	- 92.006	+597.336
March	12.233	21.463	33.696	57.05	30.97	- 54.324	+543.012
April	145.327	3.217	148.544	112.19	68.70	- 32.346	+510.666
May	157.446	-	157.466	125.18	85.21	- 52.924	+457.742
June	1011.206	-	1011.206	82.82	256.15	+672.236	+1129.978
July	1243.805	-	1243.805	89.97	860.44	+293.395	+1423.373
August	584.363	0.975	585.338	108.13	479.57	- 2.362	+1421.011
September	190.449	23.765	214.214	105.40	132.07	- 23.256	+1397.755
October	426.108	22.068	448.176	111.64	318.28	+ 18.256	+1416.011
November	193.064	22.519	215.583	103.15	146.00	- 33.567	+1382.444
December	8.572	27.267	35.839	61.49	137.12	-162.771	+1219.673

Table 4.8 (Contd.). Monthly Water Balance Statement (1976-1985)

Month	Inflow			Evapotranspiration	Stream flow	Balance available for ground water depletion or accretion (unaccounted water)	Cumulative Balance
	Rainfall	Irrigation water released from Peechi Reservoir	Total inflow				
		Mm^3	Mm^3	Mm^3	Mm^3	Mm^3	Mm^3
1981							
January	0	8.890	8.890	56.31	89.28	-138.700	+1082.973
February	0.095	21.671	21.766	50.54	67.11	- 95.844	+ 987.089
March	8.966	33.949	42.915	55.67	47.08	- 59.835	+ 927.254
April	45.945	3.711	49.656	69.01	69.73	- 89.084	+ 838.170
May	256.222	-	256.222	107.32	110.20	+ 38.702	+ 876.872
June	1217.411	-	1217.411	76.92	528.43	+612.061	+1488.933
July	497.412	-	497.412	90.69	288.70	+118.022	+1606.955
August	544.184	-	544.184	111.82	347.44	+ 84.924	+1691.879
September	721.791	16.489	738.280	99.65	405.88	+332.750	+1924.629
October	282.532	26.952	309.484	115.30	124.58	+ 69.604	+1994.233
November	134.853	24.248	159.101	99.09	121.68	- 61.669	+1932.564
December	8.038	27.559	35.597	73.00	94.41	-131.813	+1800.751

Table 4.8 (Contd.). Monthly Water Balance Statement (1976-1985)

Month	Inflow: Rainfall	Inflow: Irrigation water released from Peechi Reservoir	Inflow: Total inflow	Evapotranspiration	Stream flow	Balance available for ground water depletion or accretion (unaccounted water)	Cumulative Balance
		Mm^3	Mm^3	Mm^3	Mm^3	Mm^3	Mm^3
1982							
January	0	5.945	5.945	59.89	72.29	-126.235	+1674.516
February	0	12.201	12.201	55.25	52.07	- 95.119	+1579.397
March	5.133	15.549	20.682	57.20	41.99	- 78.508	+1500.889
April	65.024	2.285	67.309	80.93	63.73	- 77.401	+1423.488
May	147.920	-	147.920	107.26	89.92	- 49.260	+1374.228
June	846.171	-	846.171	85.74	244.15	+516.281	+1890.509
July	636.858	-	636.858	85.23	339.88	+211.748	+2102.257
August	613.376	-	613.376	110.90	478.05	+ 24.426	+2126.683
September	90.876	17.242	108.118	112.15	89.04	- 93.072	+2033.611
October	250.094	27.342	277.436	126.13	109.20	+ 42.106	+2075.717
November	112.930	24.466	137.396	111.43	111.21	- 85.244	+1990.473
December	3.797	23.386	27.183	78.45	79.69	-130.957	+1859.516

Table 4.8 (Contd.). Monthly Water Balance Statement (1976-1985)

Month	Inflow			Evapotranspiration	Stream flow	Balance available for ground water depletion or accretion (unaccounted water)	Cumulative Balance
	Rainfall	Irrigation water released from Peechi Reservoir	Total inflow				
		Mm^3	Mm^3	Mm^3	Mm^3	Mm^3	Mm^3
1983							
January	0	1.531	1.531	64.24	53.25	-115.959	+1743.557
February	0	13.111	13.111	48.18	39.67	- 74.739	+1668.818
March	0	10.129	10.129	59.01	26.17	- 75.051	+1593.767
April	9.864	-	9.864	30.30	15.45	- 35.886	+1557.881
May	60.091	-	60.091	78.07	30.45	- 48.429	+1509.452
June	425.718	-	425.718	111.25	51.28	+263.188	+1772.640
July	807.521	-	807.521	92.08	418.48	+296.961	+2069.601
August	798.406	-	798.406	87.65	581.71	+129.046	+2198.647
September	626.900	9.214	636.114	85.96	419.07	+131.084	+2329.731
October	136.023	28.028	164.051	134.79	123.30	- 94.039	+2235.692
November	114.818	27.480	142.298	116.72	105.08	- 79.502	+2156.190
December	43.954	27.566	71.520	79.96	90.79	- 99.230	+2056.960

Table 4.8 (Contd.). Monthly Water Balance Statement (1976-1985)

Month	Inflow			Evapotranspiration	Stream flow	Balance available for ground water depletion or accretion (unaccounted water)	Cumulative Balance
	Rainfall	Irrigation water released from Peechi Reservoir Mm^3	Total inflow Mm^3	Mm^3	Mm^3	Mm^3	Mm^3
<u>1984</u>							
January	1.150	3.993	5.143	66.04	70.28	-131.177	+1925.783
February	12.393	13.142	25.535	70.68	44.19	- 89.335	+1836.448
March	19.796	14.270	34.066	75.44	31.72	- 73.094	+1763.354
April	148.824	2.345	151.169	108.70	60.40	- 17.931	+1746.423
May	53.076	-	53.076	87.48	50.32	- 84.724	+1660.699
June	923.950	-	923.950	82.56	288.06	+553.33	+2214.029
July	797.809	-	797.809	93.76	658.05	+ 45.999	+2260.028
August	294.177	-	294.177	118.24	248.71	- 72.773	+2187.255
September	143.879	18.473	162.352	119.47	113.64	- 70.758	+2116.497
October	397.578	25.217	422.795	119.47	310.04	- 7.185	+2109.312
November	19.978	25.364	45.342	75.38	150.20	-180.238	+1929.074
December	17.831	27.144	44.975	83.08	50.19	- 88.295	+1840.779

Table 4.8 (Contd.). Monthly Water Balance Statement (1976-1985)

Month	Inflow			Evapotranspiration	Stream flow	Balance available for ground water depletion or accretion (unaccounted water)	Cumulative Balance
	Rainfall	Irrigation water released from Peechi Reservoir	Total inflow				
		Mm^3	Mm^3	Mm^3	Mm^3	Mm^3	Mm^3
1985							
January	36.297	7.478	43.775	84.93	42.81	-83.965	+1756.814
February	0.446	7.895	8.341	58.04	29.96	-79.659	+1677.155
March	0.577	15.151	15.728	67.16	18.47	-69.902	+1607.253
April	35.379	-	35.379	68.45	16.29	-49.361	+1557.892
May	203.350	-	203.350	111.01	36.80	+55.540	+1613.432
June	1026.985	-	1026.985	83.22	435.40	+508.365	+2121.797
July	547.194	-	547.194	93.70	610.52	-157.026	+1964.771
August	450.961	-	450.961	96.73	384.99	- 30.759	+1934.012
September	136.699	25.406	162.105	105.24	133.50	- 76.635	+1857.377
October	277.444	23.179	300.623	125.83	168.90	+ 5.893	+1863.267
November	29.450	27.480	56.930	74.98	140.00	-158.050	+1705.217
December	49.861	23.536	73.397	91.99	50.71	- 69.303	+1635.914

Table 4.9 Yearly Water Balance Statement (1976 - 1985)

Year	Inflow			Evapotransi- ration	Stream flow	Balance for ground water depletion or accretion (unaccounted water)
	Rainfall	Irrigation Water rele- ased from the Peechi reservoir	Total inflow			
	Mm^3	Mm^3	Mm^3	Mm^3	Mm^3	Mm^3
1976	2237.977	93.254	2331.231	974.680	1401.44	- 44.889
1977	3164.843	88.446	3253.289	941.710	2163.16	+148.419
1978	3454.13	129.794	3583.924	953.220	2267.35	+363.354
1979	3252.57	139.381	3391.951	880.89	2160.16	+350.901
1980	3972.70	141.563	4114.263	1079.30	2634.66	+400.303
1981	3717.50	163.467	3880.967	1005.320	2294.52	+581.127
1982	2772.20	128.416	2900.616	1070.056	1771.97	+ 58.086
1983	3023.30	116.059	3139.359	987.21	1954.70	+197.449
1984	2830.44	129.948	2960.388	1100.30	2075.80	-215.712
1985	2794.65	130.125	2924.775	1061.28	2068.35	-204.855

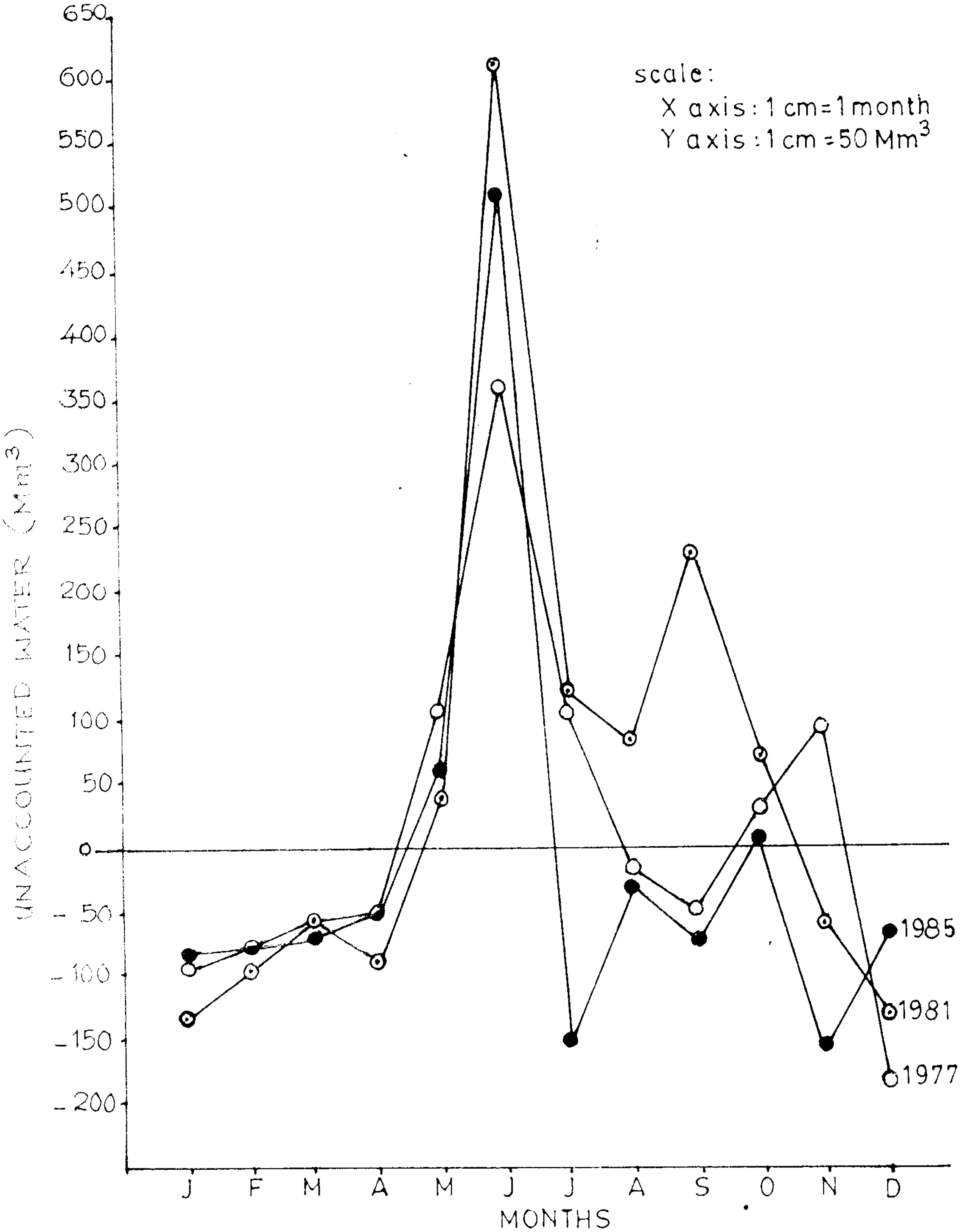


FIG. 4.7. UNACCOUNTED WATER DURING DIFFERENT MONTHS OF 1977, 1981 AND 1985

cumulated, very high values are obtained. This does not mean that the ground water storage has improved since January 1976. Immediately following the rainy season, a considerable drop in the level of the water occurs. Even during the rainy season, the water table level would go down considerably if there is no rain for three or four days together. This is a clear indication of considerable amount of subsurface runoff taking place from the basin. Portion of the runoff water flows into the Kole lands without joining the Karuvannur River. These quantities have not been accounted for in this study due to lack of data. As a result, the cumulated values of the balance water is found to be high.

In this study, the basin is considered as an independent hydrologic unit. Surface and subsurface inflow from other basins and outflow to other basins are assumed to be negligible. A detailed water balance study will require accurate assessment of surface and subsurface inflow and outflow, irrigation water applied etc.

The study clearly shows that in years with heavy rainfall, the balance available for ground water accretion is positive and in other years it is negative. The negative balance occurs mainly because of the relatively high values of runoff. By adopting appropriate rain water harvesting methods, a considerable portion of the runoff water in the dry months can be conserved. The water so collected may be used for meeting irrigation and other demands. Optimum development of water resources can be achieved only through the conjunctive use of surface and ground waters.

Summary

SUMMARY

This study was undertaken to quantitavely assess the water resources of the Karuvannur River Basin and to study the monthly water balance in order to estimate the balance for ground water recharge or depletion during the period 1976 to 1985.

The mean monthly rainfall over the basin during the period 1976 - 1985 was determined by Thiessen polygon method. Data regarding the amount of water released for irrigation from the Peechi Reservoir was also collected. Due to lack of data, contribution from other sources was not taken into account. The total runoff from the basin during each month of this period was determined. The various crop combinations in the basin were identified and the area under each of these was estimated. The actual evapotranspiration during each month was estimated using the method outlined by Doorenbos and Kassam. The basin was regarded as an independent hydrologic unit. Hence surface and subsurface inflow and outflow were assumed to be negligible.

It was found that high correlation exists between annual rainfall and annual runoff. Equations for predicting annual runoff from annual rainfall values have been developed.

The results of the frequency analysis of rainfall at Ollukkara for various durations have been presented graphically.

The study showed that accretion to ground water occurs mainly in June, July and August. Some recharge may occur in May, September, October and November also. Except during the low rainfall years viz. 1976, 1984 and 1985 the balance available for ground water accretion or depletion works out to be positive

When the values of the unaccounted water were cumulated very high values were obtained. This may be because of factors which have not been taken into account in this study such as subsurface runoff from the basins, unaccounted portion of surface runoff etc.

By adopting appropriate rain water harvesting methods runoff during the dry months can be reduced and ground water storage can be increased. Optimum development of water resources can be achieved only through the conjunctive use of surface and ground water.

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Appendices

APPENDIX 1. Mean Daily Percentage (p) of Annual Daytime Hours for Different Latitudes

Latitude North / South1/	Jan / July	Feb / Aug	Mar / Sept	Apr / Oct	May / Nov	June / Dec	July / Jan	Aug / Feb	Sept / Mar	Oct / Apr	Nov / May	Dec / June
60°	.15	.20	.26	.32	.38	.41	.40	.34	.28	.22	.17	.13
58	.16	.21	.26	.32	.37	.40	.39	.34	.28	.23	.18	.15
56	.17	.21	.26	.32	.36	.39	.38	.33	.28	.23	.18	.16
54	.18	.22	.26	.31	.36	.38	.37	.33	.28	.23	.19	.17
52	.19	.22	.27	.31	.35	.37	.36	.33	.28	.24	.20	.17
50	.19	.23	.27	.31	.34	.36	.35	.32	.28	.24	.20	.18
48	.20	.23	.27	.31	.34	.36	.35	.32	.28	.24	.21	.19
46	.20	.23	.27	.30	.34	.35	.34	.32	.28	.24	.21	.20
44	.21	.24	.27	.30	.33	.35	.34	.31	.28	.25	.22	.20
42	.21	.24	.27	.30	.33	.34	.33	.31	.28	.25	.22	.21
40	.22	.24	.27	.30	.32	.34	.33	.31	.28	.25	.22	.21
35	.23	.25	.27	.29	.31	.32	.32	.30	.28	.25	.23	.22
30	.24	.25	.27	.29	.31	.32	.31*	.30	.28	.26	.24	.23
25	.24	.26	.27	.29	.30	.31	.31	.29	.28	.26	.25	.24
20	.25	.26	.27	.28	.29	.30	.30	.29	.28	.26	.25	.25
15	.26	.26	.27	.28	..29	.29	.29	.28	.28	.27	.26	.25
10	.26	.27	.27	.28	.28	.29	.29	.28	.28	.27	.26	.26
5	.27	.27	.27	.28	.28	.28	.28	.28	.28	.27	.27	.27
0	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27

1/ Southern latitudes: apply 6 month difference as shown.

APPENDIX 2. Mean Daily Duration of Maximum Possible Sunshine Hours (N) for Different Months and Latitudes

Northern Lats	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Southern Lats	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
50°	8.5	10.1	11.8	13.8	15.4	16.3	15.9	14.5	12.7	10.8	9.1	8.1
48	8.8	10.2	11.8	13.6	15.2	16.0	15.6	14.3	12.6	10.9	9.3	8.3
46	9.1	10.4	11.9	13.5	14.9	15.7	15.4	14.2	12.6	10.9	9.5	8.7
44	9.3	10.5	11.9	13.4	14.7	15.4	15.2	14.0	12.6	11.0	9.7	8.9
42	9.4	10.6	11.9	13.4	14.6	15.2	14.9	13.9	12.6	11.1	9.8	9.1
40	9.6	10.7	11.9	13.3	14.4	15.0	14.7	13.7	12.5	11.2	10.0	9.3
35	10.1	11.0	11.9	13.1	14.0	14.5	14.3	13.5	12.4	11.3	10.3	9.8
30	10.4	11.1	12.0	12.9	13.6	14.0	13.9*	13.2	12.4	11.5	10.6	10.2
25	10.7	11.3	12.0	12.7	13.3	13.7	13.5	13.0	12.3	11.6	10.9	10.6
20	11.0	11.5	12.0	12.6	13.1	13.3	13.2	12.8	12.3	11.7	11.2	10.9
15	11.3	11.6	12.0	12.5	12.8	13.0	12.9	12.6	12.2	11.8	11.4	11.2
10	11.6	11.8	12.0	12.3	12.6	12.7	12.6	12.4	12.1	11.8	11.6	11.5
5	11.8	11.9	12.0	12.2	12.3	12.4	12.3	12.3	12.1	12.0	11.9	11.8
0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0

APPENDIX 3.

Extra Terrestrial Radiation (Ra) expressed in equivalent evaporation in mm/day

Northern Hemisphere													Southern Hemisphere											
Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Lat	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
3.8	6.1	9.4	12.7	15.8	17.1	16.4	14.1	10.9	7.4	4.5	3.2	50°	17.5	14.7	10.9	7.0	4.2	3.1	3.5	5.5	8.9	12.9	16.5	18.2
4.3	6.6	9.8	13.0	15.9	17.2	16.5	14.3	11.2	7.8	5.0	3.7	48	17.6	14.9	11.2	7.5	4.7	3.5	4.0	6.0	9.3	13.2	16.6	18.2
4.9	7.1	10.2	13.3	16.0	17.2	16.6	14.5	11.5	8.3	5.5	4.3	46	17.7	15.1	11.5	7.9	5.2	4.0	4.4	6.5	9.7	13.4	16.7	18.3
5.3	7.6	10.6	13.7	16.1	17.2	16.6	14.7	11.9	8.7	6.0	4.7	44	17.8	15.3	11.9	8.4	5.7	4.4	4.9	6.9	10.2	13.7	16.7	18.3
5.9	8.1	11.0	14.0	16.2	17.3	16.7	15.0	12.2	9.1	6.5	5.2	42	17.8	15.5	12.2	8.8	6.1	4.9	5.4	7.4	10.6	14.0	16.8	18.3
6.4	8.6	11.4	14.3	16.4	17.3	16.7	15.2	12.5	9.6	7.0	5.7	40	17.9	15.7	12.5	9.2	6.6	5.3	5.9	7.9	11.0	14.2	16.9	18.3
6.9	9.0	11.8	14.5	16.4	17.2	16.7	15.3	12.8	10.0	7.5	6.1	38	17.9	15.8	12.8	9.6	7.1	5.8	6.3	8.3	11.4	14.4	17.0	18.3
7.4	9.4	12.1	14.7	16.4	17.2	16.7	15.4	13.1	10.6	8.0	6.6	36	17.9	16.0	13.2	10.1	7.5	6.3	6.8	8.8	11.7	14.6	17.0	18.2
7.9	9.8	12.4	14.8	16.5	17.1	16.8	15.5	13.4	10.8	8.5	7.2	34	17.8	16.1	13.5	10.5	8.0	6.8	7.2	9.2	12.0	14.9	17.1	18.2
8.3	10.2	12.8	15.0	16.5	17.0	16.8	15.6	13.6	11.2	9.0	7.8	32	17.8	16.2	13.8	10.9	8.5	7.3	7.7	9.6	12.4	15.1	17.2	18.1
8.8	10.7	13.1	15.2	16.5	17.0	16.8*	15.7	13.9	11.6	9.5	8.3	30	17.8	16.4	14.0	11.3	8.9	7.8	8.1	10.1	12.7	15.3	17.3	18.1
9.3	11.1	13.4	15.3	16.5	16.8	16.7	15.7	14.1	12.0	9.9	8.8	28	17.7	16.4	14.3	11.6	9.3	8.2	8.6	10.4	13.0	15.4	17.2	17.9
9.8	11.5	13.7	15.3	16.4	16.7	16.6	15.7	14.3	12.3	10.3	9.3	26	17.6	16.4	14.4	12.0	9.7	8.7	9.1	10.9	13.2	15.5	17.2	17.8
10.2	11.9	13.9	15.4	16.4	16.6	16.5	15.8	14.5	12.6	10.7	9.7	24	17.5	16.5	14.6	12.3	10.2	9.1	9.5	11.2	13.4	15.6	17.1	17.7
10.7	12.3	14.2	15.5	16.3	16.4	16.4	15.8	14.6	13.0	11.1	10.2	22	17.4	16.5	14.8	12.6	10.6	9.6	10.0	11.6	13.7	15.7	17.0	17.5
11.2	12.7	14.4	15.6	16.3	16.4	16.3	15.9	14.8	13.3	11.6	10.7	20	17.3	16.5	15.0	13.0	11.0	10.0	10.4	12.0	13.9	15.8	17.0	17.4
11.6	13.0	14.6	15.6	16.1	16.1	16.1	15.8	14.9	13.6	12.0	11.1	18	17.1	16.5	15.1	13.2	11.4	10.4	10.8	12.3	14.1	15.8	16.8	17.1
12.0	13.3	14.7	15.6	16.0	15.9	15.9	15.7	15.0	13.9	12.4	11.6	16	16.9	16.4	15.2	13.5	11.7	10.8	11.2	12.6	14.3	15.8	16.7	16.8
12.4	13.6	14.9	15.7	15.8	15.7	15.7	15.7	15.1	14.1	12.8	12.0	14	16.7	16.4	15.3	13.7	12.1	11.2	11.6	12.9	14.5	15.8	16.5	16.6
12.8	13.9	15.1	15.7	15.7	15.5	15.5	15.6	15.2	14.4	13.3	12.5	12	16.6	16.3	15.4	14.0	12.5	11.6	12.0	13.2	14.7	15.8	16.4	16.5
13.2	14.2	15.3	15.7	15.5	15.3	15.3	15.5	15.3	14.7	13.6	12.9	10	16.4	16.3	15.5	14.2	12.8	12.0	12.4	13.5	14.8	15.9	16.2	16.2
13.6	14.5	15.3	15.6	15.3	15.0	15.1	15.4	15.3	14.8	13.9	13.3	8	16.1	16.1	15.5	14.4	13.1	12.4	12.7	13.7	14.9	15.8	16.0	16.0
13.9	14.8	15.4	15.4	15.1	14.7	14.9	15.2	15.3	15.0	14.2	13.7	6	15.8	16.0	15.6	14.7	13.4	12.8	13.1	14.0	15.0	15.7	15.8	15.7
14.3	15.0	15.5	15.5	14.9	14.4	14.6	15.1	15.3	15.1	14.5	14.1	4	15.5	15.8	15.6	14.9	13.8	13.2	13.4	14.3	15.1	15.6	15.5	15.4
14.7	15.3	15.6	15.3	14.6	14.2	14.3	14.9	15.3	15.3	14.8	14.4	2	15.3	15.7	15.7	15.1	14.1	13.5	13.7	14.5	15.2	15.5	15.3	15.1
15.0	15.5	15.7	15.3	14.4	13.9	14.1	14.8	15.3	15.4	15.1	14.8	0	15.0	15.5	15.7	15.3	14.4	13.9	14.1	14.8	15.3	15.4	15.1	14.8

APPENDIX 4 Saturation vapour pressure ea in m bar as function of mean air temperature t in °C.

Temperature °C	ea m.bar
0	6.1
1	6.6
2	7.1
3	7.6
4	8.1
5	8.7
6	9.4
7	10.0
8	10.7
9	11.5
10	12.3
11	13.1
12	14.0
13	15.0
14	16.1
15	17.0
16	18.2
17	19.4
18	20.6
19	22.0
20	23.4
21	24.9
22	26.4
23	28.1
24	29.8
25	31.7
26	33.6
27	35.7
28	37.8
29	40.1
30	42.4
31	44.9
32	47.6
33	50.3
34	53.2
35	56.2
36	59.4
37	62.8
38	66.3
39	69.9

APPENDIX 5. Values of Wind Function $f(u) = 0.27\,(1 + \frac{U_2}{100})$ for Wind Run at 2 m height in km/day

Wind km/day	0	10	20	30	40	50	60	70	80	90
	-	.30	.32	.35	.38	.41	.43	.46	.49	.51
100	.54	.57	.59	.62	.65	.67	.70	.73	.76	.78
200	.81	.84	.86	.89*	.92	.94	.97	1.00	1.03	1.05
300	1.08	1.11	1.13	1.16	1.19	1.21	1.24	1.27	1.30	1.32
400	1.35	1.38	1.40	1.43	1.46	1.49	1.51	1.54	1.57	1.59
500	1.62	1.65	1.67	1.70	1.73	1.76	1.78	1.81	1.84	1.90
600	1.89	1.92	1.94	1.97	2.00	2.02	2.05	2.08	2.11	2.15
700	2.16	2.19	2.21	2.24	2.27	2.29	2.32	2.35	2.38	2.40
800	2.43	2.46	2.48	2.51	2.54	2.56	2.59	2.62	2.64	2.65
900	2.70									

APPENDIX 6. Values of Weighting Factor (1-W) for the Effect of Wind and Humidity on ETo at Different Temperatures and Altitudes

Temperature °C	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
(1-W) at altitude m																				
0	0.57	.54	.51	.48	.45	.42	.39	.36	.34	.32	.29	.27	.25	.23*	.22	.20	.19	.17	.16	.15
500	.56	.52	.49	.46	.43	.40	.38	.35	.33	.30	.28	.26	.24	.22	.21	.19	.18	.16	.15	.14
1 000	.54	.51	.48	.45	.42	.39	.36	.34	.31	.29	.27	.25	.23	.21	.20	.18	.17	.15	.14	.13
2 000	.51	.48	.45	.42	.39	.36	.34	.31	.29	.27	.25	.23	.21	.19	.18	.16	.15	.14	.13	.12
3 000	.48	.45	.42	.39	.36	.34	.31	.29	.27	.25	.23	.21	.19	.18	.16	.15	.14	.13	.12	.11
4 000	.46	.42	.39	.36	.34	.31	.29	.27	.25	.23	.21	.19	.18	.16	.15	.14	.13	.12	.11	.10

APPENDIX 7. Values of Weighting Factor (W) for the Effect of Radiation on ETo at Different Temperatures and Altitudes

Temperature °C	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
W at altitude m																				
0	0.43	.46	.49	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77*	.78	.80	.82	.83	.84	.85
500	.44	.48	.51	.54	.57	.60	.62	.65	.67	.70	.72	.74	.76	.78	.79	.81	.82	.84	.85	.86
1 000	.46	.49	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77	.79	.80	.82	.83	.85	.86	.87
2 000	.49	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77	.79	.81	.82	.84	.85	.86	.87	.88
3 000	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77	.79	.81	.82	.84	.85	.86	.87	.88	.89
4 000	.54	.58	.61	.64	.66	.69	.71	.73	.75	.77	.79	.81	.82	.84	.85	86	.87	.89	.90	.90

APPENDIX 8. Conversion Factor for Extra-Terrestrial Radiation (Ra) to Net Solar Radiation (Rns) for a Given Reflection α of 0.25 and Different Ratios of Actual to Maximum Sunshine Hours $(1-\alpha)(0.25 + 0.50\ n/N)$

n/N	0.0	.05	.10	.15	.20	.25	.30	.35	.40	.45	.50	.55	.60	.65	.70	.75	.80	.85	.90	.95	1.0
$(1-\alpha)(0.25 + 0.50\ n/N)$	0.19	.21	.22	.24	.26	.28	.30	.32	.34	.36	.37	.39	.41	.43	.45	.47	.49*	.51	.52	.54	.56

APPENDIX 9. Effect of Temperature f(T) on Longwave Radiation (Rnl)

T°C	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36
$f(T) = \sigma Tk^4$	11.0	11.4	11.7	12.0	12.4	12.7	13.1	13.5	13.8	14.2	14.6	15.0	15.4	15.9	16.3*	16.7	17.2	17.7	18.1

APPENDIX 10. Effect of Vapour Pressure f(ed) on Longwave Radiation (Rnl)

ed mbar	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
$f(ed) = 0.34 - 0.044\sqrt{ed}$	0.23	.22	.20	.19	.18	.16	.15	.14	.13*	.12	.12	.11	.10	.09	.08	.08	.07	.06

APPENDIX 11. Effect of the Ratio Actual and Maximum Bright Sunshine Hours f(n/N) on Longwave Radiation (Rnl)

n/N	0	.05	.1	.15	.2	.25	.3	.35	.4	.45	.5	.55	.6	.65	.7	.75	.8	.85	.9	.95	1.0
$f(n/N) = 0.1 + 0.9\ n/N$	0.10	.15	.19	.24	.28	.33	.37	.42	.46	.51	.55	.60	.64	.69	.73	.78	.82*	.87	.91	.96	1.0

APPENDIX 12. Adjustment Factor (c) in Presented Penman Equation

	RHmax = 30%				RHmax = 60%				RHmax = 90%			
Rs mm/day	3	6	9	12	3	6	9	12	3	6	9	12
Uday m/sec	Uday/Unight = 4.0											
0	.86	.90	1.00	1.00	.96	.98	1.05	1.05	1.02	1.06	1.10	1.10
3	.79	.84	.92	.97	.92	1.00	1.11	1.19	.99	1.10	1.27	1.32
6	.68	.77	.87	.93	.85	.96	1.11	1.19	.94	1.10	1.26	1.33
9	.55	.65	.78	.90	.76	.88	1.02	1.14	.88	1.01	1.16	1.27
	Uday/Unight = 3.0											
0	.86	.90	1.00	1.00	.96	.98	1.05	1.05	1.02	1.06	1.10	1.10
3	.76	.81	.88	.94	.87	.96	1.06	1.12	.94	1.04	1.18	1.28
6	.61	.68	.81	.88	.77	.88	1.02	1.10	.86	1.01	1.15	1.22
9	.46	.56	.72	.82	.67	.79	.88	1.05	.78	.92	1.06	1.18
	Uday/Unight = 2.0											
0	.86	.90	1.00	1.00	.96	.98	1.05	1.05	1.02	1.06	1.10	1.10
3	.69	.76	.85	.92	.83	.91	.99*	1.05*	.89	.98	1.10*	1.14*
6	.53	.61	.74	.84	.70	.80	.94	1.02	.79	.92	1.05	1.12
9	.37	.48	.65	.76	.59	.70	.84	.95	.71	.81	.96	1.06
	Uday/Unight = 1.0											
0	.86	.90	1.00	1.00	.96	.98	1.05	1.05	1.02	1.06	1.10	1.10
3	.64	.71	.82	.89	.78	.86	.94*	.99*	.85	.92	1.01*	1.05*
6	.43	.53	.68	.79	.62	.70	.84	.93	.72	.82	.95	1.00
9	.27	.41	.59	.70	.50	.60	.75	.87	.62	.72	.87	.96

APPENDIX 13. Pan Coefficient (Kp) for Class A Pan for Different Groundcover and Levels of Mean Relative Humidity and 24 hour Wind

Class A pan	Case A: Pan placed in short green cropped area				Case B1/ Pan placed in dry fallow area			
RHmean %		low < 40	medium 40-70	high > 70		low < 40	medium 40-70	high > 70
Wind km/day	Windward side distance of green crop m				Windward side distance of dry fallow m			
Light < 175	1	.55	.65	.75	1	.7	.8	.85
	10	.65	.75	.85	10	.6	.7	.8
	100	.7	.8	.85	100	.55	.65	.75
	1 000	.75	.85	.85	1 000	.5	.6	.7
Moderate 175-425	1	.5	.6	.65	1	.65	.75	.8
	10	.6	.7	.75	10	.55	.65	.7
	100	.65	.75*	.8	100	.5	.6	.65
	1 000	.7	.8	.8	1 000	.45	.55	.6
Strong 425-700	1	.45	.5	.6	1	.6	.65	.7
	10	.55	.6	.65	10	.5	.55	.65
	100	.6	.65	.7	100	.45	.5	.6
	1 000	.65	.7	.75	1 000	.4	.45	.55
Very strong > 700	1	.4	.45	.5	1	.5	.6	.65
	10	.45	.55	.6	10	.45	.5	.55
	100	.5	.6	.65	100	.4	.45	.5
	1 000	.55	.6	.65	1 000	.35	.4	.45

APPENDIX 14. Pan Coefficient (Kp) for Colorado Sunken Pan for Different Groundcover and Levels of Mean Relative Humidity and 24 hour Wind

Sunken Colorado	Case A: Pan placed in short green cropped area				Case B1/ Pan placed in dry fallow area			
RHmean %		low < 40	medium 40-70	high > 70		low < 40	medium 40-70	high > 70
Wind km/day	Windward side distance of green crop m				Windward side distance of dry fallow m			
Light < 175	1	.75	.75	.8	1	1.1	1.1	1.1
	10	1.0	1.0	1.0	10	.85	.85	.85
	≥100	1.1	1.1	1.1	100	.75	.75	.8
					1 000	.7	.7	.75
Moderate 175-425	1	.65	.7	.7	1	.95	.95	.95
	10	.85	.85	.9	10	.75	.75	.75
	≥100	.95	.95	.95	100	.65	.65	.7
					1 000	.6	.6	.65
Strong 425-700	1	.55	.6	.65	1	.8	.8	.8
	10	.75	.75	.75	10	.65	.65	.65
	≥100	.8	.8	.8	100	.55	.6	.65
					1 000	.5	.55	.6
Very strong > 700	1	.5	.55	.6	1	.7	.75	.75
	10	.65	.7	.7	10	.55	.6	.65
	≥100	.7	.75	.75	100	.5	.55	.6
					1 000	.45	.5	.55

1/ For extensive areas of bare-fallow soils and no agricultural development, reduce Kpan by 20% under hot, windy conditions; by 5-10% for moderate wind, temperature and humidity conditions.

APPENDIX 15. Ratios Between Evaporation from Sunken Pans Mentioned and From Colorado Sunken Pan for Different Climatic Conditions and Pan Environments

		Ratio Epan mentioned and Epan Colorado			
Climate		Humid-temperate climate		Arid to semi-arid (dry season)	
Groundcover surrounding pan (50 m or more)		Short green cover	Dry fallow	Short green cover	Dry fallow
	Pan area m^2				
CGI 20 dia. 5 m, depth 2 m (USSR)	20	1.0	1.1	1.05	1.25*
Sunken pan dia. 12 ft, depth 3.3 ft. (Israel)	10.5				
Symmons pan 6 ft^2, depth 2 ft (UK)	3.3				
BPI dia. 6 ft, depth 2 ft (USA)	2.6				
Kenya pan dia. 4 ft, depth 14 in	1.2				
Australian pan dia. 3 ft, depth 3 ft	0.7		1.0		1.0
Aslyng pan 0.33 m^2, depth 1 m (Denmark)	0.3			1.0	
CGI 3000 dia. 61.8 cm, depth 60-80 cm (USSR)	0.3				
Sunken pan dia. 50 cm, depth 25 cm (Netherlands)	0.2	1.0	.95	1.0	.95

EXAMPLE: CGI 20 in semi-arid climate, dry season, placed in dry fallow land; for given month Epan CGI 20 = 8 mm/day.
Corresponding Epan sunken Colorado is 1.25 x 8 = 10 mm/day.

APPENDIX 16. kc Values for Aquatic Weeds and Coefficients for Open Water

Type of vegetation	Humid		Dry	
	light to mod. wind	strong wind	light to mod. wind	strong wind
Submerged (crassipes)	1.1	1.15	1.15	1.2
Floating (duckweed)	1.05	1.05	1.05	1.05
Flat leaf (water lilies)	1.05	1.1	1.05	1.1
Protruding (water hyacinth)	1.1	1.15	1.15	1.2
Reed swamp (papyrus, cattails)				
standing water	.85	.85	.9	.95
moist soil	.65	.65	.75	.8
Open water	1.1	1.15	1.15	1.2

APPENDIX 17. Mean Actual Evapotranspiration (ETa) in mm/day over the Irrigation Interval for Different Yields of ETm (mm/day), D.Sa (mm) and p (fraction)

D.Sa	p	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	35	40
ETm = 2.0 mm/day																		
25	0.2	2.0	2.0	1.8	1.7	1.6	1.4	1.3	1.2	1.2	1.1	1.0	0.9	0.9	0.8	0.8	0.7	0.6
	0.4	2.0	2.0	2.0	1.9	1.7	1.6	1.5	1.4	1.2	1.2	1.1	1.0	0.9	0.9	0.8	0.7	0.6
	0.6	2.0		2.0	2.0	1.9	1.7	1.6	1.5	1.3	1.2	1.1	1.0	1.0	0.9	0.8	0.7	0.6
	0.8	2.0			2.0	2.0	1.9	1.7	1.5	1.4	1.3	1.1	1.0	1.0	0.9	0.8	0.7	0.6
50	0.2	2.0	2.0	2.0	2.0	1.9	1.8	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.1
	0.4	2.0			2.0	2.0	2.0	1.9	1.9	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.3	1.1
	0.6	2.0					2.0	2.0	2.0	2.0	1.9	1.8	1.7	1.7	1.6	1.5	1.4	1.2
	0.8	2.0								2.0	2.0	2.0	1.9	1.8	1.7	1.6	1.4	1.2
100	0.2	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.9	1.9	1.9	1.8	1.8	1.7	1.7	1.6	1.6
	0.4	2.0							2.0	2.0	2.0	2.0	2.0	2.0	1.9	1.9	1.8	1.7
	0.6	2.0												2.0	2.0	2.0	2.0	1.9
	0.8	2.0														2.0	2.0	2.0
150	0.2	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.9	1.9	1.9	1.8	1.8
	0.4	2.0											2.0	2.0	2.0	2.0	2.0	1.9
	0.6	2.0															2.0	2.0
	0.8	2.0																2.0
200	0.2	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.9	1.9
	0.4	2.0														2.0	2.0	2.0
	0.6	2.0																2.0
	0.8	2.0																2.0
300	0.2	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	0.4	2.0																2.0
	0.6	2.0																2.0
	0.8	2.0																2.0
ETm = 4.0 mm/day																		
25	0.2	3.9	3.4	2.9	2.5	2.2	1.9	1.7	1.5	1.4	1.2	1.1	1.0	0.9	0.9	0.8	0.7	0.6
	0.4	4.0	3.7	3.2	2.7	2.3	2.0	1.7	1.5	1.4	1.3	1.1	1.0	1.0	0.9	0.8	0.7	0.6
	0.6	4.0	4.0	3.5	2.9	2.4	2.1	1.8	1.6	1.4	1.3	1.1	1.0	1.0	0.9	0.8	0.7	0.6
	0.8	4.0	4.0	3.8	3.1	2.5	2.1	1.8	1.6	1.4	1.3	1.1	1.0	1.0	0.9	0.8	0.7	0.6
50	0.2	4.0	3.9	3.6	3.4	3.1	2.9	2.7	2.5	2.3	2.2	2.0	1.9	1.8	1.7	1.6	1.4	1.2
	0.4	4.0	4.0	4.0	3.7	3.5	3.2	2.9	2.7	2.5	2.3	2.1	2.0	1.9	1.7	1.6	1.4	1.2
	0.6	4.0		4.0	4.0	3.8	3.5	3.2	2.9	2.6	2.4	2.2	2.1	1.9	1.8	1.6	1.4	1.2
	0.8	4.0			4.0	4.0	3.8	3.4	3.1	2.8	2.5	2.3	2.1	1.9	1.8	1.6	1.4	1.2
100	0.2	4.0	4.0	4.0	3.9	3.8	3.6	3.5	3.4	3.2	3.1	3.0	2.9	2.8	2.7	2.6	2.3	2.2
	0.4	4.0		4.0	4.0	4.0	4.0	3.9	3.7	3.6	3.5	3.3	3.2	3.1	2.9	2.8	2.5	2.3
	0.6	4.0					4.0	4.0	4.0	3.9	3.8	3.6	3.5	3.3	3.2	3.0	2.7	2.4
	0.8	4.0							4.0	4.0	4.0	3.9	3.8	3.6	3.4	3.2	2.8	2.5
150	0.2	4.0	4.0	4.0	4.0	4.0	3.9	3.8	3.7	3.6	3.5	3.5	3.4	3.3	3.2	3.1	2.9	2.7
	0.4	4.0				4.0	4.0	4.0	4.0	4.0	3.9	3.8	3.7	3.7	3.6	3.5	3.2	3.0
	0.6	4.0								4.0	4.0	4.0	4.0	3.9	3.9	3.8	3.5	3.3
	0.8	4.0											4.0	4.0	4.0	4.0	3.8	3.6
200	0.2	4.0	4.0	4.0	4.0	4.0	4.0	3.9	3.9	3.8	3.8	3.7	3.6	3.6	3.5	3.4	3.3	3.1
	0.4	4.0					4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.9	3.9	3.8	3.6	3.5
	0.6	4.0											4.0	4.0	4.0	4.0	3.9	3.8
	0.8	4.0														4.0	4.0	4.0
300	0.2	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.9	3.9	3.9	3.8	3.8	3.7	3.5
	0.4	4.0									4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.9
	0.6	4.0															4.0	4.0
	0.8	4.0																4.0

APPENDIX 17 (Contd.)

D.Sa	p	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	35	40
ETm = 6.0 mm/day																		
25	0.2	5.5	4.3	3.5	2.8	2.4	2.0	1.8	1.6	1.4	1.2	1.1	1.0	1.0	0.9	0.8	0.7	0.6
	0.4	5.9	4.8	3.7	3.0	2.5	2.1	1.8	1.6	1.4	1.3	1.1	1.0	1.0	0.9	0.8	0.7	0.6
	0.6	6.0	5.2	4.0	3.1	2.5	2.1	1.8	1.6	1.4	1.3	1.1	1.0	1.0	0.9	0.8	0.7	0.6
	0.8	6.0	5.7	4.1	3.1	2.5	2.1	1.8	1.6	1.4	1.3	1.1	1.0	1.0	0.9	0.8	0.7	0.6
50	0.2	6.0	5.5	4.9	4.3	3.9	3.5	3.1	2.8	2.6	2.4	2.2	2.0	1.9	1.8	1.7	1.4	1.3
	0.4	6.0	5.9	5.4	4.8	4.2	3.7	3.3	3.0	2.7	2.5	2.2	2.1	1.9	1.8	1.7	1.4	1.3
	0.6	6.0	6.0	5.9	5.2	4.6	4.0	3.5	3.1	2.8	2.5	2.3	2.1	1.9	1.8	1.7	1.5	1.3
	0.8	6.0	6.0	6.0	5.7	4.9	4.1	3.6	3.1	2.8	2.5	2.3	2.1	1.9	1.8	1.7	1.4	1.3
100	0.2	6.0	6.0	5.8	5.5	5.2	4.9	4.6	4.3	4.1	3.9	3.7	3.5	3.3	3.1	3.0	2.6	2.4
	0.4	6.0	6.0	6.0	5.9	5.7	5.4	5.1	4.8	4.5	4.2	4.0	3.7	3.5	3.3	3.1	2.8	2.4
	0.6	6.0		6.0	6.0	6.0	5.9	5.6	5.2	4.9	4.6	4.3	4.0	3.7	3.5	3.3	2.8	2.5
	0.8	6.0				6.0	6.0	6.0	5.7	5.3	4.9	4.5	4.1	3.8	3.6	3.3	2.9	2.5
150	0.2	6.0	6.0	6.0	5.8	5.7	5.5	5.3	5.1	4.9	4.7	4.5	4.3	4.2	4.0	3.9	3.5	3.2
	0.4	6.0		6.0	6.0	6.0	5.9	5.8	5.6	5.4	5.2	5.0	4.8	4.6	4.4	4.2	3.8	3.3
	0.6	6.0				6.0	6.0	6.0	6.0	5.9	5.7	5.5	5.2	5.0	4.8	4.6	4.1	3.6
	0.8	6.0							6.0	6.0	6.0	5.9	5.7	5.4	5.1	4.9	4.2	3.7
200	0.2	6.0	6.0	6.0	6.0	5.9	5.8	5.6	5.5	5.3	5.2	5.0	4.9	4.7	4.6	4.4	4.1	3.9
	0.4	6.0			6.0	6.0	6.0	6.0	5.9	5.8	5.7	5.6	5.4	5.2	5.1	4.9	4.6	4.2
	0.6	6.0						6.0	6.0	6.0	6.0	6.0	5.9	5.7	5.6	5.4	5.0	4.6
	0.8	6.0										6.0	6.0	6.0	6.0	5.9	5.4	4.9
300	0.2	6.0	6.0	6.0	6.0	6.0	6.0	5.9	5.8	5.8	5.7	5.6	5.5	5.4	5.3	5.2	4.9	4.7
	0.4	6.0					6.0	6.0	6.0	6.0	6.0	6.0	5.9	5.9	5.8	5.7	5.4	5.2
	0.6	6.0										6.0	6.0	6.0	6.0	6.0	5.9	5.7
	0.8	6.0														6.0	6.0	6.0
ETm = 8.0 mm/day																		
25	0.2	6.7	5.0	3.8	3.0	2.5	2.1	1.8	1.6	1.4	1.3	1.1	1.0	1.0	0.9	0.8	0.7	0.6
	0.4	7.5	5.4	4.0	3.1	2.5	2.1	1.8	1.6	1.4	1.3	1.1	1.0	1.0	0.9	0.8	0.7	0.6
	0.6	8.0	5.8	4.1	3.1	2.5	2.1	1.8	1.6	1.4	1.3	1.1	1.0	1.0	0.9	0.8	0.7	0.6
	0.8	8.0	6.1	4.2	3.1	2.5	2.1	1.8	1.6	1.4	1.3	1.1	1.0	1.0	0.9	0.8	0.7	0.6
50	0.2	7.8	6.7	5.8	5.0	4.3	3.8	3.4	3.0	2.7	2.5	2.2	2.1	1.9	1.8	1.7	1.4	1.3
	0.4	7.9	7.5	6.4	5.4	4.6	4.0	3.5	3.1	2.8	2.5	2.2	2.1	1.9	1.8	1.7	1.4	1.3
	0.6	8.0	8.0	7.0	5.8	4.8	4.1	3.6	3.1	2.8	2.5	2.3	2.1	1.9	1.8	1.7	1.4	1.3
	0.8	8.0	8.0	7.6	6.1	5.0	4.2	3.6	3.1	2.8	2.5	2.3	2.1	1.9	1.8	1.7	1.4	1.3
100	0.2	8.0	7.8	7.3	6.7	6.2	5.8	5.3	5.0	4.6	4.3	4.0	3.8	3.6	3.4	3.2	2.8	2.5
	0.4	8.0	8.0	7.9	7.5	6.9	6.4	5.9	5.4	5.0	4.6	4.3	4.0	3.7	3.5	3.3	2.8	2.5
	0.6	8.0	8.0	8.0	8.0	7.6	7.0	6.4	5.8	5.3	4.9	4.5	4.1	3.8	3.6	3.3	2.9	2.5
	0.8	8.0			8.0	8.0	7.6	6.9	6.1	5.5	5.0	4.5	4.1	3.8	3.6	3.3	2.9	2.5
150	0.2	8.0	8.0	7.8	7.5	7.1	6.7	6.4	6.1	5.8	5.5	5.2	5.0	4.7	4.5	4.3	3.9	3.5
	0.4	8.0	8.0	8.0	8.0	7.8	7.5	7.1	6.7	6.4	6.0	5.7	5.4	5.1	4.8	4.6	4.1	3.6
	0.6	8.0			8.0	8.0	8.0	7.7	7.4	7.0	6.6	6.2	5.8	5.5	5.1	4.8	4.2	3.7
	0.8	8.0					8.0	8.0	7.9	7.6	7.1	6.6	6.1	5.7	5.3	5.0	4.3	3.7
200	0.2	8.0	8.0	8.0	7.8	7.5	7.2	7.0	6.7	6.5	6.2	6.0	5.7	5.5	5.3	5.1	4.7	4.3
	0.4	8.0		8.0	8.0	8.0	7.9	7.7	7.5	7.2	6.9	6.6	6.4	6.1	5.9	5.6	5.1	4.6
	0.6	8.0				8.0	8.0	8.0	8.0	7.8	7.6	7.3	7.0	6.7	6.4	6.1	5.4	4.8
	0.8	8.0							8.0	8.0	8.0	7.9	7.6	7.2	6.9	6.5	5.7	5.0
300	0.2	8.0	8.0	8.0	8.0	7.9	7.8	7.6	7.5	7.3	7.1	6.9	6.7	6.6	6.4	6.2	5.8	5.5
	0.4	8.0			8.0	8.0	8.0	8.0	8.0	7.9	7.8	7.6	7.5	7.3	7.1	6.9	6.5	6.0
	0.6	8.0							8.0	8.0	8.0	8.0	8.0	7.9	7.7	7.6	7.1	6.7
	0.8	8.0											8.0	8.0	8.0	8.0	7.7	7.1

APPENDIX 17 (Continued)

ETm = 10.0 mm/day																		
D.Sa		2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	35	40
25	0.2	7.8	5.4	4.0	3.1	2.5	2.1	1.8	1.6	1.4	1.3	1.1	1.0	1.0	0.9	0.8	0.7	0.6
	0.4	8.7	5.7	4.1	3.1	2.5	2.1	1.8	1.6	1.4	1.3	1.1	1.0	1.0	0.9	0.8	0.7	0.6
	0.6	9.5	6.0	4.2	3.1	2.5	2.1	1.8	1.6	1.4	1.3	1.1	1.0	1.0	0.9	0.8	0.7	0.6
	0.8	10.0	6.2	4.2	3.1	2.5	2.1	1.8	1.6	1.4	1.3	1.1	1.0	1.0	0.9	0.8	0.7	0.6
50	0.2	9.4	7.8	6.4	5.4	4.6	4.0	3.5	3.1	2.8	2.5	2.3	2.1	1.9	1.8	1.7	1.4	1.3
	0.4	10.0	8.7	7.0	5.7	4.8	4.1	3.5	3.1	2.8	2.5	2.3	2.1	1.9	1.8	1.7	1.4	1.3
	0.6	10.0	9.5	7.6	6.0	4.9	4.2	3.6	3.1	2.8	2.5	2.3	2.1	1.9	1.8	1.7	1.4	1.3
	0.8	10.0	10.0	8.1	6.2	5.0	4.2	3.6	3.1	2.8	2.5	2.3	2.1	1.9	1.8	1.7	1.4	1.3
100	0.2	10.0	9.4	8.6	7.8	7.1	6.4	5.9	5.4	5.0	4.6	4.3	4.0	3.7	3.5	3.3	2.8	2.5
	0.4	10.0	10.0	9.5	8.7	7.8	7.0	6.3	5.7	5.2	4.8	4.4	4.1	3.8	3.6	3.3	2.8	2.5
	0.6	10.0	10.0	10.0	9.5	8.5	7.6	6.8	6.0	5.4	4.9	4.5	4.2	3.8	3.6	3.3	2.9	2.5
	0.8	10.0		10.0	10.0	9.3	8.1	7.1	6.2	5.6	5.0	4.5	4.2	3.9	3.6	3.3	2.9	2.5
150	0.2	10.0	9.9	9.4	8.9	8.3	7.8	7.3	6.8	6.4	6.0	5.7	5.4	5.1	4.8	4.6	4.0	3.7
	0.4	10.0	10.0	10.0	9.7*	9.2*	8.7*	8.1*	7.5*	7.0	6.6*	6.1	5.7*	5.4	5.1	4.8*	4.2	3.7
	0.6	10.0		10.0	10.0	9.9	9.5	8.9	8.2	7.6	7.0	6.5	6.0	5.6	5.3	4.9	4.3	3.7
	0.8	10.0			10.0	10.0	10.0	9.6	8.9	8.1	7.4	6.8	6.2	5.8	5.4	5.0	4.3	3.7
200	0.2	10.0	10.0	9.8	9.4	9.0	8.6	8.2	7.8	7.4	7.1	6.7	6.4	6.1	5.9	5.6	5.1	4.6
	0.4	10.0	10.0	10.0	10.0*	9.8*	9.5*	9.1*	8.7*	8.2	7.8*	7.4	7.0*	6.7	6.3	6.0*	5.4	4.8
	0.6	10.0			10.0	10.0	10.0	9.8	9.5	9.0	8.5	8.1	7.6	7.2	6.8	6.4	5.6	4.9
	0.8	10.0					10.0	10.0	10.0	9.8	9.3	8.7	8.1	7.6	7.1	6.6	5.7	5.0
300	0.2	10.0	10.0	10.0	9.9	9.7	9.4	9.2	8.9	8.6	8.3	8.0	7.8	7.5	7.3	7.1	6.5	6.0
	0.4	10.0		10.0	10.0	10.0	10.0	9.9	9.7	9.5	9.2	8.9	8.7	8.4	8.1	7.8	7.1	6.5
	0.6	10.0					10.0	10.0	10.0	10.0	9.9	9.7	9.5	9.2	8.9	8.5	7.7	7.0
	0.8	10.0								10.0	10.0	10.0	10.0	9.9	9.6	9.3	8.3	7.4

APPENDIX 18. Monthly Mean Actual Evapotranspiration (ETa in mm/day) for ASI, Remaining Available Soil Water when ETa < ETm ([(1-p) Sa.D] in mm/root depth) and Maximum Evapotranspiration (ETm in mm/day)

	ASI = 0.83					ASI = 0.67					ASI = 0.5				
(1-p)Sa.D mm/root depth	ETm, mm/day 2	4	6	8	10	ETm, mm/day 2	4	6	8	10	ETm, mm/day 2	4	6	8	10
25	1.9	3.8	5.6	7.3	9.1	1.8	3.3	4.8	6.1	7.5	1.6	2.8	3.8	4.8	5.8
50	2.0	3.9	5.7	7.6	9.4	1.9	3.6	5.2	6.7	8.1	1.7	3.2	4.4	5.5	6.5
100	2.0	3.9	5.9	7.8	9.6	1.9	3.8	5.5	7.2	8.8	1.9	3.5	5.0	6.3	7.6
150	2.0	4.0	5.9	7.8	9.7	2.0	3.8	5.7	7.4	9.1	1.9	3.7	5.3	6.7	8.1
200	2.0	4.0	5.9	7.9	9.8	2.0	3.9	5.7	7.5	9.3	1.9	3.7	5.4	7.0	8.5

	ASI = 0.33					ASI = 0.17					ASI = 0				
(1-p)Sa.D mm/root depth	ETm, mm/day 2	4	6	8	10	ETm, mm/day 2	4	6	8	10	ETm, mm/day 2	4	6	8	10
25	1.3	2.1	2.8	3.5	4.2	1.1	1.5	1.8	2.2	2.5	0.8	0.8	0.8	0.8	0.8
50	1.6	2.7	3.5	4.3	5.0	1.4	2.1	2.8	3.0	3.3	1.2	1.5	1.6	1.7	1.7
100	1.8	3.2	4.3	5.3	6.2*	1.7	2.8	3.6	4.2	4.7	1.5	2.3	2.8	3.0	3.2
150	1.8	3.4	4.7	5.9	7.0	1.7	3.1	4.2	5.0	5.7	1.7	2.7	3.5	4.0	4.3
200	1.9	3.5	5.0	6.3	7.5	1.8	3.3	4.5	5.5	6.4	1.7	3.0	4.0	4.7	5.1

APPENDIX 19. Average Monthly Effective Rainfall as Related to Average Monthly ETcrop and Mean Monthly Rainfall

(USDA (SCS), 1969)

Monthly mean rainfall mm		12.5	25	37.5	50	62.5	75	87.5	100	112.5	125	137.5	150	162.5	175	187.5	200
		Average monthly effective rainfall in mm*															
Average monthly ETcrop mm	25	8	16	24													
	50	8	17	25	32	39	46										
	75	9	18	27	34	41	48	56	62	69							
	100	9	19	28	35	43	52	59	66	73	80	87	94	100			
	125	10	20	30	37	46	54	62	70	76	85	92	98	107	116	120	
	150	10	21	31	39	49	57	66	74*	81	89	97	104	112	119	127	133
	175	11	23	32	42	52	61	69	78	86	95	103	111	118	126	134	141
	200	11	24	33	44	54	64	73	82	91	100	109	117	125	134	142	150
	225	12	25	35	47	57	68	78	87	96	106	115	124	132	141	150	159
	250	13	25	38	50	61	72	84	92	102	112	121	132	140	150	158	167

* Where net depth of water that can be stored in the soil at time of irrigation is greater or smaller than 75 mm, the correction factor to be used is:

Effective storage	20	25	37.5	50	62.5	75	100	125	150	175	200
Storage factor	.73	.77	.86	.93	.97	1.00	1.02	1.04	1.06	1.07*	1.08

WATER BALANCE STUDY OF KARUVANNUR RIVER BASIN

By

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ABSTRACT OF THE THESIS

Submitted in partial fulfilment of
the requirement for the degree

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ABSTRACT

Water balance techniques are a way of solving important theoretical and practical hydrological problems. By using the water balance approach, it is possible to make a quantitative evaluation of the water resources and to assess any changes that might occur through the influence of man's activities.

The broad objective of this project was to make a quantitative evaluation of the water resources of the Karuvannur River Basin. The ultimate objective was to study the monthly water balance for the basin in order to estimate the balance available for ground water recharge or depletion during the period 1976 to 1985.

Monthly rainfall data at all rain gauge stations in the basin were collected. The mean monthly rainfall in the basin for each month of the period 1976 to 1985 was calculated using Thiessen polygon method. Irrigation water was identified as the other input into the basin. Data regarding the amount of water released for irrigation from the Peechi Reservoir was collected. Due to lack of data, contribution from other sources was not taken into account. Surface and subsurface in flow and out flow, into and from the basin, were assumed to be negligible.

Data regarding total runoff from the basin during each month of the above period was also collected. The amount of water

used up in meeting evapotranspiration requirements was estimated.

Daily rainfall data at Ollukkara for a period of 20 years was collected and a frequency analysis was done. The result has been presented graphically.

Equations for predicting annual runoff from the basin were developed. It was found that a high degree of correlation exists between annual runoff and annual rainfall values.

For each month during the period 1976 to 1985, the balance water, available for ground water accretion or to be met from the ground water reservoir, (unaccounted water) was estimated. It was found that accretion to ground water occurs mainly in June, July and August. Some recharge may occur in the months of May, September, October and November also.

When the water balance is calculated on an annual basis, it was found that the balance available for ground water accretion is negative in 1976, 1984 and 1985. Low rainfall had been recorded during these three years.

The values of the balance water available for ground water accretion or depletion (unaccounted water) when cumulated gave very high values. This may be because of unaccounted factors such as subsurface runoff from the basin, unaccounted portion of surface runoff from the basin etc. These factors could not be accounted for due to lack of data.

The study underlines the necessity for using the available water resources most judiciously. It emphasises the need for adopting appropriate rain water harvesting methods for reducing runoff during the dry months. Optimum development of water resources can be achieved only through the conjunctive use of surface and ground waters.