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A Conceptual Model of Catchment Water Balance

by

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1.0 Introduction

Water yield refers to the volume of water available in the stream at a specified point over a specified period of time, with emphasis on the volume of flow rather than the instantaneous discharge. Therefore the water yield is the integration of discharge as a function of time for a specified duration and reflects the volumetric relationship between rainfall and runoff. The yield is expressed for monthly, seasonal or annual periods. Estimation of water yield is required for solution of water resources problems such as design of storage facilities, water availability for agriculture, industrial or drinking purpose, dependable water supply for power generation under varying patterns of rainfall, planning irrigation operation, and design of irrigation projects etc.

A number of factors affect the water yield depending on the period of its determination(DeCourcy,1965). Some of these factors are interdependent. These factors can be classified as (a) Meteorologic factors (b) Watershed factors.

Space and time distribution of precipitation and temperature are the most important meterological factors. Some important watershed factors include, surface vegetation, soil moisture, soil characteristics, surface topography, and drainage density.

There are several approaches to determine the water yield which can be grouped into three classes (a) Theoretical (b) Conceptual and (c) Emperical.

Theoretical and Emperical models are exactly opposite in meaning and conceptual models lying somewhere in between them. Conceptual models are simplified representations of the physical processes usually relying on mathematical descriptions, and simulate complex processes by relying on a few key conceptual parameters. The extensive use of conceptual models in catchment hydrology reflects the inherent complexity of the physical phenomena and the practical inability to account for deterministic components in many instances. Therefore, conceptual models are useful and practical alternative for deterministic models.

A catchment's water yield is a fundamental problem in hydrology, referring to the volume of water available at the catchment outlet over a specified period of time. The yield is expressed for monthly, seasonal or annual periods. Several methods are available for the computation of water yield which are simple empirical formulae and complex models based on continuous simulation.

A practical alternative is represented by conceptual models which use the water balance equation to separate precipitation into its various components.

Water Balance Equations;

A water balance equation applicable to an individual storm is,

$$P = Q + L \qquad (1)$$

in which P is precipitation, Q is surface runoff, and L is losses ,or hydrologic abstractions.

The losses for an individual storm consists of interception, surface storage, and infiltration.

A water balance equation applicable to on an annual basis is

$$P = R + E \qquad (2)$$

In which P is precipitation, R is runoff, including surface runoff and subsurface runoff, and E is evapotranspiration.

The term evapotranspiration comprises Evaporation from vegetated surface, evapotranspiration, Evaporation from bare ground, and Evaporation from water bodies.

A catchment water budgeting is one of the tools to estimate the water yield from the basin. The catchment water balance can be described by a set of equations (L'vovich 1979).

Precipitation can be separated into two components:

$$P = S + W \qquad (3)$$

in which

P = annual precipitation,

S = surface runoff, i.e., the fraction of runoff originating on the land surface; and

W = catchment wetting (L'vovich 1979), the fraction of precipitation not contributing to surface runoff.

Likewise, wetting consists two components:

$$W = U + V \qquad (4)$$

in which

U = baseflow, i.e., the fraction of wetting which exfiltrates as the dry-weather flow of rivers, and

V = vaporization, the fraction of wetting returned to the atmosphere as water vapor.

Deep percolation, i.e., the portion of wetting not contributing to either baseflow or vaporization, is a very small fraction of precipitation and is usually neglected on practical grounds.

Vaporization, which comprises all moisture returned to the atmosphere, has two components:

$$V = E + T \qquad (5)$$

in which

E = nonproductive evaporation has two components

Evaporation from bare soil, and small surface storage,

Evaporation from sizable water bodies such as lakes, reservoirs, and rivers and

T = productive evaporation, i.e., that resulting from plant transpiration.

From Eqs. 3 to 5, runoff consists of two components;

$$R = S + U \qquad (6)$$

in which

R = runoff. Likewise, precipitation consists of two components:

$$P = R + V \qquad (7)$$

Equations 3 to 7 constitute a set of water balance equations. Combining 6 and 7 leads to:

$$P = S + U + V \qquad (8)$$

that is, annual precipitation is separated into its three major components, surface runoff, baseflow, and vaporization.

Equations 4 and 7 enable the definition of water balance coefficients. The baseflow coefficient is (L'vovich 1979)

$$K_u = U/W = U/(U+V) \qquad (9)$$

the runoff coefficient is

$$K_r = R/P = R/(R+V) \qquad (10)$$

2.0 The Conceptual Model

The conceptual model of water balance is suitable for wide range of climatic conditions. The model separates annual precipitation into its three major components: surface runoff, baseflow, and vaporization. It is based on the two-step sequential application of a proportional relation wetting and baseflow.

The significant feature of the water balance equations, is that they all have the same structure, in which a quantity X is expressed as the sum of two components Y and Z:

$$X = Y + Z \qquad (11)$$

The Z reaches an upperbound as X and Y grow unbounded. The generic form of the proportional relation has two parameters; λ, the initial abstraction coefficient and Z_p, the potential value of Z.

$$Z = X - Y \qquad (12)$$

In the present model, the proportional relation is defined as follows (Figure 1):

$$(X - \lambda Z_p - Y)/[(1 - \lambda)Z_p] = Y/(X - \lambda Z_p) \qquad (13)$$

For the special case of zero initial abstraction ($\lambda = 0$), equation 13 reduces to:

$$(X - Y)/Z_p = Y/X \qquad (14)$$

Solving equation 13 for $Y = f(X)$ leads to :

$$Y = (X - \lambda Z_p)^2/[X + (1 - 2\lambda)Z_p] \qquad (15)$$

subject to $X > \lambda Z_p$; and $Y = 0$ otherwise.

L'vovich (1979) has shown that wetting reaches an upper bound asymptotically ($W \rightarrow Wp$) as; precipitation and surface runoff increase unbounded ($P \rightarrow \infty$; $S \rightarrow \infty$) and Vaporization reaches an upper bound asymptotically ($V \rightarrow Vp$) as; wetting and baseflow increase unbounded ($W \rightarrow \infty$;$U \rightarrow \infty$).

In this way the sequential two-step separation of annual precipitation into its three major components; surface runoff, baseflow, and vaporization can be accomplished.

Using equation 15, the surface runoff submodel is:

$$S = (P - \lambda_s W_p)^2 /[P + (1 - 2\lambda_s)W_p] \qquad (16)$$

Subject to $P > \lambda_s W_p$, and $S = 0$ otherwise,
with λ_s = surface runoff initial abstraction coefficient.

Then:

$$W = P - S \qquad (17)$$

Likewise, the baseflow submodel is:

$$U = (W - \lambda_u V_p)^2 / [W + (1 - 2\lambda_u)V_p] \qquad (18)$$

Subject to $W > \lambda_u V_p$, and $U = 0$ otherwise,
with λ_u = baseflow initial abstraction coefficient.

2.1 Calibration of the Model

In the absence of data, the initial abstraction coefficients and potentials are estimated from past experience in similar climatic and biogeographical settings, such as Rainfall, Temperature, Landuse, and Geography.

In order to calibrate the initial abstraction coefficient of surface flow λ_s and baseflow λ_u, and potentials of wetting W_p and vaporization V_p of the study area, the observed data has to be used to fit the proportional curves for precipitation and surface runoff, and wetting and baseflow. A set of paired values of precipitation and surface runoff, and wetting and baseflow has to be derived from the fitted proportional curves respectively to calibrate the parameters.

Step 1: Initially λ_s is chosen as zero for the set of paired values of precipitation and surface runoff.

Step 2:Use the equation $W_p = (P/S)(P-S)$ to find out the wetting potential values.

Step 3: Increase λ_s by 0.01 and calculate array of wetting potential using the equation:

$$Wp = 1/\lambda_s(\{P+[(1/2\lambda_s)][(1-2\lambda_s)^2 S^2 + 4\lambda_s(1-\lambda_s)PS]^{1/2}\})$$ and

Step 4: Calculate the mean, standard deviation, and coefficient of variation of the estimated array of wetting potential values.

Step 5: Go back to step 3, repeat the computation for the new value of λ_s until the coefficient of variation of the array of wetting potential is a minimum. The original fitted proportional curve may be readjusted to get a minimum standard deviation of the calculated array of wetting potential.

Step 6: Choose parameter values W_p and λ_s. W_p is the mean value of the calculated wetting potential with value of λ_s for which coefficient of variation and standard deviation is a minimum.

The same steps are followed to calibrate the vaporization potential and baseflow initial abstraction coefficient.

A computer programme has been developed for the calibration of the model parameters, to simulate surface runoff, total runoff, baseflow, wetting, runoff and baseflow coefficients and its gains

3.0 Application of Model

Several approaches are available for the computation of water balance components. They vary in complexity from the simple empirical formulae to the complex models based on continuous simulation. However, conceptual catchment water balance model(Ponce and Shetty, 1995)is an alternative model which uses the water balance equation to separate precipitation into its various components. Water balance components such as surface runoff, baseflow, wetting, and vaporisation can be estimated by using calibrated parametres of the model.

3.1 Regionalisation of Model Parameters

Most of the commonly used prediction techniques require the estimation of one or more parameters. A variety of methods are generally available for estimation of the parameters, but there is often some controversy about the effectiveness of these procedures. Most of the procedures employ a significant amount of historic hydrologic data, and therefore it is not easy to determine the parameter values for catchments in which little or no hydrologic data are available. The prospects for the successful solution of the problem of parameter estimation under these conditions do not appears to be good, but nevertheless, there is an urgent requirement for such work to be undertaken in catchment hydrology. The Regionalisation of data and parameters, is the only reasonable approach to this problem. Long term records of the basin can be synthesized and extrapolated to similar basins in the same representative region or extrapolated to basins with different combinations of geology, land form, soil and vegetation. The possible hydrologic effects of changes in land use can be forecasted in any catchment within the range of land use type sampled by the representative basin network.

The regional analysis comprises the study of hydrologic phenomena with the aim of developing mathematical relations applicable in regional context. The mathematical relations are so developed that the information from gauged or long-record catchments can be readily transferred to neighbouring ungauged catchments of similar hydrologic characteristics.

The main aim of this study is to develop a regional conceptual catchment water balance model parameters which can be used to estimate the quantity of water yield from the ungauged catchments.

The catchment water balance model(Ponce and Shetty, 1995) include parameters like wetting potential, vaporisation potential, initial abstraction coefficient of surface flow and initial abstraction coefficient of baseflow. The parameters of the model are function of annual rainfall, vegetation covers, soil moisture, soil characteristics, surface topography and drainage density.

$$(W_p, V_p, \lambda_s \text{ and } \lambda_u) = f(P_N, V_C, S_C, S_M, T_{phy}, D_D) \qquad (19)$$

where,

W_p = Wetting potential,
V_p = Vaporisation potential
λ_s = Initial abstraction coefficient of Surface flow
I_{abs} = $(W_p * \lambda_s)$ initial abstraction of surface flow
λ_u = Initial abstraction coefficient of baseflow
I_{abu} = $(V_p * \lambda_u)$ initial abstraction of baseflow
P_N = Normal rainfall ,
V_C = Vegetation cover
S_M = Soil moisture
S_C = Soil characteristics
T_{phy} = Topography and
D_D = Drainage density

Relationship may be established between the model parameters and the factors affecting water yield of the catchment. However, in the present study, percentage of vegetation cover and annual mean precipitation with model parameters have been tried to establish the regional parameters of the model with simple linear regression technique.

Keeping in view the importance of water yield in any area, an effort has been made to estimate the regional parameters of conceptual catchment water balance model, which can be used to estimate the water yield from ungauged catchments. For the study, five catchments in the western ghat region have been selected, out of which, three rivers are flowing westward and two rivers are flowing eastward.

The regionalised parameters of the catchment water balance model have been obtained by developing relationship between model parameters such as wetting potential, vaporisation potential, initial abstraction coefficients of baseflow and surface flow with mean annual rainfall, and vegetation cover of the basin. The coefficient of determination between the vegetation cover and the model parameters has been found to be very high, whereas the relationship between mean annaual rainfall and model parametres has been found to be very low. The regional parametres obtained have been compared with calibrated parametres and found to be within the specified limits. Water balance components have been simulated simulated using both the regionalised and the calibrated parameters of the model. The variation between the simulated values are within 10 per cent. The goodness of the calibration also shows that simulated water balance components using fitted and calibrated parametres are within the limit. Therefore it is suggested that the model parameters can be obtained from the established relationship between vegetation cover of the basin and the model parameters.

The study has been carried out for two eastward flowing rivers namely Malaprabha, and Dandavathi river bisins and three westward flowing rivers, Netrravathi, Sithanadi and Barchi.

4.0 The Study Area

Three westward flowing rivers originated in the Western ghat have been considered. two of these rivers are a part of the upland of Western Ghat while the other one covers the high land, midland and lowland of the area. The eastward flowing rivers include one catchment in the highland of Western Ghat and one in the midland. The location of study areas have been shown in figure 2.

4.1 Netravathi Basin

The Netravathi river is one of the important west flowing rivers of Karnataka. It rises at an elevation of 1000 m., in Western Ghats between Kudremukh and Ballalrayan Durga in the Dakshina Kannada district of Karnataka. It flows in north-south direction for the first 40 km. and then takes a turn towards the west and flows in east-west direction upto its outfall into the Arabian Sea near Mangalore. The Netravathi river basin lies between the latitudes 12^0 29'11"N and 13^0 11'11" and longitude 74^0 49'08"E and 75^0 47'53"E. The basin is nearly fan shaped and drains an area of about 3657 Km^2.

4.2 Sithanadi Basin

Sithanadi is one of the west flowing rivers of Dakshina Kannada district of Karnataka. It takes its origin in the slopes of Western Ghats near Agumbe and flows towards west. After descending the Ghats, it flows in west direction cutting across the district on three typical topographic terrains and finally falls into the Arabian sea. The river flows in a meandering course on a level ground in low land region. It confluences with Swarna river before joining Arabian sea. The catchment area of 650 sq.km. lies between 13^0 20' and 13^0 35' north latitudes and 74^0 40' and 75^0 10' east longitudes. The catchment area is relatively short in length.

4.3 Malaprabha Basin

The Malaprabha catchment sub-basin of Krishna River upstream of Khanapur in the Western Ghat.Malaprabha river originates at Kanakumbi in the Western Ghat at an altitude of about 793 m and 16 km west of Jamboti in the Belgaum district of Karnataka. The river flows in the easterly direction and joins the Krishna river. In the present study, the basin upstream of Khanapur has been considered with a catchment area 520 square kilometres. It is a principal source of water supply from Ghat section of the basin.

The location of the catchment area lies between 74^o E and 75^o E longitude and around 16^o latitude along the border of Karnataka and Maharashtra.

4.4 Dandavathi Catchment

The Dadavathi catchment upstream of Sorab located in the Western Ghat and sub-basin of Krishna River.The Dadavathi river originates at Karjikoppa in the foot hill of Western Ghat at an altitude of about 2775ft. and 16 km south of Sorab in the Shimoga district of Karnataka state. The river flows in the northerly direction and joins the Varada river a tributary of Krishna river. The total catchment area of Dandavathi basin is 118.88 square kilometres. The catchment area lies between 75^{o} E and 75^{o} 30' E longitude and around 13^{o} 45' latitude along the border of Soraba and Sagar taluk.

4.5 Barchi Catchment

The Barchi catchment upstream of Dandeli is located in the leeward side of Western Ghat and sub-basin of Kali River.

Barchi river originates at Thavargatti in the Western Ghat at an altitude of about 734m. and 20 km north of Dandeli in the Uttara Kannada district of Karnataka. The catchment is relatively short in width. The river flows in a southerly direction and joins the main Kali stream near Dandeli, flows in the westerly direction and finally flow towards the coast and joins Arabian sea. The total catchment area of Barchi is 14.5 square kilometres and lies between 75^{o} 35'E and 75^{o} 40' E longitudes and between 13^{o} 18' N and 15^{o}24' N latitudes.

High land region consists of dissection of high hills and ridges forming part of the foot hills of Western Ghats. The basin consists of steep hills and valleys intercepted with thick vegetation. The slopes of the Ghats are covered with dense deciduous forest. The red and gravelly soils are the principal soils found in the study area.

5.0 Analysis and Results

An effort has been made to regionalise the catchment water balance model for the leeward and winward side of the Western Ghat catchments. The water balance components have been separated for the selected catchments to develop a relationship between catchment characters and model parameters.

5.1 Estimation of Water Balance Components and Model Parameters

The catchment water balance model(Ponce and Shetty, 1995) has been applied to separate the precipitation into wetting and surface runoff, and then wetting into vaporization and baseflow. The model parameters were determined using measured weighted monthly rainfall for Sithanadi, Nethravathi, Malaprabha, Barchi and Dandavathi and daily discharge at (a) Kokkarne for Sithanadi(1973-1989), (b) Panemangalore for Nethravathi(1973-1986), (c) Malaprabha at Khanapur(1980-1990), (d) Barchi(1980-1995) at Barchi and (e) Dandavathi(1976-95) at Soraba. Yearly runoff has been calculated by integrating the daily hydrographs over a year.

A set of paired values of precipitation and surface runoff, and wetting and baseflow have been derived from the fitted proportional curves in order to calibrate the parameters. The calibrated parameters presented in the table 1.

Table 1. Calibrated Model Parameters

Sl. No.	Name of the basin	W_p (mm)	λ_s	V_p (mm)	λ_u
1	Sithanadi	3448	0.3	1823	0.15
2	Netravathi	1838	0.33	601	0.36
3	Malaprabha	3537	0.16	2132	0.24
4	Barchi	3616	0.24	2295	0.33
5	Dandavathi	1668	0.25	1237	0.18

(Source: Shetty A. V. 1994, Shetty A. V. 1997)

The percentage of error between observed and simulated runoff from the model is presented in the table 2.

Table 2. Percentage of error between observed and simulated runoff from the model

Sl. No.	Study Area	Percentage of Error
1	Netravathi	6.44
2	Sithanadi	5.75
3	Malaprabha	4.74
4	Dandavathi	9.84
5	Barchi	11.87

5.2 Regionalisation of Model Parameters

The main objective of this study is to develop a regional conceptual catchment water balance model which can subsequently be used to estimate the of water yield from ungauged catchments.

In the present study, per cent of vegetation cover and annual normal rainfall of all the catchments were considered to develop the regionalised parameters. Table 3. presents the model parameters, per cent of vegetation cover and annual mean rainfall of the study area.

Table 3. Model Parameters, Vegetation Cover, and Annual Mean Rainfall

Sl. No.	Name of the Basin	W_p (mm)	V_p (mm)	λ_s	λ_u	Iabs (mm)	Iabu (mm)	P (mm)	Vegetaion cover per cent
1	Sithanadi	3448	1823	0.3	0.15	1034	273	5550	69
2	Netravathi	1838	601	0.33	0.36	606	216	4050	30
3	Malaprabha	3537	2132	0.16	0.24	566	512	3000	60
4	Barchi	3616	2295	0.24	0.33	868	757	1534	75
5	Dandavathi	1668	1237	0.25	0.18	417	222	1351	38

The followings relationships have been established between model parameters and factors affecting the water yield.

(i) The correlation between mean annual rainfall and wetting potentials of selected catchments was carried out and the established relationship is,
$W_p = 0.104841*P + 2496.7$ with coefficient of determination 0.35 (20)

(ii) The correlation between mean annual rainfall and vaporisation potentials of selected catchments carried was out and regression analysis gave the following relation,
$V_p = 1844.14 - 0.0731464*P$ with coefficient of determination 0.034. (21)

(iii) The correlation between mean annual rainfall and initial abstraction of surface flow of selected catchments was carried out and followig relationship was obtained,
$I_{abs} = 0.0784157*P + 455.34$ with coefficient of determination 0.309 (22)

(iv) The correlation between mean annual rainfall and initial abstraction of baseflow of selected catchments was carried out and the following relationship was obtained,
$Iabu = 581.651 - 0.0599438*P$ with coefficient of determination 0.201 (23)

(iv) The correlation between per cent of vegetation cover and wetting potentials of selected catchments was carried out and the following relationship was obtained,
$Wp = 47.2445Vc + 251.302$ coefficient of determination 0.8926 (24)

(v) The correlation between per cent of vegetation cover and vaporisation potentials of selected catchments was carried out and the following relationship was obtained,
$Vp = 33.186Vc - 187.719$ with coefficient of determination 0.8685 (25)

(vi) The correlation between the per cent of vegetation cover and initial abstraction of surface flow of selected catchments was carried out and the following relationship was obtained,
$Iabs = 9.4713Vc + 182.95$ with coefficient of determination 0.557 (26)

(vii) The correlation between the per cent of vegetation cover and Initial abstraction of baseflow of selected catchments was carried out and the following relationship was obtained,
$Iabu = 8.82839Vc - 84.2755$ with an coefficient of determination 0.5393 (27)

The coefficients of determination of vegetation cover with wetting potential and vaporisation potential are found to be 0.89 and 0.87 respectively. The higher coefficient of determination indicates correlation between vegetation cover, wetting potential and vaporisation potential for the study areas. However, in the case of initial abstraction of surface runoff and baseflow, the coefficients of determination with vegetation cover are 0.56 and 0.54 respectively. Due to nonavailability of extensive data, these coefficients of determination can be presently accepted for the establishment of relationship between vegetation cover and initial abstraction of baseflow and surface runoff. The established relationships are given in equations (24), (25), (26), and (27) respectively.

The fitted model parameters values have been estimated using established relationships and presented in the table 4.

Table 4. Comparison of Calibrated and Regionalised Parameters of the Model

Basin	Wp		Vp		λs		λu	
	Cal	Fit	Cal	Fit	Cal	Fit	Cal	Fit
Netravathi	1838	1668	601	808	0.33	0.28	0.36	0.22
Sitanadi	3448	3511	1823	2102	0.30	0.23	0.15	0.25
Malaprabha	3537	3086	2132	1803	0.16	0.24	0.24	0.25
Dandavathi	1668	2046	1237	1074	0.25	0.27	0.18	0.23
Barchi	3616	3795	2295	2301	0.24	0.24	0.33	0.25

Based on the regionalised relationship, wetting potentials, vaporisation potentials, initial abstraction of baseflow and surface runoff have been estimated. The regionalised parameters have been compared with the calibrated parameters from observed data. It is also compared with the simulated water balance components from calibrated parameters and regionalised fitted all parameters. All those compared components have been shown in figures. 3 to 7. The simulation shows some discrepancy in the case of Dandavathi. However, all other components almost coincide with regionalised parameters and calibrated parameters. The difference between these two values are within the tolerance limit and less than 10 per cent.

The test for the errors between water balance components simulated by calibrated and fitted parametres shows a high degree of acceptance since the explained variance is very close to unity. The determination coefficient around 0.95, and correlation coefficient also close to one in most of the cases as presented in the table 5.

6.0 Concluding Remarks

The presented results indicate that catchment water balance model parameters and vegetation cover have certain kind of relationship and therefore regional model parametres can be conveniently obtained. However, consistancy of the data should be verified before the calibrating the model. The range of data used for calibration should be well distributed.

The regionalisation of the parametres need be carried out for more number of catchments so that more reliable parametres can be obtained.

As an initial effort, the regionalised parametres could be obtained from the established relationship of model parameters and vegetation cover of river basin and it can be used to estimate the water yield from ungauged catchments of Wester Ghat region.

Table 5. Goodness of the calibration

Goodness of the calibration		Explained Variance	Determination Coefficient	Correlation Coefficient
NETRAVATHI	S	0.9999	0.9945	0.9972
	U	0.9644	-0.3932	-0.0000
	W	0.9871	0.4786	0.6918
	R	1.0000	0.9987	0.9994
SITHANADI	S	0.9999	0.9977	0.9988
	U	0.9910	0.5175	0.7194
	W	0.9985	0.9747	0.9873
	R	0.9998	0.9911	0.9955
BARCHI	S	0.9981	0.9940	0.9970
	U	0.9756	0.8493	0.9216
	W	0.9981	0.9941	0.9970
	R	0.9993	0.9936	0.9968
MALAPRABHA	S	0.9977	0.9976	0.9989
	U	0.9879	0.8988	0.9481
	W	0.9966	0.9966	0.9983
	R	0.9976	0.9893	0.9947
DANDAVATHI	S	0.9926	0.9551	0.9773
	U	0.7807	-0.1823	0.0000
	W	0.9114	0.4596	0.6779
	R	1.0000	0.9999	1.0000

References

De Coursey, D.G.1965. Water yeild computations. Transactions of the American Society of Agricultural Engineers 8:367-70.

L'vovich, M.I. 1979, World Water Resources and their Future. Original in Russian, English Translation. American Geophysical Union.

Ponce and Shetty, (1995) "A Conceptual Model of Catchment Water Balance- 1. Formulation and Calibration" Journal of Hydrology, volume no.173, pp 27-40

Shetty A.V. (1994) 'Application of Catchment Water Balance Model to the Malaprabha Basin, Karnataka', NIH Report CS(AR)-149.

Shetty A. V. (1997) 'Analysis of Surface and Groundwater Flow Process in Western Bhat of Dakshina Kannada District, Karnataka State', NIH Report CS(AR)-25/96-97.

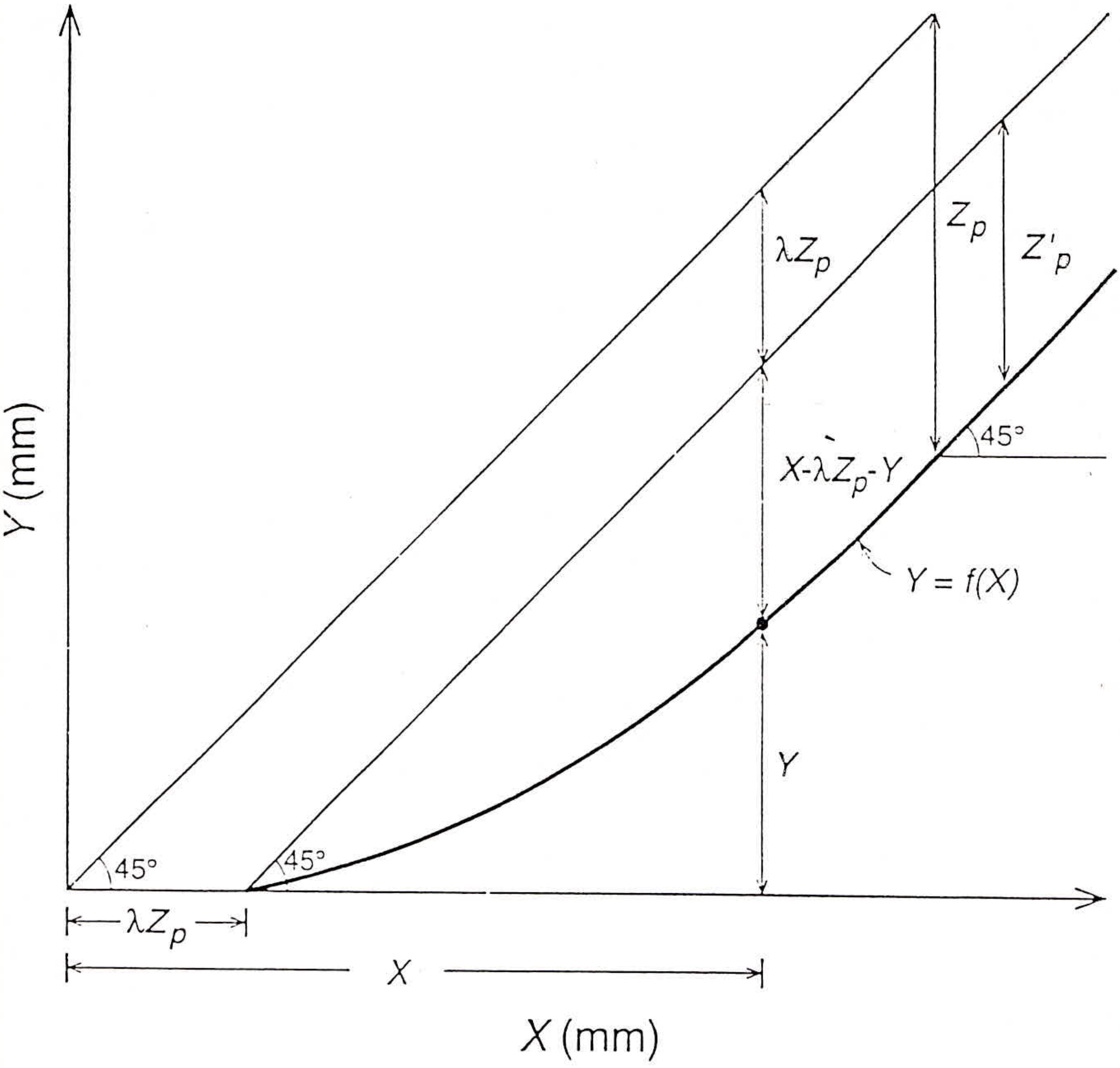
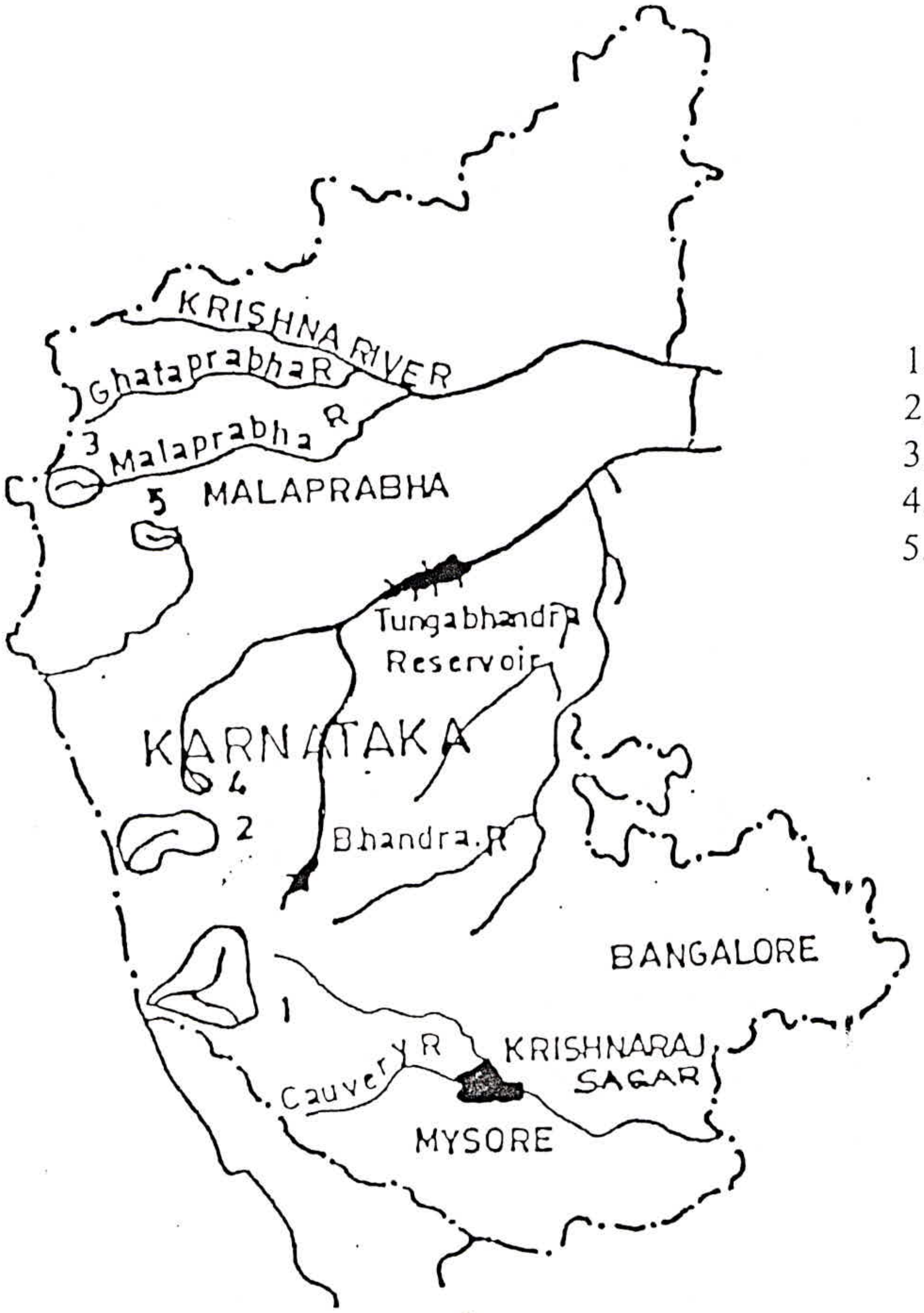


Fig. 1: DEFINITION SKETCH FOR INITIAL ABSTRACTION COEFFICIENTS AND POTENTIAL Zp.



1. Netravati
2. Sitanadi
3. Malaprabha
4. Dandavati
5. Barchi

Figure 2. Location Map