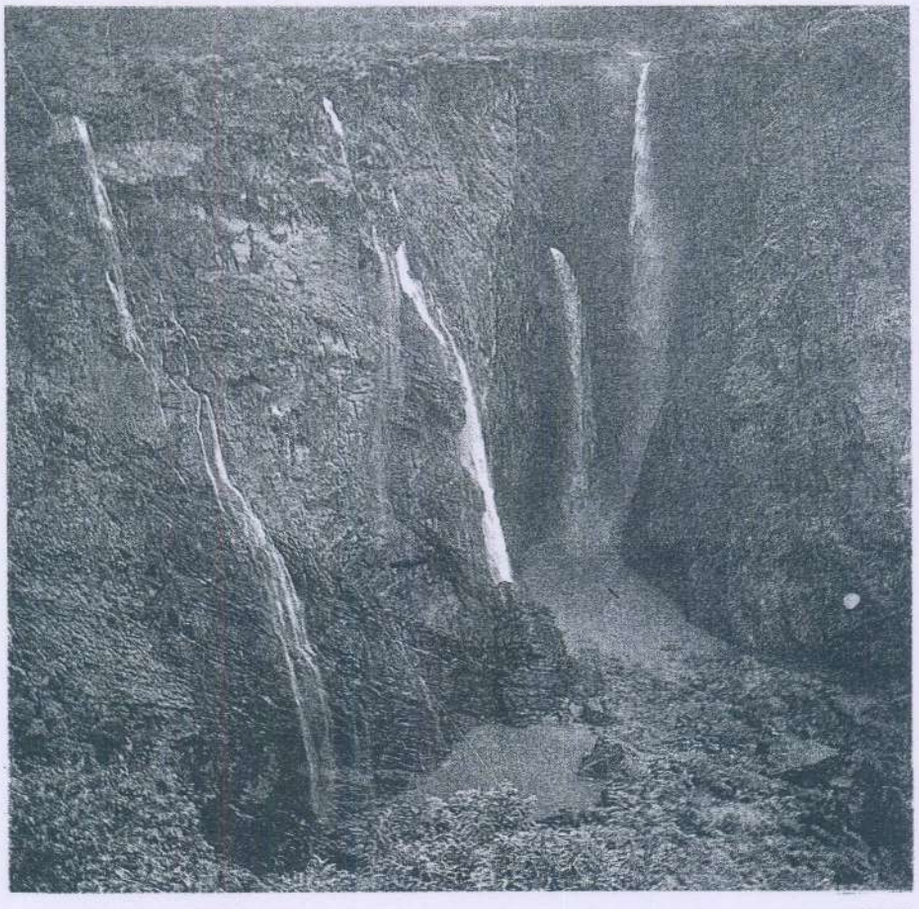
REASSESSMENT OF WATER RESOURCES POTENTIAL OF INDIA



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CENTRAL WATER COMMISSION
NEW DELHI

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CENTRAL WATER COMMISSION

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FOREWORD

Till recently availability of water has been taken for granted. It is so no more. The rapid growth in population coupled with increasing economic activities has put a tremendous pressure on the available water resources. Although irrigation is the major consumer of water at present in our country and may continue to be so in the years to come, demands from other sectors such as drinking and industries have been growing significantly. Water conservation measures to improve the efficiency of water use are being stressed upon for meeting the ever increasing demands. Inter-basin transfer of water from surplus basins to deficit basins is being studied as one of the long term strategies.

A proper assessment of water resources potential has, therefore, become a prerequisite for its sustainable development and management. Without a precise estimate of the availability of the resource, it is impossible to properly plan, design, construct, operate and maintain water resources projects catering to competing demands like irrigation, drought and flood management, domestic and industrial water supply, generation of electrical energy, fisheries and navigation.

The first ever assessment of the water resources potential of the country was attempted by the first Irrigation Commission in 1901-03. Due to lack of observed data of river flows, this first estimation was based on many assumptions. During the 1940s, Dr. A.N. khosla made an assessment of the potential using an empirical formula developed by him based on certain limited river flow observations conducted in Sutlej, Mahanadi and other river systems. Later during the 1960s, the Central Water and Power Commission once again made an assessment of the water resources potential based on limited river flow data.

However, since the early 1970s, Central Water commission set up a large number of river flow measurement stations in all the inter-State rivers of the country and by the middle of 1980s, river flow data for reasonably long periods became available for almost all the river basins. It was, therefore, felt that a reassessment exercise could be carried out based on available observed flow data.

A committee was constituted by the Ministry of Water Resources in January 1989 for the purpose of preparation of guidelines for the assessment of water resources potential of the river basins and a report on the availability of water resources of the entire country. The report of the committee forms the basis for this publication.

The water resources potential of the country which is now estimated as 1869 km^3 may not appear to be significantly

different from the assessment made by CWC in the 1960s with limited data. However, there are significant variations in the case of some individual basins.

In spite of the improvements in the standards of stream flow measurements, some uncertainties still persist in the reassessment exercise. These relate particularly to the quantum of annual withdrawals of both surface and ground water for various uses and quantifying the non-consumptive part of the withdrawals which ultimately returns to the river systems. It is very essential to correctly measure and maintain the records of diversions from irrigation projects and significant withdrawals directly from the rivers and from ground water for various purposes. Similarly for correct estimation of the quantum of return flows, it may be worthwhile to undertake some pilot studies.

This report should be useful as a benchmark study for the next reassessment which may be taken up after a decade or so.

The contribution of Godavari-Mahanadi Circle, Krishna-Cauvery Circle, Western Rivers Circle, and the Directorates of Water Utilisation, River Data, Water Resources and Basin Planning to the successful completion of the study deserves high appreciation.

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New Delhi
3 March 1993.

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SECTION I

GENERAL REPORT

1. Assessment of Water Resources Potential

Water being a precious element without which no life can be sustained on Earth, the level of its availability and development influences to a considerable extent the quality of life. The source of all fresh water on the land is the precipitation. But all the precipitation which occurs on the land is not directly available for use by the human beings. Major part of the precipitation returns back to the atmosphere by evapo-transpiration and is lost. The rest of the water becomes available either as surface water in the natural lakes, streams and rivers, or as ground water. Although all the water ultimately flows back into the oceans or is lost to the atmosphere by way of evapo-transpiration, during the land phase of the hydrologic cycle, the water can be exploited and put to beneficial use.

Apart from the basic need of drinking for sustaining human life, water is also used for other beneficial purposes such as irrigation of crops for increasing crop productivity, industrial processing, etc. But unlike other natural resources water is a dynamic resource always in motion. It cannot also be very easily transported from abundant to scarce areas like other natural resources. In our country with monsoonic type of climate which causes rainfall to occur mainly in three to four months of the year with large variations from region to region and year to year, exploitation of the resource to make it available when it is needed and where it is needed has become a major developmental activity.

Although irrigation is the major consumer of water at present in our country, water requirement for other purposes such as industrial processing is also increasing day by day due to increasing economic activities. Because of increasing use of water for varied purposes, water is already scarce in some of the regions of the country and is going to become scarce in other regions too. The assessment of the country's water potential is thus an essential pre-requisite for the efficient planning and management of the resources. River basin is the basic hydrologic unit for planning and development of water resources. It follows, therefore, that assessment of water resources has necessarily to be basin-wise.

2. Review of Earlier Studies

2.1 Study by Irrigation Commission (1901-03)[1]*

The first ever attempt to assess the average annual flow of all the river systems in India was made by the Irrigation Commission of 1901-03. The major constraint at

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*Number within square brackets refers to the serial number in the list of references.

that time was that while records in respect of rainfall were available, data in respect of river flows were not available even for many of the most important river systems. The Commission, therefore, resorted to estimation of river flows by adopting coefficients of runoff. According to this estimate, the average annual flow of all river systems of India (as it was then, but excluding Burma, Assam and East Bengal) was 1443.2 km^3.

2.2 Study of Dr. A.N. Khosla[1]

Later, when the Central Water & Power Commission was set up in 1945-46, further thought was given to the assessment of the water resources of the country as a whole. Dr. A.N. Khosla who was the Chairman of CW&PC during 1945-53 had developed an empirical relationship between mean temperature (as an expression for mean evaporation loss) and mean runoff, based on his studies of the flows of Sutlej, Mahanadi and other river systems.

On monthly basis, the developed relationship is stated as:

$R_m = P_m - L_m$ and $L_m = (T_m - 32)/9.5$

where R_m = monthly runoff
P_m = monthly rainfall
L_m = monthly evaporation loss
all expressed in inches
and T_m = mean monthly temperature in ^oF.

For areas where monthly rainfall and temperature data were not available, Dr. Khosla developed a relationship on annual basis as follows:

$$R_A = P_A - XT_A$$

where R_A = annual runoff in inches;
P_A = annual rainfall in inches;
T_A = mean annual temperature in ^oF;
and X = constant for a given catchment which is to be determined from comparative catchments for which data are available.

While applying these relationships to the entire country, Dr. Khosla divided the country into just six regions viz., (i) Rivers falling into Arabian Sea (excluding Indus), (ii) Indus Basin (in India), (iii) Rivers falling into Bay of Bengal other than Ganga-Brahmaputra system, (iv) Ganga, (v) Brahmaputra and (vi) Rajputana.

According to these studies, the total annual flow of all the systems worked out to 1673 km^3.

2.3 Study by CW&PC during 1954-66[1]

Later the CW&PC again worked out the surface water resources of different basins during the period from 1952 to 1966. This study was mostly based on statistical analysis of the flow data wherever available and rainfall-runoff relationships wherever data were meagre. The country was divided into 23 sub-basins/basins. Ganga was divided into as many as ten sub-systems. Other major peninsular river basins like Narmada, Tapi, Godavari, Krishna, Pennar and Cauvery were considered separately. Other river systems were combined together suitably into a few composite systems. According to these studies in the year 1960, the water resources of various basins amounted to 1881 km^3.

2.4 Subsequent Assessments

No further overall assessment studies were carried out subsequent to the above. However, some studies were done from time to time in respect of a few basins for speci- fic purposes. For instance, in the case of Godavari basin, Krishna-Godavari Commission[2] estimated in 1962 the average annual runoff in Godavari. Cauvery Fact Finding Committee[3] estimated the runoff in Cauvery in 1972. Similarly an estimate of Krishna flows were made in 1973 for Krishna Water Disputes Tribunal[4] and of Narmada flows in 1979 for the Narmada Water Disputes Tribunal[5]. Central Water Commission made fresh studies in respect of a few river basins such as Mahanadi, Subernarekha, Sabarmati and Tapi. Ganga Brahmaputra Water Studies (GBWS) Organisation estimated the average flows in Ganga[6]. In respect of Brahmaputra, the Brahmaputra Board[7] carried out assessment in 1987.

When Central Water Commission was compiling material for the chapter on water resources potential sometime in 1987-88 for their publication on "Water Resources of India"[8], they realized that the assessment studies made on the basis of observed river flows needed some correction since over the years ground water extraction had increased to a significant extent and the observed river flows were corrected for the additional evapotranspiration that was occurring due to the use of ground water. Estimates based on Khosla's formula, however, do not need any correction since by Khosla's formula, runoff is estimated from the observed rainfall and temperature and no observed river flows are used as such in the estimation.

For making corrections on the average annual flows worked out on the basis of observed river flows, Central Water Commission in the above report made use of the district-wise estimates of ground water drafts made by Central Ground Water Board for the year 1983-84. The total ground water draft for the country as a whole for that year was about 100 km^3. The Irrigation Commission of 1972 estimated

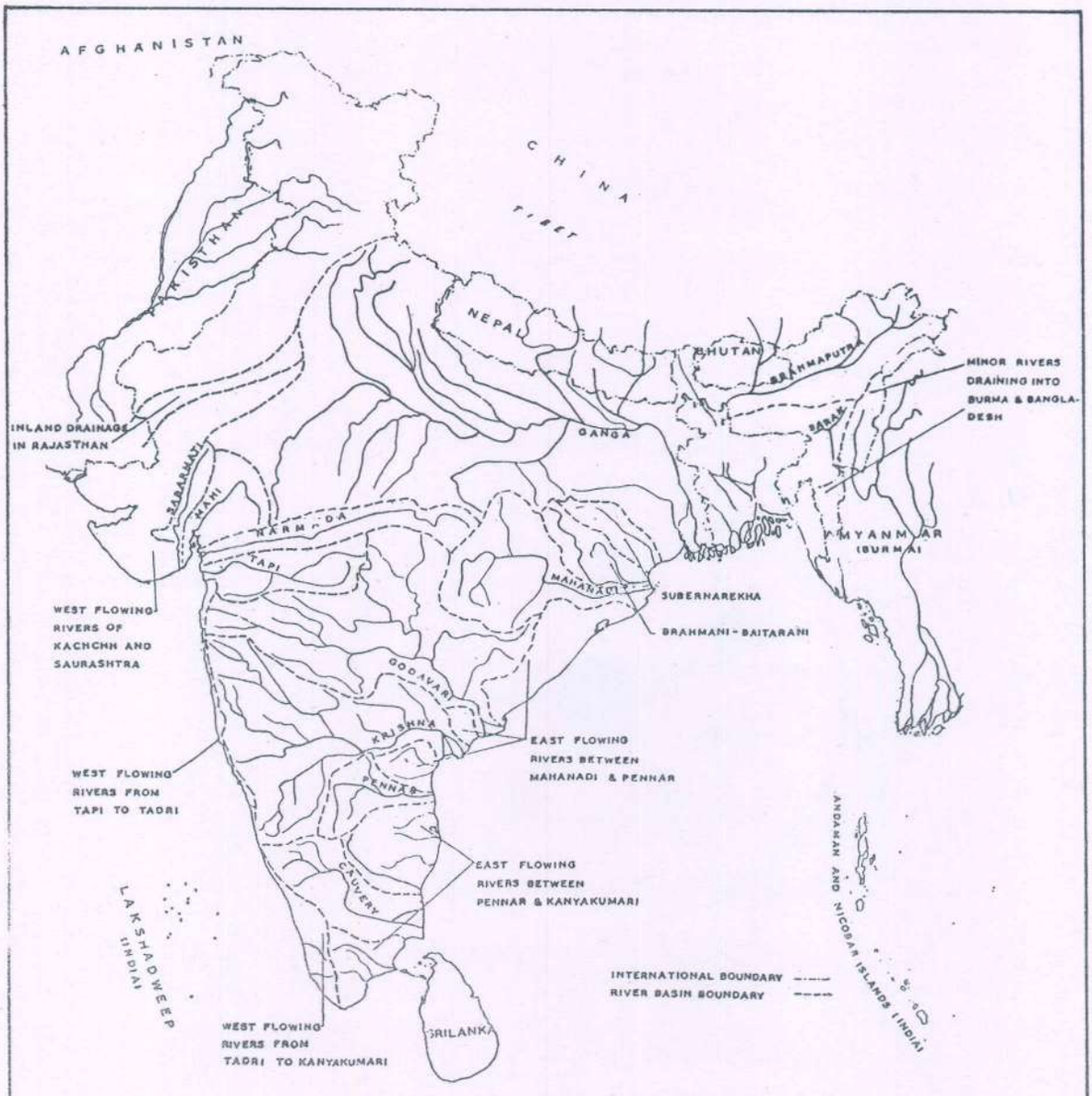


FIG.I. RIVER BASINS OF INDIA

Based upon Survey of India map with the permission of Surveyor General of India. The territorial waters of India extend into the sea to a distance of twelve nautical miles measured from the appropriate base line.

the ground water draft for the year 1967-68 as about 58 km^3. Assuming linear variation, the draft in any year in any district could be calculated. It was further assumed that the consumptive use of ground water was 70% of the withdrawal.

The average annual water resources potential of the country worked out to be 1880 km^3, after carrying out the corrections on the above lines. And as such this may be considered as the latest assessment of the water resources potential of the country.

2.5 River Basins of India

Central Water Commission's publication referred above also standardised the river basins of India. The entire country was divided into twenty river basins comprising twelve major basins: (1) Indus, (2) Ganga-Brahmaputra-Meghna (3) Godavari, (4) Krishna, (5) Cauvery, (6) Mahanadi, (7) Pennar, (8) Brahmani-Baitarani, (9) Sabarmati, (10) Mahi, (xi) Narmada and (xii) Tapi, each of these basins having a drainage area exceeding 20000 sq.km. and eight composite river basins combing suitably together all the other remaining medium and small river systems for the purpose of planning and management. These eight composite river basins are: (1) Subernarekha - combing Subernarekha and other small rivers between Subernarekha and Baitarani, (2) East flowing rivers between Mahanadi and Pennar; (3) East flowing rivers between Pennar and Kanyakumari; (4) Area of Inland Drainage in Rajasthan Desert; (5) West flowing rivers of Kutch and Saurashtra including Luni; (6) West flowing rivers from Tapi to Tadri; (7) West flowing rivers from Tadri to Kanyakumari and (8) Minor rivers draining into Myanmar (Burma) and Bangladesh. A map of India showing these twenty river basins is given in Fig. 1.

3. Need for Reassessment

3.1 Two Approaches for Assessment

The review of the earlier assessment studies presented above indicated two approaches that had been followed for assessing the average annual runoff in the rivers. One was by adopting Dr. Khosla's formula which worked out the natural runoff as the difference between the rainfall and the estimated evapotranspiration. This approach is suitable wherever observed river flow data are not available. The second approach was by using the observed flow data. In this approach the observed flows are corrected for the abstractions upstream of the point of flow measurement, assumed return flows and evaporation from reservoirs to get the natural flows. The second approach based on the actual observed flows is obviously expected to give more realistic estimates, since in the first approach, the evapotranspiration is a rough estimate. For working out the water availability in the river basins, 50-year period of observed

discharge data may be considered as fairly good and periods less than this, say 20 to 25 years, will be treated as just sufficient for working out water availability in the basin. Further in the second approach the observed flow records could also be extended by developing suitable rainfall-runoff relationships wherever found necessary due to inadequate length of flow record.

3.2 Flow Data Availability

Dr. Khosla's formula, of course, served the purpose of quick assessment of the country's water resources potential at that time, when adequate flow data were not available. The later attempts in revising Dr. Khosla's estimates were based on the flow data that become available in the various river systems of the country. In 1958, the erstwhile Ministry of Irrigation and Power set up a number of gauge and discharge observation stations in the Ganga and its tributaries to assess the flow according to accurate international standards. The stations subsequently came under Ganga Basin Water Resources Organisation which was later merged with Central Water Commission. Gauge and discharge observations were also started in Krishna and Godavari rivers following the recommendations of the Krishna Godavari Commission in 1962. Some of the State Governments too established their own gauge and discharge observation stations. However, these were mostly in connection with existing or proposed projects.

Since the early 1970s, Central Water Commission is maintaining a large number of gauge and discharge observation stations in almost all the inter-State systems of the country. As many as 500 stations are now in operation.

There is, thus, a reasonable amount of observed flow data now available in the country for most of the river systems. The available data are good enough to make a review of the assessment studies made earlier which would give a much more realistic picture of the total water resources potential of the country.

4. Overview of the Reassessment Study

4.1 Basins for which reassessment was considered not necessary

As mentioned in para 2, the country has been divided into 20 river basins.

For some of the river basins, assessment of the water resources potential has been carried out in recent times by various agencies. In all cases where estimation on the basis of actual flow data has been made recently, fresh attempt for assessment has not been made. A review of such studies is made below.

(1) Indus Basin

Indus is an international river. The water resources potential of the various sub-basins of Indus upto the Indian border has been estimated by Indus Commission, CWC and Irrigation Commission of 1972. The water resources development in this basin is governed by the provisions of the Indus Water Treaty of 1960 between India and the Pakistan. According to this Treaty, the water of the Eastern rivers, namely, Ravi, Beas and the Sutlej shall be available for the unrestricted use by India. India has also been permitted to use the waters of the Western Rivers for domestic non-consumptive purposes, for hydropower generation through run-of-the river hydroelectric plants and for specified agricultural purposes and construction of storage works. In view of the above, it is obvious that not much useful purpose will be served by reassessing the water potential of the Indian portion of the whole basin.

(2) Ganga-Brahmaputra-Meghna Basin

In respect of Ganga, the erstwhile Ganga Basin Water Studies Organisation of Central Water Commission carried out the assessment of water resources potential and have presented the details of the study in their report of 1986[6] Ganga basin has been divided into ten sub-basins for the study and the assessment was based on the actual observed flow data available at several locations for durations ranging from 5 years to 20-25 years. Simple rainfall-runoff regression analysis and multi-site data generation were resorted to wherever the observed flow data were found to be inadequate.

In respect of Brahmaputra, the Brahmaputra Board in their report of 1987 on "Master Plan of Brahmaputra Basin: Part-I Main Stem" have reported the average annual flow at Jogighopa on Brahmaputra as 537.067 km^2. Jogighopa is located 85 km upstream of the point at which the river crosses India-Bangladesh border. The average annual flow has been worked out on the basis of observed flows in the years 1955 to 1957 and 1971 to 1977. Important tributaries like Champamati, Gaurang, Sankosh, Torsa, Jaldhaka and Tista join Brahmaputra downstream of Jogighopa. The water resources potential of the area drained by these tributaries has to be accounted for separately, which has not been attempted.

In respect of Barak and other rivers joining Meghna, studies have been completed by Brahmaputra Board only for the portion of Barak upto the border of India with Bangladesh[9]. The yield of the river at Badarpurghat about 10 km upstream of the border has been reported to be 29.056 km^2. Studies in respect of other rivers originating from Assam, Meghalaya and Tripura are yet to be completed. The total catchment area of Barak in India is 41723 km^2. Therefore as

an approximation, the potential of the entire basin can be worked out on catchment area proportion basis from the potential at Badarpurghat. The result of this exercise is reported in Table 1. Potential of Barak is less by 11.443 km^3 than the potential of 59.8 km^3 reported earlier.

(3) Narmada Basin

For the use of the Narmada Water Disputes Tribunal, the annual flow series at Garudeshwar on Narmada were developed for the period 1891 to 1970, based on the observed flows at this location from 1948 to 1970[5]. The catchment area at Garudeshwar is 89345 km^2 while the total catchment area of Narmada is 98796 km^2. The tributaries of Heran and Karjan join Narmada downstream of Garudeshwar. Therefore, the water resources potential of the entire Narmada basin would be more than the potential at Garudeshwar. The potential for the entire basin can be worked, without appreciable loss of accuracy, on catchment area proportion basis from the potential at Garudeshwar. This has now been attempted for the purpose of this report and the result has been indicated in Table 1. The potential is now more by 4.366 km^3.

(4) Mahanadi Basin

Mahanadi basin has been studied in detail by the Planning and Investigation Organisation of Central Water Commission which prepared a report on the water balance in Mahanadi basin in 1980[10] and later by the Systems Engineering Unit of CWC during 1982-87 in connection with UNDP assisted project on Systems Engineering for Integrated Development of Water Resources in India. The assessment study carried out by the Systems Engineering Unit was based on observed flow data available for 10-12 years and further extended by rainfall-runoff regression analysis[11].

(5) Cauvery Basin

In respect of Cauvery basin, the assessment of the potential was carried out in 1972 by the Cauvery Fact Finding Committee[3] constituted by the Govt. of India. The assessment study was based on the observed flow data for 38 years (1934-35 to 1971-72). The assessment made is at Lower Anicut across Coleroon, a branch of Cauvery in the Delta. An area of near 8000 km^2 in the delta is not accounted for in this assessment. The potential at Lower Anicut has been taken as the potential for the entire basin.

Apart from the above five basins, in respect of the following three basins also assessment of water resources potential was considered not necessary: (i) West flowing rivers of Kutch and Saurashtra including Luni; (ii) Area of Inland Drainage in Rajasthan Desert and (iii) Minor Rivers draining into Myanmar (Burma) and Bangladesh.

4.2 Basins for which Reassessment Study has been done

Reassessment study has been carried out in respect of the remaining river basins listed below:

(1) Godavari,
(2) Krishna,
(3) Subernarekha,
(4) Brahmani-Baitarani,
(5) Pennar,
(6) Sabarmati,
(7) Mahi,
(8) Tapi,
(9) West flowing rivers from Tapi to Tadri,
(10) West flowing rivers from Tadri to Kanyakumari,
(11) East flowing rivers between Mahanadi and Pennar and
(12) East flowing rivers between Pennar and Kanyakumari.

Details of the study carried out are given basin-wise in Section II of this Report. A brief overview is given here.

4.3 Basin-wise Overview of the Study

The reassessment of water potential is generally based on a minimum flow record of 20 to 25 years. Wherever flow records are not available for such a period, rainfall-runoff regression analysis has been carried out for extending the flow record backwards for the required length of time.

(1) Godavari[12]

In Godavari basin (Catchment area 312800 km^2) observed flow data were available at Polavaram (CWC gauging site with C.A 307800 km^2) for the period 1967-68 to 1984-85 (18 years) which were used directly without resorting to rainfall-runoff regression analysis. The available 18-year record was considered adequate for the assessment.

(2) Krishna[13]

In Krishna basin (C.A. 258948 km^2) observed flow data at Vijayawada (C.A 251369 km^2) available from 1971-72 to 1984-85 (14 years) were used in the study. No rainfall-runoff regression analysis was considered necessary.

(3) Subernarekha[14]

In Subernarekha basin (C.A 29196 Km^2), the flow data at Ghatsila (CWC gauging site with C.A. 14176 km^2) available for the period 1971-72 to 1986-87 (16 years) were made use of. However the flow data were also extended to the period 1963-64 to 1970-71 on the basis of rainfall runoff regression analysis. The total period considered was thus 24 years.

(4) Brahmani-Baitarani[14]

In Brahmani-Baitarani basin (C.A.51822 km^2) for the Brahmani portion of the basin, flow data at Jenapur (CWC gauging station with C.A.36300 km^2) available for the period 1965-66 to 1984-85 (20 years) were made use of. However for the years 1964-65, 1966-67 and 1967-68 for which flow data were not available, the flows were estimated proportionately on the basis of observed flows in Baitarani. For the Baitarani portion of the basin, flow data at Biridi (C.A. 10120 km^2) available for the period 1964-65 to 1984-85 (21 years) were used. Here flow value was not available for the year 1972-73 and was estimated on the basis of the observed flow at Anandapur (CWC gauging site) upstream.

(5) Pennar[15]

In Pennar Basin (C.A. 55213 km^2) inflow data at Sangam Anicut (C.A.50253 km^2) available for the years 1944-45 to 1983-84 (40 years) were made use of.

(6) Mahi[16]

In Mahi basin (C.A.34842 km^2), flow data were available at Khanpur (CWC gauging site with C.A 32500 km^2) for the period 1979-80 to 1985-86 (7 years). Since the length of the record was inadequate, it was extended for the period 1965-66 to 1978-79 by rainfall-runoff regression analysis.

(7) Sabarmati[17]

Sabarmati basin (C.A.21674 km^2) presented a problem. There was only one CWC gauging site existing in the basin which is at Dharoi having a catchment area of only 5433 km^2 (i.e., 25% of the total area). Flow data available at this site was for the period 1972-73 to 1984-85 (13 years). The other gauging site is at Ahmedabad maintained by the State Govt. Even this site has a catchment area of only 10202 km^2 covering about 53% of the total area. Available flow data at Ahmedabad covered a period of 1960-61 to 1964-65, 1969-70 to 1984-85. The site was also shifted twice during these periods. The gap from 1965-66 to 1968-69 for which data were missing, was filled up using rainfall-runoff regression analysis. Ahmedabad site was used for the reassessment.

(8) Tapi[18]

For the Tapi basin (C.A. 65145 km^2), flow data were available for the period 1978-79 to 1986-87 (9 years) at Ghala gauging site (C.A. 63325 km^2) and were made use of for extending the flow record to 22 years by rainfall-runoff regression analysis.

(9) West flowing rivers from Tapi to Tadri[19]

This basin has as many as 45 minor river systems of which only two rivers had observed flow records for 16 years. In the basin containing west flowing rivers from Tadri to Kanyakumari, observed flow records were available for five rivers for periods ranging from 12 to 16 years. Analysing the flows in the seven river systems, a relationship between average annual catchment rainfall and runoff was developed. Using this relationship and knowing the rainfall, the average annual runoff in the other ungauged river systems was estimated.

(10) West flowing rivers from Tadri to Kanyakumari[19]

This basin has 54 minor river systems of which five rivers had observed flow records for 12 to 16 years. As explained above these flow records along with the flow records for two rivers systems in the basin containing west flowing rivers from Tapi to Tadri were analysed and a relationship was developed between average annual catchment rainfall and runoff. Using this relationship and knowing the catchment rainfall, the runoff in the remaining river systems was estimated.

(11) East flowing rivers between Mahanadi and Pennar

The basin containing east flowing rivers between Mahanadi and Pennar has been divided into two parts for the purpose of water resources potential assessment: (i) the northern part containing the river systems between Mahanadi and Godavari (C.A. 49695 km^2) and (ii) the southern part containing the river systems between Godavari and Krishna and between Krishna and Pennar (C.A. 39958 km^2). The assessment of the potential for the northern part of the basin was based on the available observed flow data at Kashinagar (C.A. 8096 km^2) on Vamsadhara river[20]. The average annual flow in the northern part of the basin was estimated on catchment area and rainfall proportionate basis from the average annual flow at Kashinagar. For want of flow records for the river systems in the southern part of the basin, the water potential assessment in this part was based on assessment made for the adjacent Pennar basin.

(12) East flowing rivers between Pennar and Kanyakumari

The basin containing east flowing rivers between Pennar and Kanyakumari was divided into northern part containing river systems between Pennar and Cauvery and the southern part containing river systems between Cauvery and Kanyakumari. For the assessment of water potential for the northern part (C.A. 65049 km^2), observed flow data available at Villupuram (C.A. 12900 km^2), on Ponnaiyar were made use of. For the southern part detailed studies have been completed by NWDA and they have been adopted as such. The

Table 1. Water Resources Potential of River Basins of India

Sl.No.	River Basin	Catchment Area (sq.km.)	Water Resources Potential (Mm^3) Average	75% Dependable	Ground Water Potential
1.	Indus	321289+	73305*	-	25543
2.	Ganga-Brahmaputra-Meghna				
	(a) Ganga	861452+	525023*	436312	171725
	(b) Brahmaputra[1]	194413+	537240*	491736	27857
	(c) Barak & others[2]	41723+	48357	-	1795
3.	Godavari	312812	110540	80545	46762
4.	Krishna	258948	78124	69411	26646
5.	Cauvery[3]	81155	21358	19375	13598
6.	Subernarekha	29196	12368	9855	2185
7.	Brahmani-Baitarani	51822	28477	20051	5879
8.	Mahanadi	141589	66879*	53786	21293
9.	Pennar	55213	6316	4393	5047
10.	Mahi	34842	11020	5713	-
11.	Sabarmati	21674	3809	3146	7908
12.	Narmada[4]	98796	45639	30829	11890
13.	Tapi	65145	14879	8860	8173
14.	West flowing rivers from Tapi to Tadri	55940	87411	65663	9479
15.	West flowing rivers from Tadri to kanyakumari	56177	113532	85285	8810
16.	East flowing rivers between Mahanadi and Pennar	86643	22520	18768	22788
17.	East flowing rivers between Pennar and Kanyakumari	100139	16458	13930	20907
18.	West flowing rivers of Kutch & Saurashtra including Luni	321851	15098*	-	13948
19.	Area of inland drainage in Rajasthan desert	-	Negl.	-	-
20.	Minor rivers draining into Myanmar(Burma) and Bangladesh	36302+	31000*	-	-
	TOTAL		1869348		452233

*Earlier estimates reproduced from CWC Publication No. 30/88 "Water Resources of India", April 1988.

+Area in Indian Territory

[1]The potential indicated for Brahmaputra is the average annual flow at Jogighopa situated 85 km upstream of Indo-Bangladesh border. The area drained by the tributaries like Champamati, Guarang, Sankosh, Torsa, Jaldhaka and Tista joining Brahmaputra downstream of Jogighopa is not accounted for in this assessment.

[2]Potential of Barak and others worked out on the basis of the average annual flow at Badarpurghat (C.A. 25070 km^2) given in Brahmaputra Board report on Barak Sub-basin.

[3]The assessment for Cauvery was made by the Cauvery Fact Finding Committee in 1972 based on 38 years flow data at Lower Anicut on Coleroon. An area of nearly 8000 km^2 in the delta is not accounted for in this assessment.

[4]The potential of Narmada basin worked out on the basis of catchment area proportion from the potential assessed at Garudeshwar (C.A. 89345 km^2) as given in the Report of Narmada Water Disputes Tribunal with its Decision (1978).

NWDA studies were based on observed flow data wherever available, resorting to rainfall-runoff regression for extension of flow record when found inadequate[21,22,23,24].

For correcting the observed flows for upstream abstractions, varying assumptions were made depending upon the data availability and other constraints. These are explained in the basin-wise detailed presentation in Section II.

The results of the study are given in the next para.

5. Water Resources Potential of the River Basins

5.1 Results of the Reassessment Study

In Table 1 are given the water resources potential of all the twenty river basins of India. As explained in the preceding paragraph, reassessment has been carried out in respect of twelve basins. In respect of the remaining eight basins, earlier estimates as assessed recently by various agencies have been reproduced. Some corrections as indicated in the foot note of the Table have been carried out in respect of Barak and Narmada basins which resulted in a negligible difference of -0.4% in the earlier assessment.

The total water resources potential of the country as assessed now is 1869 km^3.

The assessment made by the first Irrigation Commission (1902-03) for all the river systems in India (as it was then but excluding Burma, Assam and East Bengal) was 1443 km^3).

The assessment made in 1949 based on Khosla's formula was 1673 km^3.

According to the study made by the Central Water and Power Commission during 1954-66 based on statistical analysis of flow data and on rainfall-runoff relationships as discussed in para 2.3, the water resources potential of the various river systems amounted to 1881 km^3.

The CWC Publication No. 30/88 on "Water Resources of India" (1988) gives a compilation of the results of the assessment studies in respect of the twenty river basins as were available at that time with corrections for ground water abstractions, as discussed in para 2.4. According to this compilation, the water resources potential for the entire country worked out to 1880 km^3.

In the present study, as explained in para 6, earlier assessments in respect of twelve basins have been revised. Present assessment for these twelve basins is 500.978 km^3 against the earlier assessment of 508.475 km^3.

Table 2(a) Observed flows, abstractions and natural flows

Unit: Mm^3

Sl. No.	Basin	Catchment area (km^2)	Observed flow at Terminal Site	WITHDRAWAL			RETURN FLOWS		Change in Storage	Evap. loss from Reservoirs	Natural flow at Terminal Site	Natural flow for the whole basin	
				Irr.	Dom & Ind.	Ground Water	Irr.	Dom. & Ind.					
1.	Godavari	312800	89397	12504	2522	4901	1250	2018	Nil	2709	108766	110540	
2.	Krishna	258950	29729	36486	5202	4526	3186	4162	242	2713	75337*	78124	*including 4287 of Westward diversions
3.	Subernarekha	29196	5679	298	402	166	30	322	Nil	21	6214	12368	
3.	a) Brahmani	51822	19551	816	502	-	82	401	Nil	6	20391	28477	
	b) Baitarani		5610	470	49	-	47	39	Nil	1	6044		
5.	Pennar	55213	3760	1523	-	618	152	-	Nil	Nil	5740	6316	
6.	Sabarmati	21674	1068	341	92	-	-	-	-3	32	1559++	3809	++including export of 29
7.	Mahi	34842	4010	2647	44	1018	265	35	367	405	8191	11020	
8.	Tapi	65145	3676	4207	35	1637	421	28	258	623	9988	14879	
9.	West flowing rivers from Tapi to Tadri	55940										87411	
	a) Purna	2322	1347	1	43	8	-	35	-	1	1365	(1589)	
	b) Vaitarna	3647	3257	54	106	8	5	85	-	27	3362	(6602)	
10.	West flowing rivers from Tadri to Kanyakumari	56177										113532	
	a) Netravathy	3222	12580	42	65	35	4	52	-	-	12666	(12817)	
	b) Bharatapuzha	6186	5360	682	244	123	68	195	-31	28	6143	(7054)	
	c) Karuvannu	1054	1405	76	21	20	8	17	2	6	1505	(1907)	
	d) Chalakudy	1704	1868	429	56	217	43	45	-494	24	2568*	(3299)	*including diversion of 536
	e) Periyar	5398	8084	687	121	47	69	97	-658	67	9377**	(12210)	**incouding diversion of 1195
11.	East flowing rivers between Mahanadi and Pennar	86643										22520@	@Obtained by extrapolation from the flow in Vamsadhara and the flow in Pennar
	Vamsadhara	10830	1989	286	-	-	29	-	-	-	2254		
12.	East flowing rivers between Pennar and Kanyakumari	100139										16458@@	@@Obtained by extrapolation from the flows in three rive- systems in the basi
	Ponnaiyar	15865	247	393	-	1342	39	-	-	35	1978		

5.2 Discussion on the Results of the Study

Table 2(a) gives average annual observed flow at the terminal gauging sites in the twelve basins along with average annual abstractions and other parameters and the natural flows as worked out.

In Table 2(b) are given comparative figures of the potential of the twelve basins as assessed now and as assessed earlier. Possible reasons for the difference have also been indicated in the table. Although the potential of the twelve basins put together shows negligible difference (-1.5%), the difference in respect of individual basins is significant (± 10%) in the case of as many as seven basins, viz., (1) Krishna, (2) Subernarekha, (3) Brahmani-Baitarani, (4) Tapi, (5) West flowing rivers from Tapi to Tadri, (6) West flowing rivers from Tadri to Kanyakumari, and (7) East flowing rivers between Mahanadi and Pennar.

In respect of the other five basins the difference is less than ± 10%. Earlier assessments for four out of these five basins were based on Khosla's formula.

In the case of Krishna, the earlier assessment made by the Krishna Water Disputes Tribunal was based on the discharges over Vijayawada Anicut (C.A. 251369 km^2) calculated from gauge readings for the year 1894-95 to 1971-72 (78 years). The present assessment is based on the flows at Vijayawada measures by regular discharge observations conducted by CWC for the year 1971-72 to 1984-85 (14 years), which shows a difference of ± 15%. In the present assessment contribution from the catchment area downstream of Vijayawda (7581 km^2) has also been added proportionately. If only the average flows at Vijaywada are compared, the difference comes to only about 11%. The present assessment appears to be more realistic.

For Subernarekha basin, although the difference between earlier assessment and the present assessment is ±14.6%, review of earlier assessment indicates that the potential worked out was for an area of only 24471 km^2 (Subernarekha and Burhabalang river systems), while the present exercise covers an area of 29196 km^2 (including other minor river systems between Subernarekha and Baitarani). If the earlier assessment is proportionately extended to the entire area, the difference would be negligible.

In the case of Brahmani-Baitarani, the difference between earlier and present assessments is -21%. The earlier assessment was based on Khosla's formula. The present assessment which is based on about 20 years of observed flows appears to be more realistic.

In the case of Tapi basin, the difference between the earlier assessment and the present assessment is nearly

Table 2(b) Comparative Figures of Potential as assessed earlier and as assessed now

Unit: km^3

Sl. No.	Basin	Earlier Assessment Potential	Earlier Assessment Basis	Present Assessment	Diff. %	Possible Reasons for Difference
1.	Godavari	118.982	20 years observed flow data	110.540	-7.1	Difference is not significant
2.	Krishna	67.790 (at Vijayawada)	Discharge over Vijaywada Anicut calculated by weir formula for the years 1894-95 to 1971-72	78.124 (at outfall)	+15.2	Present assessment is based on measured flow at Vijaywada gauging site of CWC for the years 1971-72 to 1984-85. Contribution d/s of Vijaywada is also accounted for. At Vijaywada the difference is only 11%.
				75.837 (at Vijaywada)	+11.0	
3.	Subernarekha	10.793	Rainfall-runoff regression	12.368	+ 14.6	Earlier assessment was for an area of 24471 km^2 comprising Subernarekha and Burhabalang rivers. Present assessment is for an area of 29196 km^2 comprising other minor river systems also between Subernarekha and Baitarani.
4.	Brahmani-Baitarani	36.227	Khosla's formula	28.477	-21.4	Present assessment is based on observed river flows.
5.	Pennar	6.858	Khosla's formula	6.316	-7.9	-do-
6.	Sabarmati	4.079	Observed flow data for 1950-51 to 1964-65 (with gaps) extended to 35 years	3.809	-6.6	Difference is not significant
7.	Mahi	11.829	Khosla's formula	11.020	-6.8	Present assessment is based on observed river flows
8.	Tapi	18.389	10 years observed flows (1950-to 1960) extended to 30 years by rainfall-runoff regression analysis.	14.879	-19.1	Present assessment based on 9 years observed flows (1978 - 1986) extended to 22 years by rainfall-runoff regression.
9.	West flowing rivers from Tapi to Tadri	109.010	Inglis Formula	87.411	-19.8	Present assessment is based on rainfall-runoff relationship developed from observed flows in seven river systems
10.	West flowing rivers from Tadri to K.Kumari.	89.844	-do-	113.532	+26.4	
11	East flowing rivers between Mahandi and Pennar.	16.948	Khosla's formula	22.520	+32.9	Present assessment is based on observed flows in one of the river systems and on Pennar basin study extrapoliated for the entire basin
12.	East flowing rivers between Pennar and Kanyakumari	17.725	Khosla's formula	16.458	-7.1	Present assessment is based on observed flows in three river systems extrapolated for the entire basin
	Total	508.475		505.454	-0.1	

-19%. The earlier assessment was based on observed flow data for the period 1950-51 to 1953-54 and 1956-57 to 1961-62 i.e, 10 years, at Kathore (State Govt. site) on Tapi very close to its confluence with the Gulf of Cambay. From the observed flows for 10 years, 30 year flow series has been developed based on rainfall-runoff regression analysis. Review of the earlier studies indicates that whereas the average annual flow at Sarangkhede (C.A. 58400 km^2) was 11.8 km^3, that at Kathore (C.A. 62750 km^2) was 18.0 km^3, an increase of 52.5% in runoff for an increase of only 7.4% in catchment area. This does not appear realistic. The present assessment is based on the flows at Ghala gauging site (C.A. 63325 km^2) for the period 1978-79 to 1986-87 (9 years) extended to 22 years by rainfall-runoff regression analysis. The present assessment appears to be more realistic.

For the two basins of west flowing rivers from Tapi to Kanyakumari, the differences are -19.8% and +26.4%. The earlier assessment was carried out by the Committee constituted by the Planning Commission for assessment of the water resources of rivers flowing into Arabian Sea and their utilisation in 1982. The Committee carried out assessment studies in respect of 40 river systems. In respect of the remaining 57 river systems, average annual yields were taken from the State Govt.reports/data wherever available. In case of non-availability of the average yields, the same were computed by Inglis formula. The present assessment is based on the rainfall-runoff relationship developed from the observed flow data for 15 to 21 years in respect of seven river systems in the basins. The present assessment appears to be more realistic.

In the case of east flowing rivers between Mahanadi and Pennar, the difference is about +33%. The earlier assessment was based on Khosla's formula. The present assessment has been made considering the basin in two parts: the northern part between Mahanadi and Godavari and the southern part between Godavari and Pennar. The assessment for the northern part was based on the observed flows at one of the river systems, viz., Vamsadhara, for 14 years which were extended to 27 years by rainfall-runoff regression analysis. The assessment for the southern part was based on the assessment made for the adjacent Pennar basin. The present assessment, therefore, appears to be more realistic.

In Table 2(c) is given a summary of revisions made in the assessment of water resources potential of river basins.

6. Estimation of 75% Dependable Flows

The average annual virgin flow at the terminal point of a river is generally reckoned as the water resources potential of the river basin. However, in the planning of water resources projects, flows at varying dependabilities

Table 2(c) Summary of Revisions made in the Water Resources Potential of River Basins

Unit: Mm^3

Sl.No.	River Basin	Potential as assessed earlier*	Potential as assessed now	Remarks
1.	Indus	73305	73305	No revision
2.	Ganga-Brahmaputra-Meghna			
	(a) Ganga	525023	525023	-do-
	(b) Brahmaputra	537240	537240	-do-
	(c) Barak & others	59800	48357	Revision based on report of Brahmaputra Board.
3.	Cauvery	21358	21358	No revision
4.	Narmada	41273	45639	Revision made to include drainage area downstream of Garudeshwar at which the earlier assessment was made.
5.	Mahanadi	66879	66879	No revision
6.	West flowing rivers of Kutch & Saurashtra including Luni	15098	15098	-do-
7.	Area of inland drainage in Rajasthan desert	Negl.	Negl.	-do-
8.	Minor rivers draining into Myanmar(Burma) and Bangladesh	31000	31000	-do-
9.	Remaining 12 river basins studied in the present report	508475	505454	Variations explained in Table 3.
	Total	1879451	1869353	

*Reproduced from CWC Publication No. 30/88 "Water Resources of India"

are taken into consideration. For instance, for irrigation projects 75% dependable flows, and for hydel power projects 95% dependable flows are considered, since irrigation projects are designed for 75% success and hydel projects for 95% success. Irrigation is the major consumer of water in our country. Nearly 85% of the total demand for water is for irrigation. It is, therefore, felt that it would be beneficial if 75% dependable flows for the river basins are also worked out and included in the report. In Table 1 are indicated the results of such an exercise.

7. Limitations of the Study

The study carried out is subject to the following broad limitations:

(1) For working out the upstream abstractions for various uses, assumptions had to be made depending upon the type of data that could be obtained for the abstractions. Uniform procedure could not naturally be adopted for all the river basins. Particularly for estimating withdrawals for irrigation which is the major consumer of water varying assumptions had to be made. In many cases while diversions from major and medium irrigation projects were available, those from minor schemes were seldom available.

(2) In most of the cases the year-wise withdrawal from ground water has been estimated approximately assuming linear variation between the State-wise draft given by the Irrigation Commission of 1972 for the year 1967-68 and by the Central Ground Water Board for the year 1983-84, and interpolating for other years.

(3) Return flows have been assumed to be 10% in the case of irrigation (major and medium) and 80% in the case of domestic and industrial supplies which are only approximate.

8. General Recommendations

The accuracy of the assessment of water resources potential of a river basin made on the basis of the river flows measured at a terminal site on the river depends directly upon the accuracy of the discharge observations, and the reliability of the data on abstractions inthe up-stream.

The present assessment is mostly based on discharge observations which were conducted by CWC and hence could be considered as reliable. However the data on upstream abstractions have been collected from various sources and varying assumptions had necessarily to be resorted to wherever data were not readily available. The major consumption of water in most of the river basins is by irrigation. It is very essential that diversions for irrigation from major, medium and minor projects are recorded regularly and brought

out as yearly booklets similar to rainfall records.

Similarly ground water abstractions are generally estimated by the Central Ground Water Board and by the State Ground Water Boards. These estimates are invariably district or taluk-wise and not basin or sub-basinwise. Basinwise figures are worked out by area proportionate basis from the district-wise figures available which is obviously very approximate. It would be more convenient if ground water studies are carried out basin or sub-basinwise.

In the case of west flowing rivers composite basins and east flowing rivers composite basins, it is recommended to establish more gauging stations since the existing gauging stations are considered inadequate. There is also a need to modernise the equipment used for gauge and discharge measurements in the existing gauging stations in all the States.

All the water that is drawn for irrigation and other purposes is not consumed. A major or minor part of the water drawn depending upon the use is invariably returned back to the source. Because of the inherent difficulty in properly measuring or estimating the amount of water that is returned back, some assumptions are always made in this respect. It would be beneficial if some systematic studies are taken up by hydraulic research stations or agricultural universities atleast in a limited scale in order to arrive at a reasonably realistic assumption in this regard.

SECTION II

DETAILS OF THE STUDY

1. Godavari Basin

1.1 Basin Features

Godavari basin with a drainage area of 312800 km^2 covers nearly 10% of the total area of the country. The river Godavari rises in the Nasik district of Maharashtra about 80 km from Nasik at an elevation of about 1070 m. After flowing for about 1470 km in a generally south-east direction through Maharashtra and Andhra Pradesh, it falls into Bay of Bengal. The main tributaries of Godavari are Pravara, Purna, Manjira, Maner, Penganga, Wardha, Wainganga, Pranhita, Indravati and Sabari.

The basin receives annually a rainfall of 1132 mm on the average, 84% of which occurs during the monsoon months of June to September.

1.2 Earlier Assessments

The water potential of the Godavari river system has been assessed at different times by different authorities. The very first assessment was made by the First Irrigation Commission. This Commission used past records of the Surface flow of the Godavari from the greater part of its catchment covering a number of years to estimate the average flow. It assessed the total annual surface flow in the Godavari river system to be 1,16,765 Mm^3.

In 1949 when the assessment of the basinwise water resources of the country was worked out on the basin of Khosla's formula, the annual runoff of the Godavari river system was estimated to be 1,25,519 Mm^3.

In 1960 when the irrigation potential studies of the country were completed by the Central Water and Power Commission the total annual runoff of the Godavari system was assessed at 1,15,335 Mm^3.

In 1962 Krishna-Godavari Commission set up by the Government of India gave a figure of 1,17,996 Mm^3 as the total yield from the catchment.

1.3 Flow Data Availability

Observed river flow data are available for the period 1967-68 to 1984-85 at Polavaram with a drainage area of 307800 km^2 which covers about 98.4% of the total area of the basin. The 18 year observed flow record was considered adequate for estimating the water potential of the basin. Extending the flow record by rainfall-runoff regression analysis was considered not necessary, in this case. The basin map of Godavari showing the location of Polavaram is given in Fig.2.

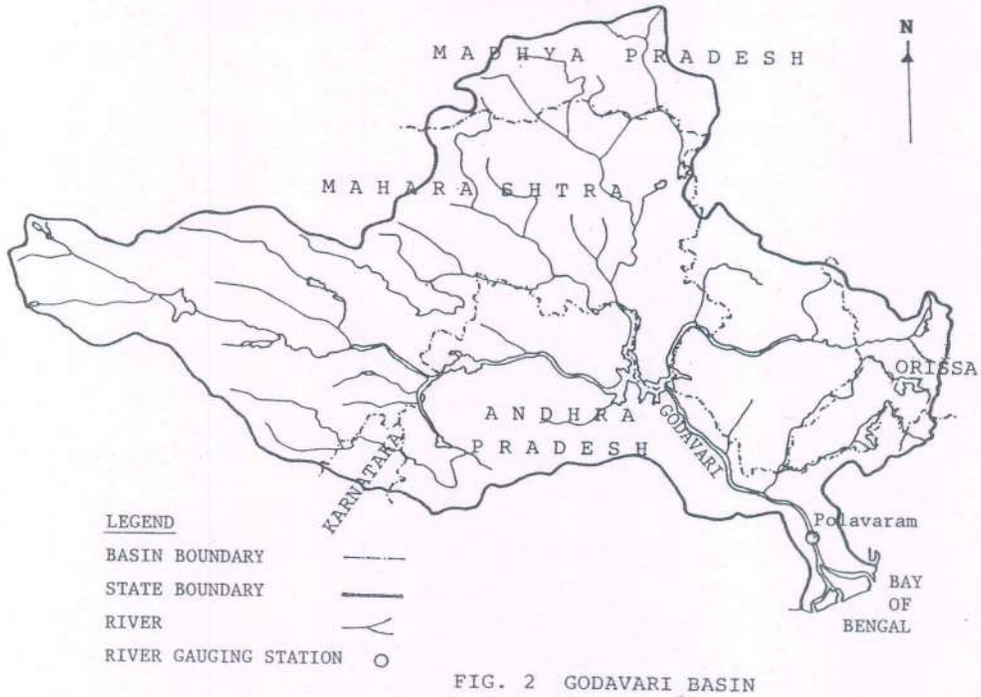


FIG. 2 GODAVARI BASIN

1.4 Methodology Adopted

The observed flows at Polavaram were corrected for the upstream abstractions to arrive at the natural flows by adopting the following equation:

$$R_N = R_O + R_{IR} + R_D + R_{GW} + R_{RI} - R_{RD} - R_{RG} + S + E,$$

(Equation-I)

where R_N is the natural flow;

R_O is the observed flow;

R_{IR} is the withdrawal for irrigation;

R_D is the withdrawal for domestic and industrial requirement;

R_{GW} is the ground water withdrawal;

R_{RI} is the return flow from irrigated areas;

R_{RD} is the return flow from domestic and industrial withdrawal;

R_{RG} is the return flow from ground water withdrawal;

S is the increase in storage of the reservoirs in the basin;

and E is the net evaporation from the reservoirs.

1.5 Data Used and Assumptions Made in Estimating Upstream Abstractions

Data on abstractions for irrigation (R_{IR}) have been obtained from the records maintained by irrigation project authorities. Wherever such records are not available, the abstractions have been estimated from the area irrigated by adopting suitable delta. Area irrigated has been mostly obtained from the reports of the Bureau of Economics and Statistics.

Withdrawals for domestic and industrial requirements have been estimated assuming per capita total requirement of 100 litre per day, using population figures as per 1981 census.

The total ground water draft for the country as a whole for the year 1967-68 has been estimated by the Irrigation Commission (1972) as 58 km^3. Subsequently the Central Ground Water Board estimated the same for the year 1983-84 as 100 km^3, out of which the draft for Godavari basin was about 6.113 km^3. Assuming the rate of variation in ground water draft between the years 1967-68 and 1983-84 the Godavari basin to be the same as that for the whole country, the ground water draft for the basin has been worked out for different years.

For some of the existing reservoirs the loss due to evaporation has been estimated by the project authorities and has been taken as such. For the remaining reservoirs the loss has been assumed as 20% of the annual utilisation.

The carry over storage is almost nil for most of the projects hence the value of S has been taken as zero.

Return flow from irrigation use has been assumed as 10% and that from ground water draft has been assumed to be negligible, as decided in the first meeting of the Committee. Return flow from domestic use has been assumed to be 80%.

1.6 Results of the Study

The estimation of yearwise water availability is indicated in Table 3. The average annual flow in Godavari basin works out to 110540 Mm^3.

Table 3. Estimation of Water Resources Potential in Godavari Basin

Unit : Mm^3

Year	Observed Flow at Polavaram R_O	Withdrawals R_{IR}	Withdrawals R_D	Withdrawals R_{GW}	Return Flows R_{RI}	Return Flows R_{RD}	Evap. loss E	Natural Flow R_N
1967-68	95652	7957	2006	3546	796	1605	1827	108587
1968-69	68347	8098	2006	3704	810	1605	1810	81550
1969-70	95463	7706	2006	3870	771	1605	1841	108510
1970-71	103920	9076	2006	4028	908	1605	2245	118762
1971-72	56307	9037	2484	4187	904	1987	2103	71227
1972-73	48567	9338	2484	4346	934	1987	2082	63896
1973-74	110898	12467	2484	4511	1247	1987	2910	130036
1974-75	41776	14028	2484	4670	1403	1987	2937	62505
1975-76	130726	13539	2484	4829	1354	1987	3034	151271
1976-77	112566	15128	2484	4988	1513	1987	3229	134895
1977-78	87160	14928	2484	5153	1493	1987	3154	109399
1978-79	120648	16127	2484	5312	1613	1987	352	144494
1979-80	66342	14393	2484	5471	1439	1987	299	88261
1980-81	102514	15703	2484	5630	1570	1987	326	126041
1981-82	103879	13715	3134	5795	1372	2507	281	125457
1982-83	56955	14357	3134	5948	1436	2507	290	79352
1983-84	152266	13921	3134	6113	1392	2507	303	174566
1984-85	55161	15560	3134	6113	1556	2507	306	78971

Average Annual Flow at Polavaram = 108766

Average Annual Flow for the whole basin = 108766 x 312800/307800

= **110540 Mm^3**

75% Dependable Flow at Polavaram = 79258

75% Dependable Flow for the whole basin = **80545 Mm^3**

The earlier estimation made by Krishna-Godavari Commission was 118982 Mm^3. The present estimation based on the latest observed stream flow records confirms the earlier estimation.

2. Krishna Basin

2.1 Basin Features

The Krishna basin with a drainage area of 258950 km^2 covers nearly 8% of the total geographical area of the country. The river Krishna rises in the Western Ghats at an altitude of 1337 metres just north of Mahabaleswar about 64 km from the Arabian Sea and flows from west to east through the States of Maharashtra, Karnataka and Andhra Pradesh before it joins the Bay of Bengal. The major tributaries of the Krishna are Koyna, Varna, Dudh Ganga, Gadhaprabha, Malaprabha, Bhima, Tungabhadra, Musi, Palleru and Munneru.

The average annual rainfall in Krishna basin is 784 mm. About 90% of the annual rainfall is received during the monsoon months of June to October. Map of the basin is given at Fig.3.

2.2 Earlier Assessments

The water potential of the Krishna river system has been assessed at different times by different authorities. The first assessment was made by the First Irrigation Commission. This Commission used the records of the surplus flow of the Krishna from the greater part of its catchment extending back for a sufficient number of years to estimate the average flow as accurately as possible. The Commission assessed the total annual surface flow in the Krishna river system as 84,863 Mm^3.

In the year 1949 when the assessment of the water resources of the country (basinwise) was made on the basis of Khosla's formula, the annual runoff of the Krishna river system was estimated to be 44,923 Mm^3.

The Technical Committee for the optimum utilisation of Krishna and Goavari waters, in its report dated 1953 estimated the average annual runoff of the Krishna river system at Vijayawada based on Khosla's formula to be 46,872 Mm^3.

The Central Water and Power Commission, when conducting the irrigation potential studies of the country assessed the total annual runoff of the Krishna river system to be 57,764 Mm^3.

The Krishna Godavari Commission, set up by the Govt. of India in their report dated July/August,1962, estimated the average annual yields, sub-basinwise and reported that the aggregate yield of all the sub-basins of the Krishna system is 62,784 Mm^3.

The Krishna Water Disputes Tribunal (1973) gave the assessment of water resources potential of Krishna basin as 67790 Mm^3.

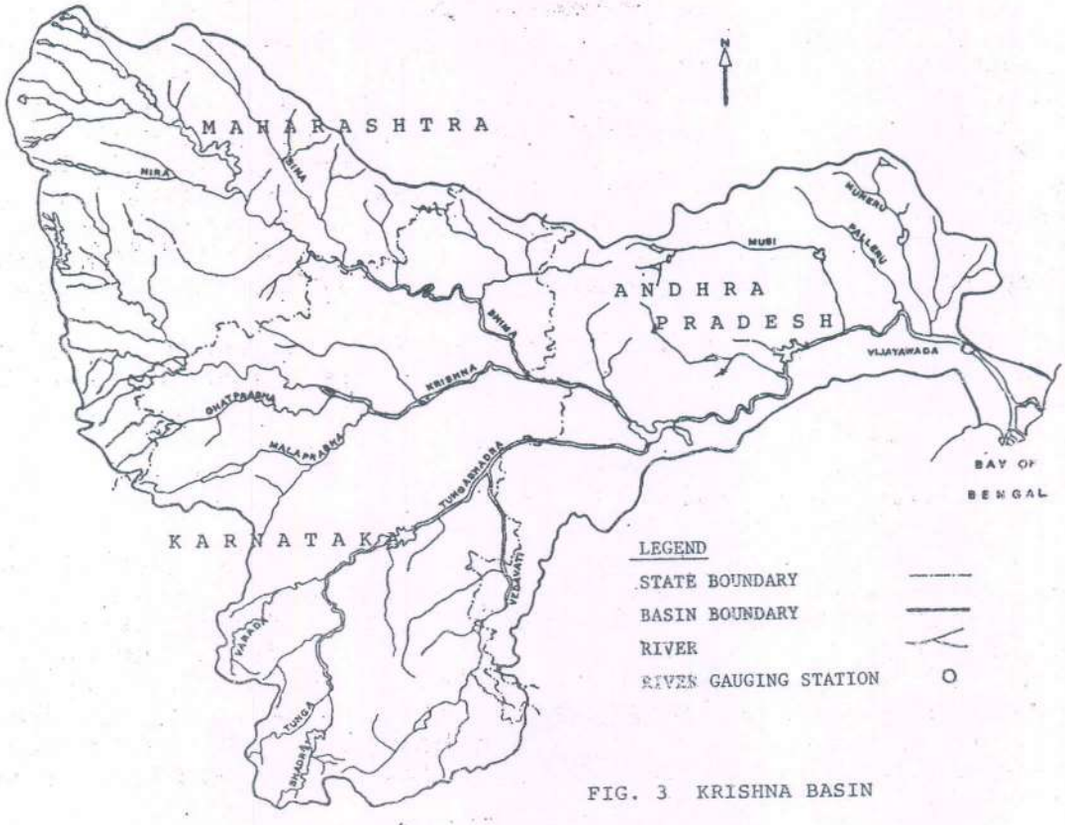


FIG. 3 KRISHNA BASIN

2.3 Flow Data Availability

Observed river flow records are available for the period 1971-72 to 1984-85 at Vijayawada just downstream of Prakasam Barrage. This point has a catchment area of 251369 km^2 which is nearly 97% of the total area of the basin. The 14 year observed flow records was considered adequate for assessing water potential of the basin without going in for the extension of the record by rainfall-runoff regression analysis.

2.4 Methodology Adopted

The observed flows at Vijayawada were corrected for the upstream abstractions to arrive at the natural flows by applying Equation-I (para 1.4).

2.5 Data used and Assumptions Made in Estimating Upstream Abstractions

Data on abstractions for Irrigation (R_{IR}) have been obtained from records maintained by the irrigation project authorities wherever available. In case where such records are not available the abstractions have been estimated from the irrigated area statistics published by the Bureau of Economics and Statistics and by adopting suitable delta. In all 67 major and medium irrigation projects and other minor irrigation projects have been considered in the study.

Withdrawals for domestic requirements have been estimated assuming the per capita requirement of 70 lpcd in rural areas and 200 lpcd in urban areas and 50 lpcd for the livestock.

In the absence of industrial water use data it has been assumed that industrial water requirements is equal to domestic water requirement.

Table 4. Estimation of Water Resources Potential in Krishna Basin

Unit : Mm^3

Year	Observed Flow at Vijaywada R_O	Withdrawals R_{IR}	Withdrawals R_D	Withdrawals R_{GW}	Return Flows R_{RI}	Return Flows R_{RD}	Change in Storage S	Evap. loss E	Westward Diversion	Natural Flow at Vijaywada
1971-72	27262	33517	4506	3532	2840	3606	-673	1889	4455	68042
1972-73	5429	27538	4603	3685	2450	3682	196	1728	4067	41114
1973-74	33064	32935	4695	3838	2805	3757	1153	2168	4505	75796
1974-75	28370	36852	4793	3992	3208	3834	-10	2212	4067	73234
1975-76	70191	37118	4902	4143	3103	3921	-116	2297	4091	115602
1976-77	29979	32850	5007	4296	2816	4006	464	2470	4208	72452
1977-78	19103	40218	5120	4450	3587	4098	1758	3121	4468	70553
1978-79	52079	36741	5232	4602	3110	4186	-163	2905	4976	99076
1979-80	26024	39389	5347	4754	3530	4278	685	3088	4088	75567
1980-81	30959	37530	5472	4909	3327	4378	-1723	3118	4435	76995
1981-82	29658	38377	5594	5064	3340	4475	1142	3216	4481	79717
1982-83	14391	40580	5720	5213	3616	4577	305	3390	3982	65388
1983-84	39478	34765	5850	5369	3019	4680	837	3203	4312	86115
1984-85	10218	42391	5986	5522	3852	4788	-466	3181	3885	62077

Average Annual Flow at Vijaywada = 75387 Mm^3

Average Annual Flow for the whole basin = 75387 x 258950/251369

= 78124 Mm^3

75% Dependable Flow at Vijayawada = 67379 Mm^3

75% Dependable Flow for the whole basin = 69411 Mm^3

As far as ground water abstractions are concerned an approximate interpolation has been made considering linear variation from the withdrawal assumed by the CGWB for the year 1984 and withdrawal for the year 1967-68 estimated by Irrigation Commission of 1972.

10% of the abstractions for irrigation and 80% of the abstractions for domestic and industrial purposes have been considered as return flows.

The data on evaporation losses are available for almost all the projects in the basins. For medium and mincr projects suitable assumptions have been made in this respect.

2.6 Results of the Study

The estimation of yearwise water availability in Krishna is shown in Table 4 The average annual flow works out to 78123 Mm^3

3. Subernarekha Basin

3.1 Basin Features

Subernarekha basin comprises not only the area drained by the Subernarekha river but also the areas drained by other small east flowing rivers like Burhabalang lying between Subernarekha and Baitarani. The area of the composite basin as a whole is 29196 km^2 of which Suberbnarekha alone accounts for 19296 km^2 and Burbahalang accounts for 4837 km^2. Four small streams account for the balance.

3.2 Earlier Assessments

In 1949 when the basinwise assessment of the water resources of the country was made on the basis of Khosla's formula, the total annual runoff of the river systems in the basin was estimated to be 20328 Mm^3.

In 1960, the Central Water and Power Commission, while conducting irrigation potential studies, assessed the total annual runoff of the river systems in the basin to be 14814 Mm^3 on the basis of Strange's rainfall-runoff coefficients for average catchments. This figure has been revised to 10794 Mm^3 in CWC Publication "River Basins of India" (1988), based on rainfall-runoff relationship.

3.3 Flow Data Availability

The lower most hydrologic observation station on Subernarekha river is located at Ghatsila which has a drainage area of 14176 Km^2. Observed river flow record available at this station from 1971-72 onwards has been used in the

assessment study. Specifically data for 16 years (1971-72 to 1986-87) have been used. The flow record was extended to 24 years by rainfall-runoff regression analysis. For this, rainfall data atg three raingauge stations, viz., Ranchi, Chaibasa and Jamshedpur were considered. The locations of the hydrological observation station at Ghatsila and the three raingauge stations are indicated in the basin map of Subernarekha given in Fig. 4.

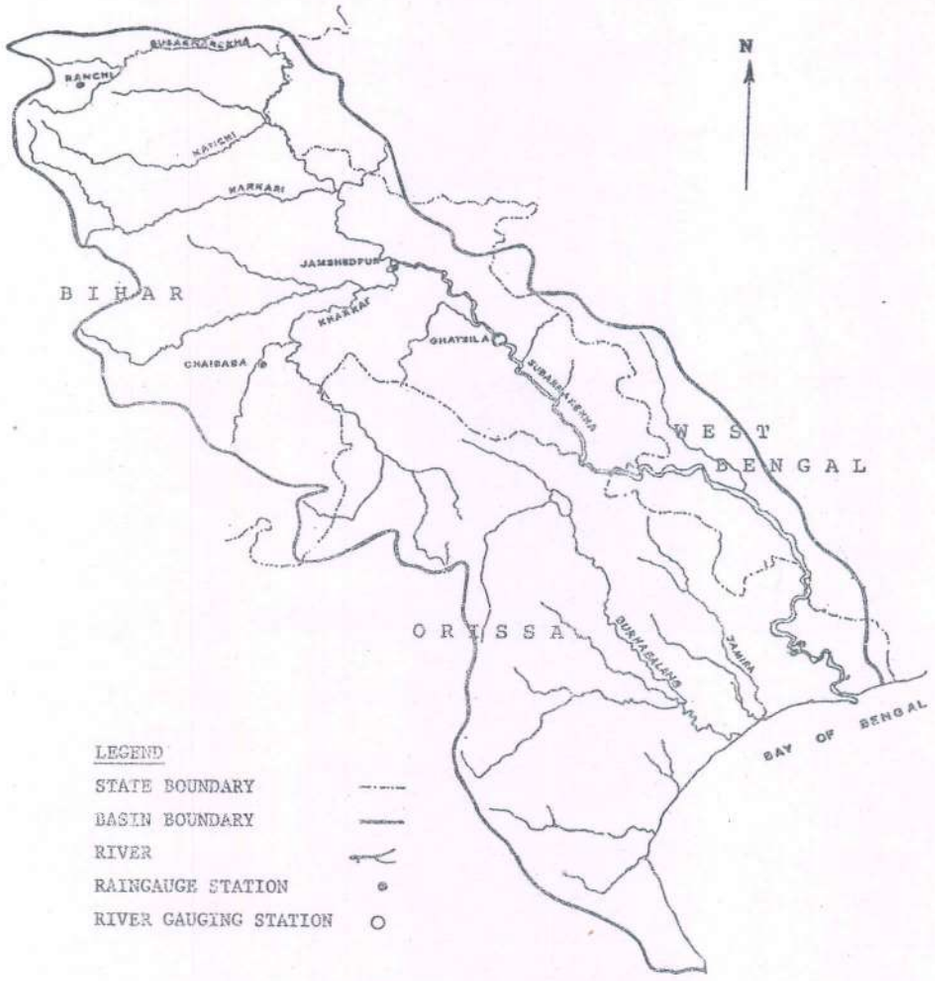


FIG. 4 SUBERNAREKHA BASIN

3.4 Methodology Adopted

Considering Ghatsila as the terminal site of the basin, the observed flows at Ghatsila were corrected for upstream abstractions to arrive at the natural flows as per Equation-I (para 1.4).

The natural flows obtained were used in rainfall-runoff regression analysis to estimate the natural flows in the year 1963-64 to 1970-71.

Table 6. Estimation of Water Resources Potential of Subernarekha Basin

Unit : Mm^3

Year	Observed Flow at Ghatsila R_O	Withdrawals R_{IR}	Withdrawals R_D	Return Flows R_{RI}	Return Flows R_{RD}	Evap. Loss E	Natural Flow at Ghatsila R_N
1963-64	-	-	-	-	-	-	6648
1964-65	-	-	-	-	-	-	6725
1965-66	-	-	-	-	-	-	5496
1966-67	-	-	-	-	-	-	4570
1967-68	-	-	-	-	-	-	5641
1968-69	-	-	-	-	-	-	5258
1969-70	-	-	-	-	-	-	6321
1970-71	-	-	-	-	-	-	4207
1971-72	5127	87	300	9	240	21	5422
1972-73	2642	87	306	9	245	21	2942
1973-74	9336	87	312	9	250	21	9641
1974-75	5566	149	318	15	254	21	5933
1975-76	6522	149	324	15	259	21	6894
1976-77	4783	149	329	15	264	21	5159
1977-78	10225	149	335	15	268	21	10607
1978-79	8884	215	341	22	273	21	9330
1979-80	1971	347	347	35	277	21	2542
1980-81	4439	479	487	48	389	21	5160
1981-82	4059	479	492	48	394	21	4784
1982-83	2754	479	498	48	398	21	3485
1983-84	4052	479	504	48	403	21	4788
1984-85	8312	479	510	48	408	21	9053
1985-86	7929	479	515	48	412	21	8675
1986-87	4264	479	521	48	417	21	5015

Average Annual Flow at Ghatsila = 6005

Average Annual Flow for the whole basin= 6005 x 29196/14176

= 12368 Mm^3

75% Dependable Flow at Ghatsila = 4785

75% Dependable Flow for the whole basin= 9855 Mm^3

3.5 Data Used And Assumptions Made in Estimating Upstream Abstractions

Withdrawal for irrigation in the year 1967-68 has been calculated based on the irrigation potential created (Ref.Report of Irrigatiom Commission, 1972) assuming a delta of 0.7m for major and medium irrigation projects. For minor projects, a delta of 0.65 m has been assumed. For later years, withdrawals was calculated based on the data on irrigation potential available in CWC.

Withdrawal for domestic use has been based on the population statistics and assuming a per capita requirement of 70 lpcd for rural areas and 140 lpcd for urban areas. Withdrawal for industrial use has been calculated taking (75 cusec) 2.2 cumec in the year 1960, and assuming it to double every 10 years.

The change in storage of the reservoirs (S) in the basin is negligible and as such assumed to be zero.

3.6 Results of the Study

The estimation of water resources potential of Subernarekha basin is indicated in Table 5. The potential works out to 12368 Mm^3.

4. Brahmani-Baitarani Basin

4.1 Basin Features

Brahmani-Baitarani basin has a drainage area of 51822 km^2. The Brahmani river rises near Nagri village in Ranchi district of Bihar at an elevation of 600m and has a total length of 799 km. Baitarani river rises in the hill ranges of Keonjhar district of Orissa at an elevation of about 9.0 m and has a length of about 355 km. Both river systems outfall into Bay of Bengal forming a common delta area. Important tributaries of Brahmani are the Karo, the Sankh and the Tirka and those of Baitarani are the Salandi and the Matai.

The annual normal rainfall in the districts falling in the basin varies from about 1435 mm to 1648 mm. Over 90% of the annual rainfall occurs during the monsoon months of June to October.

4.2 Earlier Assessments

In 1949 when the basinwise assessment of the water resources of the country was made on the basis of Khosla's empirical formula, the annual runoff of the basin was estimated as 39225 Mm^3.

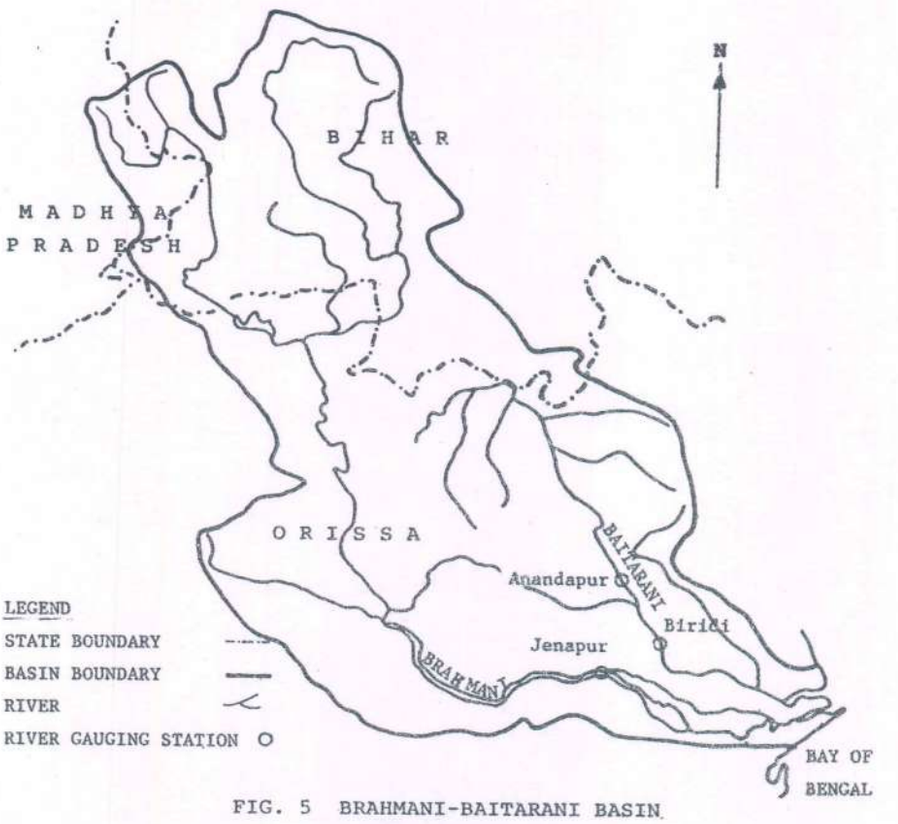


FIG. 5 BRAHMANI-BAITARANI BASIN

In 1960 the Central Water and Power Commission, while conducting irrigation potential studies, assessed the total annual runoff of the basin as 28691 Mm^3 on the basis of Strange's rainfall-runoff coefficients for average catchments CWC Publication No. 30/88 "Water Resources of India" gives a figure of 36227 Mm^3 reportedly based on Khosla's formula.

4.3 Flow Data Availability

At Jenapur (catchment area 36300 km^2) on the Brahmani, observed river flow data are available for the period 1964-65 to 1984-85. Jenapur covers about 90% of the Brahmani

sub-basin area and is therefore been considered for the study.

At Biridi (catchment area 10120 km^2) on Baitarani, observed river flow data area available for the period 1964-65 to 1984-85. This site is maintained by the Irrigation Department of Orissa and it covers nearly 97.8% of the sub-basin area. However, the flow records are not complete for the year 1964-65, 1966-67, 1967-68 and 1972-73. The maps of the basin showing Jenapur and Biridi gauging stations is given in Fig. 5.

4.4 Methodology Adopted

As far as Jenapur site on Brahmani is concerned the flow records were complete for the years 1964-65 to 1984-85 (21 years) and were directly used for estimating the natural flows.

Table 6. Estimation of Water Resources Potential of Brahmani Basin

Unit : Mm^3

Year	Obs. flow at Jenapur	Withdrawals		Return Flows		Evap. Loss	Natural Flow
	R_O	R_{IR}	R_D	R_{RI}	R_{RD}	E	R_N
1964-65	25714	650	301	65	241	0	26259
1965-66	7434	666	320	67	256	0	8097
1966-67	15338	683	340	68	272	0	16021
1967-68	20604	699	360	70	288	0	21305
1968-69	15258	716	380	72	304	0	15978
1969-70	11438	732	398	73	318	0	12177
1970-71	24709	749	419	75	335	0	25467
1971-72	40523	765	440	77	352	0	41299
1972-73	19266	787	459	79	367	0	20066
1973-74	44228	798	479	80	383	0	45052
1974-75	12212	815	501	82	401	0	13045
1975-76	21531	831	520	83	416	0	22383
1976-77	14362	848	542	85	434	0	15233
1977-78	24248	864	562	86	450	0	25138
1978-79	21869	881	582	88	466	8	22786
1979-80	7320	897	604	90	483	21	8269
1980-81	18972	914	624	91	499	21	19941
1981-82	14945	931	645	93	516	21	15933
1982-83	10018	947	666	95	533	21	11024
1983-84	16993	964	684	96	547	21	17961
1984-85	23580	980	707	98	566	21	24624

Average Annual Flow at Jenapur = 20384

Average Annual Flow for the whole basin= 20384 x 39033/36300

= 21919 Mm^3

75% Dependable Flow at Jenapur = 14139

75% Dependable Flow for the whole basin= **15204 Mm^3**

At Biridi on Baitarani the annual flows for the missing years of 1964-65, 1966-67 and 1967-68 were estimated on area proportion basis using the observed flows at Jenapur on Brahmani. For the year 1972-73 however the annual flow was estimated based on the observed flow record available at Anandpur (catchment area 8570 km^2) upstream of Biridi on Baitarani.

The observed/estimated flows at Jenapur and Biridi were corrected for the upstream abstractions to arrive at the natural flows by applying Equation-I (para 1.4).

4.5 Data Used and Assumptions Made in Estimating the Upstream Abstractions

Withdrawal for irrigation (R_{IR}) has been calculated based on the yearwise irrigation potential created assuming an average delta of 0.82 m.

Table 7. Estimation of Water Resources Potential of Baitarni Basin

Unit: Mm^3

Year	Obs. flow at Biridi	Withdrawals		Return Flows		Evap. Loss	Natural Flow
	R_O	R_{IR}	R_D	R_{RI}	R_{RD}	E	R_N
1964-65	7169	207	38	21	30	0	7363
1965-66	3442	234	39	23	32	0	3660
1966-67	4276	260	40	26	32	0	4518
1967-68	5744	286	41	29	33	0	6009
1968-69	6145	312	44	31	35	0	6435
1969-70	6941	339	44	34	35	0	7255
1970-71	5611	355	44	36	35	0	5939
1971-72	12228	391	46	39	37	0	12589
1972-73	5371	418	46	42	37	0	5756
1973-74	10781	444	48	44	38	0	11191
1974-75	4483	470	49	47	39	0	4916
1975-76	6710	496	50	50	40	0	7166
1976-77	3551	523	51	52	41	0	4032
1977-78	4937	550	53	55	42	0	5443
1978-79	2606	575	53	58	43	0	3133
1979-80	2665	602	54	60	43	0	3217
1980-81	4980	628	55	63	44	0	5556
1981-82	4905	654	57	65	45	0	5506
1982-83	4510	680	58	68	46	0	5134
1983-84	7022	707	59	71	47	0	7670
1984-85	3731	733	60	73	48	14	4417

Average Annual Flow at Birdi = 6043

Average Annual Flow for the whole basin = 6043 x 10982/10120

= 6558 Mm^3

75% Dependable Flow at Biridi = 4467

75% Dependable Flow for the whole sub-basin = **4847 Mm^3**

Withdrawal for domestic use (R_D) has been based on population statistics assuming requirement of 70 lpcd for rural population and 140 lpcd for urban population.

The change in storage in the reservoirs in the basin is negligible.

4.6 Results of the Study

The estimation of the yearwise water availability is indicated in Table 6 and 7. The average annual water availability works out to 21919 Mm^3 in Brahmani basin and 6558 Mm^3 in Baitarani basin, making a total of 28477 Mm^3 in the composite basin.

Compared to the earlier estimation of 36227 Mm^3, the present estimation is less by more than 21%. However, since the earlier estimation was based on Khosla's formula and the present estimation is based on observed streamflow records, the latter may be considered to be more accurate.

5. Pennar Basin

5.1 Basin Features

Pennar basin extends over an area of 55213 km^2. The Pennar river rises from the Chenna Kesava hills of the Nandi ranges of Karnataka and flows for about 597 km before outfalling into the Bay of Bengal. The principal tributaries of the river are the Jayamangal, the Kunderu, the Sagileru, the Chitravati, the Papagni and the Cheyyeru.

The entire basin lies in a semi-arid region with low rainfall. The normal annual rainfall decreases from 988 mm at Nellore in the eastern end of the basin to about 508 mm at the western end. Parts of Nellore and Kuddapah districts adjacent to the sea coast receives some rain from the retreating monsoon also.

5.2 Earlier Assessment

In 1949 when the basinwise assessment of the water resources of the country was made on the basis of Khosla's empirical formula, the annual runoff of Pennar river system was estimated as practically nil.

In 1960 the Central Water and Power Commission while conducting the irrigation potential studies, assessed the total annual runoff of Pennar river as 6858 Mm^3 which is also reported in CWC's Publication 30/88 "Water Resources of India".

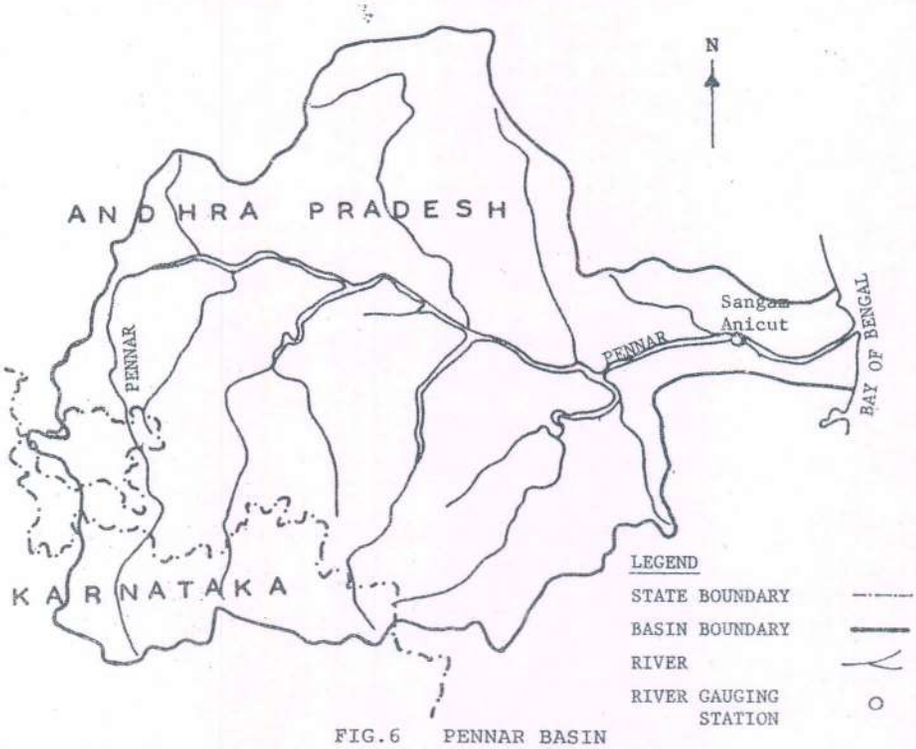


FIG.6 PENNAR BASIN

5.3 Flow Data Availability

Inflow data into Sangam anicut which covers a drainage area of 50253 km^2 (91% of the total) are available for the period from 1944-45 to 1983-84. The 40-year flow record was considered adequate for estimating the water potential of the basin. The map of Pennar basin showing the location of Sangam anicut is given in Fig. 6.

5.4 Methodollogy Adopted

The inflows at Sangam anicut were corrected for upstream abstractions to arrive at the natural flows by applying Equation-I (para 1.4).

5.5 Data Used and Assumptions Made in Estimating the Upstream Abstractions

Data on withdrawal for irrigation upstream of Sangam anicut are available in CWC for the years 1944-45 to 1983-84

Table 8. Estimation of Water Resources Potential of Pennar Basin

Unit : Mm^3

Year	Obs. flow at Sangam	Withdrawals		Return Flow	Natural Flow
	R_O	R_{IR}	R_{GW}	R_{RI}	R_N
1944-45	4987	1515	-	152	6350
1945-46	909	845	-	85	1669
1946-46	6491	1515	30	152	7884
1947-48	5418	1515	65	152	6847
1948-49	1131	981	100	98	2114
1949-50	8277	1515	135	152	9770
1950-51	904	845	165	85	1840
1951-52	2066	1515	200	152	3629
1952-53	667	712	235	71	1537
1953-54	4868	1529	265	153	6510
1954-55	3108	1529	300	153	4785
1955-56	2868	1529	335	153	4575
1956-57	8254	1529	365	153	9996
1957-58	1398	1162	400	116	2843
1958-59	4468	1560	435	156	6302
1959-60	1749	1479	465	148	3545
1960-61	6201	1586	500	159	8128
1961-62	2328	1619	535	162	8325
1962-63	6303	1619	565	162	4957
1963-64	2900	1619	600	162	4957
1964-65	8272	1619	635	162	10359
1965-66	2245	1683	665	168	4425
1966-67	4334	1683	700	168	6548
1967-68	3547	1683	735	168	5797
1968-69	1661	1601	765	160	3872
1969-70	3987	1688	800	169	6306
1970-71	3578	1688	835	169	5933
1971-72	1077	1151	865	115	2983
1972-73	3630	1688	900	169	6049
1973-74	4025	1688	935	169	6480
1974-75	4282	1688	970	169	6771
1975-76	12036	1688	1000	169	14555
1976-77	3560	1688	1035	183	6115
1977-78	2330	1818	1070	182	5037
1978-79	3523	1818	1100	182	6260
1979-80	2177	1818	1140	182	4954
1981-81	383	1133	1170	113	2572
1981-82	3523	1818	1210	182	6370
1982-83	1569	1742	1240	174	4377
1983-84	5365	1818	1270	182	8272

Average annual flow at Sangam = 5749

Average annual flow for the whole basin = 5749 x 55213/50253

= **6316** Mm^3

75% Dependable Flow at Sangam = 3998

75% Dependable Flow for the whole basin = **4393** Mm^3

and have been used as such. The return flows from irrigation utilisation has been assumed as 10% of the withdrawal.

The total ground water draft for the year 1967-68 has been estimated by the Irrigation Commission (1972). Subsequently the Central Ground Water Board estimated the same in the year 1983-84. Assuming the linear variation the yearwise ground water utilisation has been arrived at.

Abstractions for domestic and industrial uses have been assumed to be negligible.

5.6 Results of the Study

The estimation of yearwise water availability is indicated in Table 8. The average annual water availability in the basin works out to 6316 Mm^3.

The present assessment is almost equal to the earlier assessment of 6858 Mm^3.

6. Sabarmati Basin

6.1 Basin Features

Sabarmati basin extends over an area of 21674 km^2. The Sabarmati river rises from Aravalli hills in Rajasthan at an elevation of about 762 m and flows for about 572 km before outfalling into the Arabian Sea through the Gulf of Cambay. The principal tributaries of Sabarmati are the Sej, the Wakal, the Harnav, the Hathmati and the Wartak.

6.2 Earlier Assessments

In 1949 when the basinwise assessment of the water resources of the country was made on the basis of Khosla's empirical formula, the annual runoff of Sabarmati basin had been assessed as 4663 Mm^3.

In 1960, the Central Water and Power Commission, while conducting irrigation potential studies, assessed the average annual runoff of Sabarmati as 3663 Mm^3, which was subsequently revised to 4079 Mm^3 in CWC Publication 36/88 "Water Resources of India".

6.3 Flow Data Availability

Only one CWC gauge-discharge site is existing in this basin. This site is at Dharoi (catchment area 5433 km^2) which covers only about 25% of the total catchment area of the basin. River flow data for the period from 1972-73 to 1984-85 are available at this site. The only other gauge-discharge site on the Sabarmati is at Subhash bridge near Ahmedabad. This site is maintained by the Govt. of Gujarat.

However, even at this site the catchment area covered is only about 47% of the total catchment area of the basin. Moreover the site near Ahmedabad was shifted from time to time. River flow data at this site are available for the period 1960-61 to 1964-65 (at Ahmedabad), 1969-70 to 1979-80 (at Ellis bridge) and 1980-81 to 1984-85 (at Subhash bridge). The map of Sabarmati basin showing Dharoi and Ahmedabad gauging stations is given in Fig. 7.

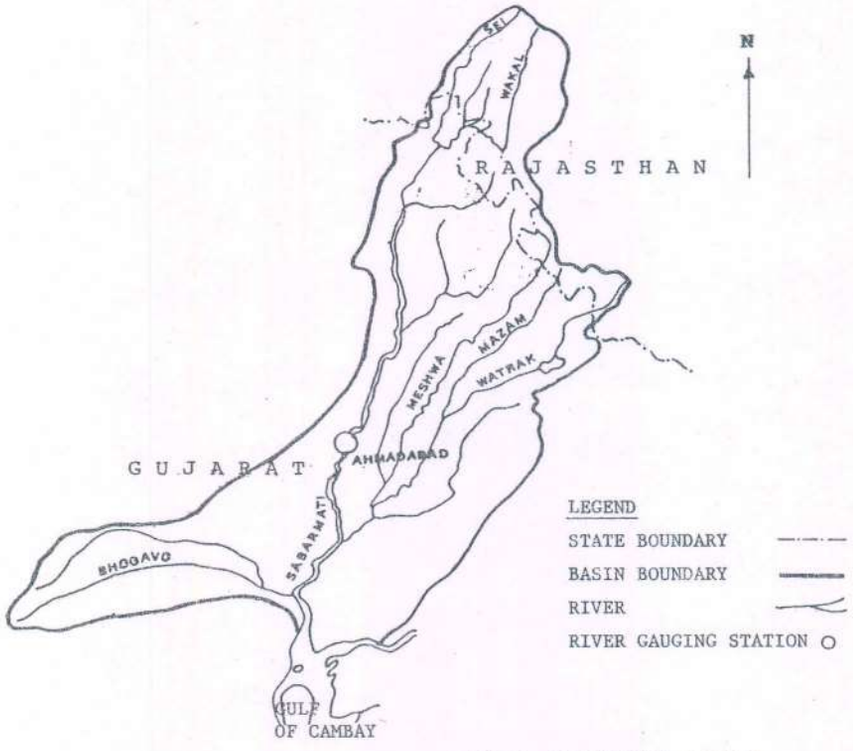


FIG. 7 SABARMATI BASIN

Table 9. Estimation of Water Resources Potential in Sabarmati Basin

Unit: Mm^3

Year	Flow at Ahmedabad	Withdrawals			Change in Storage(S)	Evap. loss	Natural Flow	
	R_O	R_{IR}	R_D	Export		E	A'abad	Basin
1960-61	-	-	-	-	-	-	684	1719
1961-62	-	-	-	-	-	-	1989	4250
1962-63	-	-	-	-	-	-	1092	2379
1963-64	-	-	-	-	-	-	1449	3405
1964-65	-	-	-	-	-	-	1194	2621
1965-66	-	-	-	-	-	-	837	1952
1966-67	-	-	-	-	-	-	898	2236
1967-68	-	-	-	-	-	-	1571	3465
1968-69	-	-	-	-	-	-	918	1883
1969-70	-	-	-	-	-	-	163*	2549
1970-71	-	-	-	-	-	-	1445	3324
1971-72	-	-	-	-	-	-	438*	2827
1972-73	276	11	-	-	-17	-	270*	1659
1973-74	1206	226	-	-	33	-	1465	5127
1974-75	208	13	-	-	30	-	251*	1607
1975-76	1924	104	-	-	16	-	2044	4198
1976-77	2113	106	-	-	-57	-	2162	5194
1977-78	2631	257	-	-	-226	-	2662	5436
1978-79	833	425	144	83	4	50	1539	3329
1979-80	259	429	144	66	129	50	1077	2516
1980-81	477	434	144	47	255	50	1407	3229
1981-82	403	409	144	47	-18	50	1035	3531
1982-83	365	420	144	47	-209	50	817	1579
1983-84	767	467	144	31	3	50	1462	3157
1984-85	770	473	144	8	34	50	1479	3205

Average Annual Flow = 3055
Ground water abstraction = 903
Return flow = 149
Average Annual natural flow in the basin = **3809 Mm^3**
75% Dependable Flow = 2094 + 1052
= **3146 Mm^3**

6.4 Methodology Adopted

The flow data available at Ahmedabad for the period from 1960-61 to 1984-85 with a gap of 4 years (1965-66 to 1968-69) have been used for estimating the water resources potential of Sabarmati basin. Rainfall-runoff regression analysis is used to estimate the flows in the missing years. Although Ahmedabad covers only 47% of the total basin area, for want of any other gauging sdtation downstream of Ahmedabad, there is no alternative available.

The observed flows at Ahmedabad were first corrected for upstream abstractions in order to work out the natural flows by using Equation-I (para 1.4).

Ground water withdrawal and return flows were not considered while working out the natural flows prior to rainfall-runoff regression analysis. These were taken care of while working out average annual flow in the basin.

The natural flows for the whole basin were worked out from the natural flows at Ahmedabad on area and catchment rainfall proportionate basis.

6.5 Data Used and Assumptions Made in Estimating Upstream Abastractions

Data on abstractions for irrigation (R_{IR}) have been obtained from the diversion data for major and medium projects in the basin. Abstractions from minor irrigation projects have been neglected since the data were not readily available. The ground water abstractions have been worked out on the basis of districtwise estimates of ground water draft worked out by Central Ground Water Board for the year 1983-84 and for 1967-68 as available in Irrigation Commission Report. Assuming linear variation, the annual yearwise draft for the period 1960-85 have been worked out and averaged to get average annual draft. Return flow is estimated to be 10% in case of irrigation withdrawals and 80% in case of domestic water supply.

6.6 Results of the Study

The estimation of average annual flow in Sabarmati basin is shown in Table 9. The average annual flow works out to 3809 Mm^3.

7. Mahi Basin

7.1 Basin Features

Mahi basin extends over an area of 34842 km^2. The Mahi river rises from the northern slopes of Vindhyas in Maadhya Pradesh at an elevation of about 500 m and flows for about 583 km before outfalling into the Arabian Sea from the Gulf of Cambay. The principal tributaries of the river are the Som, the Anas and the Panam.

7.2 Earlier Assessments

In 1949, basinwise assessment of the water resources of the country was made on the basis of Khosla's empirical formula. The annual runoff of Mahi basin has been assessed as 9313 Mm^3.

In 1960, the Central Water and Power Commission, while conducting irrigation potential studies, assessed the average annual runoff of Mahi basin as 11812 Mm^3.

7.3 Flow Data Availability

River flow data at Khanpur which covers 93.3% of the total catchment area of the basin are available for the period 1979 onwards. The map of Mahi basin showing Khanpur gauging station is given in Fig. 8.

7.4 Methodology Adopted

Since the flow record available is only for a period of six years, rainfall-runoff regression modelling has been resorted to in order to extend the flow record to a period of 20 years.

Before attempting rainfall-runoff regression analysis, the observed flows at Khanpur were corrected for the upstream abstractions for arriving at the natural flows by using Equation-I (para 1.4).

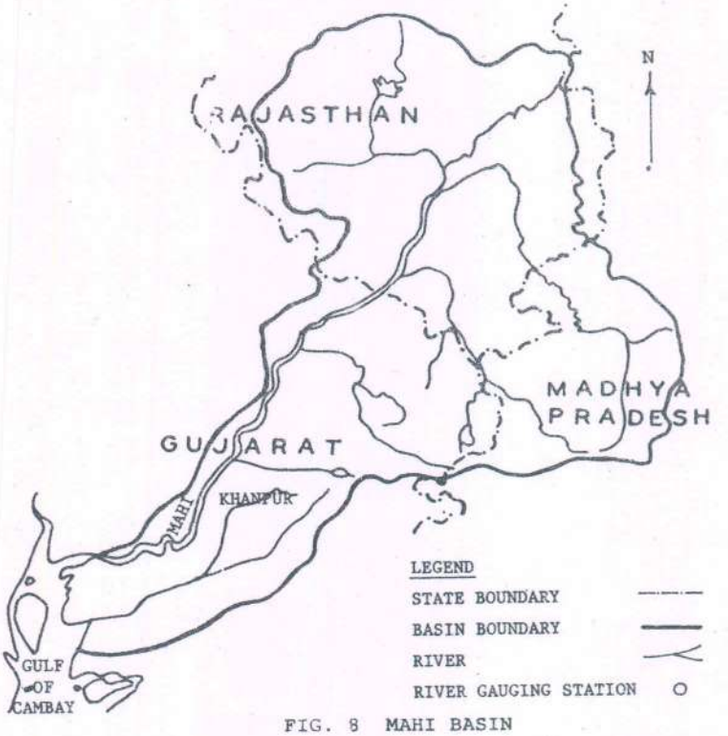


FIG. 8 MAHI BASIN

7.5 Data Used and Assumptions Made in Estimating Upstream Abstractions

The upstream abstractions for irrigation, industrial and domestic uses along with losses due to evaporation from the existing reservoirs were obtained from irrigation department.

Return flow has been assumed to be 10% in the case of irrigation and 80% in the case of industrial and domestic supplies.

The ground water withdrawal has been estimated assuming the linear variation between the years 1967-68 for which the estimate has been given by the Irrigation Commission of 1972 and 1983-84 for which an estimate has been made by the Central Ground Water Board.

Table 10. Estimation of Water Resources Potential in Mahi Basin

Unit : Mm^3

Year	Obs. Flow at Khanpur R_O	Withdrawals R_{IR}	R_D	R_{GW}	Return Flows R_{RI}	R_{RD}	Change in Storage S	Evap. loss E	Natural Flow at Khanpur
1965-66	-	-	-	-	-	-	-	-	3717
1966-67	-	-	-	-	-	-	-	-	3319
1967-68	-	-	-	-	-	-	-	-	9203
1968-69	-	-	-	-	-	-	-	-	6195
1969-70	-	-	-	-	-	-	-	-	8142
1970-71	-	-	-	-	-	-	-	-	12832
1971-72	-	-	-	-	-	-	-	-	7965
1972-73	-	-	-	-	-	-	-	-	3363
1973-74	-	-	-	-	-	-	-	-	28320
1974-75	-	-	-	-	-	-	-	-	3540
1975-76	-	-	-	-	-	-	-	-	9735
1976-77	-	-	-	-	-	-	-	-	30090
1977-78	-	-	-	-	-	-	-	-	17790
1978-79	-	-	-	-	-	-	-	-	12390
1979-80	3448	2548	173	949	255	139	-2	151	6873
1980-81	2531	2492	54	977	249	43	763	355	6880
1981-82	5394	2547	-	1004	255	-	635	454	9779
1982-83	1736	2665	-	1032	267	-	-515	389	5040
1983-84	4917	2513	14	1060	251	11	277	515	9034
1984-85	6032	3119	23	1087	312	18	1045	564	11540

Average Annual Flow at Khanpur = 10283
Average Annual Flow for the whole basin = 10283/0.933
= **11020 Mm^3**
75% Dependable Flow at Khanpur = 5330
75% Dependable Flow for the whole basin = **5713 Mm^3**

7.6 Results of the Study

The estimation of natural flows at Khanpur and the average annual runoff in Mahi basin is shown in Table 10. The water resources potential of the basin works out to 11020 Mm^3 which compares well with the earlier assessment of 11812 Mm^3.

8. Tapi Basin

8.1 Basin Features

Tapi basin extends over an area of 65145 km^2. Tapi river rises near Multai in the Betul district of Madhya Pradesh at an elevation of 752 m and flows for about 724 km before outfalling into the Arabian Sea through the Gulf of Cambay. Its principal tributaries are the Purna, the Girina, the Panjhra, the Vaghur, the Bori and the Aner.

8.2 Earlier Assessments

In 1949 when the assessment of the basinwise water resources of the country was worked out on the basis of Khosla's empirical formula, the annual runoff of the Tapi river system was estimated to be 9128 Mm^3.

In 1960 when the irrigation potential studies of the country were made by the Central Water and Power Commission, the total annual runoff of the Tapi river system was assessed at 19736 Mm^3, which was revisded to 18387 Mm^3 in the CWC study done subsequently based on 10 years of observed flows extended to 30 years by rainfall-runoff regression analysis. The flow data for the study were Kathore (State Govt. gauging station) on Tapi. Review of the study indicates that whereas the average annual flow at Sarangkheda (C.A. 58400 Km^2) in the upstream was 11.8 km^3, that at Kathore (C.A. 62750 km^2) was 18.0 km^3, an increase of 52.5% in runoff for an increase of only 7.4% in catchment area. This does not appear realistic.

8.3 Flow Data Availability

Ghala on Tapi is a CWC gauging station and covers 97% of the total catchment area of the basin. Observed flow data are available for the period 1978-79 to 1986-87 at this station. A map of Tapi basin showing the location of Ghala is given in Fig. 9.

8.4 Methodology Adopted

The observed flows at Ghala were corrected for the upstream abstractions to arrive at the natural flows by applying Equation-I (para 1.4).

FIG. 9 TAPI BASIN

Table 11. Calculation of Natural Flows at Ghala on Tapi

Unit : Mm^3

Year	Obs. Flow at Ghala R_O	Withdrawals R_{IR}	R_D	R_{GW}	Return Flows R_{RI}	R_{RD}	Change in Storage S	Evap. loss E	Natural Flow at Ghala*
1978-79	14368	4601	18	1612	460	14	35	631	20791(328)
1979-80	12469	4271	18	1629	427	15	534	614	19093(302)
1980-81	6419	4560	43	1646	456	35	1	548	12726(238)
1981-82	9401	4632	43	1663	463	34	446	607	16295(303)
1982-83	2693	3639	53	1681	364	42	23	388	8071(137)
1983-84	11354	3846	60	1697	385	48	263	499	17286(273)
1984-85	4055	4275	62	1715	428	49	103	530	10263(162)
1985-86	736	Abstractions assumed same as							6944(110)
1986-87	1913	in 1984-85							8121(128)

*Figures in brackets refer to natural flows in mm.

The natural flows derived at Ghala were extended for the period 1961-62 to 1973-74, making a total period of 22 years which is considered sufficient.

8.5 Data Used and Assumptions Made by Estimating Upstream Abstractions

Data on abstractions for Irrigation (R_{IR}) for 36 major, medium, minor and lift schemes are obtained from the records maintained by the irrigation project authorities.

Scheme for which water has been drawn for domestic and industrial purposes were identified and abstraction data were collected for the report under study.

The net ground water withdrawal in the year 1985 and the projected withdrawal for the year 1990 were collected by Central Ground Water Board. The net ground water withdrawals for the years 1975-1985 were computed based on these figures. The total districtwise figures were reduced as per the percentage area of districts falling in the basin.

Return flow from irrigation use has been assumed as 10% and that from domestic use as 80%.

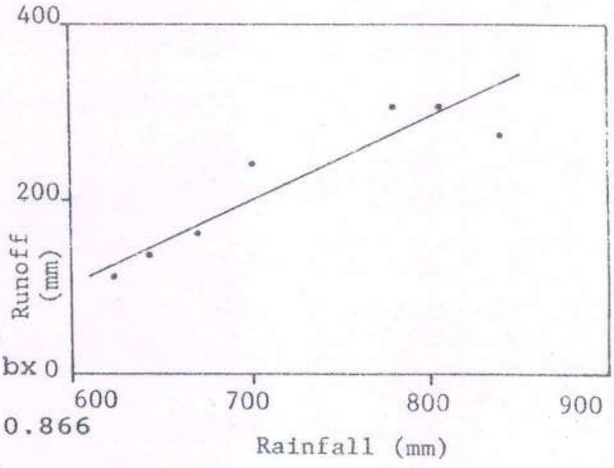
8.6 Results of the Study

The calculation of natural flows at Ghala is shown in Table 11. The rainfall-runoff regression analysis and the estimation of the average annual flows are given in Annex 8. The average annual flow in the basin works out to 14879 Mm^3.

Annex. 8

RAINFALL-RUNOFF REGRESSION ANALYSIS AT GHALA ON TAPI

Year	Rainfall (mm)	Runoff (mm)
1979-80	809	302
1980-81	699	238
1981-82	777	303
1982-83	643	137
1983-84	840	273
1984-85	669	162
1985-86	622	110



Type of Equation: $y = a + bx$

Constant a = -407.9 b = 0.866

R^2 = 0.846

Extension of Runoff Data at Ghala

Year	Rainfall	Estimated Runoff	Year	Rainfall	Estimated Runoff
1961-62	976	437	1968-69	625	133
1962-63	798	283	1969-70	739	232
1963-64	740	233	1970-71	898	370
1964-65	693	192	1971-72	514	37
1965-66	624	132	1972-73	577	92
1966-67	755	246	1973-74	916	385
1967-68	784	271	1978-79		328
			1986-87		128

Average Runoff = 228.4 mm = 14879 Mm^3

75% Dependable Runoff = 136 mm = 8860 Mm^3

9. West Flowing Rivers from Tapi to Kanyakumari

9.1 Basin Features

The composite basin comprising a large number of small west flowing rivers between Tapi and Kanyakumari extends over an area of 112117 km^2. There are as many as 99 rivers of which one in Tamil Nadu, 32 in Kerala, 10 in Karnataka, 3 in Goa, 11 in Maharashtra and 5 in Gujarat are the more important.

Although for convenience of basin management, this composite basin has been divided into two basin viz., (i) the basin comprising rivers between Tapi and Tadri and (ii) the basin comprising the rivers between Tadri and Kanyakumari, for the purpose of reassessment studies the basin has been considered as a single unit. Maps of the two composite basins are shown in Fig. 10 and 11.

9.2 Earlier Assessments

The first assessment of the water resources potential was made by the Irrigation Commission (1901-03) which estimated the annual runoff of this basin as 230,784 Mm^3 for a catchment area of 93,805 km^2.

In 1949, when the basinwise assessment of the water resources of the country was made on the basis of Khosla's empirical formula, the annual runoff of the west flowing rivers basin was estimated at 229,020 Mm^3.

In 1960, the CW&PC while conducting irrigation potential studies, assessed the total annual runoff of the basin as 217,894 Mm^3 based on the available observed data and Strange's Coefficients of rainfall and runoff.

Later in 1982 the committee for assessment of water resources of rivers flowing into Arabian Sea and its utilisation assessed the potential of the basin as 198,854 Mm^3.

9.3 Streamflow Data Availability

Out of the 99 rivers in the basin, observed stream flow records are available in respect of eight rivers viz., Purna, Vaitarana, Netravati, Varahi, Bharathapuzha, Karuvannu, Chalakudy and Periyar for periods ranging from 12 to 16 years (1970-71 to 1986-87). It has been observed that in Varahi river, the average runoff exceeds average rainfall and hence the observed flow data in Varahi have not been considered in the present study.

FIG. 10 WEST FLOWING RIVERS FROM TAPI TO TADRI

FIG. 11 WEST FLOWING RIVERS FROM TADRI TO KANYAKUMARI

9.4 Methodology Adopted

The observed flows in the seven rivers were corrected for the downstream abstractions to arrive at the natural flows by using Equation-I (para 1.4).

From yearly natural flows obtained as above, average annual flows were calculated for the seven rivers. These average annual flows were then plotted against average annual rainfall volumes. Assuming linear relationship between the streamflow and the precipitation, the flows in the remaining 92 rivers were assessed from this plot, knowing the catchment rainfalls for these rivers.

9.5 Results of the Study

The estimation of natural flows in the seven gauged rivers is shown in Tables 12 to 18. The plot of total precipitation Vs. average yield is shown in Fig. 12. Table 19 gives the estimation of average annual flows in the 99 rivers in the basin.

Table 12. Estimation of Average Annual Flow in Purna Basin

Unit : Mm^3

Year	Obs. flow at Mahuwa	Withdrawals			Return Flow	Evap. loss	Natural Flow
	R_O	R_{IR}	R_D	R_{GW}	R_{RD}	E	R_N
1971-72	874	0.7	38	3.0	30	0.7	886
1972-73	415	0.7	38	3.7	31	0.7	427
1973-74	1473	0.7	39	4.4	31	0.7	1487
1974-75	182	0.7	39	5.2	32	0.7	196
1975-76	1262	0.7	40	5.9	32	0.7	1277
1976-77	4306	0.7	41	6.6	33	0.7	4322
1977-78	2546	0.7	42	7.4	33	0.7	2564
1978-79	1150	0.7	42	8.1	34	0.7	1168
1979-80	1169	0.7	43	8.9	35	0.7	1187
1980-81	835	0.7	44	9.6	35	0.7	855
1981-82	1596	0.7	45	10.3	36	0.7	1617
1982-83	1053	0.7	46	11.1	37	0.7	1075
1983-84	1928	0.7	47	11.8	38	0.7	1950
1984-85	1249	0.7	48	12.5	38	0.7	1273
1985-86	999	0.7	49	13.3	39	0.7	1024
1986-87	514	0.7	50	14.0	40	0.7	539

Average Annual Flow at Mahuwa = 1365

Average Annual Flow for the whole basin = 1365 x 2322/1995 = **1589 Mm^3**

75% Dependable Flow at Mahuwa = 863

75% Dependable Flow for the whole basin = **1004 Mm^3**

Ratio of 75% flow to average flow = 0.6318

The total water resources potential of the basin works out to 200943 Mm^3, comprising 87411 Mm^3 for the basin containing the rivers from Tapi to Tadri and 113532 Mm^3 for the basin containing the rivers from Tadri to Kanyakumari.

Table 13. Estimation of Average Annual Flow in Vaitarna Basin

Unit : Mm^3

Year	Obs. Flow at Durvesh	Withdrawals			Return Flows		Evap. loss	Natural Flow
	R_O	R_{IR}	R_D	R_{GW}	R_{RI}	R_{RD}	E	R_N
1971-72	3606	53	89	3	5	71	27	3702
1972-73	1593	53	93	3	5	74	27	1690
1973-74	3954	53	96	4	5	77	27	4052
1974-75	2823	53	99	5	5	79	27	2923
1975-76	5027	53	102	6	5	82	27	5128
1976-77	7381	53	105	6	5	84	27	7483
1977-78	4093	53	107	7	5	86	27	4196
1978-79	2313	53	108	8	5	86	27	2418
1979-80	2995	53	109	8	5	87	27	3100
1980-81	3561	53	110	9	5	88	27	3667
1981-82	3240	53	112	10	5	90	27	3347
1982-83	1992	53	113	10	5	90	27	2100
1983-84	3646	53	114	11	5	91	27	3755
1984-85	2738	54	114	12	5	91	27	2849
1985-86	1521	61	114	12	6	91	27	1638
1986-87	1628	61	114	13	6	92	27	1745

Average Annual Flow at Durvesh = 3362

Average Annual Flow for the whole basin = 3362 x 3647/2019

= 6073 Mm^3

Diversion to Greater Bombay Water supply= 529 Mm^3

Total = 6602 Mm^3

75% Dependable Flow at Durvesh = 2180

75% Dependable Flow for the whole basin = 3938 + 529

= 4467 Mm^3

Ratio of 75% flow to average flow = 0.6766

Table 14. Estimation of Average Annual Flow in Netravathy Basin

Unit : Mm^3

Year	Obs. Flow at Bantwal	Withdrawals			Return Flows		Natural Flow
	R_O	R_{IR}	R_D	R_{GW}	R_{RI}	R_{RD}	R_N
1970-71	15925	42	49	10	4	39	15983
1971-72	14813	42	51	13	4	41	14874
1972-73	11726	42	53	16	4	42	11791
1973-74	11818	42	55	19	4	44	11886
1974-75	12617	42	57	22	4	46	12688
1975-76	15704	42	59	26	4	47	15780
1976-77	8334	42	61	29	4	48	8414
1977-78	12864	42	63	32	4	50	12947
1978-79	16195	42	65	35	4	52	16281
1979-80	10392	42	67	38	4	53	10482
1980-81	16585	42	69	41	4	55	16678
1981-82	14649	42	71	45	4	57	14746
1982-83	10662	42	72	48	4	58	10762
1983-84	11555	42	74	51	4	59	11659
1984-85	10821	42	76	54	4	61	10928
1985-86	9466	42	78	57	4	63	9576
1986-87	9732	42	80	61	4	64	9847

Average Annual Flow at Bantwal = 12666

Average Annual Flow for the whole basin = 12666 x 3222/3184

= 12817 Mm^3

75% Dependable Flow at Bantwal = 10622

75% Dependable Flow for the whole basin = 10749 Mm^3

Ratio of 75% flow to average flow = 0.8387

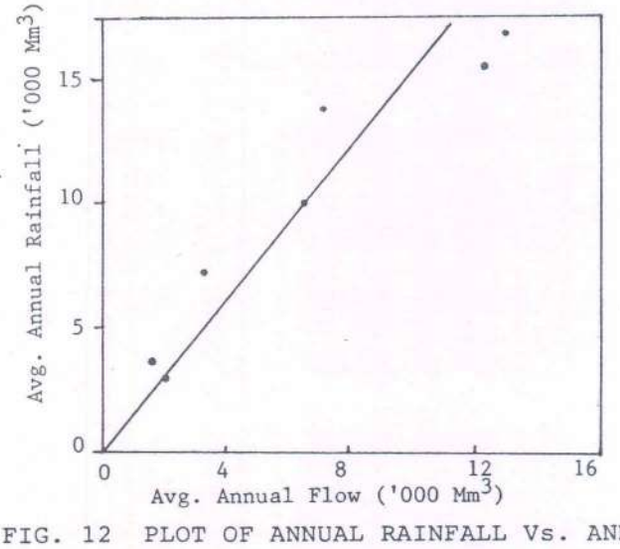


FIG. 12 PLOT OF ANNUAL RAINFALL Vs. ANNUAL FLOW

Table 15. Estimation of Average Annual Flow in Bharatpuzha River

Unit : Mm^3

Year	Obs. flow at Kumbidi	Withdrawals			Return Flows		Change in Storage	Evap. loss	Natural Flows	
	R_O	R_{IR}	R_D	R_{GW}	R_{RI}	R_{RD}	S	E	1*	2@
1954-55	-	-	-	-	-	-	-	-	-	9502
1955-56	-	-	-	-	-	-	-	-	-	5505
1956-57	-	-	-	-	-	-	-	-	-	6656
1957-58	-	-	-	-	-	-	-	-	-	6693
1958-59	-	-	-	-	-	-	-	-	-	7046
1959-60	-	-	-	-	-	-	-	-	-	8443
1960-61	-	-	-	-	-	-	-	-	-	7794
1961-62	-	-	-	-	-	-	-	-	-	9502
1962-63	-	-	-	-	-	-	-	-	-	7609
1963-64	-	-	-	-	-	-	-	-	-	6235
1964-65	-	-	-	-	-	-	-	-	-	8425
1965-66	-	-	-	-	-	-	-	-	-	5184
1966-67	-	-	-	-	-	-	-	-	-	6403
1967-68	5159	599	186	-	60	149	-31	27	5731	6160
1968-69	7585	508	190	15	51	152	-166	34	7963	8559
1969-70	6737	373	195	25	37	156	-91	26	7072	7602
1970-71	7942	654	200	44	65	160	23	28	8666	9315
1971-72	5384	582	205	56	58	164	31	27	6063	6517
1972-73	4697	681	211	73	68	169	-79	27	5373	5775
1973-74	4031	674	216	87	67	173	-5	27	4790	5149
1974-75	5903	789	223	102	79	178	-31	28	6757	7263
1975-76	7599	789	229	116	79	183	-31	28	8468	9102
1976-77	2568	831	237	131	83	190	-31	28	3491	3752
1977-78	5523	831	245	145	83	196	-31	28	6462	6946
1978-79	4226	620	258	160	62	206	-31	28	4993	5367
1979-80	5300	663	268	174	66	214	-45	28	6108	6565
1980-81	5796	687	280	189	69	224	-144	28	6543	7033
1981-82	6753	713	293	203	71	234	74	28	7759	8340
1982-83	3466	712	306	218	71	245	-58	28	4356	4682
1983-84	3783	776	319	232	78	255	18	28	4823	5184
1984-85	4028	792	335	247	79	268	72	28	5155	5541

*at Kumbidi @for Whole basin

Average Annual Flow in the basin = 6898 Mm^3
Annual Designed Export to Tamil Nadu = 155.7 Mm^3
Average Annual Flow = 7054 Mm^3

Table 16. Estimation of Average Annual Flow in Karuvannu River

Unit: Mm^3

Year	Observed Flow at Karuvannu R_O	Withdrawals R_{IR}	Withdrawals R_D	Withdrawals R_{GW}	Return Flows R_{RI}	Return Flows R_{RD}	Change in Storage S	Evap. loss E	Natural Flow at Karuvannu R_N
1964-65	1349	133	17	-	13	14	-12	6	1466
1965-66	528	74	17	-	7	14	-15	7	590
1966-67	900	132	18	-	13	14	-7	7	1023
1967-68	846	20	18	-	2	15	-1	6	872
1968-69	1504	22	19	3	2	15	-10	6	1527
1969-70	1138	22	19	6	2	15	-13	6	1161
1970-71	1222	24	20	8	2	16	23	6	1285
1971-72	1797	23	20	11	2	16	5	6	1844
1972-73	1151	22	20	14	2	16	-5	7	1191
1973-74	1229	21	21	17	2	16	-5	7	1272
1974-75	1809	22	21	19	2	17	-5	6	1853
1975-76	2363	23	21	22	2	17	-5	6	2411
1976-77	985	23	22	25	2	17	-5	6	1037
1977-78	1750	23	22	28	2	18	-5	6	1804
1978-79	1605	145	23	30	15	18	7	6	1783
1979-80	1389	152	23	33	15	18	6	6	1576
1980-81	2006	155	24	36	16	19	14	6	2206
1981-82	1488	145	25	39	15	20	24	6	1692
1982-83	1250	131	26	42	13	20	40	6	1462
1983-84	1535	139	26	44	14	21	3	6	1718
1984-85	1671	139	27	47	14	22	2	6	1856

Average Annual Flow at Karuvannu = 1506 Mm^3

Average Annual Flow for the whole basin = 1506 x 1054/832

= 1907 Mm^3

75% Dependable Flow at Karuvannu = 1176

75% Dependable Flow for the whole basin = 1490 Mm^3

Ratio of 75% flow to average flow = 0.7813

Table 17. Estimation of Average Annual Flow in Chalakudy River

Unit : Mm^3

Year	Observed Flow at Arangaly R_O	Withdrawals R_{IR}	R_D	R_{GW}	Return Flows R_{RI}	R_{RD}	S	E	Diver-sion	Natural Flow 1*	Natural Flow 2@
1964-65	-	-	-	-	-	-	-	-	-	-	4295
1965-66	-	-	-	-	-	-	-	-	-	-	1188
1966-67	-	-	-	-	-	-	-	-	-	-	2692
1967-68	-	-	-	-	-	-	-	-	-	-	2317
1968-69	-	-	-	-	-	-	-	-	-	-	4505
1969-70	-	-	-	-	-	-	-	-	-	-	3411
1970-71	1332	391	41	65	39	33	-141	24	337	1977	2510
1971-72	1919	494	43	87	49	35	-64	24	489	2908	3695
1972-73	824	540	45	108	54	36	-128	24	329	1652	2098
1973-74	1036	561	47	130	56	38	-12	24	288	1980	2514
1974-75	2068	473	50	152	47	40	-544	24	553	2689	3414
1975-76	2495	472	52	173	47	41	-1001	24	869	2996	3804
1976-77	1065	559	54	195	56	43	-550	24	441	1689	2145
1977-78	1973	535	56	217	54	44	-605	24	591	2693	3419
1978-79	2327	499	58	239	50	46	-679	24	594	2966	3766
1979-80	2364	483	60	260	48	48	-605	24	609	3099	3935
1980-81	2578	448	62	282	45	50	-808	24	916	3407	4326
1981-82	2912	294	64	304	29	51	-773	24	734	3479	4417
1982-83	1769	239	66	325	24	53	-436	24	470	2380	3022
1983-84	1736	150	67	347	15	54	-459	24	475	2271	2884
1984-85	1619	303	70	369	30	56	-608	24	645	2336	2966

1*at Arangaly 2@for whole basin

Average Annual Flow = 3206 Mm^3
Export to Periyar and Karuvannu = 93 Mm^3

Total Average Annual Flow = 3299 Mm^3
75% Dependable Flow = 2512 + 93

= 2605 Mm^3
Ratio of 75% flow to average flow = 0.7896

Table 18. Estimation of Average Annual Flow in Periyar

Unit : Mm^3

Year	Obs. flow at Neeles-waram R_O	Withdrawals R_{IR}	R_D	R_{GW}	Return Flows R_{RI}	R_{RD}	S	E	Diver-sion 1*	2@	Natural Flow R_N
1965-66	17060	646	99	0	65	79	14	39	418	-	18132
1966-67	5222	952	102	0	5	82	139	46	563	-	6937
1967-68	5973	837	103	0	84	82	-166	40	479	-	7100
1968-69	9594	955	106	6	96	85	-24	41	615	-	11112
1969-70	7585	914	108	12	91	86	133	40	438	-	9053
1970-71	8978	1013	110	18	101	88	-62	39	592	-	10499
1971-72	10129	1163	113	25	116	90	34	43	765	-	12066
1972-73	7331	945	115	31	95	92	-2	44	525	-	8802
1973-74	8083	1078	116	37	108	93	-303	43	592	-	9445
1974-75	10280	465	120	43	47	96	-10	46	538	-	11339
1975-76	11782	503	123	49	50	98	-9	42	718	-	13060
1976-77	4621	503	127	55	50	101	-811	97	322	947	5710
1977-78	5908	503	138	62	50	111	-2099	97	716	1369	6533
1978-79	8161	376	137	68	38	110	-1590	97	605	1672	9378
1979-80	7700	536	130	74	54	104	-1416	97	649	1446	9058
1980-81	8283	555	135	80	56	108	-1945	97	587	1777	9405
1981-82	9659	458	128	86	46	102	-1191	97	761	1606	11456
1982-83	3824	396	131	92	40	105	-1831	97	399	1368	4331
1983-84	5151	472	140	99	47	112	-667	97	594	993	6720
1984-85	6305	472	141	105	47	109	-1359	97	718	1395	7718

*to Tamil Nadu 2@to Muvattupuzha

Average Annual Flow at Neeleswaram = 3206

Average Annual Flow for the whole basin = 9377 x 5398/4234

= 11955 Mm^3

Annual Diversion to Tamil Nadu = 255 Mm^3

Total Average Annual Flow = 12210 Mm^3

75% Dependable Flow at Neeleswaram = 6815

75% Dependable Flow for the whole basin = 8689 + 255

= 8944 Mm^3

Ratio of 75% flow to average flow = 0.7325

Table 19. Estimation of Average Annual Flows in River Systems from Tapi to Kanyakumari

S.No.	Basin	Average Annual Rainfall (mm)	Catchment Area (sq.km.)	Total Rainfall Volume (Mm^3)	Average Annual Flow (Mm^3)
1	2	3	4	5	6
	I. River Systems from Tapi to Tadri				
1	Purna	1521	2322	3531.8	1587
2	Ambica	1999	2715	5427.3	3528
3	Damanganga	1750	1382	2418.5	1572
4	Auranga	2200	172	378.4	246
5	Par	2076	688	1428.3	942
6	Varoli (Jogni)	2200	238	523.6	340
7	Free catchment between Varoti & Vaitarna	2000	805	1610.0	1047
8	Vaitarna	2794	3647	10189.7	6700
9	Ulhas	3556	3804	13527.0	8793
10	Free catchment between Ulhas & Parval	2200	266	585.2	380
11	Parvel	2962	803	2378.5	1546
12	Patalganga	3365.5	940	3163.6	2056
13	Amba	3050	740	2257.0	1467
14	Kundalika	3143	825	2593.0	1685
15	Mandal Jansi	2655	1505	3995.8	2597
16	Savitri	3492.5	2889	10089.8	6558
17	Bharaja	3472.5	283	982.7	639
18	Ilne	3200	74	236.8	154
19	Jog	3511	385	1351.7	879
20	Vashishti	3391	2238	7589.1	4933
21	Free catchment between Vashisti & Shastri	3000	225	675.0	439
22	Shastri	3260	2174	7087.2	4607
23	Free catchment between Shastri & Kajvi	2900	279	809.1	526
24	Kajvi	2550	762	1943.1	1263
25	Free catchment between Kajvi & Machkundi	3000	94	282.0	183
26	Machkundi	2150	833	1791.0	1164
27	KOdavali (Rajapur)	3216	665	2138.6	1390
28	Vaghotan	2500	903	2257.5	1467
29	Kharda (Deogarh)	2500	455	1137.5	739
30	Piyali	3000	86	258.0	168
31	Achra	3207	297	952.5	619
32	Gad	2600	891	2316.6	1506
33	Karli	2750	753	2070.8	1346
34	Free catchment between Karli & Talwada	3000	246	738.0	480
35	Talvada	3225	137	441.8	287

1	2	3	4	5	6
36	Free catchment between Talwada & Terekhol	3125	96	300.0	195
37	Terekhol	3578	530	1896.3	1233
38	Chapora (Tillari)	3578	530	1896.3	1233
39	Mandvi	3134	2032	6368.3	4139
40	Rachol	2959	772	2284.3	1485
41	Sal	2800	344	963.2	626
42	Free catchment between Sal & Kalinadi	2900	446	1293.4	841
43	Kalinadi	2436	4188	10202.0	6631
44	Gangavali(Bedthi)	2039	3574	7287.4	4737
45	Agnashini (Tadri)	2956	1330	3931.5	2556
			Sub-total		87411

II. River Systems from Tadri to Kanyakumari

46	Sharavathy	3169	3592	11383.0	7399
47	Free catchment between Banduruholi & Sharavathy				
48	Banduruholi	4000	1041	4164.0	2707
49	Free catchment between Banduruholi & Chakra				
50	Chakra	4082	336	1371.6	892
51	Haladi (Varahi)	4587	759	3481.5	2263
52	Sita				
53	Swarna				
54	Free catchment between Swarna & Mulki				
55	Mulki	3800	3067	11654.6	7576
56	Free catchment between Mulki & Gurpur				
57	Gurpur				
58	Netravathy	5363	3222	17279.6	12813
59	Manjeshwar	3600	90	324.0	210
60	Uppala	3600	250	900.0	585
61	Shiruja	3800	587	2230.6	1450
62	Morgal	3800	132	501.6	326
63	Chandragiri	3809	1406	5355.5	3481
64	Chittari	3600	145	522.0	339
65	Nileswar	3700	190	703.0	457
66	Kariangode	4000	561	2244.0	1459
67	Kaviyi	3600	143	514.8	335
68	Peruvamba	3700	300	1110.0	722
69	Ramapuram	3600	52	187.2	122
70	Kuppam	3900	539	2102.1	1366
71	Vallapattanam	3735	1867	6973.2	4533
72	Anjarakadi	4000	412	1648.0	1071
73	Tellicherry	3900	132	514.8	335
74	Mahe	4000	394	1576.0	1024
75	Kuttiadi	3900	588	2293.2	1478

1	2	3	4	5	6
76	Korapuzha	3800	624	2371.2	1541
77	Kallai	3200	96	307.2	200
78	Chalajur	3201	2923	9356.5	6082
79	Kadalusdi	3201	1122	3591.5	2335
80	Terurpuzha	2800	117	327.6	213
81	Bharatapuzha	2276	6186	14079.3	7054
82	Keechari	2800	401	1122.8	730
83	Puzhalkal	2800	234	655.2	426
84	Karuvarnu	2800	1054	2951.2	1900
85	Chalakudy	4290	1704	7310.2	3277
86	Periyar	2919	5398	15756.8	12210
87	Moovattupuzha	3385	2004	6783.5	4409
88	Meenachil	3400	1272	4324.8	2811
89	Manimala	3800	847	3218.6	2092
90	Pamba	3600	2235	8046.0	5230
91	Achenkovil	2895	1484	4296.2	2793
92	Pallickal	2800	220	616.0	400
93	Kallada	2800	1699	4757.2	3092
94	Ithikkara	2600	642	1669.2	1085
95	Ayroor	2300	66	151.8	99
96	Vamanapuram	2400	687	1648.8	1072
97	Mamom	2000	114	228.0	148
98	Karamana	2000	703	1406.0	914
99	Neyyar	2000	497	994.0	646
				Sub-total	113532
				Total	**200943**

Adopting an average ratio of 0.7512 of 75% flow to average flow, 75% Dependable Flow = 150948 Mm^3

75% Dependable Flow for the basin from Tapi to Tadri = 65663 Mm^3

75% Dependable Flow for the basin from Tadri to Kanyakumari = 85285 Mm^3

10. East Flowing Rivers Between Mahanadi and Pennar

10.1 Basin Features

This composite basin extends over an area of 86643 km^2, comprising 49685 km^2 area of the river system between Mahanadi and Godavari and 24669 km^2 area of the river systems between Krishna and Pennar. In addition there is also a small area between Godavari and Krishna drained mainly by the small stream of Palleru. This minor portion of the basin has an area of about 12289 km^2. A map of the basin is given in Fig. 13 .

The various river systems in the basin from north to south are: (1) six small streams between Mahanadi and Rushikulya draining into Chilka Lake, (2) Rushikulya, (3)

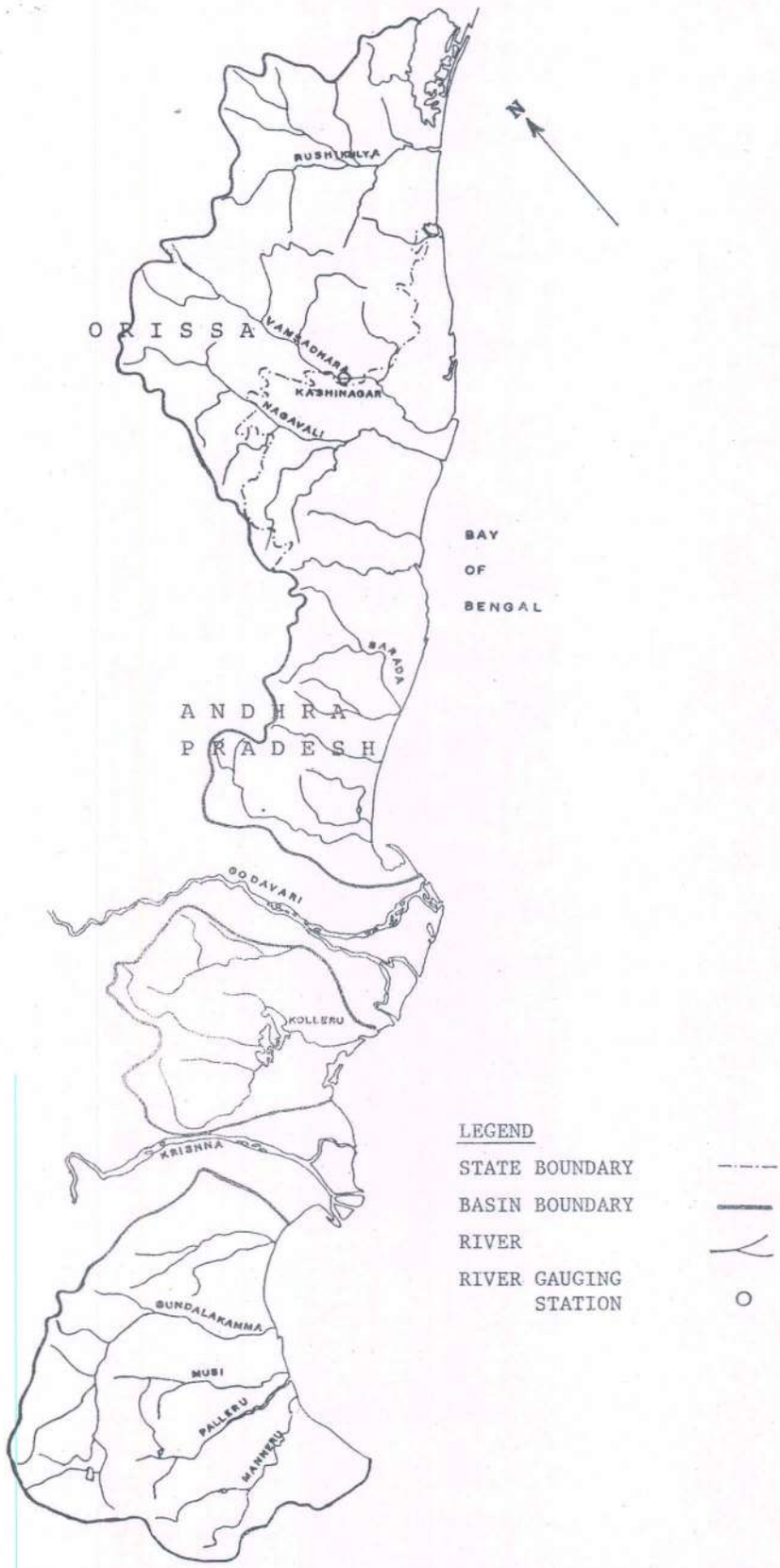


FIG. 13 EAST FLOWING RIVERS BETWEEN MAHANADI AND PENNAR

small stream between Rushikulya and Bahuda, (4) Bahuda, (5) five small streams between Bahuda and Vamsadhara, (6) Vamsadhara, (7) Nagavali, (8) eight small streams betwen Nagavali and Sarada, (9) Sarada, (10) Varaha, (11) Tandava, (12) Eluru, (13) small stream between the Eluru and Godavari, (14) Kolleru, (15) three small streams upto Vogarivagu and Gundlakamma, (18) Gundlakamma, (19) a small stream between Gundlakamma and Musi, (20) Musi, (21) Paleru, (22) Manneru, and (23) a small stream between the Manneru and the Pennar.

10.2 Earlier Assessments

When the basinwise assessment of the water resources of the country was made in 1949 on the basis of Khosla's formula, the annual runoff of the basin of the east flowing rivers between Mahanadi and the Godavari was estimated as 16072 Mm^3. Similarly the annual runoff of the basin of the east flowing rivers between Krishna and Pennar has been estimated as 1554 Mm^3.

In 1960 the Central Water and Power Commission, while conducting irrigation potential study, assessed the total annual runoff of the rivers between Mahanadi and the Godavari as 17210 Mm^3 based on the available observed data and Strange's Rainfall-Runoff Coefficients.

In CWC Publication No.30/88 "Water Resources of India" the average annual runoff in the east flowing rivers between Mahanadi and Pennar has been indicated as 16948 Mm^3 reportedly based on Khosla's formula.

10.3 Flow Fata Availability

Central Water Commission is maintaining a gauging station at Kashinagar on the Vamsadhara river (catchment area 10830 km^2). The gauging station has a catchment area of 8096 km^2. Observed flow data are available from 1973-74 at Kashinagar.

10.4 Methodology Adopted

For the purpose of assessment of water resources potential, this composite basin is divided into two parts: (i) the portion of the basin comprising east flowing rivers between Mahanadi and Godavari and (ii) the portion of the basin comprising east flowing rivers between Godavari and Krishna and between Krishna and Pennar. The area of the first part is 49685 km^2 (57.3% of total) and that of the second part is 36958 km^2(42.7% of total).

The assessment of water potential for the nmorthern part of the basin is based on the assessment made for the Vamsadhara basin, which covers about 22% of the area of this part. Since observed discharge data at Kashinagar on Vamsadhara are available only for 14 years (1973-74 to 1986-87)

the river flows were estimated for the years 1960-61 to 1972-73 to get flow data for a total of 27 years. The extension of flow record was done on the basis of rainfall-runoff regression analysis. Prior to attempting rainfall-runoff regression analysis, the observed flows at Kashinagar were corrected for upstream abstractions to arrive at natural flows by using Equation-I (para 1.4).

Rainfall records for 19 stations in and around Kashinagar catchment were made use of for rainfall-runoff regression analysis. The regression analysis was done on the basis of monsoon rainfall and monsoon runoff. From the 27 years of monsoon flows at Kashinagar, the average monsoon flow was calculated.

The average annual flow for the entire northern part of the basin was estimated by area and normal annual rainfall proportion. The normal annual rainfall for the entire part was estimated from the normal annual rainfall values for the districts falling within the basin area.

In the southern part of the basin comprising rivers flowing between Godavari and Krishna and between Krishna and Pennar, due to lack of observed flow data, the assessment was based on the studies made in respect of the adjoining Pennar basin. At Sangam anicut on Pennar basin, the average annual flow has been estimated to be 5749 Mm^3. The normal annual rainfall for this catchment was worked out on the basis of normal annual rainfall values available for the sub-basins of Pennar. The average annual flow in the southern part of the composite basins was estimated by areas as well as normal annual rainfall proportion basis.

10.5 Data Used and Assumptions Made

Most of rainfall and runoff data used in this study were taken from the report of N.W.D.A on Vamsadhara basin. The upstream abstraction for irrigation has been worked out from the areas irrigated by canals, tanks and other sources assuming a delta of 0.86 m in respect of area irrigated by canals, 0.70m in respect of area irrigated by tanks and 0.45 m in respect of area irrigated by other sources. Yearwise data on area irrigated by different sources had been obtained by NWDA from the Bureau of Economic and Statistics. Abstractions for other uses have been assumed to be negligible.

The normal annual rainfall values in the districts falling in the basin were taken from the Report of the Irrigation Commission (1972).

10.6 Results of the Study

The estimation of natural flows at Kashinagar for the period 1973-74 to 1986-87 is shown in Table 20. Rainfall-

runoff regression analysis is indicated in Annex. 10.1. The flow series at Kashinagar for the period 1960-61 to 1986-87 is shown in Table 21. The average monsoon flow at Kashinagar works out to 22155 Mm^3. The corresponding average monsoon rainfall is 981 mm.

The calculations of average annual rainfall for the whole of northern part of the basin from districtwise rainfall values is shown in Annex. 10.2.

The average annual flow in the northern part of the basin works out to 17087 Mm^3.

For the southern part of the basin, the average annual rainfall calculated on the basis of normal annual rainfalls in the concerned districts is 843 mm. The average annual flow at Sangam anicut in Pennar basin is 5749 Mm^3. The corresponding average annual rainfall calculated from the sub-basinwise normal rainfall values is 656 mm. The average annual flow in the southern part of the basin works out to 5433 Mm^3.

The water resources potential of the whole of the basin works out to 22520 Mm^3.

The earlier assessment based on Khosla's formula was 16948 Mm^3.

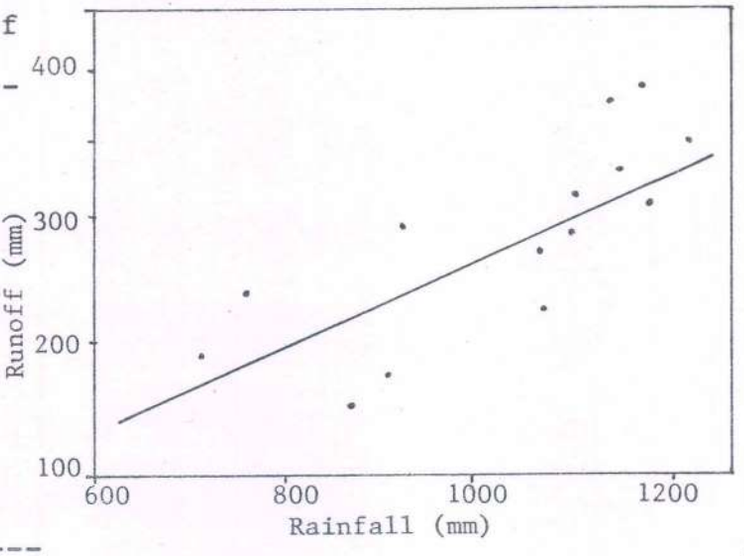
Table 20. Estimation of Natural Flow at Kashinagar on Vamsadhara

Year	Obs. Flow at Karim-nagar	u/s Abstractions for Irrigation						Return Flow	Natural Flow at Kashi-nagar
		By Canals		By Tanks		Other Sources			
	(Mm^3)	Area (ha)	Abs. (Mm^3)	Area (ha)	Abs. (Mm^3)	Area (ha)	Abs. (Mm^3)	(Mm^3)	(Mm^3/mm)
1973-74	1312	624	5.4	31849	223	486	2.2	17.9	1543/191
1974-75	994	736	6.3	32899	230	351	1.6	18.4	1233/152
1975-76	2934	720	6.2	33895	237	482	2.2	18.7	3180/393
1976-77	2587	1217	10.5	36696	257	599	2.7	21.8	2854/353
1977-78	1668	1223	10.5	36414	255	233	1.1	21.5	1932/239
1978-79	2814	1155	9.9	40135	281	199	0.9	22.8	3102/383
1979-80	2262	415	3.6	37469	262	290	1.3	20.0	2529/312
1980-81	2380	198	1.7	38780	271	300	1.4	20.5	2654/328
1981-82	2061	211	1.8	39256	274	359	1.6	20.8	2338/289
1982-83	1882	254	2.2	39708	278	337	1.5	21.0	2162/267
1983-84	2192	258	2.6	39906	278	342	1.7	21.8	2472/305
1984-85	1176	258	2.6	39800	278	340	1.6	20.2	1426/176
1985-86	1568	258	2.6	38760	272	338	1.6	21.5	1842/227
1986-87	2015	258	2.6	39780	278	336	1.6	21.6	2294/283

Annex 10.1

RAINFALL-RUNOFF REGRESSION ANALYSIS AT KASHINAGAR ON VAMSADHARA

Year	Rainfall (mm)	Runoff (mm)
1973	709	191
1974	864	152
1975	1157	393
1976	1208	353
1977	758	239
1978	1126	383
1979	1091	312
1980	1136	328
1981	917	289
1982	1056	267
1983	1165	305
1984	902	176
1985	1061	227
1986	1091	283



Regression Output:
Type of Equation: $y = ax + b$
Constant $b = -91.2$
$a = 0.363$
$R^2 = 0.596$

Table 21. Monsoon Flow Series at Kashinagar

Year	Rainfall	Estimated Runoff (mm)	Year	Runoff (mm)
1960-61	1121	316	1973-74	191
1961-62	977	264	1974-75	152
1962-63	1097	307	1975-76	393
1963-64	1063	295	1976-77	353
1964-65	1111	313	1977-78	239
1965-66	712	168	1978-79	383
1966-67	937	249	1979-80	312
1967-68	1052	291	1980-81	328
1968-69	1125	318	1981-82	289
1969-70	909	239	1982-83	267
1970-71	1033	284	1983-84	305
1971-72	910	239	1984-85	176
1972-73	811	203	1985-86	227
			1986-87	283

Average Monsoon Flow at Kashinagar = 273.6 mm
Average Monsoon Rainfall = 981 mm
75% Dependable Flow at kashinagar = 240 mm

Annex 10.2

Calculation of Average Annual Flow in Northern Part of Basin

S.NO.	District Name	Normal Annual Rainfall (mm)	Percentage of area falling in basin
1.	Srikakulam	1117	21.0
2.	Vishakapatnam	1042	21.6
3.	East Godavari	1138	9.7
4.	Puri	1449	0.4
5.	Ganjam	1296	27.4
6.	Koraput	1522	13.9
7.	Baudh	1597	3.9
8.	Kalahandi	1378	2.1

Average annual rainfall of entire northern part of basin = 1233.7 mm

Average annual flow = 273.6 x 1233.7/981

= 343.9 mm

Catchment area = 49865 km^2

Average annual flow = $\frac{343.9 \times 49865 \times 10^6}{1000 \times 10^6}$

= 17087 Mm^3

75% Dependable Flow = 14989 Mm^3

11. East Flowing Rivers Between Pennar & Kanyakumari

11.1 Basin Features

This composite basin extends over an area of 100139 Km^2 comprising 65049 km^2 area of the river systems between Pennar and Cauvery and 35090 km^2 area of the river systems between Cauvery and Kanyakumari. A map of the basin is at Fig. 14.

The various important river systems in the basin from north to south are:

(a) Between Pennar and Cauvery: (1) Kunleru, (2) Swarnamukhi, (3) Araniar, (4) Kotalaiyar, (5) Cooum, (6) Adayar, (7) Palar, (8) Gnigu, (9) Ponnaiyar and (10) Vellar.

(b) Between Cauvery and Kanyakumari: (1) Vellar, (2) Varshalu, (3) Vaigai, (4) Gundar, (5) Vaippar, and (6) Tambraparni.

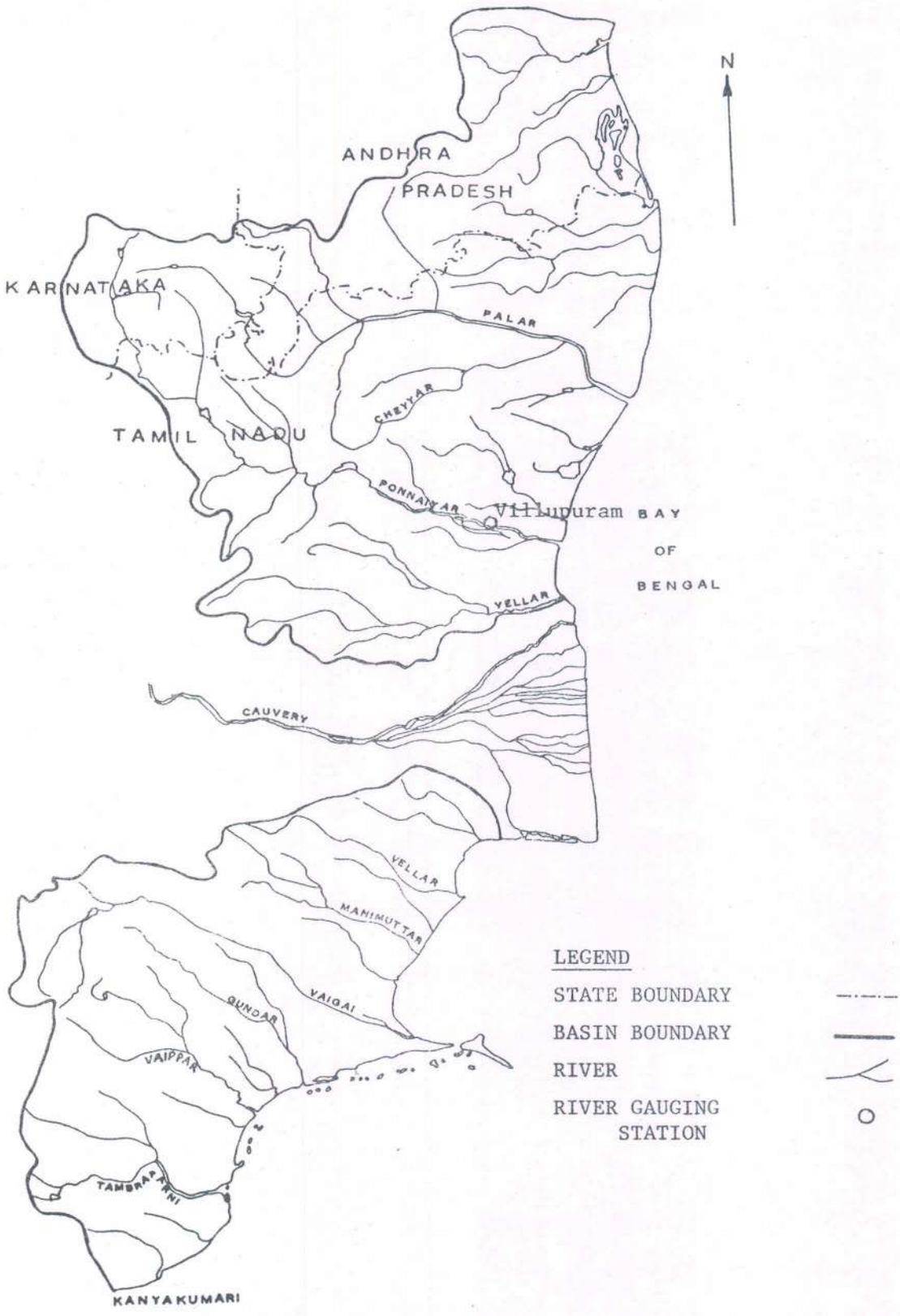


FIG. 14 EAST FLOWING RIVERS BETWEEN PENNAR & KANYAKUMARI

11.2 Methodology Adopted

For the purpose of assessment study, the basin is divided into two parts viz., the northern part between Pennar and Cauvery and the southern part between Cauvery and Kanyakumari.

For most of the river systems in the southern part of the basin, assessment studies have very recently been carried out by NWDA. The details of the studies are available in reports prepared by NWDA. The studies have been done in respect of (1) Vaigai, (2) Area between Vaigai and Vaippar, (3) Vaippar and (4) Area between Vaippar and Kanyakumari. In these studies available runoff data in the river system have been used resorting to extension of runoff data adopting rainfall-runoff regression analysis, wherever observed runoff data were found to be inadequate. Table 22 indicates the basic data used and the methodology adopted for the assessment of water potential in the above four river systems. For the purpose of the present reassessment

Table 22. Methodology followed by NWDA for assessment of water potential of rivers between Cauvery and Kanyakumari

Sl. No.	River System	Flow data availability	Methodology Followed	Water Potential (Mm^3)
1.	Vaigai	1972-73 to 1982-83 at Paramakudy on Vaigai	Flow data extended to 83 years by rainfall-runoff regression analysis	799
2.	Between Vaigai and Vaippar	Nil	Rainfall-runoff regression equation developed at Srivaikuntam weir for (4) below used for estimating flow series.	471
3.	Vaippar	Nil	-do-	452
4.	Between Vaippar and Kanyakumari	1940-41 to 1982-83 at Srivaikuntam anicut across Tambraparni	Flow data for the period 1972-73 to 1982-83 used for rainfall-runoff regression analysis and annual flows for the entire river systems worked out based on the regression equation.	4147

study, it is proposed to adopt the results of the studies carried out by NWDA. For the small portion of the southern part of the basin lying between Cauvery and Vaigai (catchment area 5958 km^2) for which study is yet to be completed by NWDA, the water potential is deducted from the potential assessed for Vaigai basin on catchment area proportionate basis. Estimation of the water potential of the southern part on the above lines is indicated in Annex. 11.1.

No studies have so far been completed by NWDA for any of the river systems in the northern part of the basin between Pennar and Cauvery. Hence fresh study was carried out for this part of the basin.

11.3 Assessment for the Northern Part of the Basin

11.3.1 Flow Data Availability

Among the river systems in the northern part of the basin, Ponnaiyar with a catchment area of 15865 km^2 is the most important river system. Observed flow data are available at Villupuram on Ponnaiyar for 1972-73 to 1987-88 (16 years). Villupuram has a catchment area of 12900 km^2. The length of observed flow record was considered adequate for the purpose of water potential assessment. No attempt was, therefore, made for extension of the available flow record.

11.3.2 Methodology Followed

The observed flows at Villupuram were corrected for upstream abstractions to obtain natural flows by applying Equation-I (para 1.4).

11.3.3 Data Used and Assumptions made in Estimating Upstream Abstractions

Withdrawals for irrigation (R_{IR}) were estimated based on the area served by the Krishnagiri and Sathanur reservoirs and other diversion structures adopting an average duty of 0.83 m on the basis of studies carried out by the Institute of Water Studies, Madras.

Average ground water abstractions has been taken from the report of the Institute of Water Studies, Madras.

Data on evaporation loss from reservoirs were obtained from project authorities.

Return flow from irrigation use has been assumed to be 10% of the withdrawal.

Annex 11.1

Estimation of Water Potential in the entire southern part of the basin

Water potential of Vaigai basin with catchment area 7741 km^2 = 799 Mm^3

Water Potential of the river systems between Cauvery and vaigai (C.A. = 5958 km^2) = 799 x 5958/7741 = 615 Mm^3

Water Potential of entire southern part = 700 + 471 + 452 + 4147 + 615
= 6484 Mm^3

75% Dependable Flow = 609 + 425 + 401 + 3242 + 609x5958/7741

= 5146 Mm^3

Table 23. Estimation of Water Resources Potential of Ponnaiyar Basin

Unit : Mm^3

Year	Obs. flow at Villupuram	Withdrawals		Return Flow	Evap. loss	Natural Flow
	R_O	R_{IR}	R_{GW}	R_{RI}	E	R_N
1972-73	437	393	1342	39	35	2168
1973-74	0	393	1342	39	35	1731
1974-75	43	393	1342	39	35	1774
1975-76	263	393	1342	39	35	1994
1976-77	44	393	1342	39	35	1775
1977-78	1127	393	1342	39	35	2858
1978-79	178	393	1342	39	35	1909
1979-80	1066	393	1342	39	35	2797
1980-81	0	393	1342	39	35	1731
1981-82	399	393	1342	39	35	2130
1982-83	0	393	1342	39	35	1731
1983-84	212	393	1342	39	35	1943
1984-85	54	393	1342	39	35	1785
1985-86	92	393	1342	39	35	1823
1986-87	36	393	1342	39	35	1767
1987-88	2	393	1342	39	35	1733

Average Annual Flow at Villupuram = 10283

Average Annual Flow for the entire northern part of the basin = 1978 x 65049/12900

= 9974 Mm^3

75% Dependable Flow at Villupuram = 1742

75% Dependable Flow for the whole basin = 8784 Mm^3

11.3.4 Results of the Study

The estimation of annual flows at Villupuram on Ponnaiyar is indicated in Table 23. The average annual flow works out to 1978 Mm^3. The average annual flow for the entire northern part works out to 9974 Mm^3.

11.4 Water Potential of the Entire Basin

The water resources potential of the entire basin comprising the east flowing rivers between Pennar and Kanyakumari is 16458 Mm^3. This compares well with the earlier assessment of 17725 Mm^3 based on Khosla's formula.

SECTION III

ASSESSMENT OF REPLENISHABLE GROUND WATER POTENTIAL

1. Background

A scientific assessment of the ground water potential of the country was not undertaken until a few years ago. The ground water mapping and ground water exploration were sporadic and limited to specific areas. The Geological Survey of India (GSI) was initially responsible for systematic investigation and mapping of ground water in the country as a whole.

In 1968, the Central Working Group constituted for working out the Fourth Plan proposals on Minor Irrigation estimated the ground water potential state-wise assuming certain percentages of infiltration rates for different rock types/formations and taking also into account seepage from irrigation canals and distributaries. The estimation thus made for the annual replenishable ground water recharge was of the order of 268 km^3 for the whole country. However, the Task Force on Ground Water Resources of the Planning Commission in its report of 1971 suggested a figure of 204 km^3 for the long term potential for development and 263 km^3 as the ultimate potential in view of the anticipated induced recharge from the surface water development and soil conservation measures. The Task Force also suggested that the Central Ground Water Board should take initiative to further refine the methodology for estimation of ground water potential in consultation with the States.

In 1972, guidelines for approximate evaluation of ground water potential was formulated and circulated by the Ministry of Agriculture to all concerned. The guidelines specified the norms for ground water recharge from rainfall for different areas (alluvial, hard rock and project areas) and recharge from other sources like seepage from canals, storage tanks etc.

In 1977, a high level Committee known as "Ground Water Over Exploitation Committee" was constituted by the NABARD (National Bank for Agriculture and Rural Development) to suggest a unified methodology for assessing the ground water on scientific lines. The Committee in its report of 1979 recommended norms for ground water potential evaluation. In addition to the norms, the Committee also suggested the water table fluctuation and specific yield approach wherever sufficient data were available and also gave the specific yield values for different types of geological formations. The Committee had, however, recommended that the methodology may be revised later on to make it more scientific as and when more data are available.

Since the preparation of the Over Exploitation Committee Report in 1979, considerable work had been carried out by the Central Ground Water Board, State Ground Water Organisations, Universities and Research Institutes in the coun-

try for updating the methodology for ground water resources evaluation suited to the hydro-geological conditions, existing in different parts of the country.

In 1982, the Government of India constituted a Committee known as "Ground Water Estimation Committee" in order to consider the methodologies suggested by the Over Exploitation Commitee and Recommended a suitable methodology for adoption.

2. Methodology Recommended by Ground Water Estimation Committee[25]

The Ground Water Estimation Committee recommended ground water level fluctuation and specific yield approach to be followed for the estimation of the recharge. The Committee suggested to have one hydrograph station for every 100 km^2 area and monitoring of ground water regime six times in a year. Specific yield values for different geological formations were also suggestd. Only in places where adequate ground water fluctuation data were not available, adhoc norms given by the Committee for rainfall infiltration method were to be followed.

The specific yield values suggested are:

(i)	Sandy alluvial area	12-18%
(ii)	Vallley fills	10-14%
(iii)	Silty/clayey alluvial area	5-12%
(iv)	Granites	2-4%
(v)	Basalts	1-3%
(vi)	Laterite	2-4%
(vii)	Weathered phyllite, shales schists and associated rocks	1-3%
(viii)	Sandstone	1-8%
(ix)	Limestone	3%
(x)	Highly karstified limestone	7%

Adhoc norms specified for rainfall infiltration are as follows:

(1)	Recharge from rainfall	Percent of normal rainfall
	(a) Alluvial areas in sandy areas. In areas with higher clay content	20-25
	(b) Semi-consolidated sandstones friable highly porous	10-20
	(c) Hard rock areas	
	(i) Granitic terrain	
	(a) Weathered and fractured	10-15
	(b) Unweathered	5-10

(ii) Basaltic terrain
  (a) Vesicular and jointed 10-15
  (b) Weathered 4-10
(iii) Phyllites, limestones, sand stones, quartzites, shales etc. 3-10

(2) Recharge Due to Seepage from Unlined Canals

(a) For unlined canals in normal type of soil with some clay content along with sand 15-20 ha.m./day/10^6 sq.m.

(b) For unlined canals in sandy soils 25 to 30 ha.m./day/10^6 sq.m. of wetted areas.

(c) For lined canals the seepage losses may be taken as 20 per cent of the above values.

(3) Return seepage from irrigation fields

(a) Irrigation by surface water sources - 35% of water delivered at the outlet and 40% of water delivered at the outlets for paddy irrigation only.

(b) Irrigation by ground water sources - 30% of water delivered at outlet and 35% for paddy irrigation.

(4) Seepage from tanks

(a) 9 to 20 per cent of the live storage or 40 to 60 cm year over the total waterspread.

(b) Seepage from percolation tanks 50 per cent of its gross storage.

(5) Contribution from influent seepage

Influent seepage from the rivers may be computed by using Darcy's Law.

For calculating the annual recharge during monsoon, the following formula was recommended to be adopted.

Recharge during monsoon

$$= (s + DW - Rs - Rigw - Ris) \times \frac{\text{Normal Monsoon RF}}{\text{Annual Monsoon RF}} + Rs + Ris$$

where S = Change in ground water storage volume during pre and post-monsoon period, (April/May to Nov)
DW = Gross ground water draft during monsoon
Rs = Recharge from canal seepage during monsoon
Rigw = Recharge from recycled water from ground water irrigation during monsoon

Table 24. Replenishable Ground Water Potential

Unit: Mm^3

Sl. No.	River Basin	Replenishable Ground Water Potential
1.	Indus	25543
2.	Ganga-Brahmaputra-Meghna	
	(a) Ganga	171725
	(b) Brahmaputra	27857
	(c) Barak & others	1795
3.	Godavari	46762
4.	Krishna	26646
5.	Cauvery	13598
6.	Subernarekha	2185
7.	Brahmani-Baitarani	5879
8.	Mahanadi	21293
9.	Pennar	5047
10.	Mahi	
11.	Sabarmati	7908
12.	Narmada	11890
13.	Tapi	8173
14.	West flowing rivers from Tapi to Tadri	9479
15.	West flowing rivers from Tadri to kanyakumari	8810
16.	East flowing rivers between Mahanadi and Pennar	22788
17.	East flowing rivers between Pennar and Kanyakumari	20907
18.	West flowing rivers of Kutch & Saurashtra including Luni	13948
19.	Area of inland drainage in Rajasthan desert	-
20.	Minor rivers draining into Myanmar(Burma) and Bangladesh	-
	Total	452233

Ris = Recharge from recycled water from surface water irrigation during monsoon
RF = Rainfall

To eliminate the effects of drought or surplus rainfall years, it is recommended that the recharge during monsoon may be estimated as above for a period of 3 to 5 years and an average figure is taken. Recharge from winter rainfall may also be estimated on the same lines.

The annual recharge includes the following components:

Total Annual Recharge = Recharge during monsoon + non-monsoon rrainfall recharge + seepage from canals + return flow from irrigation + inflow from influent rivers etc. + recharge from submerged lands, lakes etc.

3. Ground Water Potential Assessed by CGWB

The Central Ground Water Board and the State Ground Water Organisations reassessed the ground water potential district-wise based on the above recommendations. According to this reassessment done in 1984, the total utilisable ground water was 418 km^3.

The ground water potential has been once again reassessed by the Central Ground Water Board recently based on the additional data that became available since the earlier assessment in 1984. According to this latest reassessment the replenishable ground water potential is 452 km^3.

The ground water potential assessment has all along been done treating a revenue district as the basic unit for assessment. However, as only a river basin or a sub-basin is the hydrologic unit for water resources planning, the basinwise ground water potential is normally worked out on pro-rata basis from the districtwise figures.

In Table 24 are given the basinwise replenishable ground water potential as worked out by the Central Ground Water Board from districtwise figures according to their latest reassessment[26]. The figures for composite basins have been adjusted to suit the basin divisions adopted by CWC.

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