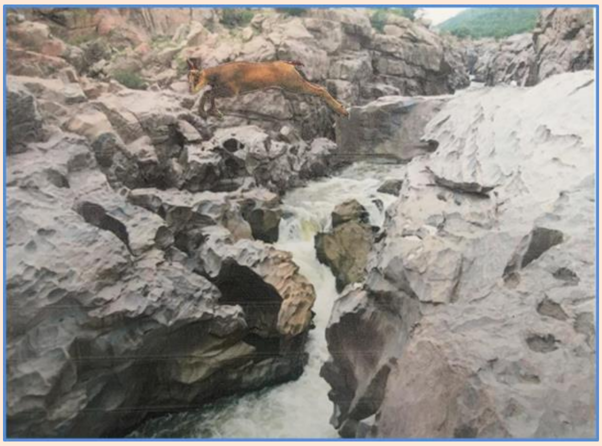
GOVERNMENT OF KARNATAKA
(Water Resources Department)



MEKEDATU BALANCING RESERVOIR CUM DRINKING WATER PROJECT

ANNEXURE 4 - HYDROLOGY
(submitted as a part of Detailed Project Report)
JANUARY 2019

Managing Director
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As per CWC guidelines

Annexure No	Details	Remarks
Annexure-4	Guidelines for preparation of hydrology volume of detailed project report	Refer Chapter 5 of the Vol -I Report
Enclosure-A		
E	Areas and Reaches of interest	Refer Index map, Vol III - Drawings
E-1	Drainage basins upto control points i.e.sites of hydraulic structures; hydrometric . sites, flood damage points, confluence with large rivers etc.	Refer Index map and Catchment area map , Vol III - Drawings
E-2	Potential irrigation area	NA
E-3	Potential flood damage area	NA
E-4	Potential drainage congestion area	NA
E-5	Hydrometeorologic region surrounding the project basin. The region E-5 system will thus include all other regions and .reaches E-1 to E-4 and E-7 to E-13 described here and in addition which include surrounding areas of similar hydrometeorologic characteristics	--
E-6	River system reach within and slightly upstream of a reservoir	Refer Index map
E-7	Potential ground water recharge area	NA
E-8	Reservoir submergence area	Refer Report (Vol -I)
E-9	River system reach from a hydraulic structure to a downstream point which is a control point causing critical flood or a point sufficiently downstream for friction controlled channels or a confluence with major river or sea	NA
E-10	River reach through the area of potential flood damage or potential drainage damage	NA
E-11	River reach in which industrial or domestic water supply is contemplated and where the quantity and quality of water is to be monitored...	NA
E-12	River reach in which navigation is to be sustaineby monitoring low flows.	NA
E-13	River reach in which water quallity (salinity) of low flows area to be monitored tor fish and wild life substance and for recreation.	NA
Enclosure-B		
A		
A-1	Diversion projects without pondage	NA
A-2	Diversion projects with pondage	NA
A-3	Within the year storage projects	NA
A-4	Over the year' storage projects	NA

Annexure No	Details	Remarks
A-5	Complex system involving combinations of 1 to 4 above mentioned.	
Enclosure-C		
B	Classification by use of Project	
B-1	Irrigation	NA
B-2	Hydropower	Yes
B-3	Water supply and industrial use	Yes
B-4	Navigation	NA
B-5	Salinity control	NA
B-6	Water quality control	NA
B-7	Recreation, fish and wild life	NA
B-8	Flood control	NA
B-9	Drainage	NA
B-10	Surface to ground water recharge	NA
B-11	Multipurpose	Yes
Enclosure-D		
C	Types of Hydrologic inputs required	
C-1	For simulation studies	
C -1.1	Water inflows	Yes, Refer Chapter 5, Vol-I
C -1.2	Lake evaporation	Yes, Refer Chapter 5, Vol-I
C -1.3	Potential evapo-transpiration and rainfall	NA
C -1.4	Sediment inflows	Yes, Refer Chapter 7, Vol-I
C -1.5	Flood inputs	Yes, Refer Chapter 5, Vol-I
C -1.6	Water•quality inputs	NA
C -1.7	Low flow inputs	NA
C -1.8	Surface to ground water recharge	NA
C -2	For studies other than simulation	
C -2.1	Design floods for the safety of structures	Yes
C -2.2	Design floods and flood levels for flood control works	NA
C -2.3	Design floods for design of drainage works	NA
C -2.4	Design floods for planning construction and diversion arrangements	NA
C -2.5	Studies for determination of levels for locating structures on river banks or for location of outlets.	NA
C -2.6	Tail water rating curves	Yes, Refer Appendix 9 - Vol II
Enclosure-E		---
Enclosure-F		---

Abbreviation

CA	Catchment Area
CBIP	Central Board of Irrigation and Power
CEA	Central Electricity Authority
CNNL	Cauvery Neeravari Nigam Limited
CWC	Central Water Commission
CWDT	Cauvery Water Disputes Tribunal
FEASIBILITY REPORT	Detailed Project Report
EIA & EMP	Environmental Impact Assessment and Environmental Management Plan
EL	Elevation
FRL	Full Reservoir Level
GOI	Government of India
GOK	Government of Karnataka
GTS	Geometric Trigonometric Survey
IS	Indian Standards
KPCL	Karnataka Power Corporation Limited
KPTCL	Karnataka Power Transmission Corporation Limited
KRS	Krishna Raja Sagara
NHPC	National Hydro Power Corporation
NA	Not Applicable
PWD	Public Works Department
R & R	Resettlement and Rehabilitation
SIA	Aocial Impact Assessment
TMC	Thousand Million Cubic Feet
USBR	United States Bureau of Raclamation
REIA	Rapid Environmental Impact Assessment
EMP	Environment Management Plan
mbgl	Meters below ground level
lpm	Litres per minute
lps	Litres per second
MLD	Million litres per day

OSHA	Occupational Safety and Health Administration
PERT	Program Evaluation and Review Technique
CPM	Critical Path Method
BC Ratio	Benefit Cost Ratio
MWL	Maximum water level
MOE&F	Ministry of Environment and Forest

REPORT

Chapter 1 Hydrometeorological Information

1.1 General information about region

The River Cauvery is designated as the 'Dakshina Ganga' or 'the Ganga of the South'. The Cauvery River rises at an elevation of 1,341 m at Talakaveri on the Brahmagiri range near Cherangala village of Kodagu (Coorg) district of Karnataka.

The total length of the river from origin to outfall is 800 km. The Cauvery basin extends over states of Tamil Nadu, Karnataka, Kerala and Union Territory of Puducherry draining an area of 81 thousand Sq.km. It is bounded by the Western Ghats on the west, by the Eastern Ghats on the east and the south and by the ridges separating it from Krishna basin and Pennar basin on the north. The Nilgiris, an offshore of Western ghats, extend Eastwards to the Eastern ghats and divide the basin into two natural and political regions i.e., Karnataka plateau in the North and the Tamil Nadu plateau in the South.

Physiographically, the basin can be divided into three parts – the Westen Ghats, the Plateau of Mysore and the Delta.The delta area is the most fertile tract in the basin. The principal soil types found in the basin are black soils, red soils, laterites, alluvial soils, forest soils and mixed soils. Red soils occupy large areas in the basin. Alluvial soils are found in the delta areas.

The basin in Karnataka receives rainfall mainly from the S-W Monsoon and partially from N-E Monsoon. The basin in Tamil Nadu receives good flows from the North-East Monsoon. Its upper catchment area receives rainfall during summer by the south-west monsoon and the lower catchment area during winter season by the retreating north-east monsoon. It is, therefore almost a perennial river with comparatively less fluctuations in flow and is very useful for irrigation and hydroelectric power generation.

Thus the Cauvery is one of the best regulated rivers and 90 to 95 per cent of its irrigation and power production potential already stands harnessed. The river drains into the Bay of Bengal. The major part of basin is covered with agricultural land accounting to 66.21% of the total area.

Tributaries of the Cauvery River

Left Bank: Harangi, Hemavati, Shimsha and Arkavati.

Right Bank: Lakshmantirtha, Kabini, Suvarnavati, Bhavani, Noyil and Amaravati

The river descends from the South Karnataka Plateau through the Sivasamudram waterfalls (101 m high) and travelling beyond up to the border with Tamil Nadu before entering Tamil Nadu Plains

At Shivanasamudram, the river branches off into two parts and falls through a height of 91 m. in a series of falls and rapids. The falls at this point is utilized for power generation by the power station at Shivanasamudram.

The two branches of the river join after the fall and flow through a wide gorge which is known as 'Mekedatu' (Goats leap) and continues its journey to form the boundary between Karnataka and Tamil Nadu States for a distance of 64 km.

At Hogennekkal Falls, it takes Southerly direction and enters the Mettur Reservoir. A tributary called Bhavani joins Cauvery on the Right bank about 45 Kms below Mettur Reservoir. Thereafter it enters the plains of Tamil Nadu. Two more tributaries Noyil and Amaravathi join on the right bank and here the river widens with sandy bed and flows as 'Akhanda Cauvery'.

Immediately after crossing Tiruchirapalli district, the river divides into two parts, the Northern branch being called 'The Coleron' and Southern branch remains as Cauvery and from here the Cauvery Delta begins. After flowing for about 16 Kms, the two branches join again to form 'Srirangam Island'.

On the Cauvery branch lies the "Grand Anicut" said to have been constructed by a Chola King in 1st Century A.D. Below the Grand Anicut, the Cauvery branch splits into two, Cauvery and Vennar. These branches divide and sub-divide into small branches and form a network all over the delta.

1.1.1 Topography

The Cauvery basin is bounded on the north by the ridges separating it from Krishna and Pennar basins, and the basin area covered by the streams between Palar and Cauvery on the south and by the Eastern Ghats on the east and by Western Ghats on the west. The upper reach of the basin is covered with hill ranges of the Western Ghats and the basins area is broad and open with gently undulating country. In the north – west and south, there are a number of hill ranges which have steep slopes. The maximum length of Cauvery basin from west to east is 540 km in Karnataka. The maximum width from north to south is 255 km.

1.1.1.1 General Climatic Condition

Karnataka witnesses three types of climate. The state has a dynamic and erratic weather that changes from place to place within its territory. Due to its varying geographic and physio-graphic conditions, Karnataka experiences climatic variations that range from arid to semi-arid in the plateau region, sub-humid to humid tropical in the Western Ghats and humid tropical monsoon in the coastal plains.

More than 75 percent of the entire geographical area of Karnataka, including interior Karnataka, witnesses arid or semi-arid climate. Karnataka has about 15 percent of the total semi-arid or 3 percent of the total arid areas marked in India.

Due to the climatic difference Karnataka is divided into three meteorological regions:

Coastal Karnataka: This region stretches over the Districts of Udupi, Uttara Kannada and Dakshina Kannada. The entire coastal belt and the adjoining areas have tropical monsoon. The area receives heavy rainfall. The average annual rainfall in Coastal Karnataka is about 3456 mm, which is much more than the rainfall received in the other parts of the state.

North Interior Karnataka: This region extends over the districts of Bagalkot, Belgaum, Bijapur, Bidar, Bellary, Dharwad, Haveri, Gadag, Gulbarga, Koppal and Raichur. This area is an arid zone. North Interior Karnataka receives the least amount of rainfall in the state and the average annual rainfall is just 731 mm.

South Interior Karnataka: This region spreads over the districts of Bangalore Rural, Bangalore Urban, Chitradurga, Chamrajnagar, Chikmagalur, Hassan, Kodagu, Kolar, Mysore, Shimoga and Tumkur. This zone experiences semi-arid type of climate. South Interior Karnataka receives an annual average of 1286 mm rainfall.

1.1.1.2 Climatic condition of the project area

The Cauvey basin lies in South Interior Karnataka.. The year may broadly be classified into four seasons. The dry season is from January to February, followed by hot weather from March to May. The SW monsoon season is from June to September and the NE monsoon period is from October to December.

The normal rainfall in the project area is 854 mm and varies from 822 mm at Kanakapura to 868 mm at Magadi. December to March represents very low rainfall months. The rainfall occurs in nearly 49 rainy days. The pre monsoon period has a normal of 345 mm (35%),SW monsoon period has 363 mm (37%) and the NE monsoon period receive 263mm (27%) rainfall. It is observed that there is not much variation in the distribution of rainfall during pre monsoon, SW monsoon and NE monsoon periods.

<u>Ramanagar District</u>

The year may broadly be classified into four seasons. The dry season is from January to February, followed by hot weather from March to May. The SW monsoon season is from June to September and the NE monsoon period from October to December

The amount of rainfall is being measured from rain guage stations located in the district. A study of the rainfall data from 2001 t0 2010 from various rain gauge stations has shown that the amount of rainfall is relatively uniform through out the district. The normal rainfall of the district is 854mm and varies from 822 mm at Kanakapura to 868 mm at Magadi. December to March represents very low rainfall months. The rainfall occurs in nearly 49 rainy days. The pre monsoon period has a normal of 345mm (35%),SW monsoon period has 363 mm (37%) and the NE monsoon period receive 263mm (27%) rainfall. It is observed that there is not much variation in the distribution of rainfall during pre monsoon, SW monsoon and NE monsoon periods. During the year 2011, the district received an average rainfall of 970 mm.However it varies from a lowest 800 mm at Kanakapura to a highest 1130 mm at Magadi station.

The temperature starts rising from January to peak in April, the hottest month with a maximum temperature of 34°C. Thereafter it declines during the monsoon period. December is the coldest month with the temperature dipping down to 16°C.

The humidity is lowest during the dry season and highest during the monsoon period with an average value of about 49% and 86% respectively.

The winds are predominantly south westerly during the summer monsoon and northeasterly during the winter monsoon.

The annual potential Evapotranspiration is 1531 mm with monthly rates more than 100mm throughout the year and the maximum is 166 mm in the month of March.

Chamarajanagar (C.R.Nagar) District

The climate of C.R.Nagar district is quite moderate through out the year with fairly hot summer and cold winter. March to May is summer months, where mean maximum temperatures ranges from 32.6°C to 34°C. June to September is the southwest monsoon period, October and November is the post monsoon retreating monsoon season with clear bright weather and during December to February weather remains dry. The skies clouded or overcast during southwest monsoon. During October and November some of the depressions and cyclonic storms originates in Bay of Bengal, which passes through the district, causing wide spread heavy rains and high winds.

The mean maximum temperature in the district is 34°C. and the mean minimum temperature is 16.4°C. during January month. Relative humidity ranges from 69 to 85% in the morning and in the evening it ranges from 21% to 70%. The wind speed ranges from 8.4 to 14.1 kmph. The potential evopotranspiration in the district ranged from 106mm to 165mm/year.

C.R.Nagar district receives rainfall from southwest monsoon from June to September and northeast monsoon from October to December. Overall on an average, there are 67 normal rainy days, which is minimum in Yalandur taluk with 63 days, maximum in Gundlupet taluk with 73 rainy days. As per the last three decades (1970-2000) rainfall analysis, the precipitation during southwest monsoon accounts for 61.17% of the total amount of rainfall and during northeast monsoon it is 31.88%. September is the wettest month in the year. Annual rainfall for the last three decades in Chamarajanagar- 799.3mm, Gundlupet-785.5mm, Kollegal-768.1mm and in Yalandur-894.1mm. Average rainfall in the district is 811.75mm. The analysis of the last ten years rainfall data (1997-2006) shows that the highest rainfall occurred in C.R.Nagar taluk with 731.80mm and the lowest at Gundlupet with 586.1mm. Deficiency in rainfall is observed in the four taluks for the last ten years except during the years 2000, 2004, and 2005 where excess rainfall in the range of 3% to 40% was observed.

1.1.1.3 Physiography

The Southern Karnataka Plateau covers the districts of Bangalore urban , Bangalore Rural, Hassan, Kodagu, Kolar, Mandya, Mysore and Tumkur. This region largely covers the area of the Cauvery river basin lying in Karnataka. It is bounded by 600 metres contour and is characterised by a higher degree of slope. In the west and south, it is enclosed by the ranges of Western Ghats and the northern part is an interrupted but clearly identifiable high plateau.

In the east the valleys of the Cauvery and its tributaries open out to form undulating plains. The general elevation of the region varies from 600 to 900 metres. However, residual heights of 1,500 to 1,750 metres are found in the Biligirirangan hills of Mysore district and the Brahmagiri range of Kodagu district.

1.1.1.4 Geology

The region comprise of rocks belonging to Charnockite group, Sargur group, Peninsular gneissic complex (PGC), Closepet granite, and basic and younger intrusives. Charnockite group is represented by Chanockite. Sargur group comprises of ultra mafic rocks, amphibolite, banded magnetite quartzite, occurring as small bands, and lenses within the migmatite and gneisses. The PGC includes granites, gneisses and migmatite and occur to the east and west of Closepet granite. Transformation of PGC into Charnokite is reported locally in the district. The Closepet granite occurs as intrusive bodies trending nearly N-S within the gneisses over a distance of 50km and for a width of 15-20km. The Closepet granite contains enclaves of migmatite, gneisses, quartzite and amphibolites and is reported to be of variable composition. The basic intrusives are represented by dolerite, gabbro, occasionally Norite and pyroxenite. The dolerite is dominant among the basic dykes. There are three major lineaments in the district trending NNW-SSE direction. These lineaments range in length from 45 km to 70 km. Interpretation of this data revealed the presence of deep seated fault tending NNW-SSE, which cuts across the Closepet granites.

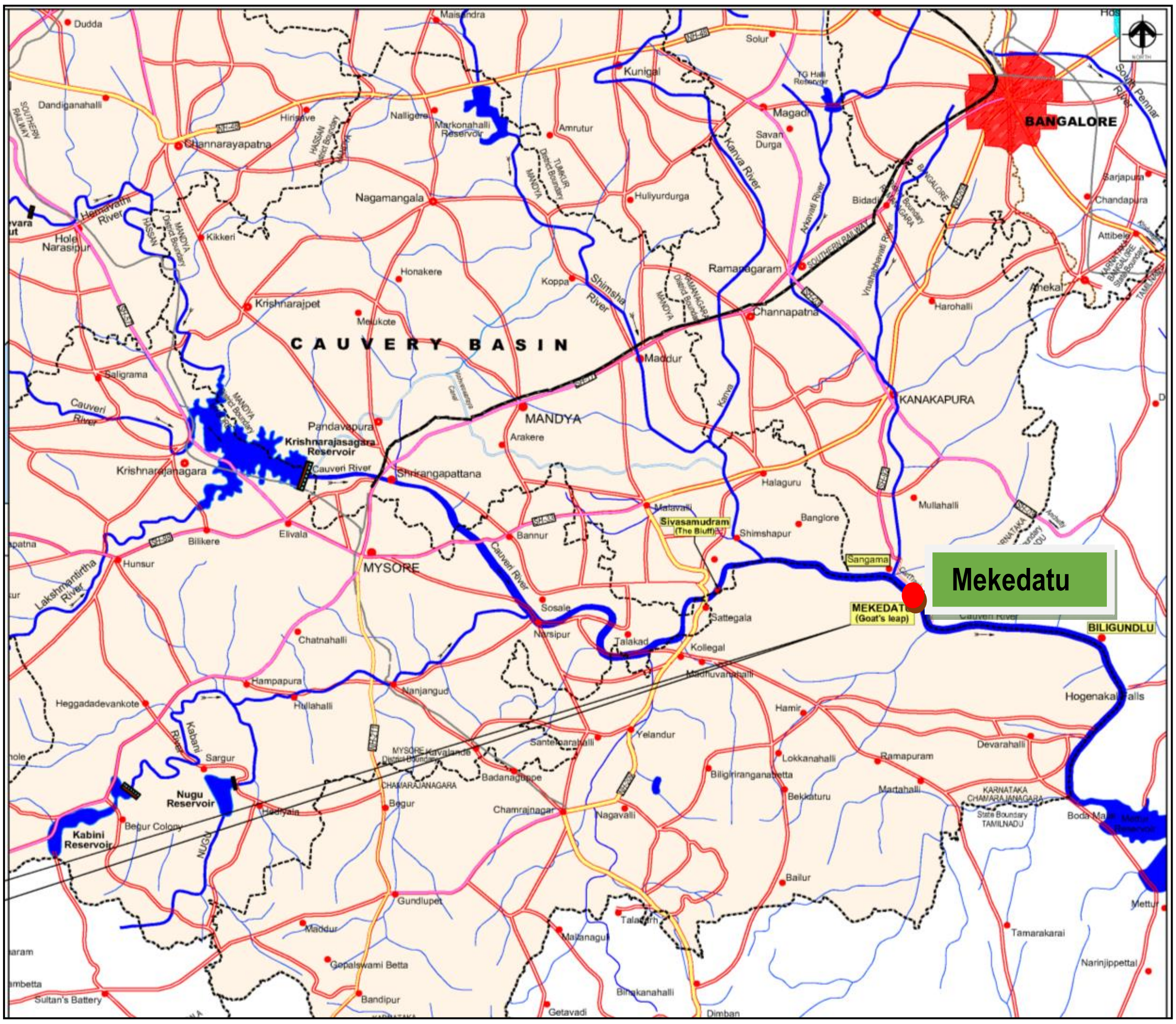


Fig. 1.1: Index map showing area of Interest

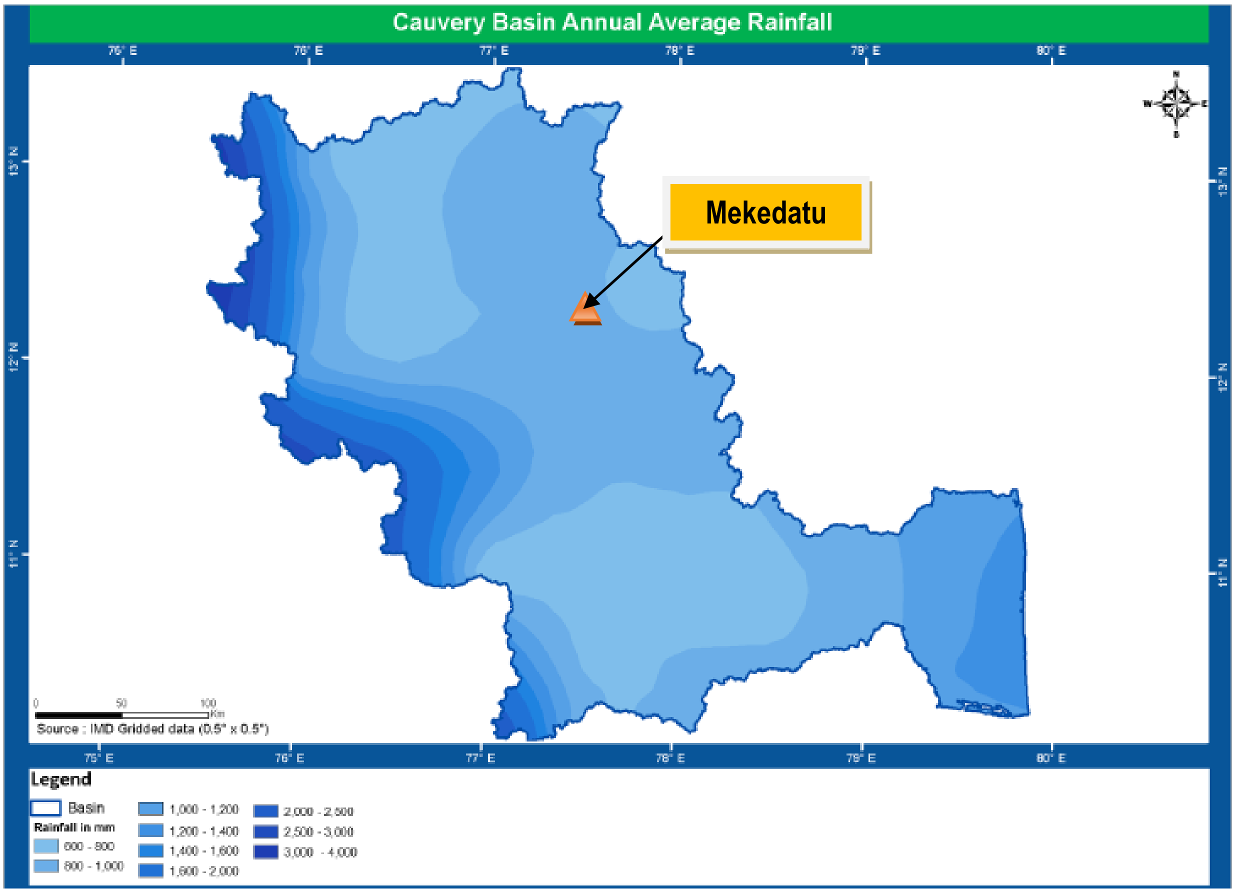


Fig. 1.2: Annual normal rainfall map of the region

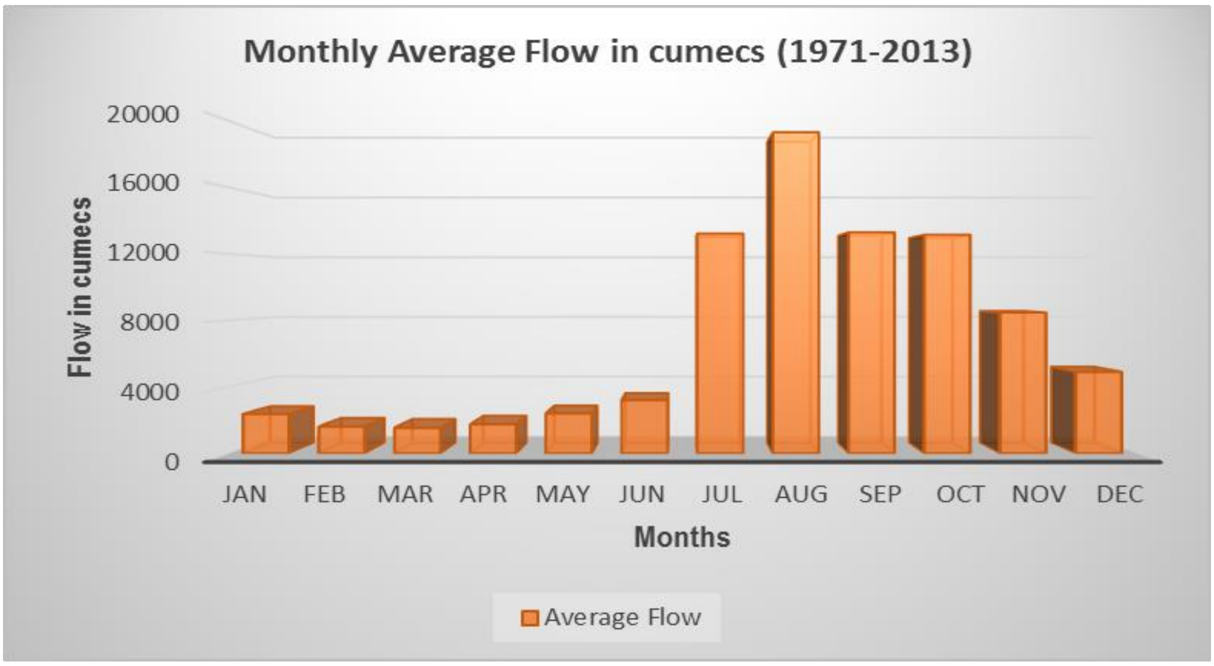


Fig. 1.3: Bar chart showing average flow data for Biligundlu station

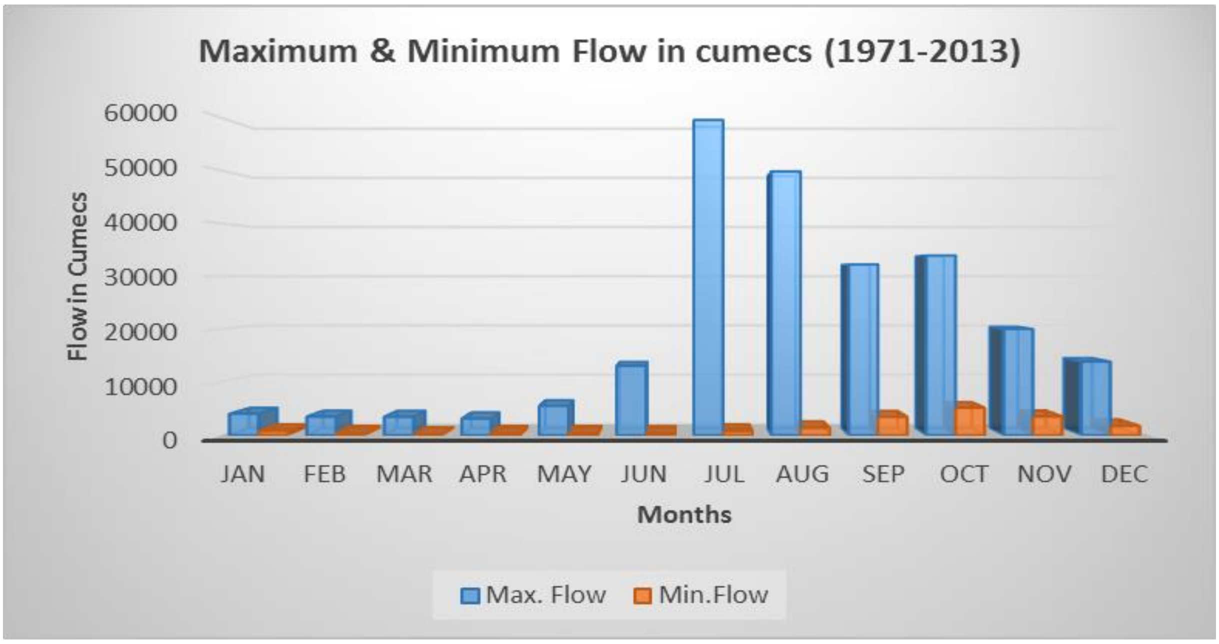


Fig. 1.4:Bar chart showing max and min monthly flow data for Biligundlu station

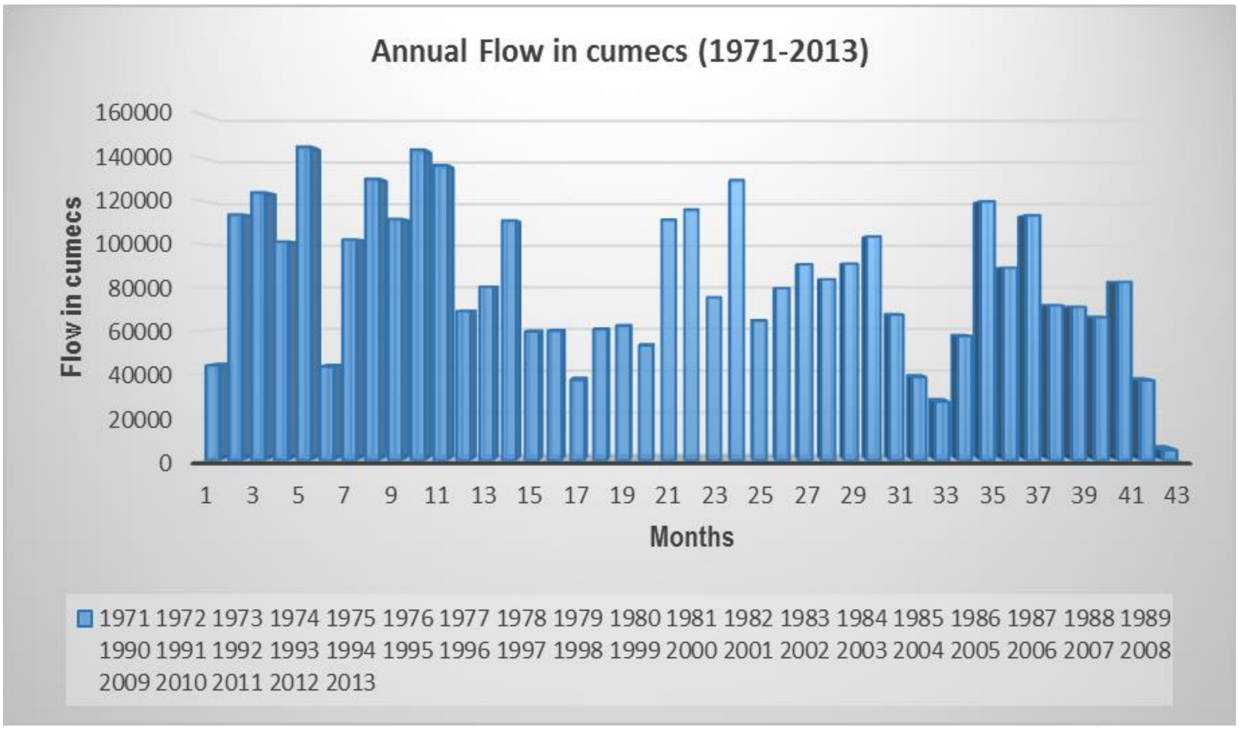


Fig. 1.5:Bar chart showing annual flow data for Biligundlu station

1.2 Specific information of area of Interest

1.2.1 Drainage basin

Cauvery basin extends over an area of 87900 sq. km. which is nearly 2.7% of the total geographical area the country. It is bounded on the west by the Western Ghats, on the east and south by the eastern Ghats and the north by the ridges separating it from the Tungabhadra and Pennar basins. The basin lies in the States Tamil Nadu, Karnataka and Kerala. The State-wise distribution of drainage area is given below:

State	Drainage area (sq. km.)
Tamil Nadu	48730
Karnataka	36240
Kerala	2930
Total	87900

1.2.2 Hydrometeorological Data Observations

The hydrometric network in the basin includes 159 rain gauges and 24 meteorological stations maintained by IMD falling in the States of Karnataka, part of Kerala and Tamilnadu. CWC observe stream flow (GD), sediment (GS) and water quality (WQ) at 12 stations in Karnataka, 1 in Kerala and 17 in Tamil Nadu . Six streamflow stations are in the delta area, concentrated around a small area that is a part of Pondicherry.

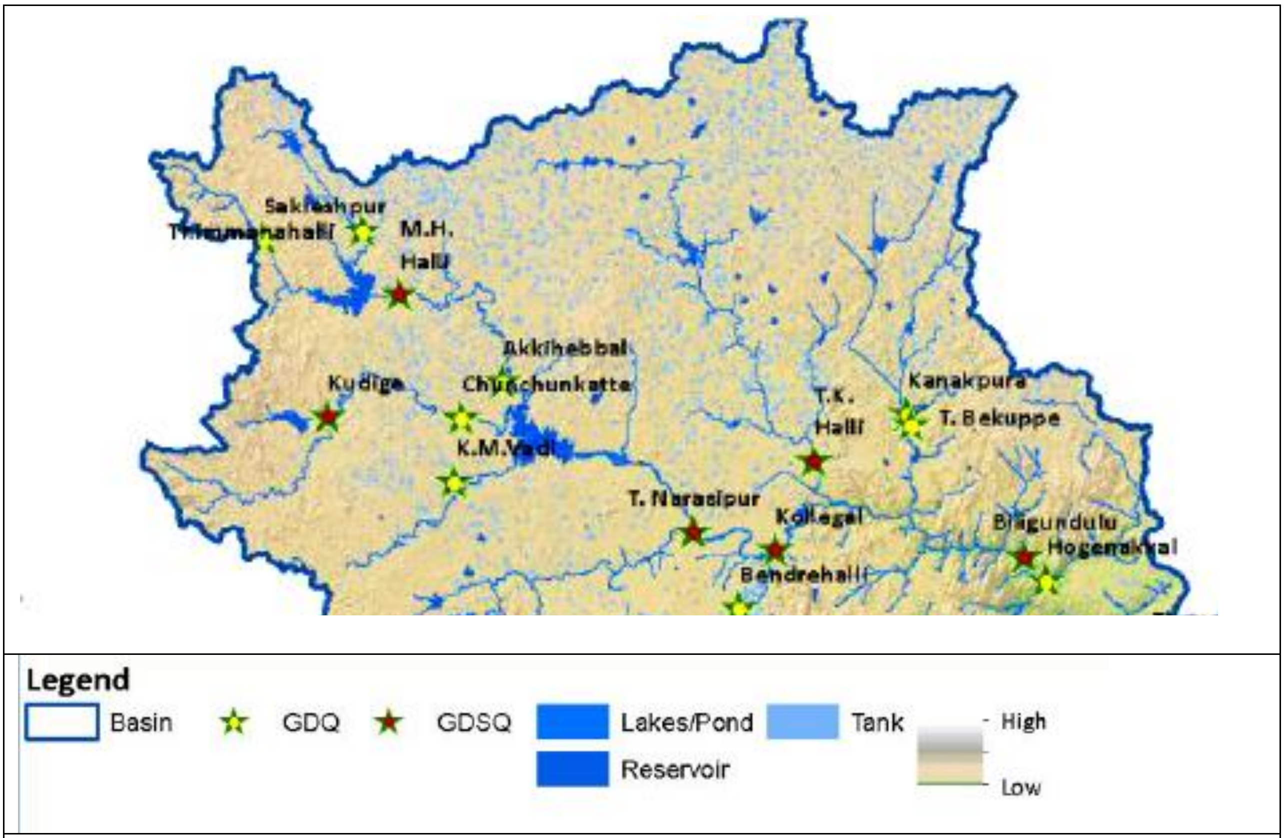


Fig. 1.6: Hydrometeorological Data Observations network in the basin

1.2.3 Area

1.2.3.1 Command area

Not envisaged as this is basically a balancing reservoir cum drinking water project

1.2.3.2 Floods and Drainage

The gauge and discharge data are being observed by CWC at Biligundlu G&D site across Cauvery river just on the downstream of proposed Mekedatu dam site. The annual maximum flow series is available for the period from 1971 to 2013. As per the data the maximum observed flood at Biligundlu G&D site was 6688 Cumecs on 30/07/1991.

The Cauvery basin is fan shaped in Karnataka and leaf shaped in Tamil Nadu. The run-off does not drain off quickly because of its shape and therefore no fast raising floods occur in the basin.

1.2.4 River geometry

Cauvery river originates in the Mercara District of Karnataka in the Brahmagiri range of hills in the Western Ghats at an elevation of 1341 m above mean sea level. It traverses 765 Km and has the following dams built across it and its tributaries. Cauvery River enters the State of Tamil Nadu near Biligundlu and has Metter dam (1934) immediately after impounding 95.6 TMC of water for use in the Cauvery Delta area. At Upper Anicut, about 177 kms from Metter dam, the river splits into two branches the northern branch called the Coleroon, a flood carrier and the southern branch in the main Cauvery which carries water for irrigation.

1.2.5 Ground water recharge

The proposed project has been planned as a balancing reservoir (cum drinking water) project to meet 177.25TMC requirement of Tamil Nadu as per the CWDT Award (in a normal year) further modified by the Ho'ble Supreme Court of India 0n 16/02/2018 and also to meet the drinking water needs of Bangalore Metropolitan Region, its surroundings and other identified Cities, towns and villages in the Cauvery Basin. The Project does not envisage providing irrigation and no canal network is planned. As such, recharge of Ground water is expected due to formation of the proposed reservoir and subsequent storage in it.

1.2.6 Reservoir area

1.2.6.1 Pan evaporation

Refer 1.3.2

1.2.6.2 Elevation – Area Capacity curve and methodology used in the computation

In order to arrive at the capacity of the proposed reservoir, a study was carried out considering the following aspects:

- FRL of the reservoir,
- the subsequent storage,
- Meeeting the demand of release of 177.25 TMC water to Tamil Nadu as per CWDT Award further modified by the Hon'ble Supreme Court of India on 16/02/2018.
- Meeting the drinking water requirement of Bengaluru Metropolitian Region as envisaged
- Power generation from the releases to the downstream

All the above factors have been considered for study.

1.2.6.2.1 Fixing FRL of the Reservoir

In order to fix the FRL or to fix the height of the dam, the study was carried out to arrive at the capacity at 2.00 m contour intervals. However, a detailed study earlier undertaken by the Karnataka Power Corporation Limited (further accepted by the Advisory Committee appointed by the government of Karnataka) envisaged construction of Hydroelectric project at Mekedatu site denoted as 'C' Site with an FRL at RL 440.00 m. The reservoir was planned as a storage to release the water downstream and utilize the elevation difference available to generate power. The same has been considered for the present proposal also.

1.2.6.2.2 Methodology for arriving at the capacity

The Methodology adopted for arriving at the capacity of the reservoir at each contour (with 2.00 m interval) is described below.

- The FRL is considered as RL 440.00 m (as per the selected site by KPC in their earlier proposal accepted by the Government of Karnataka) and the water spread area is calculated.
- The level of the bed is then considered as the last contour level at the proposed location.
- The capacity at this FRL is calculated using the formula,

  Capacity V(Sq m) = h/3 x [A1 + A2 + √ A1 x A2) where,

  h = contour interval

  A1 = Water spread area of the previous contour

  A2 = Water spread area of the present contour

- The capacities at each 2.00 m interval upto the bed level is then calculated accordingly

- Cumulative capacity in terms of Sq m , Mcft and TMC are then arrived at.

1.2.6.2.3 The Area Elevation capacity curve

Topographic survey of the reservoir area should form the basis for obtaining these curves, which are respectively the plots of elevation of the reservoir versus surface area and elevation of the reservoir versus volume. For preliminary studies, in case suitable topographic map with contours, say at intervals less than 2.5 m is not available, stream profile and valley cross sections taken at suitable intervals may form the basis for computing the volume.

In the present study, the Elevation Area Capacity relationship has been developed based on the 2 m contour intervals for Location (considered for preparation of preliminary feasibility report) and additional locations viz, Location 1, Location 2 and Location 3. While Location near Mekedatu (considered for preparation of preliminary feasibility report) has been based on the survey. Additional locations (1,2 and 3) are based on 1: 50000 scale topo maps.

1.2.6.2.4 Area Elevation Capacity curve for location near Mekedatu

The graphical representation of the Elevation Area Capacity for this location is indicated hereunder.

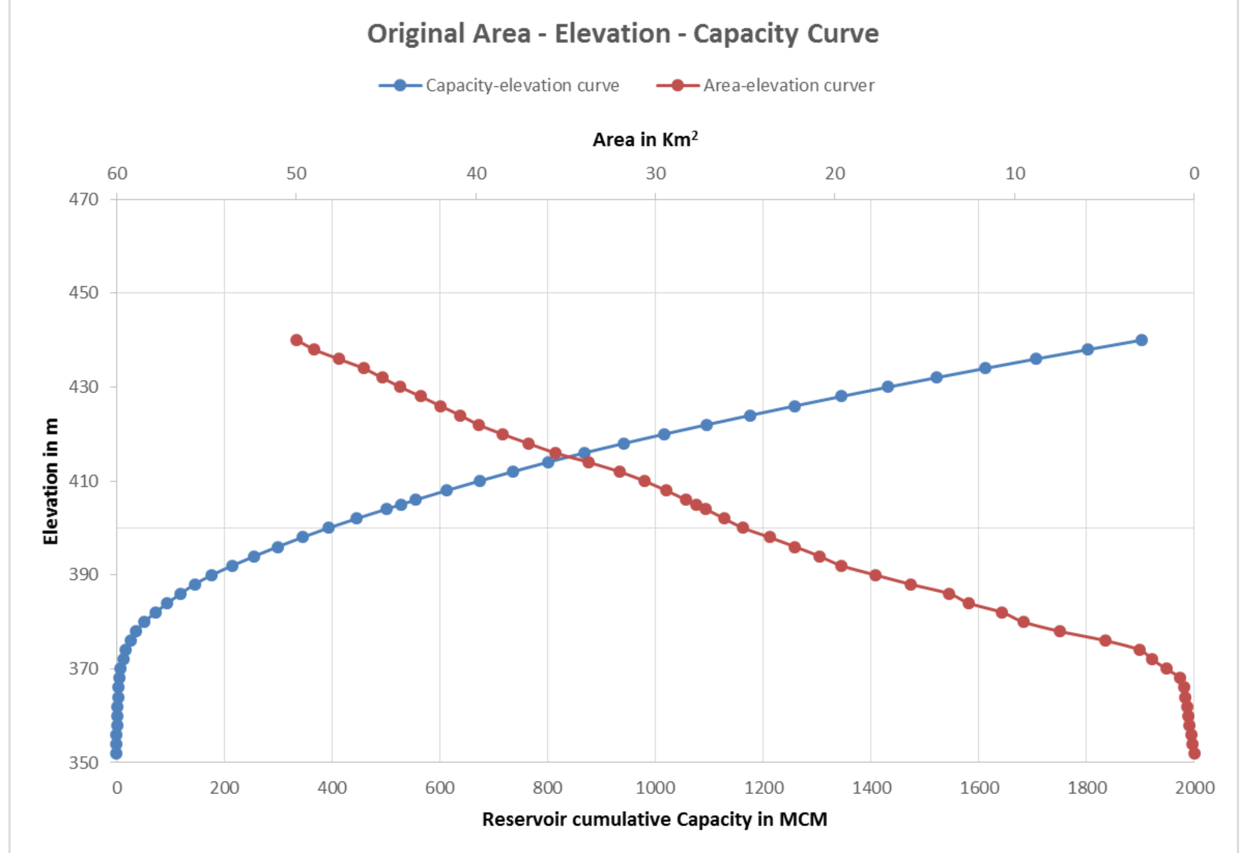


Fig. 1.7: Original Area- Elevation - Capacity Curve

1.2.7 Other water usage

The water to be stored in the balancing reservoir will be mainly used for releasing 177.25 TMC in a normal year to Tamil Nadu and providing drinking water supply to Bangalore Metropolitan Region, its surrounding areas in the Cauvery basin.

1.2.8 Navigation

The River Cauvery is not presently used for any navigation purpose.

1.3 Data availability

1.3.1 Rainfall and Snowfall

There is no snowfall observed in Cauvery basin. The observational network of rainfall data is fairly good in the vicinity of the project area. There are number of rain gauge stations and G&D sites in the Cauvery basin where long term data is available.

Rainfall data from the well-established meteorological stations located within the catchment area of the project is vital in order to estimate the flood discharge for design of any Hydraulic structure. In the present scenario, it is envisaged to plan and design water impounding structure/s downstream of major reservoir(s) across interstate river, Cauvery which has a well-established monitoring / Rain gauging stations at every taluk headquarters (48 in number) and other strategic locations.

The information regarding the rainfall data are collected from the stations located within the Cauvery basin in the State which will have influence on the proposed balancing reservoir and also on the demand at various specific locations. Daily rainfall data are collected for at least preceding 30 years and checked for consistency as per requirement and compiled in to monthly values.

1.3.2 Pan Evaporation

Christiansen et al (1966) provided an empirical formula to permit the estimation of pan evaporation from Climatic data when reliable measured pan evaporation is not available. The formula is as below:

$$Ep = 0.459 * R * C_t * C_w * C_h * C_s * C_e$$

Where, Ep = Computed pan evaporation equivalent to class A pan evaporation

R = Extra –terrestrial radiation

C_t, C_w,C_h,C_s and C_e are the coefficents of Temperature, wind velocity, relative humidity, percent of possible sunshine and elevation respectively.

The pan evaporation is calculated month wise using the Climatic normals data of **Bangalore Station** from period 1971 to 2000 furnished by IMD, Pune.

Table 1.1: Pan Evaporation result

No	Month	Evaporation (Ep) mm/day
1	Jan	7.00
2	Feb	8.56
3	Mar	9.83
4	Apr	9.02
5	May	7.98
6	Jun	6.43
7	Jul	5.66
8	Aug	5.29
9	Sep	5.11
10	Oct	5.00
11	Nov	5.24
12	Dec	5.62

1.3.3 Climatological parameters like temperature-humidity-wind-sunshine etc. (Bangalore IMD Station)

Station:	**Banglore**
Latitude	**12°58' N**
Longitude	**77°35' E**
Height above Mean Sea Level:	**921 m**
Height of wind instrument above ground level in m (z)	**10 m**

Month	**Daily temp (°C)**		**Relative Humidity (%)**		**Cloud Amount (Oktas)**		**Rainfall (mm)**	**Max Wind Speed (km/hr)**			**Sunshine (%)**
	Max	**Min**	**Max**	**Min**				**Wind speed U_z (Km/hr)**	**U_2 (m/sec) Wind speed at 2m height above the ground**	**U_2 (Km/day)**	
January	27.6	15.3	80	39	3.2	2.8	1.8	7.3	1.52	131.04	83
February	30.2	17.2	72	32	2.3	2.6	7.9	6.5	1.35	116.68	87
March	32.9	19.6	64	27	1.6	2.5	7	5.8	1.21	104.11	91
April	34.1	21.8	71	33	3.1	4.6	40	4.8	1.00	86.16	72
May	33.3	21.5	76	46	4.6	5.6	110.2	5.7	1.18	102.32	56
June	29.4	20.2	84	61	6.3	6.6	89.1	8.9	1.85	159.76	32
July	28.1	19.8	87	64	7.1	6.9	108.9	8.8	1.83	157.97	24
August	27.5	19.6	89	67	7.1	6.8	142.5	8.2	1.70	147.20	25
September	28.3	19.7	87	64	6.4	6.4	241	5.7	1.18	102.32	31
October	28	19.4	84	64	5.5	6	154.5	4.8	1.00	86.16	45
November	27	17.7	80	60	4.6	5.1	54.1	5.7	1.18	102.32	58
December	26.2	16.0	82	53	4.2	4	17.5	7.5	1.56	134.63	67

Source : Climatological Tables (1971-2000) IMD – GOI

1.3.4 River gauge and discharge

The gauge data from the guaging station at Biligundlu maintained by the CWC is considered

1.3.5 Sediment inflow and grain size composition

Refer Appendix 5 (Volume II)

1.3.6 Water quality

The present proposal being a drinking water supply project, the quality of the water will be thouroughly tested before supply.

Chapter 2
Hydrological Inputs

2.1 Alternatives and Classifications

As per the requirement of CWC, the said classification of alternative plans by storage is according to one or combination of the following:

A-1 Diversion projects without pondage
A-2 Diversion projects with pondage
A-3 Within the year storage
A-4 Over the year storage
A-5 Complex system involving combinations of 1 to 4 above mentioned

According to the above, the proposed balancing reservoir cum Drinking water project can be classified as A -5 since it involves storage to meet the main objective of releasing 177.25 TMC of water to Tamil Nadu (during a normal year) and also providing drinking water to Bengaluru Metropolitan Region, its surrounding areas in the Cauvery Basin.From the releases effected to as per the CWDT award further modified by the Hon'ble Supreme Court of India vide its Judgement dated 16/02/2018, it is proposed to generate power by utilizing the available fall in the bed level between the Mekedatu Site and Biligundlu.

By use, the said project can be classified as Multipurpose (B-11) on account of it being a balancing reservoir to be utilized for releasing 177.25 TMC of water (in a normal year) to Tamil Nadu and at the same time to meet the requirement of drinking water to Bengaluru, its surrounding areas etc in the Cauvery basin besides generating power from the releases effected to.

2.2 Types of Inputs required

As per CWC guidelines, if Classification is B-11 then all inputs from C-1.1 to C – 1.8 are required depending on individual uses for simulation studies. Further, C -1.4 is also required in case of large pondage / storage as indicated below:

C 1.1 Water inflows
C 1.2 Lake evaporation
C 1.3 Potential evapo-transpiration and rainfall
C 1.4 Sediment inflows
C 1.5 Flood inputs
C 1.6 Water quality inputs

C 1.7 Low flow inputs

C 1.8 Surface to ground water recharge

Accordingly, in the present proposal, all the indicated inputs are considered and simulation study undertaken.

2.3 Time unit for hydrological inputs required for simulation studies

As per Enclosure G, CWC stipulates for adoption of minimum of the time unit required by each of the component storages involved in the complex system.

In the present proposal, 10 daily discharge is considered for simulation study.

2.4 Length of Hydrological inputs

As per the CWC, in fixing the length of hydrological inputs for simulation, type of development and variability of inputs shall be kept in view. Brief guidelines states as under:

Type of project (Enclosure B) for simulation	Minimum length of data for use in
A1 and A 2	10 years
A 3	25 years
A 4	40 years
A 5	Depending upon the predominant element (A 1 to A 4)

In the present proposal, predominant element is storage and meeting the drinking water requirement. As such, the length of data considered is from 1972 onwards (as per the gauge data available at Biligundlu).

2.5 Requirements of the inputs for the project

Already discussed above.

Chapter 3
Compilation and Processing of Basic Hydrological data

3.1 Hydrological investigations

CWC has maintained a G & D site near biligundlu which is at the border of Karnataka and Tamil Nadu States. The G & D data at this site is available from 1971-72 onwards which has been used to develop the yield series in the river at the proposed Mekedatu balancing reservoir cum Drinking water Project site.

3.2 Data from other sources

The data used in this study were also collected from various agencies. The Climatological and evapotranspiration data etc were collected form IMD. Gauge data at Biligundlu was collected from WRIS. The data related to the Water Resources projects such as location, water utilization and other salient features were collected from Cauvery Neeravari Nigam Limited including the allocation for drinking water purposes of Bengaluru Metropolitan region, its suurounding areas etc as per the recent Judgement of the Hon'ble Supreme Court of India vide its Judgement dated 16/02/2018 modifying the Award of the CWDT. For Inter State aspects, the Award of Cauvery Tribunal further modified by Hon,ble Supreme Court of India on 16/02/2018 has been considered.

Data regarding the earlier proposed project for Power generation was collected from Karnataka Power Corporation Ltd.

3.3 Processing of data

It is observed that usually, the time units of available and required time series often differ. The discharges are measured and is obtained from the gauge records. Since, the Gauge discharge data for the River is available at Biligundlu (G & D station maintained by CWC), the hydrological variables were processed from the available data. Furthermore, data is available for a fairly long time from 1971-72 to 2016-17.

3.3.1 Quality of data

As indicated above, the discharge data is available from 1972 onwards at Biligundlu G & D site (maintained by CWC) on the downstream of the proposed location of Mekedatu Balancing Reservoir cum Drinking Water Project. The data has been checked for consistency and homogeneity. Both internal and external consistency checks are also made on the discharge data.

3.3.2 Filling up of Short data gaps

There are no short data gaps in the available data of discharge at Biligundlu.

3.4 Consistency check for Discharge data

Double mass curve analysis (Rainfall vs. Runoff) is carried out between cumulative average annual rainfall and the cumulative annual flow .

A trend analysis and a test for Stability of Variance (f-test) and Mean (t-test) are conducted on the Discharge data of Biligundlu station. **The discharge time series is found to be stationary.**

Conclusion: The Discharge data has been checked for internal and external consistency by Double mass curves and Statistical test and it is found that the data is consistent. Refer **Appendix 7** (Volume II).

3.5 Presentation of data

3.5.1 Data for simulation studies

The observed discharge data at Biligundlu G & D site on the downstream of the proposed Mekedatu Balancing Reservoir cum drinking water Project is available from 1972 onwards. This daily discharge data have been considered to work out the 10 daily yield at the site.

3.6 Water Availability

Detailed computation of the working tables shows that the main project objectives of releasing mandated quantum of water to Tamil Nadu at 50% dependability and providing drinking water to Bangalore Metropolitan Region can be met.

Clause XXVIII of the final order of the Tribunal states thus,

“Nothing in the order of this Tribunal shall impair the right or power or authority of any State to regulate within its boundaries the use of water or to enjoy the benefit of water within that State in a manner not inconsistent with the order of this Tribunal”.

As per the above order of CWDT, the water flowing in a State can be regulated within its boundaries for using it and enjoying the benefit of the same. Karnataka, by building Mekedatu balancing reservoir cum drinking water project would be ensuring releases as per the order (both by CWDT and Hon’ble Supreme Court),

Sub point No 391 of the order of the Hon’ble Supreme Court of India states thus

"At this juncture, we need to recount that as per the National Water policies, not only drinking water has been placed at the top of the other requirements in the order of priority but it has also been predicated that adequate drinking water facilities should be provided for the entire population, both in urban and rural areas and that drinking water should be made a primary consideration. It was declared as well that drinking water needs of Human being and animals should be the first charge on any available water".

3.6.1 Distribution of Water

The primary objective of Mekedatu reservoir is to ensure flows at Biligundlu in accordance with the CWDT Award further modified by the Hon'ble Supreme Court. Other objectives are to provide drinking water to Bangalore Metropolitan region and to generate power from the flow released to Biligundlu.

The most accurate method of analyzing the ability of a reservoir at Mekedatu to meet demands for different end uses is by preparing working tables. The end uses are:

- Ensuring Biligundlu flows as per CWDT Award/SC Order
- Generating power from the above flows
- Utilisation of water to the extent allowed by Hon'ble Supreme Court – such that 177.25 TMC of water is ensured at Biligundlu at 50% dependability.

Chapter 4
Preparation of Hydrologic Inputs for simulation

4.1 River

The River Cauvery which originates in the Western ghat region of Karnataka depends mainly on the monsoon rainfall as is the case with most of the rivers in Peninsular India. The present project is being proposed mainly as a storage reservoir. As per “Guidelines for Preparation of Feasibility Report of Irrigation & Multipurpose projects, 2010” and further revised during 2016, the minimum length of Hydrological inputs required is about 25 years. In the present proposal, the yield series have been generated on 10 daily basis for the available discharge data of 43 years.

4.2 Water inflows

Guage flows are available at Biligundlu from 1972 to 2017. This data has been used in the formulation of this project.

4.3 Sedimentation studies

It is necessary to study the sediment data before finalizing the planning and implementation of a Reservoir which is proposed to be used for multipurpose usage. In this connection, it is pertinent to note that storage reservoirs built across rivers tend to loose their capacity over years on account of deposition of sediment. The sediment accumulation in a reservoir is progressive which reduces its active capacity thereby affecting the capability to provide required quantum of water for use through passage of time.

The collection of sediment near the dam will affect the future functioning of water intakes which in turn affects decision regarding location and height of various outlets (in case it is an irrigation project). The reservoir may also face problems of rise in flood levels in the head reaches which will definitely affect the area in question.

Before planning of a new project, it is necessary to view the sedimentation as an additional factor and study its effect and evaluate the performance of the reservoir.

4.3.1 Planning of new Storage reservoir

Before planning of any new storage reservoir, it is necessary to assess the seriousness of the sediment problem and classify it as insignificant , significant or serious. This is usually done by comparing the expected average annual volume of sediment deposition with the gross capacity of the reservoir.

In case, ratio is greater than 0.5% per year, the problem is usually considered serious and special care needs to be taken in estimating the sediment yield from the catchment.

In case it is less than 0.1% per year, the problem is insignificant and changes in reservoir capacity can be neglected for study of reservoir performance.

For cases falling in between these two limits, the problem is considered significant and requires further studies.

This project is planned as a Balancing reservoir with the objective of ensuring releases to Tamil Nadu (in a normal year) of 177.25 TMC as per the CWDT Award further modified by the Hon'ble Supreme Court of India 0n 16/02/2018 coupled with drinking water supply to Bangalore Metropolitan Region, its surrounding areas in the Cauvery Basin. Further, the elevation difference in the bed level between the project site and the State border will be utilized to generate power from the releases effected to. Thus for supplying power to a grid, its full service time has been taken as not less than 25 years, feasible service time as not less than 17 years. (As per IS: 12182-1987)

4.3.2 Rates of sedimentation

Before fixing the capacity of reservoir it is necessary to compute the sediment yield for predicting the probable sediment distribution in the reservoir below the normal FRL.

The measurement of sediment yield/ estimation is done by any one of the following methods

a. Sedimentation surveys of reservoirs with similar catchment characteristics or
b. Sediment load measurements of the stream

In case of Cauvery River in which the proposed Mekedatu Balancing Reservoir cum Drinking Water Project is envisaged, the sediment load measurements have been carried out by CWC at its gauging station at Biligundlu from year 1973 – 2017, which lies on the downstream of the proposed 'C' site. As such, for working out the capacity at various FRLs and probable sediment load calculation, the said data has been considered as the basis.

The sediment rate at Biligundlu is 0.075 while in the projects lying on the same river like Hemavathy, Harangi, Kabini, KRS on the upstream and Mettur on the downstream of the proposed 'C' site, the rate of sediment is as under. For calculation purpose, the rate of sediment at Biligundlu is considered for the proposed 'C" site as both sites are quite close to each other.

A comparative statement of sedimentation rate is indicated below:

No	Name of the Reservoir	Average rate of sedimentation in Thousand cum/Sq.Km
1.	Hemavathy	0.903
2.	Harangi	2.081
3.	Kabini	0.300
4.	KRS	0.115
5.	Mettur	0.242
6.	At Biligundlu	0.075

(Source: Compendium on silting of reservoirs in India- 2015, Water and reservoir sedimentation Directorate, CWC)

4.3.3 Sedimentation fraction expected

The following are the sediment fraction expected in the reservoir as per the available data at Biligundlu.

- Medium and Coarse fraction
- Fine fraction

4.3.4 Quantity of sediment

As per observations at the gauge site maintained by CWC, the quantity of sediment accumulation in a year will be 0.075 thousand cum / Sq Km of the area.

The estimated 50 year sediment at Biligundlu = 0.075 * 50 (years) * 23920 Sq. Km {CA of Biligundlu - (CA of Kabini + CA of KRS}

= 89700 Thousand cum

= **89.7 MCM or 8970 Ha-m**

4.3.5 Type and shape of reservoir

It is an Ogee type concrete gravity dam.

4.3.6 Sediment studies

As indicated in 4.3.4 above, the rate of sedimentation including the probable volume of sediment accumulation in 50 years have been worked out based on the sediment data available at Biligundlu.

4.3.7 Methodology

Boreland and Miller (1958) classified the distribution pattern of sediment in a reservoir into four standard types. The data showed that a definite relationship between the percent of total reservoir depth to the percent of total reservoir sediment volume existed for each of the four different reservoir types based on physical shape. The type of the reservoir is defined by plotting the reservoir depth (ordinate) against capacity (abscissa) on logarithmic coordinates. This curve plots as a straight line, although some reservoirs may have a shape resulting in two straight lines. The reciprocal of the slope of the line indicates the reservoir type. Curves showing a rapid increase in capacity with depth indicate large basin type reservoir, whereas a small increase in the relationship indicates gorge type reservoirs. The classification on this basis is given in the **Table 4.1**.

Table 4.1: Reservoir types for sediment distribution

m	Reservoir Type	Standard Classification
1-1.5	Gorge	IV
1.5-2.5	Hill	III
2.5-3.5	Flood Plain Foot Hill	II
3.5-4.5	Lake	I

Two methods have been suggested for approximate determination of the sediment distribution with elevation:

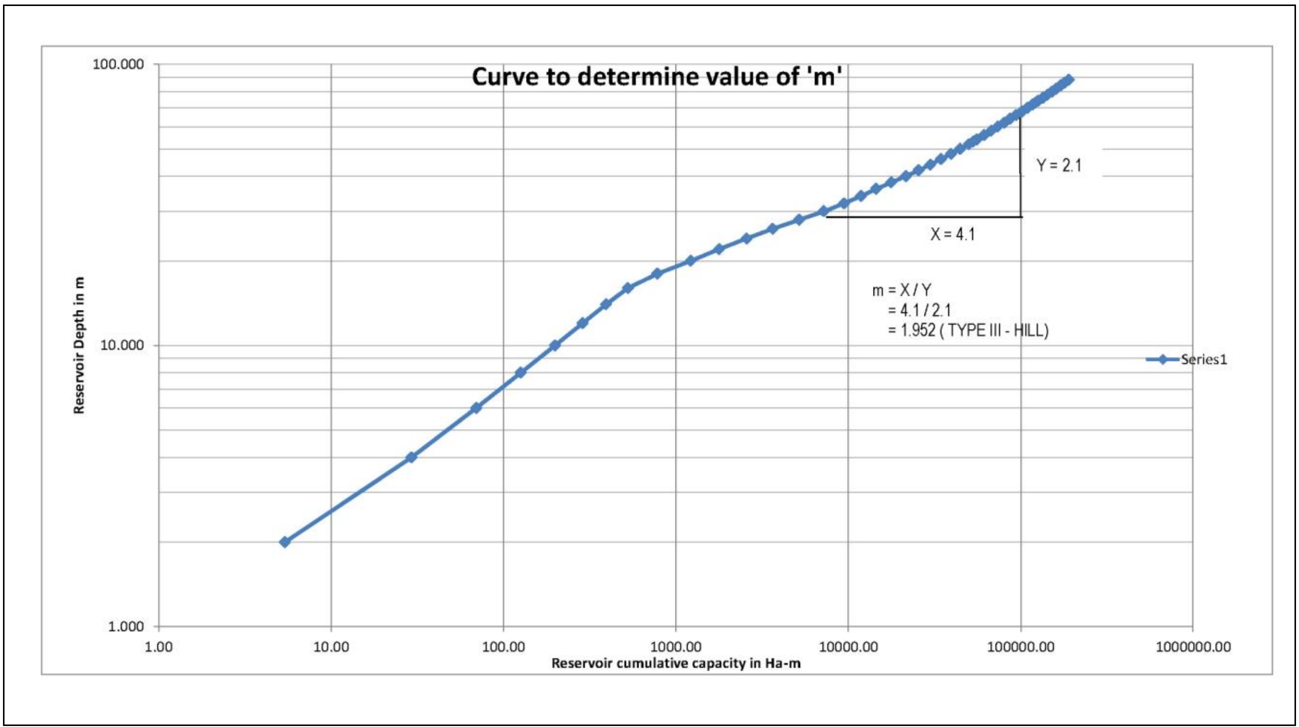
- The area increment method, and
- The empirical area reduction method, particularly applicable to large multipurpose reservoirs.

In the present study, Empirical Area reduction method is adopted.

4.3.8 Determination of 'm' value

The reservoirs are classified into four types, namely, (IV) gorge, (III) hill, (II) Flood plain-foot hill, and (I) lake, based on the ratio of the reservoir capacity to the reservoir depth plotted on a log-log scale. Refer Fig.

From figure, The present reservoir is classifies as Type III - Hill.



4.3.9 Determination of New Zero Elevation

This method is used to determine the new zero elevation 0, directly without trial and error process. Two parameters f (p) and f' (p) as explained below are made use of:

$$f(p) = \frac{1 - V(p)}{a(p)} \quad \text{....(3)}$$

$$f'(p) = \frac{S - V(pH)}{H\,A(pH)} \quad \text{....(4)}$$

where

- $f(p)$ = a function of the relative depth of reservoir for one of the four types of theoretical design curves,
- $V(p)$ = relative volume at a given elevation,
- $a(p)$ = relative area at a given elevation,
- $f'(p)$ = a function of the relative depth of reservoir for a particular reservoir and its anticipated sediment storage,
- S = total sediment in the reservoir in hectare metres,
- $V(pH)$ = reservoir capacity at a given elevation in hectare metres,
- H = the total depth of reservoir for normal water surface in metres, and
- $A(pH)$ = reservoir area at a given elevation in hectares.

4.3.10 Empirical Area reduction Method

The method was developed by Borland and Miller (1958) from analysis of sediment distribution data obtained from surveys of 30 reservoirs. They prepared area design curves for the four standard types of reservoirs with relative sediment area as ordinate and relative depth as abscissa, the area under the curve being unity in each case. The curves could be represented by the equation,

$$A_p = C\ p^m (1-p)^n$$

Where

Ap = Relative sediment area at depth h,

p = Relative depth = h/H,

h = Depth of water level measured from the original stream bed level, and

C, m and n = Constants.

The four standards curves were used to compute sediment distribution in reservoirs and the method was termed as empirical area reduction method. It may be noted that the method gives only the distribution of sediments in the reservoir at different elevations; the total sediment accumulation for a given period has to be estimated separately. The values C, m and n for different types of reservoir are as below in **Table 4.2**

Table 4.2: The values C, m and n for different types of reservoir

Type	C	m	n	Equation of area design curve
I	3.4170	1.5	0.2	$A_p = 3.417p^{1.5} (1\text{-}p)^{0.2}$
II	2.3240	0.5	0.4	$A_p = 2.324p^{0.5} (1\text{-}p)^{0.4}$
III	15.8820	1.1	2.3	$A_p = 15.882p^{1.1} (1\text{-}p)^{2.3}$
IV	4.2324	0.1	2.5	$A_p = 4.232p^{0.1} (1\text{-}p)^{2.5}$

The stepwise procedure for computation is as below:

(i) Determine the type of the reservoir on the basis of value of M from Table 8.1.

(ii) Determine the relative depth for each increment at each value of h.

(iii) Select as a first approximation a NZE (an elevation upto which the reservoir is expected to be filled up completely by sediment). Sediment area at and below this elevation will be equal to the original reservoir area. Sediment areas for each depth increment above the assumed NZE would be obtained by finding, K = A_o/A_p and multiplying K by the A_p value at each h.

(iv) After computing the sediment areas the incremental sediment volumes can be computed as explained earlier. If the cumulative sediment volume does not tally with the anticipated sediment accumulation in the reservoir, the second approximation for the NZE would have to be made.

Refer **Appendix 10** for Determination of New Zero elevation at RL 440.00 m and Detailed Sediment analysis using Empirical Area reduction Method.

i. Area Elevation Capacity (Before sediment – 50 years)

Topographic survey of the reservoir area should form the basis for obtaining these curves, which are respectively the plots of elevation of the reservoir versus surface area and elevation of the reservoir versus volume. For preliminary studies, in case suitable topographic map with contours, say at intervals less than 2.5 m is not available, stream profile and valley cross sections taken at suitable intervals may form the basis for computing the volume.

In the present study, the Elevation Area Capacity relationship has been developed based on the 2.5 m contour intervals and is shown in **Appendix 2**. The graphical representation of the Elevation Area Capacity is indicated hereunder.

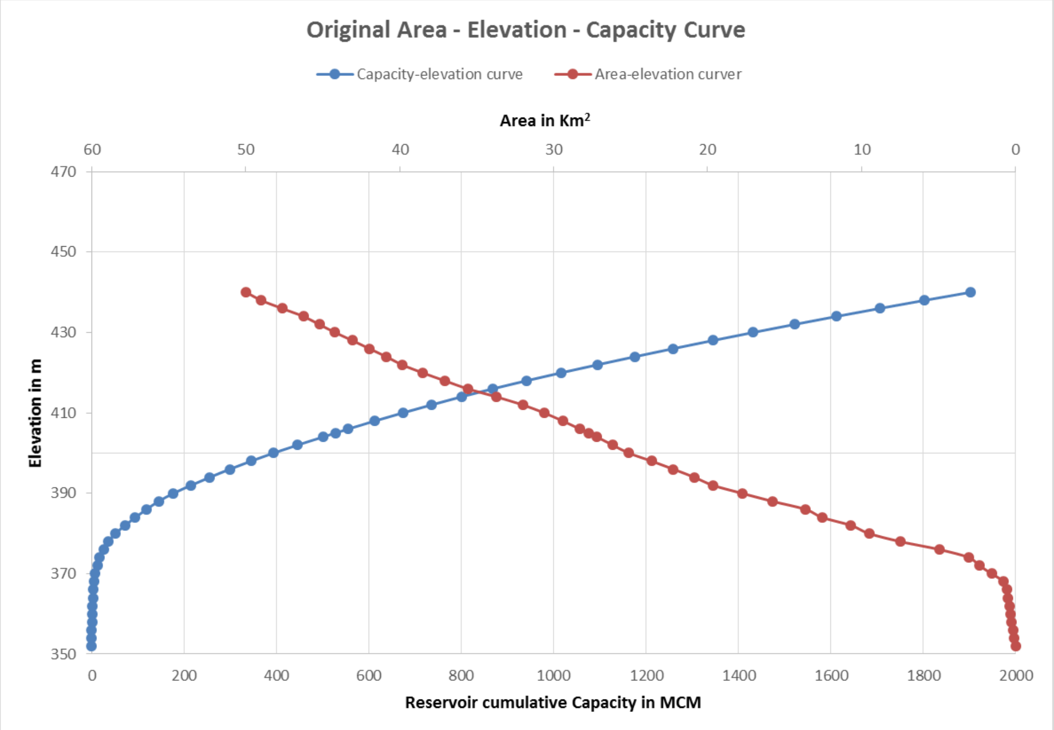


Fig. 4.1: Original Area- Elevation - Capacity Curve

ii. Sedimentation in the reservoir after 50 years

After 50 years, The Sedimentation accumulation will be **8970 Ha-m** working out to a loss of about 3 TMC.

iii. Revised Area Capacity Curve after Sedimentation

The revised area capacity curve after sedimentation i.e. after 50 years is as indicated in Fig. 4.2

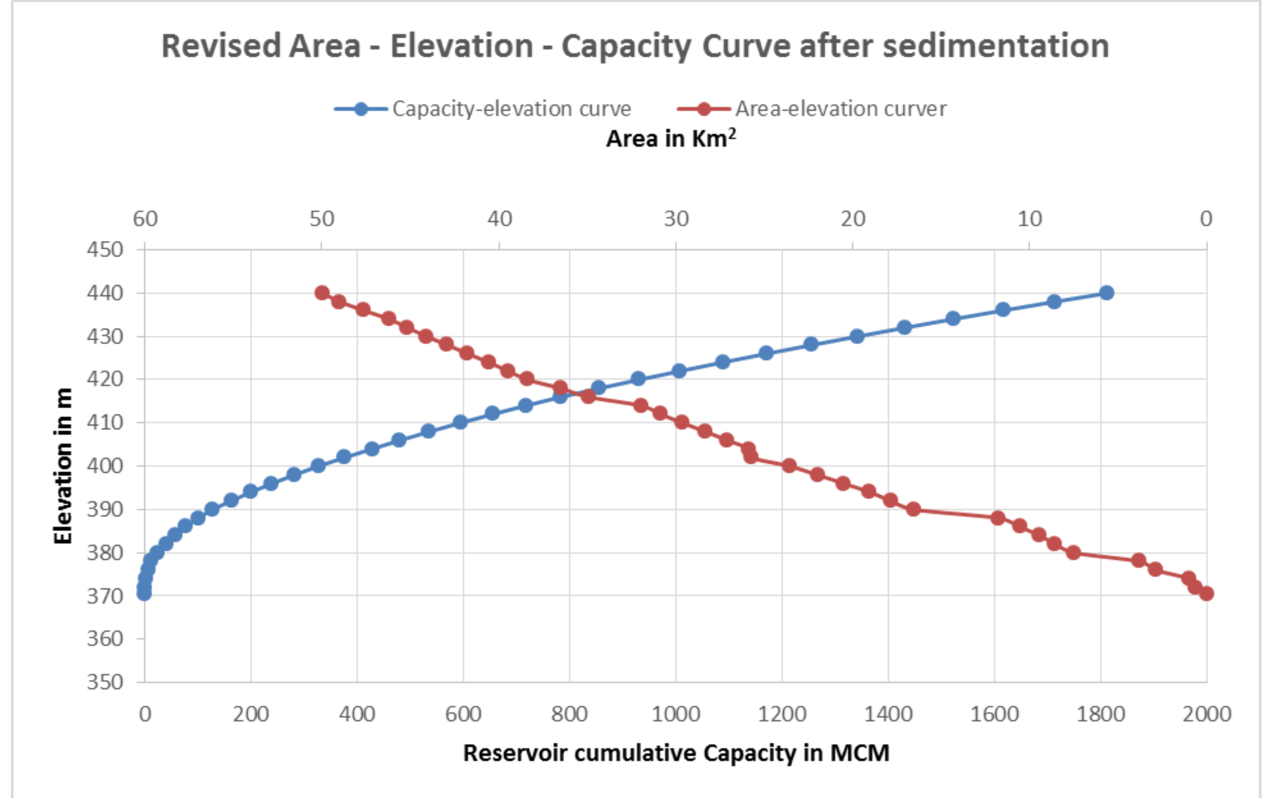


Fig. 4.2: Revised Area- Elevation - Capacity Curve after sedimentation (50 years)

4.4 Potential evapotranspiration and rainfall

The present project is envisaged as a Balancing reservoir and Drinking water supply scheme. As such, irrigation and command area are not a part of the project.

4.5 Inputs of water quality

There are no water quality / salinity problems in the Cauvery basin in Karnataka.

4.6 Low flow inputs

The CWC has a G & D site located at biligundlu on the downstream of the proposed Mekedatu Balancing Reservoir cum Drinking Water Project. The daily G & D data is available from 1972 onwards. The analysis of the daily observed data indicates that the flow is low during the months of February to April.

Since it is a storage project, the influence of low flows on the performance of the project is insignificant. From the gauged flows at Biligundlu from 1984-85 to 2016-17, the monthly average flows expressed as a percentage of annual flows are as follows.

Month	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Percentage	3.3	14.5	20.0	15.0	17.2	11.3	6.4	3.2	2.2	2.0	2.3	2.6

It is seen from the above table that most of the flow (about 84%) occurs from July to December. The low flow season can be considered to be from January to June and about 16% of the flow occurs during this season. The proposed reservoir therefore receives most of its storage from July to December. The low flows being only 16% of the annual flows, fluctuations of flow in this season do not affect the performance of the reservoir significantly.

4.7 Surface to ground water recharge

The project does not have a specific recharge component. The only recharge is what takes place from the bed of the reservoir.

Chapter 5
Preparation of Hydrologic Inputs for studies other than simulation

5.1 Design floods for safety of structures

5.1.1 Criteria for selection of Design floods for each structure

Para 3.1.2.& 3.1.3. of I S Code 11223 classifies the dam / reservoir to their size, Hydraulic head and fixes the design flood for safety of dam for each of them a under.

Table 5.1: Classification for the dam

Classification	Gross Storage	Hydraulic Head
Small	Between 0.50 M Cum & 10.00 M Cum	Between 7.50 m & 12.00m
Intermediate	Between 10.00 M Cum & 60.00 M Cum	Between 12.00 m & 30.00 m
Large	Greater than 60.00 M Cum	Greater than 30.00 m

The proposed balancing Reservoir by virtue of having a height of more than 60.00 m falls under the Category of Large Dams.

Table 5.2: Inflow design flood for safety of the dam

Size as determined in 3.1.2	Inflow design flood for design of dam
Small	100 year flood
Intermediate	Standard Project Flood (SPF)
Large	Probable Maximum Flood (PMF)

As per above Table 5.2, for designing of the balancing Reservoir, it is necessary to consider Probable maximum Flood (PMF).

It is also stated that larger or smaller magnitude may be used if the hazard involved in the eventuality of a failure is particularly high or low.

5.1.2 Overall approach adopted

As per the above Classification, the proposed balancing Reservoir has to be designed for PMF.

The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum participation, and where applicable coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against the event. The PMF defines the extent of flood prone land, that is, the floodplain.

The extent, nature and potential consequences of flooding associated with a range of events rather than flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.

5.1.3 Hydro meteorological approach

In the Hydrometerological Approach, attempt is made to analyze the causative factors responsible for production of severe floods. The design flood computation mainly involves **estimation of a design storm hyetograph** and derivation of **catchment response function**. The catchment response function used can be either a lumped system model or a distributed lumped system model. In the former, a unit hydrograph is assumed to represent the entire catchment area and in the distributed model, the catchment is divided into smaller sub-regions, and the **unit hydrographs** of each sub-region applied with channel routing will define the catchment response. The main advantage of this method is, it gives a complete flood hydrograph and this allows making a realistic determination of the moderating effect while passing through a reservoir or a river reach. The method has certain limitations also such as requirement of long term Hydrometerological data, knowledge of rainfall process etc.

The river Cauvery in Karnataka rises in Kodagu district. Several tributaries join it in Karnataka upstream of the Mekedatu dam site. The tree diagram, with major tributaries and the four major dams *viz* Hemavati, Harangi, Kabini and KRS, is shown in Fig. 5.1. The dam is designed for the PMF, obtained with the hydro meteorological approach.

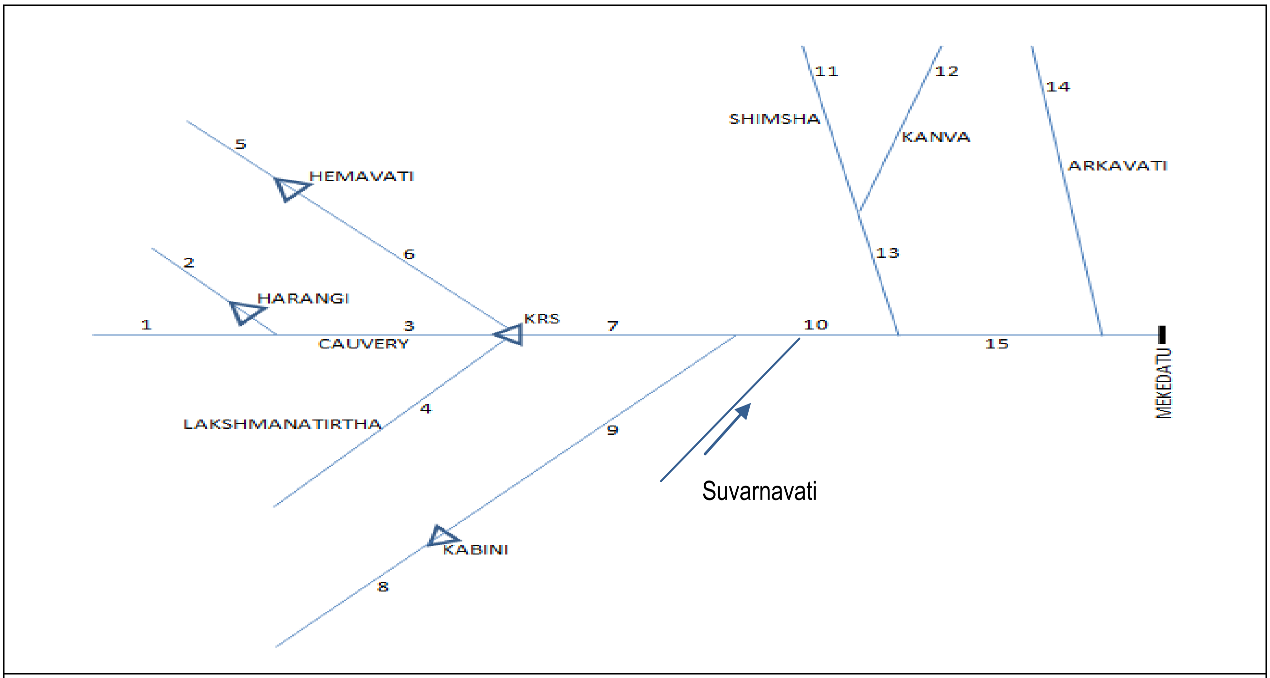


Fig. 5.1:Catchment Area Map with Subcatchment

5.1.3.1 Design Storm

Design storm determination is the most important part of the Hydrometerological approach. The design storm can be a SPF or PMF or a T-Year storm. In the present proposal, as per the Classification of dams (IS 11223), for design storm PMF has to be considered. Accordingly, PMF is calculated by using the 1 day, 2 days and 3 days PMP values as per "*PMP Atlas for Cauvery and Other East Flowing River Basins*", Volume I prepared by CWC & IMD.

5.1.3.2 Methodology

The catchment area above Mekedatu is 34273 km^2. It is divided into 15 sub catchments as shown in Table 1, each of area less than 5000 km^2 except one. The method described in the CWC publication "*Flood Estimation Report for Kaveri Basin Subzone*-3(i)" (Design Office Report No. CB/11/1985) is adopted to determine synthetic unitgraph and design hydrograph for each sub catchment. It consists of the following steps:

- Preparation of catchment area plan
- Determination of physiographical parameters *viz* sub catchment area (A), length of longest stream in the sub catchment (L), length of longest stream from a point opposite the centre of gravity to the outlet of the sub catchment (L_c), and equivalent stream slope (S)
- Determination of 1-hour synthetic unitgraph *i.e.* peak discharge per km^2 (q_p), peak discharge in the sub catchment (Q_p), basin lag (t_p), peak time of UG (T_m), and time base of unitgraph (T_B)
- Determination of UG ordinates at 1-hour intervals
- Estimation of design storm duration (T_D). This was taken to be the same as T_B since the PMF is being determined for a storage reservoir
- Estimation of point rainfall and areal rainfall for design storm duration
- Distribution of areal rainfall during design storm duration to obtain hourly rainfall increments
- Estimation of rainfall excess
- Estimation of base flow
- Computation of design flood hydrograph

The catchment area plan and the subcatchments numbered from 1 to 15 are shown in Fig. 5.2, corresponding to those shown in the tree diagram of Fig. 5.1.are shown in Table 5.3.

Table 5.3: Details of the Sub catchments

No	Description	Catchment area in Sq. Km (A)	Length of Longest Stream (L) in Km	Length of longest stream from a point opp the CG of Catchment to the d/s end of the river segment (Lc) in Km	Equivalent Stream Slope (S)
A	B	C	D	E	F
1	Origin of Cauvery up to Confluence with Harangi	1117.58	72.6	35.4	1.73
2	Origin of Harangi up to Harangi dam	419.60	31.3	17.17	4.86
3	Harangi confluence up to KRS	1591.19	64	29.8	1.65
4	Origin of Lakshmanatirtha up to confluence with KRS	1697.67	96.8	45.3	0.33
5	Origin of Hemavati up to Hemavati dam	2810.00	86.6	38.6	1.99
6	Hemavati dam up to confluence with KRS	2537.38	126	63.3	1.33
7	KRS dam up to confluence with Kabini	1570.90	46.13	32.14	1.54
8	Origin of Kabini up to Kabini dam	2141.90	78.3	42	1.59
9	Kabini dam up to confluence with Cauvery	4533.21	109.5	63	2.26
10	Confluence of Kabini to confluence of Shimsha	3007.94	106.7	54.24	6.20
11	Origin of Shimsha up to confluence with Kanva	6412.41	171.8	81.4	3.71
12	Origin of Kanva up to confluence with Shimsha	1094.26	112	53.4	3.80
13	Shimsha- Kanva confluence up to Shimsha confluence with Cauvery	780.89	38.89	20.04	7.90
14	Origin of Arkavati up to confluence with Cauvery	4352.69	140.12	69.74	2.56
15	Shimsha-Cauvery confluence up to Mekedatu	205.36	23.2	12.08	2.53
	Total Catchment Area (A)	**34273.00**	**1303.94**	**657.61**	

The values of A, L, L_c and S were determined using GIS.

The UG parameters were determined using the following formulae:

$$t_p = 0.553(LL_c/\sqrt{S})^{0.405}$$

$$q_p = 2.043/(t_p)^{0.872}$$

$$T_B = 5.083(t_p)^{0.733}$$

$$T_m = t_p + t_r/2$$

$$Q_p = q_p \times A$$

The unitgraph adopted is in the form of a triangle with the above time base and peak discharge. No attempt was made to reduce the unitgraph widths at 50% and 75% of Q_p with a view to adopt a conservative approach. A one-hour rainfall excess is considered, so t_r = 1.

The calculations are shown in Table 1, the last column of gives the peaks of the unitgraphs. The time base T_B is rounded off to the nearest hour. The unitgraph ordinates are given in **Appendix 6.1 of FEASIBILITY REPORT (Volume II)**

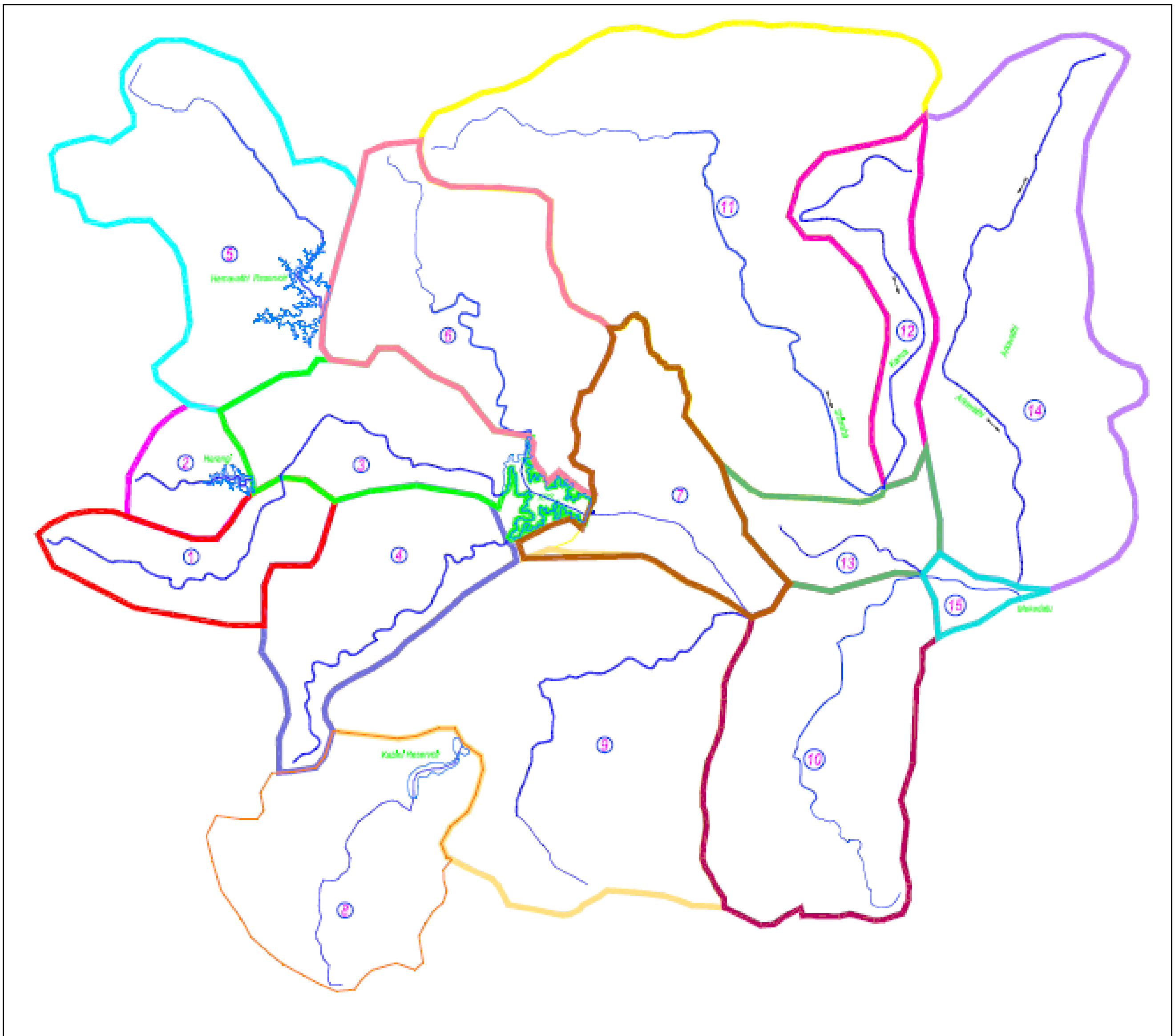


Figure 5.1: Catchment Area Map with Subcatchment

5.1.3.3 Probable Maximum Precipitation

The CWC and IMD have prepared a PMP atlas entitled "PMP Atlas for Cauvery and Other East Flowing River Basins", Volume I of which contains 1-day, 2-day and 3-day PMP values. Fig. 5.2 shows the area considered by them, where the Cauvery basin up to KRS dam is designated by 302U (high rainfall), and from KRS dam to a point downstream of Mekedatu by 302M (lower rainfall). The sub basin 302U consists of subcatchments 1 to 6 of the present report, and the remaining subcatchments 7 to 15 come within 302M. The PMP values for 302U are shown in Table 5.5, and those for 302M in Table 5.6 of this report. The 3-day PMP values are chosen for the calculation of PMF in this report. They are taken from Table 5.5 for subcatchments 1 to 6 and 8, and Table 5.6 for subcatchments 7 and 9 to 15. Although subcatchment 8 (Origin of Kabini up to Kabini dam) is included in 302M, it actually lies in the high rainfall region of Western Ghats, and hence its PMP is taken from 302U.

The PMP is based on point rainfall, and hence needs to be multiplied by an area correction factor. This factor is shown in Table 5.7. The rainfall is then distributed in time as per Table 5.8 over the duration TB. Hourly rainfall increments are then derived from the distributed rainfall. A loss rate of 0.5 cm/hr is assumed, and this is deducted from the rainfall increments to obtain the rainfall excess increments. These increments are then sequenced such that the highest increment is paired with the highest UG ordinate, the second highest increment is paired with the second highest UG ordinate, and so on. The sequence is then reversed to maximize the flood. These rainfall excess increments are shown for all the subcatchments in **Appendix- 6.1 of Detailed Project Report (Volume II)**

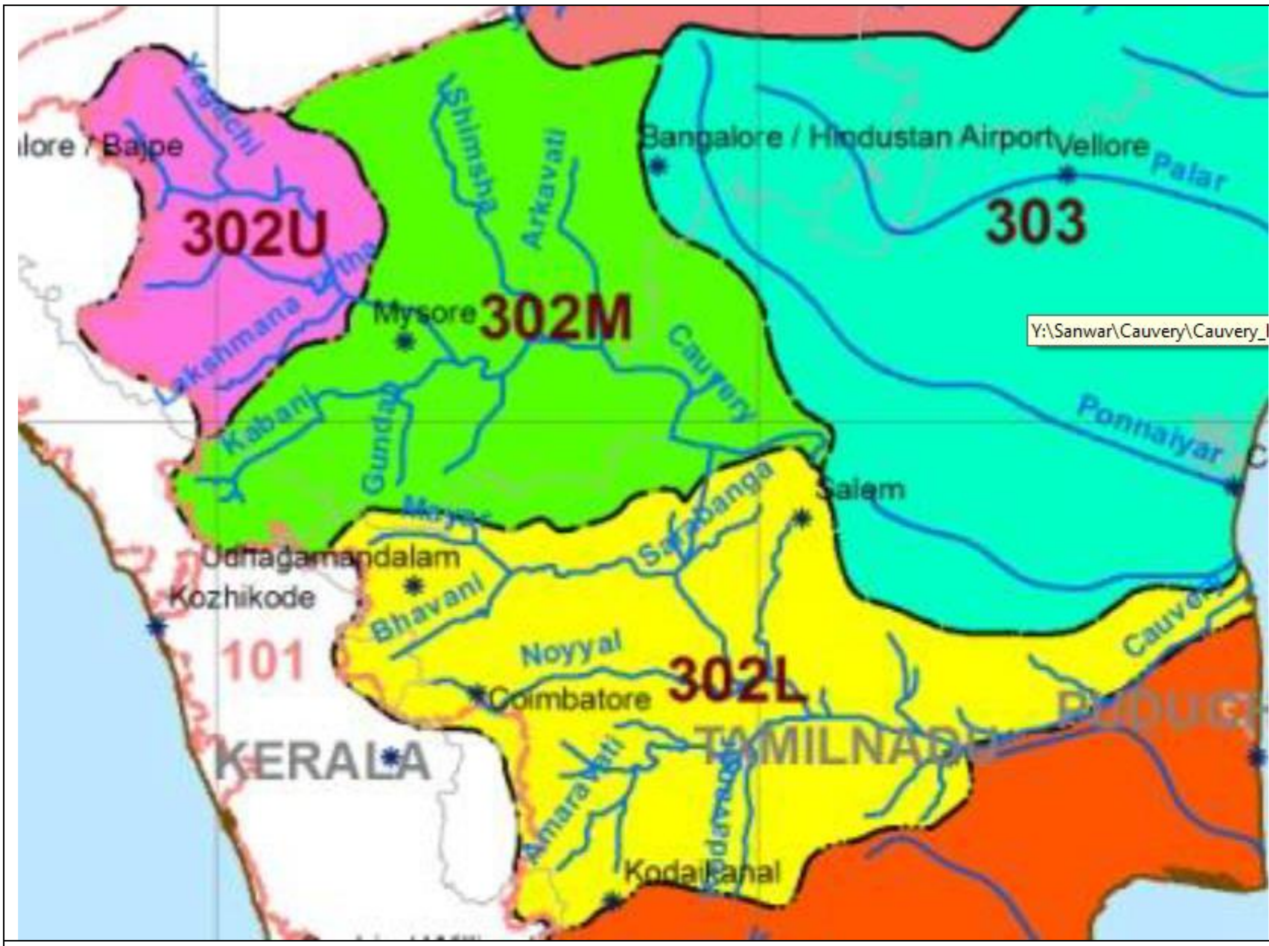


Fig. 5.2: PMP Atlas for Cauvery and Other East Flowing River Basins", Volume I of which contains 1-day, 2-day and 3 day PMP values

5.1.3.4 Generation of Direct Runoff Hydrograph

Direct runoff hydrograph is computed for each subcatchment by the convolution of the corresponding UG and rainfall excess increments. This was done using a Fortran program, which is shown in **Appendix 6.2 of Detailed Project Report (Volume II)**

5.1.3.5 Base Flow and Flood Hydrograph

Base flow for each subcatchment is calculated as 0.05 cumec/km^2 of catchment area. This is added to the direct runoff hydrograph to obtain the flood hydrograph for the subcatchment. These hydrographs for all 15 subcatchments are shown in **Appendix 6.3 of Detailed Project Report (Volume II)**

5.1.3.6 Flood Routing

The hydrographs have to be routed through reservoirs and river channels from the first subcatchment up to Mekedatu. All four reservoirs in the catchment being meant for conservation storage, the gates are in practice operated during floods to keep the reservoir level constant, i.e., outflow is kept equal to inflow.

Hence routing through the reservoirs is done by equating outflow to inflow. This is on the conservative side, since flood moderation by the reservoirs is not taken into account.

The hydrographs are routed through river channel by the Muskingum method. The equations used are (Engineering Hydrology, K Subramanya)

$$Q_2 = C_0I_2 + C_1I_1 + C_2Q_1$$

$$C_0 = (Kx + 0.5\Delta t)/(K – Kx + 0.5\Delta t)$$

$$C_1 = (Kx + 0.5\Delta t)/(K – Kx + 0.5\Delta t)$$

$$C_2 = (K \;\; Kx + 0.5\Delta t)/(K – Kx + 0.5\Delta t)$$

where Q1 and Q2 are the outflows at the beginning and end of the time interval Δt and I1 and I2 are the corresponding inflows. K and x are constants. Value of x is taken as 0.2.

The constant K is approximately the time taken by a flood wave to traverse the length of the river channel. For the subcatchments, the celerity of the flood wave is assumed as 5 m/s and the value of K is calculated based on the length of the longest stream L. Muskingum coefficients calculated in the above manner are shown in Table 5.9.

5.1.3.7 Results

The routing sequence is as follows where the numbers refer to the subcatchments:

(i) Hydrograph 2 is routed through Harangi reservoir and added to Hydrograph 1. The combined Hydrograph is routed through 3 and added to Hydrograph 3

(ii) Hydrograph 5 is routed through Hemavati reservoir and then through 6. This Hydrograph is added to Hydrographs 6, 4 and the Hydrograph obtained in step (i) to obtain inflow to KRS

(iii) KRS inflow is routed through 7 and added to Hydrograph 7

(iv) Hydrograph 8 is routed through Kabini reservoir and then through 9, and added to Hydrograph 9. This is added to the Hydrograph obtained in step (iii)

(v) Hydrograph obtained in step (iii) is routed through 10 and added to Hydrograph 10

(vi) Hydrograph 11 and Hydrograph 12 are added, routed through 13, and added to Hydrograph 13. The resultant Hydrograph is added to that obtained in step (v)

(vii) Hydrograph obtained in step (vi) is routed through 15 and added to Hydrograph 15 and then to Hydrograph 14. This gives the PMF at Mekedatu.

Appendix 6.4 of Detailed Project Report (Volume II) for routing calculations.

With the above procedure, the PMF obtained is 19039 cumecs, or 6.73 lakh cusecs. However, Karnataka Engineering Research Station(KERS - **Appendix 6.5 Vol II**) conducting the studies for estimation of the PMF as per CWC recommendations for the KRS dam have estimated the PMF at 16,876 cumecs (5,96,060 cusecs). Thus considering the downstream catchment area influence between the KRS and Mekedatu, a design flood at 22,654 cumecs (8,00,000 cusecs) has been adopted.

Table 5.4: Subcatchment and Unitgraph Parameters

No	Description	A	L	L_c	S	LLc/√S	tp	qp	TB	Tm	Qp
1	Origin of Cauvery up to Confluence with Harangi	1117.58	72.6	35.4	1.73	1952.397	11.896	0.236	31.217	12.396	263.509
2	Origin of Harangi up to Harangi dam	419.60	31.3	17.17	4.86	243.697	5.122	0.492	16.831	5.622	206.304
3	Harangi confluence up to KRS	1591.19	64	29.8	1.65	1483.379	10.643	0.260	28.772	11.143	413.403
4	Origin of Lakshmanatirtha up to confluence with KRS	1697.67	96.8	45.3	0.33	7625.708	20.656	0.146	46.779	21.156	247.400
5	Origin of Hemavati up to Hemavati dam	2810.00	86.6	38.6	1.99	2369.779	12.867	0.220	33.065	13.367	618.738
6	Hemavati dam up to confluence with KRS	2537.38	126	63.3	1.33	6920.694	19.860	0.151	45.451	20.360	382.658
7	KRS dam up to confluence with Kabini	1570.90	46.13	32.14	1.54	1193.072	9.745	0.281	26.971	10.245	440.764
8	Origin of Kabini up to Kabini dam	2141.90	78.3	42	1.59	2611.128	13.383	0.213	34.031	13.883	455.747
9	Kabini dam up to confluence with Cauvery	4533.21	109.5	63	2.26	4584.266	16.809	0.174	40.220	17.309	790.686
10	Confluence of Kabini to confluence of Shimsha	3007.94	106.7	54.24	6.20	2325.008	12.768	0.222	32.878	13.268	666.799
11	Origin of Shimsha up to confluence with Kanva	6412.41	171.8	81.4	3.71	7256.651	20.245	0.148	46.095	20.745	950.990
12	Origin of Kanva up to confluence with Shimsha	1094.26	112	53.4	3.80	3069.935	14.289	0.201	35.706	14.789	219.896
13	Shimsha- Kanva confl to Shimsha confl with Cauvery	780.89	38.89	20.04	7.90	277.251	5.396	0.470	17.488	5.896	366.839
14	Origin of Arkavati up to confluence with Cauvery	4352.69	140.12	69.74	2.56	6112.378	18.886	0.158	43.806	19.386	685.855
15	Shimsha-Cauvery confluence up to Mekedatu	205.36	23.2	12.08	2.53	176.102	4.490	0.551	15.284	4.990	113.246
	Total	**34273**									

Table 5.5: PMP Values for Subcatchments 1 to 6 and 8

Table 3-21: SPS (insitu) and PMP (insitu) values for catchment-302U

Area, sq. km.	1-Day				2-Day				3-Day			
	Storm	In-situ SPS (mm)	MMF	PMP (mm)	Storm	In-situ SPS (mm)	MMF	PMP (mm)	Storm	In-situ SPS (mm)	MMF	PMP (mm)
25	16 Jun 1984	644	1.09	702	15-16 Jun 1984	1037	1.09	1130	15-17 Jun 1984	1309	1.09	1427
100	16 Jun 1984	502	1.09	547	15-16 Jun 1984	806	1.09	879	15-17 Jun 1984	1010	1.09	1101
200	16 Jun 1984	446	1.09	486	15-16 Jun 1984	735	1.09	801	15-17 Jun 1984	924	1.09	1007
500	16 Jun 1984	369	1.09	402	15-16 Jun 1984	665	1.09	725	15-17 Jun 1984	849	1.09	925
1,000	16 Jun 1984	314	1.09	342	15-16 Jun 1984	601	1.09	655	15-17 Jun 1984	772	1.09	841
1,500	16 Jun 1984	292	1.09	318	15-16 Jun 1984	552	1.09	602	15-17 Jun 1984	728	1.09	794
2,000	16 Jun 1984	274	1.09	299	15-16 Jun 1984	515	1.09	561	15-17 Jun 1984	688	1.09	750
3,000	16 Jun 1984	248	1.09	270	15-16 Jun 1984	455	1.09	496	15-17 Jun 1984	623	1.09	679
4,000	16 Jun 1984	226	1.09	246	15-16 Jun 1984	408	1.09	445	15-17 Jun 1984	572	1.09	623
5,000	16 Jun 1984	206	1.09	225	15-16 Jun 1984	375	1.09	409	15-17 Jun 1984	529	1.09	577
7,500	22 Jul 1975	139	1.18	164	23-24 May 1957	214	1.20	257	14-16 May 1972	230	1.15	265
10,000	22 Jul 1975	120	1.18	142	23-24 May 1957	197	1.20	236	14-16 May 1972	215	1.15	247
20,000	14 May 1972	86	1.15	99	14-15 May 1972	152	1.15	175	14-16 May 1972	178	1.15	205
30,000	14 May 1972	74	1.15	85	14-15 May 1972	129	1.15	148	14-16 May 1972	156	1.15	179
40,000	14 May 1972	64	1.15	74	14-15 May 1972	112	1.15	129	14-16 May 1972	139	1.15	160
50,000	14 May 1972	50	1.15	58	14-15 May 1972	98	1.15	113	14-16 May 1972	126	1.15	145

Table 5.6:PMP Values for Subcatchments 7 and 9 to 15

Table 3-19: SPS (insitu) and PMP (insitu) values for catchment-302M

Area, sq. km.	1-Day				2-Day				3-Day			
	Storm	In-situ SPS (mm)	MMF	PMP (mm)	Storm	In-situ SPS (mm)	MMF	PMP (mm)	Storm	In-situ SPS (mm)	MMF	PMP (mm)
25	22 Jul 1975	321	1.18	379	22-23 Jul 1975	351	1.18	414	22-24 Jul 1975	406	1.18	479
100	22 Jul 1975	304	1.18	359	22-23 Jul 1975	340	1.18	401	22-24 Jul 1975	380	1.18	448
200	22 Jul 1975	291	1.18	343	22-23 Jul 1975	330	1.18	389	22-24 Jul 1975	368	1.18	434
500	22 Jul 1975	272	1.18	321	22-23 Jul 1975	312	1.18	368	22-24 Jul 1975	350	1.18	413
1,000	22 Jul 1975	250	1.18	295	22-23 Jul 1975	291	1.18	343	22-24 Jul 1975	327	1.18	386
1,500	22 Jul 1975	235	1.18	277	22-23 Jul 1975	276	1.18	326	22-24 Jul 1975	310	1.18	366
2,000	22 Jul 1975	222	1.18	262	22-23 Jul 1975	263	1.18	310	22-24 Jul 1975	296	1.18	349
3,000	22 Jul 1975	198	1.18	234	22-23 Jul 1975	241	1.18	284	22-24 Jul 1975	272	1.18	321
4,000	22 Jul 1975	180	1.18	212	14-15 May 1972	223	1.15	256	14-16 May 1972	257	1.15	296
5,000	22 Jul 1975	169	1.18	199	14-15 May 1972	214	1.15	246	14-16 May 1972	249	1.15	286
7,500	22 Jul 1975	139	1.18	164	14-15 May 1972	197	1.15	227	14-16 May 1972	230	1.15	265
10,000	22 Jul 1975	120	1.18	142	14-15 May 1972	185	1.15	213	14-16 May 1972	215	1.15	247
20,000	14 May 1972	86	1.15	99	14-15 May 1972	152	1.15	175	14-16 May 1972	178	1.15	205
30,000	14 May 1972	74	1.15	85	14-15 May 1972	129	1.15	148	14-16 May 1972	156	1.15	179
40,000	14 May 1972	64	1.15	74	14-15 May 1972	112	1.15	129	14-16 May 1972	139	1.15	160
50,000	14 May 1972	50	1.15	58	14-15 May 1972	98	1.15	113	14-16 May 1972	126	1.15	145

Table 5.7:Area Reduction Factors for 3-day PMP

Table 3-50: Selected area reduction factor for various catchments (3-day)

Area, sq. km.	Catchment No.						
	301	302L	302M	302U	303	304	305
25	1.00	1.00	1.00	1.00	1.00	1.00	1.00
100	0.96	0.95	0.93	0.92	0.95	0.96	0.96
200	0.94	0.93	0.89	0.87	0.93	0.94	0.94
500	0.90	0.88	0.82	0.80	0.90	0.92	0.92
1,000	0.86	0.84	0.75	0.74	0.87	0.90	0.90
1,500	0.83	0.81	0.71	0.71	0.85	0.87	0.88
2,000	0.81	0.79	0.69	0.69	0.84	0.86	0.86
3,000	0.78	0.75	0.64	0.65	0.81	0.83	0.84
4,000	0.75	0.73	0.61	0.62	0.79	0.80	0.81
5,000	0.74	0.71	0.59	0.60	0.77	0.78	0.79
7,500	0.70	0.67	0.54	0.55	0.72	0.74	0.75
10,000	0.67	0.65	0.50	0.52	0.68	0.71	0.72
20,000	0.58	0.57	0.44	0.45	0.56	0.61	0.63
30,000	0.52	0.51	0.38	0.41	0.48	0.55	0.57

Table 5.8:Time Distribution for 9-Day PMP

Table 3-46: Smoothened TD coefficients for entire Cauvery and Adjoining River Basins and for different catchments for 72-hour rainspells

Sub-durations (hours)	Catchment Wise Smoothened TD Coefficient (%)					All Rainspells
	301	302	303	304	305	Entire Basin
1	11.5	5.9	8.3	8.0	14.5	9.3
3	25.3	13.9	17.8	17.5	26.3	18.5
6	35.7	21.4	24.7	26.3	35.7	27.6
9	42.6	28.1	30.9	32.8	41.2	33.6
12	48.9	33.4	36.6	39.2	46.5	38.6
15	54.8	38.0	42.2	45.2	51.7	43.3
18	59.9	42.6	47.7	51.1	56.7	48.0
21	63.8	46.9	52.9	56.6	60.7	52.2
24	67.7	51.1	57.7	61.2	64.7	56.3
27	71.5	55.2	62.1	65.5	68.6	60.3
30	74.6	59.3	66.0	69.4	72.2	64.2
33	77.7	63.3	69.5	73.2	75.5	68.1
36	80.6	67.1	72.9	77.0	78.4	71.9
39	83.2	70.6	76.4	80.2	81.2	75.6
42	85.9	74.1	79.9	83.3	83.7	79.2
45	88.2	77.3	82.8	86.2	86.1	81.9
48	90.6	80.3	85.5	88.9	88.0	84.5
51	92.6	83.1	88.2	91.3	89.9	87.1
54	94.2	85.7	90.8	93.1	91.8	89.5
57	95.8	88.3	93.2	95.0	93.6	91.8
60	97.1	90.8	95.6	96.8	95.2	94.0
63	98.2	93.2	97.8	98.4	96.7	96.1
66	99.2	95.6	98.8	99.0	98.1	97.5
69	99.6	97.8	99.4	99.6	99.1	98.9
72	100.0	100.0	100.0	100.0	100.0	100.0

Table 5.9:PMP and Muskingum Routing Coefficients

Subcatchment	PMP, cm	L, km	K	x	C0	C1	C2
1	36.88	72.6	4	0.2	-0.08108	0.351351	0.72973
2	31.84	31.3	1	0.2	0.230769	0.538462	0.230769
3	45.82	64	3	0.2	-0.03448	0.37931	0.655172
4	43.24	96.8	5	0.2	-0.11111	0.333333	0.777778
5	28.83	86.6	4	0.2	-0.08108	0.351351	0.72973
6	36.78	126	7	0.2	-0.14754	0.311475	0.836066
7	43.49	46.13	2	0.2	0.047619	0.428571	0.52381
8	47.77	78.3	4	0.2	-0.08108	0.351351	0.72973
9	20.86	109.5	6	0.2	-0.13208	0.320755	0.811321
10	20.31	106.7	5	0.2	-0.11111	0.333333	0.777778
11	21.46	171.8	9	0.2	-0.16883	0.298701	0.87013
12	25.65	112	6	0.2	-0.13208	0.320755	0.811321
13	16.64	38.89	2	0.2	0.047619	0.428571	0.52381
14	22.32	140.12	7	0.2	-0.14754	0.311475	0.836066
15	16.48	23.2	1	0.2	0.230769	0.538462	0.230769

5.1.4 Frequency approach

The flood frequencies are determined from the above data by the Gumbel method (Engineering Hydrology, K. Subramanya, 1984, pp. 212-215). The flood of a return period T is given by the equation

$$X_T = X_m + K\sigma$$

where X_T = flood of return period T, X_m = Mean annual flood, $K = (Y_T - Y_n)/S_n$, $Y_T = -\ln \ln (T/(T-1))$, Y_n = Reduced mean in Gumbel's distribution corresponding to the record length n, S_n = Reduced standard deviation in Gumbel's distribution corresponding to the record length n, and σ = standard deviation of the annual peak flood.

Since 43 years data are available, n = 43. From the Tables, Y_n = 0.5453 and S_n = 1.148. From the peak flood data, X_m = 2345 and σ = 1372. Value of Y_T is 3.1985 for T = 25 years and 3.9019 for T = 50 years. With these values, the 25-year flood works out to 5517 cumecs and the 50-year flood to 6357 cumecs.

Similar calculations give the 100-year flood as 7192 cumecs, 500-year flood as 9120 cumecs, and 1000-year flood as 9950 cumecs.

5.1.4.1 Backwater Computation

The backwater computation was carried out using the HEC-RAS software package developed by the US Army Corps of Engineers. The software uses the standard step method and requires flow cross sections to be input for solving the problem. A total of 32 cross sections were generated from toposheets at 1 km intervals covering 32 km length of the river from the dam site, and were input to the software. Reservoir level was assumed to be at FRL (RL 440 m) and the 25-year or 50-year flood was assumed to enter at this condition. The program was then executed to determine the water levels.

For comparison, normal water levels (i.e., pre-Mekedatu dam condition) were also calculated for the two floods with the same software. The downstream boundary condition for these cases were given as the normal depth corresponding to the slope 0.0016, which is the average longitudinal slope of the river bed near the dam site.

5.1.4.2 Results

The water levels are presented in Fig. 5.2 for the 25-year flood. It is seen that the backwater level is practically horizontal at RL 440 m from the dam up to Ch 30 km up stream. Beyond this point, the backwater level merges with the normal water level. This happens because the bed slope of the river is steep.

Fig. 5.3 shows water levels for the 50-year flood. It is very similar to the 25-year flood case. The backwater level merges with the normal water level in this case also at Ch 30 km up stream. Hence land acquisition is necessary only up to RL 440 m.

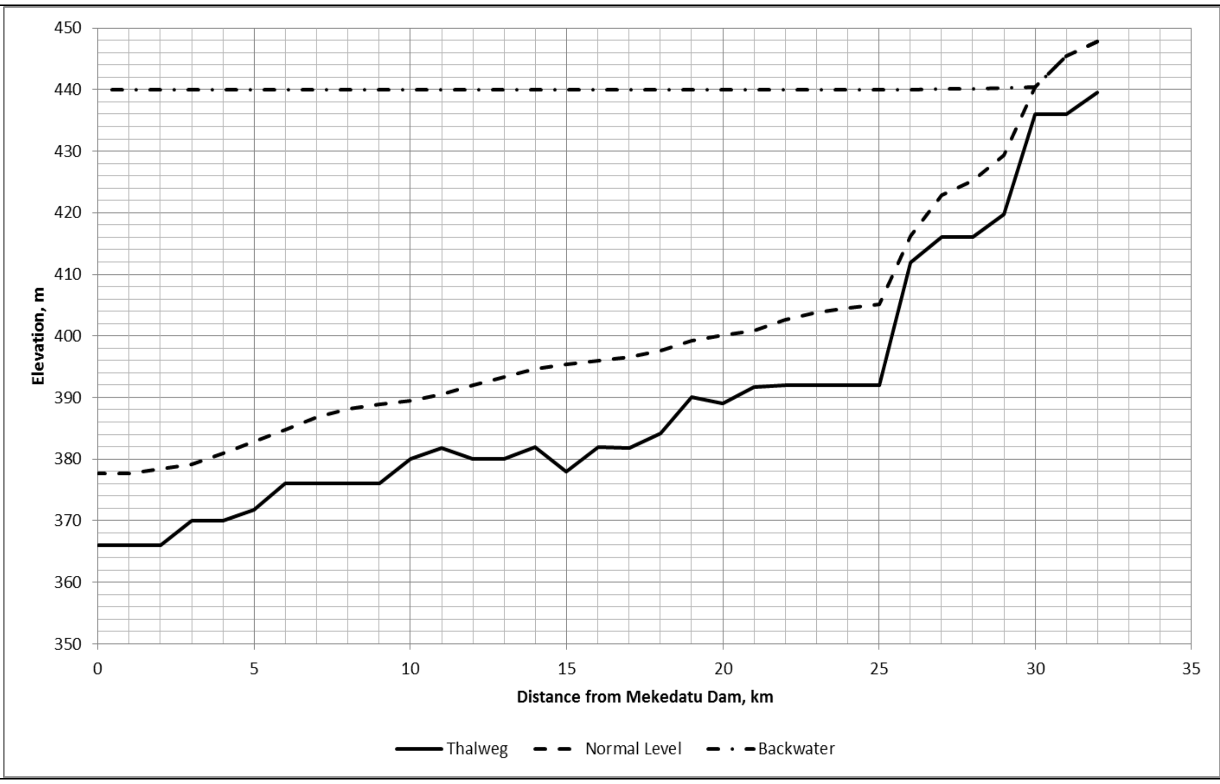


Figure 5.2 :Normal and Backwater Levels for 25-Year Flood

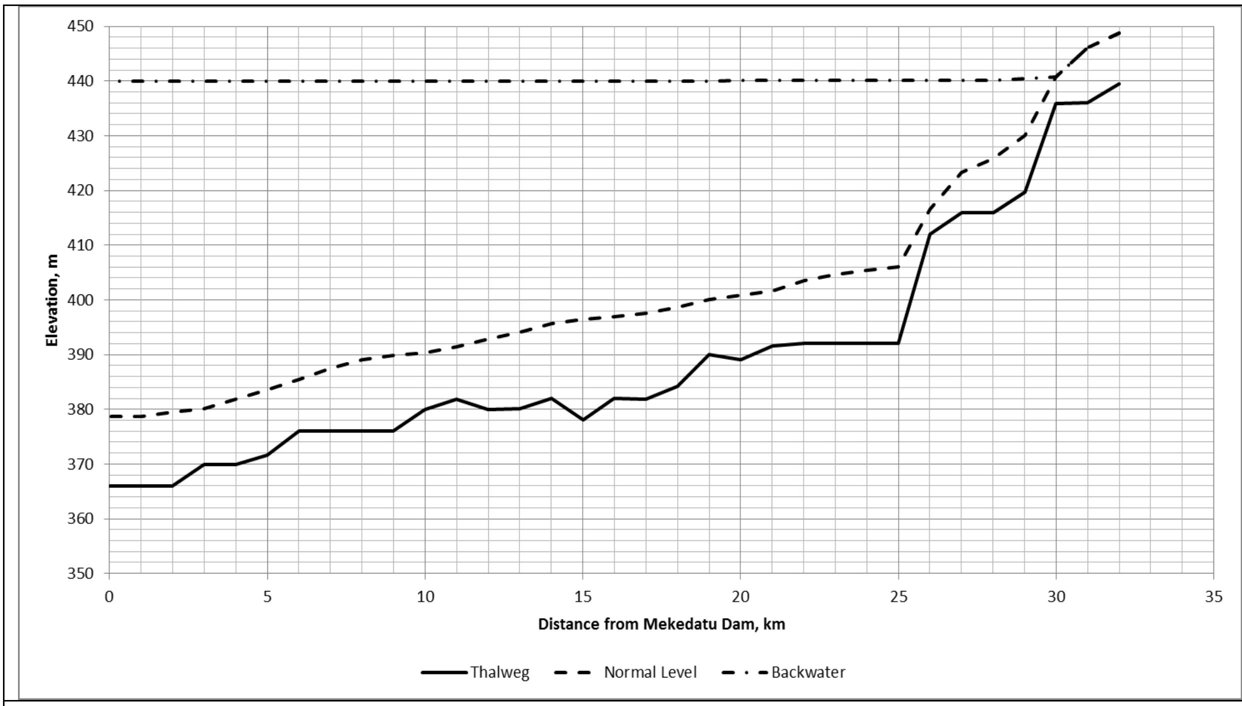


Figure 5.3: Normal and Backwater Levels for 50-Year Flood

5.1.5 Comparison of design flood estimates

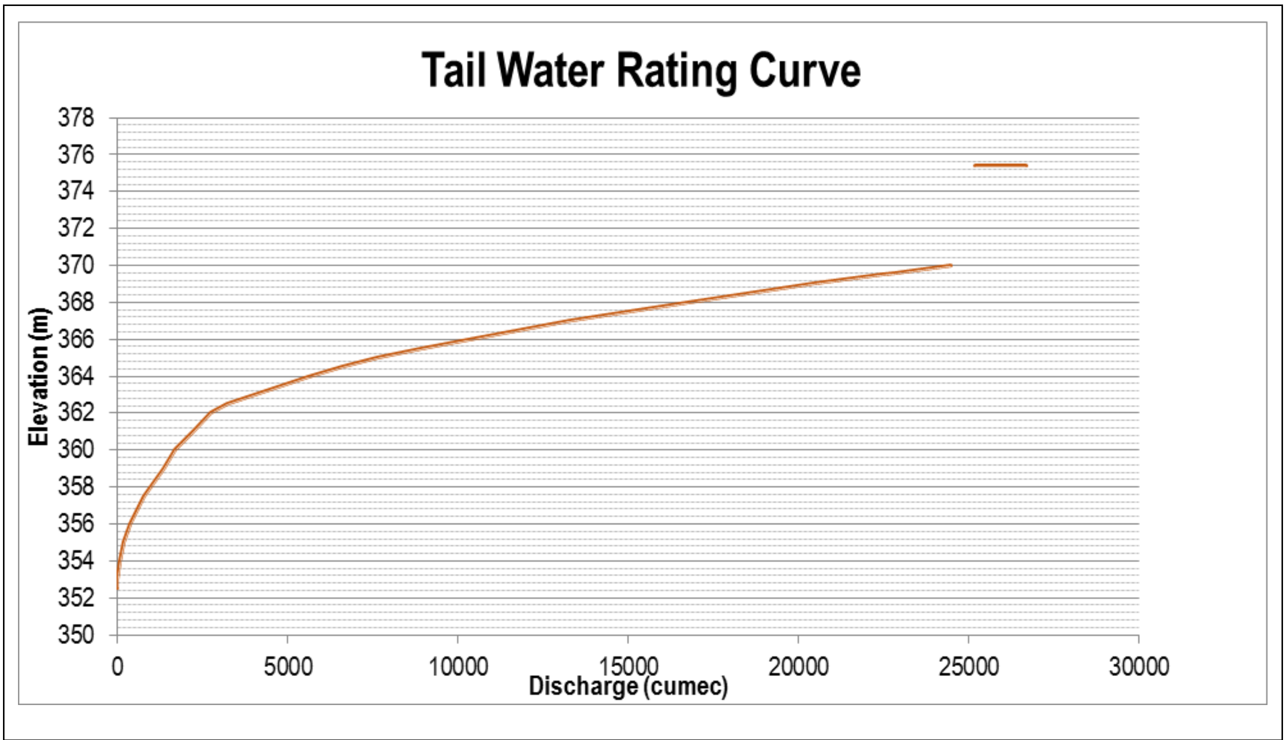
The design flood is the PMF calculated by the Hydrimeteorological approach. Flood frequency analysis has also been carried out vide para 5.1.4 above. The PMF adopted is 22653 cumecs (8,00,000 Cusecs).

5.2 Tail water rating curves

Flow is the variable usually required for hydrological analysis but, continuous measurement of flow past a river section is usually impractical or prohibitively expensive. However, stage can be observed continuously or at regular short time intervals with comparative ease and economy. Fortunately, a relation exists between stage and the corresponding discharge at the river section. This relation is termed a stage-discharge relationship or stage-discharge rating curve or simply, rating curve.

A rating curve is established by making a number of concurrent observations of stage and discharge over a period of time covering the expected range of stages at the river gauging section.

At many locations, the discharge is not a unique function of stage; variables such as surface slope or rate of change of stage with respect to time must also be known to obtain the complete relationship in such circumstances. The rating relationship thus established is used to transform the observed stages into the corresponding discharges.



The details rating curve generated for the present study is attached as **Appendix 9 of Detailed Project Report (Volume II)**

Chapter 6 Simulation studies

6.1 Simulation studies (Working tables)

The primary objective of Mekedatu reservoir is to ensure flows to Tamil Nadu at Biligundlu in accordance with the CWDT Award further modified by the Hon'ble Supreme Court of India on 16/02/2018. Other objectives are to provide drinking water to Bengaluru Metropolitan Region, its surrounding areas etc in the Cauvery Basin by utilizing the water allocated to Karnataka by the Cauvery Water Disputes Tribunal (CWDT) further modified by the Hon'ble Supreme Court of India on 16/02/2018 (4.75 TMC) . Further, the releases to the downstream of the project shall be utilized to generate power by taking advantage of the available elevation difference between the proposed site and the State border.

The most accurate method of analyzing the ability of a reservoir at Mekedatu to meet demands for different end uses is by preparing working tables.

The objectives of the project are:

- ✓ Utilizing additional 4.75 TMC of water to provide drinking water facility to Bengaluru Metropolitan Region, its adjoining area etc by way of proposing a scheme to tap water from the foreshore of the intended Mekedatu Balancing Reservoir cum Drinking water project.
- ✓ To regulate the required quantum of water to Tamil Nadu on a monthly basis (in a normal year) as per the CWDT award, as modified by the Hon'ble Supreme Court of India vide its Judgement dated 16.02.2018. It is further proposed to store the flood waters otherwise escaping to sea as it happened in the monsoon of 2018.
- ✓ Harnessing nearly 400 MW (650.28 MU of renewable energy annually @90 % dependable year) of renewable energy annually by utilizing the fall in the natural bed profile of the Cauvery River upto the State border from the monthly releases effected to (in a normal year) as per the modified award (by the Hon'ble Supreme Court of India vide its Judgement dated 16.02.2018.)

6.1.1 Drinking Water Supply

Population of Bengaluru (since the Cauvery Award) has increased considerably due to amalgamation of a large number of villages and towns into the City which is further referred to as Bangalore Metropolitan Region leading to enormous demand for drinking water from the system. Drinking water needs for the areas falling within the Cauvery basin (73.47 % of the region) need to be met.

This fact has also been acknowledged by the Supreme Court in its judgement which states:

"We are inclined to think so as the perception of a basin State inheres in it a degree of flexibility in approach in a unique fact situation to justify a warrantable flexibility and departure from such rigoristic approach. We are disposed to think so, for the city of Bengaluru, as an evident phenomenon, has burgeoned over the years and has grown today into a progressively sophisticated, sprawling, vibrant and a much aspired seat of intellectual excellence particularly in information technology and commercial flourish. It has transformed into a nerve centre of contemporaneous significance and its population is daily on the rise, thus registering an ever enhancing demand for all civic amenities. Having regard to its exclusive attributes, it is incomparable in many ways not only to other urban areas in the State, but also beyond. The requirements of its dependent population as a whole for drinking and other domestic purposes, therefore, cannot justifiably, in the prevailing circumstances, be truncated to their prejudice only for consideration of its physical location in the context of the river basin, We think so since the city of Bengaluru cannot be segregated having an extricable composition and integrated whole for the purposes of the requiremets of its inhabitants, more particularly when the same relates to allocation of water for domestic purposes to meet their daily errands. ***It will be inconceivable to have an artificial boundary and deny the population the primary need of drinking water. We hold so in the special features of the case keeping in view the global status the city has attained and further appreciating the doctrine of equitable proportionality on the bedrock of pressing human needs."***

6.1.2 Working tables of Mekedatu Reservoir

The primary objective of Mekedatu reservoir is to ensure flows at Biligundlu in accordance with the CWDT Award further modified by the Hon'ble Supreme Court. Other objectives are to provide drinking water to Bangalore Metropolitan region and to generate power from the flow released to Biligundlu.

The most accurate method of analyzing the ability of a reservoir at Mekedatu to meet demands for different end uses is by preparing working tables. The end uses are:

- Ensuring Biligundlu flows as per CWDT Award/SC Order
- Generating power from the above flows
- Utilisation of water to the extent allowed by Hon'ble Supreme Court – such that 177.25 TMC of water is ensured at Biligundlu at 50% dependability

Eq (2) gives the inflow at Mekedatu, but it contains the unknown R_{MB}. There is a way to eliminate this unknown. If B_m is the flow to be ensured at Biligundlu in the n^{th} period, then the flow to be released from Mekedatu will be $B_m – R_{MB}$. Thus,

Inflow at Mekedatu from eq (2) = $Q_M = Q_B – R_{MB}$

Flow to be released from Mekedatu = $B_m – R_{MB}$

Hence net inflow available at Mekedatu = $Q_B – R_{MB} – (B_m – R_{MB}) = Q_B – B_m$

Thus, the situation is the same as if inflow at Mekedatu is Q_B and a quantity B_m is released from Mekedatu. The term R_{MB} cancels out, and does not have to be calculated. Accordingly, inflow at Mekedatu is assumed to be equal to the flow at Biligundlu and the flow to be ensured at Biligundlu is released at Mekedatu in preparing the working tables.

6.1.2.1 Releases mandated by CWDT Award, Post Supreme Court Verdict

As per the CWDT Award, a total flow of 192 TMC should have been ensured at Biligundlu in a normal year, with the following monthly distribution:

Month	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total
Flow, TMC	10	34	50	40	22	15	8	3	2.5	2.5	2.5	2.5	**192**

These flows can be reduced pro-rata in a sub-normal year.

On 16.2.2018, the Hon'ble Supreme Court passed an order allocating 284.75 TMC as Karnataka's share of Cauvery water, reducing the total flow to be ensured at Biligundlu from 192 TMC to 177.25 TMC. The Order has not specified how the reduction of 14.75 TMC is to be effected in the monthly distribution. For the purpose of preparing the working tables, the releases are proportionately reduced in the months from June to January as follows

Month	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Flow, TMC	9.19	31.24	45.95	36.76	20.22	13.78	7.35
Month	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Total**
Flow, TMC	7.35	2.76	2.5	2.5	2.5	2.5	**177.25**

Dependability of 100% is accorded to Bengaluru drinking water and 50% to the above release commitment in preparing the working tables. A scheme for determining releases to Biligundlu in subnormal periods is described later.

6.1.2.2 Availability of Water

Detailed computation of the working tables shows that the main project objectives of releasing mandated quantum of water to Tamil Nadu at 50% dependability and providing drinking water to Bangalore Metropolitan Region can be met.

Clause XXVIII of the final order of the Tribunal states thus

“Nothing in the order of this Tribunal shall impair the right or power or authority of any State to regulate within its boundaries the use of water or to enjoy the benefit of water within that State in a manner not inconsistent with the order of this Tribunal”.

As per the above order of CWDT, the water flowing in a State can be regulated within its boundaries for using it and enjoying the benefit of the same. Karnataka, by building Mekedatu balancing reservoir cum drinking water project would not only be ensuring releases effected to as per the order (both by CWDT and Hon’ble Supreme Court), but at the same time is entitled to utilize this 60.45 TMC of water by way of storage in the proposed project.

Sub point No 391 of the order of the Hon’ble Supreme Court of India states thus

“At this juncture, we need to recount that as per the National Water policies, not only drinking water has been placed at the top of the other requirements in the order of priority but it has also been predicated that adequate drinking water facilities should be provided for the entire population, both in urban and rural areas and that drinking water should be made a primary consideration. It was declared as well that drinking water needs of Human being and animals should be the first charge on any available water”.

6.1.2.3 Evaporation Losses

Evaporation losses are calculated in the working tables based on the mean waterspread area during the concerned ten-day period and the corresponding evaporation rate. Evaporation rates at KRS reservoir are assumed to be valid for Mekedatu also. These rates are as follows:

Month	Jun	Jul	Aug	Sep	Oct	Nov
Evaporation, mm/day	4.199	3.212	3.195	3.293	4.048	3.319
Month	Dec	Jan	Feb	Mar	Apr	May
Evaporation, mm/day	3.187	3.122	3.048	3.408	4.885	5.120

6.1.2.4 Releases to Biligundlu in a Normal Year

The schedule for releases to Tamil Nadu in a normal year is as follows (3.1)

Month	Release TMC	Cumulative Release, TMC
Jun	9.18	9.18
Jul	31.24	40.43
Aug	45.95	86.38
Sep	36.76	123.14
Oct	20.22	143.36
Nov	13.78	157.14
Dec	7.35	164.49
Jan	2.76	167.25
Feb	2.5	169.75
Mar	2.5	172.25
Apr	2.5	174.75
May	2.5	177.25

Releases from June to January are for utilization in Tamil Nadu and from February to May for environmental purposes

6.1.2.5 Proposed releases from Mekedatu

Whether a water year is normal or subnormal will be known only at the end of the year, but releases to Biligundlu have to be made from the beginning of the year itself. It is therefore necessary to have a subnormality criterion from June itself. The flow measured at Lower Coleroon Anicut is a small fraction of the virgin flow because of enormous utilization upstream. Hence it cannot serve as a basis to estimate the extent of shortfall in the river flow. It is therefore proposed to use inflows into the four major Karnataka reservoirs, viz Hemavathi, Harangi, Kabini and KRS, as the basis for this purpose.

Over a number of years consisting of normal as well as subnormal years, the criterion to be satisfied is that 50% dependable release to Biligundlu is 177.25 TMC.

6.1.2.5.1 Inflows into Karnataka reservoirs

The total inflows into the four Karnataka reservoirs are shown in Table 2. The total was calculated from the equation

Total Inflow into the four reservoirs = Inflow into Hemavathi + Inflow into Harangi + Inflow into Kabini + Inflow into KRS – Outflow over Hemavathi Spillway – Outflow over Harangi Spillway

Monthly inflow data are available for 43 years from 1974-75 to 2016-17 for all the four reservoirs. Harangi reservoir was commissioned in 1979-80 and Hemavathy reservoir in 1977-78, but their inflows before their commissioning are reflected in the KRS inflow.

6.1.2.5.2 Downstream Release Criterion

As already stated, release criterion is needed for every month from the beginning of every water year. Such a criterion is proposed here purely for the purpose of preparing working tables. It is not to be understood that this criterion has any official approval. The total inflow into Hemavathi, Harangi, Kabini and KRS is taken as a measure of the virgin flow in the Cauvery at LCA. Sub-normality is assumed to occur when the total inflow into the four reservoirs in any given period (which may be one or more ten-day periods) in a particular year is less than the long term average flow in that period.

Cumulative monthly inflows into the four Karnataka reservoirs are calculated from the 41 years data of Table 2. Table 3 shows these cumulative flows (for example, cumulative flow up to end of September in the year 1979-80 = 29514 + 80035 + 154318 + 31665 = 295532 Mcft). The average monthly cumulative flows are shown in the last row of Table 3. Then the ratio of cumulative flow up to end of each month to the corresponding average cumulative flow is calculated for all the 41 years. These are tabulated in Table 4 (for example, ratio for October in year 1985-86 = 208601/287024 = 0.727). After preparing the working tables, it was found that the ratio has to be multiplied by a factor of 1.09 in order to ensure 177.25 TMC release at 50% dependability. Hence all the ratios in Table 4 are multiplied by 1.09 when used in the working tables, subject to a maximum value of 1.000. Release to Biligundlu is determined by multiplying the normal release by this revised ratio.

Since working tables are prepared for 10-day periods, release to Biligundlu during a 10-day period is calculated in the following way:

(i) For all three periods in a month of a given year, the ratio is taken to be the same as that for the month. For example, from Table 4, the ratio for the month of August 1988-89 is 0.704. This ratio is applicable for all three 10-day periods of that month. This procedure is adopted since the CWDT Award specifies only monthly flows to be ensured at Biligundlu.

(ii) The Supreme Court-mandated Biligundlu demands are divided into three equal parts for the three 10-day periods of a month and cumulative amounts are calculated (in Mcft):

	10-daily	Cumulative			10-daily	Cumulative			10-daily	Cumulative
1-Jun	3063	3063		1-Oct	6740	129880		1-Feb	833	168083

	10-daily	Cumulative		10-daily	Cumulative		10-daily	Cumulative
2-Jun	3063	6127	2-Oct	6740	136620	2-Feb	833	168917
3-Jun	3063	9190	3-Oct	6740	143360	3-Feb	833	169750
1-Jul	10413	19603	1-Nov	4593	147953	1-Mar	833	170583
2-Jul	10413	30017	2-Nov	4593	152547	2-Mar	833	171417
3-Jul	10413	40430	3-Nov	4593	157140	3-Mar	833	172250
1-Aug	15317	55747	1-Dec	2450	159590	1-Apr	833	173083
2-Aug	15317	71063	2-Dec	2450	162040	2-Apr	833	173917
3-Aug	15317	86380	3-Dec	2450	164490	3-Apr	833	174750
1-Sep	12253	98633	1-Jan	920	165410	1-May	833	175583
2-Sep	12253	110887	2-Jan	920	166330	2-May	833	176417
3-Sep	12253	123140	3-Jan	920	167250	3-May	833	177250

(iii) The cumulative Biligundlu demand up to end of a given 10-day period is multiplied by the ratio for the corresponding month or unity, whichever is lower. Let the result be *x*. For example, consider the last 10-day period in the month of July in year 1983-84. The ratio for this month is 0.811 from Table 4. Multiplying by the factor 1.037, the ratio becomes 0.811 × 1.037 = 0.841. The cumulative Biligundlu demand up to the end of that period is 40430 Mcft from the Table given under (ii) above. Product of the two is 0.841 × 40430 = 34002. So, *x* = 34002 Mcft.

(iv) From x, subtract the releases made and spills that have occurred in the previous 10-day periods, i.e., June, 1-July and 2-July in year 1983-84. This will be the release obligation for 3-July. Thus, from the working tables for 1981-82,

Quantity to be released in 3-July is 34002 – 2528.92 – 2528.92 –1919.81 – 8905.96 – 8760.96 – 609.1 = 8748.33 Mcft (the slight difference between this figure and that in the working table is due to round-off).

It is to be noted that even in a normal year (when flow at the end of the water year turns out to be 740 TMC or more), cumulative flows up to some period may be subnormal (*vide* working tables for 1983-84, col 6 August and September). The above method is therefore applied for every year, and if the inflow becomes normal, the downstream release also adjusts itself accordingly. For example, in the year 1983-84, the ratio for June is 0.796 from Table 4, which becomes 0.826 when multiplied by the factor 1.037. Hence the release obligation in each 10-day period in June is not the mandated 3063 Mcft, but is 0.826×3063 = 2530 Mcft, which is what has been released (ignoring round-off effect).

6.1.2.5.3 Release for Bengaluru Water Supply

Mekedatu balancing reservoir cum drinking water project will ensure monthly releases to downstream riparian states as per CWDT award modified by Hon'ble Supreme Court. Consequent to the fulfillment of downstream riparian states' requirement, water available in the reservoir will be utilized by Karnataka to meet its drinking water requirements amounting to 1374 Mcft (which is the use in a 10-day period corresponding to annual utilization of 49.48 TMC).

6.1.2.5.4 Biligundlu Flows

The downstream releases from Mekedatu together with spill over spillway constitute the flow at Biligundlu. In addition, in very bad years, releases from upstream of Mekedatu will also flow to Biligundlu if required (§4.8). Col 17 in the working tables (vide Annexure) shows the flow at Biligundlu realized in this way

1. Results from the Working Tables

Ten-daily working tables are prepared for Mekedatu with FRL of 440 m and MDDL of 395 m, and utilization of 49.48 TMC. The detailed 10-daily working tables are given in the Annexure 8. Annual abstracts of the results are shown in Table 5. Although data is available from 1974 75 to 2016-17, results from 1974-75 to 1984-85 may not be representative since utilizations from Hemavathi, Kabini and Harangi projects were not fully developed during that period. Hence, results for the 32 years from 1985-86 to 2016-17 only are given.

It is seen from Table 5 that flow ensured at Biligundlu is equal to the obligation in distress years. During normal years, it is seen that there is excess as compared to the obligation. In such years, the flow can be stored at Mettur. In particular, it is seen from col 5 of Table 5 that the flow at Biligundlu is equal to or more than 177.25 TMC in 16 out of the 32 years, thus ensuring the mandated release at 50% dependability.

Table 6.1: Monthly Flows at Biligundlu (Mcft)

Year	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Annual
1974-75	1443	48894	120444	55871	43393	15064	11845	3672	2777	2020	3066	8188	**316678**
1975-76	13883	71783	136132	83824	56153	48421	12715	6389	4104	5834	7743	8426	**455408**
1976-77	4388	5552	28701	28208	16594	10841	5447	3304	2662	3076	5942	13461	**128175**
1977-78	6231	41570	48500	49663	86701	35522	15071	8742	4148	4398	8516	8595	**317656**
1978-79	19503	75397	137794	58549	31091	28734	11905	7682	6219	4648	7720	11349	**400589**
1979-80	9820	32109	137048	52960	28956	27895	14254	7220	4828	3630	5416	7339	**331476**
1980-81	29795	181454	89530	40872	33409	21605	13503	8479	4275	5283	5606	9136	**442946**

Year	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Annual
1981-82	21283	27492	151892	98375	39866	28170	16826	8317	5922	5293	5365	8276	**417078**
1982-83	14122	19155	62752	26817	23436	18264	12806	8222	7950	5660	5467	9660	**214312**
1983-84	10748	23770	58366	49774	28123	21187	16108	10110	9548	10630	7050	9253	**254669**
1984-85	27272	91848	50944	30115	57494	20020	14298	7681	4014	4790	5668	6342	**320485**
1985-86	14165	21457	37397	27209	22369	16789	13826	6599	5065	3587	3550	3711	**175722**
1986-87	3342	11494	47190	27934	30796	26616	12815	10666	10728	4731	3547	4736	**194595**
1987-88	5171	3392	5688	10573	23648	18514	12104	4965	7088	4164	4548	7563	**107417**
1988-89	4485	18821	33170	55304	20427	13766	10518	10976	8331	5385	4688	5476	**191346**
1989-90	4380	29353	36429	25518	29880	17223	12126	6873	8496	4528	4867	7229	**186903**
1990-91	4752	16311	43182	18688	15827	18223	12932	6696	4297	4606	5220	7056	**157790**
1991-92	14258	77866	84959	31184	41147	41887	20616	9477	5019	4317	4633	5210	**340576**
1992-93	16695	61486	99197	53083	47688	31278	15981	8870	4708	5369	5989	8239	**358582**
1993-94	7721	26585	57395	24244	42711	21639	16496	9340	5188	4493	5941	8608	**230361**
1994-95	8138	118622	60896	52680	68373	36357	16937	9117	5371	4725	6181	6600	**393998**
1995-96	5111	23993	24418	48152	31623	19925	11680	12388	4548	4295	5071	4308	**195512**
1996-97	5236	19742	37132	40438	67153	23196	19428	9261	4883	6663	6304	7367	**246804**
1997-98	5673	27652	82947	29579	35227	37704	23460	9986	5327	5673	6858	6960	**277045**
1998-99	3923	40455	40594	43158	44951	30333	17432	8159	5468	6299	7544	10829	**259146**
1999-00	12038	29695	56794	16921	68838	34454	20581	9480	6077	5718	6929	6130	**273656**
2000-01	6133	22033	41950	59497	103547	27586	20923	9367	5710	5835	8827	7835	**319243**
2001-02	8249	27580	25996	24488	38096	29175	14409	6736	4190	4500	4461	3919	**191800**
2002-03	3360	7897	21634	13773	17946	19104	9812	6476	4545	2368	1503	1543	**109960**
2003-04	1408	2441	13397	13385	18010	11178	6464	2503	1523	701	2059	2489	**75557**
2004-05	11094	23767	42883	28863	30512	19863	9114	3980	2956	3401	3763	3712	**183906**
2005-06	3865	36733	87333	53373	90867	51108	24566	9366	4507	7520	5906	8768	**383912**
2006-07	12480	62940	69480	27579	25260	25434	12605	5304	4279	5165	4040	4003	**258568**
2007-08	3516	83355	88470	60382	48955	25781	12632	3729	3588	7629	7085	8501	**353623**
2008-09	7765	10946	58437	39308	35747	20440	15489	4537	3689	4335	3918	5509	**210119**
2009-10	4967	39040	33954	55514	27312	21840	11740	5337	3477	4418	6912	8148	**222657**
2010-11	7674	9230	24585	25393	28085	61171	17489	5996	4909	6590	9627	11008	**211756**
2011-12	9306	31055	37344	56371	32924	32406	14268	5503	4476	4593	6250	5954	**240451**
2012-13	4117	4153	11120	20759	21799	11787	12267	4222	4311	2280	2047	1576	**100438**
2013-14	11610	68909	73739	31128	22254	19878	7874	4061	2271	3099	3800	4954	**253577**
2014-15	5942	34379	60385	41342	37802	16698	10413	3973	1571	2594	5202	8302	**228603**
2015-16	12594	27259	26478	22345	19038	28435	9230	3683	1918	1924	1371	2011	**156287**
2016-17	2772	15507	14645	20074	7847	3173	1941	703	306	332	136	1330	**68765**

Table 6.2: Monthly Total Inflows into Four Karnataka Reservoirs (Mcft)

Year	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1974-75	2535	102400	123026	36858	21187	5762	4003	1636	1521	1415	1177	2587
1975-76	69917	82747	150143	68412	35490	17363	4106	2937	2893	3051	5409	2789
1976-77	2199	41172	55527	32081	6893	11322	2516	1293	1298	1280	2674	7234
1977-78	28704	101702	52170	52836	50586	24675	8780	1868	1292	1663	5193	7055
1978-79	61932	110338	158467	45422	18677	16462	5337	3623	1317	2277	4552	4142
1979-80	29514	80035	154318	31665	17144	17922	5353	0	3902	1405	4019	7483
1980-81	73646	209861	93801	41608	22883	15148	6661	1850	962	1144	0	4504
1981-82	41261	78947	173311	60739	23639	14157	5659	4235	1390	1244	416	3309
1982-83	24047	58118	105515	18344	13287	8803	4071	2850	459	39	0	1291
1983-84	24170	74116	100404	44653	27622	11735	8118	3245	2710	5559	2315	2668
1984-85	67682	128377	67706	29714	42229	5827	5546	3267	697	463	2752	2212
1985-86	46966	51034	73225	22702	14674	10376	7554	2364	528	0	341	2158
1986-87	32284	59495	101434	21664	12754	17026	2889	3328	30	0	0	0
1987-88	8199	26320	35416	20842	28643	15824	7684	1799	603	0	1438	1285
1988-89	9463	73335	69139	42949	16675	6488	6456	1302	0	924	283	1231
1989-90	20988	103288	70774	28962	21442	9167	6879	1238	1101	0	0	0
1990-91	29253	72689	103797	24753	22672	15234	8139	1622	824	0	2695	2118
1991-92	45152	167152	94872	23427	26971	14337	3883	232	0	0	0	3894
1992-93	75890	115611	116533	61958	34989	34469	8474	1371	0	0	1043	3804
1993-94	22157	79562	95951	21105	36549	10650	5434	308	0	0	1379	2419
1994-95	52072	197063	83175	58403	56120	21648	6597	2228	1033	980	3875	7112
1995-96	10312	93515	50877	81054	17400	13126	5562	946	232	0	1800	0
1996-97	35176	77922	65506	32429	53715	10535	11481	1816	559	0	0	4310
1997-98	8092	106652	133868	29609	22532	24484	9561	1286	1800	1485	2573	4045
1998-99	21489	111808	65800	45155	40649	19326	10151	1408	1938	0	2215	9660
1999-00	32897	104247	74272	18631	53376	13248	7875	1009	141	753	1193	1726
2000-01	36930	76797	88512	57864	42896	9846	11275	1573	1044	542	6259	4136
2001-02	36214	80806	67298	26006	24219	15348	6244	1271	301	0	138	920
2002-03	18566	26323	78175	20659	35673	15047	6257	1887	836	986	1282	227
2003-04	12102	41161	43697	18336	19960	6289	4114	1391	665	289	1061	9042
2004-05	59165	47133	103571	19435	21305	11622	2997	1448	923	1125	1166	1680
2005-06	16495	121325	117787	56518	50834	19866	10715	2303	922	905	2171	11156
2006-07	39434	134207	93947	40022	20721	18943	9205	2561	984	474	36	288
2007-08	28191	183845	113486	70376	46147	18794	14195	5424	3090	7678	4652	2843
2008-09	21507	48651	106939	43416	38692	16761	10037	3732	1347	846	1082	1619
2009-10	4913	146019	61418	78153	40062	27298	16229	7181	459	0	677	3666
2010-11	13299	48795	60254	52011	40765	62122	19660	7243	1766	1183	5005	3964
2011-12	40736	69868	72409	75693	33533	26924	15703	7673	3594	1899	3307	2427
2012-13	5776	33442	63009	49165	16645	11386	6056	1938	1088	1354	688	711
2013-14	55709	156402	92196	36521	21769	11139	9469	3573	919	84	605	5206
2014-15	18070	111433	97196	59584	30693	9580	14040	3843	983	872	1075	4771
2015-16	61599	43408	34250	25258	20089	19495	7084	2548	1023	644	661	447
2016-17	15132	58216	41941	18129	4504	2360	2130	1048	0	597	569	990

Table 6.3:Cumulative Total Inflows into Four Karnataka Reservoirs (Mcft)

Year	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1974-75	2535	104935	227961	264819	286006	291768	295771	297407	298928	300343	301520	304107
1975-76	69917	152664	302807	371219	406709	424072	428178	431115	434008	437059	442468	445257
1976-77	2199	43371	98898	130979	137872	149194	151710	153003	154301	155581	158255	165489
1977-78	28704	130406	182576	235412	285998	310673	319453	321321	322613	324276	329469	336524
1978-79	61932	172270	330737	376159	394836	411298	416635	420258	421575	423852	428404	432546
1979-80	29514	109549	263867	295532	312676	330598	335951	335951	339853	341258	345277	352760
1980-81	73646	283507	377308	418916	441799	456947	463608	465458	466420	467564	467564	472068
1981-82	41261	120208	293519	354258	377897	392054	397713	401948	403338	404582	404998	408307
1982-83	24047	82165	187680	206024	219311	228114	232185	235035	235494	235533	235533	236824
1983-84	24170	98286	198690	243343	270965	282700	290818	294063	296773	302332	304647	307315
1984-85	67682	196059	263765	293479	335708	341535	347081	350348	351045	351508	354260	356472
1985-86	46966	98000	171225	193927	208601	218977	226531	228895	229423	229423	229764	231922
1986-87	32284	91779	193213	214877	227631	244657	247546	250874	250904	250904	250904	250904
1987-88	8199	34519	69935	90777	119420	135244	142928	144727	145330	145330	146768	148053
1988-89	9463	82798	151937	194886	211561	218049	224505	225807	225807	226731	227014	228245
1989-90	20988	124276	195050	224012	245454	254621	261500	262738	263839	263839	263839	263839
1990-91	29253	101942	205739	230492	253164	268398	276537	278159	278983	278983	281678	283796
1991-92	45152	212304	307176	330603	357574	371911	375794	376026	376026	376026	376026	379920
1992-93	75890	191501	308034	369992	404981	439450	447924	449295	449295	449295	450338	454142
1993-94	22157	101719	197670	218775	255324	265974	271408	271716	271716	271716	273095	275514
1994-95	52072	249135	332310	390713	446833	468481	475078	477306	478339	479319	483194	490306
1995-96	10312	103827	154704	235758	253158	266284	271846	272792	273024	273024	274824	274824
1996-97	35176	113098	178604	211033	264748	275283	286764	288580	289139	289139	289139	293449
1997-98	8092	114744	248612	278221	300753	325237	334798	336084	337884	339369	341942	345987
1998-99	21489	133297	199097	244252	284901	304227	314378	315786	317724	317724	319939	329599
1999-00	32897	137144	211416	230047	283423	296671	304546	305555	305696	306449	307642	309368
2000-01	36930	113727	202239	260103	302999	312845	324120	325693	326737	327279	333538	337674
2001-02	36214	117020	184318	210324	234543	249891	256135	257406	257707	257707	257845	258765
2002-03	18566	44889	123064	143723	179396	194443	200700	202587	203423	204409	205691	205918
2003-04	12102	53263	96960	115296	135256	141545	145659	147050	147715	148004	149065	158107
2004-05	59165	106298	209869	229304	250609	262231	265228	266676	267599	268724	269890	271570
2005-06	16495	137820	255607	312125	362959	382825	393540	395843	396765	397670	399841	410997
2006-07	39434	173641	267588	307610	328331	347274	356479	359040	360024	360498	360534	360822
2007-08	28191	212036	325522	395898	442045	460839	475034	480458	483548	491226	495878	498721
2008-09	21507	70158	177097	220513	259205	275966	286003	289735	291082	291928	293010	294629
2009-10	4913	150932	212350	290503	330565	357863	374092	381273	381732	381732	382409	386075
2010-11	13299	62094	122348	174359	215124	277246	296906	304149	305915	307098	312103	316067
2011-12	40736	110604	183013	258706	292239	319163	334866	342539	346133	348032	351339	353766
2012-13	5776	39218	102227	151392	168037	179423	185479	187417	188505	189859	190547	191258
2013-14	55709	212111	304307	340828	362596	373735	383204	386778	387696	387780	388385	393590
2014-15	18070	129503	226699	286283	316976	326557	340596	344439	345422	346294	347369	352140
2015-16	61599	105008	139258	164516	184605	204100	211184	213732	214756	215400	216061	216508
2016-17	15132	73348	115289	133418	137922	140282	142411	143459	143459	144057	144626	145616
Average	**30361**	**121146**	**201098**	**240810**	**271413**	**287916**	**296388**	**298878**	**299769**	**300499**	**302076**	**305108**

Table 6.4. Ratios of Monthly Cumulative Inflows to the Average

Year	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1974-75	0.083	0.866	1.134	1.100	1.054	1.013	0.998	0.995	0.997	0.999	0.998	0.997
1975-76	2.303	1.260	1.506	1.542	1.498	1.473	1.445	1.442	1.448	1.454	1.465	1.459
1976-77	0.072	0.358	0.492	0.544	0.508	0.518	0.512	0.512	0.515	0.518	0.524	0.542
1977-78	0.945	1.076	0.908	0.978	1.054	1.079	1.078	1.075	1.076	1.079	1.091	1.103
1978-79	2.040	1.422	1.645	1.562	1.455	1.429	1.406	1.406	1.406	1.410	1.418	1.418
1979-80	0.972	0.904	1.312	1.227	1.152	1.148	1.133	1.124	1.134	1.136	1.143	1.156
1980-81	2.426	2.340	1.876	1.740	1.628	1.587	1.564	1.557	1.556	1.556	1.548	1.547
1981-82	1.359	0.992	1.460	1.471	1.392	1.362	1.342	1.345	1.345	1.346	1.341	1.338
1982-83	0.792	0.678	0.933	0.856	0.808	0.792	0.783	0.786	0.786	0.784	0.780	0.776
1983-84	0.796	0.811	0.988	1.011	0.998	0.982	0.981	0.984	0.990	1.006	1.009	1.007
1984-85	2.229	1.618	1.312	1.219	1.237	1.186	1.171	1.172	1.171	1.170	1.173	1.168
1985-86	1.547	0.809	0.851	0.805	0.769	0.761	0.764	0.766	0.765	0.763	0.761	0.760
1986-87	1.063	0.758	0.961	0.892	0.839	0.850	0.835	0.839	0.837	0.835	0.831	0.822
1987-88	0.270	0.285	0.348	0.377	0.440	0.470	0.482	0.484	0.485	0.484	0.486	0.485
1988-89	0.312	0.683	0.756	0.809	0.779	0.757	0.757	0.756	0.753	0.755	0.752	0.748
1989-90	0.691	1.026	0.970	0.930	0.904	0.884	0.882	0.879	0.880	0.878	0.873	0.865
1990-91	0.964	0.841	1.023	0.957	0.933	0.932	0.933	0.931	0.931	0.928	0.932	0.930
1991-92	1.487	1.752	1.527	1.373	1.317	1.292	1.268	1.258	1.254	1.251	1.245	1.245
1992-93	2.500	1.581	1.532	1.536	1.492	1.526	1.511	1.503	1.499	1.495	1.491	1.488
1993-94	0.730	0.840	0.983	0.908	0.941	0.924	0.916	0.909	0.906	0.904	0.904	0.903
1994-95	1.715	2.056	1.652	1.622	1.646	1.627	1.603	1.597	1.596	1.595	1.600	1.607
1995-96	0.340	0.857	0.769	0.979	0.933	0.925	0.917	0.913	0.911	0.909	0.910	0.901
1996-97	1.159	0.934	0.888	0.876	0.975	0.956	0.968	0.966	0.965	0.962	0.957	0.962
1997-98	0.267	0.947	1.236	1.155	1.108	1.130	1.130	1.124	1.127	1.129	1.132	1.134
1998-99	0.708	1.100	0.990	1.014	1.050	1.057	1.061	1.057	1.060	1.057	1.059	1.080
1999-00	1.084	1.132	1.051	0.955	1.044	1.030	1.028	1.022	1.020	1.020	1.018	1.014
2000-01	1.216	0.939	1.006	1.080	1.116	1.087	1.094	1.090	1.090	1.089	1.104	1.107
2001-02	1.193	0.966	0.917	0.873	0.864	0.868	0.864	0.861	0.860	0.858	0.854	0.848
2002-03	0.612	0.371	0.612	0.597	0.661	0.675	0.677	0.678	0.679	0.680	0.681	0.675
2003-04	0.399	0.440	0.482	0.479	0.498	0.492	0.491	0.492	0.493	0.493	0.493	0.518
2004-05	1.949	0.877	1.044	0.952	0.923	0.911	0.895	0.892	0.893	0.894	0.893	0.890
2005-06	0.543	1.138	1.271	1.296	1.337	1.330	1.328	1.324	1.324	1.323	1.324	1.347
2006-07	1.299	1.433	1.331	1.277	1.210	1.206	1.203	1.201	1.201	1.200	1.194	1.183
2007-08	0.929	1.750	1.619	1.644	1.629	1.601	1.603	1.608	1.613	1.635	1.642	1.635
2008-09	0.708	0.579	0.881	0.916	0.955	0.958	0.965	0.969	0.971	0.971	0.970	0.966
2009-10	0.162	1.246	1.056	1.206	1.218	1.243	1.262	1.276	1.273	1.270	1.266	1.265
2010-11	0.438	0.513	0.608	0.724	0.793	0.963	1.002	1.018	1.021	1.022	1.033	1.036
2011-12	1.342	0.913	0.910	1.074	1.077	1.109	1.130	1.146	1.155	1.158	1.163	1.159
2012-13	0.190	0.324	0.508	0.629	0.619	0.623	0.626	0.627	0.629	0.632	0.631	0.627
2013-14	1.835	1.751	1.513	1.415	1.336	1.298	1.293	1.294	1.293	1.290	1.286	1.290
2014-15	0.595	1.069	1.127	1.189	1.168	1.134	1.149	1.152	1.152	1.152	1.150	1.154
2015-16	2.029	0.867	0.692	0.683	0.680	0.709	0.713	0.715	0.716	0.717	0.715	0.710
2016-17	0.498	0.605	0.573	0.554	0.508	0.487	0.480	0.480	0.479	0.479	0.479	0.477

Table 6.5. Annual Abstracts of Mekedatu Reservoir Working Tables

	Initial Level	Inflow*	At Biligundlu		
			Obligation	Met	Excess
1	*2*	*3*	*4*	*5*	*6*
Year	**m**	**Mcft**	**Mcft**	**Mcft**	**Mcft**
1985-86	440.00	167647	139718	139718	0
1986-87	425.16	186178	151154	151154	0
1987-88	418.48	104240	89193	89193	0
1988-89	398.85	184724	137503	137503	0
1989-90	406.88	178023	158946	158946	0
1990-91	397.98	148924	148924	149665	741
1991-92	394.95	331276	177250	223593	46343
1992-93	440.00	349282	177250	297091	119841
1993-94	440.00	221838	165980	169751	3771
1994-95	440.00	384698	177250	332521	155271
1995-96	440.00	187914	165564	165564	0
1996-97	421.40	237953	176784	176784	0
1997-98	433.01	268628	177250	204718	27468
1998-99	440.00	250150	177250	198047	20797
1999-2000	440.00	264369	177250	212275	35025
2000-01	440.00	310025	177250	257968	80718
2001-02	440.00	182853	155890	155890	0
2002-03	424.61	104818	104818	123992	19174
2003-04	394.95	71139	71139	71139	0
2004-05	394.95	174938	163604	163604	0
2005-06	394.95	375111	177250	274117	96867
2006-07	440.00	249268	177250	197968	20718
2007-08	439.49	344365	177250	291312	114062
2008-09	440.00	202693	177250	177250	0
2009-10	423.46	214618	177250	177250	0
2010-11	412.79	206086	177250	177250	0
2011-12	406.45	231480	177250	177250	0
2012-13	414.34	96251	96251	105755	9504
2013-14	394.95	244277	177250	177250	0
2014-15	414.09	219740	177250	177250	0
2015-16	407.45	148746	130432	130432	0
2016-17	394.95	63302	63302	63302	0
Average	**424.56**	**242141**	**157973**	**200187**	**42214**

6.1.2.5.5 Justification for taking up the Mekedatu Balancing Reservoir cum Drinking Water project by Karnataka – Water availability

The proposal of GoK to take up Mekedatu Balancing Reservoir cum Drinking Water project can be justified by the following.

- ✓ Regarding the Hydro-Electric Schemes the Tribunal has stated in Clause XIII of final decision dt: 5th February 2007 as follows:

"*The State of Karnataka and Tamil Nadu brought to our notice that a few Hydro-Electric Power Projects in the common reach boundary are being negotiated with the National Hydro-Power corporation (NHPC). In this connection, we have only to observe that whenever any such hydro-power project is constructed and Cauvery waters are stored in the reservoir, the pattern of downstream releases should be consistent with our order so that the irrigation requirements are not jeopardized.*"

- ✓ The Tribunal, in its award has clearly stated that "**Nothing in the order of this Tribunal shall impair the right or power or authority of any State to regulate within its boundaries the use of water, or to enjoy the benefit of waters within the State in a manner not inconsistent with the order of this Tribunal".**
- ✓ This means, Karnataka can plan and build Mekedatu Balancing Reservoir cum Drinking Water Project since it is located well within its boundary and with the Primary Objective that the releases as per the allocated share of water to Tamil Nadu (in a normal year) is ensured besides taking care of the drinking water needs of Bengaluru and its surrounding areas. **This will be consistent with the order of the Tribunal.**
- ✓ As per the Cauvery Disputes Tribunal, "**any delay in the advent of monsoon would affect the inflows and consequently dislocate the schedule of releases from Krishnaraja Sagara & Kabini Reservoirs, the Tribunal felt it to be advisable that at the end of May each year, as much storage as was possible during a good year should be consciously conserved as that would help in adhering to the schedule of monthly deliveries".**
- ✓ If Karnataka has to meet these objectives, then it becomes necessary to plan a reservoir with sufficient storage capacity. This is inevitable considering the fact

that both KRS & Kabini do not have the capability to hold excess water in times of good monsoon.

- ✓ As per the study that has been carried out and also the recommendation of the earlier Committee set up by the Government of Karnataka, it has been decided to restrict the FRL of the proposed Balancing Reservoir to RL 440.00 meters.
- ✓ Further, the need for conserving water to ensure environmental releases (2.50 TMC every month from February to May of every year) is also considered while fixing the capacity of the proposed reservoir due to the following reasons.

- ➢ During the period from February to May, flow in the River will be either very lean or nil flow and hence releases have to be from KRS or Kabini
- ➢ The distance between KRS /Kabini to Biligundlu is about 130 km and 175 km respectively, which in effect means the water let out from either of the dams have to travel a long distance when the river is in a dry condition.
- ➢ To ensure that 10 TMC water reaches Biligundlu in the months indicated above, it is necessary to release a little more than 10 TMC of water from KRS /Kabini
- ➢ Kabini being a small dam with limited capacity cannot be relied upon for releases. Hence, it becomes necessary to release a little more than 10 TMC of water from KRS itself in order to meet the specified quantum of releases to Tamil Nadu during these months.
- ➢ However, in the months of June and July, the past data shows that there is a shortfall of 5 TMC and 8 TMC respectively in the water to be released to Tamil Nadu as per the obligation (as computed in the working tables enclosed as Annexure-IV, Hydrology report). This 13 TMC has to be accommodated in the Mekedatu Balancing Reservoir Cum Drinking Water Project.
- ➢ The obligatory environment flow of 10 TMC to be released from February to May (summer months) has to be stored in the Reservoir.
- ➢ Utilizing additional 4.75 TMC of water (Consumptive use) to provide drinking water facility to Bengaluru metropolitan region, its adjoining area etc as per the CWDT award, further modified by the Hon’ble Supreme Court of India vide its Judgement

dated 16.02.2018, by way of proposing a scheme to tap water from the foreshore of the intended Mekedatu Balancing Reservoir cum Drinking water project amounting to 23.75 TMC. This allocation is based on the 2011 census data of population. As at present (between 2011 and 2018), the city has witnessed further growth of nearly 28 %.

- As per CPHEEO guidelines, the drinking water requirement of Bangalore Metropolitan Region will be 64.0 TMC as per projected requirement for the year 2044. Drinking water is a fundamental right under the Constitution and it gets the highest priority as per National Water Policy. Presently, 14.52 TMC is being drawn from Netkal balancing Reservoir (vide para 13, page 101-102, Volume-5 of CWDT report.. Hence the amount of water to be stored to meet Bangalore Metropolitan Region drinking water requirement will be 49.48 TMC i.e., (64 TMC – 14.52 TMC). Two-Thirds of this namely 33.15 TMC will be required as storage. Since the height of the dam cannot be increased as and when needed (as per the then requirement), it is prudent to plan for this additional storage to be provided in the present proposal of the Mekedatu Balancing Reservoir cum Drinking Water Project itself.
- Allowing for evaporation losses and sedimentation, a provision of 3.85 TMC is considered in the storage.

<u>Thus the total live storage required at Mekedatu Reservoir is 13+10+33.15+3.85 = 60.00 TMC.</u>

The gross storage of the reservoir is 67.16 TMC and the dead storage is 7.7 TMC. Hence the live storage available will be 59.46 TMC which almost matches with the required storage of 60 TMC. The intake structure on the foreshore of the Mekedatu reservoir shall be designed to meet this ultimate requirement

Clause XXVIII of the final order of the Tribunal states thus,

“Nothing in the order of this Tribunal shall impair the right or power or authority of any State to regulate within its boundaries the use of water or to enjoy the benefit of water within that State in a manner not inconsistent with the order of this Tribunal”.

As per the above order of CWDT, the water flowing in a State can be regulated within its boundaries for using it and enjoying the benefit of the same. Karnataka, by building Mekedatu balancing reservoir cum drinking water project would not only be ensuring releases effected to as per the order (both by CWDT and Hon'ble Supreme Court), but at the same time is entitled to utilize this 60.45 TMC of water by way of storage in the proposed project since it will be within the allocated share of water as per CWDT Award and modified by the Hon'ble Supreme Court.

Sub point No 391 of the order of the Hon'ble Supreme Court of India states thus

"At this juncture, we need to recount that as per the National Water policies, not only drinking water has been placed at the top of the other requirements in the order of priority but it has also been predicated that adequate drinking water facilities should be provided for the entire population, both in urban and rural areas and that drinking water should be made a primary consideration. It was declared as well that drinking water needs of Human being and animals should be the first charge on any available water".

6.1.2.5.6 Reservoir Capacity Determination

The storage requirement of Mekedatu Reservoir is arrived at on the following considerations.

- ✓ In the months of June and July, the past data shows that there is a shortfall of 5 TMC and 8 TMC respectively in the water to be released to Tamil Nadu as per the obligation (as computed in the working tables enclosed as Annexure-IV, Hydrology report). This 13 TMC has to be accommodated in the Mekedatu Balancing Reservoir Cum Drinking Water Project.
- ✓ The obligatory environment flow of 10 TMC to be released from February to May (summer months) has to be stored in the Reservoir.
- ✓ Utilizing additional 4.75 TMC of water (Consumptive use) to provide drinking water facility to Bengaluru metropolitan region, its adjoining area etc as per the CWDT award, further modified by the Hon'ble Supreme Court of India vide its Judgement dated 16.02.2018, by way of proposing a scheme to tap water from the foreshore of the intended Mekedatu Balancing Reservoir cum Drinking water project amounting to 23.75 TMC. This allocation is based on the 2011 census data of population. As at present (between 2011 and 2018), the city has witnessed further growth of nearly 28 %.
- ✓ As per CPHEEO guidelines, the drinking water requirement of Bangalore Metropolitan Region will be 64.0 TMC as per projected requirement for the year 2044. Drinking water is a fundamental right under the Constitution and it gets the highest priority as per National Water Policy. Presently, 14.52 TMC is being drawn from Netkal balancing Reservoir (vide para 13, page 101-102, Volume-5 of

CWDT report.. Hence the amount of water to be stored to meet Bangalore Metropolitan Region drinking water requirement will be 49.48 TMC i.e., (64 TMC – 14.52 TMC). Two-Thirds of this namely 33.15 TMC will be required as storage. Since the height of the dam cannot be increased as and when needed (as per the then requirement), it is prudent to plan for this additional storage to be provided in the present proposal of the Mekedatu Balancing Reservoir cum Drinking Water Project itself.

- ✓ Allowing for evaporation losses and sedimentation, a provision of 3.85 TMC is considered in the storage

Thus the total live storage required at Mekedatu Reservoir is 13+10+33.15+3.85 = 60.00 TMC.

The gross storage of the reservoir is 67.16 TMC and the dead storage is 7.7 TMC. Hence the live storage

available will be 59.46 TMC which almost matches with the required storage of 60 TMC. The intake structure on the foreshore of the Mekedatu reservoir shall be designed to meet this ultimate requirement Stages / Phases of development of project

The present Project is proposed to be implemented in a single Stage of 4 working seasons scheduled from September 2020 after a mobilisation period of 3-4 months prior to construction activity and completed by June 2024.

Chapter 7
Effect of Project on Hydrologic Regime.

7.1 Low flows

Out of the 177.25 TMC to be released to Tamil Nadu, 10 TMC is earmarked as Environmental flows to take care of the low flows on the downstream as per CWDT award further modified by The Hon'ble Supreme Court of India vide its Judgement dated 16/02/2018 during February, March, April and May of every year at 2.50 TMC each.

7.2 Flood hydrology

The flood will be moderated on account of construction of this dam.

7.3 Total run-off

Between Mekedatu & Mettur, the total run off is about 27 TMC (2 TMC upto Biligundlu and 25 TMC between Biligundlu & Mettur). The release of 177.25 TMC will therefore dominate the flow.

7.4 River hydraulics (short & long terms)

Since the flow will be regulated as per the Schedule prescribed by CWDT which is further modified by the Hon'ble Supreme Court of India on 16/02/2018, the river Hydraulics will be in a stable regime.

7.5 Sediment yields, sediment carrying capacities, aggradations & degradations at various locations

After construction of this reservoir, the sediment load will be reduced downstream. Since the bed in the downstream is rocky, there will not be any degradation.

7.6 Water quality

Since the volume of water stored in the dam is large (67.16 TMC), any pollution will be diluted and water quality will improve.

7.7 Water demand

The release of 177.25 TMC is meant to meet the water demand as per CWDT Award further modified by the Hon'ble Supreme court of India on 16/02/2018.