Chapter 5
Water Resources and Hydrology

5.1 General

Planning for water resources development in a basin requires careful assessment of the available water resources and reasonable needs of the basin in foreseeable future for various purposes such as, drinking, irrigation, hydropower, industries, navigation, etc. Hydrological studies are carried out to assess the available quantity of water in a given basin. Hydrological analyses are done and presented in this chapter for arriving at the quantity of water at Srisailam that would be available in part exchange to the surplus waters of Mahanadi and Godavari proposed to be brought to Krishna river. These waters are proposed to be used in Pennar and Cauvery basins. As a part of these analysis, a total yield of water at Srisailam is computed. The balance of water that could be available is assessed after meeting the in-basin requirements, for transfer to the river Pennar through Krishna (Srisailam) – Pennar link canal.

5.2 Hydrological Analysis

There are eight sub-basins viz., Upper Krishna, Middle Krishna, Ghataprabha, Malaprabha, Upper Bhima, Lower Bhima, Tungabhadra and Vedavati and part catchment of Lower Krishna sub-basin up to Srisailam dam site.

Hydrological studies of these sub-basins have been carried out and the yield series were generated. The year-wise yields of all the upstream sub-basins were added to get the annual yield series of Krishna basin at Srisailam dam site, from which the 75% and 50% dependable yields were determined. The balance at 75% dependability has been estimated after deducting the ultimate water requirement for various uses viz., irrigation, domestic, industrial and hydro power needs and considering import, export and regeneration.

The methodology is explained in detail, in subsequent sections.

5.3 Methodology Adopted by NWDA for Working out Water Balance

The methodology adopted by NWDA for computing the water balance is discussed below:

5.3.1 Surface Water Availability

Observed flow data at the terminal G&D site and the rainfall observed at various raingauge stations in and around the catchment of a sub-basin are collected. To these observed flows, year-wise upstream utilisations are added to get virgin yields. Weighted rainfall for the catchment up to the G&D site and for the whole sub-basin are worked out. Using these virgin flows and weighted rainfall up to the G&D site, a rainfall-runoff relationship (linear/non-linear) is worked out by statistical methods. Using the best fit equation and weighted rainfall for the entire sub-basin, monsoon yields are computed. To the monsoon yields non-monsoon yields are added for arriving at annual gross yields for the entire sub-basin. The annual gross yield series thus arrived at is arranged in descending order from which 50% and 75% dependable annual gross yields are obtained.

The overall surface water available in a sub-basin is arrived at by summing up the yield, regeneration and imports and by deducting the exports, if any.

5.3.2 Water Requirement

The requirements of water at the ultimate stage (by 2025 AD) for various uses viz., irrigation, domestic, industrial and hydropower are worked out as under :

Irrigation Needs: The requirements for irrigation are worked out for all the existing, ongoing and proposed major, medium and minor projects in a sub-basin. For this purpose, all the projects existing/ongoing and planned by the states, as per their master plans/reports are considered. The designed annual utilisation is considered for the existing and ongoing projects. The requirements for future projects are determined by adopting intensities of irrigation as 150%, 125% and 100% for major, medium and minor projects respectively. The deltas are worked out by climatological approach, taking the irrigation efficiency as 55% for major/medium projects and 70% for minor projects. For assessing the

crop water requirements by climatological approach, the potential evapotranspiration values for various stations as given in the IMD scientific report No.136 (1971) are adopted. If the ultimate annual irrigation considering all the existing, ongoing and proposed major, medium and minor projects works out to less than 30% of the maximum culturable area of the sub-basin, the requirements are calculated by increasing the annual irrigation to 30% of the maximum culturable area of the sub-basin. In case of a surplus basin, the annual irrigation at the ultimate stage is increased to 60% of the maximum culturable area. 50% of such increased annual irrigation is considered to be under future medium projects and the remaining 50% under future minor schemes.

Domestic Needs: The requirement of water for domestic consumption in the rural and urban areas and for livestock population is estimated by projecting the rural, urban and the livestock population of the sub-basin to 2025 AD using the available census data and considering the corresponding per capita per day water requirements of 70 litres, 200 litres and 50 litres for the rural, urban and livestock population respectively as per the recommendations of the Ministry of Works and Housing in their manual “Water Supply and Treatment”. The requirement of 50% of the rural population and the entire livestock population is considered to be met from groundwater and the requirement for the remaining 50% of rural population and the entire urban population is considered to be met from surface water.

Industrial Needs: In the absence of relevant data to estimate precisely the industrial water needs, industrial requirement is taken to be equivalent to the total domestic requirement. The entire industrial requirement is considered to be met from surface water.

Hydropower Needs: Requirement for the hydropower is taken to be the evaporation losses at the reservoirs with hydropower production. Wherever the evaporation data of the projects is available, the same is considered and wherever the data is not available the same is worked out from the surface area of water in the reservoir, considering suitable evaporation values of near by sites or hydro-meteorologically similar sites.

5.3.3 Regeneration

The regeneration is considered as (a) 10% of the net utilisation for irrigation from all the existing, ongoing and future identified major and

medium projects and (b) 80% of the domestic and industrial uses to be met from the surface water.

5.3.4 Water Balance

The total water requirement of a sub-basin worked out on the methodology outlined above is deducted from the overall surface water availability at 75% and 50% dependabilities to determine the water balance (surplus/deficit) at 75% and 50% dependabilities respectively.

5.4 Yield of Krishna Basin at Srisailam Project

To develop yield series for Krishna basin up to Srisailam project, annual yields available from the water balance study carried out by NWDA for all the upstream sub-basins and yield of the catchment of Lower Krishna sub-basin up to Srisailam project are added for each year for the period from 1951-52 to 1983-84. From this series, annual yields at Srisailam project at 75% and 50% dependabilities are determined.

From the annual yield series for Krishna basin at Srisailam generated as explained in the preceding, the 75% and 50% dependable yields are determined to be 57398 Mm^3 and 66428 Mm^3 respectively.

5.5 Water Balance at Srisailam Project

5.5.1 Import/Export

There is no import of water into Krishna basin up to Srisailam project from any other basin/sub-basin.

There is export of water from existing, ongoing and proposed projects from Krishna basin catchment up to Srisailam project. The details are given below:

I. Existing Projects

(a)	1911 Mm^3 and 1274 M^3 of water by way of westward diversions through Koyna and Tata hydel works respectively.
(b)	387 Mm^3 from Tungabhadra Right Bank High Level Canal Stage-I for irrigation of areas in Upper Pennar sub-basin.
(c)	992 Mm^3 from Tungbhadra sub-basin through Kurnool-Cuddapah Canal for irrigation of areas in Middle Pennar sub-basin.

Thus the total export from the existing projects works out to 4564 Mm^3.

II. Ongoing Projects

(a)	538 Mm^3 of water through Srisailam Right Bank Canal for irrigation in Middle Pennar sub-basin.
(b)	850 Mm^3 through Srisailam Left Bank Canal for irrigation in Lower Krishna sub-basin downstream of Srisailam project and Musi sub-basin.
(c)	1246 Mm^3 of water through Telugu Ganga project for irrigation in Middle Pennar sub-basin and water supply to Chennai city.
(d)	256 Mm^3 of water through Tungabhadra Right Bank High Level Canal Stage-II for irrigation in Upper Pennar sub-basin.

Thus the total export from the ongoing projects works out to 2890 Mm^3.

III. Proposed Projects

(a)	394 Mm^3 of water from the proposed Upper Bhadra project of Tungabhadra sub-basin for irrigation in Upper Pennar sub-basin.

Thus, the total export of water from the existing, ongoing, and proposed projects works out to 7848 Mm^3.

5.5.2 Water Requirements

I. Domestic Requirement

The requirement for livestock population and 50% of the requirement for the rural population in the catchment, which comes to 1409 Mm^3, is proposed to be met from groundwater sources. The requirement for the urban population and the remaining 50% of the requirement for rural population, which works out to 3278 Mm^3, is proposed to be met from surface water sources.

II. Irrigation Requirement

The annual irrigation under all the existing, ongoing and proposed projects in the catchment comes to 4773859 ha which is 29.29% of the maximum culturable area of the catchment. It is considered that at least 30% of the maximum culturable area for each sub-basin should come

under irrigation from surface water resources. The annual irrigation is less than 30% of maximum culturable area in respect of Malaprabha, Upper Bhima, Lower Bhima, Tungabhadra and Vedavati sub-basins. As such, the annual irrigation has been increased to 30% of culturable area in these sub-basins. The additional area computed to be 545760 ha is proposed to be irrigated from the future medium and minor projects in the sub-basins.

The annual irrigation including the additional area from all the existing, ongoing and proposed projects works out to 5319619 ha which is 32.64% of the maximum culturable area of the catchment. The state-wise ultimate annual irrigation and annual utilisation up to Srisailam project are given in Table 5.1.

Table 5.1
Ultimate annual irrigation and annual utilisation in Krishna basin up to Srisailam project

State	Annual irrigation (ha)			Total irrigat-ion (ha)	Cultur-able area (ha)	% of cultur-able area	Annual utilisa-tion (Mm^3)
	Existing projects	Ongoing projects	Proposed projects				
Maharash-tra	441320	646974	717212	1805506	5386072	33.52	14403
Karnataka	1363649	946962	651005	2961616	8710309	34.00	24151
Andhra Pradesh	264444	90257	197796	552497	2203755	25.07	5005
Total	2069413	1684193	1566013	5319619	16300136	32.64	43559

III. Industrial Requirement

In the absence of relevant data on the industrial water needs, industrial requirement by 2025 AD has been assumed to be of the same order as that of the total domestic water requirement which is 4687 Mm^3. This is proposed to be fully met from the surface water resources.

IV. Hydropower Requirement

There are three existing hydro-electric projects viz. Koyna and Radhanagari projects in Upper Krishna sub-basin and Tungabhadra hydro-electric project in Tungabhadra sub-basin. There are two ongoing hydro-electric projects viz. Ghataprabha hydro-electric project in Ghataprabha sub-basin and Srisailam multipurpose project in Lower Krishna sub-basin. The total evaporation losses from all the hydel

projects in the catchment work out to 1154 Mm^3 which is considered as hydropower requirement.

V. Total Surface Water Requirement

The total surface water requirement for irrigation under all the existing, ongoing and proposed projects and for the proposed additional area works out to 43559 Mm^3. The part of domestic water requirement to be met from surface water resources will be 3278 Mm^3. In addition, the entire industrial requirement of 4687 Mm^3 is also to be met from surface water resources. Thus the total surface water requirement works out to 52678 Mm^3 which includes 1154 Mm^3 towards evaporation losses from the hydel projects.

5.5.3 Regeneration

Quantity of water available due to regeneration in Krishna basin up to Srisailam is obtained by adding together the regeneration from the irrigation, domestic and industrial uses for all the sub-basins and part of the sub-basin up to Srisailam project. As per the methodology already described, the total quantum of regeneration works out to 9145 Mm^3.

5.5.4 Water Balance

Details of the surface water balance at 75% dependability for the catchment of Krishna basin up to Srisailam project are given in Table 5.2.

Table 5.2
Water balance of Krishna basin up to Srisailam Project

Unit : Mm^3

1.	**Surface water availability at 75% dependability**			
	a)	Gross annual yield		57398
	b)	Surface water import		-
	c)	Surface water export		(-) 7848
2.	**Regeneration**			
	a)	Domestic	2624	
	b)	Industrial use	3748	
	c)	Surface water irrigation	2773	
		Sub-total	9145	(+) 9145
3.	**Overall availability**			(+) 58695
4.	**Surfacewater requirement**			
	a)	Irrigation use	43559	
	b)	Domestic use	3278	

	c)	Industrial use	4687	
	d)	Hydropower needs (evaporation losses)	1154	
	Sub-total		52678	(-) 52678
5.	**Surface water balance**			**(+) 6017**

5.6 Water Transfer from Srisailam Reservoir

Out of the balance water of 6017 Mm^3 available in Krishna basin at Srisailam project site, a quantum of about 1980 Mm^3 is proposed to be diverted from the ongoing Upper Krishna project through Almatti-Pennar link. Thus, the balance quantity that would be available at Srisailam for any diversion works out to 4037 Mm^3. But keeping in view the revision of upstream sub-basin reports, it is proposed to divert only 2310 Mm^3 of water from Srisailam reservoir to Pennar river through Krishna (Srisailam) – Pennar link in exchange of surplus waters of Mahanadi and Godavari brought to the river Krishna. Krishna basin as a whole is a water deficit at 75% dependability and no water of Krishna is proposed for diversion without replacement.

5.7 Transmission Losses

The loss of water by seepage from unlined canals in India generally varies from 0.3 to 7 cumecs per Mm^2 of wetted area depending on the permeability of soil through which the canal passes, location of water table, distance of drainage, bed width, side slope and water depth in the canal. In addition, flow velocity, soil, water temperature, atmospheric pressure and stratification of underlying soil also affect the seepage rate. In the present study, these losses are computed considering 2.76 cumec per Million Square metre of wetted area. The total transmission losses in the link worked out to be 215 Mm^3.

5.8 Simulation Studies of Srisailam Reservoir

5.8.1 Inflows

The gross annual yield series as worked out for all the eight upstream sub-basins and part of Lower Krishna sub-basin up to Srisailam project site for the period from 1951-52 to 1980-81 have been considered. The net inflows into Srisailam reservoir are computed for each sub-basin by deducting the ultimate surface water requirements for various uses i.e. irrigation, domestic, industrial, hydropower losses from the yearly virgin yields, duly considering the import, export and the regeneration

etc. and also considering the deficit of the downstream sub-basins up to Srisailam. The sub-basin wise inflows thus worked out are added to arrive at the net surplus flows at Srisailam project site in each year after considering the transfer of 1980 Mm^3 through Almatti – Pennar link. These annual inflows are distributed into monthly inflows by using the monthly weights calculated based on actual monthly inflow data observed at Srisailam project site for the period from 1982-83 to 1991-92. The monthly inflows into Srisailam reservoir thus worked out for the period from 1951-52 to 1980-81 are used in the simulation studies.

The reservoir at Srisailam as proposed by the Government of Andhra Pradesh with FRL of 269.75 m has a gross storage capacity of 8723 Mm^3. The dead storage level is 244.75 m. The live storage capacity of the reservoir is 7078 Mm^3. The area-capacity table of Srisailam reservoir has been considered for carrying out the simulation studies.

5.8.2 Demands

The demands from the Srisailam reservoir comprise the requirements of Srisailam Left Bank Canal (SLBC), Srisailam Right Branch Canal (SRBC), Telugu Ganga Canal, Water supply to Chennai city and the diversion quantity through Krishna (Srisailam) – Pennar link. It is proposed to divert water from Srisailam reservoir to Gorakallu and Owk balancing reservoirs of SRBC and Velugodu and Sri Pothuluri Veera Brahmendra Swamy balancing reservoirs of the Telugu Ganga Canal to the extent possible and the field requirements to be met from these balancing reservoirs.

The gross and live storage capacities of the balancing reservoirs viz. Gorakallu and Owk on SRBC are 370 Mm^3, 304 Mm^3 and 138 Mm^3, 79 Mm^3 respectively. The gross and live storage capacities of Velugodu and Sri Pothuluri Veera Brahmendra Swamy balancing reservoirs on Telugu Ganga Canal are 480 Mm^3, 406 Mm^3 and 465 Mm^3, 389 Mm^3 respectively.

The demands to be met from Srisailam reservoir under SLBC, SRBC and Telugu Ganga and Chennai Water Supply Scheme are adopted from Expert Committee Report-1985 of Andhra Pradesh on utilisation of river waters in Andhra Pradesh. The demands to be met from Srisailam Right Branch Canal balancing reservoirs (Gorakallu and Owk) are taken from the “Srisailam Right Bank Canal irrigation scheme project report” – Vol., prepared by the Government of Andhra Pradesh. The demands to be

met from Telugu Ganga balancing reservoirs (Velugodu and Sri Pothuluri Veera Brahmendra Swamy) are taken from "Telugu Ganga Project Report" prepared by the Government of Andhra Pradesh.

The demands to be met from the Srisailam reservoir are as follows.

(i)	Committed downstream releases from Srisailam reservoir to Nagarjunasagar and Prakasam barrages as proposed by the Govt. of Andhra Pradesh amounting to 9858 Mm^3. These requirements will be met from the link projects proposed by NWDA i.e Inchampalli-Nagarjunasagar link (7593 Mm^3) by lift and Godavari (Polavaram)-Krishna (Vijayawada) link (2265 Mm^3) by gravity. Hence the downstream releases from Srisailam reservoir for these two projects are considered as nil.
(ii)	SLBC requirement as proposed by the Govt. of Andhra Pradesh is amounting to 850 Mm^3. Out of this, a quantity of 807 Mm^3 will be met through the Inchampalli-Nagarjunasagar link canal proposed by NWDA. The remaining 43 Mm^3 is taken as a demand under SLBC from Srisailam reservoir.
(iii)	Irrigation requirements of SRBC through the balancing reservoirs to the extent of 538 Mm^3.
(iv)	Irrigation requirement under Telugu Ganga Canal through the balancing reservoirs to the tune of 821 Mm^3.
(v)	Water supply requirement of 425 Mm^3 for Chennai city as proposed under the ongoing Telugu Ganga Canal.
(vi)	Transfer quantity of 2310 Mm^3 to Pennar river through the proposed Krishna (Srisailam) – Pennar link.

Monthly demands as proposed by the Govt. of Andhra Pradesh under each canal, after deducting the requirements met from the link projects proposed by NWDA, are given in Table 5.3.

Table 5.3
Monthly demands of each canal

Unit : Mm^3

Month	From Srisailam reservoir					From balancing reservoirs		
	SLBC	SRBC	Telugu Ganga Canal		S-P Link	SRBC	Telugu Ganga canal	
			Irri-gation	Water supply to Chennai			Irri-gation	Water supply to Chen-nai
Jun	0	0	0	0	0	19	5	0
Jul	0	0	0	107	386	0	7	107
Aug	16	207	318	107	386	57	11	107
Sep	16	207	318	104	383	77	12	104
Oct	11	124	185	107	386	62	12	107
Nov	0	0	0	0	383	117	21	0
Dec	0	0	0	0	386	93	133	0
Jan	0	0	0	0	0	76	277	0
Feb	0	0	0	0	0	37	249	0
Mar	0	0	0	0	0	0	80	0
Apr	0	0	0	0	0	0	7	0
May	0	0	0	0	0	0	7	0
Total	43	538	821	425	2310	538	821	425

It is proposed to draw supplies from Srisailam reservoir to meet the irrigation requirement of SLBC to the extent of 43 Mm^3 in 3 months i.e from August to October and water supply to Chennai city through Telugu Ganga canal to the tune of 425 Mm^3 in 4 months from July to October as proposed by the Govt. of Andhra Pradesh. The transfer of 2310 Mm^3 to Pennar river through the proposed Krishna (Srisailam) – Pennar link canal will be diverted in 6 months from July to December. It is also proposed to draw as much water as possible from Srisailam reservoir to the balancing reservoirs of SRBC and Telugu Ganga canals from the flood waters keeping in view the storage capacities of the balancing reservoirs and demand pattern from these balancing reservoirs. Water from the Srisailam reservoir will be released to the balancing reservoirs if the water level in the reservoir is above 266.70 m. From the balancing reservoirs water will be released as per the field irrigation requirements of SRBC and Telugu Ganga canals as proposed by the Govt. of Andhra Pradesh as shown in Table 5.3.

Possible firm and seasonal power generation from Srisailam project including that due to left bank power house has been assessed by Central Electricity Authority (CEA) considering 78 years of inflow data at Vijayawada. The net inflows at Srisailam after allowing for full upstream utilisation as per KWDT award were worked out by Andhra Pradesh authorities for the study. Simulation studies for integrated operation of Srisailam and Nagarjunasagar reservoirs were carried out to work out the possible firm and seasonal power generation from the project under different conditions of water availability. According to these studies, the firm power generation at Srisailam by 2006-07 and beyond will be 60 MW.

The irrigation demands are proposed to have minimum interference with the working of Srisailam reservoir for a firm power generation of at least 61 MW.

5.8.3 Order of Priority

The order of priority considered for various demands proposed to be met from Srisailam reservoir is as follows:

(i)	Requirements for firm power production as proposed at Srisailam.
(ii)	Water supply to Chennai city as committed under ongoing Telugu Ganga Canal.
(iii)	Irrigation requirements under SLBC, SRBC and Telugu Ganga Canal.
(iv)	Release of water through the link canal.
(v)	Release for irrigation requirements of SRBC and Telugu Ganga canal to fill the balancing reservoirs to the possible extent.

The reservoir simulation studies are carried out for a period of 30 years from 1951-52 to 1980-81 and it was found that a maximum firm power of 61 MW could be generated with the irrigation requirements as explained above.

5.8.4 Results of Simulation

Outcome in terms of the success rate of meeting the various demands at Srisailam reservoir on yearly basis are :

(i)	96.67% success in meeting the requirements for firm power generation of 61 MW at Srisailam reservoir.
(ii)	96.67% success in meeting the requirement of water supply to Chennai city as proposed under the ongoing Telugu Ganga Canal.
(iii)	96.67% success in providing the committed irrigation requirements under SLBC, SRBC and Telugu Ganga Canal.
(iv)	76.67% success in the proposed transfer of water to Pennar river through Krishna (Srisailam) – Pennar link.

In the analysis, a year in which 95% of the demands are met has been considered as a successful year.