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, hydro-power, industries, navigation, etc. Hydrological studies are carried out to estimate the available quantity of water in a given basin. In this chapter, hydrological analysis done for arriving at the water balance at Almatti dam across river Krishna is discussed. The surplus water at Almatti dam is proposed for diversion by exchange of the surplus water of the Mahanadi and Godavari rivers proposed to be brought to the Krishna river through various links.

Even though, the surplus water available at Almatti dam is estimated as 5611 Mm^3, this water could not be considered as surplus as per the downstream commitments as envisaged under the provisions of the KWDT. Hence, the present diversion under the Krishna (Almatti) – Pennar link, proposed as a scheme based on the principle of substitution and exchange and, is discussed in the following sections.

The surplus water of Mahanadi diverted from Manibhadra (+86 m level) is proposed to be delivered in Godavari at Dowlaiswaram (+14 m level) through the Mahanadi – Godavari link canal which flows by gravity. It has been proposed that a quantity of 6500 Mm^3 could be made available to Godavari delta at Dowlaiswaram from the diverted water of Mahanadi, thus releasing the already committed water of Godavari to the delta for diversion to outside the basin from any upstream location on Godavari. The water received from Mahanadi added to the surplus of Godavari is proposed to be diverted to Krishna through three link canals. The diversion from Godavari is proposed to be done from Inchampalli (+112 m level) through two canals and from Polavaram (+45 m level) through one canal.

The Godavari water would be delivered at Nagarjunasagar on the Krishna (+180 m level) and, in exchange, water will be drawn from Almatti and Srisailam reservoirs. The catchment area of the river Krishna from its source to Almatti dam includes the catchments of the sub-basins of Upper Krishna, Ghataprabha and part of Middle Krishna sub-basin up to Almatti

dam. The hydrological studies in respect of these sub-basins have been carried out by NWDA.

5.2 Methodology Adopted by NWDA for Working out Water Balance

Water balance studies for all the sub-basins of Krishna basin have already been done and brought out by NWDA as separate reports. These studies include assessment of total surface water availability, existing uses, reasonable requirements in the foreseeable future (2050 AD) and determination of surplus or deficit.

The methodology adopted for working out water balance is discussed in the following paragraphs.

5.2.1 Surface Water Availability

For realistic estimation of the water availability in sub-basin, a long term yield series for that sub-basin is required. Generally, observed flow data for a sub-basin is not available for long duration. As such long-term yield series for a sub-basin is developed from the available concurrent rainfall and runoff data using regression analysis. Usually terminal river gauging site is considered for this purpose. However, reliability and period of availability of data are the other considerations for selecting the gauging site. To the observed flows of the selected gauging site upstream utilisations in respect of irrigation, hydropower, domestic and industrial requirements are added to get the virgin yields. Weighted rainfall values for the catchment up to G&D site and also for the whole sub-basin are worked out. Using these virgin flows and weighted rainfall up to the G&D site, the regression analyses are carried out. Using the best-fit equation and the weighted rainfall for the entire sub-basin, long-term yield series are generated. From the long term yield series the 75% and 50% dependable yields of the sub-basin are computed.

5.2.2 Water Requirement

The requirement of water at the ultimate stage for various uses viz., irrigation, drinking, industry and hydropower are worked out as under:

Irrigation Needs: Water requirements for irrigation are assessed for all the existing, ongoing and proposed major, medium and minor projects in the sub-basin. For this purpose, all the projects planned by the states, as

per their master plans are considered. While the designed annual utilisation as per the detailed project reports 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 as 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. In case of deficit sub-basin, where the ultimate annual irrigation, considering all the existing, ongoing, proposed major, medium and minor projects works out to be 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. 50% of such increased annual irrigation is considered to be under future medium projects and the remaining 50% under future minor schemes. 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: Based on 1991 census, human population as well as livestock population is projected to 2050 AD using suitable annual compound growth rates, based on the publication of the United Nation entitled "World Population Prospects - 1994 Revision". The requirements are worked out separately for the rural and urban human and livestock population. In case of rural and urban human population, per capita daily needs of 70 liters and 200 liters respectively have been adopted as per the recommendations of the Ministry of Works and Housing in their manual "Water Supply and Treatment". The per capita daily needs of livestock population are considered as 50 liters. The entire water requirement of livestock population and the water requirement of 50 % of the rural human population are considered to be met from groundwater, and the requirement for the remaining 50% of the rural human population and the entire urban population is considered to be met from surface water.

Industrial Needs: Due to lack of data to estimate precisely the industrial water needs, the industrial requirement is taken to be equivalent to the total domestic requirement for human population and livestock. 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 designed for hydropower generation. Wherever the evaporation data for the reservoirs are available, the same has been made use of and wherever the data is not available the same is worked out from the submergence area of the reservoir assuming suitable evaporation values.

5.2.3 Regeneration

Regeneration is considered as 10% of net utilisation for those projects having utilisations more than 85 Mm^3 for irrigation under major and medium projects and 80% of the domestic and industrial uses met from surface water.

5.2.4 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 surplus/deficit of water at 75% and 50% dependabilities, respectively. Regeneration, imports to and exports from the basin are also taken into account while arriving at water balance.

5.3 Water Balance at Almatti Reservoir

The catchment area from the source of the Krishna river up to Almatti dam site is 33375 km^2. The catchment includes the entire sub-basins of Upper Krishna and Ghataprabha and a part of Middle Krishna sub-basin up to Almatti dam. The details of catchment area of these three sub-basins are given in Table 5.1.

Table 5.1
Sub-basin wise catchment areas of Krishna basin up to Almatti dam

Sl. No.	Name of the Sub-basin	Catchment area (km^2)	% of Krishna basin up to Almatti dam
1.	Upper Krishna (up to its confluence with Dudhganga)	17972	53.85
2.	Ghataprabha	8829	26.45
3.	Middle Krishna (from its confluence with Dudhganga to Almatti dam)	6574	19.70
	Total	**33375**	**100.00**

5.3.1 Computation of Yield at Almatti Reservoir

Water balance at Almatti has been assessed by considering the Krishna basin up to Almatti. The yield series of this catchment has been developed for the period from 1901-02 to 1999-2000 by adding the year wise monsoon and non-monsoon yields of each of the sub-basins.

The annual gross yields from Upper Krishna, Ghataprabha and part catchment of Middle Krishna sub-basin up to Almatti dam site have been added for the period from 1901-02 to 1999-2000 to get the gross annual yields up to Almatti dam. From this, the 75% and 50% dependabilities have been determined as 21405 Mm^3 and 24041 Mm^3 respectively.

5.3.2 Import/Export

There is no import of water from any sub-basin/basin to the catchment.

There is an existing export of 1911 Mm^3 towards westward diversion from Koyna Hydroelectric Project. There is an ongoing export of 4930 Mm^3 from Hippargi barrage and Upper Krishna Project (Almatti and Narayanpur Dams) to the catchment downstream of Almatti dam and other sub-basins of Krishna basin viz., Malaprabha, Upper Bhima, Lower Bhima and Lower Krishna sub-basins. There is no export of water from the proposed projects. Thus the quantity of export from the catchment of Krishna basin up to Almatti dam is 6841 Mm^3.

5.3.3 Water Requirements for Various Purposes

Domestic Needs: The total domestic water requirement has been assessed as 936 Mm^3, out of which 706 Mm^3 will be met from surface water resources.

Irrigation Needs: The ultimate surface water requirement for all existing, ongoing and proposed projects in the catchment has been assessed to be 8979 Mm^3 and is shown in Table 5.2.

Table 5.2
Annual Irrigation and Utilisation in Krishna Basin
Up to Almatti Dam

Area: ha
Utilisation: Mm^3

Name of the Sub- basin	Annual Irrigation				Annual Utilisation			
State	Exist-ing	On-going	Propo-sed	Total	Exist-ing	Ong-oing	Propo-sed	Total
UpperKrishna								
Maharashtra	158214	244943	189336	592493	1250	2309	1320	4879
Karnataka	2524	53687	2266	58477	7	382	15	404
Sub -total	160738	298630	191602	650970	1257	2691	1335	5283
Ghataprabha								
Maharashtra	14626	3983	64456	83065	69	28	324	421
Karnataka	126407	80388	118723	325518	764	558	626	1948
Sub -total	141033	84371	183179	408583	833	586	950	2369
Middle Krishna up to Almatti dam								
Maharashtra	7136	636	7976	15748	33	3	49	85
Karnataka	99522	97207	533	197262	688	551	3	1242
Sub -total	106658	97843	8509	213010	721	554	52	1327
Total	408429	480844	383290	1272563	2811	3831	2337	8979

Industrial Needs: The Industrial need is assumed to be of the same order as that of domestic water requirement i.e. 936 Mm^3. It is proposed to be fully met from the surface water resources.

Hydro Power Needs: There are three hydropower projects (Koyna, Radhanagiri and Ghataprabha) in the catchment of Krishna up to Almatti. Evaporation losses from these projects work out to 220 Mm^3.

5.3.4 Regeneration

The total regeneration from all the uses works out to be 1888 Mm^3.

5.3.5 Water Balance

The surface water balance of Krishna basin up to Almatti dam at 75% dependability, works out to 5611 Mm^3 as shown in Table 5.3.

Table 5.3
Water balance of Krishna basin up to Almatti dam

Unit: Mm^3

1	a) Surface Water availability		
	At 75% dependability		21405
	At 50% dependability		24041
	b) Surface water import (+)		-
	c) Surface water export (-)		6841
2	Regeneration from (+)		
	a) Domestic use	565	
	b) Industrial use	748	
	c) Irrigation use	575	
	Sub-total	1888	1888
3	Overall availability		
	At 75% dependability		16452
	At 50% dependability		19088
4	Surface water requirement for		
	a) Irrigation use	8979	
	b) Domestic use	706	
	c) Industrial use	936	
	d) Evaporation losses from hydro power projects	220	
	Sub-total	10841	10841
5	Surface water balance		
	At 75% dependability		5611
	At 50% dependability		8247

5.4 Transmission Losses

The quantity of water that is proposed for diversion from Almatti reservoir will be utilised enroute for various uses. The total length of the link canal is 587.175 km. The month-wise total water requirement of the link canal has been worked out considering the Kharif demands for enroute irrigation for six months from June to November and domestic and industrial requirements for twelve months. The transmission losses are assumed as 0.6 cumec per million m^2 of wetted area as per IS Code 10430-1982. It is proposed to operate the canal daily for one hour only since the daily requirement is only 0.16 Mm^3 from December to May. Accordingly, the transmission losses have been worked out to be 210 Mm^3.

5.5 Simulation Studies

Since Narayanpur Dam is mainly a diversion structure meeting a part of its requirements from the Almatti Dam releases and Kalvapalli being an enroute balancing reservoir of the link canal, the simulations studies for Almatti reservoir were carried out integrating Narayanpur and Kalvapalli reservoirs with Almatti. For the purpose of simulation, data of 46 years (from 1954 to 2000) has been considered.

5.5.1 Input Data

The following data were considered for the simulation studies:

1. Inflows into Almatti and Narayanpur reservoirs.
2. Evaporation losses of Almatti reservoir and irrigation requirements of Almatti LBC and RBC.
3. Evaporation losses of Narayanpur reservoir and irrigation requirements of Narayanpur LBC and RBC.
4. Irrigation requirements of Krishna (Almatti) - Pennar link between Almatti and Kalvapalli reservoirs.
5. Evaporation losses of Kalvapalli reservoir and the irrigation requirement of Krishna (Almatti) – Pennar link beyond Kalvapalli.

5.5.2 Inflows

The catchment area of the river Krishna from the source up to Almatti dam includes the catchments of Upper Krishna and Ghataprabha sub-basins and Middle Krishna sub-basin up to Almatti dam. The annual yields of all the above sub-basins are added to get the total yield up to Almatti dam site. The requirements of the entire catchment up to Almatti dam are deducted from the gross annual yields at the Almatti dam site to get the net annual inflows. These net annual inflows have been distributed into monthly inflows on prorata basis, based on the G&D data of Kurundwad and Huvanur sites for the period from 1954 to 1973 and 1974 to 2000, respectively.

Similarly, the net annual inflows at Narayanpur dam have also been obtained by deducting the requirement of Malaprabha sub-basin from the gross annual yields of the Malaprabha sub-basin and then adding to the spills from Almatti dam. Other than Malaprabha, no tributary joins Krishna between Almatti and Narayanpur. The direct draining area is also small and therefore inflow from the direct draining area between Almatti and

Narayanpur has not been considered. The yield into Narayanpur reservoir due to Malaprabha River has been distributed into monthly inflows on prorata basis based on the G&D data of Kurundwad and Huvanur sites.

Inflows at the Kalvapalli reservoir are earmarked for uses downstream of Kalvapalli reservoir and hence not considered for simulation studies.

5.5.3 Demands

The annual irrigation requirement of Almatti project, including Narayanpur reservoir is considered as 4900 Mm^3 (173 TMC) as per the KWDT Award. The monthly requirement of Krishna (Almatti) - Pennar Link is divided into two parts. The first part pertains to the requirement of command area between Almatti dam and Kalvapalli reservoir. The second part pertains to the requirement of command area between Kalvapalli dam and tail end of the canal. The requirement for irrigation from June to May is worked out based on climatological approach for the command area falling in the respective sub-basins.

5.5.4 Assumptions

Following assumptions were made for conducting simulation studies:

1. The initial storages of the reservoirs are assumed as dead storage.
2. The monthly evaporation losses of the reservoirs are estimated using the submergence area at the beginning of each month multiplied with pan evaporation of the corresponding month.
3. If the storage in the Almatti reservoir is more than the gross storage after meeting all the requirements then the water is proposed for diversion to Narayanpur and Kalvapalli reservoirs for storing the water.
4. Inflows into Kalvapalli reservoir from its catchment have not been considered. This inflow is earmarked for use in the downstream area of the reservoir.

5.5.5 Results of the Simulation

Simulation studies were carried out for the Almatti reservoir integrating it with the Narayanpur and Kalvapalli reservoirs. The study indicates that diversion of 1980 Mm^3 of water from Almatti dam to link canal is 100% successful in 40 years out of 46 years. The deficit except for 1987 is less than 5% of the annual diversion. The simulation studies carried out by Karnataka Power Corporation shows that the average power generation at

Almatti with FRL at 519.60 m is about 800 MU. With the introduction of link canal, the reduction in power generation is 85.5 MU only. This reduction can also be eliminated by further raising the FRL of Almatti reservoir as envisaged in Upper Krishna Project.