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 assess the available quantity of water in a given basin. This chapter deals with the assessment of water balance in the Mahanadi basin upto the Barmul dam site, and simulation study of Barmul reservoir.

5.2   Hydrological analysis

The hydrological study of Mahanadi river at Barmul site has been carried out by NWDA through National Institute of Hydrology (NIH), Roorkee (Revised April-2018) and assessed the yield availability at Barmul dam site by using latest scientific methods for planning further diversion through Mahanadi (Barmul) - Godavari (Dowlaiswaram) Link.

NWDA has prepared water balance study reports of (i) Godavari basin upto Polavaram dam site (about 40 km upstream of Dowlaiswaram barrage (cotton barrage)) and (ii) The basins lying en route the link alignment between Mahanadi and Godavari. From Water balance study of Godavari basin upto Polavaram dam site, the water balance in Godavari basin at Dowlaiswaram barrage has been computed and presented in this report.

5.3 Hydrological and water balance studies of the Mahanadi basin upto Barmul dam site

The hydrological study of Mahanadi river at Barmul site has been carried out by NWDA through National Institute of Hydrology (NIH), Roorkee and assessed the yield availability at Barmul dam site by using latest scientific methods for planning further diversion through Mahanadi (Barmul)- Godavari (Dowlaiswaram) Link. The study by NIH reveals that the net water balance at 75% dependability is 6794 MCM at Barmul site (NIH revised Report-April 2018). The gross storage capacity of Barmul reservoir at FRL(80m) is 1835.58 MCM. Live storage capacity is 1619 MCM and sill level of the link canal (MDDL) is 66.0m. As per the simulation study conducted by the NIH, the estimated annual demand of link canal is 10105 MCM and average annual spills are 28486 MCM. The   annual average link diversion is 9434 MCM.

Govt. of Odisha submitted their observations On NIH revised Report-April 2018 and expressed that there is a deficit of 18718 MCM of water at Barmul

site on Mahanadi river at 75% dependability. NWDA reviewed the same and modified the surface water balance showing that there is a surplus of 3417 MCM of water at Barmul on Mahanadi river at 75% dependability.

As per the NIH study report, water balance at Barmul site has been worked out considering only one-year data ie, 75% dependable year. However, the simulation has been done by NIH, Roorkee considering available data of 40 years from 1973 to 2012. On NIH revised Report-April 2018, Govt. of Odisha submitted again their observations and expressed that after considering all the latest demands of Odisha and Chhattisgarh States, there is a deficit of 18718 MCM of water at Barmul site on Mahanadi river at 75% dependability. NWDA considered their enhanced demands for irrigation and considered the guidelines of TAC of NWDA for assessment of water requirements for various purposes including Environmental and Ecological purpose and regeneration etc, worked out the surface water balance at 75% dependability and assessed a surplus of 3417 MCM of water at Barmul on Mahanadi river.

While carrying out the simulation study by NIH, the net flow at the Barmul was estimated by considering the net contributing area at the Barmul site and catchment areas of the upstream six projects namely Ong, Tel, Upper udanti, Uttai-Roul, Khadaga and Salki projects; spills and releases from Hirakud dam. Simulation had been carried out by taking flow data of 40 years from 1973 to 2012 of Tikkarapara G&D site (CWC). River flow, upstream project releases, evaporation, committed downstream demands for irrigation in delta area of Mahanadi, E- flow in the river downstream of Barmul dam and diversion to M-G link canal are considered in the study. The total diversion into link canal has been assessed to 10105 MCM taking all the demands of link canal ie, Irrigation requirement, Domestic & industrial requirement enroute the link canal, transmission losses and transfer to Godavari with 77.5% of success failing in 9 years and success in 31 years out of 40 years. Detailed simulation results have been appended in the study submitted by NIH, Roorkee, using their softwares and considering all the necessary hydrological inputs of Mahanadi basins, computing crop water requirement by climatological approach and adopting proposed cropping pattern based on existing cropping pattern in all sub basins of Mahanadi and considering other climate factors and soil types etc. The report has been accepted by sub-committee on "System Studies for identification of most appropriate alternative plan". Results provided by National Institute of Hydrology have been considered in the present Feasibility report of Mahanadi (Barmul) – Godavari (Dowlaiswaram) link project. The NIH study report (April -2018) is appended in **Volume – IV (Appendices).**

5.3.1 Water balance

The surface water balance in the Mahanadi basin up to Barmul dam site at the ultimate stage of in basin development assessed by NIH and as modified by NWDA at headquarters are presented in **Table 5.1**.

Table 5.1
Surface water balance at Barmul dam site

Unit: MCM

S. No.	Details	As per NIH	As per NWDA
1.	Availability Gross annual yield at 75% dependability	48856	48856
	b) Surface water import (+)	2407	2407
	c) Surface water export (-)	2162	2162
	d) Overall availability at 75% dependability	**49101**	**49101**
2	Surface water requirement for (-) i) Irrigation(Odisha)		
	Existing	9083	15957
	Ongoing	1183	1183
	Identified	14854	4854
	Gross Irrigation(Odisha)	**25120**	**31994**
	ii) Irrigation(Chhattisgarh)	26825	26825
	iii Domestic	2754	2754
	(Chhattisgarh 2240.65+Odisha 513)		
	iv Industrial Use	9092	9092
	(Chhattisgarh 4832+Odisha 4260)		
	v Hydro Power	801	801
	vi Environment & ecology	3498	-
	Sub-total	**68089**	**71466**
3	Regeneration (+) i) Irrigation	16305	16305
	ii) Domestic	2203	2203
	iii) Industrial	7274	7274
	Sub-total	**25782**	**25782**
4	Surface water balance at 75% dependability	**6794**	**3417**

The surface water balance at 75% dependability at Barmul site on Mahanadi river is considered as 3417 MCM in the present report.

5.4 Hydrological and Water balance studies of intermediate basins between Mahanadi and Godavari

There are several basins/streams lying between the river Mahanadi and Godavari flowing east and draining into the Bay of Bengal. The Water Balance

Studies of these basins have been carried out by NWDA and updated time to time. The availability and water balance of these basins are furnished in **Table 5.2.**

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Table 5.2
Availability and water balance of intermediate basins
between Mahanadi and Godavari

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Unit: MCM

Sl.No.	Name of basin/streams	Gross availability at 75%	at 50%	Water balance at 75%	at 50%
1.	Streams between Mahanadi and Rushikulya	814	954	263	403
2.	Rushikulya basin	5166	5650	1673	1857
3.	Streams between Rushikulya and Vamsadhara	1431	1725	439	733
4.	Vamsadhara basin	2124	2779	623	1278
5.	Nagavali basin	3730	4787	1480	2537
6.	Streams between Nagavali and Godavari	5367	6803	-1203	233

5.5 Hydrological and water balance studies of Godavari basin upto Dowlaiswaram barrage.

The Godavari basin has been divided into 12 sub-basins for the purpose of hydrological studies. These are (1) Upper Godavari (from sources to its confluence with Manjira), (2) Pravara, (3) Purna, (4) Manjra, (5) Middle Godavari, (from its confluence with Manjra to its confluence with Pranhita), (6) Maner, (7) Penganga, (8) Wardha, (9) Pranhita, (10) Lower Godavari (from its confluence with the Pranhita to the mouth),   (11) Indravati and (12) Sabari.

The catchment area of the Godavari basin is 312813 km^2 and spread in the states of Maharashtra, Karnataka, Madhya Pradesh, Chhattisgarh, Odisha, Telangana and Andhra Pradesh. The state/district/sub-basin-wise breakup of the catchment area of the Godavari basin is given in **Annexure 5.2.** The catchment area of the basin upto the existing Dowlaiswaram barrage extends over an area of 309558 km^2, which works out to 98.96% of the total catchment area of the Godavari basin. This catchment includes the catchments of 11 upper sub-basins and part of Lower Godavari up to Dowlaiswaram barrage. Preliminary studies conducted so far on water balance in respect of different sub-basin of the Godavari basin revealed that the water available upstream of the existing Sriramsagar Project (SRSP) on main Godavari is not fully sufficient to bring the available culturable area in the upper reaches of the project area under irrigation. Further, it is also

seen that the yield available below Sriramsagar project in the Godavari basin gives rise to sizable surplus water after meeting all the surface water requirements. Since it is not possible to divert this surplus water available below Sriramsagar to the upper reaches of the Godavari basin by gravity, to assess the water balance at Dowlaiswaram barrage on Godavari river in a realistic way, the water balance up to Sriramsagar project in Godavari basin is considered as nil and to assess the water balance of the Godavari basin at Dowlaiswaram, the catchment area of the Godavari basin between Sriramsagar Project and Dowlaiswaram barrage only is considered. By arranging the combined annual yield series of the sub-basins of the intermediate catchment between Sriramsagar project and Dowlaiswaram in descending order, the 75% and 50% dependable annual gross yields have been found to be 81003 MCM and 97553 MCM respectively.

The existing Sriramsagar project Stage-I provides irrigation in this part of the Godavari basin utilising 2898 Mm^3 of water. The proposed stage-II of the project will provide irrigation to the tune of 990 Mm^3. Thus, the total import works out to 3888 Mm^3

The water balance has been then worked out deducting the ultimate water requirements for various uses like irrigation, industrial, domestic and other uses from the overall availability, duly considering the regeneration, import and export. The NWDA has prepared Water balance study of the Godavari basin between Sriramsagar project (SRSP) and Polavaram dam site (about 40 km upstream of Dowlaiswaram barrage). The ultimate irrigation and surface water requirement in the Godavari basin between SRSP and Polavaram dam site are presented in **Table 5.3.**

Table 5.3
Ultimate irrigation and surface water requirement in the Godavari basin between SRSP and Polavaram dam site

Project	Annual irrigation (ha)			Annual utilisation (MCM)		
Category/State	In-basin	Import	Total	In-basin	Import	Total
Existing	935888	326292	1262180	6550	2898	9448
Ongoing	1515888	-	1515888	11122	-	11122
Proposed	3774773	117172	3891945	25981	990	26881
Total	6226549	443464	6670013	43653	3888	47541

The existing Cotton barrage provides irrigation in Yeleru and Kolleru lake catchments to the tune of 3951 MCM. The ongoing Upper Indravati project of Indravati sub-basin provides irrigation in Mahanadi basin utilising a quantity of 1723 MCM. The ongoing Upper Penganga project provides irrigation in Upper Godavari sub-basin utilising 655 MCM. The proposed Polavaram project provides irrigation to the tune of 2564 MCM out side the basin, besides diverting 2265 MCM of water to Krishna basin and 664 MCM towards

domestic and industrial needs to Visakhapatnam. The proposed extension of Samalkot canal of Cotton barrage will provide irrigation to a tune of 234 MCM. The proposed Lower Indravati project provides irrigation in Mahanadi basin utilizing 1413 MCM of water. Thus, the total export from this basin works out to 13469 MCM.

There are a number of existing, ongoing and proposed Hydro power projects in various sub-basins of Godavari basin. The evaporation losses from these projects which works out to 6380 MCM is considered as Hydropower needs of the basin.

The requirements of water for domestic use in the rural and urban areas and for livestock have been computed by projecting the rural and urban population and livestock to 2025 AD. The total domestic water needs are assessed to be 2562 MCM. Details are given in **Table 5.4.**

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Table 5.4
Domestic water requirement by 2050 AD in Godavari basin between SRSP and Polavaram dam site

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Category requirement	Population ('000')	Per capita daily needs (litres)	Water (Mm^3)
Rural	41464	70	1059
Urban	18600	135	916
Livestock	32165	50	587
Total			**2562**

The entire urban population water requirement and 50% of the rural population water requirement are proposed to be met from the surface water resources. 80% of domestic water use to be met from surface water source is considered to be available as regeneration to the stream. The industrial requirement by 2050 AD has been assumed to be of the same order as that of domestic water requirement which is 2562 MCM. It is proposed to be met from the surface water sources. 80% of this use is considered to be available as return flow to the stream.

5.5.1 Net water requirement of Godavari basin below Polavaram dam site

The surface water requirement in Godavari basin below Polavaram dam site will also have to be met from the Polavaram reservoir. The net water requirement below Polavaram is computed to be 3808 MCM, as shown below.

a) In basin irrigation requirement
including Polavaram requirement   =   4460 Mm^3
b) Domestic and Industrial water requirement   =   181 Mm^3
c) The contribution from intermediate
catchment between Polavaram and
Cotton barrage on prorata basis   =   833 Mm^3
d) Net d/s water requirement to be met
from Polavaram reservoir   =   3808 Mm^3

The water balance computations at Polavaram barrage taking into account the availability, import, export, regeneration and water needs is given in **Table 5.5.**

Table 5.5
Surface water balance between SRSP and
Polavaram dam in Godavari basin

1. Availability	**Units: Mm^3**
a) Gross annual yield	
i) At 75% dependability	78876
ii) At 50% dependability	95675
b) Surface water import (+)	3350
c) Surface water export (-)	22460
d) Overall availability	
i) At 75% dependability	59756
ii) At 50% dependability	76565
2. Surface water requirement for	
i) Irrigation	51398
ii) Domestic use	1758
iii) Industrial use	2763
iv) Hydro-power use	2641
Sub-total	**58560**
Regeneration (+)	
i) Irrigation	6570
ii) Domestic use	1460
iii) Industrial use	2210
Sub-total	**10186**
3. Surface water balance	
i) At 75% dependability	11382
ii) At 50% dependability	28196

Source: Technical Study No. WB 100 prepared by NWDA.

NWDA has prepared draft DPR of Godavari – Cauvery link (alternative to proposed Godavari – Krishna – Pennar – Cauvery links). As per this DPR 7000 MCM water from Godavari basin is proposed to be diverted through Godavari – Cauvery link. The Mahanadi – Godavari link will provide 6500 CM water in Godavari basin up-stream of existing Dowlaiswaram barrage. This water will also be diverted by substitution to Krishna, Pennar, Cauvery etc basins via Nagarjunasagar and Somasila projects.

5.6 Contribution from the intermediate basins / sub-basins between Mahanadi and Godavari

In the above paras, the status of water balance of the intermediate catchments between Mahanadi and Godavari rivers has been presented**.** All these rivers are seasonal only and the quantum of water available is just sufficient to meet needs of respective basins. Hence, no contribution from these intermediate streams is considered into the Mahanadi-Godavari link canal. The quantity of water proposed to be diverted through this link is from the surplus water available in Mahanadi basin at Barmul dam site at the ultimate stage of development. The state-wise and district-wise break up of the basins / sub-basins lying between Mahanadi and Godavari is presented in **Annex 5.1**

5.7 Simulation studies at reservoirs.
5.7.1 Yields available at Barmul barrage site at 75% dependability

Hydrological studies and Multi- Reservoir simulation for the proposed Mahanadi - Godavari link have been carried out by NWDA through NIH, Roorkee (April-2018). As assessed by NIH, the annual water balance at Barmul dam site is 6794 MCM at 75% dependability considering the requirements of all the existing, ongoing and identified future projects including domestic and industrial needs of Odisha and Chhattisgarh States in Mahanadi basin above Barmul dam site. However, the annual water balance at Barmul dam site considered in this report is 3417 MCM at 75% dependability as modified by the headquarters, New Delhi after considering the observations of Govt. of Odisha.

NIH carried out the simulation for all the six reservoirs proposed to be integrated with M-G link viz., Salki and Ong in Ong sub-basin and Uttei Roul Integrated Project, Khadago, Udanti and Tel Integrated Project in Tel sub-basin in Mahanadi basin. As per the simulation study conducted by the NIH at Barmul reservoir, the estimated annual demand and spills are 10105 MCM and 28486 MCM respectively. The simulation study reveals that there will be average annual deficit of 671 MCM against total demand of 10105 MCM of M-G link which is very marginal. However, after meeting the average annual deficit of 671 MCM, still the link has considerable spill of 27826 MCM. The

area capacity at different elevations of Barmul reservoir is given at **Annexure 5.3.** The abstract of simulation study carried out by NIH is shown in **Table -5.6.**

Table-5.6
Simulated working table at Barmul dam (MCM)

Year	Loc Flo	Us Flo	Evap	Downstream demands			Downstream releases				Link Div.	Spill	Defi-cit	Spill After Meeting deficit
				Irri.	EF	WS	Irri.	EF	WS	Total				
1973	31801	2735	228	5508	3498	1163	5508	3498	1163	10169	9458	13506	647	12859
1974	74810	4638	260	5508	3498	1163	5508	3498	1163	10169	10105	58436	0	58436
1975	19178	871	135	5508	3498	1163	4557	3498	1163	9218	5938	6247	4167	2080
1976	48788	1596	207	5508	3498	1163	5508	3498	1163	10169	9785	29451	320	29131
1977	43234	2846	149	5508	3498	1163	5508	3498	1163	10169	8700	28011	1405	26606
1978	50191	2696	199	5508	3498	1163	5508	3498	1163	10169	9836	31720	269	31451
1979	53156	3695	199	5508	3498	1163	5508	3498	1163	10169	10105	36661	0	36661
1980	16724	1250	108	5508	3498	1163	4482	3498	1163	9143	5629	3765	4476	0
1981	60434	3539	169	5508	3498	1163	5508	3498	1163	10169	10010	43400	95	43305
1982	32250	1760	156	5508	3498	1163	5508	3498	1163	10169	8470	14909	1635	13274
1983	30228	1707	137	5508	3498	1163	5406	3498	1163	10067	6785	15296	3320	11976
1984	39843	1758	180	5508	3498	1163	5508	3498	1163	10169	8304	22305	1801	20504
1985	47647	2305	172	5508	3498	1163	5508	3498	1163	10169	9395	31001	710	30291
1986	62799	5330	228	5508	3498	1163	5508	3498	1163	10169	9700	46867	405	46462
1987	55067	3014	185	5508	3498	1163	5508	3498	1163	10169	10079	38672	26	38646
1988	23099	838	173	5508	3498	1163	5508	3498	1163	10169	9500	3412	605	2807
1989	24463	822	166	5508	3498	1163	5292	3498	1163	9953	8636	7103	1469	5634
1990	27085	1349	176	5508	3498	1163	5508	3498	1163	10169	9370	8476	735	7741
1991	73207	6744	269	5508	3498	1163	5508	3498	1163	10169	10105	58143	0	58143
1992	53024	3586	265	5508	3498	1163	5508	3498	1163	10169	10105	36654	0	36654
1993	44793	3367	191	5508	3498	1163	5508	3498	1163	10169	9933	28890	172	28718
1994	38728	2034	210	5508	3498	1163	5508	3498	1163	10169	10017	19762	88	19674
1995	110513	6355	275	5508	3498	1163	5508	3498	1163	10169	10105	95316	0	95316
1996	38172	2426	244	5508	3498	1163	5508	3498	1163	10169	10105	20313	0	20313
1997	27084	894	175	5508	3498	1163	5508	3498	1163	10169	9558	9059	547	8512
1998	44386	2740	252	5508	3498	1163	5508	3498	1163	10169	8998	26491	1107	25384
1999	32383	954	281	5508	3498	1163	5508	3498	1163	10169	10105	12976	0	12976
2000	40263	1719	288	5508	3498	1163	5508	3498	1163	10169	10105	21227	0	21227
2001	23518	1504	244	5508	3498	1163	5508	3498	1163	10169	10105	5004	0	5004
2002	76767	6270	300	5508	3498	1163	5508	3498	1163	10169	10105	61963	0	61963
2003	20190	1029	148	5508	3498	1163	5281	3498	1163	9942	7968	4573	2137	2436
2004	72999	5311	270	5508	3498	1163	5508	3498	1163	10169	10105	56354	0	56354
2005	41710	3439	261	5508	3498	1163	5508	3498	1163	10169	10105	24365	0	24635
2006	49651	2352	291	5508	3498	1163	5508	3498	1163	10169	10105	31417	0	31417
2007	62038	6169	239	5508	3498	1163	5508	3498	1163	10169	10105	47980	0	47980
2008	58418	4481	293	5508	3498	1163	5508	3498	1163	10169	10105	42047	0	42047
2009	51075	5031	276	5508	3498	1163	5508	3498	1163	10169	10105	35838	0	35838
2010	35513	3040	207	5508	3498	1163	5508	3498	1163	10169	10105	18828	0	18828
2011	33538	2597	248	5508	3498	1163	5508	3498	1163	10169	10105	14574	0	14574
2012	44573	1955	180	5508	3498	1163	5508	3498	1163	10169	9415	28149	690	27459
Average											9434.35	28486	671	27826

As per this study, diversion of 9434 MCM (10105-671) to M-G link is only possible against total demand of 10105 MCM. Month wise breakup of this quantity available for diversion at Barmul site has been worked out based on

40 years monthly releases into link canal found in simulation studies carried out by NIH and distributed on the basis of monthly flow pattern of 75% dependable year (2010-11). The month wise link demands, diversion to link canal as per NIH study and deficits at Barmul site are shown in **Table-5.7**

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Table- 5.7
Month-wise breakup of diversion to link canal,
demands & deficits at Barmul dam site

(Unit: MCM)
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Sl. No.	Month	Link demand	Demond meet as per NIH study div. to link canal	T. Loss as per NWDA	Deficit at Barmul (3-4)
1	2	3	4	5	6
1.	Jun.	702	327	31	(-)375
2.	Jul.	1859	1133	81	(-)726
3.	Aug.	1609	2501	71	(+)892
4.	Sep.	1376	2733	60	(+)1357
5.	Oct.	1044	664	46	(-)380
6.	Nov.	776	330	34	(-)446
7.	Dec.	786	314	34	(-)472
8.	Jan.	618	275	52	(-)343
9.	Feb.	447	270	42	(-)177
10.	Mar.	445	300	39	(-)145
11.	Apr.	304	303	30	(-)1
12.	May	139	284	13	(+)145
	Total	**10105**	**9434**	**533**	**671**

The transmission losses in the link canal are considered as 1073 MCM in the feasibility report (December - 2004). These were worked out by using emperical formula 0.6 cumec per one million sq.km of wetted perimeter area of canal section designed for maximum discharge. The earlier assessment made on the assumption that link canal runs with maximum discharge throughout the year which seems on higher side. Later, as per the revised guidelines of NWDA, the transmission losses have been worked out based on the actual discharge in the link canal which varies from month to month using the same rate as 0.60 cumecs per one million sqkm of wetted perimeter area. According to this phenomenon the transmission losses works out 569 MCM thus reducing by 504 MCM annually.

The total annual deficit is 671 MCM which is very marginal. NIH in their report states that the Mahanadi river has considerable spill of 27826 MCM even after meeting the deficiency. If storage is created in the enroute area of the link alignment and filled during monsoon, water may be gradually released from these storages in the lean season and diverted to the M-R-G link. The cropping pattern adopted in the command area under link canal is presented in **Annex 5.4**

5.8 Spill and Deficits at Barmul Dam

Tables 5.6 and 5.7 gives the annual summary results of simulation of the operation of Barmul Dam without MSTG contribution. The annual demand of the link is 10105 MCM and the average annual link deficit in meeting link demands is 671 MCM. At the current level of development, the average annual volume of spill is 28486 MCM. Some of the spills can be used to improve reliability of M-R-G link substantially if storage space is created in the basin states and filled during monsoon. Water may be gradually released from these storages in the lean season and diverted to the M-G link. This way, the link will require only small augmentation from the M-S-T-G contribution.

5.9 Contribution from MSTG link

As per the original planning of Mahanadi – Godavari link off taking from proposed Manibhadra dam, about 6500 MCM water is reaching to Godavari River up-stream of existing Dowlaiswaram Barrage for further transfer along with surplus Godavari water for utilization in drought affected Krishna, Pennar and Godavari basins. With a view to keep the planning of link projects to further south beyond Godavari, an attempt has been made that even with alternative proposal Mahanadi (Barmul) – Godavari link off taking from proposed Barmul dam 6500 MCM water reaches Godavari at existing Dowlaiswaram barrage. The shortage of 1454 MCM will be augmented from the contribution of MSTG link reaching Mahanadi through Ganga – Damodar – Subarnarekha link and Subarnarekha – Mahanadi link.