WATER BALANCE ANALYSIS FOR LARGE SCALE WATER TRANSFER – A CASE STUDY

M.L. KANSAL
Department of Water Resources Development and Management, Indian Institute of Technology Roorkee, Roorkee

ABSTRACT *In view of the disparities in different river basins, inter-basin transfer of water has been receiving attention from Indian water resources planners for diversion of water from surplus river basins to water deficit basins. As envisaged in the National Water Policy, water resources development and management plans should be for a hydrological unit such as drainage basin as a whole or a sub-basin, taking into account surface and ground waters for sustainable use. All individual development projects and proposals should be formulated and considered within the frame work of such an overall plan keeping in view the existing agreements/awards for a basin or sub-basin. Water should be made available to water deficit areas by transfer from other areas including transfers from one river basin to another, if necessary, based on a national perspective, after taking into account the requirements of all areas/basins. Integrated and coordinated development of surface water and groundwater resources and their conjunctive use should be envisaged right from the project planning stage and should form an integral part of the project implementation. To identify water surplus and water deficit in the basin, water balance studies should be carried out. The Mahanadi-Godavari link is one of the 16 proposed links in the Peninsular region. Objective of the present study is to discuss the water balance of Mahanadi Basin at Manibhadra. The water balancing has been carried out on monthly basis with 75% and 90% dependability with and without groundwater. From the monthly 75% and 90% dependability flow series, the annual surface water potential of 32717 MCM and 22654 MCM has been estimated. The utilizable groundwater is around 2602.9 MCM. The total water requirement to meet different needs comes to 37133 MCM. From the water balance study it has been found that the Mahanadi basin at Manibhadra is a deficit basin and to solve this problem it is suggested to develop the groundwater potential, so that the deficit condition can be met.*

Key words Mahanadi basin; water balance; dependable flow; water requirement assessment.

INTRODUCTION

Water is not only essential for the existence of all forms of life on the earth but it is also a vehicle for the progress and prosperity of a nation. Water is also required in almost all the activities of man and livestock for drinking and municipal use, for irrigation to meet the growing food and fiber needs, for industries, hydropower generation, environmental purposes, navigation and recreation. The development, conservation and use of water, therefore, forms one of the main elements in the country's development and planning. In India, around 21% of the area receives less then 750 mm of rainfall annually while 50% receives more then 500 mm. Large areas of peninsular India have rainfall less than 600 mm. Further, rainfall is mainly confined to the monsoon season and is unevenly distributed both in space and time even during the monsoon season. As a result, frequent droughts and floods affect

the country's economy. The drought prone area in the country is more than 50 Mha, while the area susceptible to floods is around 40Mha (GOI, 1999). The utilizable surface and ground water flows in the country are 690 BCM and 432 BCM, respectively giving a total of 1 122 BCM (IWRS, 1996). Thus, it is desirable to store and divert water for later use in space and time. Also, it is essential to harness the water resources in a most scientific and efficient manner.

According to the National Water Policy 2002 of the Govt. of India, integrated water resources development and management will have to adopt a drainage basin as a whole taking into account both surface and ground water potential. A National Prospective Plan for water resources and development was framed in August 1980 by the Ministry of Water Resources, Govt. of India. After various discussions at national level, an organization called National Water Development Authority was set up as an autonomous society to promote scientific development for optimum utilization of water resources of the country.

Water balance is a quantitative study of balancing available inflow with the different uses to be met from thereof. It gives an idea about the surplus and deficit of resources within a stipulated time period. In the present study, the aim is to study the water balance for 75% and 90% dependable water yield with and without groundwater of Mahanadi Godavari link, and in particular of Mahanadi at Manibhadra and to estimate the water demands by the year 2050 for different uses.

AREA UNDER STUDY

The Mahanadi is one of the major rivers in the country flowing towards east and draining into the Bay of Bengal. The Mahanadi basin extends over an area of 1,41,589 km^2 and lies between longitudes $80^0 30'$ and $84^0 50'$ East and latitudes $19^0 20'$ and $23^0 35'$ North. The basin lies in the North-Eastern parts of Deccan plateau and covers large areas in Madhya Pradesh and Orissa and comparatively small areas in Bihar and Maharashtra (refer Fig. 1). The total length of the river from its origin to outfall in the sea is about 851 km of which 357 km is in Madhya Pradesh and 494 km is in Orissa. The catchment area of this basin upto Manibhadra is 125820 km^2, which consists of 10 hydrological units such as catchment areas of Sheonath sub-basin (30761 km^2), Jonk sub-basin (3484 km^2), Hasdeo sub-basin (9856 km^2) Mand sub-basin (5200 km^2), Ib sub-basin (12447 km^2), Upper Mahanadi sub-basin (21652 km^2), Ong sub-basin (5128 km^2), Middle Mahanadi sub-basin (12654 km^2), Tel sub-basin (22818 km^2) and Lower Mahanadi sub-basin upto Manibhadra (1820 km^2) as shown in Fig. 1.

The study reveals that the catchment up to Manibhadra mostly comprises of arching terrain and consolidated gneiss rock formation greatly influenced by geomorphic features. Alluvium is also found in the catchment. The hills have igneous and metamorphic rocks under Gangpur series, the important type being granite. Groundwater is available in the alluvium region in confined and unconfined forms below 300 m. The climate of the entire basin is of tropical monsoon type. Most of the rainfall is received from the South West Monsoon. Depressions in the Bay of Bengal affect the basin in the monsoon season causing cyclones and wide spread heavy rain.

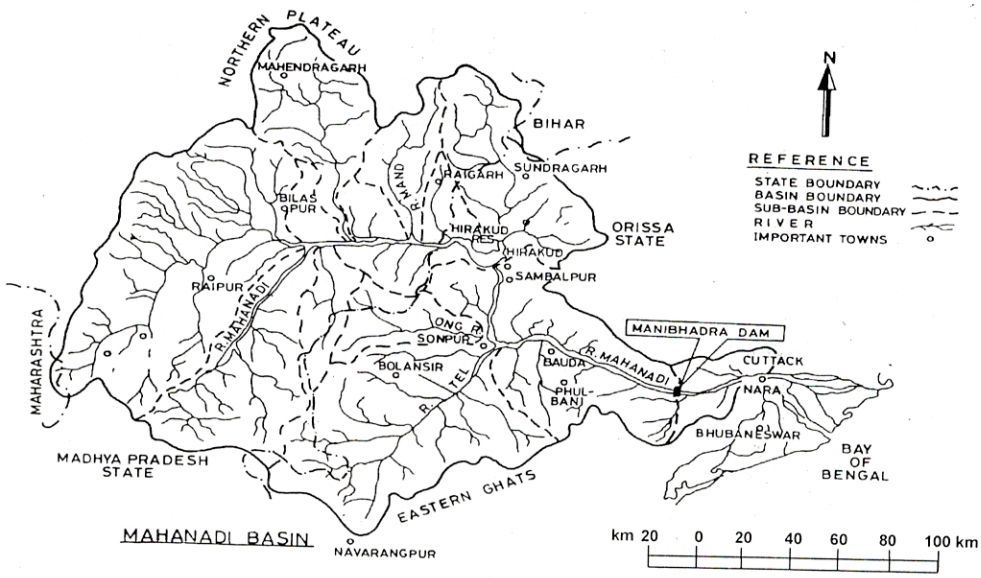

Fig. 1 Mahanadi Basin.

METHODOLOGY USED FOR WATER BALANCE STUDY

The data required for the water balance study, such as the total annual irrigation requirement of ongoing, existing and proposed major, medium, and minor irrigation projects, exports and imports, rural, urban, livestock population, regeneration from irrigation projects, hydropower use etc., were collected from the various reports of preliminary water balance studies and feasibility reports of Mahanadi Basin from NWDA, and Govt. of Orissa.

The following steps have been used for computation of water balance on monthly basis for the Mahanadi basin at Manibhadra reservoir site.

1. The total monthly water availability in a basin is computed by summing monthly imports from other basins, monthly regeneration from irrigation, domestic and industrial water uses, and monthly surface water and groundwater yields. Following norms have been adopted in this study:
   a. The monthly imports are computed by distributing of total annual import in proportion of the importing sub basin.
   b. The monthly regeneration from irrigation water uses are computed as 10 to 20% of the monthly irrigation water requirements. Regeneration from domestic purpose is computed as 80% of the domestic water use. The monthly regeneration from industrial water use is taken as 80% of the monthly industrial use.
   c. Surface yield: The monthly surface water yield in the basin is taken in proportion of the monthly-observed runoff in the basin.

d. Groundwater: The monthly groundwater yield in the basin is computed by distributing the annual groundwater yield in proportion of the monthly irrigation water requirements.

2. The monthly gross water requirements are estimated by summing all the monthly water requirements for irrigation, domestic, industrial, environmental uses and exports. Following norms have been used in this study:
   a. The monthly net irrigation requirements for the proposed, ongoing and existing major, medium and minor irrigation project are estimated by using the modified Penman method. Reservoir evaporation loses have been taken as 20% of the net irrigation requirements.
   b. The requirement of water for domestic consumption, taken as per capita per day for rural and urban and lives stock population, is considered as 70 ltrs, 100 ltrs and 50 ltrs respectively.
   c. The water requirement for industrial use is taken equal to the water requirement for domestic purpose.
   d. The monthly environmental water requirements are taken equal to 1% of the monthly surface water available in the basin.
   e. Export: The monthly exports are calculated by distributing the total annual exports in a basin in proportion of the monthly availability of surface water in that basin.

Finally, the water balance at the specified site (Manibhadra diversion point) has been estimated as:

Surplus or Deficit = (75% water year dependability flow/yield + groundwater availability + regeneration + imports) - (total water requirement + exports)

Assessment of Water Requirements

Domestic water requirements

The population data for past years a s well as the forecasted population have been found out from census data and from the 3rd spiral study made by Orissa Govt., respectively. The estimated population in different years is shown in Table 1.

Table 1 Estimated population for different years.

Human Population				Live Stock Population	
Year	Rural	Urban	Total	Year	Total
1991	12033954	2212881	14246835	1977	4878223
2001	13024909	3177223	16202132	2001	6194049
2011	13859635	4073071	17932706	2025	7864798
2021	14451031	4872940	19323971	2051	10186930
2031	14857496	5454705	20312201		
2041	15037724	5767269	20804993		
2051	15082946	5847177	20930123		

Per capita daily requirement of water for the urban, rural and live stock population as per the recommendations of the Ministry of Works and Housing in its annual "Water Supply and Treatment" was taken to be 200 ltrs, 70 ltrs, and 50 ltrs, respectively and the domestic requirement was worked out. The requirement of water for the urban population and for 50% of the rural population was considered to be met from surface water resources. The needs for livestock and for 50% of remaining rural population were to be met from groundwater resources; 50% of surface water utilized for domestic purposes was considered to be available as return flow to the streams.

Irrigation water requirements

The details of gross command area, culturable command area, designed annual irrigation and utilization for the existing, ongoing and proposed projects were collected for major, medium and minor projects falling in the catchments upto Manibhadra. The designed annual irrigation and utilization data in respect of all he existing and ongoing projects were kept undisturbed in assessing the surface water requirements. The annual irrigation from future identified major, medium and minor projects was assessed considering the irrigation intensities to be 150%, 125%, and 100%, respectively. The water requirements of crops for the identified future major, medium and minor projects were assessed based on climatological approach.

It was assumed that 10% of the surface water (excluding evaporation losses from reservoirs) utilized or to be utilized from all the existing, ongoing and identified future major and medium projects would be available as return flow to the stream.

Industrial water requirements

The water needs for all the existing and future industries which are to be located in the basin up to Manibhadra were collected from respective State Govt. Departments. In the absence of information regarding water needs of the industries, in some areas the industrial water requirement in that area was assumed to be of the same order as that of the domestic water requirements. The entire industrial water needs were proposed to be met from surface water resources and 80% of the surface water utilized or to be utilized was considered as regeneration.

Evaporation losses

Existing and ongoing reservoirs = As per actual data
Proposed = 20% of utilizable water

Environmental

The monthly environmental water requirements have been taken equal to 1% of the monthly surface water availability in the basin.

Import and export

All imports/exports as specifically mentioned in indicative master plans of states have been taken into account. For those projects in the sub-basin, whose command area falls partly or wholly in adjacent sub-basin, the quantum of water required for irrigation areas outside the sub-basin has been considered as export from the sub-basin and return flow has been considered as flow for the same, if command area of any irrigation project is located outside the sub-basin. The import of water from other basins and the export of water to other basins, both with respect to the basin under consideration have been worked out.

The total water requirement by the year 2050 for all purposes like irrigation, drinking, industrial use and other purposes as well as the total water utilization including export is presented in Table 2.

Surface Water Resources Assessment

For overall assessment of the water balance of a river basin, availability of both surface water and groundwater is required to be assessed. To establish the surplus/deficit in a river basin with reasonable reliability, it is necessary to take into consideration, the total available water, the present water utilization and the utilization that could possibly be made in the foreseeable future.

Estimation of 75% and 90% dependable flow

The 75% and 90% dependable flow at Manibhadra site was estimated from 30 years of historical data. Further the groundwater potential was estimated from the data collected by Central Ground Water Board and Govt. of Orissa. The monthly water yield has been estimated by distributing the annual groundwater yield in proportion to the monthly irrigation water requirements. The regeneration of flow from upstream water utilization was considered and incorporated in estimating the flow. The total water availability for 75% and 90% dependable flow without and with groundwater have been shown in Tables 3 to 6.

RESULTS AND DISCUSSION

The results of the water balance study of Mahanadi basin at Manibhadra, are presented graphically in Figs. 2 to 5. The balancing has been done on monthly basis with 75% and 90% dependability without groundwater (Figs. 2 and 3) and with groundwater (Figs. 4 and 5) in the basin. Result of water balance study shows that the availability of 75% dependability flow is 32717 MCM (NIH, 1986) while according to Manibhadra Irrigation Project by Govt. of Orissa, 75% dependable yield was 32556 MCM which is almost the same. As per the preliminary calculation, it is clear that in the year 2050 the basin will be a deficit basin on an annual average basis. But if considered month wise, during some months in monsoon, it seems to have surplus water available during floods, which the proposed canal in the Mahanadi-Godavari link cannot carry in any way.

Table 2 Estimated water demand of Mahanadi Basin at Manibhadra by year 2050.

Month	Water utilization												
	Water requirements								Export				
	Utilisation under irrigation project				Domestic	Industrial	Enviro-nmental	Total	Tikira	Brahmani - Baitarani	Rushikulya	Total	Gross total utilisation
	Exist-ing	Ongoing	Proposed	Total									
Jun	808.7	141.9	1252.9	2203.5	52.0	83.0	44.6	2383.1	98.8	72.7	47.6	219.1	2602.2
Jul	2553.8	448.2	3956.6	6958.5	52.0	83.0	730.5	7824.0	311.9	229.5	150.4	691.8	8515.9
Aug	2553.8	448.2	3956.6	6958.5	52.0	83.0	1226.9	8320.4	311.9	229.5	150.4	691.8	9012.3
Sep	2553.8	448.2	3956.6	6958.5	52.0	83.0	624.7	7718.2	311.9	229.5	150.4	691.8	8410.1
Oct	895.8	105.6	1064.4	2065.8	52.0	83.0	163.5	2364.3	0.0	0.0	0.0	0.0	2364.3
Nov	530.4	62.5	630.2	1223.2	52.0	83.0	96.5	1454.7	0.0	0.0	0.0	0.0	1454.7
Dec	530.4	62.5	630.2	1223.2	52.0	83.0	66.0	1424.2	0.0	0.0	0.0	0.0	1424.2
Jan	530.4	62.5	630.2	1223.2	52.0	83.0	65.8	1424.0	0.0	0.0	0.0	0.0	1424.0
Feb	530.4	62.5	630.2	1223.2	52.0	83.0	59.8	1418.0	0.0	0.0	0.0	0.0	1418.0
Mar	0.0	0.0	0.0	0.0	52.0	83.0	72.4	207.4	0.0	0.0	0.0	0.0	207.4
Apr	0.0	0.0	0.0	0.0	52.0	83.0	66.3	201.3	0.0	0.0	0.0	0.0	201.3
May	808.7	141.9	1252.9	2203.5	52.0	83.0	54.7	2393.2	98.8	72.7	47.6	219.1	2612.3
Total	12296.3	1984.2	17960.9	32241.4	624.0	996.0	3271.7	37133.1	1133.4	833.7	546.5	2513.7	39646.8

Table 3 75% dependable water availability without groundwater.

Month	Water availability					
	Regeneration from uses				Surface water yield	Gross water available
	Irrigation	Domestic	Industrial	Total		
Jun	220.35	41.6	66.4	328.35	446.0	774.35
Jul	695.86	41.6	66.4	803.86	7305.0	8108.86
Aug	695.86	41.6	66.4	803.86	12269.0	13072.86
Sep	695.86	41.6	66.4	803.86	6247.0	7050.86
Oct	206.59	41.6	66.4	314.59	1635.0	1949.59
Nov	122.32	41.6	66.4	230.32	965.0	1195.32
Dec	122.32	41.6	66.4	230.32	660.0	890.32
Jan	122.32	41.6	66.4	230.32	658.0	888.32
Feb	122.32	41.6	66.4	230.32	598.0	828.32
Mar	0.00	41.6	66.4	108.00	724.0	832.00
Apr	0.00	41.6	66.4	108.00	663.0	771.00
May	220.35	41.6	66.4	328.35	547.0	875.35
Total	3224.14	499.2	796.8	4520.14	32717.0	37237.14

Table 4 90% dependable water availability without groundwater.

Month	Water availability					
	Regeneration from uses				Surface water yield	Gross water available
	Irrigation	Domestic	Industrial	Total		
Jun	220.35	41.6	66.4	328.35	375.0	703.35
Jul	695.86	41.6	66.4	803.86	3277.0	4080.86
Aug	695.86	41.6	66.4	803.86	10080.0	10883.86
Sep	695.86	41.6	66.4	803.86	3665.0	4468.86
Oct	206.59	41.6	66.4	314.59	1128.0	1442.59
Nov	122.32	41.6	66.4	230.32	758.0	988.32
Dec	122.32	41.6	66.4	230.32	506.0	736.32
Jan	122.32	41.6	66.4	230.32	565.0	795.32
Feb	122.32	41.6	66.4	230.32	549.0	779.32
Mar	0.00	41.6	66.4	108.00	683.0	791.00
Apr	0.00	41.6	66.4	108.00	616.0	724.00
May	220.35	41.6	66.4	328.35	452.0	780.35
Total	3224.14	499.2	796.8	4520.14	22654.0	27174.14

Table 5 75% dependable water availability with groundwater.

Water availability								
Regeneration from uses				Surface water yield	Ground-water available	Ground-water recharge	Total ground water	Gross water avail-able
Irriga-tion.	Dome-stic	Indus-trial	Total					
220.3	41.6	66.4	328.3	446.0	71.1	232.2	303.3	1077.7
695.9	41.6	66.4	803.9	7305.0	224.6	413.5	638.2	8747.0
695.9	41.6	66.4	803.9	12269.0	224.6	481.8	706.4	13779.3
695.9	41.6	66.4	803.9	6247.0	224.6	234.2	458.9	7509.7
206.6	41.6	66.4	314.6	1635.0	66.7	64.6	131.3	2080.8
122.3	41.6	66.4	230.3	965.0	39.5	18.0	57.5	1252.8
122.3	41.6	66.4	230.3	660.0	39.5	5.8	45.2	935.6
122.3	41.6	66.4	230.3	658.0	39.5	12.5	52.0	940.3
122.3	41.6	66.4	230.3	598.0	39.5	17.2	56.7	885.0
0.0	41.6	66.4	108.0	724.0	0.0	18.0	18.0	850.0
0.0	41.6	66.4	108.0	663.0	0.0	18.8	18.8	789.8
220.3	41.6	66.4	328.3	547.0	71.1	45.4	116.6	991.9
3224.1	499.2	796.8	4520.1	32717.0	1040.8	1562.1	2602.9	39840.1

Table 6 90% dependable water availability with groundwater.

Water availability								
Regeneration from uses				Surface water yield	Ground-water available	Ground-water recharge	Total ground-water	Gross water available
Irriga-tion	Domestic	Industrial	Total					
220.3	41.6	66.4	328.3	375.0	71.1	232.2	303.3	1006.7
695.9	41.6	66.4	803.9	3277.0	224.6	413.5	638.2	4719.0
695.9	41.6	66.4	803.9	10080.0	224.6	481.8	706.4	11590.3
695.9	41.6	66.4	803.9	3665.0	224.6	234.2	458.8	4927.7
206.6	41.6	66.4	314.6	1128.0	66.7	64.6	131.3	1573.8
122.3	41.6	66.4	230.3	758.0	39.5	18.0	57.5	1045.8
122.3	41.6	66.4	230.3	506.0	39.5	5.8	45.2	781.6
122.3	41.6	66.4	230.3	565.0	39.5	12.5	52.0	847.3
122.3	41.6	66.4	230.3	549.0	39.5	17.2	56.7	836.0
0.0	41.6	66.4	108.0	683.0	0.0	18.0	18.0	809.0
0.0	41.6	66.4	108.0	616.0	0.0	18.8	18.8	742.8
220.3	41.6	66.4	328.3	452.0	71.1	45.4	116.6	896.9
3224.1	499.2	796.8	4520.1	22654.0	1040.8	1562.1	2602.9	29777.1

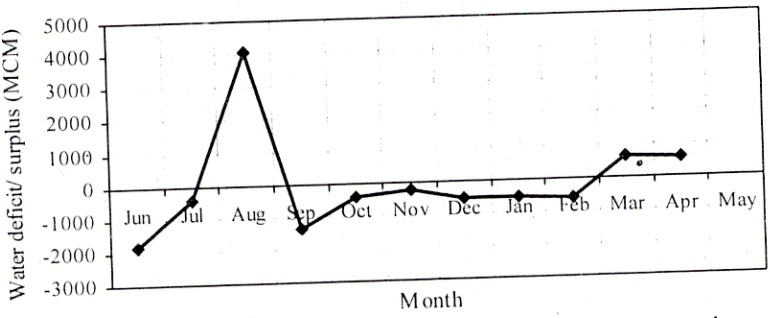

Fig. 2 Water balance with 75% dependability (without groundwater).

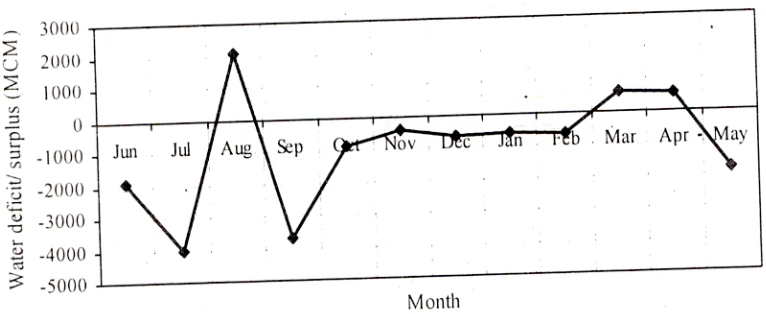

Fig. 3 Water balance with 90% dependability (without groundwater).

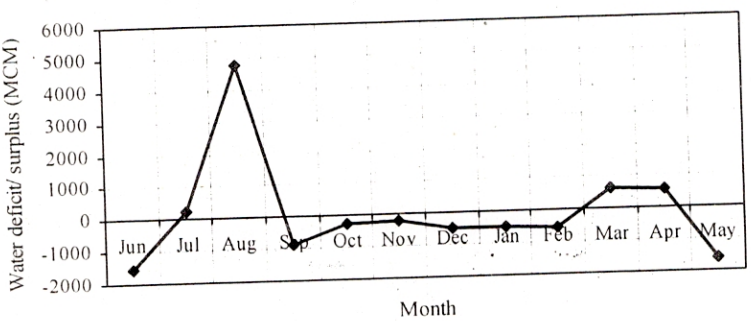

Fig. 4 Water balance with 75% dependability (with groundwater).

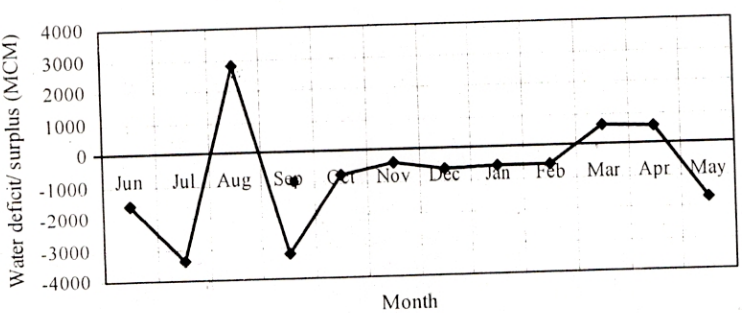

Fig. 5 Water balance with 90% dependability (with groundwater).

CONCLUSIONS

The following conclusions can be drawn from the water balance study of Mahanadi basin at Manibhadra:

- The 75% and 90% dependable annual yield at Manibhadra dam site are 32717 Mm^3 and 22654 Mm^3, respectively.
- The gross groundwater potential of the Mahanadi basin up to Manibhadra in Orissa portion works out to be 2602.92 Mm^3 and 2513.66 Mm^3 of water is exported from Mahanadi basin to other basins.
- The water balance values at 75% and 90% dependability work out to be (-) 2409 Mm^3 and (-) 11466 Mm^3, without groundwater and 1933 Mm^3 and (-) 8863.4 Mm^3, respectively with groundwater.
- It has been found that the existing, ongoing and proposed projects in Mahanadi basin are sufficient to meet the future irrigation demand by 2050.
- The water balance can be increased by way of improving the irrigation efficiency.
- In future the surface water will decrease and demand will increase. Hence the groundwater utilization is very important for all purposes.
- There is a need for analyzing the reliability of estimation. The reliability of water balance study depends on the reliability of input data. Further work can be carried out for reliability assessment of such projects.

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