BASINWISE ASSESSMENT OF WATER RESOURCES

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1.0 Background

Water being a precious resource without which no life can be sustained on Earth, the level of its availability and development influences quality of life to a considerable extent. The source of all fresh water on the land is precipitation. But all the precipitation that occurs on land is not directly available for use by human beings. Major part of precipitation returns back to the atmosphere by evaporation & evapo-transpiration. Rest of the water becomes available either as surface water in natural lakes, streams and rivers, or as ground water. Although all the water ultimately flows back into oceans or is lost to the atmosphere by way of evapo-transpiration, during the land phase of hydrologic cycle, water can be exploited and put to beneficial use.

Apart from basic need of drinking for sustaining human life, water is also used for other beneficial purposes such as irrigation for increasing crop productivity, industrial processing, etc. In our country with monsoonic type of climate which causes rainfall to occur mainly in three to four months of a year with large variations from year to year, exploitation of the resource to make it available when it is needed and where it is needed has been a major developmental activity.

Although irrigation is major consumer of water in the country, water requirement for other purposes such as industrial processing is also increasing day by day due to increasing economic activities. Because of increasing use of water for varied purposes, water is already scarce in some regions of the country. The assessment of country's water potential is thus an essential pre-requisite for efficient planning and management of the resources. River basin is basic hydrologic unit for planning and development of water resources. It, therefore, follows that assessment of water resources has to be necessarily basinwise.

Natural (virgin) flow in a river basin is reckoned as water resources of basin. The mean annual flow is obtained on pro-rata basis from the mean annual flow at terminal site of the basin. Natural flow at any location on a river is obtained by summing up the observed flow, upstream utilization for irrigation, domestic and industrial uses both from surface and ground water sources, increase in storage of reservoirs (both surface and sub-surface) and evaporation losses in reservoirs, and deducting return flows from different uses from surface and ground water.

2.0 Work done in the past

2.1 First Irrigation Commission (1901-03)

The first ever attempt to assess the average annual flow of all the river systems in India was made by the Irrigation Commission of 1901-1903. The major constraint at that time was that while records in respect of rainfall were available, data in respect of river flows were not available even for many of the most important river systems. The Commission, therefore, resorted to estimation of river flows by adopting coefficients of runoff. The average annual flow of all the river systems in India (as it was then, but excluding Burma, Assam and East Bengal) was assessed as 1443 BCM.

2.2 Dr.A.N. Khosla (1949)

Dr. A.N Khosla developed an empirical relationship between mean temperature (as an expression for mean evaporation loss) and mean runoff based on his studies on the flows of Sutlej, Mahanadi and other river systems.

While applying the above empirical relationships to the entire country, Dr. Khosla divided the country into six regions, viz (i) Rivers falling into Arabian Sea excluding Indus, (ii) Indus Basin within India, (iii) Rivers falling into Bay of Bengal other than the Ganga-Brahmaputra system, (iv) the Ganga, (v) the Brahmaputra, and (vi) Rajputana.

According to these studies, the total annual flow of all the systems worked out to 1673 BCM.

2.3 Central Water and Power Commission (1954-66)

CWPC estimated the surface water resources of different basins during the period from 1952 to 1966. The study was mostly based on the statistical analysis of the flow data wherever available and rainfall-runoff relationships wherever data were meagre. The country was divided into 23 sub-basins / basins. Ganga was divided into as many as ten sub-systems. Other major peninsular river basins like Narmada, Tapi, Godavari, Krishna, Pennar and Cauvery were considered separately. Other river systems were combined together suitably into a few composite systems. According to these studies, the water resources of various basins amounted to 1881 BCM.

2.4 National Commission on Agriculture (1976)

NCA estimated total annual water resources of the country as 1850 BCM based on water balance approach taking into account rainfall, percolation of water in soils, evaporation and evapo-transpiration.

2.5 Central Water Commission (1988)

As per the report ‘Water Resources of India’, CWC (1988), the natural run-off of a basin could be computed by adding to the surface flow measured at the terminal site, the net export

of the surface water out of the basin, the net increase of the surface water storage, additional evapotranspiration caused by use or storage of surface water, direct ground water flow from the river basin below or along the terminal site, the net export of ground water out of the basin, the net increase in ground water storage and soil moisture storage, and the additional evapotranspiration caused by use or storage of ground water. This is general water balance approach, applicable to any basin for any period. However, if averages over a long time period are taken, storage change would be zero or negligible. Also assuming a case of no export or import, and neglecting the ground water flow below or along the terminal site, a simplification is possible. With this simplification, the average annual natural flow can be computed by adding to the average annual surface flow measured at the terminal site, the average annual extra evaporation / evapotranspiration due to use or storage of surface water and the average annual extra evaporation / evapotranspiration due to storage or use of ground water.

Earlier, estimate of the natural runoff have been made by two approaches. The approach adopted by Dr. Khosla does not directly use the measured surface flow at terminal site but works out the natural runoff from the observed rainfall and temperature. This approach would, thus require no correction for utilization of surface or ground water. The second approach utilizes the observed flow record and thus gives a more realistic estimate. In this approach the observed surface flow at the terminal site is corrected for extra evapotranspiration due to utilization of water. However, mostly the correction due to additional evapotranspiration due to use of ground water was not done in actual working.

Districtwise estimates of ground water draft i.e withdrawal from ground water storage were worked out by Central Ground Water Board for the year 1983-84. 1983-84 districtwise figures were converted into basinwise figures. The total draft for the country for the year 1983-84 was about 100 BCM / year.Similar estimates for 1967-68 as available in Irrigation Commission report, indicate that the draft for that year was about 58 BCM / year. Assuming linear variation, the annual draft for any year was calculated. Basinwise figures for any other year were estimated on the same proportion as the overall national figures. It was assumed that the consumptive use of ground water was 70% of the withdrawal.

The basinwise average annual water resources was estimated as 1880 BCM after carrying out the corrections on the above lines. The above however excluded the groundwater which flows directly to the sea or to the neighbouring countries bypassing the terminal site. Studies, carried out elsewhere indicate that this quantum is not appreciable and would be around 5% of the runoff.

3.0 Recent Estimates

3.1 Reassessment of Average Annual Water Resources Potential (1993)

Basinwise reassessment of water resources potential in the country was carried out by Central Water Commission (CWC) in 1993 and detailed in the report entitled ‘Reassessment of Water Resources Potential of India’.

While assessing the water resources of India, the country was divided into 20 river basins comprising 12 major basins and 8 composite river basins.

The twelve major basins are: (1) Indus; (2) Ganga-Brahmaputra-Meghna; (3) Godavari; (4) Krishna; (5) Cauvery; (6) Mahanadi; (7) Pennar; (8) Brahmani-Baitarni; (9) Sabarmati; (10) Mahi; (11) Narmada; and (12) Tapi.

The eight composite river basins are: (1) Subernarekha – combining Subernarekha and other small rivers between Subernarekha and Baitarni; (2) East flowing rivers between Mahanadi and Pennar; (3) East flowing rivers between Pennar and Kanyakumari; (4) Area of Inland Drainage in Rajasthan Desert; (5) West flowing rivers of Kutch and Saurashtra including Luni; (6) West flowing rivers from Tapi to Tadri; (7) West flowing rivers from Tadri to Kanyakumari; and (8) Minor rivers draining into Myanmar (Burma) and Bangladesh.

For some of the river basins, assessment of the water resources potential was carried out in the past by various agencies. In all cases where estimation on the basis of actual flow data was already made, fresh attempt for reassessment was not done. These basins included Indus, Ganga-Brahmaputra-Meghna, Narmada, Mahanadi and Cauvery. Apart from the above five basins, reassessment of water resources potential was also considered not necessary in respect of the three basins which included West flowing rivers of Kutch and Saurashtra including Luni, Area of inland drainage in Rajasthan desert, and Minor rivers draining into Myanmar (Burma) and Bangladesh.

The study of reassessment of water resources potential was therefore carried out for the river basins of Godavari, Krishna, Subernarekha, Brahmani-Baitarni, Pennar, Sabarmati, Mahi, Tapi, West flowing rivers from Tapi to Tadri, West flowing rivers from Tadri to Kanyakumari, East flowing rivers between Mahanadi and Pennar, East flowing rivers between Pennar and Kanyakumari.

3.1.1 Methodology

The observed flows at terminal sites of the basins were corrected for upstream abstractions to arrive at the natural flows by adopting the following equation:

$$R_N = R_O + R_{IR} + R_D + R_{GW} - R_{RI} - R_{RD} - R_{RG} + S + E$$

R_N is the natural flow
R_O is the observed flow
R_{IR} is the withdrawal for irrigation
R_D is the withdrawal for domestic and industrial requirement
R_{GW} is the ground water withdrawal
R_{RI} is the return flow from irrigated areas
R_{RD} is the return flow from domestic and industrial withdrawal
R_{RG} is the return flow from ground water withdrawal
S is the increase in storage of the reservoirs in the basin
E is the net evaporation from the reservoirs

3.1.2 Results of the Study

Based on the above methodology, CWC assessed the average annual water resources potential of the country as 1869 BCM in the year 1993 **(Annex-I)**.

3.2 Assessment by National Commission for Integrated Water Resources Development (1999)

The National Commission for Water Resources Development (NCIWRD) while assessing the potential, agreed with the estimates of the Reassessment study carried out by CWC (1993) excepting the cases of Brahmaputra and Krishna basins. In case of Brahmaputra basin, the NCIWRD assessment included additional contribution of 91.81 BCM which was estimated to be the flow of the 9 tributaries joining Brahmaputra downstream of Joghighopa site. In the case of Krishna basin the figures adopted by the NCIWRD was based on the mean flow of the yield series that is accepted by the KWDT Award. Taking into account the above two variations, the estimation of NCIWRD yielded that the average annual water resources potential of the country is 1953 BCM.

4.0 Pilot study regarding Reassessment of basin wise water situation based on the strategy identified by the Comprehensive Mission Document of National Water Mission

One of the strategies identified for implementation under the Comprehensive Mission Document of National Water Mission is “Reassessment of basin wise water situation under present scenario including water quality by using latest techniques”, which inter-alia may include:

- development or adoption of comprehensive water balance based model,
- fitting models to basin using current data, and
- assessment of likely future situation with changes in demands, land use, precipitation and evaporation.

The steps for implementation of the strategy envisage coordination with NRSC for “Assessment of National Water Resources” using Remote Sensing and GIS based modelling.

In pursuance to the above, a Committee was constituted by MoWR under the Chairmanship of Chairman, CWC for reassessment of water resources availability in all the river basins of the country. National Remote Sensing Centre (NRSC) and Central Water Commission (CWC) jointly executed demonstrative pilot studies in Godavari and Brahmani-Baitarani river basins wherein Space based geo-spatial inputs were used to estimate basin-level mean annual water resources. The highlights of the methodology include water balance approach; precipitation as primary resource (spatial interpolation); new technology tools i.e. satellite derived spatial data (land use, land cover, elevation, soil), GIS; Semi-Distributed modeling approach; Concept of Hydrologic Response Unit (HRU) for water balance computation; Calibration and validation using CWC observed discharge observations. The study therefore indirectly estimated the utilization of water by various sectors.

The pilot studies demonstrated the usefulness of space based geo-spatial data sets for estimating basin level mean annual water resources through hydrological modelling. Hydrological models simulate river/stream flow through estimation of water balance components such as evapotranspiration, soil moisture, runoff. Satellite data derived geospatial

data sets are providing the spatial and temporal heterogeneities in parameters that control and distribute water resources. Exploiting these data sets, semi distributed process based hydrological modelling approach has been used for water balance studies and water resources computations.

4.1 Water Balance Equation

- The annual water balance of a basin can be represented as follows:

  $P = I + AET + R$ ---- (1)

  Where, P = Precipitation; AET = Actual Evapotranspiration; I = Interception by the vegetation which can be ignored when the water balance is computed at monthly time step and R= Balance Surplus Precipitation

  Hence, the equation (1) becomes;

  $P = AET + R$ ---- (2)

- $AET = AET_{iag} + AET_{rag} + AET_{o}$ ---- (3)

  AET_{iag} = AET from irrigated agriculture area (canals and well irrigated)

  AET_{rag} = AET from rain-fed agriculture area

  AET_{o} = AET from other landuse classes (forest, other vegetation, water bodies, and other landuse classes)

- $R = Ro + \Delta GWS + \Delta SWS + UDI$ ---- (4)

  Ro = Observed flow at terminal gauge (field discharges from CWC)

  ΔGWS = Annual change in ground water storage

  ΔSWS = Annual change in surface water storage (in reservoirs)

  UDI = effective consumptive use for domestic, industrial and livestock purposes.

- Water balance equation thus finally takes the shape of:

  $P = AET_{iag} + AET_{rag} + AET_{o} + R_{o} + \Delta GWS + \Delta SWS + UDI$ ---- (5)

  Water Resources Availability (WRA) of the basin comprises of runoff in the river at final outlet, upstream effective utilisations for irrigation, domestic industrial and livestock purposes, groundwater flux, and surface water flux. Thus, it can be expressed as;

  $WRA = R_{o} + IS + E + \Delta GWS + \Delta SWS + UDI$ ---- (6)

  Where, E = evaporation from the reservoirs

  IS = Estimated Consumptive Irrigation Input Provided

4.2 Assumptions /Limitations of pilot study

1. The model is setup at annual time-step, monthly calibrations are not carried out.
2. Kharif crop outside of the command area boundary is assumed as rain-fed and rest is assumed as irrigated agriculture.
3. In irrigated agriculture land AET is calculated by assuming that 100% water requirements are met from the rainfall and irrigation supplies together (AET=PET condition).
4. Landuse/landcover maps of the period 2004-05, 2005-06, 2006-07, 2007-08 are used for runoff calculations in the study. For runoff computations prior to 2004-05, landuse map of 2004-05 is used during the year in which rainfall is less than 1000mm, and landuse map of 2006-07 is used when the annual rainfall is more than 1000mm. Landuse maps of 1995 and 1985 were also analysed but could not be used since in these landuse grids, agricultural area has been classified as a single unit and number of classes also less.

5.0 Comparison of two studies (CWC 1993 study and Joint pilot study by CWC and NRSC)

Reassessment in 1993 by CWC	**Pilot study for Brahmani-Baitarani and Godavari Basins jointly by CWC and NRSC**
Calculations were based on the observation at the terminal site with corrections due to upstream abstractions adjusted by return flows, change in storage and evaporation from reservoirs	This is a water balance approach which attempts to indirectly estimate the utilization in agriculture because of non-availability of abstraction data which is essential for carrying out the assessment of availability in a river basin
1993 study didn't provide details such as total precipitation in the basin, evapotranspiration in the natural vegetation including forests, evapotranspiration in rainfed agriculture, etc.	The pilot study being a water balance approach such details are available
Future prediction on the trend of variation in water availability if there is some variation in rainfall cannot be made effectively with confidence from this study	Precipitation being the primary input, such prediction in the trend of variation in water availability against variation in rainfall can be made.
Major limitation of 1993 study was non-availability of abstraction / withdrawal data of irrigation.	Such limitation is not there.

6.0 Present Status of assessment of water resources potential jointly by CWC and NRSC

The report of the pilot study on assessment of water resources at basin scale using space inputs in the Godavari and Brahmani-Baitarani Basin has been finalised jointly by CWC and NRSC. After being apprised about the methodology being adopted for reassessment of water availability in India, it was decided in the Ministry to complete the reassessment studies in all the 20 basins of the country through regional offices of CWC. NRSC would provide necessary support, guidance and training required for carrying out the above studies.

Accordingly, a proposal is formulated to estimate basin-wise mean annual water resources potential of all the river basins of the country through the field offices of CWC with technical support of NRSC and submitted to MoWR for necessary approval. The studies would be commenced immediately after receipt of the approval of the competent authority. While carrying out the above studies, some improvements over Pilot Studies have been proposed.

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Annex-I

WATER RESOURCES POTENTIAL OF RIVER BASINS OF INDIA

S. No.	River Basin	Catchment area (Sq.Km)	Average Water Resources Potential (BCM)*	Utilisable surface water resources (BCM)**
1	2	3	4	5
1	Indus	321289	73.3	46
2	Ganga-Brahmaputra-Meghna			
	(a) Ganga	861452	525	250
	(b) Brahmaputra	194413	537.2	24
	(c) Barak & others	41723	48.4	
3	Godavari	312812	110.5	76.3
4	Krishna	258948	78.1	58
5	Cauvery	81155	21.4	19
6	Subernarekha	29196	12.4	6.8
7	Brahmani-Baitarni	51822	28.5	18.3
8	Mahanadi	141589	66.9	50
9	Pennar	55213	6.3	6.9
10	Mahi	34842	11	3.1
11	Sabarmati	21674	3.8	1.9
12	Narmada	98796	45.6	34.5
13	Tapi	65145	14.9	14.5
14	West Flowing Rivers from Tapi to Tadri	55940	87.4	11.9
15	West Flowing Rivers from Tadri to Kanyakumari	56177	113.5	24.3
16	East Flowing Rivers between Mahanadi and Pennar	86643	22.5	13.1
17	East Flowing Rivers between Pennar & Kanyakumari	100139	16.5	16.5
18	West Flowing Rivers of Kutch and Saurashtra including Luni	321851	15.1	15
19	Area of Inland Drainage in Rajasthan	---	Negl.	--
20	Minor Rivers draining into Myanmar (Burma) and Bangladesh	36302	31	--
	Total		**1,869.4**	**690**

*CWC Publication “Reassessment of Water Resources Potential of India, 1993”

** CWC Publication “Water Resources of India, 1988”

1/17/2014-BO (BPMO)/
Government of India
Central Water Commission
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Dated: - 29 /12/2014

To
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Sub: - Lecture notes on Basin- Wise Assessment of Water Resources for training program on "Integrated River Basin Planning and Management" at National Water Academy, Pune during 05-09 January, 2015 -regarding.

Sir,

In continuation to Reservoir Operation Directorate letter No. 6/20/2014-RO/1526-28 dated 19.12.2014 vide which it has been informed that the lecture on 'Basin- Wise Assessment of Water Resources' will be delivered by Shri Navin Kumar, Director (BP Dte) through video conferencing on 09.01.2015, the lecture notes prepared by Shri Navin Kumar, Director (BP) on Basin- Wise Assessment of Water Resources are enclosed for further necessary action at your end please.

Encl: As above

Yours faithfully,

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