Geotechnical issues related to inter-basin transfer of water for efficient management of water resources of the country

Y. P. Sharda

Introduction

Water is a scarce utilizable natural resource in India. It would become scarcer with the growth of population and expansion in economic activities and rapid urbanization. Inevitably, this would lead to accelerated demand of water for different purposes such as drinking, irrigation, hydro-power generation, agro-industries and non-agricultural industries, navigation, recreation and ecological requirements.

Due to variable topographic and climatic conditions, the water is not equitably distributed in different parts of the country. The per capita annual water availability varies drastically from 18417 m^3 in Brahmputra basin to 380 m^3 in some east flowing river basins of Tamilnadu. This results into woeful flood hazards in certain river basins in contrast to severe drought conditions in other parts. These inter basin differences would become complex with growing demand and could lead to socio-economic consequences. Such issues of water resources cause a deep concern and warrant immediate attention. Keeping these in view, the National Water Resources Council in its second meeting held on 2nd September 1987 adopted the National Water Policy. Since then this Policy has been guiding the formation of policies and programmes for development of water resources and their management. However, due to emergence of new challenges since then, this was further updated and adopted as National Water Policy-2002 on 10th April 2002.

National Water Policy (NWP-2002), addressing the challenges and issues related to water resource and its demand in India, enunciates scientifically evolved concept of sustainable Water Resource Management. It rises to the challenges and puts forth twin concepts of "Watershed Management" and "Inter-Basin Transfer" as cardinal measures in water-resource planning with an objective of bringing "water resource available" to the category of "water resource utilisable", and thus alleviating the problems arising out of drought prone-deficits and flood ravaging surpluses. In this context the NWP, focussing on issues of water allocation priority, water-zoning, conjunctive use of surface and ground water, water quality, water conservation, flood control, land erosion, and effective command development to obviate water-logging and salinity, invokes scientific management of water resources. The NWP emphasizes generation of efficient "Information System" with support of well documented "ground data base" and "data bank".

In order to find solution to the problems of water management, NWP encourages the scientists to conduct researches in the field of performance improvement, safety of the structures, maintenance and modernization, and monitoring of the impact of the water-management projects. In this regard NWP identified 27 fields of research, out of which

Director, Disaster Management, Liaison Office, NC-II Block, Pushpa Bhawan, 2nd Floor, Madangir Road, New Delhi 110 062

20 fields need evaluation from a geological perspective.

With this objective in view, a draft outline of an integrated development of water resources was indicated in National Perspective Plan for Water Resources Development. Subsequently, to give practical shape to this outline, National Water Development Agency (NWDA) was set up in 1982. As per the water balance studies by NWDA based on the water availability and requirements, the basins of the country have been divided into five zones viz. surplus, marginal surplus, deficit, marginal deficit and marginal deficit (surplus by import). This map indicates that only Brahmputra and Mahanadi basins in the east and river basins draining into Arabian Sea in the west have surplus water which can be transferred outside after meeting local requirements. Ganga, Godavari and Par river basins fall in marginal surplus category and can contribute only to some extent in the transfer of water. The Cauvery and Pennar rivers fall in deficit category, which need import of water to meet their requirements whereas Krishna, Tungbhadra, Pailar and Vaigai-Vaippar rivers fall in marginal deficit category, which can become surplus if water is imported. The whole concept has been developed for transferring the water from surplus and marginal surplus basins, after meeting their requirements, to deficit and marginal deficit areas/basins for optimum utilization of this natural resource of prime importance.

The milestone dates set by NWDA indicated the Peninsular Component to be completed by 2035 and Himalaya component by 2043. Expressing concern over the plan to link all major rivers in the country by the year 2043, the Supreme Court of India, hearing a PIL, directed the Government of India on 31st October, 2002 to constitute a task force to consider the completion of planning and execution of river linking projects by 2012. The bench, after hearing the Central Government's plea about major constraints like huge amount of finances (Rs. 560,000 crore at current prices), likely objections of States, environmental impact and the issue of relief and rehabilitation, opined that the Union Government could effectively implement the project by passing necessary orders under Entry 56 of the List I of Constitution of India.

To fulfill the dream of trans-river diversion in the speculated period of 10 years as per the directives above, an accelerated scientific endeavor will be needed for (a) generating data base (b) planning the appurtenants of the engineering structures viz. dams, reservoirs, water conductor systems for river linking and irrigation and power development, (c) planning the water resource management by taking lessons from past experiences for obviating the negative environmental impacts (viz. water logging, salinity development, etc.) as per the directives contained in NWP to dissuade endemic apprehensions regarding the environmental impact, (d) rising to the challenges and issues as regards to water management with peoples' perspective, especially eliminating scope of environmental hazards and (e) evolving information system for dissemination of the desired data, taking advantage of state-of-art technology in field informatics. The onus of addressing to these challenges lies on national agencies, especially those which have long experience and expertise of water management. Accordingly, a multi-disciplinary multi-institutional endeavor with effective coordination is needed to be invoked.

The paper briefly describes the proposals for Inter-basin water diversions and discusses the geotechnical issues and related problems.

Water resources of the country and their development - futuristic projections

As per the latest assessment, out of a total precipitation including snow fall of around 4000 BCM in the country, the availability from surface water and replenishable ground water is put at 1869 BCM. Thus the per capita annual availability of ground water is 2200 cubic meters which is much lower than the world average of 8500 cubic meters. Because of the topographic and other constraints, about 60% of this natural resource i.e. 690 BCM from surface water and 432 BCM of groundwater, can be put to beneficial use through conventional structures. Demand of water would further escalate steeply with the rise of population, industrial and agricultural growth. The country's population which is 1027 million at present is expected to reach around 1980 million by 2050.This would require 450 million tones of food grain. To cater to these needs, the agricultural yield shall have to be enhanced from 2.5 tones/ha to 3.5 tones / ha creating an irrigation requirement of 130 Million ha for food crop alone and 160million ha for all crops. With the growth, the projected power demand by 2050 would be 8.3 million MW. At 40%, the requirement of power from hydel sources for peaking would be 3.3 Million MW, which is by far higher than the 84000 MW of estimated hydel power potential of the country.

The availability of water is highly uneven in both space and time. Precipitation is only confined to about 3 or 4 months in a year and varies from 100 mm in western parts of Rajasthan to over 10,000 mm at Cherrapunji in Meghalaya in the northeast. The per capita annual water availability in Brahmaputra is as high as 18417 cubic meters as compared to 380 cubic meters in some of the east flowing river basins of Tamilnadu. Brahmaputra basin with 5.9% geographic area and 3.2% population has 2.9% of annual water resource of the country. This contrasting pattern of distribution results into a scenario where one-sixth of the area of the country is drought stricken and about 40 million hectares of land is ravaged by floods

The problems of inequitable distribution of the water availability in the country and over all scarce nature of the water resource is a cause of major concern and calls for a strategy for scientific and sustainable development of water resources. National Water Policy-2002 (NWP-2002) addresses these issues and calls upon judicious and scientific resource management and conjunctive use and conservation of surface and ground water. Watershed Management and Inter–Basin Water Transfer have been invoked as twin tools of water management. In this context, it is contained in the NWP-2002 that rivers and underground aquifers do not confine to state boundaries, so water as a resource is one and indivisible; rainfall, river waters, surface storages, lakes and ground water storages being part of one system. The water sharing/distribution amongst the States should be guided by a national perspective with due regard to the water resource availability and requirements within the river basin. Necessary guidelines including those for the water deficit states even outside the basin need to be evolved for facilitating future agreements amongst different basin states.

Inter basin transfers in India and abroad

Inter basin transfer of water for its optimal utlisation has been in practice all over the world since ancient times. In United States of America, the California State Water Project, the first phase of which was completed in 1973, provides for diversion of 4 BCM of water from water surplus area of northern California to water deficit central and southern parts of the State. The conveyance system includes 715 km long California Aqueduct, a complex system of lined and unlined canals, pumping stations, siphons and tunnels. The lift involved is of the order of 1000m. The Texas Water Plan envisages redistribution of water in Texas and New Mexico to meet the water requirements in the year 2020. Similarly, the water of Colorado River (an international river between USA and Mexico) is being diverted to Imperial Valley in California outside the basin of Colorado River.

Major existing and under construction inter-basin transfers in Canada include Kemano- Churchill Diversion, Well and Canal, James Bay, Churchil Falls, Bay d' Espoir, etc. Proposed inter-basin transfers in Canada include Ogoki, Long Lake (for transfer within Canada and North American Water and Power Alliance (NAWAPA), Grand Canal Concept, Canadian Water Magnum Plan, Central North American Water Project (CeNAWP), Smith Plan etc for transfer of water from USA to Canada.

In Mexico, the project involving the transfer of ground water from Lerma Basin to Mexico City for water supply was completed in 1958. The Water Plan for NW Region conceived a set of inter-basin transfers within Noroeste Region. Mahaveli-Ganga Project of Sri Lanka includes several inter-basin links. Inter-basin transfer projects have also been planned and completed in China and erstwhile USSR. A notable scheme executed in former USSR is Irtysh - Karganda scheme in Central Kazakhistan. The scheme includes about 450 km long link canal with maximum capacity of 75 cumecs and the lift involved varies between 14 and 22 m. There is another plan to transfer 90,000 mcm from the north flowing river to the areas in the south. Other proposals include partial redistribution of water resources of northern rivers and lakes of European part of the Caspian Sea basin involving 2 m ham of water.

The Lingua Canal was completed in China in 214 BC and Grand Canal in 605 AD. Recently completed projects involving inter-basin transfer of water in China include Biliuha-Dalian inter-basin water supply system. Trans transfer of Luhana river to Tiajian, Tengshan trans-basin diversion of Guanglong Province and inter basin diversions in Fujian Province, diversion of Quiantang river water, diversion of Yellow river surpluses and South to North transfer projects with the West route, Middle route and East route.

Long distance inter-basin transfer of water is not a new concept and has been in practice in India for over five centuries. The western Yamuna Canal and Agra Canal constructed during Moghul times are examples of this. Water was carried from Himalayas to the distant part of Punjab, Uttar Pradesh and Rajasthan through link canals. Lt. General Arthur Cotton, as far back as 1839, who pioneered the water resource development in southern India from 1839 onwards, proposed a plan to interlink Indian rivers for inland navigation. A small portion of the plan was implemented before getting abandoned, as decision was taken in favour of the Railways. The Kurnool– Cuddapah Canal (1860-1870) and Periyar- Vaigai Canal (1896) are live examples of inter basin transfer link executed in India during 19th Century.

More recent example of inter basin transfer in the country is Rajasthan Canal Project (Indira Gandhi Canal Project) which diverts water from Himalayas to the deserts of Rajasthan. Other important inter basin transfer schemes constructed in the country, which are functioning satisfactorily include inter basin transfers, in the Indus basin from Ravi to Beas, Beas to Satluj, which were implemented overcoming complex geotechnical and design problems, and the Ramganga Link in Uttar Pradesh. Narmada Main Canal is a mega inter-basin transfer project for which cross drainage works of unprecedented magnitude have been designed and executed. Other projects involving inter basin transfers, which have either been executed or planned in the country include Satluj-Yamuna Link Project, Sarda-Yamuna Link, Ghagra-Yamuna Link and Teesta-Mahananda Link projects which can be considered small beginnings towards transfer of water from mighty Brahmputra basin to Ganga basin. Kishanganga Hydroelectric Project proposed in Jammu & Kashmir proposes to transfer water from Kishanganga basin to Jhelum basin in addition to generating power. This would help in firming up the water supply to downstream hydroelectric projects in Jhelum basin.

With a view to meet the requirement of equitable distribution in different parts of the country, various proposals/plans have been suggested by different agencies/individuals active in the field of water resources development. Based on earlier work in Central Water and Power Commission, Dr. K. L. Rao proposed a National Water grid in 1972 for providing navigation and reducing the spatial disparities between different river basins. The main component of his plan envisaged Ganga- Cauvery Link, taking off from Ganga near Patna and enroute passing through the basins of Sone, Narmada, Tapti, Godavari, Krishna, and Pennar, and ultimately joining Cauvery upstream of Grand Anicut. This 2640 km long link involved transfer of 1680 cumecs of flood flows of Ganga for about 150 days in a year. Out of this 1400 cumecs was to be pumped over a head of 549m for transfer to Peninsular region and balance utilised within Ganga Basin. Dr. Rao also proposed a few additional links like (a) Brahmputra- Ganga Link to transfer 1800-3000 cumecs with a lift of 12-15m (b) Link transferring 300 cumecs of Mahanadi water southwards (c) Canal from Narmada to Gujarat and Western Rajasthan with a lift of 275m and (d) Links of rivers from Western Ghats towards east. The proposals were examined by the Central Water Commission and found to be grossly under estimated in terms of costs. It was also observed that the scheme would require large quantity of power (5 to 7 million KW) for lifting water and would have no flood control benefits. Therefore proposal was not pursued further.

Captain M. N. Dastur, an Air Lines Pilot proposed an imaginative scheme called Garland Canal Scheme which mainly comprised two canals, viz (a) 4200 km long, 300m wide Himalayan Canal at elevation between 457m and 335m above MSL aligned along the southern slopes of Himalayas running from Ravi in the west and Brahmputra and beyond in the east. It was to be fed by the waters of Himalayan rivers stored in 50 integrated lakes proposed to be created by cutting the hill slopes of Himalayas to the same level as bed level of canal and another 40 reservoirs beyond Brahmputra (b) 9300 km long and 300 m wide Central and Southern Garland Canal at a constant elevation of 244m and 355m above MSL. It was proposed to have about 200 integrated storage reservoirs. The Himalayan and Garland Canals were proposed to be interconnected at two points (Delhi and Patna) by 5 nos. of 3.7m diameter pipelines for transfer of water. The proposal was examined by two committees of experts who opined that the proposal was technically unsound and economically prohibitive. The scheme was therefore, given up.

There are numerous other proposals suggested by different individuals like R.N. Malik of Technology Mission Gurgaon, which envisaged linking of Ganga with Yamuna, Yamuna with Ghaggar, Ravi with Beas and Satluj with Ghaggar. Dr. Subir Kar, IIT-Bombay who envisaged creation of lakes of size of Chilka in every state and interconnecting them with huge pipelines to solve the problems of floods and recharging of ground water; Major S. Dhawan who suggested construction of a 50m high bund from Dhaleshwari river in Mizo Hills in the east to Ravi in west along the Himalayan foot hills to form a canal of 1448m width and another 50m high bund in the form of 9800 km long and 247m wide canal around Deccan Plateau. He also proposed a high level 400 km long and 500m wide canal along the ridge between Indus and Ganga, and reservoirs in main river systems. There are numerous such proposals that were of very preliminary stage and conceptual in nature and seemed to be lacking the engineering practicability and so can hardly qualify as alternatives worth serious considerations.

Proposals for inter basin transfer of water in India

The proposals for involving inter-basin transfer of water suggested earlier were rejected on techno-economic grounds but they formed the basis for evaluation of present concepts of linking of river basins for optimisation of water utlisation. With this objective in view, a draft outline of an integrated development of water resources was included in the Notional Perspective Plan for Water Resources Development. The National Water Policy was adopted by the Government of India in September, 1987. This policy emphasized for the inter-basin transfer of water. It states that *"Water should be made available to water deficit areas by transfer from the other areas including transfer from one river basin to another based on National Perspective after taking into account requirements of the areas/ basins"*. The erstwhile Ministry of irrigation (now Ministry of Water Resources) and Central Water Commission had in the year 1980 prepared a National Perspective Plan for Water Resources Development for optimum utilisation of water of various river basins in India. It comprised two main components viz. The Himalayan Component having 19 links, and the Peninsular Component having 17 links.

The National Water Development Agency (NWDA) was set up in July, 1982 with a view to promote scientific development for optimum utilisation of water resources in the country; to carryout surveys and investigations of possible storage reservoirs' sites and inter connecting links; to establish the feasibility of proposals of National Perspective Plan prepared by erstwhile Ministry of Irrigation and Central Water Commission; and to carry our field studies to assess the quantum of water which can be transferred to other basin states after meeting the reasonable requirements of intra basin states including the requirements of down stream river regimes in foreseeable future. The studies carried out by NWDA for the Peninsular Component include water balance studies of 137 basins/ sub-basins, water balance studies of 49 diversion points, storage capacity studies of 55 reservoirs, and preliminary studies of 16 link alignments. The studies in respects of Himalayan Component were started by NWDA in 1991-92. The studies for the Himalayan Component include water balance studies of 19 diversion points, preliminary studies of 16 reservoirs sites and toposheet studies of 14 links.

The water balance map has been prepared by NWDA based on above studies (Fig. 1). This map divides major parts of country into five zones viz. surplus, marginal surplus, deficit, marginal deficit and marginal deficit (surplus by import). It also indicates that Brahmputra and Mahanadi and West Coast basins fall in surplus category; Ganga, Godavari and Par into marginal surplus category; Cauvery, Pennar in deficit category and Krishna, Tungbhadra, Pallar and Vagal- Vaippar in marginal deficit category. The whole concept has been developed for transferring water from surplus and marginal surplus areas to deficit and marginal deficit areas/ basins for optimum utilisation.

Keeping this objective in view, the National Water Development Agency (NWDA) created for this purpose, came up with the National Project of Linking of Rivers in the country. This National Project comprises two main components:

- Himalayan Rivers Development Component and
- Peninsular Rivers Development Component

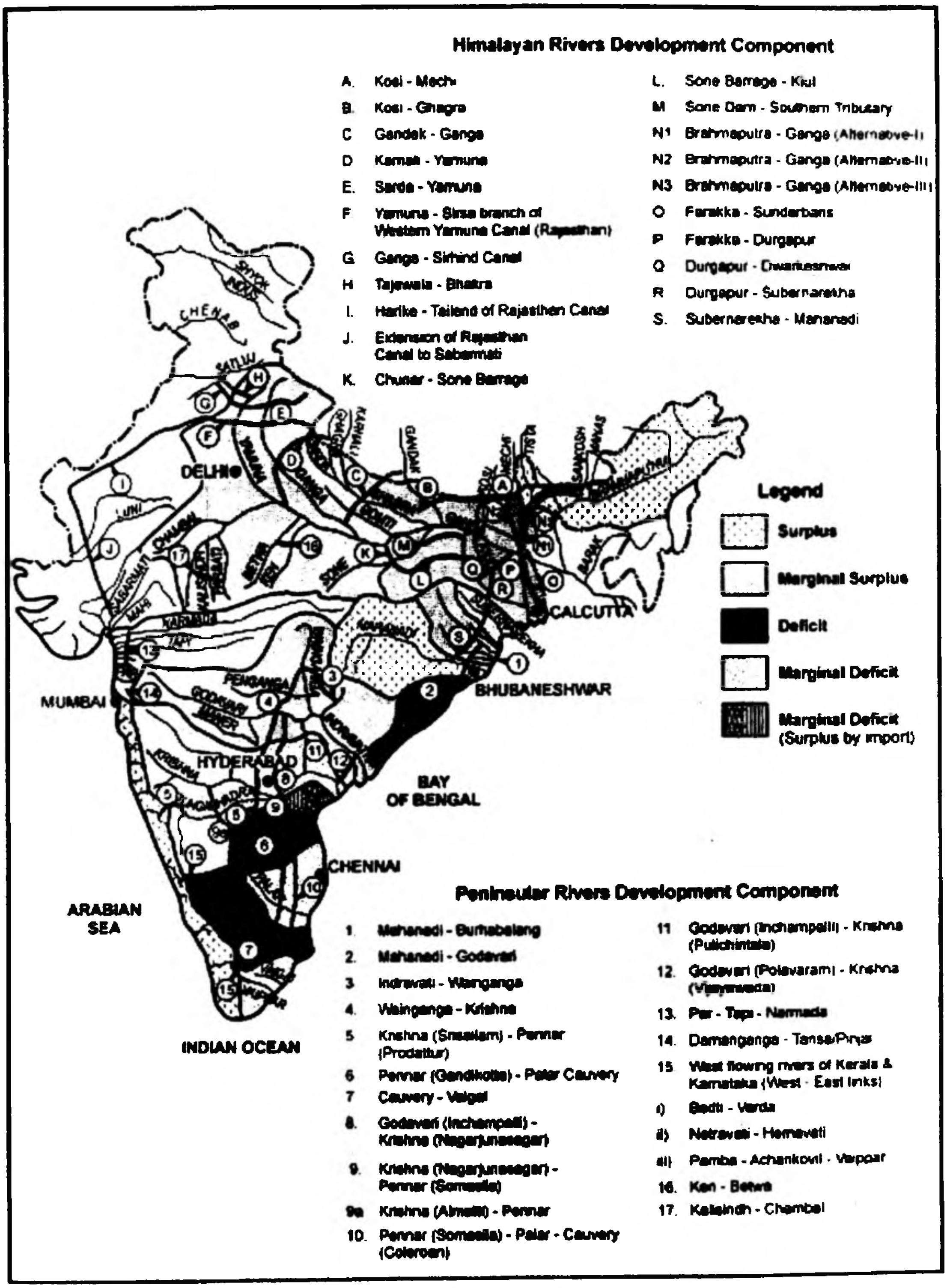
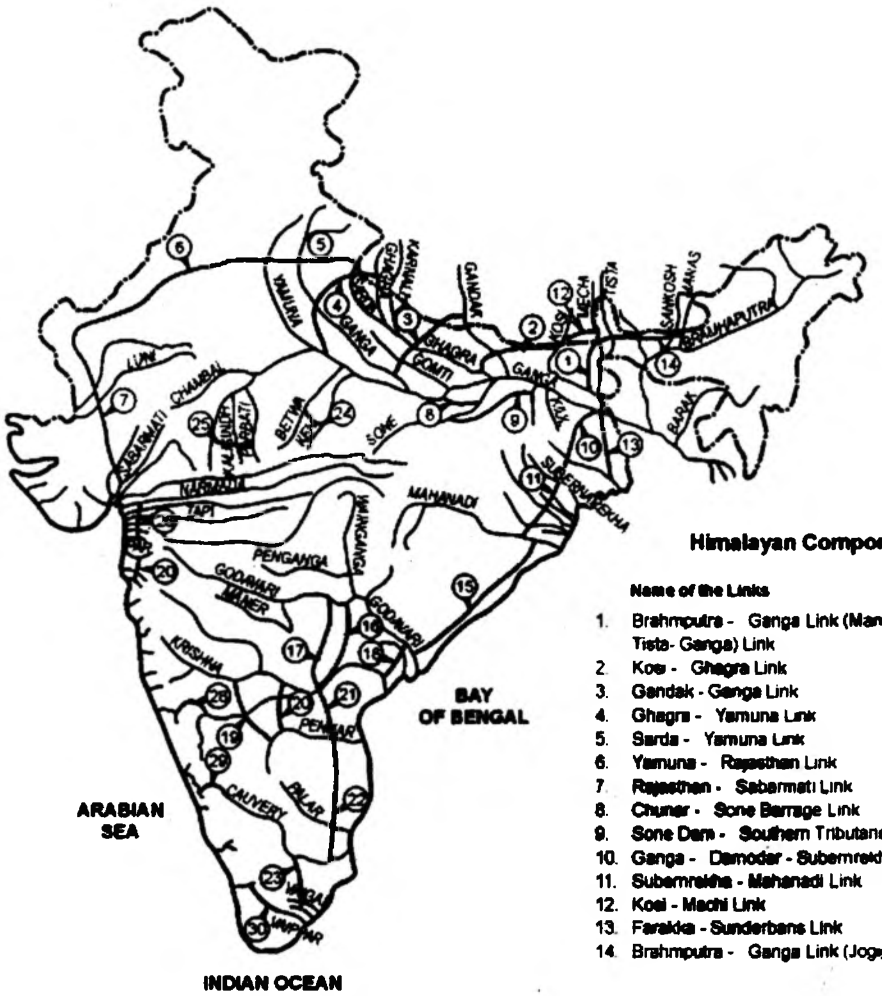


Fig. 1: National Perspective Proposal and Water Balance Map



Himalayan Component

Name of the Links

1. Brahmputra - Ganga Link (Manas- Sankosh-Tista- Ganga) Link
2. Kosi - Ghagra Link
3. Gandak - Ganga Link
4. Ghagra - Yamuna Link
5. Sarda - Yamuna Link
6. Yamuna - Rajasthan Link
7. Rajasthan - Sabarmati Link
8. Chunar - Sone Barrage Link
9. Sone Dam - Southern Tributaries of Ganga Link
10. Ganga - Damodar - Subernrekha Link
11. Subernrekha - Mahanadi Link
12. Kosi - Mechi Link
13. Farakka - Sunderbans Link
14. Brahmputra - Ganga Link (Jogigopa -

Peninsular Component

Name of the Links

15 Mahanadi (Manibhadra) - Godavari (Dowlaiswaram) Link
16 Godavari (Inchampalli Low Dam) - Krishna (Nagarjunsagar Tail Pond) Link
17 Godavari (Inchampalli) - Krishna (Nagarjunsagar) Link
18 Godavari(Polavaram) - Krishna (Vijaywada) Link
19 Krishna (Almatti) - Pennar Link
20 Krishna (Srisailam) - Pennar Link
21 Krishna (Nagarjunsagar) - Pennar (Somasila) Link
22 Pennar (Somasila) - Cauvery (Grand Ani Cut) Link

Name of the Links

23. Cauvery (Kattalai) - Vagai - Gundar Link
24. Ken - Betwa Link
25. Parbati - Kalisindh - Chambal Link
26. Par - Tapi - Narmada Link.
27. Damanganga - Pinjal Link
28. Bedti - Varda Link
29. Netravati - Hemavati Link
30. Pambe -Achankovil - Vaippar Link

Fig. 2: Proposed links under Himalayan and Peninsular river development components

Himalayan rivers development component

It envisages construction of storage reservoirs on the principal tributaries of Ganga and Brahmputra in India, Nepal and Bhutan along with inter-linking canal systems to transfer surplus flows of eastern tributaries of the Ganga to the west, apart from linking of main Brahmputra and its tributaries with the Ganga, and Ganga with Mahanadi. The Himalayan component would provide additional irrigation of about 22 million ha and generation of about 30 million KW of hydro power, besides providing substantial flood control in Ganga and Brahmputra basins. It would also provide necessary discharge for augmentation of flows required at Farakka inter alia to flush the Calcutta Port and inland navigation facilities across the country.

In the Himalayan Rivers Development component following links (Fig.2) are proposed by NWDA:-

1. Brahmputra - Ganga Link (Manas-Sankosh- Tista- Ganga) Link
2. Kosi - Ghagra Link
3. Gandak - Ganga Link
4. Ghagra - Yamuna Link
5. Sarda - Yamuna Link
6. Yamuna - Rajasthan Link
7. Rajasthan - Sabarmati Link
8. Chunar - Sone Barrage Link
9. Sone Dam - Southern Tributaries of Ganga Link
10. Ganga - Damodar - Subernrekha Link
11. Subernrekha - Mahanadi Link
12. Kosi - Machi Link
13. Farakka - Sunderbans Link
14. Brahmputra - Ganga Link (Jogigopa - Tista - Farakka) Link

This component includes formation of 16 reservoirs and construction of 14 links for transferring water from Brahmputra, Ganga and Yamuna basins to Mahanadi Basin and to Sabarmati in Gujarat. Many new structures are envisaged apart from existing ones to divert and store water.

Peninsular rivers development component

It is divided into following four major parts:

(i) Interlinking of Mahandi- Godavari-Cauvery rivers and constructing storages at potential sites: This is a major interlinking of river systems where surpluses from Mahanadi and Godavari are proposed to be transferred to areas where these are required.

ii) Inter linking of West flowing rivers, North of Bombay and south of Tapti: This scheme envisages construction of many optimal storages on these streams and make available the resultant quantity of water for transfer to areas where additional quantities of water are required. This scheme includes canals for taking water to the metropolitan areas of Bombay and coastal areas of Maharashtra for drinking and irrigation purposes.

iii) Inter linking of Ken- Chambal Rivers: The scheme includes provision of water for Madhya Pradesh and Uttar Pradesh and inter linking canals backed by as many storages as possible.

iv) Diversion of other West Flowing Rivers: Heavy rainfall on the western side of the "Western Ghats" runs down numerous streams that debouch into the Arabian Sea. Construction of an internal canal system backed up by adequate storages could be planned to meet all the requirements of Kerala as well as to transfer some water towards east to meet the requirements of draught prone areas.

The Peninsular component is expected to provide additional irrigation of about 13 million ha and generate about 4 million KW of power. This component envisages formation of 58 reservoirs, 49 diversion structures and 17 link alignments (Fig.2). The links envisaged under this component are as follows.

1. Mahanadi (Manibhadra) - Godavari (Dowlaiswaram) Link
2. Godavari (Inchampalli Low Dam) - Krishna (Nagarjunsagar Tail Pond) Link
3. Godavari (Inchampalli) - Krishna (Nagarjunsagar) Link
4. Godavari (Polavaram) - Krishna (Vijaywada) Link
5. Krishna (Almatti) - Pennar Link
6. Krishna (Srisailam) - Pennar Link
7. Krishna (Nagarjunsagar) - Pennar (Somasila) Link
8. Pennar (Somasila) - Cauvery (Grand Ani Cut) Link
9. Cauvery (Kattalai) - Vagai - Gundar Link
10. Ken - Betwa Link
11. Parbati - Kalisindh - Chambal Link
12. Par - Tapi - Narmada Link
13. Damanganga - Pinjal Link
14. Bedti - Varda Link
15. Netravati - Hemavati Link
16. Pamba - Achankovil - Vaippar Link

The work on the perspective plan of inter-linking of river basins was initiated by NWDA in 1991-92 and the Agency has completed water balance studies of all the 137 basins /sub- basins and diversion points. Toposheet studies have been completed for 58 reservoir sites and 18 link alignments. All pre-feasibility studies have been completed under this component. Field surveys, and investigations and preparation of feasibility reports for five links viz. Par-Tapi-Narmada, Pamba- Achankovil-Vaippar, Ken - Betwa, Godavari (Polavaram) - Krishna (Vijayawada) and Krishna (Srisailam)-Pennar are in progress. In addition, survey and investigation of Krishna (Nagarjunsagar) - Pennar (Somasila) were also completed and feasibility report was under finalisation till March, 2001. In addition, survey and investigation of Godavari (Inchampalli)-Krishna (Nagarjunsagar) link were also initiated in 2000-2001.

In case of Himalayan Rivers Component, water balance studies of all the 19 diversion points, toposheet studies of 16 reservoirs and 19 link alignments, pre-feasibility reports of 14 links have been completed. Field surveys and investigations for preparation of feasibility for following seven links are in progress.

- Manas - Sankosh - Tista - Ganga Link
- Sarda - Yamuna Link
- Ghagra - Yamuna Link
- Yamuna - Rajasthan Link
- Ganga - Damodar - Subernrekha Link
- Chunar - Sone Barrage link
- Sone - Southern Tributaries of Ganga Link

Milestones for Perspective Plan

The important mile stone dates for completion of various activities as envisaged in the perspective plan are completion of feasibility reports of Peninsular and Himalayan components by 2004 and 2008, respectively; negotiations and signing of agreements by 2009 and 2015 respectively; completion of Detailed Project Reports by 2015 and 2020, respectively; Techno-economic appraisal and clearances by 2017 and 2023, respectively; and completion of Peninsular Projects by 2035 and Himalayan Projects by 2043. However, this schedule drawn by the NWDA has become redundant as a result of the directions given by the Supreme Court of India to the Government of India to constitute a Task Force to accelerate the process of completion of the project by 2012 during the course of hearing of a Public Interest Litigation (PIL) filed by Shri Ajit Kumar.

The National Water Development Plan is expected to provide additional irrigation benefits of 35 million ha including 25 million ha from surface water and 10 million ha by increased use of ground water over and above the ultimate irrigation potential of 140 million ha from major, medium and minor projects of flood control, inland navigation, water supply, fisheries and pollution control etc.

Geotechnical issues related to river linking projects

The proposed mega project involving linking of various river basins of the country calls for meeting the challenges posed by varied physiographic, geologic and geomorphologic conditions. Due to its enormous size and tight schedule the challenges posed by the project would be of mega nature and have to be met with full preparedness. Due to the location of various components of the project in different geomorphic, seismo-tectonic and geologic domains, the geo-tectonic and environmental issues to be faced are also likely to be of varied nature. These would require in-depth studies of the hazards in each domain, and plans would have to be formulated in advance to meet challenges in each domain. The challenges likely to be encountered in geotechnical field include the problems arising due to the construction of large dams and reservoirs in geologically fragile and seismo-tectonically active Himalayan domain; meta stable river regimes in Indo-Gangetic-Brahmputra Plains and coastal areas; and thin alluvial cover, variable pattern of weathering in Central India and suspected Reservoir Induced Seismicity (RIS) in South Indian Domains. Similarly the geo-environmental problems likely to be encountered in different domains would have to be addressed accordingly. Based on the geology, seismo-tectonic setup, climatic variations, geomorphology, and prevalent land use patterns both Himalayan and Peninsular components can further be divided into following zones as far as geotechnical and geo-environmental issues are concerned.

- Himalayan Rivers Component
  - (a) Himalayan Zone
  - (b) Indo-Gangetic - Brahmputra Plains Zone
  - (c) Western Desert Zone.
- Peninsular Rivers Component
  - (a) Central Indian Zone
  - (b) Southern Indian Zone
  - (c) Coastal Zone

The geotechnical problems and environmental issues that are anticipated in each of these zones which would require detailed studies during feasibility, DPR, construction and post construction stages of this mega project are discussed below.

Himalayan Rivers Component

It envisages the construction of storage reservoirs on principal tributaries of Ganga and Brahmputra in India, Nepal and Bhutan along with canal systems to transfer surplus flows of Ganga to west, apart from linking of Main Brahmputra and its tributaries with Ganga and Ganga with Mahanadi. Based on the experiences of construction various hydroelectric, irrigation and multipurpose water resource projects in the past, the geotechnical and geo-environmental problems likely to be encountered on various project components in different zones are as follows:

(a) Himalayan Zone: This geo-dynamically active zone is characterized by the rugged topography and the presence of high seismicity and highly active geo-morphological processes. The geotechnical issues anticipated in this zone, which is likely to host most of the diversion points, storage reservoirs and some of the linking routes are as under.

i) Slope stability: The topography in this zone is rugged, characterised by high relief ratio and steep slopes. The problems of slope stability, likely to be encountered at storage reservoir, affect the stability of reservoir rims. Similar problems are likely to be encountered along link canal routes. These problems have to be addressed by carrying out landslide hazard zonation for identifying vulnerable reaches and implementing treatment measures.

ii) Geomorphic processes: Due to the active nature of geomorphic processes, the problem of shifting courses of rivers, and active slopes may be encountered. These have to be identified through detailed geomor-phological mapping of different basins and sub-basins utilising advanced remote sensing and photo-geological techniques. The active geomor-phological processes along with climatic factors are also responsible for the large amount of silt load in these Himalayan rivers. This problem has to be addressed through catchment area treatments and that should be the responsibility of Basin Development Authority that could be conceived as an integral part of the project.

iii) Geotechnical issues: The vast experience of Indian geotechnical community, acquired during its association with innumerable multipurpose, hydro electric and irrigation projects constructed in the Himalayan terrain, indicates that the complex tectonic setup resulting in presence of various structural features like thrusts, faults, shear zones, folds, thick overburden, and presence of buried channels and distressing/ gliding on abutments can be anticipated at almost all the sites in this zone. These aspects have to be investigated through detailed innovative geotechnical investigations within a limited time frame using latest techniques in the fields of geo-technology and engineering geology at all the stages of the project to avoid the so called geological surprises.

iv) Seismo-tectonics: The whole of Himalayan zone is one of the most seismically active areas in the world. The higher status of seismic activity is evident from the fact that the area has experienced four great earthquakes (M>8) during the last one hundred years. These are Assam Earthquake of 1897, Kangra Earthquake of 1905, Bihar-Nepal Earthquakes of 1934 and Assam Earthquake of 1950. Additionally a number of moderate earthquakes have also occurred in the area. Keeping in view the high seismicity, the area has been kept in zone V and IV of Seismic Zoning Map of India. (IS:1893-2002). It is recommended that detailed seismo-tectonic analysis of each site, in addition to the assessment of background seismicity, maximum credible earthquake and maximum design earthquake be carried out, which may be used for the closed dynamic analysis and determination of optimum seismic coefficient, to be incorporated in the design of appurtenant structures.

v) Construction material: Though availability of construction material both for fine and coarse aggregates should not be a major problem in this zone, it is suggested that the required quantities of construction material should be located at feasibility and DPR stages, and the appurtenant structures of the project designed accordingly. Particular attention should be directed to examine the suitability of coarse aggregates vis- a- vis the alkali aggregate reaction, a common deleterious attribute in the domain. In case, the diversion structures are designed as earth or rockfill dams, there could be problems of locating suitable material for impervious and filter zones. Presence of dispersive soils could create problems at certain sites in this domain. Therefore adequate laboratory tests to detect dispersivity in soils should be made integral part of laboratory testing. In case non dispersive fill materials are not available with in the reasonable distance, proper measures need to be evolved to cope with it. Similarly, if filter material of required specification is not available within reasonable distance, alternatives will have to be planned at DPR stage.

(b) Indo-Gangetic- Brahmputra Plains Zone: This densely populated zone is expected to host most of the link canals. Therefore link canals have to be planned in such a way that minimum population is

affected and loss of agricultural land is also minimum. The geotechnical issues likely to be encountered in this zone are:
(i) Geomorphology: Geomorphologically this zone comprises pediment surfaces with huge fan deposits and extensive alluvial plains. The link canals tracts on fanglomerate zones could face bank stability problems. Another major problem in this area is existence of unstable river regimes with erratic lateral migration. This requires detailed studies on fluvial morphology, identification of migration pattern and delineation of palaeo-channels through detailed geo-morphological mapping. In case the link canals are located in the unstable regimes, the same has to be stabilised while constructing main canals and cross drainage works.
(ii) Quaternary deposits: Since the link canals in this zone are located in unconsolidated Quaternary Deposits, the stability of cut slopes, where the excavations are deep, has to be studied in detail.
(iii) Water logging: Canals can lead to water logging in case the foundations have poor permeability and canal embankments may obstruct natural drainage system of the area. This issue has to be studied through remote sensing methods and reaches vulnerable to water logging identified to design preventive measures.
(iv) Construction material: The major problem anticipated in the domain is non-availability of construction material, particularly acute shortage of coarse aggregates. Therefore, innovations may have to be developed through sustained research, so that the cost does not increase due to this aspect.

(c) Western Desert Zone: The most important problem which is likely to be encountered in the western part of the area in case of Yamuna- Sabarmati link in deserts is instability induced in dunal regime by the wind action. This could adversely affect the structure. Therefore, route alignments should be planned carefully locating these in fairly stable region. Additionally, measures to protect the structure against wind action should also be evolved. This could be done by studying the detailed geomorphology along the proposed routes. The detailed geomorphological investigation in this zone could also help in delineating the lost ancient mighty Saraswati River along which a very advanced civilization flourished during ancient times. It may also lead to identification of the palaeochannels of this lost river, which may be utilised for tapping their ground water for conjunctive use.

Peninsular Component

The river linking endeavors in Peninsular Domain as per NWDA plans are spread over 137 basins/sub basins and include 58 storage reservoirs, 49 diversion points and 16 link alignments. The geotechnical, geo-environmental issues are different from those likely to be encountered in Himalayan River Component due to different geomorphological, geological and seismotectonic environs. This component on the basis of physiography and other attributes can be divided into three zones.

(a) Central Indian Zone: This zone extends from Chambal– Ken– Betwa and Sone basins in the north to Godavari basin in the south. The geotechnical issues of this zone are:
(i) Geomorphology of this zone is varied and includes Central Indian Highlands and large valleys of Mahanadi, Narmada and Tapi rivers in middle and coastal zones both in east and west. The detailed geomorphological mapping utilising modern remote sensing techniques should be carried out to identify locales and extents of geodynamic processes, and also the problems arising out of these.
(ii) Quaternary/ Recent deposits: Some of the diversion sites in the north are likely to be located in thick overburden areas north of Satpuras. Geotechnical problems likely

to arise in these areas are thick over burden and slope stability problems resulting due to deep excavations.

(iii) Topography: Due to large variations in altitudes and ruggedness of topography, it may be more economical to design certain reaches of the links as tunnels. These alternatives should be examined and such alternative proposals suggested wherever feasible.

(iv) Soil profile developed in this zone is generally thin. This can result in water logging along the routes of link canals due to lower rates of percolation of seepage water. The reaches susceptible to water logging be identified and remedial measures like lining be anticipated and planned in such reaches.

(v) Construction material may not be a problem in this zone. However, investigations for locating adequate quantities of suitable construction material shall have to be conducted in feasibility and DPR stages.

(vi) Seismicity: Seismicity of the area is lower as compared to that of Himalayan Zone. However, medium to large size earthquakes have been experienced in recent past. The background seismicity has also been high in some areas. Keeping this in view, it is suggested that the detailed seismotectonic analysis, especially of the diversion points and reservoir sites be carried out for determining seismic coefficients to be included in designs. It is believed by some scientists that creation of large reservoirs has led to the development of Reservoir Induced Seismicity (RIS). In view of this, the background seismicity be monitored at potential reservoir sites for long periods prior to impoundment and after, so that occurrence of RIS is confirmed or otherwise.

(b) Southern Zone: This zone includes southern part of Peninsula and basins of Krishna, Pennar, Cauvery and Vaigai-Vaippar. These are mostly recipient basins and will have diversion points and link canals apart from some diversion structures. Since some link projects are already in operation in this domain, experiences of these can be utilized in proposed schemes after necessary modifications. The geotechnical issues likely to be encountered in this domain are:

(i) Geomorphology is variable in this terrain which has varied physiography. Therefore, applied geo-morphological map of each basins/sub-basins should be prepared, active geomorphic processes identified and measures to check the effects of these be formulated.

(ii) Geotechnical problems likely to be encountered in this vast terrain would be different in different areas due to complex tectonics, presence of faults/shear zones, thick Quaternary deposits in some of the river valleys. Due to variable topography, it may be more economical to realign some of the link canals and design them as tunnels in certain sectors. One of the major geotechnical problems likely to be encountered in this domain is erratic weathering pattern particularly in granitic terrain. This problem will have to be overcome with innovatively planned explorations.

(iii) Slope stability: The problems of slope stability at some of the diversion sites and few canal routes could be another geotechnical hazard in this terrain in Western Ghats where landslide incidences are not infrequent. The critical slopes can be identified through landslide hazard zonation along the proposed canal routes and necessary measures planned to combat them.

(iv) Construction material may not be critical factor in this zone. However, adequate quantities of suitable construction material required should be located within the reasonable distances of user sites.

(v) Seismicity: This area as per the Seismic Zoning Map of India lies in zones II and III (IS: 1893-2002) and seismic events of moderate size have occurred here in the recent past. It is also believed by a section of scientists that the construction of storage reservoirs has lead to increase in seismicity in certain areas in the form of Reservoir Induced Seismicity (RIS). In this context, it is considered necessary that the background seismicity of various potential reservoir sites should be monitored so that this phenomenon is confirmed later after the impoundment. Keeping in view the seismo-tectonic setup of the area, the seismotectonic analysis will have to be carried out so that the optimum design seismic coefficient is evolved and adopted.

(c) Coastal Zone: Few of the components of link canals are likely to be located in this zone, both along the east and west coasts. The geotechnical and geo-environmental issues anticipated in this zone are:

(i) Geomorphology: The most important geomorphic factor operative in the zone is coastal geodynamics. The effect of this geomorphic process should be studied in detail vis-à-vis the link routes and strategies evolved to minimize its effect on the proposed structures.

(ii) Presence of estuaries: The rivers and estuaries that are to be negotiated by link canals are very wide and vulnerable to attack from sea water. Therefore adequate geotechnical investigations have to be planned so that these are negotiated without problems.

(iii) Cyclone hazard: Another natural hazard that is more frequent on east coast is the cyclone hazard. Keeping this hazard in view, the safety of the structures located very near to the coastline has to be evaluated and protection measures designed.

(iv) Seismicity: Areas falling under coastal zone are located in zones II and III as per the Seismic Zoning Map of India (IS: 1893-2002). This necessitates the seismo-tectonic evaluation of sites and determination of proper seismic coefficients for incorporation in the designs.

Conclusions and Recommendations

The water is not equitably distributed in different parts of the country due to variable topographic and climatic conditions. The per capita annual water availability varies drastically from 18417 m^3 in Brahmputra basin to 380 m^3 in the basins some east flowing river basins of Tamilnadu. This leads to woeful flood hazards in certain river basins in contrast to severe drought hazards in other areas. These inter basin differences are likely to become more complex with growing demand of water and could lead to socio-economic consequences.

Keeping these in view, the National Water Resources Council in its second meeting held on 2nd September, 1987 adopted the National Water Policy. Since then, this Policy has been guiding the formation of policies and programmes for water resources development and management. Due to emergence of new challenges since then, the National Water Policy has been updated, and was adopted as National Water Policy-2002 on 10th April, 2002.

National Water Policy (NWP-2002), addressing the challenges and issues, related to water resource and demands in India, enunciates scientifically evolved concept of sustainable Water Resource Management. It rises to the challenges and puts forth twin concepts of "Watershed Management" and "Inter-Basin Transfer" as cardinal measures in water-resource planning with an objective of bringing "water resource available" to the category of "water resource utilisable" and thus alleviating the problems arising out of drought prone-deficits and flood ravaging surpluses.

Inter basin transfer of water for its optimal utlisation has been in practice all over the world since ancient times.

With a view to meet the requirement of equitable distribution in different parts of the country, various proposals/plans have been put forth by different agencies/individuals active in the field of water resources development. Prominent proposals among these include National Water grid proposal of Dr. K. L. Rao that was suggested in 1972 for providing navigation and reducing the spatial disparities between different river basins, and an imaginative Garland Canal Scheme proposed by Captain M. N. Dastur, an Air Lines Pilot which mainly comprised two canals, viz (a) 4200 km long, 300m wide Himalayan Canal at elevation between 457m and 335m above MSL aligned along the southern slopes of Himalayas running from Ravi in the west and Brahmputra and beyond in the east, and a 9300 km long and 300 m wide Central and Southern Garland Canal at a constant elevation of 244m and 355m above MSL.

The proposals for involving inter-basin transfer of water suggested earlier were rejected on techno-economic grounds but they formed the basis for evaluation of present concepts of linking of river basins for optimisation of water utlisation.

The erstwhile Ministry of irrigation (now Ministry of Water Resources) and Central Water Commission had in the year 1980 prepared a National Perspective Plan for Water Resources Development for optimum utilisation of water of various river basins in India. It comprised two main components i.e. Himalayan Component having 19 links and Peninsular Component having 17 links.

Keeping this objective in view, the National Water Development Agency (NWDA) created for this purpose came up with the National Project of Linking of Rivers in the country. This National Project comprises two main components - Himalayan Rivers Development Component and Peninsular Rivers Development Component.

Himalayan Rivers Development Component envisages construction of storage reservoirs on the principal tributaries of Ganga and Brahmputra in India, Nepal and Bhutan along with inter-linking canal systems to transfer surplus flows of eastern tributaries of the Ganga to the west, apart from linking of main Brahmputra and its tributaries with the Ganga and Ganga with Mahanadi. The Himalayan component would provide additional irrigation of about 22 million ha and generation of about 30 million KW of hydro power, besides providing substantial flood control in Ganga and Brahmputra basins. It would also provide necessary discharge for augmentation of flows required at Farakka interalia to flush the Calcutta Port and inland navigation facilities across the country.

Peninsular Rivers Development Component is divided into following four major parts-interlinking of Mahandi-Godavari- Cauvery rivers and constructing storages at potential sites, linking of west flowing rivers, north of Bombay and south of Tapti, linking Ken- Chambal Rivers, diversion of other West flowing rivers. The Peninsular component is expected to provide additional irrigation of about 13 million ha and generate about 4 million KW of power. This component envisages formation of 58 reservoirs, 49 diversion structures and 17 link alignments.

The proposed mega project involving linking of various river basins of the country calls for meeting the challenges posed by varied physiographic, geologic and geomorphologic conditions. Due to its enormous size and tight schedule the challenges posed by the project would be of mega nature and have to be met with full preparedness. Due to location of different components of the project in different geomorphic, seismo-tectonic and geologic domains, the geo-tectonic and environmental issues to be faced are likely of varied nature. These would require in-depth studies of the hazards in each domain and plans would have to be formulated in advance to meet the challenges in each domain. The challenges likely to be encountered in geotechnical and geoenvironmental fields include the problems arising due to the construction of large dams and reservoirs in geologically fragile and seismo-tectonically active Himalayan domain; meta stable river regimes in Indo-Gangetic-Brahmputra Plains and coastal areas; and thin alluvial cover, variable pattern of weathering in Central India and suspected Reservoir Induced Seismicity (RIS) in South Indian domains.

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