The Ganga-Brahmaputra-Barak Basin

M C CHATURVEDI

Applied Mechanics Department, Indian Institute of Technology, New Delhi 110016, India

Abstract. The physiographic-hydrologic-agroclimatic characteristics of the Greater Ganga Basin, one of the biggest river basins of the world and supporting the largest human population are described. A brief historical background of the development of the basin and the reasons for the desperately poor conditions are also discussed. The various issues involved in the planning of the water resources of this basin are outlined and a scenario of technological choices for the development at macro and micro levels has been developed. It has been brought out that interlinked competing issues, multipurpose and multiobjective considerations, spatial and temporal variations in the availability, and the large number of possible technological choices have made the application of a systems approach mandatory for integrated planning for future economic development of the basin.

Keywords. Ganga Basin; systems approach

1. Introduction

The river Ganga and its tributaries, and the flat and fertile plain through which they flow, are one of the earth's great natural resources. For thousands of years, abundant water and generous land have provided the foundation for a highly developed civilization based on agriculture and for one of the world's largest concentrations of human populations. But the farming is mainly traditional and at a subsistence level, with little surplus, and as a result the population has remained overwhelmingly rural and desperately poor. Although irrigation from canals and wells has been practised for millennia, chiefly to protect against uncertainties of the monsoon rains, the water resources are largely untapped; the small fraction of water used for irrigation is poorly managed, its productivity is low, and the people continue to be exposed to the vagaries of nature—droughts and floods.

Deeply-embedded cultural, social and economic practices inhibit modernization of agriculture and fuller utilization of water resources. Capital investment and technological changes on a large scale are also required. As experience elsewhere shows, the introduction of technological changes on the required scale might break the chains of tradition that now bind the people in misery and poverty.

The development of such a large and complex system is a tremendous technological challenge. It is a typical systems problem as the various elements are interlinked in a variety of ways. Several studies have been undertaken by Chaturvedi & Rogers (1985) to explore essentially, an approach to analysis. As a prelude to systems studies, the salient characteristics of the system, a brief historical background of the development and the possible future approaches to it are given. The data is based on published material and papers from various sources, particularly background material presented at a Workshop on Integrated Development of the Ganga-Brahmaputra-Barak Basin (1978) held at the Gandhi Peace Foundation, New Delhi. This data, however, must be

considered tentative, and the studies demonstrate only the applicability of a systems approach.

2. System characteristics

The system comprises the drainage basins of three international rivers, the Ganga, the Brahmaputra, and the Barak or Meghna. This is also called the Greater Ganga Basin and is shown in figure 1, with a schematic developmental sketch in figure 2 showing the projects and the schemes. It covers parts of four countries: India, Nepal, Tibet and Bangladesh, although primarily the system is focussed on India. In area as well as in population and development opportunities the Ganga again has the central focus. The Ganga basin itself is usually divided into eight or nine sub-basins (i) the Main Ganga (including Ramganga), (ii) the Yamuna, (iii) the Chambal, (iv) the Tons, Karmnasa and others between the Chambal and the Son; (v) the Son; (vi) the right-bank tributaries east of the Son; (vi) the Gomti, the Ghagra and others between them; (vii) the Gandak and other left-bank tributaries. Sometimes the Ramganga is treated separately.

The Greater Ganga system, next to the Amazon in South America, is the second largest international river basin in the world so far as runoff is concerned. It drains an area of 1.38 million sq km. With 326 million (1971), nearly a twelfth of the world's total population, the basin is the most populous in the world. The system carries a peak flow of over 1,41,000 cumec at its estuary and empties annually about 127.61 m ha m of water into the Bay of Bengal of which 80% is in the monsoon.

The physiographic characteristics of the system are the steep and geologically young Himalayas in the north and east and the Vindhya in the south. On the west a low unnoticeable watershed separates this basin from the Indus basin. The Brahmaputra and the Barak/Meghna meet the Ganga at its tail end. The extensive alluvial plains of the Ganga and its tributaries and the Brahmaputra valley as they meet the Bay of Bengal form a vast delta comprising most of Bangladesh and West Bengal in India. More than half of the territory of Bangladesh is less than 7 m above sea level.

The system has a monsoon climate. The annual precipitation in the region is shown in figure 3. The problems of land and water development in the Greater Ganga Basin arise from the highly seasonal flow of the river and its tributaries. This can be observed in figure 4. These figures represent the average seasonal flows in the river Ganga alone. Further, there is considerable yearly variation leading to the most severe floods and droughts. The flows of three of the major rivers are shown in figure 5.

2.1 *The Ganga*

The great river of the north Indian plains is officially as well as popularly known as the Ganga, although internationally it is known by its anglicized name, Ganges. From time immemorial it has been the holy river of the Hindus. For most of its course it is a wide and sluggish stream, flowing through one of the most fertile and densely populated tracts of territory in the world. Despite its importance, its length of 2506 km makes it the 15th longest river in Asia and the 39th longest river in the world (Encyclopaedia Britannica 1978).

Rising in the Himalayas and emptying into the Bay of Bengal it drains a quarter of the territory of India, while its basin supports a concentration of about 300 millions, a population larger than any state or even continent, except China and India.

Figure 1. The Ganga-Brahmaputra-Meghna river system

Figure 2. Macro and micro level projects for irrigation and hydel energy development in Ganga-Brahmaputra-Meghna river system (schematic)

Figure 3. Annual isohyets (cm)

The Ganga rises in the southern Himalayas on the Indian side of the Tibet border. Its five head streams—the Bhagirathi, the Alakhnanda, the Mandakini, the Dhaul Ganga and the Pindar—all rise in the Uttarakhand division of the state of Uttar Pradesh (UP). Of these, the two main head streams are the Alakhnanda (the longer of the two) and the Bhagirathi. The Bhagirathi, which is traditionally known as the source of the Ganga, rises in India from the Gangotri glacier in the Himalayas at an elevation of about 7,010 m above mean sea level. After its confluence with the Alakhnanda at Dev Prayag, the river assumes the name Ganga. After draining the middle ranges of the Himalayas the river debouches into the plains at Hardwar. From Hardwar down to Allahabad where the Yamuna joins it on the right bank, a distance of about 720 km, it generally flows in a south/south-easterly direction. Lower down, the river flows eastwards and past Varanasi, in UP the Ganga is joined by a number of tributaries on both banks. Of

Figure 4. Surface water resources in the system

the left-bank tributaries in the upstream reaches, prior to Varanasi, the Ramganga and the Gomti are the most important. The Yamuna has a number of important tributaries like the Chambal, the Sind, the Betwa and the Ken joining it from the South. The Tons and the Karamnasa are other right-bank tributaries in UP.

After leaving UP the Ganga forms the boundary between UP and Bihar for a length of about 110 km and in this reach the Ghagra which flows down from Nepal joins it near Chapra. The river then enters Bihar below Ballia and flows more or less through the middle of the State. During its course of nearly 445 km in Bihar the river flowing eastwards is joined by a number of major tributaries on both banks. The Great Gandak, the Bagmati and the Kosi and the Burhi Gandak join it on the left bank. The first three flow down from Nepal into North Bihar. The Son, the Pun Pun, the Kiul, the Chandan, the Gerua and others join the Ganga on the right bank.

Before entering West Bengal, the river swings and flows almost due south. The delta of the Ganga can be said to start from Farakka. The river divides into two arms about 40 km below Farakka. The left arm, known as the Padma, flows eastwards into Bangladesh while the right arm, known as the Bhagirathi, continues to flow in a

Figure 5. Monthly mean flows of some major rivers at their tail ends

southerly direction in West Bengal. Till some three hundred years ago, the Bhagirathi-Hooghly constituted the main arm of the Ganga carrying the bulk of the flow. Thereafter the Padma arm opened up more and more leaving Bhagirathi a mere spill channel of the Ganga flowing mostly during high stages of flow. The river ultimately flows into the Bay of Bengal about 145 km downstream of Calcutta. The length of the river (measured along the Bhagirathi and the Hooghly) during its course in West Bengal is about 520 km. Several tributaries join the Bhagirathi-Hooghly in West Bengal. The Ganges in Bangladesh flows past Kushtia and Pabna till the Brahmaputra (locally called Jamuna) joins it at Goalundo.

The united stream of the Brahmaputra and the Ganga beyond Goalunda continues to flow south-east under the name Padma. At Chandpur, 105 km below Goalunda, the Padma is again joined on the left bank by the Meghna, whose source is in the high

mountains, which are subjected to intense rainfall. From this confluence downwards, the river, known as the lower Meghna becomes a very broad estuary making its exit into the Bay of Bengal.

The precipitation over the Ganga basin is brought about by the south-west monsoon as well as by cyclones originating over the Bay of Bengal. The average annual rainfall in India varies from 35 cm on the western end of the basin to about 200 cm near the delta. The river drains an area of 106.96 m ha (excluding Tibet) and the average annual flow of the Ganga at Farakka is about 55.01 mham.

2.21 *The Brahmaputra*

The Brahmaputra rises in the great glacier in the northern-most chain of the Himalayas in the Kailash range just south of a lake called Konggyu Tsho. The river under its Tibetan name of Tsangpo flows eastwards through southern Tibet for about 1700 km keeping a course roughly parallel to the main range of the Himalayas. In this long journey it meets a number of tributaries. After turning south or southeast it enters Arunachal Pradesh in India as the Dihang river. At the town of Sadiya, India, the Dihang turns to the southwest and is joined by the two mountain streams of Luhit and Dihang. After the confluence, about 1500 km from the Bay of Bengal, the river is known as the Brahmaputra (the son of Brahma, the creator).

The river then rolls down the Assam valley from east to west for about 720 km with its channels meandering from side to side forming many islands. In Assam the river is mighty even in the dry season and during the rains its banks are more than 10 km apart. The largest island Majuli covers an area of 1250 sq km. As the river follows its braided 700 km course through the valley, it receives several rapid Himalyan streams, including the Subansiri, the Kaneng, the Dhansiri, the Manas, the Champamati, the Saralbhanga and the Sankosh. On the south bank, the main tributaries are the Noa Dihing, the Buri Dihing, the Disang, the Dikhu and the Kopili. The Brahmaputra also has some important tributaries flowing through North Bengal. They are the Tista, the Jaldhaka, the Torsa, the Kaljani and the Raidok. Emerging swiftly from narrow gorges with steep slopes, these rivers widen out considerably in the plains.

Swinging round the western spurs of the Garo Hills, near Goalpara, the river enters the alluvial plains of Bangladesh, through which it flows southwards for another 270 km until it joins the Ganga at Goalundo. Below the confluence of the Tista, the old channel of Brahmaputra branches off the left bank. From here to Goalunda the river is called the Jamuna.

In Tibet the precipitation is in the form of snow which begins to melt in March following the intrusion of warm air. Coming down the central basin in India, the annual rainfall, brought by the southwest monsoon, is about 250 cm. Further down in Bangladesh the rainfall over the basin averages about 240 cm. The river drains a total catchment area of 23.41 m ha (excluding Tibet and Bhutan) at Bahadurabad (Bangladesh) and the average annual runoff at this site is 61.5 m ha m.

2.3 *The Barak/Meghna*

The Barak river, the head stream of the Meghna rises in the hills in Manipur (India) at an elevation of about 2900 m. It flows south-westerly winding its way along hill ranges for about 250 km. Thereafter it takes a sharp reflex bend and flows north. It changes

direction to west when emerging from the hills and follows a meandering course till it enters Bangladesh. Many tributaries join the Barak. Near the border, the Barak bifurcates into two rivers, the Surma and the Krishiyara which again join and flow in a southerly direction under the name of Kali. It takes the name Meghna before it meets the Padma, which carries the combined flow of the Ganga and the Brahmaputra, at Chandpur.

Below Chandpur the combined river, also known as the Lower Meghna, becomes a very wide and deep estuary. It enters the Bay of Bengal through four principal channels. The distance between Chandpur and the sea is about 130 km. The Meghna is thus about 950 km long, of which 550 km including the estuary from Chandpur to the sea lies in Bangladesh.

The river has a steep slope while flowing in the hills in India. After entering Bangladesh it travels through the low-lying alluvial basin. When the Meghna flood meets that of the Padma at Chandpur, its floods are backed and its basin acts as a gigantic detention reservoir, without which the area between Goalundo and Chandpur would be under much deeper water. At flood stages, the slope of the Meghna downstream of Bhairab Bazar, where it meets the old Brahmaputra, is only about 1:88,000 which reflects the influence of back-water from the Ganga-Padma.

There is copious rainfall in the watershed of the Meghna and the Barak rivers. Around the foothills in Assam, the rainfall reaches 500 cm on the windward side. At and near Cherrapunji, where rainfall is amongst the highest in the world, the average annual precipitation is about 1100 cm. In the plains of Bangladesh the rainfall varies from 200 to 300 cm. The drainage area of the Meghna at Bhairab Bazar is about 8.02 m ha and average annual runoff is 11.1 m ha m.

2.4 Some systems characteristics

Despite the wide physiographic-geographical diversities some characteristics of the system may be mentioned.

The Ganges-Jamuna area was once densely forested; historical writings indicate that in the 16th and 17th centuries, wild elephants, buffaloes, bison, rhinoceroses, lions and tigers were hunted there. Most of the original natural vegetation has disappeared from the Gangetic basin as a whole and the land is intensely cultivated to meet the needs of an ever-growing population. Hence, irrigation is increasingly depleting the low flows.

In ancient times the Ganga and some of its tributaries in the east were navigable. The Ganga was navigable upto Agra. It has almost disappeared now and is practical only in West Bengal and Bangladesh.

The Ganga as well as its tributaries and distributaries, are constantly vulnerable to changes in their course in the delta region. Such changes have occurred in comparatively recent times, specially since 1750; the most spectacular of these changes was the eastward diversion of the Tista river and the ensuing development of the new channel of the Jamuna, which occurred in 1787 with an exceptionally high flood in the Tista.

The delta of the Greater Ganga system is one of the biggest in the world covering an area of 56,700 km².

The salient statistics of the region are shown in table 1. Some important characteristics of the region are summarised in table 2. The salient pieces of information about the entire Ganga basin and relevant statistics for India are given in table 3. The details for the Ganga Basin in terms of eight sub-basins are given in table 4.

Table 1. Salient characteristics of the Greater Ganga basin

No	Item	Unit	Ganga			Total or average figure for basin	Brahmaputra	
			India	Nepal	Bangladesh		India	Bangladesh
1	2	3	4	5	6	7	8	9
<i>A. Land</i>								
1.	Geographical area	Mha	86.14	14.08	6.74	106.96*	18.71	4.7
2.	Cultivable area at present cultivation	Mha	60.30	3.98	3.64	67.92	12.15	3.0
<i>B. Population</i>								
1.	1971 Census	Million	221.19	11.29	27.03	259.51	17.65	24.83
2.	Population density	per sq km	257.00	80.00	401.00	243	94	528
3.	Agr. population	Million	149.74	10.34	19.06	179.14	11.93	17.5
4.	Agr. population	%	67.6	91.6	70.5	69.03	67.6	70.5
<i>C. Water</i>								
1.	Mean annual rainfall	cm/yr	60-200	100-250	150-212	120	212	200
2.	Total annual runoff	mhm	55.01***	—	Neg	55.01	51.25	10.25
3.	Irrigation potential (present)	Mha	17.81	1.202	2.95	21.96	2.3	1.46
<i>D. Energy</i>								
1.	Hydropower potential	Mkw	13.274	85.00	Neg	98.27	13.43	Neg
2.	Hydropower installed	Mkw	1.83	0.41	Neg	2.24	00.18	Neg
3.	Hydropower installed	%	13.79	0.49	Neg	2.33	1.34	0.0
<i>E. Unit figures</i>								
1.	Land per capita	Ha	0.39	1.25	0.25	0.4	1.06	0.189
2.	Utilizable water/unit cultivable land	m ³	116.00	—	—	—	171.0	—
3.	Cropping intensity	%	125	—	—	—	118.0	—
4.	Irrigation intensity	%	23	—	—	—	21.3	—
5.	Utilizable and utilized water resource							
a.	Surface	mhm	18.5/70.4	—	—	—	0.61/70	—
b.	Ground	mhm	10.64/39.4	—	—	—	0.02/1.1	—
c.	Total	mhm	29.14/59.4	—	—	—	2.68/23.5	—

Note:

A. (i) *** Inclusive of runoff of Nepal; (ii) ** 29.3 Mha in Tibet and 5.29 Mha in Bhutan not included in this figure; (iii) * 2.9 Mha in Tibet not included in this figure; (iv) Neg = Negligible; Agr. = Agricultural; (v) These figures are derived from Irrigation Commission Report.

B. The figures have been taken from various published sources and are only indicative.

3. Developmental issues

Although technological activities for water resources development have been undertaken in the past, the region still provides unique opportunities for the development of the huge unutilised potential. The best way would be to have an integrated approach, treating the entire river basin as one. This may not be possible from political considerations, but at least developmental planning may be carried out in totality, as well as from each country's point of view and then a bargained developmental plan for each country may be developed.

The development in the Ganga basin in the pre- and post-Independence period has been *ad hoc* and of the project-oriented technological type. The policy in the pre-Independence period was one to support sustenance agriculture. It is now necessary to develop an appropriate integrated future developmental policy. The approach has

Total or average figure for basin	Barak/Meghna		Total or average figure for basin	Total for greater Ganga basin	Total in each country		
	India	Bangladesh			India	Nepal	Bangladesh
10	11	12	13	14	15	16	17
23.41**	4.4	3.62	8.02	138.39	109.25	109.25	15.06
15.15	1.11	2.87	3.98	87.05	73.56	3.98	9.51
42.48	5.33	19.10	24.43	326.42	244.17	11.29	70.96
181	121	528	305	236	223	80	471
29.43	3.60	13.46	17.06	222.03	165.27	10.34	50.02
69.28	67.6	70.5	69.83	68.02	67.69	91.58	70.5
212	450	240	350	—	—	—	—
61.5	6.0	5.1	11.1	127.61	112.26	—	—
3.76	0.115	0.47	0.585	26.305	20.225	1.202	4.88
13.43	2.5	Neg	2.5	114.2	29.2	85	Neg
0.18	0.08	Neg	0.08	2.5	2.09	0.41	Neg
1.34	3.2	Neg	3.2	2.23	7.16	0.49	Neg
0.55	0.82	0.189	0.33	0.42	0.45	1.25	0.18
—	379.0	—	—	—	—	—	—
—	124.0	—	—	—	—	—	—
—	13.0	—	—	—	—	—	—
—	0.20/27	—	—	—	19.21	—	—
—	0.75/11.3	—	—	—	10.735	—	—
—	1.03/9.7	—	—	—	32.85	—	—

been briefly reviewed in the context of an overall policy for India (Chaturvedi 1985), but it is reviewed in greater detail for the Greater Ganga Basin.

3.1 Technological choice

The physiography, hydrologic input, vector specification of precipitation and demand characteristics and the socio-economic milieu largely determine the technological choice. The salient characteristics are as follows.

The basin is like an elongated bowl with very high and steep mountains on the north and comparatively low mountains on the south and east and a very flat alluvial plain in between. The precipitation takes place during 3 or 4 months of the monsoon and thus there is tremendous variation in the water availability over the year, as shown in figure 4. Even during the monsoons, precipitation is neither uniform nor dependable. The physiographic condition of steep mountains followed by flat plains and the hydrologic characteristic of monsoon-concentrated precipitation lead to heavy floods.

Table 2. Summary of salient features of the Greater Ganga Basin

Item	Total for Greater Ganga basin	Share for India
<i>Land</i>		
Geographical area (10 ⁶ ha)	138.39	109.25
Cultivable area (10 ⁶ ha)	87.05	73.56
<i>Population</i>		
1971 Census (million)	326.42	244.17
Population density (per km ²)	80—645 with an average of 240	223.0
Agricultural population (million)	222.03	165.27
Agricultural population (% of total)	68.02	67.69
<i>Water</i>		
Mean annual rainfall (cm/yr)	60—450 with an average of 350	—
Total annual runoff (m ha m)	127.61	112.26
Irrigation potential (m ha)	26.3	20.2
<i>Energy</i>		
Hydropower potential (MW)	114.2	29.2
Hydropower installed	2.5	2.09
<i>Unit figures</i>		
Land per capita	0.42	0.45
Utilizable water/unit culturable land (m ³)	116—379	—
Cropping intensity	—	118—125
Irrigation intensity	—	13—23
Utilizable water (m ha m)		
(a) surface	—	19.21
(b) groundwater	—	10.735

The Himalayas, which form a considerable portion of the catchment area of the Greater Ganga Basin, are very young, erodible and have very steep slopes leading to high flows and very heavy sediment loads—the highest in the world during the monsoons (Leeden 1975). While the storage potential is large, it is a very small proportion of the total water resources of the region—only about 8% (Rao 1976).

Most of the storage and hydroelectric potential of the Himalayan region is in Nepal. Increasing population in Nepal is going to exacerbate the erosion, sedimentation and flood problem due to cutting of forests for agriculture and energy demands. Thus, it is both in India's and Nepal's interest to collaborate in the rapid development of the watershed, social forestry, storage and hydroelectric energy, in the Himalayan region for utilising the valuable water resources and hydroelectric potential and reducing the hazards of erosion and floods. Water for this region is like oil for the middle east countries with the further advantage of non-depletability. It can be said that gravity is the biggest asset of this region. The economy of this region can be built around the development of water, light industry and tourism rather than food crop-oriented agriculture as necessity demanded in the past. Of course, these transitions will take

Table 3. Salient statistics of the Ganga basin

Item	Ganga Basin	Total India	Ganga (% of total)
<i>Land</i>			
Geographical area (10 ⁶ ha)	86.14	328.06	26.3
Cultivable area (10 ⁶ ha)	60.30	199.92	30.1
<i>Population</i>			
1971 Census (million)	221.19	546.9	40.4
Population density No/sq. miles	286-1180	470	—
Rural population (%)	80-93	—	—
Cultivators and agricultural labour (%)	55 + 22	of total labour force	
<i>Water</i>			
Mean annual precipitation (cm/year)	60-200	118	—
Potential evapotranspiration (cm/year)	155-175	228	93
Total annual runoff (m ha m)	55.01	188.12	29.3
Groundwater (percent of total)	26.6	—	—
Utilizable water resources			
(a) surface	18.50	66.60	27.8
(b) surface as percent of total	34	—	—
(c) groundwater	10.64	26.10	41.0
(d) total	29.14	92.70	31.4
<i>Unit figures</i>			
Land/Capita (hectares)	0.27	0.37	
Utilizable water/unit culturable land (m ³)	116.0	115.00	100%
Cropping intensity	125	—	—
Irrigation intensity	23.0	20.6	—
Hydropower potential (MW)	13,285	—	—
Hydropower installed (MW)	1,830	—	—

place integrally and over the course of time. Agriculture has to be developed taking into account the agro-climatic-environmental implications. Transportation will have to be developed and roads built as development takes place. These should be undertaken on priority in accordance with an appropriate modernization policy because if these activities are undertaken after the construction of dams, erosion will seriously reduce the storage potential of the region. The highest priority has also to be laid on watershed management and afforestation. Sectoral activity in the area of water-energy resources has to be planned in the context of a long-term modernization policy and a techno-economic developmental programme. Of course consistency of resource-allocation in different sectors will have to be borne in mind.

The Vindhya region is also mountainous. Similar considerations of watershed management and afforestation apply but the problem is not so acute. Secondly, the region provides excellent storage facilities for dams but the water availability is correspondingly limited. The implication of this aspect will be discussed later.

In the plains the physiographic-agroclimatic-resources and base conditions are quite different. Agriculture has a tremendous potential for employment generation and economic development. Of the several inputs required for this transformation

Table 4. Salient water land and population statistics of Ganga basin

Sl. No.	Sub basin	Land				Water				
		Catchment area (inside India)	Culturable area (% of 1)	Net sown area (% of 2)	Cropping intensity	Precipitation	Evaporation	Annual runoff	Surface runoff	Annual ground water recharge
		m. ha	%	%	%	cm	cm	m hm	m hm	m hm
		1	2	3	4	5	6	7	7a.	8
1	Main Ganga (including Ram Ganga)	13.98	64.1	86.9	132	128	175	6.12	1.33	3.0
2	Chambal	13.95	72.6	64.4	110	79	275	2.43	1.80	1.24
3	Yamuna	22.68	73.8	77.8	125	87	260	6.56	1.43	3.05
4	Tons, Karamnasa & others between Yamuna & Son	2.86	66.3	77.9	131	106	225	1.41	1.04	0.47
5	Gomati, Ghagra & others between them	10.11	76.0	84.7	131	108	225	12.28	2.66	1.89
6	Son	7.13	50.5	60.4	121	139	180	4.23	3.13	1.09
7	Gandak and other left bank tributaries	5.73	76.4	87.7	137	154	180	17.47	3.77	1.36
	Right bank tributaries east of Son	9.71	69.3	69.2	117	130	175	4.51	3.34	2.52
	Total	86.15	68.6	76.0	125.5	116.39	211.8	55.01	18.50	14.62

dependable and adequate water supplies are most important. The possible technologic options are described by Chaturvedi (1985). The choice of technology should be based on detailed analysis but the following may guide the analysis.

Provision of water through river diversion is most economical for irrigation and has, therefore, been given priority in the past, but there is a certain limit over which the low flows cannot be reduced. Secondly, river-diversion based surface flows cannot give assured supplies. The region is rich in groundwater which can be readily exploited by the people, individually and collectively. Conjunctive surface and groundwater is more advantageous technologically and economically, and should be given the highest emphasis. Possibly, both development and distribution are done through cooperatives. Detailed systems analysis is required to identify the specification of appropriate capacities of surface and groundwater timing and trajectory, cropping pattern, organisation and operation of the system.

Emphasis in the past has been on flow diversions limited to low flows. Recently, canals with capacities to cater for kharif irrigation have been developed. This is attractive, because it provides for irrigation from groundwater recharge. Appropriate design will again require detailed analysis and groundwater dynamics modelling.

Utilizable		Utilized % of utilizable		People		Unit figures					
Surface runoff (% of 7)	Ground water (% of 7)	Surface (% of 9)	Ground water (% of 10)	Total utilized % of utilizable	Population	% of total population	Density/km ²	Culturable area/capita	Water/capita	Water/culturable land	% gross sown area irrigated
%	%	%	%	%	m	%	No/km ²	ha	m ³	%	
9	10	11	12	13	14	15	16	17	18	19	20
21.7	35.1	80.0	37.2	74.0	49.69	9.25	353	0.18	1830	101.80	18.3
74.2	35.8	46.1	64.0	52.0	15.35	2.91	110	0.66	2400	36.15	13.3
21.8	33.7	109.2	43.0	70.0	45.66	8.60	201	0.37	2100	57.25	23.6
73.8	26.5	36.5	29.5	35.10	6.83	1.37	239	0.28	2750	99.0	25.0
21.9	12.0	80.0	89.5	80.9	36.29	6.35	259	0.21	3910	184.3	26.1
74.0	18.9	32.85	10.0	29.5	7.88	1.57	111	0.45	6750	148.0	15.7
21.5	5.9	69.04	11.0	56.6	26.22	4.85	457	0.17	7200	431.0	9.0
74.3	38.7	85.0	9.2	60.0	33.27	6.30	342	0.20	2100	104.60	37.1
33.6	19.3	71.0	39.4	59.1	221.29	41.20	259	0.32	3630	145.26	21.0

We have emphasized conjunctive surface and groundwater development, but since surface water resources have already been considerably developed the focus will be on groundwater development along with modernization of the existing systems. Groundwater development represents the so-called 'divisible technology' and is very attractive for the development and diffusion of the culture of technology. It could provide employment in construction as well as through intensive irrigation, leading to the most productive agriculture and the highest possible cropping intensity.

There is a serious problem of energy scarcity as electrical energy supplies have not been developed adequately and diesel is going to be in increasingly short supply. There is thus a case for urgently resolving the energy problem through a scientific energy policy. On an *ad hoc* basis we may plan on development through diesel tubewells.

Groundwater is a major user of energy and surface water is a rich source of energy through hydroelectric generation. There is thus a strong case for conjunctive surface-groundwater and energy development.

In surface water resources development, the focus has been entirely on diversion of the low flows of the major rivers. Mostly, the diversion site has been the mountain foothills and the diverted flows basically represent the low flows of the Himalayan

Table 5. Developmental programme

Phase	Alluvial plains	Himalayan region	Vindhyan region
A. 1st five years	<ol style="list-style-type: none"> 1. Intensive groundwater development through energised/diesel pump sets for 100% irrigation intensity 2. Development and modernisation of existing systems for conjunctive water energy development with kharif channels 3. Development and modernization of water distribution and field management such as efficient water use, land levelling and environmental development. 4. Watershed development for flood mitigation, groundwater recharge and soil conservation with development of minor rivers and streams. 	<ol style="list-style-type: none"> 1. Complete road network 2. Intensive water-shed development 3. Start storage projects, hopefully in Nepal as well 	<ol style="list-style-type: none"> 1. Start development of storage projects with provision for additional storage from annual pumped storage schemes and develop surface and groundwater irrigation 2. Start modernization as in 2 of plains 3. Environmental management
B. 2nd five years	<ol style="list-style-type: none"> 1. Increasingly energise A.1 2. Complete A. 2 3. Continue A. 3 4. Continue A. 4 	<ol style="list-style-type: none"> 1. Continue A. 2 2. Continue A. 3 	<ol style="list-style-type: none"> 1. Continue A. 1 2. Continue A. 2 3. Continue A. 3
C. 3rd five years	<ol style="list-style-type: none"> 1. Complete B. 1 and continue B. 3 and B. 4 	<ol style="list-style-type: none"> 1. Complete A. 2 2. Continue A. 3 	<ol style="list-style-type: none"> 1. Complete A. 2 and A. 3 2. Continue A. 1 3. Start transfer part of annual pump storage projects
D. Next 15 years	<ol style="list-style-type: none"> 1. Continue increasing efficiency of water use and environmental management <i>ie</i> B. 3 and B. 4 	<ol style="list-style-type: none"> 1. Complete all development and continue increasing environmental efficiency 	<ol style="list-style-type: none"> 1. Complete C. 3 and continue increasing environmental and resources efficiency

catchment region. The flows of the vast catchment of the plains are carried down in the numerous minor streams. Some, which may even be quite large according to international standards, like the Gomti, have been neglected. The runoff from the plain area, which is a major component of the total runoff, thus causes floods and is wasted.

The focus should be on land-water dynamics, attempting to develop the land by organic as well as structured means, so that floods and soil erosion are mitigated and water resources are developed through groundwater recharge and storage. Possible technologies are bunding, appropriate watershed management through cropping practices and afforestation, storage through check dams to prevent submergence, and to increase water detention, additional groundwater recharge by heavy pumping before monsoons. The approach is so far conceptual, but its feasibility warrants detailed study. In this connection the concept of the Ganges-Water Machine along perennial and non-perennial rivers and forced groundwater recharge may also be mentioned (Chaturvedi 1981a). For convenience, we may consider the above issue under two heads (a) development of minor rivers and streams for flood mitigation, groundwater recharge and irrigation and (b) watershed development for flood mitigation, groundwater recharge and soil conservation.

In groundwater development the question arises about the annual quantum to be developed. Under the natural land-water dynamics a certain utilizable potential known as safe yield is estimated. With the increasing perturbation of land water, a long-term groundwater developmental policy has to be developed, which may lead to mining in the short run. Mining may have repercussions on the yield of shallow wells and surface discharge and, therefore, land-water dynamics has to be modelled to identify an appropriate dynamics policy of groundwater development.

The foregoing discussion relates to macrolevel development and distribution. An equally important aspect is field-level distribution and use. In the past, due to certain colonial-bureaucratic reasons, use of water and development of land was left almost entirely to the farmers. It is well known that our water use is most wasteful, and integral lining of water courses, land levelling and associated technological activities at the field level have to be carried out. Technology is, however, more than development of projects. It is a process of social change and has to embrace adequate institutional and motivational mechanisms. Field-level development has to be integrated with rural development and can be a major source of employment generation and promotion of modernization. Workshops can be developed in mofussil towns for the construction of pumpsets and strainers. Drilling of tubewells and canal lining can be developed through rural entrepreneurship. Command area development and water management activities have been started but they have to be considerably extended and strengthened.

Our concern is primarily the development of water resources for irrigation. To a certain extent, this will contribute to flow reduction although specific conventional and non-conventional technological alternatives will have to be developed as flood damage is a serious matter in this region. Besides loss of life and property, agricultural development is seriously affected by floods in these regions.

We have developed five conceptual interacting technological sets: (i) development of resources in the mountain zones, (ii) modernization of existing systems for conjunctive water-energy development with kharif channels, (iii) development of minor rivers and streams for flood mitigation, groundwater recharge and irrigation, (iv) watershed development for flood mitigation, groundwater recharge and soil conservation and (v) field level modernisation. A long-term regional water resources system plan has to

be developed to identify the optimal portfolio of projects so that land-water development is obtained over optimal time. This exercise has to be carried out for each planning region to arrive at the optimal plan for the Ganges basin. Water resources availability continuously increases from west to east, but it is almost equally unreliable all over. There should thus be increasing emphasis on groundwater development as we move eastward. In fact, the problem increasingly becomes one of managing excess monsoon water through groundwater recharge and drainage without disrupting the local terrain. To this extent, the problem in Bangladesh is essentially hydraulic rather than hydrologic, as discussed later.

The north-east, the Barak and the deltaic regions have certain specific physiographic-hydrologic characteristics although as discussed earlier their development is integrally linked with the rest of the region. The problems of the north-east region are similar to the Himalayan region, but increasing attention has to be paid to integrated flood management along with hydroelectric generation. The problem of the Barak region is essentially a problem of flood management. The problem of the deltaic region is essentially a hydraulic problem as mentioned earlier.

One of the important aspects of water resources development is the generation of electricity. Although this is generally accepted, several policy issues and outstanding potential technological options have been completely missed in the development activities so far, as discussed below.

The storage-hydroelectric potential in the Himalayas is large and very economical. There is also a very large run-of-river hydroelectric potential in the Himalayan region. The Vindhya region also provides considerable potential, which is also exceedingly economical for two reasons—the storage/height ratio is one of the highest in the world and the foundation conditions are faultless.

The point to be emphasized is that first, the storage and run-of-river plants have to be developed jointly so that, through suitable operating policies, optimal capacities in each plant and in the system are obtained. Implicit is integrated planning of the total power sector (Chaturvedi 1981b, 1985). Even then, if there is surplus potential of secondary energy, it can be converted into primary energy, by using the secondary energy to pump the large monsoon surface flows for storage in the Vindhya region, either in the Ganga basin or in the adjoining Narmada basin. In principle, this is a novel annual pumped-storage scheme for both hydro-energy and resource conservation.

Implicit in these suggestions is integrated water sector and power sector planning. Besides the interlinkage of water and energy sector for supply, there is an important supply-demand interlinkage. Groundwater development may account for a major portion of electric energy demand (as much as 20 to 60% at different stages of development) while water supplies may be met either from surface or groundwater sources. An integrated surface-groundwater-energy planning as discussed under systems planning can contribute to significant economics.

Further issues relate to environment and navigation. From both considerations, minimum flows have to be maintained. It is again a matter of economic analysis, but it can definitely be said that the largescale low-flow diversions of the past may be unacceptable both economically and environmentally. It is interesting to note that when the first major canal of the region, the Ganga Canal, was contemplated it was considered mandatory to ensure that navigation did not suffer and therefore the canal was joined again with the Ganga at Kanpur (Cautley 1860). The importance of navigation diminished not only because more attractive technological options like the

railways or the roads developed, but also because economic development did not take place. River transport would be the most attractive means of transportation for the increasing agricultural and other bulky commodities that constitute about 80–90% of the goods traffic. It is often not realized that only about 4 meters of draft is needed for river transport and even 2 m would be enough. River transport should be complementary to other modal choices instead of being competitive, and integrated water, energy and transportation systems planning can lead to significant economies.

To consider the complex, interlinked as well as competing issues, involving large variations in technological choices and capacities—spatially and temporally, for multipurpose use, integrated systems planning is mandatory. Before identifying a programme of development, it is necessary to consider the international issues involved in the development of the Greater Ganga Basin. These have been discussed elsewhere (Chaturvedi 1985).

In the dispute with Bangladesh, the simple fact that the development of Nepal is crucial for the development of the Ganga basin and is in the interest of both countries has been lost sight of. Highest priority has to be given to the integrated development of water resources in the region irrespective of whether the sites are located in Nepal or India.

3.3 Development programme

The developmental policy for the water resources of the basin may now be summarised and a tentative schedule may be postulated, as shown in table 5. In the schedule, our concern has been mainly development of water supply for irrigation. We have concentrated on the three main physiographic regions. Similar policy schedules can be drawn up for energy and navigation and then integrated-hierarchical systems planning can be carried out as discussed later. It will be seen that the schedule depends primarily on management potential, the internal and international political and financial policy of giving credit for development rather than on technological considerations. We have postulated a time schedule from our experience of developing the water resources of this region over the last 30 years, considering only management and technological factors and not considering the financial or political factors as a constraint. If the latter are uncongenial, it can only slow down the development and make it slightly less economical. We believe that if earnest efforts are made, in 5 years almost complete and dependable irrigation can be provided in almost the entire region. It can be made more and more economical with full development in 30 years of irrigation, flood control, hydroelectric energy and the environment. This may be contrasted with the contemplated attainment of about an additional 5% irrigation at a crawling rate. Of course the proposed schedule, will require a revolution in technological management and institutions, and a high order of political and social commitment.

The conceptual policy issues developed so far have to be quantified through systems studies.

4. Conclusion

As stated at the outset, the Greater Ganga basin is one of the world's great natural resources with an outstanding potential for hydroelectric energy and agricultural production. Neglect over the last few centuries has led to serious environmental

degradation and human depravation, leading to one of the most intense concentrations of population. The natural resources and environmental development offers an outstanding opportunity for economic development and employment generation. It is a very complex problem, making a systems approach mandatory.

For the successful application of technology, institutional modernization is a precondition. Concepts and approaches developed in colonial days still reign supreme; these have to be jettisoned first and foremost.

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