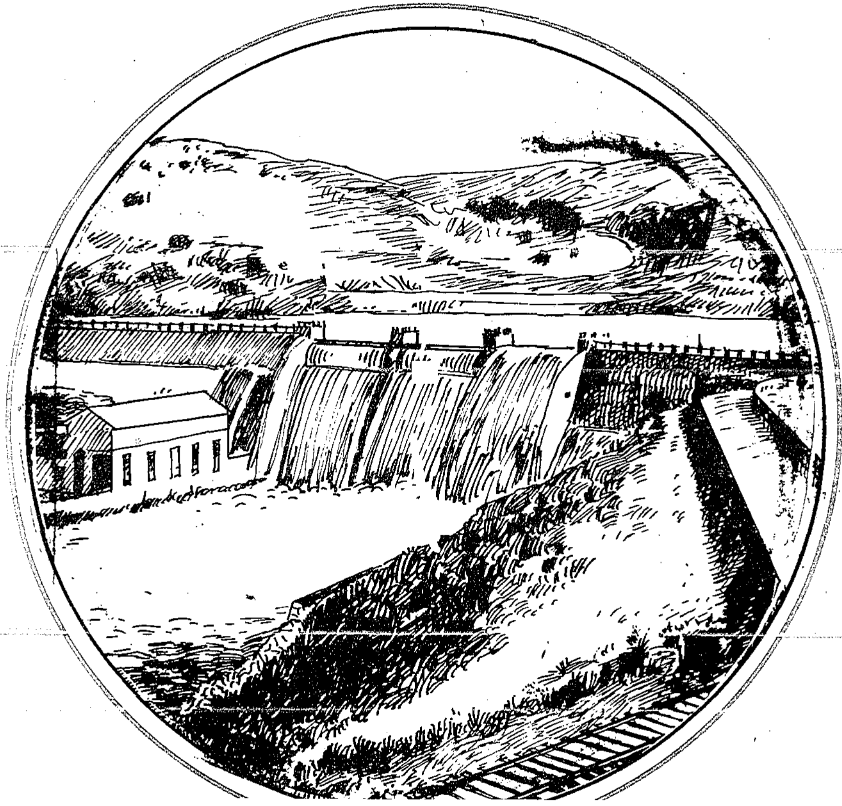
IRRIGATION ENGINEERING AND HYDRAULIC STRUCTURES

SANTOSH KUMAR GARG



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IRRIGATION ENGINEERING AND HYDRAULIC STRUCTURES

For

[Civil Engineering degree students ; AMIE (Section B) Exams-New Scheme ; U.P.S.C. and Other State Service Competitions ; and For Professionals]

(Containing updated Questions of Civil Services and Engineering Services Competitions)

By

Santosh Kumar Garg

B.Sc. Engg. (Civil)

First Class First (Delhi University)

Superintending Engineer

Flood Control and Irrigation Deptt.

Govt. of N.C.T. of Delhi

Member Indian Water Resources Society

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DEDICATION

This book is dedicated to the memory of those unknown workers who have lost their lives in the execution of world's gigantic water resources projects.

FOREWORD

I feel both pleasure and pride in being called upon to write the Foreword to this book. This is Shri Garg's second book and he has fully justified the promise shown by his first one—"Water Resources and Hydrology". This is not surprising as he has had a brilliant academic career culminating in **First Class First** Degree in Civil Engineering from Delhi University.

Shri Garg has fully covered the subject of irrigation engineering and the design of hydraulic structures connected with irrigation. The book is expected to be specially useful for students of engineering colleges, and those preparing for the A.M.I.E. Examinations in their spare time. It will also be useful for practising engineers concerned with irrigation engineering. The language has been kept simple, making the book extremely readable.

I wish the author all success in this as well as in future efforts in this direction.

Pritam Singh
Formerly, Chairman,
Central Water Commission,
Govt. of India, New Delhi.

New Delhi

PREFACE TO THE NINETEENTH EDITION

The first edition of this popular book was published in August 1976. At that time, the book contained 25 Chapters with 963 standard sized pages, as compared with the 33 chapters and 1572 large sized pages in this 19th edition. Never, even in his dreams, the author thought at that time, that this book will become the 'darling' of the students and professionals dealing in irrigation and water resources subjects, and shall be followed by students from almost every engineering college of the country, including the prestigious IIT's, D.C.E., Regional Engineering and other Colleges.

The growing popularity of the book continued to push up its sales, encouraging the author to go on revising and enlarging the text, from edition after edition. So far, 18 editions of this book have been sold out with 1,06,600 printed copies, and the present edition is its 19th one, whose 4400 copies are being allowed to be printed.

The continuous revision, edition after edition, had infact caused the book to become too bulky to be handled with convenience. There were suggestions for bifurcating the book into two volumes ; but again there were suggestions for not doing so. The Publishers, therefore, decided to increase the size of the pages used in the book in order to reduce their numbers. This change did help in reducing the thickness of this popular book from about 1900 pages to about 1500 pages.

The M.K.S. units earlier adopted in the book have also been changed to the **S.I. Units**, since these modern international units have by now, gained enough popularity in our country. Various other changes have also been affected at several places in the text, as to make some of the explanations easier and more definite. The question banks of the *Engineering Services* as well as of the *Civil Services* Competitions have also been updated, up to the year 2004. Similar exercise has been affected in respect of the Objective Questions of the AMIE Examinations.

Modern equations developed for the design of irrigation channels in India on the basis of Kennedy's and Kutter's equations have been given, which will help in obtaining more definite and quick solutions for the optimal designs of alluvial canals, besides developing computer programming for their designs. Articles on estimating sediment load likely to enter a reservoir, and reservoir sedimentation studies on existing reservoirs have also been included. In the present 19th edition, thorough revision has been carried out in the first 8 chapters of the book to provide simpler & easier explanations, besides updating the various datas, as to make the book more & more useful to the students, teachers & professionals.

Acknowledgements. In going through the nineteen editions of the book, the author has accumulated an enormous amount of intellectual debts from students and teachers over the years, who had written to him about their satisfaction with the book and extended suggestions for the improvement of its various editions. If the book today, is so strikingly popular, they all deserve much of the credit. The author certainly wants them to know of his gratitudes and openness to further suggestions, and is hence enlisting their names below :

Sh. R. Palnivelu of Government College Coimbatore ; *Sh. M.P. Raghavan* of Government College Salem ; *Sh R. Chandrasekharan* and *Dr. A. Achutyanan* of Regional Engineer-

ing College Calicut ; *Sh. P. Sen,* the then Chief Engineer in Central Water Commission ; *Sh. Punya Prasad Khanal,* an old student of Jaipur Engineering College ; *Sh. V.K. Raju,* Asstt engineer in I & P.D. Deptt. Govt of Andhra Pradesh ; *Mr K. Chandrasekharan Nair,* Asstt Professor of Regional Engineering College Calicut ; *Sh. Mohammad S. Mian,* Head of Water Engg. Natural Resources Development College Lusaka ; *Sh. Biswaroop Ghosh,* an Ex. Student of Bengal Engineering College Calcutta ; *Sh. Soumenda Ghosh,* a student of Burla Engineering College, Sambalpur (Orissa) ; *Sh. K.R. Ganesh Hegde,* Sh. L.V.N. *Malleswara Rao,* Lecturer in College of Engineering Visakhapatnam (Andhra Pradesh) ; *Mr A.L. Lalani,* Lecturer in L.K. College Morbi (Gujarat) ; *Mr. Sasank Sekhar Hota* — Lecturer in Barapada School of Engineering and Technology Balasore (Orissa) ; *Mr. STATES KABASIA* from Nairobi (Kenya) ; *Mr. Shri Ram,* Lecturer in Madan Mohan Malviya Engineering College, Gorakhpur (UP) ; *Mr. Girma G. Hawariat from Harar Ethopia ; Mr. K.R. Thamhane, Mr. Liladhar Roratkar* and *Mr. R.S. Mirje* all students from Govt. College of Engineering Shivaji Nagar (Pune) ; *Professor Arun Kumar* from Delhi College of Engineering ; *Mr. Bishoke Sil* of Irrigation and Waterways Directorate of Govt of West Bengal ; Sh. Vijay Singh, a final year student of H.B.T.I., Kanpur ; Sh. Avadh Pratap Singh, a final year student of MITS Gwalior, etc.

The author further wants to record his highest degree of gratitudes to **Prof. M.D. Pol** of Aurangabad for sending & suggesting modifications at several places in the text, based on which, large scale changes have been made in this 19th edition.

The author also wish to record his heartiest thanks and gratitudes towards **Rajeshwari,** his beloved wife, without whose untiring efforts and tolerance, he would never had been able to write and publish even the first edition of this book at the young age of 30 years.

The author also takes this opportunity to express his reverred gratitudes towards **Prof. Dr. R. Narayanan**, the then Head of the Civil Engineering Department at Delhi College of Engg. (now emirtus Professor at IIT, Chennai), who encouraged him to take up writing work, when he was highly depressed in life, at its prime stage.

New Delhi
August 11, 2005

Santosh Kumar Garg
3A/2 WEA, Sat Nagar
Karol Bagh,
New Delhi - 110005
Tel. No. (011)2576 8304
Mobile for SMS : (+91)9810079973

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Introduction to the Subject

Water is the greatest resource of humanity. It not only helps in survival but also helps in making life comfortable and luxurious. Besides various other uses of water, the largest use of water in the world is made for irrigating lands. *Irrigation, infact, is nothing but "a continuous and a reliable water supply to the different crops in accordance with their different needs".* When sufficient and timely water does not become available to the crops, the crops fade away, resulting in lesser crop yield, consequently creating famines and disasters. Irrigation can, thus, save us from such disasters.

The fact that the provision of irrigation facilities can enhance the yield of our crops by a large extent, can be found from the fact that in Madhya Pradesh State, the crops yield is only 40% more than that in Punjab State, while the cropped area in Madhya Pradesh is about 3 times that in Punjab. The reason is that the gross area under irrigation in Madhya Pradesh is only about 30% as compared to about 91% in Punjab. On an average, in India, the yield from irrigated land is about 2.5 tonnes/hectare ; while that from unirrigated land is about 0.5 tonne/hectare.

It can, therefore, be concluded that if full irrigation facilities are not developed, the production of food grains shall be reduced, as the yield of different crops will be reduced. And if sufficient food grains are not available, the people will remain hungry, leading to all round chaoes, looting and economical destruction of the country, hampering its progress & prosperity. In the light of these facts, it can be easily emphasised that 'irrigation' is inevitable, at least in every tropical* or subtropical* country like India.

The adoption of irrigation practice in our country is not a new thing, as it appears to be, because sufficient proofs are available in Indian history, which confirm that irrigation was being practised not only during the periods of Mughals and Aryans, but even during the periods of Pandavas (about 3150 B.C.). Besides the various ancient books which confirm the above facts, there are ruins of various ancient irrigation works, a few of which are till today existing. For example, the most famous old irrigation work, which is functioning even today, is the **'Grand Anicut'** which was built by Chola rulers in the first century A.C. on the Cauvery river. At the site of the Anicut, the river divides into two branches ; the right branch, which is a lower one, is called *Coleroon*. The Grand Anicut must have been constructed to prevent the flow of water into this low levelled branch (Coleroon) to ensure supplies into Cauvery river, so as to irrigate the fertile Tanjavoor delta land. The importance of irrigation was well recongnised by the Mughal rulers, and as such, *the Western Yamuna Canal* which was built by Ferozshah Tughlaq in the year 1355, was got renovated by Emperor Akbar for irrigating lands in the Hissar district (now in Haryana State) in the year 1568. *The Eastern Yamuna Canal*, was also built by Emperor Mohammad Shah Abdali (1712–1748).

***Tropical climate** is hot all the year with much rain. **Sub-tropical climate** is the one in which the heat is under control with less hot summers and less cool winters. **Temperate climate** is represented by warm summers, cool winters, with rain falling evenly throughout the year, or there may be rainy and dry seasons.

During the British regime, starting from the year 1818, considerable attention was paid towads utilising the surface water for irrigation, so as to overcome the frequent famines that used to occur in our country. The first public work of Britishers was the re-renovation of the historic Western Yamuna Canal, which used to provide water to Delhi and the neighbouring areas, but had fallen into disuse during the long period of turmoil. This activity was ofcourse undertaken from considerations of demonstrating the new rule of the *East India Company*, as the emerging rulers of India. It was very much appreciated by the people, and more than that, it was found to be financially very remunerative, yielding a return of 14% in 1847. The Eastern Yamuna Canal built by Emperor Mohammad Shah Abdali, was also soon repaired and renovated in the year 1830.

The 1040 km long *Upper Ganga Canal System*, the longest in the world, was also planned, executed and completed in 1854 for carrying a discharge of 191 cumecs to irrigate 0.62 Mha of land, at a cost of Rs. 2.15 million, *about half of the cost of construction of Taj Mahal.* It is still one of the longest canal systems in the world. Modern engineering in India infact, started from that date, when the first Diploma engineering college was also started at Roorkee in 1846, to provide supporting junior staff for the construction of upper Ganga Canal system. Considerable development of irrigation subsequently took place in the Indus basin* also.

Besides the construction of several irrigation canal projects, such as the *Upper Ganga Canal, the Sirhind Canal, the Lower Chenab Canal* in the Ganga and Indus basins, a lot of work was also done in South India on various rivers, such as *Cauvery, Godavari* and *Krishna.* Construction was taken up and completed on *Khadakvasla dam and its link canals,* the *Periyar dam and its link canals,* etc. It may, however, be stated that the primary emphasis during British regime was on developing extensive irrigation through surface water canals. (The storage irrigation was not executed to any appreciable extent). All the low season flows after monsoon floods were diverted for irrigation for winter (Ravi) season crops, and not to contribute to high yields. The diversion arrangements, when first developed, were also temporary, which used to wash away during the next monsoon floods, and had to be constructed again every year. The **extensive irrigation** (covering a large command area though irrigating only a part of it) was a preferred strategy to overcome the frequent famines over large commands, besides preventing water-logging, since drainage was not developed to keep the costs down. Thus, only about 30% of the canal command was irrigated. The process ended with the delivery of 1 cusec (0.0283 m^3/s) of water at the farm head, and further use and management of water was left to the farmers. There was little agriculture extension, and only three waterings were scheduled. *As spring season approached, river flows dwindled and since there was no upstream storage, the supplies became inadequate. The irrigation for summer (Kharif) period agriculture was not developed. Very few storage and virtually no ground water development was undertaken. There was little hydro-electric development except for some run-of-canal works on Ganga Canal, that too developed just prior to independence. There was no concern for development of drinking water and sanitation facilities, much less flood mitigation. Environmental concerns were totally neglected, as almost all the lean season flows were diverted for irrigation, and the rivers in downstream were left almost bone dry. In the downstream reaches, even the regenerated ground water flows were not allowed to flow freely, and were again diverted for irrigation, again leaving the rivers dry.* But then, it was perhaps

*The *Indus river* having five famous tributaries—the *Satluj*, the *Beas*, the *Ravi*, the *Chenab*, and the *Jhelum* do constitute the Indus basin.

the need of the hour, as it was necessary to stabilise agriculture and mitigate famines. The large scale efforts made by the Britishers resulted in providing irrigation to 28.2 Mha of area, out of total net cultivated area of 116.8 Mha, thus bringing about 24% of the net cultivated area under irrigation. In order to develop irrigation in the country, the first irrigation commission* was even appointed in 1901, which submitted its report in 1903, based on which, large scale canal development works were undertaken, besides preparing blue prints of various important storage projects, including that of the Bhakra dam. Although in undivided India, about 24% of the countrys cropped area came under irrigation, yet with the unfortunate partition of the country, 31% of the country's irrigated area stood transferred to Pakistan, as against the transfer of only 18% of its population.

The independent India in the year 1947 was, thus, left high and dry with only 19% of its cropped area under irrigation ; whereas Pakistan at the time of its creation found 44% of its cropped area under irrigation.

The Indian Government of the independent India, at its very outset, was thus faced to face acute famines and food grain shortages, because most of the country's area was dependent upon natural rainfall, which proved highly unreliable and erratic. Large scale import of wheat from USA as soft term asistance under the famous PL-480 programme, did help the nation to overcome hunger, death and destruction at that time.

Large scale efforts were then made by the Indian Government under the prime ministership of our beloved leader Pt. Jawahar Lal Nehru, to develop and harness our vast water resources, so as to ensure collection of water during monsoons, and its subsequent use for irrigation during non-monsoon periods. **Several dam reservoirs**** were, therefore, planned and constructed across various rivers to store water during rainy season to reduce the fury of floods, and long **canal networks** constructed to move down the stored water during dry weather to the fields, to ensure irrigation supplies to the crops. Hydro-power development was also undertaken as a side-product.

The zeal shown in the construction of dams can be gauged by the mere fact that Pt. Jawahar Lal Nehru, the then Prime Minister of India, while inaugurating and dedicating the **Bhakra Dam** to the Nation on 22.10.1963, called it a "*New temple of resurgent India'* and '*Symbol of India's progress*'. The great Pt. Nehru gave a great impetus to the construction of such new temples, and did all what he could, for the execution of several multi-purpose projects, by investing huge funds at a time when money was badly required for other important sectors, like Eduction, Housing, Roads and Railways, Hospitals, etc.

With the construction of multipurpose dams, hydropower became available, which helped to develop tubewell irrigation in the country. This was an important change that took place from early 1960's, when rapid development of tube-wells took place. So much so that, at present, we are using ground water for irrigating about 51% of our gross irrigated area, as against irrigating 33% of the area in 1965-66. Whereas, although development of

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*The second irrigation commission was appointed in 1969, and it submitted its report in March 1972.

From less than 300 large dams existing at the beginning of planned development, the number of large dams constructed (excluding about 700 dams under construction) has gone upto about **3600, as to create **live storage capacity of 213 b.cum** on different rivers by the completed projects, and an additional 76 bcum shall be created by the ongoing projects. Projects to further create 108 bcum of live storage are also under consideration of the Govt. of India. Out of such a large number of dam reservoirs, CWC-GOI regularly monitors the storage position of 71 major reservoirs, which together account for a design storage of 113 bcum.

minor irrigation through the use of ground water did help in controlling water–logging in areas where canal irrigation did exist, yet it has resulted in abnormal fall in the ground water tables in several areas, where no attention has been paid to the ground water recharge. The lowered water-tables over vast areas of the country has resulted in making the available ground waters saline and contaminated with fluorides and arsenic, making them unfit for drinking and other domestic requirements*, for which they have largely been used, since olden days**.

Inspite of all such shortcomings and drawbacks, impressive achievements in developing and harnessing our water resources have been made after independence to create an irrigation potential of about 105 Mha (by end of 9th plan ; *i.e.,* March 2002), by incurring an expenditure of about Rs. 1,15,000 crores.

The plan wise investments made under irrigation section during 1951–2002 are reflected in table I.

Table I. Planwise Expenditure Incurred on Irrigation in India

S.No.	*Plan*	*Period*	*Expenditure Incurred (Rs. Crores) in*		
			Major and Medium Irr. Projects	*Minor Irr. Projects**	*Total*
1.	First Plan	1951–56	376	67	443
2.	Second Plan	1956–61	380	162	542
3.	Third Plan	1961–66	576	443	1,019
4.	Annual Plan	1966–69	430	561	991
5.	Fourth Plan	1969–74	1,242	1,173	2,415
6.	Fifth Plan	1974–78	2,516	1,410	3,926
7.	Annual Plan	1978–80	2,079	982	3,061
8.	Sixth Plan	1980–85	7,369	3,417	10,786
9.	Seventh Plan	1985–90	11,107	6,280	17,387
					41,000 (app.)
10.	Two annual Plans and 8th Plan	1990–97			27,000
11.	9th Plan	1997–02			47,000 crores
	Total upto 2001–02				1,15,000 crores

The planwise irrigation potential developed and utilised up to March 2002 (end of 9th plan) in India are shown in Table II. It can be seen from this table that the created irrigation potential has gone up from **22.61 Mha.** In 1951, to **105.33 Mha** by the end of IXth plan (March 02), against the ultimate irrigation potential of **140 Mha** from conventional inbasin storage techniques (Table III). Out of the total created potential of **105.33 Mha,** we have, however, utilised only **83.91 Mha** during the year 2001–02. This has resulted in irrigating about 45% of our total gross cropped area of 189 Mha, which has helped the

*Pl refer "Environmental Engg. Vol I—Water Supply Engineering" by the same author.

**Ground water still provides about 80% of the domestic water supply in rural areas, and about 50% of urban and industrial water requirements (Planning Commission, 1999).

country to achieve self sufficiency in food grains, the production of which has touched about 210 million tonnes (Mt) as against our present consumption of about 160. Mt for 1050 Million population at an average annual per capita consumption of about 150 kg/year. The actual 210 Mt production of food grains is found to be inconsonance with the theoretical production at our observed production rates of 2.5 t/ha for irrigated land, and 1.0 t/ha for unirrigated (rain-fed) land, for 65% of the cropped area growing food grain crops, as :

$$84 \text{ Mha} \times 0.65 \times 2.5 \text{ t/ha} + (189 - 84)\ 0.65 \times 1.0 \text{ t/ha} = \mathbf{205\ Mt.}$$

Table II. Planwise Position of Irrigation Potential Created and Utilised (Cumulative Figs. in Mha)

Plan	*Potential Created*					*Potential Utilised*				
	Major & Medium**	*Minor* Surface Water*	*Minor* Ground Water*	*Minor* Total*	*Total Major Medium Minor*	*Major & Medium*	*Minor Surface*	*Minor Ground*	*Minor Total*	*Total Major, Medium & Minor*
Preeplan upto 1951	9.71	6.40	6.50	12.90	22.61	9.71	6.40	6.50	12.90	22.61
Ist Plan (51-56)	12.19	6.43	7.63	14.06	26.25	10.99	6.43	7.63	14.06	25.05
II Plan (56-61)	14.33	6.45	8.28	14.73	29.06	13.05	6.45	8.28	14.73	27.78
III Plan (61-66)	16.57	6.48	10.52	17.00	33.57	15.17	6.48	10.52	17.00	32.18
Annual Plans (66–69)	18.10	6.51	12.51	19.02	37.12	16.75	6.51	12.51	19.02	35.77
IV Plan (69–74)	20.70	6.96	16.44	23.40	44.20	18.69	6.69	16.44	23.40	42.09
V Plan (74–78)	24.72	7.50	19.80	27.30	52.02	21.16	7.50	19.80	27.30	48.26
Annual Plans (78–80)	26.61	8.00	22.00	30.00	56.61	22.65	8.00	22.00	30.00	52.65
VI Plan (80–85) (Reapprised)	27.70	9.70	27.82	37.52	65.22	23.57	9.01	26.24	35.25	58.82
VII Plan (85–90)	29.92	10.99	36.62	46.61	76.53	25.47	9.97	33.15	43.12	68.59
Annual Plans (90–92)	30.74	11.46	38.89	50.35	81.09	26.32	10.29	36.25	46.54	72.86
VIII Plan (92–97)	32.95	12.09	50.29	62.48	95.43	28.41	8.20	40.09	48.29	80.37
IX Plan (1997–2002)	37.05	13.67	54.61	68.29	**105.33**	31.01	9.05	43.85	52.90	**83.91**

The impressive development of an irrigation potential of about 105 Mha by end of 9th plan has been achieved by execution of about 1232 major, medium and ERM**, irrigation projects, besides a huge number of minor irrigation projects. In addition to this, by the end of IXth plan, 468 (162 Major, 221 Medium & 85 ERM) projects with balance cost of Rs. 863.77 crores have spilled over to the Xth plan. Moreover, 268 new Major, Medium and ERM projects are proposed to be taken up in Xth plan. In all, an additional irrigation potential of 17.91 Mha is likely to be created during the Xth plan ; and out of this,

* Projects having CCA upto 2000 ha are classified as *minor* irrigation projects. Those having CCA of more than 10,000 ha are classified as *major* projects ; and others between 2000 to 10,000 hectares are *medium* proejcts.

**Extension , Renovation and Modernisation (ERM) projects.

Table III : Statewise Ultimate Irrigation Potential

S.No.	*Name of State*	*From Major and Medium Surface Water Schemes*	*From Minor Irrigation*			*Total (Major, Medium and Minor)*
			Surface Water	*Ground Water*	*Total Minor*	
1.	Andhra Pradesh	5.000	2.300	3.960	6.260	11.260
2.	Arunachal Pradesh	0.00	0.150	0.018	0.168	0.168
3.	Assam	0.970	1.000	0.900	1.900	2.870
4.	Bihar	5.224	1.547	4.117	5.664	10.888
5.	Chhatisgarh	1.147	0.081	0.490	0.571	1.718
6.	Goa	0.062	0.025	0.029	0.054	0.116
7.	Gujarat	3.000	0.347	2.756	3.103	6.103
8.	Haryana	3.000	0.050	1.462	1.512	4.512
9.	Himachal Pradesh	0.050	0.235	0.068	0.303	0.353
10.	Jharkhand	1.277	0.353	0.830	1.183	2.460
11.	Jammu & Kashmir	0.250	0.400	0.708	1.108	1.358
12.	Karnataka	2.500	0.900	2.574	3.474	5.974
13.	Kerala	1.000	0.800	0.879	1.679	2.679
14.	Madhya Pradesh	4.853	2.119	9.242	11.361	16.214
15.	Maharashtra	4.100	1.200	3.652	4.852	8.952
16.	Manipur	0.135	0.100	0.369	0.469	0.604
17.	Meghalaya	0.020	0.085	0.063	0.148	0.168
18.	Mizoram	0.000	0.065	0.005	0.070	0.070
19.	Nagaland	0.010	0.070	0.005	0.075	0.085
20.	Orissa	3.600	1.000	4.203	5.203	8.803
21.	Punjab	3.000	0.050	2.917	2.967	5.967
22.	Rajasthan	2.750	0.600	1.778	2.378	5.128
23.	Sikkim	0.020	0.050	0.000	0.050	0.070
24.	Tamil Nadu	1.500	1.200	2.832	4.032	5.532
25.	Tripura	0.100	0.100	0.081	0.181	0.281
26.	Uttar Pradesh	12.154	1.186	16.295	17.481	29.635
27.	Uttaranchal	0.346	0.014	0.504	0.518	0.864
28.	West Bengal	2.3000	1.300	3.318	4.618	6.918
29.	Total UTs	0.098	0.035	0.116	0.151	0.249
	Grand Total (All India)	58.465 ; Say **58.46 Mha**	**17.372**	64.171	81.543 Say **81.54 Mha**	140.008 ; Say **140 Mha**

9.92 Mha is likely to be created through Major and Medium surface irrigation schemes, which are more important than ground water schemes in present days, when ground waters are already over-exploited in various States.

As a matter of fact, a large number of river valley projects have spilled over from plan to plan, mainly because of financial constraints faced by the state Governments. Due to this, despite, huge investments having already been made on thse projects, the country is not able to derive the desired benefits There, in fact, existed 171 Major, 859 Medium and 72 ERM ongoing irrigation projects in the country pendng at various stages of construction by the end of VIIIth plan (*i.e.* end of year 1996–97) with spill over cost of Rs. 75,690 crores. This was a matter a grave concern for the Union Government, and hence measures for expeditious completion of some of the projects which were in advanced stage of completion were initiated by launching an *Accelerated Irrigation Benefits Programme (AIBP)* during 1996-97, under which central financial assistance is being made available to the States by creating special category States (including HP, J & K, Uttranchal, Sikkim and North-eastern States) and General Category States (including all other States except those included in the special category). A *Fast Track Programme* for projects which can be completed in one year has also been started under this scheme wef Feb. 2002. The central financial assistance in this programme include 70% loan and 30% grant for General category States ; and 10% loan and 90% grant for Special category States. For projects which donot come within the preview of Fast Track Programme, an incentive for conversion of loan to grant criteria is provided, if projects are completed on schedule. This extension of central financial assistance to the State Govts. have resulted in disbursement of about Rs. 14,670 crores from 1996-97 to 2003-04, and has resulted in giving a great impetus to the early completion of irrigation projects. All such serious efforts made by the Govt. of India has already resulted in creation of total irrigation potential to *about 105 Mha,* as against the figure of about 95 Mha at the end of 8th plan.

The statewise irrigation potential created and utilised in the country upto the year 2001-02 (*i.e.* as on 31.3.2002) are given in table IV.

The net and gross cropped areas as well as net & gross irrigated areas in various States of India are shown in table V, along with computing annual intensities of irrigation in Col. (9) and plotted in Fig. I. The data used here is of year 1999–2000. The extent of the use of the different sources of water for irrigation is also given in table VI.

Inspite of such large scale efforts made by India, in having generated an irrigation potential of about 105 Mha, we are still, much short of our requirement, since our entire gross cropped area of about 189 M.ha needs irrigation water, which also needs to be considerably increased by producing more than one crop on larger portion of cropped area by increasing cropping intensity to about 150% from the present value of about 134%*.

As can be seen from Col. (4) of Table V, the total cultivated area in the country is about 184 Mha, which is about 60% of the total geographical area of about 329 Mha. The four States of Madhya Pradesh, Maharashtra, Rajasthan and U.P. account for almost 50% of the total cultivated area. For the country as a whole, the gross sown area (189 Mha) exceeds the net sown area (141 Mha) by about 34%.

As a matter of fact, during the last two decades, the net cropped area has not changed much, fluctuating in a narrow range between 140 to 143 Mha ; while the Gross cropped area has increased from 166 Mha to 189 Mha. The cropping intensity has, thus, increased from 118% in 1979 to about 134% in 2002. However, the area under *food grain crops* (like

*Cropping intensity $= \dfrac{\text{Gross cropped area}}{\text{Net cropped area}} = \dfrac{189.24 \text{ Mha}}{141.23 \text{ Mha}} = 134\%.$

Table IV : Ultimate, Created and Utilised Statewise Irrigation Potential in India upto End of 9th Plan, i.e. year 2001-02.

S.No.	State	Ultimate Irrigation potential Mha from major, medium & minor surface as well as Ground water	Irrigation potential created (PC) in Mha			Irrigation potential utilised (PU) in Mha		
			Major and medium surface irrigation	Minor irrigation (total) i/e surface Tanks as well as ground water irrigation	total	Major and medium surface irrigation	Minor irrigation (total) surface Tanks as well as ground water irrigation	Total
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1.	Andhra Pradesh	11.260	3.303	5.437	8.740	3.052	3.677	6.729
2.	Arunachal Pradesh	0.168	0.000	0.076	0.076	0.000	0.046	0.046
3.	Assam	2.870	0.244	0.890	1.134	0.174	0.587	0.761
4.	Bihar	10.888	2.680	4.743	7.423	1.715	3.074	4.789
5.	Chhatisgarh	1.718	0.923	0.001	0.924	0.761	0.000	0.761
6.	Goa	0.116	0.021	0.021	0.042	0.015	0.019	0.034
7.	Gujarat	6.103	1.430	2.882	4.312	1.301	1.963	3.264
8.	Haryana	4.512	2.100	2.375	4.475	1.850	2.283	4.088
9.	Himachal Pradesh	0.353	0.013	0.223	0.236	0.008	0.188	0.196
10.	Jharkhand	2.460	0.354	0.459	0.823	0.230	0.393	0.623
11.	J & K	1.358	0.180	0.000	0.180	0.169	0.000	0.169
12.	Karnataka	5.974	2.121	1.754	3.875	1.845	1.334	3.179
13.	Kerala	2.679	0.609	0.626	1.235	0.559	0.560	1.119
14.	Madhya Pradesh	16.214	1.387	5.750	7.137	0.876	4.100	4.976
15.	Maharashtra	8.952	3.239	5.262	8.521	2.147	3.553	5.700
16.	Manipur	0.604	0.156	0.049	0.205	0.111	0.029	0.140
17.	Meghalaya	0.168	0.000	0.085	0.085	0.000	0.049	0.049
18.	Mizoram	0.070	0.000	0.013	0.013	0.000	0.011	0.011
19.	Nagaland	0.085	0.000	0.079	0.079	0.000	0.049	0.049
20.	Orissa	8.803	1.827	1.676	2.903	1.794	0.951	2.745
21.	Punjab	5.967	2.543	6.986	9.529	2.486	6.353	8.839
22.	Rajasthan	5.128	2.482	4.839	7.321	2.314	4.295	6.609
23.	Sikkim	0.070	0.000	0.029	0.029	0.000	0.020	0.020
24.	Tamil Nadu	5.532	1.549	3.843	5.392	1.549	3.096	4.645
25.	Tripura	0.281	0.005	0.069	0.074	0.005	0.056	0.061
26.	U.P.	29.635	7.910	16.725	24.635	6.334	13.885	20.219
27.	Uttranchal	0.864	0.280	0.001	0.281	0.185	0.001	0.186
28.	West Bengal	6.918	1.683	3.293	4.976	1.527	2.282	3.809
29.	Total UTs	0.249	0.007	0.096	0.103	0.003	0.090	0.093
	Grand Total (All India)	140.008	37.046	68.282	**105.328**	31.010	52.899	**83.909**

Table V : Statewise Extent of Cultivation & Irrigation done in India (1999-2000)

S.No.	*Name of State*	*Geographical area*	*Total cultivable area i.e. CCA in Mha*	*Net cropped Mha*	*Gross cropped Area Mha*	*Gross irrigated Area Mha*	*%age of gross area under irrign.* $= \frac{G.Irr}{G.Cropped} \times 100 = \frac{(7)}{(6)} \times 100$	*Annual intensity of irrigation* $= \frac{Gross\ Irr}{CCA} = \frac{(7)}{(4)} \times 100$
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*
1.	Andhra Pradesh	27.51	15.93	10.610	13.023	5.746	44.12	36.07
2.	Arunachal Pradesh	8.37	0.27	0.166	0.264	0.036	13.64	13.33
3.	Assam	7.84	3.22	2.701	4.093	0.572	13.98	17.76
4.	Bihar	9.42	6.94	5.902	7.919	4.255	53.73	63.31
5.	Chhatisgarh	13.52	5.60	4.135	5.446	0.761	13.97	13.59
6.	Goa	0.38	0.22	0.142	0.171	0.034	19.88	15.45
7.	Gujarat	19.60	12.31	9.667	10.152	3.840	37.83	31.94
8.	Haryana	4.42	3.77	3.552	6.029	5.124	84.99	135.92
9.	Himachal Pradesh	5.57	0.82	0.551	0.957	0.179	18.70	21.82
10.	Jharkhand	7.97	4.19	1.535	2.060	0.553	26.84	13.20
11.	Jammu & Kashmir	22.22	1.05	0.733	1.078	0.438	40.63	41.71
12.	Karnataka	19.18	12.89	10.259	12.097	3.162	26.14	24.53
13.	Kerala	3.89	2.45	2.239	3.002	0.471	15.69	19.22
14.	Madhya Pradesh	30.92	17.23	15.763	20.761	6.330	30.49	36.74
15.	Maharashtra	30.77	21.00	17.691	22.351	3.769	16.86	17.95
16.	Manipur	2.23	0.16	0.140	0.199	0.075	37.69	46.88
17.	Meghalaya	2.24	1.10	0.240	0.266	0.055	20.68	5.00
18.	Mizoram	2.11	0.58	0.091	0.091	0.011	12.09	1.90
19.	Nagaland	1.66	0.64	0.261	0.295	0.073	24.75	11.41
20.	Orissa	15.57	8.09	6.075	8.524	2.512	29.47	31.05
21.	**Punjab**	5.04	4.37	4.238	8.240	7.487	**90.86**	**171.33**
22.	Rajasthan	34.22	25.71	15.509	19.286	6.934	35.95	26.97
23.	Sikkim	0.71	0.11	0.095	0.112	0.016	14.29	14.55
24.	Tamil Nadu	13.01	8.44	5.464	6.519	3.585	54.99	42.48
25.	Tripura	1.25	0.31	0.277	0.420	0.060	14.29	19.35
26.	Uttar Pradesh	24.09	19.43	16.387	25.296	17.515	69.24	90.14
27.	Uttranchal	5.35	1.42	1.198	1.344	0.161	11.98	11.34
28.	West Bengal	8.88	5.93	5.472	9.545	2.491	26.10	42.01
29.	Total UTs	1.09	0.21	0.135	0.189	0.092	48.68	43.81
	Grand Total (All India)	**328.13**	**184.35**	**141.231**	**189.74**	**76.336**	**40.23**	**41.41**

S. No.	State	Annual Intensity of Irrigation (Per cent)*
1.	Andhra Pradesh	36.07
2.	Arunachal Pradesh	13.33
3.	Assam	17.76
4.	Bihar	63.31
5.	Chhatisgarh	13.59
6.	Goa	15.45
7.	Gujarat	31.94
8.	Haryana	135.92
9.	Himachal Pradesh	21.82
10.	Jharkhand	13.20
11.	J & K	41.71
12.	Karnataka	24.53
13.	Kerala	19.22
14.	M.P.	36.74
15.	Maharashtra	17.95
16.	Manipur	46.88
17.	Meghalaya	5.00
18.	Mizoram	1.90
19.	Nagaland	11.41
20.	Orissa	31.05
21.	Punjab	171.33
22.	Rajasthan	26.97
23.	Sikkim	14.55
24.	Tamil Nadu	42.48
25.	Tripura	19.35
26.	U.P.	90.14
27.	Uttranchal	11.34
28.	West Bengal	42.01
29.	All Union Territories	43.81
	Total of All India	41.41

Extent of Cultivation and Irrigation done in India During 99.00

$$\frac{\text{*Gross irrigated area in a year}}{\text{CCA}} \times 100 = \text{Annual intensity of irrigation}$$

Total Geographical area = 328.73 M.ha
Culturable comm area (CCA) = 184.35 M.ha
Total gross cropped area = 189.74 M.ha
Estimated ultimate irrigation potential (gross area) = 140.00 M.ha**
Gross irrigated area = 76.336 M.ha

Annual intensity of irrigation $= \frac{76.336}{184.35} \times 100$
$= 41.41\%$

**58.46 M.ha from major & medium schemes ; and 81.54 M.ha from minor irrigation schemes.

Fig. 1

Table VI. Extent of Irrigation being done from various sources in India

S.No.	*Source*	*%age of Irrigation (app.)*
1.	Canals	39% ⎤ surface Irr. (49%)
2.	Tanks and other minor surface sources	15% ⎦
3.	Tubewells and other wells	51% Ground water Irr.
	Total	100%

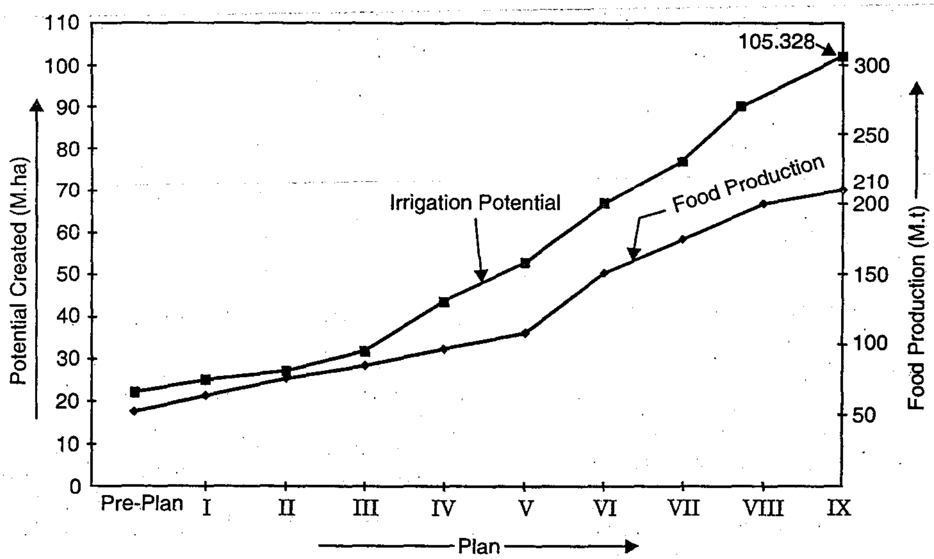

Fig. II. Plan wise growth of Irrigation potential and Food Production in India.

rice, wheat, coarser cereals) has declined from 75% in 1970 to about 65% in 2002. The important aspect of this, however, is the fact that absolute area allotted to **food grain crops** has remained almost unchanged at about **124 Mha** and most of the increase in cropped area has been for the non-food grain crops. Another important feature observed is that the area under wheat and rice has increased from 56 Mha in 1970 to about 69 Mha in 1995 at the expense of coarser cereals. The combined production of rice and wheat during 1970 to 1995 has increased from 66 Mt to 148 Mt, while that of coarse cereals remained constant at about 30 Mt. The increase in production of food grain during the last 32 years (1970–2002) to about 210 tonnes from 108 tonnes (Fig. II) has, of course, largely been caused due to extension of irrigation facilities over a larger cultivated area (about 45%), since the average food grain production per hectare of area for irrigated area has been found to be of the order of 2.5 t/ha, while that for rain-fed area, its value is found to be about 1.0 t/ha. The average food grain production per hectare of cultivated area has, thus, increased from 0.84 t/ha in 1970 to 1.60 t/ha in 2002. It has also been observed that while about 70% of unirrigated area is being used for food grain crops, only about 65% of the irrigated area is being used for food grain crops. With an assumption that 65% of the irrigated as well as unirrigated cultivated area shall be continued to be used for producing food grain crops, the production of food grains in the country based on the already developed irrigation potential of about 105 Mha, as well as on development of the entire ultimate irrigation potential of 140 Mha, are worked out below :

(*i*) Likely food production with utilisation of entire developed irrigation potential of about 105 Mha

$$= 105 \text{ Mha} \times 0.65 \text{ (use factor for food grain crops)} \times 2.5 \text{ t/ha} + (189 - 105) \text{ Mha} \times 0.65 \times 1.0 \text{ t/ha}$$

$$= 171 + 54 = \mathbf{225\ tonnes}$$

(*ii*) Likely food production with utilisation of entire ultimate irrigation potential of 140 Mha

$$= 140 \text{ Mha} \times 0.65 \times 2.5 \text{ t/ha} + (189 - 140) \text{ Mha} \times 0.65 \times 1.0 \text{ t/ha}$$

$$= 228 + 32 = \mathbf{260\ tonnes}$$

It can, thus, be seen that even if we are able to create and utilise the entire ultimate irrigation potential of 140 Mha, we can produce only about 260 M.t of food grains, which may just suffice for our future population of the year 2025, which is projected to be about 1350 million (M) at a moderate average food grain per capita consumption level of about 180 kg/year (*i.e.* 0.5 kg/day), although at present, with our population of 1050 M, our average per capita consumption level is hardly 160 kg/year, but the same is likely to go up in future with progressive removal of poverty and better distribution of food grains, amongst the poor rural and urban dwellers.

It can, thus, the concluded that even if we develop the entire ultimate irrigation potential of 140 Mha, which by better management of minor irrigation projects, has already been increased by 27 Mha from its earlier estimated figure of 113 Mha, we can grow food grains, which would be just sufficient to meet our future requirements upto the year 2025, or so.

Efforts will, therefore, have to be made to plan something more for the future, rather than simply targetting to exploit the ultimate irrigation potential of our conventional in basin development methods. One of the proposed method to achieve this aim is to increase the cropping intensity and to promote dry land farming. These measures, however, are not going to create any prominent impact on increasing food grain production. *The only viable method left to meet our future requirement is the* ***interbasin transfer of water from surplus regions to the deficit regions.*** *It may therefore, become imperative to transfer the water from surplus river basins like Brahmaputra, Barak, Mahanadi, Godavari, etc. to the water deficit areas. Interbasin transfer of water,* which is very much required for the country, is not a new concept, since such transfers had been practised even in the 18th and 19th centuries, when canals like *Western Yamuna Canal, Agra Canal, Kurnool-Cuddapah Canal, Periyar-Vaigai Canal,* etc. were constructed to carry waters of river basins of surplus waters over long distances to the regions of deficit waters. *Indira Gandhi Canal (Rajasthan Canal), Ravi-Beas link, Beas-Sutlej link,* and *Sutlej-Yamuna link* (not yet completed due to differences between Punjab and Haryana on sharing of waters) are the modern examples of inter-basin transfer projects of 20th century. **Several additional links*** are still needed to be planned, cleared and got executed to ensure optimum development of country's water resources, which is likely to help in creating an additional irrigation potential of about 35 Mha, besides providing drinking water, generating 34 M kW of hydropower and providing large scale protection against floods.

In addition to developing and harnessing greater water supplies for use by developing inter-basin transfers of water, there also exists an urgent need to **conserve our water supplies,** and to reduce our water demands by developing modern technologies.

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*For details of such links, please refer **"International and Interstate River Water Disputes"**, by the same author.

While industrial water demand can be reduced by developing recycling of waste water and by using superior modern methods to reduce consumption of water, the irrigation water demand can be reduced by using faming techniques like **sprinkler irrigation** and **drip irrigation** (called micro irrigation), on a large scale, which utilize the valuable water in an economical manner, by avoiding its wastage through infiltration and evaporation. Realizing its necessity, the Govt. of India has recently started paying greater attention to promote the use of *micro-irrigation*, by ensuring supply of equipment and know-how at subsidized rates to the farmers. A task force to suggest institutional mechanism needed for promoting such technologies and to ensure reaching of the intended benefits to the target group, has also been constituted by the Union Ministry of Finance, Govt. of India. The present status of use of these modern technologies in the country is however, very limited, since only 1.15 Mha (0.7 Mha under sprinkler and 0.45 Mha under drip irrigation) of cropped area is presently estimated to be under such faming techniques, as against 27 Mha found suitable for developing sprinkler and drip-irrigation farming.

It would also be pertinent to mention here that the adoption of intensive irrigation in certain States like Punjab, Orissa, Andhra Pradesh, etc. has caused alarming rise in the ground water-tables, which has resulted in causing water-logging and reduced crop yields. The non-provision of surface and sub-surface drainage and improper management of irrigation command area has compounded the problem to such an extent that a lot of land has become saline and even alkaline, making it unfit for cultivation. The land affected due to these reasons is estimated to be about 6 Mha (2.7 Mha affected by water-logging + 3.06 Mha affected by salinity + 0.24 Mha affected by alkalinity) **Conjunctive use** of surface and ground water collectively together is an accepted solution for removing water-logging problem, to enhance our crop yields. There is a large scope of making such improvements in alluvial plains, particularly in the *Gangetic plain, the coastal areas of Orissa and Anhdra Pradesh, the Brahmaputra Valley, the Cauvery delta*, and in parts of the Narmada basin.

Although irrigation facilities are so very important and essential for the development of any nation, they are complex and intricate. *Proper development of water resources involves the most economical exploitation of the entire available water of a country to meet the needs of its various regions, not only for irrigation but also for drinking, domestic and industrial requirements which are in no way, less important. Such optimum developments of water resources must also give due consideration to* **ecological aspects** *by proper allocation of low river flows for* **environmental conservation,** *rather than diverting them entirely for irrigation or water supply demands.* Aiming for such an **optimum and integrated utilisation** of the country's entire water-resources, makes this field very complex, intricate, and interesting too. It is here, that the real job of an Irrigation engineer or more precisely, a water-resources expert, comes into play.

How to plan our available water sources to fulfil requirements of various sectors, and to ensure maximum benefits keeping in view the socialistic distribution of the achieved benefits within the available funds, is the real tough job. The design of various irrigation works is another job, which must be accomplished with a fair degree of economy and correctness. Here is a book, which provides the basic fundamental principles, broad guide lines, and details of this intricate and interesting field in a simple language. It is hoped that this book will prove useful to every student, to every teacher, as well as to every design and field engineer.

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*Explained in article 1.6(7) and 1.6(6), respectively.