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MANAGEMENT OF LARGE IRRIGATION SYSTEMS FOR ENHANCING WATER PRODUCTIVITY

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Water has played vital role for evolution of human being, agriculture, urban as well as industrial development. In fact, all great ancient civilizations be it Mesopotamian, Egyptian or Indus flourished along the rivers as water is the most important natural resources. Globally, the potential availability of water has decreased from 12900 m^3 per capita per year in 1970 to less than 7000 m^3 in 2000 and projected to hit as low as 5100 m^3 per capita by the year 2025. However, this availability is not uniform and has wide variations. In densely populated Asia, Africa, Central and Southern Europe, current per capita water availability ranges between 1200-5000 m^3. By the year 2025, about 3 billion people will be in water stress category with 1700 m^3 of available water. India receives an average annual rainfall of 119.4 cm amounting to about 4000 billion cubic meter (BCM) of water that generates an average annual runoff of 1869 BCM. Due to various constraints about 1121 BCM of water can be put to beneficial use of which 690 BCM is through surface water and 431 BCM by groundwater. Out of 690 BCM of surface water, so far about 253.4 BCM of storage are built through major and medium irrigation projects. Another 51 BCM of storage are under construction/consideration. Similarly, out of 431 BCM of groundwater resource, about 360 BCM of groundwater is expected to be available for irrigation, out of which present usage is about 222 BCM. The per capita water availability in the year 2005 was 1703 cubic meter which is projected to further reduce to 1401 and 1191 cubic meter by the years 2025 and 2050, respectively. The projected total water demand of the country is estimated at 1447 BCM by the year 2050, which is more than the present availability of utilizable water resources (CWC 2010). In that the share of agriculture itself will be 1072 BCM. Thus, there is a need for proper planning, development and management of water resources.

Further, the availability of water for agriculture in India is projected to decline from 84% in 2010 to 74% by 2050. Therefore to produce 375 M t food grain from shrinking water resources would put existing water sources under immense pressure. It has been estimated that about 1% annual increase in water productivity (quantity per unit consumptive water use) would meet additional water demand for grain production and its further increase to 1.3% would satisfy all crops water demand. Present low crop water productivity provides enough scope for improving present low crop water productivity through scientific agricultural water management practices and the demand of water from other sector can be met with present water resources. As the total projected water demand for irrigation sector will be 324 BCM more than the present level of utilizable water resources, the challenge will be (i) more production from less water by efficient use of utilizable water resources in irrigated areas, (ii) increased production from sub-productive challenged ecosystems, *i.e.*, rainfed and water logged areas, and (iii) making use of grey water (waste water) for agriculture production. In addition, there is need of improving productivity of two sub-productive challenged ecosystems rainfed and flood prone/waterlogged areas through efficient irrigation and drainage network development in rainfed areas and combined approach of engineering, crop selection, crop management and aquaculture practices in waterlogged areas would be critical. However, the objective of this paper is to present the technological options for management of large irrigation systems so that their prevailing low irrigation efficiencies can be improved and the water productivity may be enhanced.

AGRICULTURAL SCENARIO

India has net sown area of 140.9 M ha and with a cropping intensity of 138.7 its gross sown area is 195.2 M ha. As surface water resources are quite important for crop cultivation through development of large or medium irrigation projects, rainwater harvesting and groundwater recharge, the distribution of annual rainfall is given in Table1. The net sown area in the country is about 140.8 M ha. The distribution of cropped area in different category based on rainfall received clearly indicates prospect of bringing at least 70% area under assured irrigation by developing various means of water resource development (Table 2). The net irrigated area is 65.3 M ha (46 %) with gross irrigated area is 91.5 M ha. The remaining 75.5 M ha area is rainfed which is nearly 54% of the net sown area (Table 3). The development of groundwater accounts for 58% of annual replenishment, it needs to be developed further for crop production keeping in mind the sustainability aspect (Table 4).

Table 1: Distribution of annual rainfall in different season

Season	Duration	Rainfall (%)
Pre-monsoon	March - May	10.4
SW Monsoon	June - September	73.7
Post-Monsoon	October - December	13.3
NE Monsoon	January - February	2.6

Table 2: Distribution of cropped area according to rainfall

Rainfall (mm)	Category	Area receiving rainfall (%)
0-750	Dry	30
750-1150	Medium	42
1150-2000	High	20
Above 2000	Very High	8

IRRIGATION SCENARIO

In India, irrigation development has received high priority in the successive five year plans and has the second largest irrigated area in the world. The ultimate irrigation potential of the country through major, medium and minor irrigation projects has been assessed at 139.9 M ha by conventional storage and diversion works. About 113 M ha of irrigation potential has already been developed through construction of 382 major projects, 1147 medium projects, 146 Extension, renovation and modernization schemes and millions of minor schemes. The overall irrigation efficiency in most of the major and medium irrigation projects is 30-40% which is quite low. The prevailing inequity, irregularity and non-reliability of canal water supply and poor efficiency at conveyance, distribution and application of irrigation are considered as a main cause for the low productivity (1.5-4.0 t/ha against achievable 5-6 t/ha) of irrigated agriculture. Over irrigation in some of the canal command areas has also resulted in waterlogging and salinity. Being, major consumer of water, even a marginal improvement in the efficiency of water use in irrigation sector will result in saving of substantial quantity of water. The performance of the irrigation sector thus needs an improvement through improved water delivery and application systems. Presently, about 2.32 M ha of cultivated land have been put under micro-irrigation and needs to be further intensified for improving the overall efficiency.

Table 3: State-wise extent of net sown, rain-fed and irrigated area ('000 ha) (2011-12)

Sr. No.	States	Net Sown Area	Rainfed area	Net irrigated area
1	Andhra Pradesh	11161	6071	5090
2	Arunachal Pradesh	215	158	57
3	Assam	2811	2650	161
4	Bihar	5396	2344	3052
5	Chattisgarh	4677	3262	1415
6	Goa	132	91	41
7	Gujarat	10302	6069	4233
8	Haryana	3513	440	3073
9	Himachal Pradesh	538	432	106
10	Jammu & Kashmir	746	427	319
11	Jharkhand	1085	960	125
12	Karnataka	9941	6501	3440
13	Kerala	2040	1631	409
14	Madhya Pradesh	15237	7350	7887
15	Maharashtra	17386	14134	3252
16	Manipur	365	296	69
17	Meghalaya	285	220	65
18	Mizoram	97	84	13
19	Nagaland	379	295	84
20	Orissa	4394	3135	1259
21	Punjab	4134	48	4086
22	Rajasthan	18034	10912	7122
23	Sikkim	77	63	14
24	Tamil Nadu	4986	2022	2964
25	Tripura	256	196	60
26	Uttarakhand	714	375	339
27	Uttar Pradesh	16623	3212	13411
28	West Bengal	5198	2120	3078
29	A & N Island	15	15	0
30	Chandigarh	1	0	1
31	D &N Haveli	17	13	4
32	Daman & Diu	3	3	0
33	Delhi	22	0	22
34	Lakshadweep	2	2	0
35	Pondicherry	18	3	15
	Total	**140800**	**75534**	**65266**

(Source: MoA, 2014)

Groundwater played a major role in the success of green revolution and contributes 60% of the total irrigated area of the country. In case of groundwater irrigation efficiency is estimated at 65-70%. Over exploitation of groundwater has reached at alarming levels in Punjab, Haryana, Rajasthan and Tamil Nadu. The Punjab-Haryana region could lose its production potential in a few decades if current patterns of groundwater extraction and pollution, soil salinization and rice-wheat monoculture persist. Groundwater remains underdeveloped in regions where surface water is adequate. But it is mined in some blocks. A recent estimate reveals that in 15% of the blocks, the annual extraction of groundwater exceeds annual recharge. In 4% of the blocks, it is more than 90% of the recharge. Groundwater extraction in such blocks needs to be better regulated. Conjunctive use of surface and groundwater is desirable to fulfill the irrigation requirements of crops by judiciously utilizing the water from both the sources which may also help in minimizing the problem of waterlogging and groundwater mining. Strengthening of knowledge base on geology and aquifer characteristics, hydrology of surface' and groundwater, and existing surface and ground water facilities is required to develop appropriate conjunctive use system.

Table 4: State-wise groundwater potential and development

S.N.	State	Ann Replenishable GW (BCM)	Net Ann GW availability (BCM)	Ann GW Draft (BCM)	GW Development (%)
1	Andhra Pradesh	35.89	32.57	14.51	45
2	Arunachal pradesh	4.51	4.06	0.003	0.08
3	Assam	28.52	25.79	3.49	14
4	Bihar	29.34	26.86	11.95	44
5	Chhatisgarh	12.42	11.63	4.05	35
6	Delhi	0.31	0.29	0.39	137
7	Goa	0.24	0.145	0.04	28
8	Gujarat	18.57	17.59	11.86	67
9	Haryana	10.78	9.79	13.05	133
10	Himachal Pradesh	0.56	0.53	0.38	71
11	Jammu & Kashmir	4.25	3.83	0.81	21
12	Jharkhand	6.31	5.76	1.86	32
13	Karnataka	17.03	14.81	9.41	64
14	Kerala	6.69	6.07	2.84	47
15	Madhya Pradesh	9.41	64	18.83	57
16	Maharashtra	2.84	47	17.18	53
17	Manipur	0.44	0.40	0.004	1.02
18	Meghalaya	1.78	1.60	0.0017	0.08
19	Mizoram	0.03	0.027	0.001	3.52
20	Nagaland	0.62	0.55	0.03	6.13
21	Odisha	18.83	57	4.73	28
22	Punjab	17.18	53	34.88	172
23	Rajasthan	4.73	28	14.84	137
24	Sikkim	--	0.044	0.011	26
25	Tamil Nadu	34.88	172	14.93	77
26	Tripura	2.587	2.358	0.163	7
27	Uttar Pradesh	77.19	71.66	52.78	74
28	Uttarakhand	2.04	2.00	1.13	57
29	West Bengal	29.25	26.58	10.69	40
	Total	432.11	397.60	244.85	62

(Source: CGWB, 2011)

THE CHALLENGES

The projected total water demand of 1447 BCM in 2050 will outstrip the present level of utilizable water resources (1123 BCM) out of which 1074 BCM will be for agriculture alone. Since the total projected demand will be 324 BCM more than the present level of utilizable water resources, the challenge will be to (i) produce more from less water by efficient use of utilizable water resources in irrigated areas, (ii) enhance productivity of challenged ecosystems, i.e., rainfed and water logged areas, and (iii) utilize a part of grey water for agriculture production in a sustainable manner.

Most of the irrigation projects are operating at an overall efficiency of only about 30 to 40% against the achievable efficiency of more than 50%. Thus, there is enormous scope to improve the productivity and efficiency of irrigation systems which can be achieved both by technological as well as social interventions. It is estimated that with 10% increase in the present level of efficiency in irrigation projects, an additional 14 M ha area can be irrigated from the existing irrigation capacities which would involve a very modest investment compared to what is required for creating equivalent potential through new schemes.

Groundwater is the largest source of irrigation contributing about 60% of the net irrigated area of the country. Overall, only 58% of the total groundwater resources have been developed indicating scope for its further development. However, there exists wide variability in its development across different geographical regions of the country. The over-exploitation of groundwater resources in North-western states coexist with under-utilization in the water abundant Eastern region. Further, government policies of providing free/subsidized electricity and pumps in many states are adding fuel to the water crisis. Reduced farm profitability via increasing pumping cost, deceleration in productivity of irrigation water and equity issues in groundwater distribution are also being considered as major challenges in this context. Groundwater pollution is another emerging threat to the sustainability of water resources.

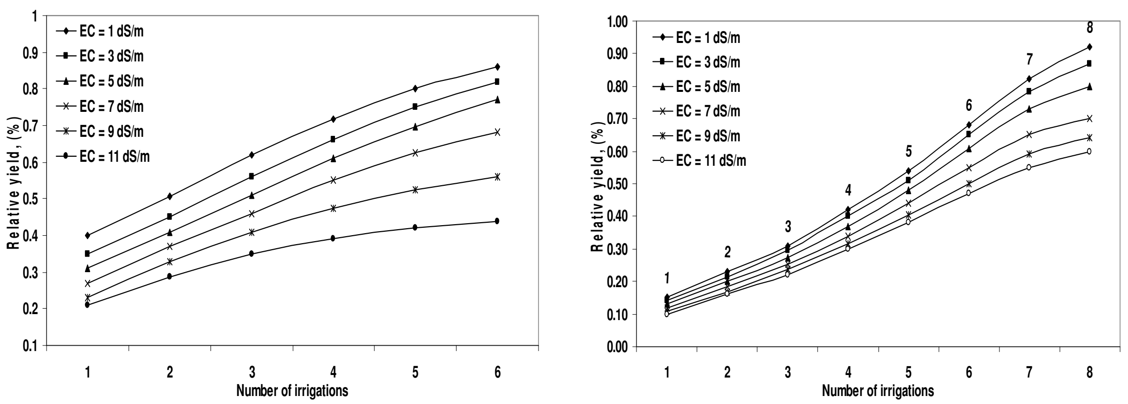
About 350 Class I and Class II urban centres having >50,000 population generate around 38,254 million litres per day (mld) of waste water out of which only 11,787 mld (31%) get treated. It has been projected that wastewater generation will cross 170,000 mld (62 BCM) by 2051 in addition to 30 BCM wastewater generated per year from various industries (CSE 2010). Recycling and reuse of this huge wastewater resource is a challenge for maintaining food security and restore health of the natural resources vis-à-vis the environment.

The country has huge area under two challenged ecosystems, i.e., rainfed and flood prone/ waterlogged areas which have low productivity. Presently about 78 M ha area is under rainfed and it is estimated that even with exploiting all utilizable water resources, approximately 55% of the gross cropped area will remain rainfed. Presently rainfed production system accounts for 91% production of coarse cereal, 49% of rice, 91% of pulses, 80% of oilseed and 65% of cotton. Thus, to ensure food and nutritional security, it is essential that the productivity of rainfed areas is increased significantly. However, the approach cannot be uniform for all rainfed areas. It is noteworthy that about 33% of rainfed area receives more than 1100 mm of rainfall and another 33% between 750-1100 mm. Enhancing productivity from this region will help in modifying the approach for other two rainfed zones receiving 500-750 mm and less than 500 mm rainfall. It has been found that in these two regions, farmers tend to go for water guzzling crops replacing traditional crops which have more resilience against climatic variations. This has led to unsustainable cropping system.

The other challenged ecosystem is waterlogged areas which account for about 8.5 M ha in India. There are two types of waterlogged areas: one where the water table has risen due to over irrigation up to within root zone (approx 2.16 M ha) and another where water congestion occurs due to high rainfall coupled with land topography which hinders drainage. While the first situation can be remedied through efficient irrigation and creating drainage network, the second situation requires a multipronged approach of having an optimal mix of engineering, crop selection, crop management and aquaculture practices supported by market intervention, processing and value addition.

IMPROVING WATER PRODUCTIVITY IN IRRIGATED ENVIRONMENT

Performance evaluation of irrigation systems: Space-borne remote sensing measurement can provide information on agricultural and hydrological conditions of the land surface for vast areas at regular intervals. An application of remotely sensed data in the Sone Low Level Canal (SLLC) system in India for assessing irrigation system performance have been used to evaluate the extent of cultivated area, water



(a) (b)

Fig. 1: Relative wheat yields due to change in irrigation frequency (a) in conventionally levelled (6 cm/irrigation) and (b) in precision levelled (4 cm/irrigation) fields

availability and its distribution, crop yield performance and water productivity for each branch canal and distributaries (Ambast et al., 2008). Even though the capability of satellite remote sensing to monitor agricultural and hydrological conditions of the land surface has undergone major improvements in the past decade, it remains under-utilized by practicing water resource managers.

Irrigation scheduling: Judicious use of water resources is sine-qua-non for enhanced productivity, improved economy and environment. It becomes all the more critical when water supply is scarce. How productive and safe is the water use, largely depends on the quality of the land levelling accomplished by the farmers. Precision land levelling becomes even more important when both the quality and the quantity of available water are limiting. Such a situation exists in the northwest India, where protective canal irrigation supported by good/marginal quality groundwater is in vogue. In such situations, use of saline/alkaline water supplies often requires the application of smaller depths at relatively more frequent intervals (Mandare et al., 2006). Since the total depth water applied per irrigation is greatly influenced by the quality of land levelling, it is important to achieve precision land levelling for efficient irrigation. Salinity and non-uniformity in irrigation water have much the same effect on the yield-water response function and both result in consuming larger volumes of irrigation water to produce the same yields as can be obtained with non-saline water and uniformly applied water (Fig.1).

Deficit irrigation supplies: Alternative cropping patterns have been evaluated for their water productivity and economic returns to improve irrigation system performance (Ambast, 2001). After the modernization of the SLLC system and release of Govt of Bihar share of water from Bansagar project, it is expected that an additional parallel canal will run during *kharif* season, whereas the existing canals will run with designed capacity of water throughout the *rabi* season. The proposed cropping pattern after modernization and the alternative cropping patterns during *rabi* season are given in Table 5. Cropping patterns, CP1-CP2-CP5 have increased cropping intensity, however, CP3-CP5 have the maximum intensity (100%) with increased area for the wheat crop due to deficit irrigation practiced (Table 6).

Pressurized irrigation system: Pressurized irrigation system is proved to be an efficient method in saving water and increasing water use efficiency as compared to the conventional surface method of irrigation, where use efficiency is only about 35-40%. The field experiments conducted across the country under AICRP on Water Management have indicated saving of irrigation water depending upon the soil type, e.g. in clay, the saving is from 30 to 48%, leading to increased area by 1.4 to 1.9 times, in sandy loam, from 40 to 50% saving with 1.7 to 2.0 times increased irrigated area, in silt loam, from 55 to 61% water saving with 2.2 to 2.6 times enhanced irrigated area, in silty clay loam 38 to 47% water saving leading to 1.6 to 1.9 times enhanced irrigated area and in clay loam from 21 to 39% with 1.3 to 1.6% irrigated area (Table 7). Drip fertigation reduces the wastage of water and fertilizers, optimizes nutrient use by applying them at proper place and time which increases the water and nutrient use efficiency. In sandy loam soil, the increase in yield due to fertigation was from 47 to 50%, in clay loam from 32 to 87%, in silty clay loam around 14 %, in silt loam around 34% and in clay from 28 to 59% over conventional fertilizers (Table 8).

Table 5: Proposed and alternative cropping patterns

Cropping pattern	Area (%)					
	Wheat I	WheatII	Pulses	Oilseeds	Vegetables	Perennial
CP1 (proposed)	35.0	20.0	15.0	5.0	3.0	2.0
CP2	40.0	25.0	15.0	5.0	3.0	2.0
CP3	45.0	30.0	15.0	5.0	3.0	2.0
CP4	50.0	35.0	5.0	5.0	3.0	2.0
CP5	60.0	40.0	0.0	0.0	0.0	0.0

Table 6: A summary of irrigation scheduling for different cropping patterns

Crop	ETc (mm)	Net Irrig. (mm)	Lost Irrig (mm)	Prod Loss (%)	Production (kg)	WP (Kg/m^3)
CP1 - Wheat-I	401.9	460.0	96.3	0.0	1575	0.98
Wheat-II	446.6	460.0	87.5	1.5	887	0.96
Pulses	230.5	208.0	0.0	2.8	194	0.47
Vegetable	357.5	391.0	50.5	2.5	585	5.11
Sugarcane	88.4	90.0	0.0	0.0	1000	-
CP4 - Wheat-I	385.7	340.0	48.9	4.3	2153	1.27
Wheat-II	401.2	340.0	45.1	12.0	1386	1.17
Pulses	100.5	78.0	0.0	7.2	93	1.28
Vegetable	357.5	391.0	50.5	2.5	585	5.11
Sugarcane	88.4	90.0	0.0	0.0	1000	-
CP5 - Wheat-I	385.7	340.0	48.9	4.3	2584	1.27
Wheat-II	401.2	340.0	45.1	12.0	1584	1.17

Table 7: Percent saving of irrigation water with drip irrigation & enhanced cultivated area

Centre & State	Test Crops	Soil type	% saving in water	Increase in area (times)
Dapoli (MS)	Brinjal	Lateritic	38	1.6
Navsari (Guj)	Onion	Clay	30	1.4
	Turmeric		32	1.5
	Brinjal		40	1.7
	Chillies		48	1.9
Bhawanisagar (TN)	Jasmine	Sandy loam	50	2.0
	Sugarcane		40	1.7
	Tomato		42	1.7
	Banana		48	1.9
Madurai (TN)	Sugarcane	Clay loam	21	1.3
	Red Gram		39	1.6
Kota (Raj)	Onion	Clay loam	23	1.3
	Garlic		22	1.3
	Turmeric		23	1.3
Faizabad(UP)	Sugarcane	Silt loam	59	2.4
	Marigold		55	2.2
	Cowpea		61	2.6
Palampur (HP)	Broccoli cauliflower	Silty clay loam	47	1.9
			38	1.6

Table 8: Fertigation vs conventional method of fertilizer application

Centre & State	Test Crop	Soil type	Yield (kg/ha)		% yield increase
			Conventional	Fertigation	
Dapoli (MS)	Brinjal	Lateritic	1876	3234	72
Jorhat (Assam)	Assam Lemon	Sandy Loam	10100	14880	47
Palampur (HP)	Broccoli	Siltyclayloam	7400	8440	14
Navsari (Guj)	Onion Turmeric	Clay	28740	45690	59
	Round melon	Clay	13100	16800	28
	Sugarcane	Clay	12000	15300	28
	Tomato	Clay	140000	183000	31
		Clay	48000	68000	42
Bhawanisagar (TN)	Coconut	Sandy loam	10974 nuts	16461 nuts	50
	Sugarcane		115300	171700	49
Madurai (TN)	Red Gram	Clay loam	1108	1515	37
Kota (Raj)	Onion Cabbage	Clay loam	16350	24960	53
	Garlic Turmeric	Clay loam	17756	23373	32
	Bitter Gourd	Clay loam	6953	10575	52
		Clay loam	14670	27360	87
		Clay loam	21226	30139	42
Faizabad (UP)	Marigold	Silt loam	161	216	34

Conjunctive use of canal and groundwater: In the arid and semi-arid regions, where canal water availability is scarce and groundwater quality is marginally poor, conjunctive use of waters is quite common. Earlier studies for conjunctive use of canal water with saline water were conducted for well-designed treatments of cyclic and blending mode of irrigations under controlled conditions (Sharma and Rao, 1998). However, canal water supply is highly unreliable and inadequate in the region that leaves limited scope for application of recommendations emerged from earlier studies. Therefore, SWAP model has been calibrated and validated in the Kaithal irrigation circle, Haryana in the northwest India (Mandare et al., 2006) to accommodate farmers' fields observation on canal water availability and groundwater applications to suggest (i) water management options for improving productivity of wheat crop during rabi season. Further, there is a need to assess long term impact of various combinations of saline water applications in different wheat based crop rotations feasible in the region.

CONCLUSIONS

The natural resource scenario is changing fast both in terms of availability as well as quality. Looming climate change will alter the paradigm of natural resources in which our production system operates. Water has been and will remain a critical resource which is being affected by increasing population, industrialization, urbanization, pollution, deforestation and above all climate change. Certainly the business as usual will not suffice. Technological options of performance evaluation, lase land levelling, irrigation scheduling, deficit irrigation, precision irrigation and conjunctive use are the possible options for improving water productivity in the large irrigation systems. Thus it is essential to visualize the future scenario and prepare strategies for equipping ourselves with technologies which will provide solution for maintaining our food and nutritional security in changing/projected scenarios.

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