Groundwater Externalities of Large Surface Irrigation Transfers:

Lessons from *Indira Gandhi Nahar Pariyojana,* Rajasthan, India

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Introduction

Indira Gandhi Nahar Pariyojana (IGNP) was among the first group of large surface water transfer projects taken up in the country aiming to transform the wastelands of Thar Desert in Rajasthan into agriculturally productive zones along with improvement of afforestation and environment, development and protection of livestock/animal health, human rehabilitation and settlement, and economic growth of the poor people of the desert. The project had laudable objectives of "drought proofing, provision of drinking water, industrial and irrigation facilities, creation of employment opportunities, settlement of human population of thinly populated desert areasi; improvement of fodder, forage and agriculture facilities, check spread of desert area and improve ecosystem through large-scale afforestation, develop road network and provide requisite opportunities for overall economic development" (IGNB 2002). Over the years, some of these objectives have been adequately met. At the same time, this large transfer of surface water from alluvial plains to a desert region with no natural drainage and over 250 km away leads to a massive spread of waterlogging and salinity, inundation of vast land depressions and adjoining habitations, roads and public property and fast spread of water-induced animal and human diseases. IGNP presents a great lesson to water infrastructural planners and managers on how inadequacies in planning and operation of large surface irrigation transfers can create negative groundwater externalities of unforeseen magnitude which fail to be tackled by normal quickfix solutions. This paper, a part of the Strategic Analyses of the National River Linking Project, attempts to diagnose and analyze this problem, and drawing lessons from the past failed-interventions offers a certain viable strategy for IGNP and other large future projects of surface water transfers elsewhere.

IGNP-The Project

IGNP is a large water infrastructural project designed for transferring 9.36 Bm^3 (7.59 milion acre feet) of Rajasthan's share agreed under the Indus Water Treaty (1960)/and Inter-State Water Agreement (1981). The water from the Harike Barrage in Punjab is transferred to the western desert region of Rajasthan through a 200 km long feeder canal. The system is designed to irrigate 2.5 Mha of Thar Desert through an extensive network of a more than 9,000 km length of distribution system and 450 km length of main canals. Irrgation in IGNP is developed in stages popularly known as Stage-I and Stage-II. The IGNP Stage-I consists of a head feeder reach of 204 km offtaking from the Harike Barrage, a 189 km main canal and a 3,454 km long distribution system with a culturable command area (CCA) of 541,000 ha. The IGNP Stage-II, commencing with a 189 km main canal, consists of the lower reaches of the project comprising a 256 km long main canal and a 5,606 km long distribution system with a CCA of 1,319,000 ha.

The canal network is lined and able to bring large quantities of water to irrigate an extensive area of what was a low-value desert. Land brought into the scheme is allotted to persons applying for land, with a carefully developed system of prioritization of applications to identify the most deserving applicants. Each allotment is 25 *bighas* (6.32 ha) in area. The applicants with the highest priority are from the region being developed; nevertheless, there have been extensive population shifts into the project area to take advantage of the potential created. Stage-I started receiving irrigation since October 1961 and Stage-II is still under construction.

By 2004-05, 559,000 ha irrigation potential was created under Stage I and 510,000 ha under Stage II. Irrigation potential is deemed to be created only when watercourses are constructed, and water is provided through outlets for a *murabba* of 6.32 ha. Irrigation potential created and utilized for some selected years for Stage-I and Stage-II of IGNP is given in Table 1. The development activities of the command area for the IGNP command, which included, among others, the construction of lined watercourses to the outlets, land leveling and shaping and soil conservation, started in 1974.

Table 1. Progressive development of irrigation potential created and utilized under Stage-I and Stage-II of IGNP.

Year	Stage-I					Stage-II				
	Through canal		Through watercourse		Utilized	Through canal		Through watercourse		Utilized
	Area opend (lakh ha)	Potential created (with 110% irrigation intensity)	Area covered (lakh ha)	Irrigation potential created (110%)		Area opend (lakh ha)	Potential created (with 110% irrigation intensity)	Area covered (lakh ha)	Irrigation potential created (110%)	
74-75	2.86	3.15	0	0	2.58	-	-	-	-	-
81-82	4.86	5.35	2.07	2.28	4.02	0.35	0.28	0	0	0
88-89	5.22	5.74	4.08	4.49	5.53	1.45	1.16	0.3	0.24	0.12
95-96	5.31	5.84	4.42	4.86	6.64	5.09	4.07	2.85	2.28	1.37
2000-01	5.42	5.96	4.69	5.16	6.28	7.55	6.04	5.13	4.1	2.08
2004-05	5.46	6.01	5.08	5.59	6.88	9.26	7.41	6.37	5.1	1.44

However, the data clearly indicate a substantial lag period between the release of water through the canals, completion of the watercourses for conveyance of water to the fields and actual utilization of the water. The large amounts of unused water became a major source of inundation of the depressions and subsequent waterlogging.

Irrigation and Agricultural Transformation

Before the advent of IGNP there was very little irrgated area in Jaisalmer (0.54%) and Bikaner (7%) districts which have now increased substantially in all the four districts (Table 2) under the command. Most of the irrigated area in all the four districts in 2001-02 is from canal irrigation. As a result of irrigation, the net sown area in Bikaner and Jaisalmer districts increased gradually, whereas there is not much change in Sri Ganaganagar and Hanumangarh districts.

Table 2. District-wise irrigated area as a percent of net sown area in the IGNP command.

Year	Sri Ganganagar	Hanumangarh	Bikaner	Jaisalmer
1988-89	70.54	*	7.04	0.54
1996-97	43.31	38.69	10.23	8.47
2000-2001	81.73	49.39	18.38	20.86
2001-2002**	75.05	40.05	17.94	22.33

*Until 1992/93, ster the Hanumangarh District was part of the Sri Ganganagar District.
**2002 was a drought year in the region.

In 1974-75, the cropping pattern generally followed by the farmers was cotton, pearl millet, *kharif* (monsoon from May to september) pulses and *guar* (cluster bean) in the kharif season and wheat, barley, gram and mustard in the *rabi* (October to April) season. However, with the introduction of irrigation under IGNP, the area covered under cotton, wheat and mustard, and their productivity has increased over the years. The data indicate that the total coverage under kharif and rabi crops during 1974-75 under Stage I was only 258,178 ha, which increased to 653,948 ha in 2000-01, an increase of about 250%. In Stage II, the area under kharif and rabi crops in 2001-02 was 152,859 ha. The area decreased in 2002-03 due to scanty rainfall and less water availability in the canal, but picked up in the subsequent years. The areas under cotton and groundnut have increased whereas the area under pearl millet has decreased (Table 3). In the rabi season the area under wheat, mustard and fodder increased. Yields of cotton and wheat have more than doubled in Stage I (Table 4) and in Stage II the crop yields are still low. Overall, except for the wheat crop, the yield gains have not been very impressive perhaps due to widespread prevalence of waterlogging and salinity and very limited use of groundwater. Studies made in neighboring Punjab showed that areas purely under canal irrigation had lower wheat yields than those with conjunctive and pure tube well irrigation.

Table 3. Area under different crops in Stage-I of the IGNP command.

Crops	1974-75		1990-91		1995-96		2000-01*	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Cotton	23,090	24.9	153,809	63.3	206,282	70.3	180,626	54.6
Pearl millet	14,435	15.8	2,148	0.9	3,047	1.1	2,003	0.6
Paddy	6,655	7.2	6,926	2.8	8,563	3.0	18,426	5.6
Wheat	49,973	30.2	133,392	44.5	179,396	45.5	158,956	49.2
Gram	66,733	40.3	59,798	19.9	61,058	15.5	42,117	13.0
Mustard	32,941	19.9	83,741	27.9	95,815	24.3	59,419	18.4
Barley	9,859	5.9	4,642	1.6	7,265	1.8	21,486	6.7

*Low rainfall year.

Table 4. Changes in yield of various crops under the IGNP command.

Years	Cotton	Groundnut	Guar	Wheat	Gram	Mustard
STAGE- I	8.91	-	-	12.71	7.36	6.22
74-75	10.41	16.00	-	18.25	8.20	6.20
80-81	16.72	14.21	9.21	27.72	5.53	10.84
90-91	13.15	10.80	7.52	29.64	7.54	10.11
99-2000	11.50	13.00	6.50	13.00	8.00	7.00
2000-01*						
STAGE- II	8.83	15.70	4.32	17.13	10.81	8.82
95-96	10.50	13.00	6.00	15.00	9.00	8.00
2000-01	8.50	11.50	2.50	20.00	10.00	10.00
2004-05						

* Low rainfall year.

Groundwater: The Resource and the Threat

Most of the command area of IGNP-Stage I has an alluvial cover of more than 20 m and can be a potential source of groundwater depending on the aquifer characteristics and the quality of recharged water. The tube wells of 250 m depth in unconsolidated formations, covering 95% of the investigated area, are capable of yielding 12 to 120 m^3/hr for a drawdown from 4 to 15 m. However, the drilling data of Central Groundwater Board (CGWB 1999) and Rajasthan Groundwater Department have exhibited considerable lateral and vertical variations in lithology in the IGNP Stage-I area. In the northeast to southwest directions three main aquifers between the depth ranges of 15-50 m, 45-100 m and 80-170 meters below ground level (m bgl) have been revealed in the investigations down to a depth of 210 m bgl.

The formations in Stage-II comprise mainly quaternary (47% of CCA) and tertiary (47% of CCA) formations. The formation of Jaisalmer and Barmer districts contains water that is highly mineralized, but at many places usable for small livestock. The most worrying feature is that beneath the sandy surface soil shale/clay, hard compact friable carbonate nodules and lime-coated gravel with clay are present at varying depths having a poor infiltration rate and behaving as an impervious barrier. In about 30 to 35% of the area under Stage II, the depth up to these hydrological barriers is less than 10 m bgl, being shallower in lift areas and becoming deeper towards the international boundary (CAD 1997, 1999). Based on available data, distribution of area having a hard pan layer within 0 to 10 m bgl in different *tehsils* is given in Table 5.It appears that about 33.4% in flow command and 76.4% in lift command (excluding the Sahwa lift area) are prone to waterlogging due to the presence of the hardpan layer. Due to lack of detailed investigations before the development of the irrigation commands, this particular feature of hydrogeology perhaps did not receive adequate attention during the irrigation planning and operations phase and was one of the major reason for the catastrophic spread of waterlogging and salinity in the IGNP command areas.

The deeper groundwater is mostly saline and about 530,500 ha (or 47% of the total area) have groundwater salinities of more than 8 dS/m. About 145,000 ha (or 13% of the area) have groundwater salinity less than 2 dS/m. Deeper native saline groundwater is often overlain by better-quality groundwaters originating from percolation and seepage in the canal irrigated area. Overall, there is very little groundwater irrigation in all the four districts (DoES 1988, 1995, 1996, 2004). But in the recent years the area under tube well irrigation has been increasing. This may be due to the reduced canal supplies and low rainfall.

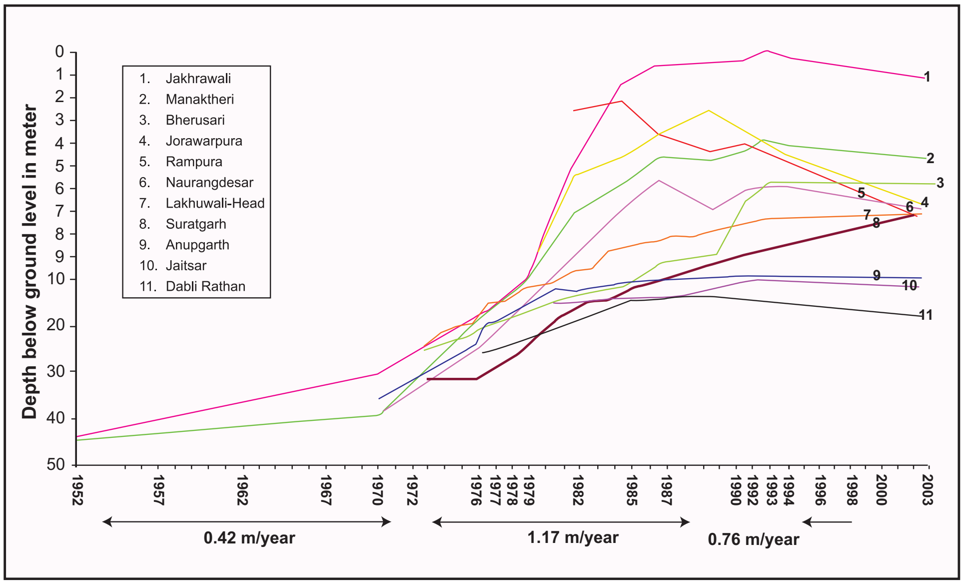
Table 5. Distribution of area with hardpan 0 to 10 m from ground level - IGNP Stage II.

System	Tehsil	CCA, ha	Hardpan area	
			ha	%
Flow area				
Dattor distributary	Pugal	18,820	13,770	73.2
Birsalpur branch	Kolayat	44,970	9,110	20.3
Charanwali branch	Kolayat, Nachana	102,240	16,390	16.0
Shahid Birbal branch	Mohangarh	101,160	31,580	31.2
Sagar Mal Gopa branch	Ramgarh, Jaisalmer	255,450	92,300	36.1
Other direct outlets, etc.		98,730	44,740	45.3
Subtotal		621,370	207,890	33.4
Lift area				
Gajner lift	Bikaner, Kolayat	49,540	21,600	43.6
Kolayat lift	Kolayat, Phalodi	86,260	63,470	73.6
Phalodi lift	Phalodi, Pokaran	56,750	56,750	100.0
Pokaran lift	Pokaran	22,700	22,700	100.0
Subtotal		215,250	164,520	76.4
Grand total		836,620	372,410	44.5

Spread of Waterlogging and Soil Salinity

Rise of Water Levels: With the expansion of area under irrigation, the command area witnessed an alarming expansion of waterlogging and soil salinity. Before the advent of irrigation in 1952, the groundwater table was at a depth of about 40 to 50 m. With the commissioning of IGNP and flow of canals and return flows for the period, an average rise of groundwater of 0.42 m/annum was observed for the two-decade period of 1952-72 (Figure 1).

Figure 1. Hydrograph showing grounderwater depth chages (Year 1952 to 2003).



An abrupt rise in water levels was also recorded in Lakhuwali, Naurangdesar, Rampura, Jorawarpura, Bherusari, Manaktheri and Jakharawali. The maximum and minimum rise of water levels was observed as 1.30 and 0.6 m per year in the areas of Suratgarh and Dabli Kalan, respectfully, during the period 1973-93.

During a decadal period of 1972-88, there was a substantial rise in water levels up to 1.17 m per year, which could be attributed to return flow of irrigation, high water allowances of 5 m^3/sec./1,000 acres, excess irrigation applications (Table 6) and filling up of depressions. By 1994/95, the rate of rise was found to be 0.80 m in Stage I and 0.33 m in

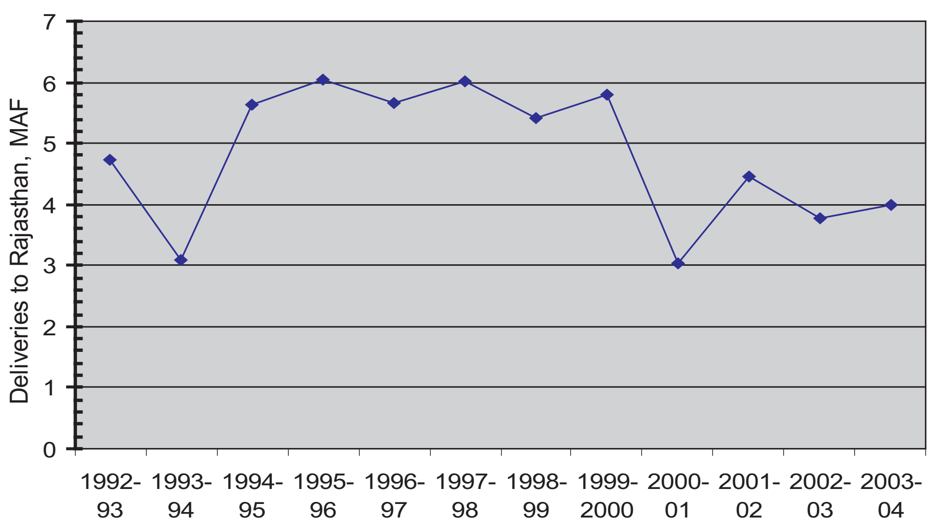
Stage II. Fortunately, after 2000 a declining trend of groundwater depths is noticed, attributed to less than normal rainfall and poor availability of water supply in canals. Even during normal years, supplies to Rajasthan have been lesser than the agreed quota, but recent years have witnessed a marked reduction (Figure 2). This was also aided by some additional groundwater development by the farmers in Hanumangarh and Bikaner districts under Stage-I and to a lesser extent in Stage-II.

Table 6. Depth of seasonal water requirement and deliveries (in cm of water) in selected reaches of IGNP.

System		Kharif			Rabi		
		1984	1985	1986	1984	1985	1986
Surathgarh branch Controlled area	Irrigation requirement	71.0	53.9	59.1	65.8	52.4	52.1
	Actual supplies	140.8	102.7	114.8	55.5	114.9	69.8
Anupgarh branch Controlled area	Irrigation requirement	66.8	51.5	59.4	52.7	53.3	52.7
	Actual supplies	125.2	96.0	108.0	53.6	86.3	63.4
Rawatsar distributary IWMZ*	Irrigation requirement	68.0	51.5	61.3	53.9	53.9	53.0
	Actual supplies	97.2	60.4	76.2	57.0	68.0	59.1
Naurangdesar distributary IWMZ*	Irrigation requirement	70.1	60.0	68.3	54.3	54.6	53.3
	Actual supplies	61.6	48.2	51.5	46.0	46.6	44.8

* Improved water management pilot project initiated in 1981 in about 4,000 ha and expanded to about 89,098 ha by 1991 in Phase I of Stage I (IGNB 2002).

Figure 2. Actual water supplies to IGNP.



Spread of Waterlogging: Rise in groundwater levels afflicted large areas with waterlogging and critical water table conditions. The extent of such areas increased continuously up to the year 1997-98 and has shown some respite only in recent years (Table 7). During 1997-98, an area of 23,251 ha was affected with severe waterlogging. The causes of such a spread were both natural and man-made. This region has no natural drainage system and the water transferred is either lost through evaporation (and transpiration) or is stored in the groundwater system. Wherever the groundwater system is exposed to the topographically low areas, pools of surface water are formed. Additionally, about 30% of the area in Stage I and about 45% of the area in Stage II have hydrological barriers in the form of gypsum, clay and kankar layers which appear in the shallow region of less than 10 m in most of the area causing buildup of perched water tables.

Table 7. Development of waterlogging (area in ha) in the IGNP command.

Category	1992-93	1997-98	2000-01	2003-04
Potentially sensitive area (water table within 1.5 to 6.0 m)	202,960	328,123	237,337	195,000
Critical area (water table within 1.0 to 1.5 m)	22,000	32,552	15,654	9,576
Waterlogged area (water table within 0.0 to 1.0 m)	13,750	23,251	13,041	2,535
All categories	238,710	383,926	266,032	207,111

Besides the natural causes, several management and operational practices have also exacerbated the situation:

i. Ghaggar river floodwater stored in depressions contributed substantially to groundwater recharge in the neighboring areas.

ii. Several inter-dunal low-lying areas filled up with canal water to meet requirements during construction remained unused.

iii. Very high water allowance of 5.23 cusec/1,000 acres in Stage I caused high seepage losses from unlined watercorses/field channels and return flows.

iv. Uncontrolled high discharge direct outlets from the main canal and branches caused flooding of large areas.

v. Absence of gates and controls on minors and watercourses caused flooding of low areas during low/no irrigation requirements.

Impact of Waterlogging

Rise of the water table closer to the surface and inundation of the low-lying areas have caused submegence of agricultural lands and village common lands, submergence of the villages/ habitations, damages to road communication and public utilities and constraints in the choice of crops and loss of production. The damages have taken place extensively in several areas and about 4,000 ha of agriculture, village common lands and government lands have been partly or completely submerged resulting in complete loss of the assets. Waterlogging conditions have resulted in the submergence of 22 villages due to exposure of the hydrostatic line of the groundwater and leakages and return flows from the irrigation system. The main pockets of submerged lands are shown in Table 8. Several of the marooned villages (Rangmahal, Samnala Quarter, Manaktheri, Baropal, Jakharawali, Bherusari, Rawatsar, Dabli Kalan, Dabli Khurd, Lunio ki Dhani, Ghandheli, 13/15 SPD, Kalalon ki Dhani, Jowrapura, etc.) had to be shifted to higher elevations at huge public costs and distress. Large sections of the road systems also got submeged and required repeated raising of road levels. Several schools, hospitals, and other public service utilities also got submeged affecting the society as a whole.

Table 8. Pockets of submerged lands in the IGNP command (ha).

1.	Manaktheri-Baropal-Jakharawali-Bherusari, Kalalon Wali Dhani	2,500
2.	Dabli Khurd and Dabli Kalan	500
3.	Lunio ki Dhani	55
4.	Masitawali head and head reaches of Naurangdesar	33
5.	Rawatsar, Gandheli, Dasuwali, 2,3 RWD, 34 RWD	650
6.	Nachana	50

Loss to Agricultural Production: By the end of year 1997-98, a total CCA of 514,000 ha in Stage I, which is around 56% of the total area, had become potentially sensitive to waterlogging (CAD, 2004, 2005, 2007b). In Stage II, out of 182,000 ha utilized for irrigation about 23,000 ha (about 13%) had become potentially sensitive to waterlogging. Some waterlogged areas have completely gone out of cultivation, where the water table is either above the ground surface or very close to the surface. Waterlogged areas have also gone out of cultivation due to salinization. Waterlogging seriously constrains the choice of crops, enhances expenditure on farm operations and strongly affects the growth and yield of crops.

To have a better understanding of the existing cropping patterns, sources of irrigation, yield levels and net returns of the farmers in the command, a survey of 253 farmers (184 farmers in Stage I and 69 farmers in Stage II) cultivating an area of 1,241 ha was undertaken during 2007. Salient findings from the farm survey were:

i. More than 50% of the irrigated area in Stage I had water tables within sensitive zones during the late nineties. About 10% of the soil surveyed in the command showed high salinity conditions. It is, therefore, necessary to safeguard the gains of IGNP in terms of increased cropped area and production, socioeconomic life of the settled farmers and public utilities from the vagaries of waterlogging and soil salinity. Primary data collected by IWMI (IWMI 2007) showed that 98% of farmers depend only on agriculture for family income and livelihoods. Most of the farmers are marginal to medium with an average cultivated area of 5.58 ha per farm family. Only about 14.6% are large farmers.

ii. Canal irrigation (96.4%) remains the major source of irrigation. However, in recent years farmers have shown good interest in tube well irrigation as 44% of the surveyed farmers also owned tube wells. In the early 1990s, the major source of irrigation in these districts was only canal water. The average depth of tube wells is about 38 m indicating that tube wells are shallow and mostly tapping freshwater lenses floating on parent saline water. The average pump set capacity is about 9.0 hp, cost of installation is about INR 51,000 and operation and maintenance (O&M) cost is high at INR 1189/ha as almost all the tube wells are diesel-operated.

iii. The cropping intensity in IGNP is 130% with 149% under Stage I and 110% under Stage II. About 31% in kharif and 30% in rabi have remained fallow mainly due to deficit canal supplies. In Stage I only about 20% remained fallow against 44% fallow lands in Stage II, mainly due to deficit water supplies for Stage II and more groundwater availability in Stage I. Cultivation in about 4.4% of the area has been abandoned due to waterlogging and salinity - about 5.7% area in Stage I and 2.4% in Stage II.

iv. Cotton occupied the largest area (55%) in the kharif season followed by cluster bean (29%) and oil seeds (7%) in Stage I. In the same season, water-deficit farmers in Stage II mainly cultivated cluster bean (64%), groundnut (17%) and cotton (8%). During rabi, wheat (64%) and mustard (26%) were the main crops under Stage I as compared to barley (37%), mustard (29%) and gram (24%) under Stage II. So the farmers in Stage II cultivate the crops having minimum water requirements during both seasons.

v. The average crop yields in the command were somewhat comparable to the average yields of the state with variations of 1.7 t/ha cotton in Hanumangarh and 0.7 t/ha in Lunkaransar. Similarly, wheat yields varied from 0.4 to 3.4 t/ha with an average yield of 2.3 t/ha in Stage I and 2.0 t/ha in Stage II. The data did not support a good impact of source of irrigation on crop yields.

vi. Waterlogging (28% of respondents) and soil salinity (26% of respondents) are major problems in IGNP with a lot of area submerged under pools of water, cultivation of some areas abandoned and other lands producing much less than crop potential yields. The farmers reported that, on average, the additional expenditure due to waterlogging and soil salinity on practices like field preparation, enhanced seed rate and fertilizer applications is to the tune of Rs 1,095/ha. With the problem of waterlogging and soil salinity, the average cotton crop yields are low at 13 quintal/ha (q/ha) compared to about 15 q/ha in normal soils under Stage I. The same is the case with cluster bean, wheat, mustard and gram. In fact, the reduction in gram yields due to waterlogging and soil salinity is about 50%.

vii. The cropping pattern of cotton and wheat gives an average net return of about INR 25,000/ha/year. The net return from the gram crop is about INR 8,000/ha. In the case of areas affected by waterlogging and soil salinity the net returns are lower by about 25% in the case of cotton and by 46% in the case of the wheat crop.

With about 56% of the command having some degree of waterlogging problems, the loss to agricultural economy, with the increased crop production expenses and reduced crop yields, is huge. The problem is also causing extensive social costs as a result of submerged villages and the road network and migration of farmers from affected areas to new areas.

Interventions Attempted

Several ameliorative interventions have been attempted on a pilot scale to mitigate waterlogging and salinity in the IGNP command. These interventions, mainly biophysical in nature, included reduction in water allowance and drainage pilots for surface drainage, subsurface drainge, tube well drainage, skimming wells and bio-drainage (CAD 2007a). Most of the interventions faced operational, managemental, financial and institutional challenges and could not be upscaled for wider adoption in the command.

i. The CAD-installed vertical drainage systems faced considerable problems in terms of infrastructural arrangements for operation, availability of electricity, and a shared institution and have been put under operation for a short period of 2 to 3 years with periodical interruptions in pump operations. Though the results indicated that, to some extent, groundwater levels can be controlled, these projects have been discontinued due to huge costs involved.

ii. Installation of the subsurface drainage shows its beneficial effects in reclaiming waterlogged saline soils in a short span of 2 to 3 years in several subsurface drainage projects in the country (HOPP 2001). The subsurface drainage projects installed in IGNP also showed similar improvements. However, the technology is new to the area. The pilot projects need to be operated and monitored for evaluating the impacts and the effects on society and environment including the options for disposal of drainage effluent, which is a major challenge. The costs involved are huge (Rs 30,000 to 40,000/ha) and can be implemented only inder a state-sponsored program.

iii. Attempts were also made to decongest the large surfce water pondages. The experince showed that pumping for dewatering the stagnated water bodies is not a one-time activity, but it has to be a perennial one. Further, the cost of pumping of water is also very high. It has been concluded that dewatering through pumping operations would not be an economically viable proposition. Moreover, it is very likely that the decrease in standing water levels achieved by pumping will be nullified with inflows during the seasonal rains and irrigation spills.

iv. Bio-drainage with eucalyptus species was also attempted along small stretches of the canals. The experiences were good only along certain patches where the plants survived but failed due to continuous water stagnation. The bio-plantations may be used in certain waterlogged wastelands with suitable species and management practices. It has very limited success for controlling waterlogging of the agricultural lands.

v. However, the farmers are taking up tube well irrigation increasingly (especially under Stage I) and the adverse impact of fluctuating canal supplies on cropping intensity could be mitigated to some extent by adopting large-scale conjunctive use. The spread is slow due to higher costs and nonavailability of electricity to run the tube wells. Diesel-operated medium/deep tube wells are less cost-effective.

Moreover, most of these scientific interventions were top-down with limited participation of the communities and setting up of effective institutions for asset ownership, O&M and cost and benefit sharing mechanisms. As such, these had limited acceptance and had to be abandoned after the initial enthusiasm for implementation subsided and ground realities were sincerely appreciated.

Strategy for Groundwater Management

Provision of canals, the distribution system and the application of surface water to such a large area, besides providing direct irrigation benefits, also assists in modification of the groundwater regime. Such groundwater externalities may be both positive in the form of additional recharge and improvements in the water table in a water-stressed area and negative through creation of waterlogging, water-quality problems and soil salinity in previously water-congested pockets. The planning for integrated use of canal and groundwater will mot likely alleviate some of these problems and improve water use efficiency and productivity. Attempts have been made earlier in planning conjunctive use of groundwater and canal supplies for Haryana (Tyagi 2006) and for Punjab (Sondhi and Kaushal 2006) using simulation modeling techniques. Some studies have also been made in IGNP for projecting the problems of waterlogging and soil salinity and evaluating various options for problem amelioration (ORG 1996, 1999; NIH 1996).

From the experiences of IGNP and experiences elsewhere, it is certain that there are no global solutions to problems of such unprecedented magnitude. It is proposed that according to the extent of the problem, the affected areas may be broadly divided into the following three categories and appropriate measures implemented both on short- and long-term bases.

i. *Converting water-ponded areas as wetlands*: As the IGNP command has no natural and man-made drainage, the inundated areas may be designated as wetlands and used as receiving bodies for the irrigation return flows and surface and subsurface drainage effluents. These wetlands can also be put for economic use like freshwater and saline water fisheries according to the water quality. The alternative plan of transferring such poor-quality water through a dedicated canal to the Arabian sea requires large investments and cooperation of the neighboring country.

ii. *Enhancing tube well development in waterlogged areas*: Areas afflicted with the waterlogging problem may be ameliorated, among others, through appropriate groundwater management practices. A large portion of the command has developed freshwater layers closer to the surface and below, and conjunctive use of canal water and groundwater in this area will result in controlling of the groundwater table. The installation and operation of tube wells by the government have not produced encouraging results. The increasing installation of private tube wells and successful use of groundwater for irrigation by the farmers in the last few canal supply deficit years have shown that the conjunctive use of canal water and groundwater is viable in the IGNP command. However, the results of the conjunctive use on the control of the water table will not be visible in a short time. Long-term planning is required in promoting conjunctive use of canal water and groundwater, which involves :

   a. Institutional support for delineating the aquifers suitable for tube well installation and identifying appropriate technologies for well construction to avoid rising of saline water.

   b. Canal supply management practices for providing reduced irrigation allowance on *warabandi* and subsidies and policy support.

   c. Priority in energization of the tube wells in the IGNP command can be one of the supports from the government that will encourage the farmers to opt for tube well irrigation.

iii. *Subsurface drainage for saline-waterlogged areas*: The areas with soil salinity associated with saline groundwater require subsurface drainage to leach out salts and maintain a favorable salt balance in the root zone. The pilot projects on subsurface drainage have shown that salinity in the root zones can be quickly reduced when the cropping intensity will increase and crop yield will be more than double. However, this technology requires the participation of a group of farmers having contiguous land parcels and also issues like disposal/reuse of drainage effluent need to be addressed before embarking on large-scale adoption. The already installed successful pilots on subsurface drainage (SSD) systems may be operated and monitored for deriving experience on these issues. Besides the technical operation of the infrastructure, establishing an effective drainage farmer group/association is crucial for its long-term sustainability.

Conclusions and Recommendations

Transfer of large amounts surface irrigation water through an elaborate water conveyance and distribution infrastructure under IGNP helped India to make use of its share of the Sutlej river water as established under the Indus Water Treaty. Availability of water in this dry area helped tremendously in the expansion in cropped/irrigated area and a substantial change in agricultural land productivity, improved socioeconomic conditions, and in the general well-being of the local poor and immigrant communities, and greening of the desert area. The advent of irrigation has resulted in rapid changes in the hydrologic regime and groundwater conditions. During the past about four decades, the groundwater levels have risen by more than 1.0 m per year and more than 50% of the command area now has groundwater levels in sensitive zones (> 6.0 m bgl). Substantial areas have gone out of cultivation due to water stagnation/inundation, waterlogging and soil salinity. A considerable loss to the agro-economy is being incurred due to constraints in the choice of crops, higher costs of cultivation and low crop yields caused by waterlogging and soil salinity. Several of the ad-hoc technical measures implemented in the form of pilot projects on the hot-spots have met with little success and acceptance by the farming communities and have been either abandoned or operated on a lower scale. The recent spurt in the development of private tube wells, especially under Stage I of IGNP, caused by deficit canal water supplies as a whole to the IGNP and also opening up of areas under Stage II of the command, have shown a positive impact through lowering of water tables and better crop yields.

The waterlogging and soil salinity areas of IGNP require interinstitutional cooperation and action plans with irrigation, groundwater, agriculture and other concerned departments, CAD and other research and development institutions, local NGOs and farmer bodies to develop and implement short- and long-term plans of groundwater management strategy and other innovative ideas. Among the strategies this paper suggests dividing the affected areas into three broad categories and introducing appropriate interventions. These include i) water-ponded areas—treat them as wetlands and use appropriate economic activities such as saline water fisheries, ii) waterlogged areas—enhance tubewell irrigation in waterlogged areas and provide policy and institutional support on technology, management of canal water supply and energy provision, and iii) saline groundwater affected areas—provide subsurface drainage for leaching out the salt and create a favorable soil-balance condition at the root zone.

The planning, development, implementation and operation of the large and long-distance surface irrigation water transfer and distribution infrastructure under the IGNP have provided several important lessons of enormous cost for all those involved in improving the welfare of people and ensuring food security through large-scale land- and water-centric interventions. Professionals with their defined areas of expertise will draw lessons so as to sharpen the future line of thinking and action. But one thing is certain, which is that all future water infrastructural plans elsewhere and especially those envisaged under the National River Linking Project of India must ensure that while achieving the highest positive impacts the present and future negative externalities must remain at a minimum.

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