MANAGING SALINITY IN NORTH-WEST INDIA: THE CONJUNCTIVE USE OPTION

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ABSTRACT

North-West India which comprises south-western Punjab, northern Haryana and north-western Rajasthan is a region with distinct agro-ecology with peculiar land and water management problems. The major part of the area lies in a semi-arid to hyper-arid zone where evaporation exceeds rainfall by a factor of 2 to 15. Alluvial deposits that underlie most of the area, contain to a great depth, a continuous body of water which occurs under phreatic conditions in a large part of the area with few semi-confined to confined aquifers occurring at varying depths. The ground water availability as well as quality decreases with increase in aridity from northeast to southwest. To correct the water demand/supply imbalance in this agriculturally productive region, extensive irrigation has been introduced through large scale diversion of surface water. In spite of surface water diversions, the water availability per unit area is low and the region is under the influence of waterlogging, salinity and alkalinity which are undermining the capacity of the region to meet its food production targets. Various long and short term options including preventive and curative measures have been examined to maintain the agricultural productivity at high levels. The long term solution lies in provision of drainage to lower the water table and leach salts, which should be disposed in a permanent sink. The existing geo-political situation and the absence of natural drainage outlets favour conjunctive use of marginal quality ground waters and drainage effluents with canal waters to tide over the water scarcity, to minimize the rise of the watertable and to reduce the disposable drainage effluents.

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In land areas afflicted with salinity under high watertable situations, conjunctive use is permissible only in conjunction with sub-surface drainage. Agro-chemical amendments together with salt tolerant cultivars promote the use of high residual sodium carbonate waters in a medium term plan. In areas with deep watertable but with high ground water salinity, cropping choices are limited and salt tolerant trees/halophytes are better options. Conjunctive use planning in ground water areas with a declining trend calls for increased emphasis on ground water recharge to sustain the existing cropping pattern. In the absence of large scale investment in the near future, the technical and socio-economic situation favours conjunctive use as medium term option for managing salinity in North-West India.

INTRODUCTION

Conjunctive use management of multi-source/multi-quality waters can be defined as the management of multiple water resources in a coordinated operation such that the total water yield of the system over a period of time exceeds the sum of water yields of the individual components of the system resulting from uncoordinated operation. The net output in the conjunctive mode is more compared to the net output when each source/quality of water is used separately. As a result of conjunctive use of surface and ground water resources, it is possible to have optimum utilization of water resources as ground water could act and function as a storage reservoir, regulation agent and conveyance medium. The separate use of surface and ground water in itself may not always constitute a conjunctive use. The conjunctive use concept recognizes:

i) the unified nature of water resources as a single natural resource

ii) advantage of the interactions between the surface and ground waters in planning the use from the two resources.

Conjunctive use is planned and practiced with the following objectives:

(1) Mitigating the effect of the shortages in canal water supplies often subject to steep variations in river flow during different periods in the year.

(2) Increasing the dependability of the existing water supplies.

(3) Alleviating the problem of high water table and salinity resulting from introduction of canal irrigation.

(4) Facilitating the use of high salinity ground water, which cannot otherwise be used without appropriate dilution.

A number of conjunctive use planning models have been developed to determine pumping rates for a sustainable potentiometric surface, allocation of water to areas under different crops and optimal hydro-salinity regimes in a basin. The economic aspects of water allocations have received greater attention and both linear (Khepar and Chaturvedi, 1982; Bhirud, 1989) and dynamic programming models (Knapp and Wichelns, 1990) have been used in such studies. Ground water simulations have also received greater attention and analytic as well as numerical approaches have found use (Helweg and Labadie, 1976; Lefkoff and Gorelick, 1990). Models that develop a quantitative understanding of economic, agronomic and hydrologic processes that occur in a saline irrigated system have been rather limited. Srinivaslu et al. (1997) developed and applied such a model to lower Ghaggar Basin.

AREA AND THE PROBLEM

North-West (N.W.) India includes parts of the states of Punjab, Haryana and Rajasthan. Agriculturally this is one of the most productive areas contributing a major part of rice, wheat, cotton, pulses and oilseeds. The climate of the area being arid to sub-humid, large-scale irrigation development has taken place in this region. The major irrigation projects that have been undertaken include Bhakra, Western Yamuna, Gang and IGNP (Fig. 1).

Fig. 1. Location Map and Major Canal Systems of North-West India.

A major part of N.W. India is underlain by saline ground water. At a macro scale, distribution of ground water quality in a few of the states shows that on average 59% of the ground water falls in the marginal or poor quality zones (Table 1). Specifically in the region covering Haryana and Rajasthan more than 50% of the area is underlain with poor quality waters(Fig. 2).

Table 1. Distribution of Ground Water Resources with Respect to its Quality in Some States.

State	Ground water quality (%)		
	Good	Marginal	Poor
Haryana	37	8	55
Punjab	59	22	19
Gujarat	70	20	10
Rajasthan	16	16	68

Source: Manchanda et al. (1989)

Irrigation development in this region has taken place without adequate drainage systems. In arid regions, the natural drainage, as a rule, is not very well developed. Consequently salt and water have been accumulating in various irrigation projects. An area of about 1.0 million ha has become salinized and waterlogged. It maybe mentioned that annual irrigation intensity from canal irrigation in this region is less than 100 percent and water allowance varies from 0.2 litre/sec/ha to 0.4 litre/sec/ha. The overall water supply is much below the requirements. The problems facing N.W. India are:

- Insufficient surface water supplies to irrigate the entire cultivable command area.
- Saline/sodic ground waters occurring in aquifers of low transmissivity
- Rising trend in watertable leading to salinization of productive agricultural land.
- Falling trend in watertable in fresh ground water areas leading to increased pumping costs.
- Absence of outlets for disposing of saline drainage effluents.

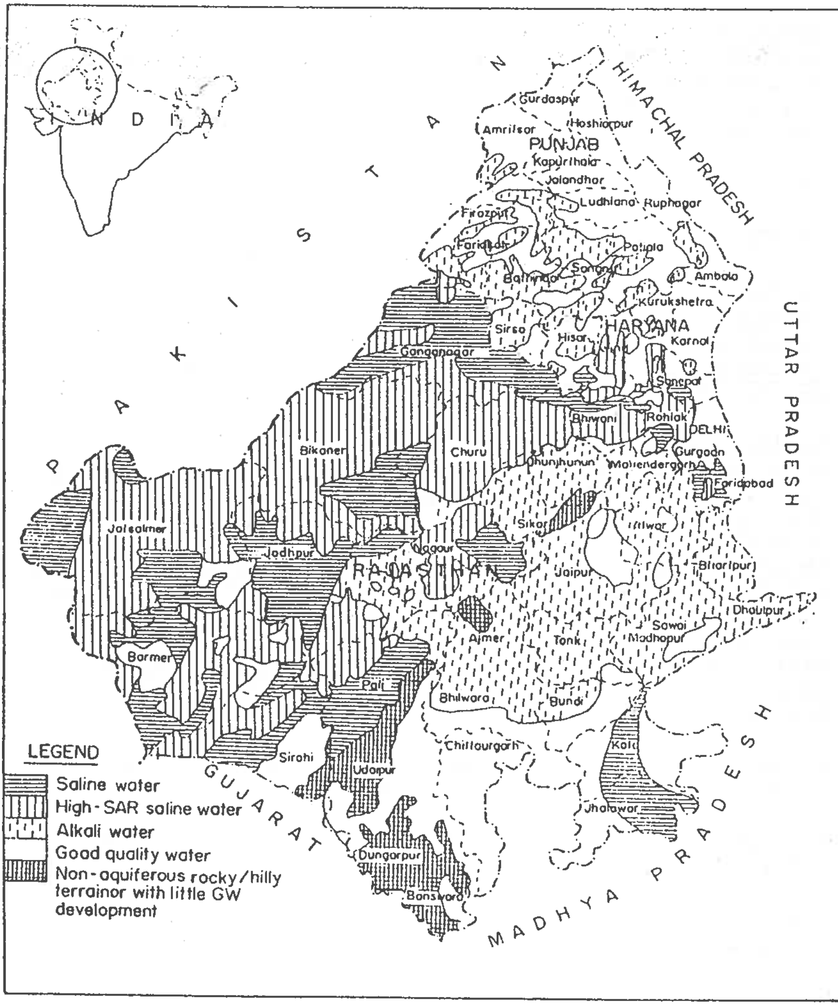

Fig. 2. Ground Water Quality in Haryana, Punjab, and Rajasthan.

The requirement for additional water supplies to increase the irrigation intensity from less than 100 percent to about 150 percent annually and the requirement of keeping the water table at a safe distance or reduction in disposable drainage volumes can, to same extent, be fulfilled by resorting to conjunctive use of surface and saline ground waters.

CONJUNCTIVE USE FOR SALINITY CONTROL

For surface water development alone, the water table in most irrigated areas would rise sooner or latter and waterlogging of the root zone would occur. There could be some limited situations where sub-soils are permeable and water table gradients are sufficiently steep to allow excess ground water to flow to other areas. With waterlogging, salt accumulates in the root zone because only pure water is utilized in evapotranspiration, leaving the salt behind.

In planning conjunctive use in a saline environment, two things are important. These are: (1) water table fluctuations and (2) river basin salinity balance. With conjunctive use of surface and ground waters, where a free hydraulic contact between the root zone and the sub soil water exists, this problem can generally be resolved over large part of the area, by lowering the water. In such a situation with conjunctive use, the maximum water level can be kept by design at some safer distance below the root zone. One can then maintain both water balance as well as salinity balance.

Conjunctive use however, does not permanently resolve the problem of salinity. It usually postpones this problem, maybe for decades. However, the salinity problem remains unless and until salts are transported out of the basin from each and every unit. Very few ground water storages allow for an adequate water flow rate to accomplish salt transport and maintain the levels of dissolved solids below acceptable level. The problem of root zone salinity materializes rapidly but the problem of the ground water basin takes more time to appear. It should be clearly understood that the root zone salinity problem is easier to resolve as compared to the ground water salinity. Positive actions have to be taken to restore salinity balance before the problem becomes irreversible. Larger basins reach the point of no return later in time than the smaller basins. An appropriate plan for maintaining the proper salt and water balance over the entire basin is an important element of conjunctive use planning which essentially requires transport of salt outside the basin. The salt flows with water, it means that a certain amount of annual ground water recharge will have to be thrown outside the basin. The quantity of the water to be thrown out will depend upon the concentration of the ground water. It was worked out by Srinivaslu et al (1993) that for part of the Lower Ghaggar Basin in Haryana (India) about 15% of the annual recharge would have to be thrown out of the system to maintain salinity balance at desired level.

TECHNOLOGICAL OPTIONS FOR GROUND WATER ABSTRACTION

There are various technical options available to abstract ground water/drainage water. Generally the water of relatively good quality is underlain by higher salinity ground water. Generation of drainage effluents would, therefore, involve manipulation of relatively fresh water without disturbing the deep saline waters. The possible technological options for drainage water abstraction may include: (i) several variations of vertical drainage and (ii) horizontal drainage.

Vertical Drainage

When aquifer formations provide favorable, vertical drainage through wells and tubewells as an efficient means of generating irrigation resource as well as producing drainage relief. Tubewells are relatively inexpensive to install and employ proven technology. Shallow tubewells which pump water from the first aquifer and cause larger draw-down per unit of water pumped are more suitable for lowering the water table. Experiences from Peoples Republic of China (You and Wang, 1983) and Pakistan (Chaudhary, 1992), and India (FAO, 1985) support this argument.

The possible variations of shallow wells for vertical drainage include (1) common filter and cavity tubewells (2) skimming wells and tubewells and (3) well points.

Cavity and Filter Tubewells

If water table control is the objective, filter tubewells are better alternative as compared to cavity tubewells. In filter tubewells, the well field for watertable control is so designed that average watertable is maintained at a preselected level. Well spacing, aquifer depths to be tapped and pumping rates are the important design considerations.

Skimming Wells

If it is desired to pump only the fresh water overlying the saline ground water, pumping from such aquifers has to be managed carefully. This requires special types of wells known as skimming wells. These may be tubewells or open wells. The design of these wells depends upon the thickness of fresh water aquifer, hydraulic properties, water table conditions and the discharge rates. A typical lithology where installation of skimming tubewells would be possible is shown in Fig.3.

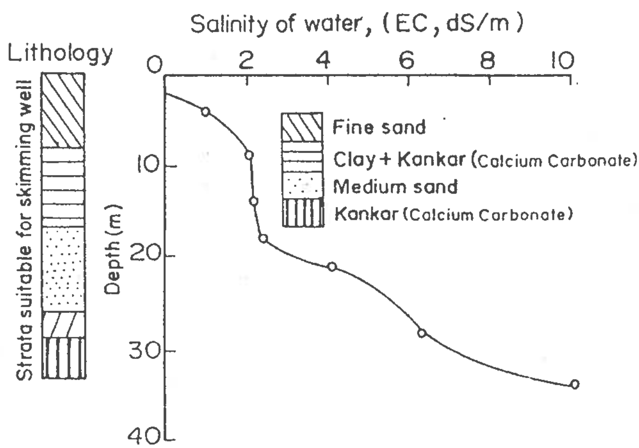

Fig. 3. Lithology and Water Quality of Bore Hole Suitable for Skimming Well. (Vill. Chiri, Rohtak, Haryana).

Studies were conducted at CSSRI to determine the rate of pumping at various penetration depths (Gupta and Tyagi, 1986) and it was concluded that for conditions prevailing in Ghaggar-Yamuna basin, skimming tubewells should be lowered for 50 percent penetration depth and for about 15 m^3/hr discharge. Skimming wells of 3-4 m diameter sunk up to 3.5-5.0 m depth were found useful in lowering the water table and in generating irrigation resource at Hisar (Kumar et al, 1990).

Horizontal Drainage

Where subsurface waters are relatively more saline, the water table remains above 2.0m for a considerable length of time and hydrogeological conditions do not permit the installation of tubewells, horizontal drainage can be effectively used to control waterlogging. Although the drainage water, to begin with, may be more saline, the salinity generally reduces with time. Because only first few meters of ground water flows towards horizontal drains in stratified soils, the system is more effective in skimming shallow ground water of fresh quality. The feasibility of horizontal drainage has been established through experimentation at several locations in North-West India (Rao et al, 1986). Based on cost optimization studies for a part of the irrigation system in North-West India, it was found that: (i) skimming wells and shallow tubewells are more cost effective in abstraction of drainage effluents, if hydrogeological conditions favoured their installation. (ii) it is possible to work out a scheme of operation that would permit reuse and thereby increase supply of water for irrigation and reduce the quantity of water required to be disposed through evaporation ponds or regional drainage network.

Assuming that it is technically feasible to intercept and pump the net annual recharge out of the irrigated area, it is necessary to determine an optimal mix of the technical alternatives that may be adopted in a given area. This could be achieved through model based on linear programming algorithms. A schematic diagram of the hydrological process is shown in Fig 4.

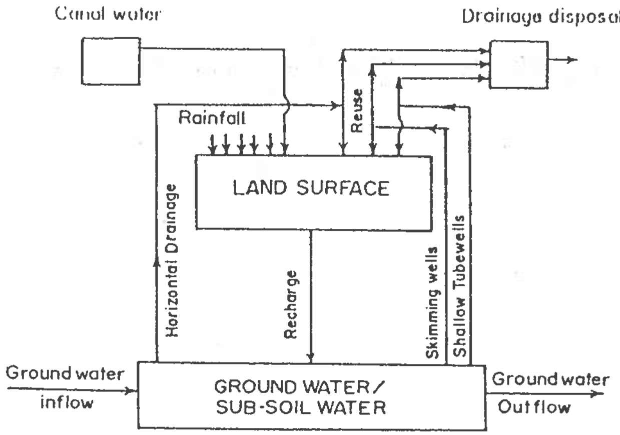

Fig. 4. Schematic Diagram of the Hydrological Process of Ground Water Abstraction and Reuse.

CONJUNCTIVE USE MANAGEMENT MODEL

Once the ground water quantity to be developed and its mode of development has been decided, the next step is to allocate water in conjunction with canal water. Such a model has been formulated by Srinivaslu et al (1997) to aid in planning strategies for water allocation and disposal so as to maintain salt and water balance in the crop root zone as well as the aquifer. The problem is treated as a non-linear optimization problem and a conjunctive use management model is developed. The schematic diagram of the process is shown in Fig. 5. The model allocates water to a number of crops according to their sensitivity to saline water so as to maximize net returns. The income is generated from disposal of crop produce while the cost is incurred in purchase of canal and tubewell waters. The non-water production inputs are treated as fixed costs. To keep the ground water salinity at the original level, part of the pumped ground water is disposed through evaporation ponds and has a cost. The allocations essentially center around crop-water-salinity production functions which are non-linear in nature.

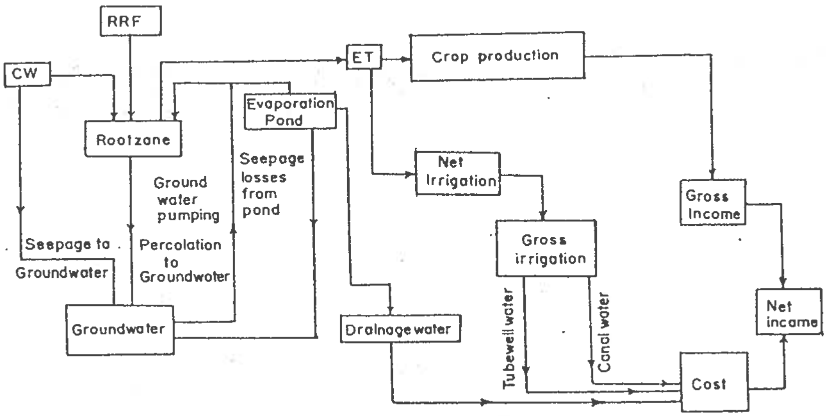

Fig. 5. Schematic Diagram of the Conjunctive Use Management Model.

The required production functions have been developed (Srinivasulu and Tyagi, 1993) with basic data on crop-water production functions and crop-applied water salinity production functions obtained from published and experimentally determined relationships (Tyagi 1980, Bhirud 1989). The two functions were synthesized into a single water-quality-quantity production function adapting the approach given by Letey et al. (1985). The required cost and benefit estimates for crop activities, canal water, ground water pumping and disposal etc., were developed using standard techniques of estimating and costing. The estimates of ground water in different water quality zones are based on water quality information from shallow tubewells which was subjected to analysis by the statistical software called 'GEO-EAS'.

The outputs from the model were cropping patterns, ground water disposal policies, total benefits and benefits per unit area/applied water.

SUSTAINABILITY OF SALINE GROUND WATER USE

Whereas it is possible to maintain the watertable at the prescribed level without ground water disposal by adjusting pumping, it is not a practice that can be sustained on a long term basis. In the absence of disposal, the salt load in the ground water reservoir will continue to increase and after some time, the negative effects of rise in ground water salinity will start appearing in the form of reduced yields and lower net benefits. In order to evaluate the level of ground water salinity at which the cost of disposal and benefits from increased availability of ground water without disposal will balance yield and income reductions, the model was run at various ground water salinity levels. The resulting benefits from water use without disposal were compared with benefits occurring with ground water disposal at various salinity levels (Fig. 6).

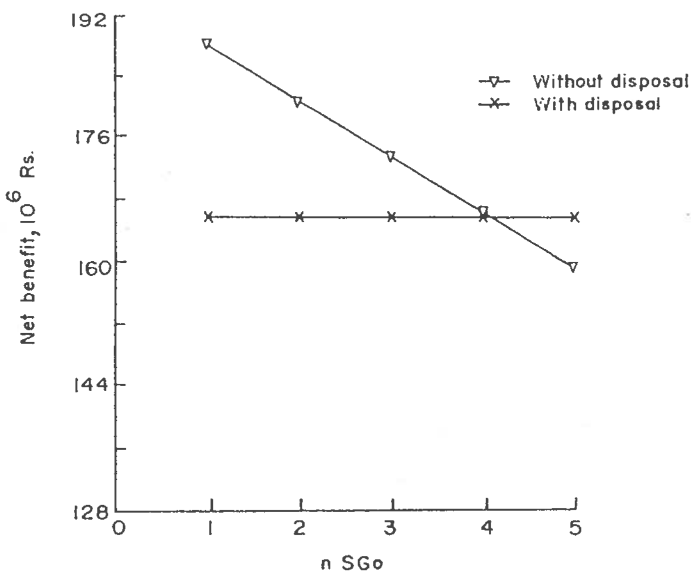

Fig. 6. Net Benefit With and Without Disposal of Various Levels of Ground Water Salinity (SG).

It may be seen that the benefits from optimization scheme without disposal were higher than benefits with disposal upto a salinity level nearly 4.1 times that of original salinity. It has several implications from the viewpoint of operation and management of saline ground water in conjunction with canal water. These are:

(1) Investment on disposal in the form of evaporation ponds can be deferred until such a time that the yield losses from increased ground water salinity nearly balance the cost of disposal. How long the investment can be deferred will depend upon the original salinity of the ground water, rainfall amount and its distribution, canal water quality and quantity.

(2) The level of investment in ground water disposal through evaporation ponds should be less than or equal to the annual reduction in net benefits.

(3) Whereas lowering the watertable and keeping it below critical levels is a necessary condition for sustainable conjunctive use of fresh and saline waters, it is not a sufficient condition. The sufficiency is provided by salt disposal only.

CONJUNCTIVE USE TECHNOLOGIES FOR MULTI-QUALITY WATERS

In conjunctive use, fresh and saline water is used in a manner that salinity of the soil would not exceed a pre-decided level so that the desired crop could be grown. In this strategy, a number of alternatives are available as shown in the following chart.

- Conjunctive use strategies
  - Blending
  - Cyclic use
    - Sequential applications
    - Switching model
      - Switching within a cropping season
      - Seasonal switching

PRESENT STATUS OF CONJUNCTIVE USE IN NORTH-WEST INDIA

If we look around, we find very few examples of conjunctive use in the irrigation command. The only planned conjunctive use project that can be cited, as an example is the construction of augmentation tubewells in the Western Yamuna Canal Command in the state of Haryana. Construction of percolation tanks in the state of Karnataka and Maharashtra could also be cited in this context. However, major efforts have been voluntary and unplanned. In this category, one may cite the example set by the farmers in the states of Punjab, Haryana, Western Uttar Pradesh and the Maharashtra. As an example, one may look at the case of Haryana where joint use in areas with saline ground water has been picking-up over the years. More than 0.3 million ha area is being irrigated with saline waters covering a large zone in the irrigation commands. The increasing area under irrigation with saline water is also reflected in the number of minor irrigation structures that have tremendously increased during the last three decades. The increase has been both in the canal irrigated (more than 50% area irrigated by canals) as well as tubewell irrigated districts (more than 50% area irrigated by tubewells)(Table 2). The increased number of structures, has helped in arresting the rate of rise in water table to a certain extent.

A similar situation has been developing in the Mahi Canal Command in Gujarat particularly in areas underlain with ground water of EC < 3 dS/m. However, conjunctive use in the Ukai-Kakrapar command has not picked up because of the excess water available through the canals. A policy issue on the closure of the canal system during the hot season has been taken although the same is yet to be implemented.

In Rajasthan, conjunctive use of saline and fresh water has been limited as a result of ample water available through the IGNP canal in stage I. Moreover the ground water quality is poor in most of the stage I of IGNP. The Government of Rajasthan has proposed an incentive scheme to encourage conjunctive use of canal and ground waters. According to this scheme, sums of Rs. 282.6 lakhs are to be spent as incentive for the construction of about 1600 tubewells for this purpose.

Table 2. Progress of Minor Irrigation Units (Tubewells) in Haryana State.

District	Irrigated area by source (%)		District	Irrigated area by source (%)	
	Canal	Tube-wells		Canal	Tube-wells
Hisar	86	14	Panipat	28	72
Sirsa	84	16	Karnal	14	86
Jind	73	27	Gurgaon	13	87
Rohtak	68	31	Mahendragarh	7	93
Sonepat	67	33	Rewari	3	97
Kaithal	60	40	Kurukshetra	3	97
Bhiwani	58	42	Yamuna Nagar	3	97
Faridabad	36	64	Ambala	0	100

Source: Tanwar (1996)

SUMMARY

Conjunctive use of canal (fresh water) and ground waters in fresh water quality zones has been developed successfully in alkali affected areas. The development of ground water in these areas facilitated leaching and drainage leading to successful reclamation of alkali soils in Punjab and Haryana.

The conjunctive use in saline ground water areas with rising trend in water table is progressing gradually and there is need for refining the technology of ground water exploration in poor aquifers. Research on water application and scheduling to moderate the effect of poor water quality use on soil and crop health is also needed. In North-West India, the salinity balance can be maintained only if salts are disposed outside the region through a constructed drainage canal to the sea. Investigations on the techno-economic feasibility of this venture should be evaluated.

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