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Reuse and disposal of brackish and saline drainage water in Haryana, India

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The state of Haryana is located in the northwestern part of India and covers a total area of 44,200 km², of which about 97% is on an alluvial plain between the Ghagger River (which is part of the Indus river system), and the Yamuna River (which belongs to the Ganges river system). This plain is part of the Indogangetic plain and constitutes a topographical depression between the Siwalik hills in the north and the Aravalli hills in the south, sloping gently downwards from both sides. The axis of the depression runs from Delhi towards the northwest, as shown in **Figure 1**.

The mean rainfall from June to September decreases from 1,100 mm in the northeast to 300 mm in the southwest. The surface runoff created by the monsoon rains drains to the Yamuna and Ghagger rivers from their respective drainage basins. The surface runoff from the internal drainage basin in the central part of Haryana is drained off by pumping it into the irrigation canals.

About 35,000 km² of Haryana is agricultural land. The soil texture ranges from sand and loamy sand to sandy loam and loam, with sandy loam being the most widespread soil.

Approximately 20,000 km² of land is irrigated: 8,000 km² with groundwater and 12,000 km² with canal water. The northeastern part of the stage (which is underlain by fresh groundwater) and the fresh water areas along the Yamuna and Ghagger rivers and some branches of the canal system, are irrigated with groundwater. In the northeast there is a net decline of the groundwater level because of the extraction of the fresh groundwater.

About 28,000 km² of Haryana is underlain by brackish or saline groundwater and depends mainly on canal water for irrigation. The water allowance from the canal system is rather low, between 0.16 and 0.19 l/s/ha. Therefore, the farmers only irrigate part of their land during the same season, whereas a part remains fallow. Losses by percolation in the conveyance system and in the field result in a rising groundwater level. At present, the rise ranges between 0.15 and 1.0 m per year, with an average of 0.3 m, except in the so-called critical areas, where the water table is at a depth of less than 3 m in June before the start of the *monsoon and the percolation of irrigation and rainwater is offset by upward capillary movement and increased evapotranspiration. These critical areas are mainly concentrated in the district of Rohtak and already cover more than 4,000 km^2. Areas where the water table is at a depth of less than 1 m in October after the monsoon are considered to be waterlogged. About 500 km^2 are concurrently affected by waterlogging.*

From 1983-1985 a project was carried out by the Haryana State Minor Irrigation (Tubewells) Corporation and the FAO in order to study the future rise of the groundwater level, its agroeconomic consequences and the technical solutions for water table control in which the reuse and disposal of saline drainage water play a major part. A groundwater model was made for the whole state of Haryana, to predict the development of the water table for the next 30 years. This model forecast that approximately 20,000 km^2 will be waterlogged after 30 years. An agroeconomic study was done in order to establish a timetable of the agroeconomic deterioration, to identify the areas with the highest losses and to estimate the investment ceiling and the internal rate of return for the technical measures for water table control. The technical solutions and the reuse and disposal of drainage water which play a major part, will be discussed in the following paragraphs.

I - Water table control

1. Future development of soil salinity

The technical measures required to reduce and control the rise of the water table and soil salinization should aim at minimizing the percolation of irrigation and rain water and at draining off the remaining recharge of the groundwater.

Minimizing percolation of irrigation water can be obtained by proper surface water management: improving surface drainage, lining the water conveyance system, promoting farm water management, especially land levelling, and planting trees along field boundaries and water courses.

Draining off the remaining recharge of the groundwater can be done by subsurface drainage. In this respect the presence of brackish or saline groundwater, the salinity of which generally increases with depth, and the very limited disposal possibilities for drainage water, present particular problems. Moreover, if the solution is to be appropriate, the phenomenon of salinization in an almost flat plain with slight local depressions, which consists of silty soils with a high capillary conductivity and is partially irrigated, should be well understood.

The rise of the water table will first be felt in the local depressions. Previously, rainfall could be stored in the soil, and flooding only occured during very heavy rainstorms, but flooding is now a normal phenomenon and water remains on the surface for some time after the monsoon. Farmers are unable to grow a Khariff crop during the monsoon or even a Rabi crop after the monsoon if they cannot prepare the soil in time. If no crop is grown, no irrigation water will be applied, and on the silty soils the only countercheck to capillary rise from a shallow water table is provided by seasonal rainfall. This is insufficient. After firstly being affected by waterlogging, the soils in the depressions are subsequently affected by salinization. Moreover, when the water table in the depressions falls owing to capillary rise and evaporation, there is an inflow of groundwater from neighbouring areas, where the water table is higher although its depth below surface may be greater (see **Figure 2**). Draining of these depressions only makes sense if, simultaneously, surface runoff can be removed, the water table can be lowered and irrigation water can be made available for growing crops on the reclaimed land.

Even in the case of flat land without depressions, part of the area may become salinized because not enough water is available to irrigate all the land. Soils that are not irrigated and where for that reason the water table is deeper than on neighbouring irrigated soils, will receive seepage water from the latter and become salinized by capillary rise, as shown in **Figure 3**. The rate of salinization depends on the depth and salt concentration of the groundwater and on the difference between percolation and capillary rise. When a fallow period alternates with crop growing, the percolation from rain and irrigation water will generally be sufficient to keep salinity at a level acceptable for crops, but when fallows predominate, the soil will salinize in the long term if the water table is less than 5 m deep. In this case too, artificial drainage only makes sense when irrigation water can be made available for irrigating the fallow land which, like the depressions, serves as a natural water and salt drain for neighbouring soils. The loss of these soils by salinization is the price of such a natural drainage system.

Although the areas where the water table is at a depth of less than 3 m are considered to be critical, this does not mean that all the soils in these areas will salinize in the future. The water table only indicates a risk of salinization but does not indicate increasing salinity. It should always be considered together with the water flow in the unsaturated zone. As long as percolation prevails over capillary rise, there is no risk of increasing salinity.

Given the conditions outlined above, a careful survey must be made of the local topography, depth and salt concentration of the groundwater, possibilities for reuse or disposal of drainage water and the cost/benefit ratio of drainage, so that an appropriate solution can be chosen. The solution may even consist of not installing any drainage system at all and relying on the natural drainage towards already salinized lands if no irrigation water is available for these soils.

2. Subsurface drainage

In choosing the methods for subsurface drainage, two special conditions prevailing in Haryana must be taken into account. First, the possibilities for disposing of drainage water into rivers, lakes or otherwise are limited, and therefore drainage water should be reused as much as possible, either directly or after mixing with canal water. This implies the necessity of keeping the salinity of the drainage water as low as possible. Secondly, the salinity of the groundwater generally increases with depth. The groundwater consists of fresh to brackish water overlying saline water, or of saline water sometimes intermixed within layers of fresh or brackish water.

Under these conditions the drainage system must skim off the upper water of the aquifer in order to minimize the salt burden of the drainage water. The options for skimming drainage are: horizontal drainage by a system of laterals and collectors at a depth beween 2 and 3.5 m, from where the water is pumped into a surface drain or irrigation canal, or vertical drainage by a system of shallow wells.

The choice depends on the salinity and transmissivity of the aquifer. In the case of saline water, horizontal drainage should always be used. Although the drainage water will at first be saline, the salinity will decrease with time, because a layer of less saline water supplied by percolation will gradually be built up. Because only the upper 5 to 10 m of the groundwater flows towards horizontal drains, especially in stratified soils, horizontal drainage is more effective than vertical drainage in skimming this less saline water.

A horizontal drainage system is assumed to act as a large well that not only serves the depression in which the system is laid out but also the surrounding, higher land. When calculating the drain spacing, a water table depth of 1 m for irrigated land was assumed, together with a design discharge of 0.003 m per day (the latter on account of the estimated drainage surplus, the ratio between the area of the depression and the total area of land, and the number of pumping hours per day). These criteria yielded a spacing between 60 and 120 m, to a large extent depending on what anisotropy ratio is assumed for the hydraulic conductivity of these stratified soils. Since the one-acre plots of 60 m $\times$ 67 m should not be crossed by drains, the laterals should be placed at the boundaries of these plots, at spacings of 60, 67, 120 or 134 m. In view of the silty and sandy subsoil, the laterals must be protected from silting up by a gravel envelope or a filter of synthetic material. Because of the drain depth and the unstable subsoil, the construction must be performed by special drainage trenchers.

The greatest potential for horizontal drainage is in the depressions of the critical areas, where the groundwater often has a high salinity. However, as already mentioned, the construction of a subsurface drainage system in the depressions is only useful if surface drainage is adequate and irrigation water can be provided.

Well pumping is applied on a large scale in the fresh water zone in the northwestern part of Haryana, primarily to provide irrigation water but also to provide drainage. The main problem in that area will be the fall of the water table caused by overpumping. The transmissivity of the aquifer to a depth of 150 m varies from 100 to more than 2,500 m^2 per day and allows for the installation of deep wells with a high capacity of 30 to 50 l/s or shallow wells of lower capacity.

In the area underlain by brackish and saline water the transmissivity to the depth of 150 m is less than 500 m^2 per day. Because of the lower transmissivity and the need to skim the least saline water, shallow wells of much lower capacity are necessary.

The best protection against upcoming of saline water is offered by the presence of a clay intercalation that serves as an impervious barrier. The capacity of the pump can then be estimated from the transmissivity of the aquifer, which in turn enables the radius of influence of the well and the well spacing to be calculated. If the transmissivity is between 100 and 150 m^2 per day for a shallow aquifer above an impervious barrier, the pump capacity can be estimated at about 6 l/s and the average well spacing at about 300 m.

Without the presence of an impervious barrier the safe yield of the pump, which avoids upcoming and can be calculated with skimming well equations, drops to values of less than 1 l/s, since the aquifer containing fresh or brackish water generally does not extend beyond 30 to 40 m. In such cases the wells cannot be operated individually but must be interconnected in a well point system.

The so-called cavity well is particularly suitable for the local conditions. It is constructed by drilling a hole until a sand layer is encountered below a layer of stiff clay. After retracting the casing pipe into the clay layer, sand is pumped out until a stable cavity has developed in the sand below the clay layer and the water clears. The yield of these wells is about 6 l/s and the depth usually from 15 to 20 m. The life-time may be as much as 20 years and depends on the quality and thickness of the clay layer and the grain size of the sand. The farmer operates the well for several hours per day and skims the least saline water by stopping the pump as soon as the salinity of the water increases.

A field survey showed that because aquifer characteristics change rapidly over short distances, it is impossible to indicate at district level the zones that are suitable or unsuitable for vertical drainage. Local entrepreneurs of cavity wells use their experience and operate by trial and error. In the past ten years, farmers have considerably increased the number of shallow wells for supply or irrigation water. At the same time, they have already explored to a large extent the possibility of vertical drainage by wells.

II - Reuse of drainage water

In the fresh water zone, as already mentioned, the rise of the water table has been converted into a fallowing to the introduction of well drainage which provides irrigation water at the same time.

In the brackish and saline water zone farmers are actually already using these waters for irrigation on a large scale, since the canal water allowance is limited between 0.16 and 0.19 l/s/ha and they want to augment their water supply. Of a total number of 360,000 shallow tubewells in Haryana, 65,000 are installed in the area underlain by brackish water and 3,900 in the saline water area, yielding densities of 3.4 and 0.6 wells per 100 ha respectively, against 15.6 for the fresh water zone.

Table 1 presents for the eight districts located in the brackish and saline water zone of Haryana the amount of water supplied by the canal system and by extraction of brackish and saline groundwater as well as the remaining potential. The total extraction was estimated from the number of wells and an average yearly extraction of 15,000 m^3 per well. The remaining potential was estimated from the average rise of the water table during the period 1974-1984, a specific yield of 0.125 and the area underlain by brackish and saline groundwater. The table clearly shows that especially brackish water is used on a large scale and plays an important part in supplementing the canal supply. The comparison between the extraction and the remaining potential shows that pumping brackish water also plays an important part in providing drainage and is already largely responsible for a decrease in the rise of the water table. Farmers started to construct cavity wells in the brackish zone on a large scale about ten years ago.

A survey has shown that farmers are using brackish groundwater either for direct irrigation or by alternating between fresh canal water and brackish well water or after mixing both waters. **Table 2** presents the yield reduction for these three methods of water applications, three EC ranges of well water and four crops, obtained from a field survey in the district of Hissar. Although water with an EC between 2 and 4 dS/m may already have produced a yield reduction, the yield obtained in the range between 2 and 4 dS/m was assumed to be 100%.

Since neither the different methods of water application nor the crops show systematic differences in yield reduction, the results can be summarized as follows:

EC of well water, dS/m	2-4	4-6	6-8
Yield in percentage	100	83	65

As only a few wells show an EC that exceeds 7 dS/m, farmers apparently consider a yield depression in the range between 30% and 40% as the limit above which irrigation with saline water is not economically attractive. Rice, a more salt sensitive crop, is only irrigated with water in the range between 2 and 4 dS/m. Well water with an EC above 6 dS/m should only be used on loamy sand or sand where the water table is deep, in order to guarantee excellent leaching conditions.

When using brackish or saline water, the period of germination and emergence of the seedlings is the most critical stage of crop growth. A failure at this stage leads to a poor stand and a considerable yield decrease. Failures recorded where saline water was used can often be attributed to failures during germination and emergence and not to excessive soil salinity at a later stage.

The soil salinity that prevails during germination and emergence is easily underestimated because samples are usually taken from a top layer of 20 cm whereas the salinity of the upper 2 to 5 cm attains a much higher value during this stage. This is caused by capillary transport of water and salt towards the surface, because during the first stage after sowing only evaporation occurs from the bare soil and there is no water uptake by roots. So the salt concentration of the soil water in the top centimetres increases strongly, not only because the moisture content decreases but especially because of the salt transported by capillary flow. The salt concentration can attain a value many times that of the original salt concentration, depending upon moisture content, capillary conductivity and evaporation.

Irrigation and cultural practices should aim at obtaining a good stand by rapid and uniform germination of the seed and emergence of the seedlings. Whereas germination can be delayed by salinity, emergence can suffer far more severely and even be prevented under unfavourable soil and weather conditions when a crust is formed at the surface. Good emergence of the seedlings with the shortest delay is of primary importance for the development of the crop. The following irrigation and cultural practices will promote a good stand by rapid and uniform germination and seedling emergence:

– land grading, to obtain a uniform water distribution;

– sprinkling, to avoid large water applications that spoil the soil structure. Once the seedlings are established, sprinkling can be stopped and water can be applied by surface irrigation. In this way, sprinkling equipment is used during a short period of low demand and can serve a large area.

– sowing at the bottom of corrugations or furrows, where soil salinity is lowest. Moreover, the seedlings are protected against hot winds. When sowing at high temperature and evaporation, this method of sowing can be very useful;

– applying fresh canal water before and after sowing. Once the crop is well established, brackish water can be applied. This practice is limited to those areas where fresh canal water is available.

The methods described above can contribute to rapid and uniform germination and emergence. Experience is necessary in order to know the maximum salt concentration of brackish and saline waters that is usable during this stage under local conditions of soil, climate and irrigation practices. Whether brackish and saline drainage water must be used for direct irrigation or can be used together with canal water in alternate irrigation or after mixing, depends on local conditions. In the case of wells, the operators can more or less choose the period and hours of pumping, and often the three methods of water application are possible. Some farmers even prefer direct irrigation, reserving all brackish water for salt tolerant crops and all canal water for salt sensitive crops.

In the case of horizontal drainage, the drainage flow is almost continuous and the water must be pumped into branches, distributaries, minors or water courses, depending on the distance from the outlet of the drainage unit. Mixing is only possible during the period that the canal water is flowing: at other times the drainage water must be used with or without alternation of fresh water. In preparing drainage projects the different possibilities for application of drainage water must be carefully assessed, taking into account the period during which canal water is available and the discharge and salinity of the drainage water.

In principle, brackish and saline water can be used not only for irrigation but also for salt extraction and for fish culture. An evaluation of these possibilities showed that the use of saline groundwater for salt production and for fish culture is very limited and, at most, can only provide a local solution.

III - Disposal of drainage water

The following possibilities for disposing of drainage water were evaluated: disposal into rivers, in depressions, by infiltration in areas with a deep water table and by an outfall drain towards the sea.

The Yamuna River, bordering the eastern part of Haryana, is the only perennial river in Haryana, but the period for disposal is limited to the monsoon period, as, except for that period, the entire flow is diverted for irrigation at the Tajewala headworks. Notwithstanding the limited period, disposal into the Yamuna River represents a substantial contribution to the disposal problem for the eastern part of Haryana, since the highest discharge of the subsurface drainage system can be expected during that period.

The following EC values in dS/m were assumed for the study of the disposal possibility from June through October: river water 0.2; surface drainage water 1.2; subsurface drainage water 6 and 10; and 0.75 as criterion for river water after mixing. Using the results of an analysis of 80% frequency discharge of the river and the main drains of the area, the additional allowable discharge of subsurface drainage water was calculated. Then the drainable area was calculated, assuming a subsurface drainable surplus of 0.0015m/ha/day during the monsoon period. The study showed a drainable area in July and August of between 150,000 and 280,000 ha in the case of subsurface drainage water with a EC of 6 dS/m and between 80,000 and 160,000 ha for an EC of 10/dS:m, decreasing respectively to 40,000 and 20,000 ha in September and to 20,000 and 10,000 ha in October.

The disposal of saline water in depressions may be a local, small-scale solution, if accompanied by salt production or fish culture, whereas disposal by infiltration in areas with a deep water table does not appear feasible.

Since the recycling of brackish and saline drainage water within the irrigated area will ultimately lead to an increase in the salt concentration of the irrigation water and the soil, disposal by an outfall drain towards the sea should be considered as a long-term solution. A desk study was made of the feasibility of evacuating 12.5 m^3/s, about half of the estimated discharge of subsurface water drained from the currently critical area. The outfall drain would run 450 km to the Luni River in Rajasthan to the south of Haryana, where it would flow towards the Rann of Kutch, and the water would have to be lifted about 100 m over the Aravalli range by pumping. The cost per ha seems high at the moment, but as agricultural production and land values rise, this solution may prove to be economically feasible in the future.

Reference

FAO, 1985. Studies for the use of saline water in command areas of irrigation projects. Haryana (India): *Technical Report* No. 1 (pr).

Table 1: Supply of canal water, extraction and remaining potential of brackish and saline water in eight districts located in the brackish and saline zone of Haryana (in million m3)

Supply canal system	Extraction brackish	Extraction saline	Remaining potential brackish	Remaining potential saline
8400	1000	60	800	400

Table 2: Yield in percentage according to a field survey in Hissar

	Direct irrigation EC, dS/m			Alternate irrigation EC, dS/m			After irrigation EC, dS/m		
	2 - 4	4 - 6	6 - 8	2 - 4	4 - 6	6 - 8	2 - 4	4 - 6	6 - 8
Cotton	100	70	55	100	83	75	100	76	68
Millet	100	79	52	100	90	70	100	80	54
Wheat	100	89	60	100	88	61	100	92	73
Mustard	100	86	67	100	65	54	100	96	80
Averages	100	81	59	100	81	65	100	88	71

Figure 1: Topographic contours and groundwater quality

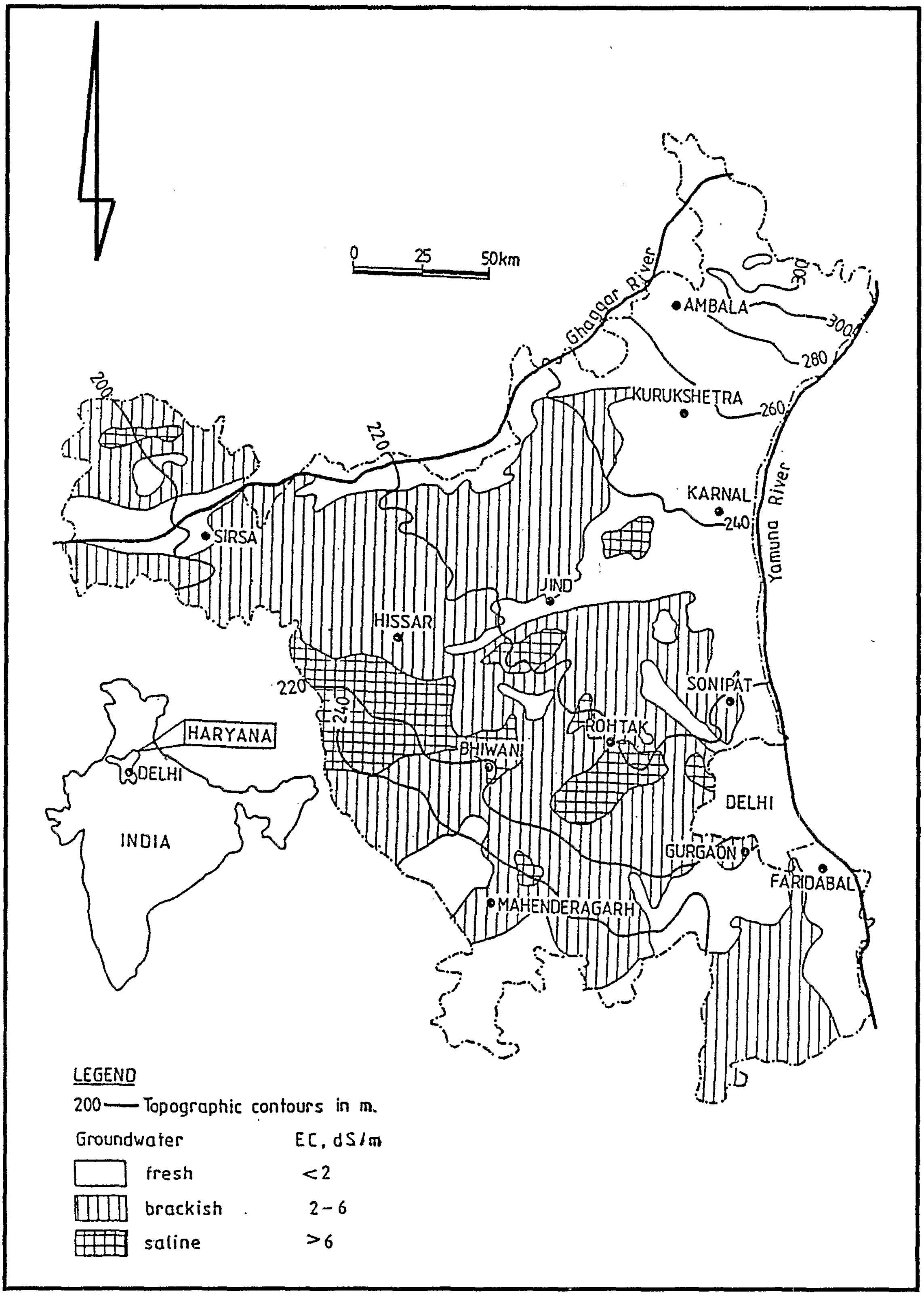

Figure 2: Water flow in irrigated land and depression

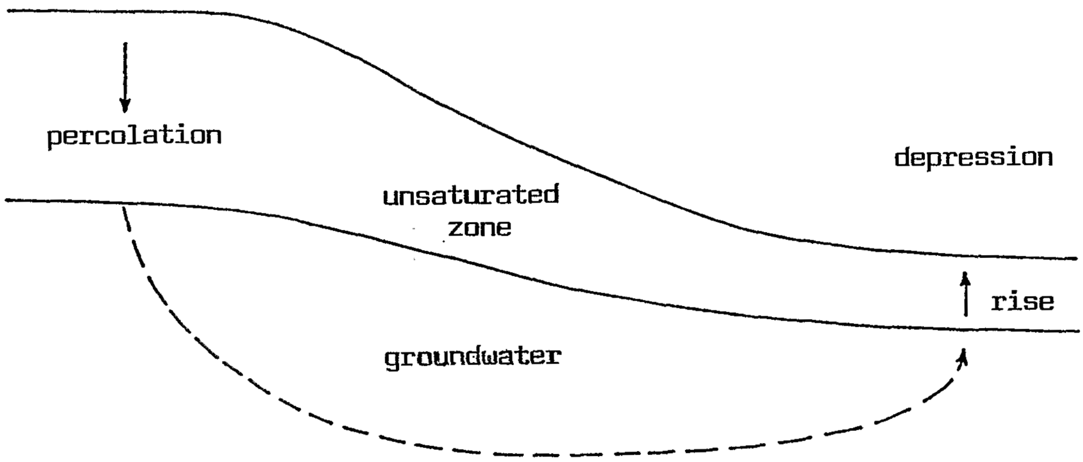

Figure 3: Water flow in irrigated land and fallow land