BIO-DRAINAGE: TO CONTROL WATER LOGGING AND SALINITY IN IRRIGATED LANDS

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ABSTRACT

Irrigated agriculture faces the problem of water logging and salinisation. Presently practised drainage measures cause water pollution and environmental degradation. Bio-drainage, in which the property of transpiration of trees is used to strike a water balance and check the rise of ground water table above critical depth, can be an option to control water logging and salinisation of soils. In case irrigation water is of good quality, total minerals removed annually by crop and forest bio mass can match the total annual import of minerals with the irrigation water. A case study of Indira Gandhi Canal Project (IGNP), Rajasthan, India is presented.

Feasibility of bio-drainage and how water balance and salt balance can be achieved are described with the help of theoretical principles as well on the basis of research results and field experience. In case of the IGNP, forest plantations in no more than in about 10 percent area, can provide satisfactory insurance against water logging.

IRRIGATION, WATER LOGGING AND SALINITY

Large investments have been made, world over, in expanding areas under irrigation and this has made significant contribution to world food production. In dry arid regions, rain-fed agriculture gives poor returns while with irrigation there is many fold increase in agriculture productivity of lands. But irrigation in arid and dry regions very often leads to water logging and salinisation. There is an apprehension that salinisation of land is inevitable and irrigation schemes can have only a finite life, and cannot be sustained indefinitely.

The Sumerian Empire flourished about four thousand years ago in Mesopotamia, in the plains of rivers Tigris and Euphrates, on the base of highly developed irrigation system. Later, large scale salinisation rendered the farm lands unproductive and this contributed to the collapse of the Empire. In California's Imperial Valley, drainage water from irrigated lands is discharged into the Salton Sea, whose salinity is on the increase. Similarly discharge of drainage water from

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irrigated lands in San Joaquin Valley, California into the Kesterson Reservoir has resulted in problems of toxicity and discovery of selenium in the biota.

On the other hand, ancient civilisation of Egypt depending on irrigation from the river Nile has survived for thousands of years. Aswan Dam has brought about remarkable changes but extensive drainage systems have been constructed during the last two decades to overcome the water logging and salinisation problems.

In the Indus basin, in India and Pakistan, extensive water storage and distribution systems have been constructed since the Nineteenth Century. These have made great contribution to agriculture productivity but have led to problems due to inadequate drainage in some parts.

All major irrigation schemes face problems of water logging and soil salinity which must be faced and tackled by proper management. Failure to do so may jeopardize the sustainability of irrigated agriculture.

PRESENT STATUS OF DRAINAGE MEASURES

About one third of some 255 Mha. of irrigated area worldwide is threatened by water logging and salinity. Thatte et al, using FAO 1996 data estimate that an area of 60 Mha is water logged and about 20 Mha is salt affected. ICID (Schultz 1990) estimated that about 150 Mha of world's irrigated area has been provided with drainage facility, out of which about 30 Mha has been equipped with sub-surface pipe drainage system (horizontal drainage). It has been installed on a large scale in more than 35 countries including Canada, Egypt, Pakistan, Iran, Iraq, Mexico, Turkey, Malaysia and Uzbekistan (Chedieng and Visvanathan 1997).

In the fifteen countries of the European Union (Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Luxemberg, Netherland, Denmark, Portugal, Spain, Sweden and the United Kingdom), the climate is mostly humid and oceanic temperate, with precipitation occurring evenly distributed throughout the year. The winter storage of precipitation in shallow soil cover over an impervious barrier results in perched water tables, more often in Belgium, France, Germany and the United Kingdom. In some regions the groundwater tables are already high due to the influence of rivers or sea and precipitation causes further rise resulting in permanent problem of water logging as along coastal areas, alluvial valleys and in the Netherlands. It is only in the southern part of Europe that irrigated areas may encounter salinization hazard.

Leasaffre et al (1995) report that agriculture intensification drive in Western Europe resulted in land improvement and more than 50 percent of water logged areas were reclaimed by sub-surface drainage. This resulted in over production of cereals and a policy change was made in year 1992 to set aside roughly 15 percent of the arable land.

The detrimental effects of drainage towards environment were recognised and drainage was restricted, even prohibited in wet biotopes, such as uncultivated marsh lands, small ponds and alluvial plains. The annual rate of installation of sub-surface drainage that was about 3,00,000 ha during the 80's came down about one-half in the 90's. In some places (Germany and U.K.etc.), drained areas were converted back to marshlands. In several countries (Netherlands, Switzerland, Germany etc.) investments on drainage are restricted to rehabilitation of ancient systems.

In the wet humid regions of North America, drainage is required to remove excess soil water, especially on poorly drained soils. Of the 53 million ha. of cropland drained in North America (45 million in the U.S. and 8 million in Canada), about one-third is sub-surface drained. Total annual precipitation (snowmelt and rain) exceeds evapotranspiration.

In Egypt a special authority called the Egyptian Public Authority for Drainage Projects (EPADP) was established in 1973. Sub-surface drainage systems have been installed in 1.9 Mha area out of 2.7 Mha irrigated area. Drainage in financed by the State, but the farmers have to pay back the investment over 20 years period at no interest which amounts to more than 50% subsidy.

In Pakistan, drainage has been implemented on some 1.0 Mha out of 15.4 Mha of irrigated area including 0.23 Mha with pipe drainage and 0.5 Mha with vertical well drainage system. An additional 4-6 Mha area is estimated to require drainage facility.

In Western U.S.A. 25 to 30% irrigated area is reported to be provided with sub-surface drainage (Rao, KVGN 1998).

In India, which had 50 Mha irrigated area in 1993 (CWC 1996), sub-surface drainage has been installed in less than 0.02 percent area (Rao, 1998).

TREE WATER USE

The reported results of capacity of trees to grow and transpire water show great variance. This is not surprising because of the many factors, influencing the rate of transpiration. It is quite difficult to carry out experiments under controlled conditions to determine the rates of transpiration. But fairly dependable data is available on rate of evapotranspiration from crops (ETo) and rate of evaporation from free water surface (Apan). Crop evapotranspiration (ETo) is defined as the rate of evapotranspiration from an extensive surface of 8 to 15 cms tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water (FAO Paper No.24). Apan is the observed rate of evaporation from water surface in a pan of standard size and is generally 1.15 to 1.20 times of ETo.

The published annual tree water use values range from 0.6 Apan for irrigated Eucalyptus with full canopy cover in Western Australia (Marshall and Chester 1991) to 1.9 Apan for *Eucalyptus* Camaldulensis irrigated with seepage affluent (Morris and Wefner, 1987). Diwan, quoting Greenwood et al (1979) reports *Eucalyptus* Globulus and Camaldulensis at the age group of 11, 16 and 24 months transpired about 0.8, 6.8, 37 and 0.4, 8.5, 21 litres per day per tree respectively of the two species.

In a study in California, U.S.A., total evapotranspiration from tree plantations during 220 days (April-November 1990) was estimated as 1153 mm, which was nearly equal to the applied water.

Grattan et. al. report that the extent to which *Eucalyptus* can reduce drainage volumes depends on maintaining high rates of evapotranspiration. In non-stressed environments, the literature reports crop coefficients (Kc) for a full cover of *Eucalyptus* trees between 1.2 to 1.5 (Stribbe 1975; Sharma 1984). However *Eucalyptus camaldulensis* was irrigated with saline drainage water (Ec = 10 ds/m and 12 mg/l B), evapotranspiration (ET) was estimated using two energy balance methods and Kc values were 0.83 (i.e. ET of *Eucalyptus* was 0.83 reference crop ET) (Dong et. al. 1992).

In a study in desert area of Rajasthan, India, annual evapotranspiration from tree plantations with a density of 1900 trees/ha was estimated as 3446 mm which is about 1.2 Apan.

Chhabra et al (1998) report the results of a study carried out at Central Soil Salinity Research Institute (CSSRI), Karnal, India Lysimetres of 1.2 m diameter and 2.5 m depth made of R.C.C. were filled with sandy loam and planted with eucalyptus (Eucalyptus tereticornis). The water table was maintained at 1.0, 1.5 and 2.0 m from the surface and ground water salinity at 0.4, 3, 6, 9 and 12 ds/m. The eucalyptus plant bio drained 2168, 3057, 3673, 3382 and 3357 mm water during the 1st, 2nd, 3rd, 4th and 5th year from non-saline ground water and a water table depth between 1.0 m to 2.0 m. At salinity levels of 3, 6, 9 and 12 ds/m, the eucalyptus plant bio drained 81, 64, 63 and 53 percent of that under non-saline conditions.

Colder I.R. et al (1994) on the basis of studies in Karnataka, India, report measurements on young eucalyptus plantations and establish a close corelation between the transpiration rate of an individual tree and its stem cross-sectional area as follows:

Basal (stem) area (m2)	*0*	*0.002*	*0.004*	*0.006*	*0.008*	*0.01*
Transpiration rate	*0*	*0.01*	*0.025*	*0.040*	*0.050*	*0.062*

Under the same study, the annual water use of (eucalyptus) forest was found to be higher than that of agricultural crops (about 2 times higher than finger millet).

Water hungry plants like *Eucalyptus* Camaldulensis, Acacia nilotica, Ziziphus spp., Delbergia sissoo, Prosopis Cineraria, Tecomnella undulata etc., on full development, with a tree density of 1100 trees/ha or more can be expected to transpire water in a year equal to annual Apan evaporation. *Eucalyptus* species are salt tolerant and grow faster than other trees and are therefore generally preferred, but some other species of trees can also give almost equally good results.

BIO DRAINAGE

All plants transpire water. The rate of transpiration depends primarily upon climatic condition, type and species of plantation, and availability of soil moisture in the root zone. Agricultural crops consume a major part of the irrigation water by transpiration but the water lost in percolation during field application and that lost through seepage in the conveyance system, goes down to the ground water reservoir. When the water table surface comes up sufficiently high, and is within the reach of roots of trees in plantations, the trees start drawing water from the ground water reservoir through the process of transpiration. This process of withdrawal of ground water by plantations is termed '***Bio-drainage***'.

Plantations, particularly in dry arid regions, can transpire large quantity of ground water and can be used to control rise of ground water table. Plantations also draw salts and minerals from the soil to some extent. Where the irrigation water is of good quality, plantations through bio-drainage can help achieve water balance as well as salt balance in the ground water regime.

BIO DRAINAGE FEASIBILITY

For bio-drainage to be effectively adaptable, following requirements are to be met:

(a) Water balance : The quantity of water removed from the ground water annually should equal the quantity of recharge.

(b) Salt balance : The quantity of minerals removed annually should be nearly equal to the quantity of mineral import.

(c)	Area under plantation	:	Irrigation is practised primarily to promote agriculture, horticulture, dairy etc. Therefore in term of economic returns afforestation or agro-forestry should be comparable with that from other alternative uses of land. If it is not so, afforestation may still be justified, on considerations of the environmental and drainage benefits.
(d)	Water for plantations	:	Under ideal situation, trees in afforestation area on full development should be able to draw most of their requirement of water from the ground water table, so that surface irrigation water can be put to other productive uses. If this is not possible, plantation trees would need some irrigation water. They may also need some water periodically to leach down salts from the root zone, if and when the salinity levels approach threshold limits.
(e)	Ground water quality	:	The quality of ground water, when the water table approaches the root-zone of trees, should be such as can be tolerated by the plant species, otherwise the trees would need to be supplied irrigation water.
(f)	Effect on lowering ground water table	:	Trees can lower the ground water table directly underneath the plantation area, to a depth up to which the tree roots can extend. This can be upto 15 m from ground surface or even more. To be effective as a drainage measure, the ground water table must be lowered in the irrigated area to a minimum critical depth (say 2 m below ground level), at the farthest point from the edge of the plantation area.

WATER BALANCE

Before the introduction of irrigation, the ground water system is in a state of equilibrium. The inflows, mostly from natural precipitation, seepage from water bodies and ground water in-flow match the outflows on account of withdrawal of water for agriculture and other uses, ground water out flow etc. There are some fluctuations in the water table level from season to season and from dry year to wet year, otherwise the ground water system over a period of time, reaches a state of equilibrium and remains fairly stable. With the advent of irrigation when a large quantity of water is brought from outside area, the state of equilibrium is disturbed and ground water table no longer remains stable. Depending upon the quantity of net incremental recharge, the ground water table starts rising and continues to do so until a new balance is reached. As long as balance is not reached, the water table continues to rise and may come up to ground surface or rise even higher, causing water logging. Ultimately, evaporation from ground surface in water logged area and from surface of formed water pools along with other withdrawals, strikes a balance with the quantity of recharge. But by this time, large areas may be lost from agriculture use, on account of water logging.

To overcome the above problem, the objective of any drainage scheme, is to achieve water balance before the ground water table rises up to the critical depth, which in general may be taken as 2.0 m below ground level. This would be possible if the annual rate of withdrawal from ground water equals or exceeds the rate of recharge, when or before the ground water table creeps upto the critical depth.

AREA UNDER PLANTATION FOR WATER BALANCE

It is described earlier that for stable water balance, total annual withdrawal of water Wb (=P x Apan), where P is the area under plantation and Apan is surface evaporation from standard pan, should equal the total annual recharge R (=Rc + Rp) where Rc is the net annual recharge from water conveyance system and Rp that in the field during water application.

Apan is largely dependent on climatic conditions and can be determined for any region by simple experiments. The efficiency of water conveyance system depends upon the method of water conveyance and physical conditions. In long unlined canals in permeable strata, conveyance losses can be very large. In lined canals and in impermeable strata, they are much less. In piped supply systems, the losses may be negligible.

The efficiency of water application in field can vary widely. In well levelled or graded fields with small border strips or basins, high efficiencies of field application can be achieved. With sprinkler or drip methods of irrigation, the field losses can be minimised.

Some water is inevitably lost by evaporation during conveyance and field application. The net recharge to ground water from a reasonably managed surface irrigation system may range between 20-40 percent of the total irrigation supply. It would be significantly less with sprinkler and drip irrigation systems and can be higher in poorly managed surface irrigation systems. Let the ratio of net recharge to ground water to the total irrigation water supply be called Recharge Factor R_F.

Irrigation water is supplied to crops to meet evapotranspiration requirement (ETcrop). Following the procedure described in FAO paper No.24, Reference Crop Evapotranspiration (ETo) is generally determined by modified Penman method. Appropriate value of crop coefficient (Kc), which depends upon crop characteristics, time of sowing, stage of crop development and climatic conditions is determined. ETcrop is then taken equal to Kc x ETo. The irrigation requirement is decided after allowing for effective precipitation (rain fall) during the crop period. The gross irrigation requirement (I_R) is determined taking into account the water conveyance and field application efficiencies.

All culturable land is not irrigated and put to agriculture use through out the year. In dry arid regions where quantity of available water is limited and the area of available culturable land is relatively very large, the area under irrigation and agriculture, at any point of time, is less than one-half of the whole culturable area. Very often, two crops are raised in a year. The total cropped area, counting area under both winter and summer crops, may generally range between 80 percent to 150 percent of the culturable area. In desert areas, lower intensities of irrigation of up to about 60 percent have been practised. Let the intensity of irrigated agriculture be represented by the factor A_F.

Therefore, if total culturable area be 'C', the annual irrigation water supply would be $C \times A_F \times I_R$ and the net recharge to the ground water would be $R_F \times (C \times A_F \times I_R)$.

If the entire quantity of recharge is to be withdrawn by bio-drainage, the requirement of area under afforestation (P) would be ;

$$P = \frac{R_F \times (C \times A_F \times I_R)}{\text{Apan}}$$

or

$$\frac{P}{C} = \frac{R_F \times A_F \times I_R}{\text{Apan}}$$

Where

P/c	represents the fraction of culturable area that must be under afforestation
R_F	is the recharge factor i.e. ratio of net recharge (to ground water) to total irrigation water supply
A_F	is the area intensity factor of irrigated agriculture
I_R	Gross irrigation requirement

Apan is surface evaporation from a standard pan

The position is depicted in *Figure 1*.

As an illustration, if $R_F = 0.3$, $A_F = 1.0$, $I_R = 600$ mm and Apan = 1500 mm, P/c would be 0.12, that is 12 percent of culturable area under afforestation can provide the needed bio-drainage.

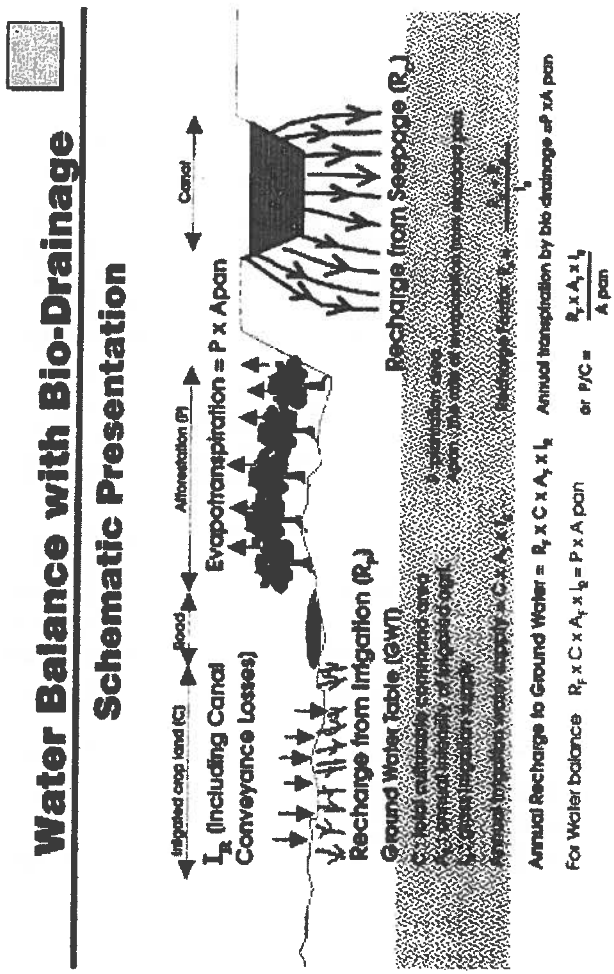

Figure 1.

SALTS IN IRRIGATION WATER

The major source of salt input in an irrigated region, is the salt content in irrigation water imported from outside the region. As long as the water table is deep, the salts are washed down by the percolating water to the ground water. But when the ground water table rises and comes up near the ground surface, the salts contained in the ground water as well as in the irrigation water contribute to salinisation of the soil.

While considering salt balance, at the beginning of irrigation, the impact of weathering, oceans and winds, except in special situations and conditions, can be ignored. The salt content in ground water does not affect salinity levels of soils for agriculture as long as it is deep. The net import of salts with irrigation water can be estimated with the knowledge of salt content and volume of irrigation water.

Composition of Average River Waters of the world is shown in Table 1. Most natural water in rivers is of very good quality for use in irrigation. The mineral content and electrical conductivity values are quite low. But the natural quality of river water can be greatly affected by the reduction in quantity of normal flow, discharge of pollutants, industrial affluents, irrigation saline drainage water into the river stream and other human activities.

Table 1: Composition of Average River Waters of the World[a]

Region	Ece[b] (μ mhos/cm at 25°C)	Total Concentration		B mg/l)	Ca	Mg	Na	K	Alkali[c]-nity	So_4	Cl	No_3	SAR
		mg/l	meq/l		(meq/l)								
North America	220	142	1.89	-	1.05	0.41	0.39	0.04	1.11	0.42	0.23	0.02	0.5
Europe	270	182	2.28	-	1.55	0.46	0.23	0.04	1.56	0.50	0.19	0.06	0.2
Australia	95	59	0.58	-	0.19	0.22	0.13	0.04	0.52	0.50	0.28	trace	0.3
World	190	120	1.42	-	0.75	0.34	0.27	0.06	0.96	0.23	0.22	0.02	0.4

[a]Adopted from Rhodes and Bernstein, 1971
[b]Electrical conductivity
[c]Alkalinity is titrable bases made up mostly of HCO_3^-, with small amounts of CO_3^{-2} and OH

Source : James David.W 'Modern Irrigated Soils' (1982)

QUANTITY OF SALTS IN IRRIGATION WATER

The amount of dissolved salts in irrigation water is generally expressed as total dissolved solids (TDS) in milligrams per litre (mg/l) and as electrical specific conductance i.e. the conductivity per unit volume (1 cm^3) of saturated solution in siemens (s) per cm.(ds/m = ms/cm = m mhos/cm)

If V (in cubic metres) be the volume of imported water used for irrigation containing m_w (in mg/l or g/m^3) minerals constituents, the total quantity of minerals brought in by irrigation water would $m_w V \times 10^{-6}$ tons.

MINERALS IN PLANT BODY WEIGHT

According to Palladin, the bulk of dry weight of a plant is made up of :

Carbon	45.1 percent
Oxygen	42.0 "
Hydrogen	6.5 "
Nitrogen	1.5 "
Mineral constituents	5.0 "
Total :	100.0 "

Pandey & Sinha give average chemical composition of plant body by weight as follows :

Carbon	20.0 percent
Oxygen	62.0 "
Hydrogen	10.0 "
Nitrogen	3.0 "
Mineral constituents	5.0 "
Total :	100.0 "

It would therefore be reasonable to assume that mineral constituents in a plant, which are all derived from the soil water, form about 5 percent of the dry body weight of the plant. In case more dependable data on mineral content in plants is available for a site under consideration, it would be advisable to use such data.

QUANTITY OF MINERALS REMOVED BY CROPS AND PLANTS

If total annual utilisable dry bio-mass produce from agriculture in an irrigated area be 'A' (in tons) and that from afforestation over an area 'P' (in ha) at the rate of 'b' tons/ha/year be P x b, then the total quantity of minerals removed from the soil by crops and trees would be $(m_c \times A) + (m_p \times b \times P)$,where m_c and m_p are percentage mineral contents in crops and plantations respectively, that are grown in the area.

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SALT BALANCE

In case the annual import of minerals ($m_w V \times 10^{-6}$) exceeds the total annual extraction and removal which is ($m_c \times A$) + ($m_p \times b \times P$) the salinity in soil and/or ground water would progressively increase. On the other hand, if annual extraction and removal of minerals exceeds the quantity of annual import, the salinity in soil and/or ground water should decrease progressively and there would be no threat to sustainability of irrigated agriculture on account of increase in soil salinity, if the rise of ground water table is kept in control.

It is possible that even though salt balance may be achieved by accounting for all minerals taken together, it may not be so in respect of all individual elements. The important common cations in water and plants are Calcium, Sodium, Magnesium and Potassium. Exercise for salt balance in respect of each individual element can be done in the same manner as for total minerals, by using the respective 'element content values' in place of 'mineral content values' in the above equations.

In case of imbalance, the rate at which mineral (or element) content in ground water would be expected to rise can be estimated and the period it is likely to take to reach threshold limits can be forecast. This in turn can help to assess the feasibility and expected life-span of the proposed measures and throw light on additional supplementary steps that need be taken.

A CASE STUDY

Irrigation Development in Indira Gandhi Nahar Project (IGNP), India

The IGNP has been receiving water for irrigation since the year 1961. The figures of actual annual irrigated area are shown in Table 2.

Table 2: Development of Irrigation in IGNP

Year	Area Irrigated (in thousand hectares)		
	Stage I	Stage II	Total
1975-76	289	-	289
1985-86	463	2	465
1995-96	664	137	801
1996-97	682	159	841

Down stream areas having not been opened for irrigation, the quantity of available water for the limited opened area has so far been quite liberal. During the period 1988 to 1995, the average rate of water use, released at the head of feeder canal, was 1260 mm against the designed value of 560 mm. The values for neighbouring project areas of Gang and Bhakra commands, during the same period, were 575 and 515 mm. respectively.

WATER LOGGING

The depth of water table in the command of Stage I in the year 1952 generally varied between 40 to 50 meters below ground level (bgl). With introduction of irrigation the ground water table started rising. During the decade 1981-82 to 1991-92, the average annual rate of rise of water table was 0.92 m.

In Stage II of the project, the ground water table before advent of irrigation generally ranged between 20 to 100 m bgl. With irrigation it has been rising though not with the same rate as in Stage I.

A survey conducted in the year 1991 indicated that the total number of locations where pools of water were formed on both sides of the canal was 127 and the total area where the water appeared on the surface was 900 hectares. Because of the plantations subsequently raised along the canals, and around the pool areas, there has been progressive reduction in the affected area and in June, 1997, there were only 8 locations of water pools with a total area of 20 ha. The position of progressive reduction in affected area is shown in Table 3.

Table 3: Indira Gandhi Main Canal Rd 750-1365 Area with Ground Water at Surface

Location	June 91	June 93	June 95	June 97
RD 750 - 861	254	35	24	10
RD 860 - 961	83	-	-	-
RD 961 - 1121	533	471	83	4
RD 1154 - 1365	30	24	20	6
Total	900	530	127	20

Area in ha.
RD - Unit of 1000 Ft. = 328m.

<u>Plantation in the reach RD 952-957 (Km 290-291.7) Left side</u>

A 1524 m long and 261 m wide strip along the left side of the main canal from RD 952-957 (Km 290 to 291.77), was selected for detailed study. The plantation work was carried out during the years 1987 to 1994. A field census was carried out and the distribution of different species of actually growing trees in July ,1997 is shown in Table 4.

Table 4: Distribution of Different Species of Growing Trees Along Left Bank of Main Canal RD 952 – 957

S.No.	Location	Number of growing trees of species							
		Eucalyptus camaldulensis	Acacia nilotica	Azadirachta indica	Ziziphus spp.	Delbergia sisso	Prosopis Cineraria	Tecomnella undulata	Total No. of Trees
1.	RD 952.00 to RD 952.200	396	1077	-	134	-	-	-	1607
2.	RD 952.200 to 952.450	566	902	-	93	-	-	44	1605
3.	RD 952.450 to 953.00	3296	3411	36	27	-	133	-	6903
4.	RD 953.00 to RD 953.250	1465	325	-	-	-	-	-	1790
5.	RD 953.250 to RD 953.500	1527	494	-	115	-	-	-	2136
6.	RD 953.500 to 953.800	1090	643	-	380	-	-	-	2113
7.	RD 953.800 to 954.00	659	580	-	-	-	-	-	1248
8.	RD 954.00 to 955.00	6950	3352	-	-	506	648	-	11456
9.	RD 955.00 to RD 955.300	1220	870	-	153	22	-	83	2348
10.	RD 955.300 to RD 955.500	995	285	-	414	3	-	-	1697
11.	RD 955.500 to RD 956.00	2932	1238	-	219	-	-	159	4545
12.	RD 956.00 to RD 957.00	7137	2022	-	-	-	214	386	9759
	Total	28233	15208	36	1535	531	995	672	47210

FORMATION OF WATER POOLS ALONG THE CANAL RD 952-957

The canal was first filled with water in the year 1983. Soon after, pools of water were formed on both sides of the canal. The maximum water pool area on the left side of the canal in this reach was 25 ha (year 1988). The plantation work was taken in hand in the year 1987 along the canal and around the water pool area. With the growth of trees, the water pool area reduced progressively as follows:

Year	Water pool areas (ha)
Up to year 1988	25
1989	23
1990	20
1991	15
1992	9
1993	2
1994	-

The deepest pool bed was about 3.5 m lower than the natural ground surface level (NSL). In April 1994, the ground water went down to 4.9 m below the NSL in April 1996, to 8.8 m below NSL in Sept 96, to 10.3 m below NSL and in July 1997, to 12.9 m below NSL. At Cross-section at RD 953.2, the ground water level has gone down by as much as 15 m.

Peizometers were installed in year 1997 to determine the ground water profile at two cross-section across the canal. The position of observed water levels and other details are shown in *Fig. 2*. Annual rate of transpiration from the plantations was estimated as 3446 mm.

DISTANCE UP TO WHICH PLANTATIONS CAN PROVIDE EFFECTIVE BIO-DRAINAGE

If there are two plantation areas separated by distance L, the depression of water table underneath them would result in ground water flow behaviour similar to that as in case of flow towards parallel ditches penetrating an unconfined aquifer. On equilibrium, the position would be as shown in *Fig. 3*, and the relationship between depression of ground water table, rate of recharge, hydraulic conductivity, depth to barrier layer and distance between plantations can be expressed by Donnan equation (DONNAN-1946) :

$$L^2 = \frac{8\,k\,y_o\,h}{R} + \frac{4\,k\,h^2}{R}$$

Where

L= distance between plantations
R= rate of recharge
Yo= height of water level above barrier layer underneath plantations
k= hydraulic conductivity
h= head difference

Figure 2.

Ground Water Level Fluctuations in Piezo Meters

at RD 953-212 of IGMN

Cross Section

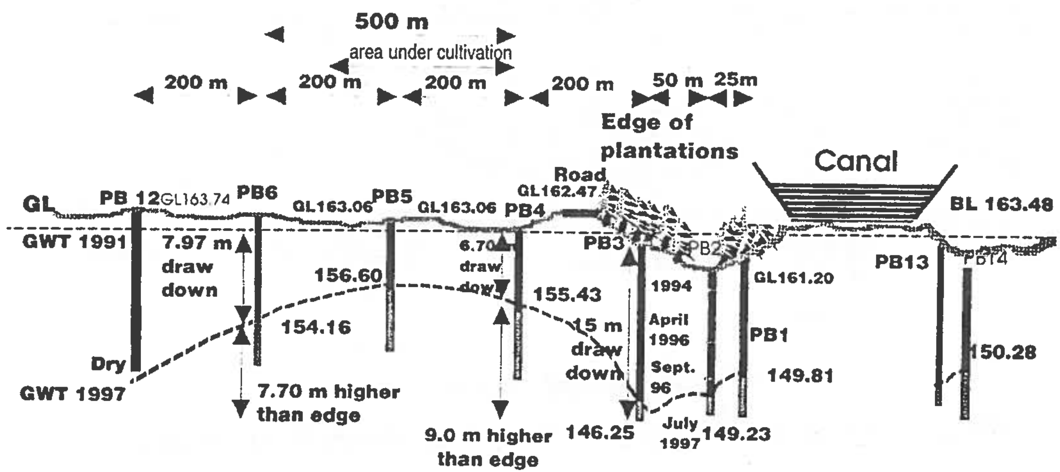
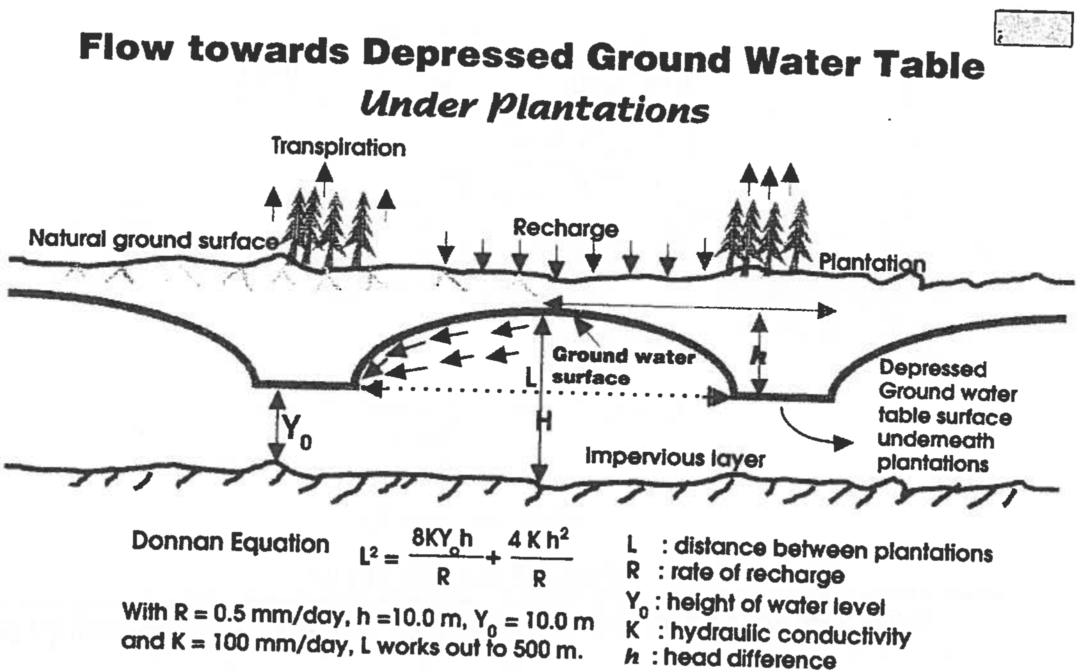


Figure 3.


Flow towards Depressed Ground Water Table
Under Plantations
Transpiration
Natural ground surface
Recharge
Plantation
Ground water surface
L
h
H
Y0
Depressed Ground water table surface underneath plantations
Impervious layer
Donnan Equation $L^2 = \frac{8KY_0h}{R} + \frac{4Kh^2}{R}$
With R = 0.5 mm/day, h =10.0 m, Y_0 = 10.0 m and K = 100 mm/day, L works out to 500 m.
L : distance between plantations
R : rate of recharge
Y_0 : height of water level
K : hydraulic conductivity
h : head difference

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