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Conjunctive Use of Surface Water and Ground Water

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1.0 Introduction

Optimal utilisation of the existing water resources is an issue of ever increasing importance because of limited water resources available. It is appropriate and necessary to develop a methodology for optimising the conjunctive use the available surface water and groundwater resources. The need for such an optimal development and use of groundwater and surface water resources is brought into sharper focus in the National Water Policy document (1987). It stipulates the integrated and coordinated development of surface water and groundwater and their conjunctive use should be envisaged right from the project planning stage and should form an integral part of the project.

Operation of both surface and groundwater reservoirs with a scientifically planned approach provides a larger water storage and hence greater water conservation. Greater utilisation of groundwater in the command area of surface water project leads to smaller surface distribution system. Since pumping well would act as a vertical drainage and would aid in controlling the water table, a smaller drainage system is required where conjunctive use is in practice. In conjunctive use planning, canal lining can be reduced as seepage from canals provides augmentation of groundwater recharge. Conjunctive use leads to lesser evapotranspiration loss because of greater underground storage with lower groundwater table position.

Utilisation of aquifer storage in conjunction with surface reservoir has been thought of since 1940. The specific problem of inter-relationship between surface and groundwater for arid zones has been studied and reported by Khosla.

A number of developments took place in U.P., Punjab, Maharashtra, Tamilnadu and other States in the forties with respect to utilisation of groundwater. However, conjunctive use of surface and groundwater was adopted to meet specific requirements without considering optimum utilisation. From 1960 onwards, increased attention of Central and State Governments was focused on increased use of surface and groundwater resources conjunctively.

In general, groundwater has been developed in private sector and it has been found to be haphazard and ill-planned. Over exploitation of groundwater has resulted in mining of groundwater. On the other hand, in some major irrigation project commands, problems of waterlogging have been experienced. Waterlogging problems could be averted conjunctive use is envisaged in the canal command area during project planning stage itself.

Evolving an optimal and practically feasible strategy for conjunctive utilisation of groundwater and surface water resources in the command areas underlined by hard rock formations is the main objective of the present day. The hard rock formation form small and discontinuous shallow aquifers of limited thickness and low well yields. The carry over storage of these aquifers is limited and groundwater development in these formations is essentially a farmer's enterprise. It is therefore necessary to develop a methodology for optimising conjunctive use of these resources in these formations. The determination of optimal allocations of surface water and groundwater resources that will accomplish the objective efficiently as measured by maximising net benefits is to be developed by the help of the available models after taking into consideration of various alternative options.

The concept of conjunctive use of surface water and groundwater is based on surface reservoirs impounding stream flow, Which is then transferred at an optimum rate to groundwater storage. Surface storage in reservoirs behind dams supplies most annual water requirement, while the groundwater storage can be retained for cyclic storage to cover years of subnormal precipitation. During periods of above normal precipitation, surface water is utilised to the maximum extent possible and also for artificial recharge into the ground to augment groundwater storage and raise water table. Conversely, during drought periods, limited surface water resources are supplemented by pumping groundwater, thereby lowering groundwater levels. The feasibility of conjunctive use approach depends on operating groundwater basin over a range of water levels, that is, there must be space to store recharge water, and in addition, there must be water in storage for pumping when needed.

Rational planning and management of a study area is not possible without comprehensive assessment of the need and the availability of water. In the present study, the evaluation or the assessment of the need and the availability of water, and the extent of waterlogging in the study area is to be carried out by the following analyses and estimations.

1. Rainfall Analyses
2. Groundwater Trend analyses
3. Water Requirement
4. Groundwater Balance
5. Surface water Balance
6. Water Quality analyses
7. Management Strategy

2.0 Rainfall Analysis

The analysis of rainfall trend over the study area is carried out by annual rainfall departure analysis and probability analysis of annual rainfall. The annual rainfall departure analysis is a good indicator of the deviation of the rainfall from the normal rainfall over a period of time. The probability analysis of annual rainfall is useful to predict the relative frequency of occurrence in different group of intervals of annual rainfall.

2.1 Annual rainfall departure analysis

Percentage departures on annual basis are worked out based on rainfall and normal annual values. The difference of annual rainfall and annual normal gives the departure which is converted into percentage which gives how much annual rainfall is deviated from the normal rainfall of the study area.

2.2 Probability analysis of annual rainfall

Probability is a constant characterising a given set of objects or incidents in a particular period. The probability analysis of annual rainfall is useful to predict with reasonable accuracy the relative frequency of occurrence in different group intervals of annual rainfall. It is also possible to work out the percentage probability of occurrence of 75% of annual normal rainfall or more for identification of drought proneness of the study area.

3.0 Ground Water Level Analysis

The change in storage of groundwater in an aquifer is reflected by change in groundwater level. Usually change in groundwater storage is a seasonal phenomenon. Representative wells are uniformly distributed over the study area has to be chosen for the analysis based on the availability of data. The analysis is carried out using quarterly data for the desired period depending on the data availability.

3.1 Average ground water level

The water levels in the wells have been reduced with respect to mean sea level. Average groundwater level has been calculated using Thiessen Polygon Method. For this purpose Theissen weights for all wells being considered for analysis were established and groundwater levels calculated with respect to mean sea level multiplied by respective Thiessen weight has been taken as average groundwater level for the study area. The average values (pre-monsoon and post-monsoon) of groundwater level computed for the study has to be plotted against time unit. The average fluctuations of the water levels between pre-monsoon and post-monsoon and the aggregate water level fluctuation of the study area for the study period is to be estimated.

3.2 Trend analysis of groundwater level

The trend in groundwater level fluctuations was worked out by carrying out simple regression analysis. In order to work out the trend of rainfall, the seasonal values (monsoon season) of rainfall were plotted for each year of available data. A simple regression line is to be fitted to show the trend of groundwater table. The graph will show the trends of seasonal groundwater levels over the period of analysis.

3.3 Water logging identification

Groundwater build up in the soil zone affects the air water ratio and has a adverse ill effect on the yield of the crops and other vegetations. The changes in ground water levels of the study area are to be monitored to find whether the area is affected by water logging or not. To identify the area subject to water logging, the ranges of the depth to groundwater level (below ground level) were drawn over the study area for pre-monsoon and post-monsoon. The area, where groundwater level is shallower than 2m below ground surface during pre-monsoon and post-monsoon season has to be marked and is considered as water logged area.

4.0 Water Requirement

A rational planning and management of water resources is not possible without a comprehensive assessment of the need and the availability of water. In the assessment of water requirement that is, the irrigation water requirement, domestic water requirement which includes drinking water requirement and the requirement for Livestock and industrial water requirement have been considered.

4.1 Irrigation water requirement

The estimation of the water requirement of crops is one of the basic needs for crop planning of any irrigation project. Water requirement may be defined as the quantity of water, regardless of its source, required by a crop or diversified pattern of crops in a given period of time for its normal growth under field conditions at a place.

The irrigation requirement for a crop depends on the irrigation need of the crop, the area occupied by the crop and the losses in the water distribution system.
Irrigation water requirement, IR is given by

$$IR = WR - ER + \text{Losses}$$

in which,

WR = Crop water requirement, and
ER = Effective rainfall.

4.2 Crop water requirement

Crop water requirement may be defined as the quantity of water, regardless of its source, required by the crop for its normal growth under field conditions at a place. Water requirement may be formulated as follows:

$$WR = \text{Evapotranspiration} + \text{application losses} + \text{special needs}$$

where,

ET = Evapotranspiration

Application losses include the loss of water during water application. These losses are unavoidable losses. Special needs include water required for land preparation, transplanting, leaching, etc,. Some part of the total water requirements of crop may be met by rainfall and hence it is calculated as follows

4.3 Effective rainfall

Effective rainfall is that part of rain which enters the root zone and remains there as soil moisture. Crop water need can fully or partly be met by rainfall. All the rainfall is not effective. A part may be lost by surface runoff, and deep percolation and evaporation. In case of rainfall of high intensity only a part of the rain enters and is stored in the root zone and the quantity of effective rain is low. Frequent light rains on an area covered by a crop is more effective. With dry soil surface and little or no vegetative cover, rainfall upto 8 mm/day may be lost totally by evaporation. For rains of 25 mm to 30 mm per day with low percentage of vegetative cover only 60 percent of it is effective.

4.4 Estimation of effective rainfall

A number of empirical formulae can be used for estimating effective rainfall. The formula developed under a given set of conditions may not be applicable to different conditions elsewhere. However, in this study, consumptive use/precipitation ratio method which has been developed, by Soil Conservation Service of USDA (1969) has been adopted. In this method, the monthly effective rainfall is related to consumptive use. The effective monthly rainfalls which have been used are shown in table 1. The soil water storage capacity in the crop root zone at the time of irrigation is assumed to be equal to 75 mm.

4.5 Estimation of consumptive use

The consumptive use depends on the type and stage of growth of crop and the extent to which plants cover the soil moisture status, soil type and environmental conditions such as climate.

Consumptive use for a specific crop can be found using the relation

$$ET = K_C E_P$$

in which K_C = the crop coefficient
E_P = pan evaporation

The factors affecting the crop coefficient (K_C) are mainly the crop characteristics, crop planting, sowing date, rate of crop development, length of growing season and climatic conditions. Crop coefficient has been taken according to Water Management Division, Department of Agriculture, Irrigation, Govt. of India, 1971 as given in the table 2.

4.6 Drinking water requirement

Drinking water requirement includes the domestic water requirement and live stock water requirement. The water requirement for the domestic purposes normaly taken as 135 LPCD and for the live stock 100 LPCD. The industrial use can also be estimated based on the number of industies and daily consumption in the study area.

Table 1: Normal Monthly Effective Rainfall as Related to Normal Monthly Rainfall and Average Monthly Consumptive Use

Normal Monthly Rainfall (mm)	Average Monthly Consumptive Use in mm													
	25	50	75	100	125	150	175	200	225	250	275	300	325	350
	Normal Monthly Effective Rainfall (mm)													
25	15	17	18	18	19	20	21	22	25	25	25	25	25	25
50	25	33	35	36	37	40	41	44	48	50	50	50	50	50
75		47	51	54	56	58	61	65	69	74	75	75	75	75
100		50	65	69	73	75	79	83	88	95	100	100	100	100
125			75	83	89	91	96	102	108	116	123	125	125	125
150				97	104	106	113	120	127	136	144	150	150	150
175				100	117	120	128	136	143	154	166	172	175	175
200					125	131	140	148	158	169	184	191	197	200
225						142	152	162	175	189	200	210	220	225
250						148	164	175	192	206	216	226	236	245
275						150	173	188	205	223	233	242	255	265
300							175	195	215	235	246	258	273	288
325								199	220	242	258	275	290	304
350								200	224	245	265	285	303	320
375									225	248	270	292	310	328
400										250	273	296	317	335
425											275	298	320	340
450												300	322	343
475													324	346
500													325	349
525														350

Table 2: Consumptive Use (Evapotranspiration) Coefficient K, with respect to Class A Pan Evaporation

Percent of growth	Crop group							
	A	B	C	D	E	F	G	R
0	0.20	0.15	0.12	0.08	0.90	0.60	0.50	0.80
5	0.20	0.15	0.12	0.08	0.90	0.60	0.55	0.90
10	0.36	0.27	0.22	0.15	0.90	0.60	0.60	0.95
15	0.50	0.38	0.30	0.19	0.90	0.60	0.65	1.00
20	0.64	0.48	0.38	0.27	0.90	0.60	0.70	1.05
25	0.75	0.56	0.45	0.33	0.90	0.60	0.75	1.10
30	0.84	0.63	0.50	0.40	0.90	0.60	0.80	1.14
35	0.92	0.69	0.55	0.46	0.90	0.60	0.86	1.17
40	0.97	0.73	0.58	0.52	0.90	0.60	0.90	1.21
45	0.99	0.74	0.60	0.58	0.90	0.60	0.85	1.25
50	1.00	0.75	0.60	0.65	0.90	0.60	1.00	1.30
55	1.00	0.75	0.60	0.71	0.90	0.60	1.00	1.30
60	0.99	0.74	0.60	0.77	0.90	0.60	1.00	1.30
65	0.96	0.72	0.58	0.82	0.90	0.60	0.95	1.25
70	0.91	0.68	0.55	0.88	0.90	0.60	0.90	1.20
75	0.85	0.64	0.51	0.90	0.90	0.60	0.85	1.15
80	0.75	0.56	0.45	0.90	0.90	0.60	0.80	1.10
85	0.60	0.45	0.36	0.80	0.90	0.60	0.75	1.00
90	0.46	0.35	0.28	0.70	0.90	0.60	0.70	0.90
95	0.28	0.21	0.17	0.60	0.90	0.60	0.55	0.80
100	0.20	0.20	0.17	0.20	0.90	0.60	0.50	0.20

5.0 Groundwater Balance of the Study Area

Water balance technique has been extensively used to make quantitative estimates of water resources and the impact of man's activities on the surface water and groundwater regimes. With water balance approach, it is possible to evaluate quantitatively individual contribution of sources of water in the system. After the water balance studies, modelling can be done for evaluating impact of alternative policies so as to select a safe abstraction policy.

The basic concept of water balance is :
inflow to the system - outflow from the system = change in storage of the system, over a period of time.

5.1 Ground water balance equation

Considering the various inflow and outflow components, the terms of the ground water balance equation can be written as:

$$R_i + R_c + R_r + R_t + I_g + S_i = T_p + E_t + O_g + S_e + \Delta S$$

where

R_i = recharge from rainfall;
R_c = recharge from canal seepage
R_r = recharge from field irrigation
= $R_{rs} + R_{rg}$
R_{rs} = recharge from surface water irrigation
R_{rg} = recharge from ground water irrigation
R_t = recharge from reservoirs and tanks;
I_g = subsurface inflow to the study area;
S_i = influent seepage from rivers;
T_p = draft from ground water
E_t = evapotranspiration losses
= $E_{tf} + E_{tw}$
E_{tf} = evapotranspiration losses from forested area,
E_{tw} = evapotranspiration losses from water-logged area;
O_g = sub-surface outflow from the study area;
S_e = effluent seepage to rivers; and
ΔS = change in ground water storage, positive for increase and -ve for depletion

The estimation of the various inflow and outflow components and the methodology adopted for estimating each ground water balance component are discussed below.

5.2 Draft from ground water (T_p)

Draft is the amount of water lifted from the aquifer by means of various lifting devices. The withdrawal can be made by means of (i) Deep tubewells, (ii) Shallow tubewells, (iii) Pumping sets, (iv) Rahats and other means. An inventory of wells and sample survey data are prerequisites for computation of ground water draft.

The yearly draft is computed by multiplying unit draft with the number of devices. Seasonal draft values for monsoon and non-monsoon seasons may be taken as 20% and 80% of the yearly draft values.

5.3 Evapotranspiration Losses (E_t)

Evapotranspiration is the amount of water loss by evaporation and that transpired through plants for a certain area. When this evapotranspiration is from an area where the water table is close to the ground surface, the evaporation from the soil and transpiration from the plants will be at the maximum possible rate i.e. at potential rate. This potential evapotranspiration will take place in a water-logged tract due to the rise in the water table or the forested or other tree vegetation area which has the roots extending to the water table or upto the capillary zone. The evapotranspiration from such area can be worked out by usual methods of computing evapotranspiration using the known data.

5.4 Effluent and influent seepage (S_e and S_i)

The aquifer and stream interaction depends on the transmissivity of the aquifer system and the gradient of the water table in respect to the river stage. Depending upon the gradient, either aquifer may be contributing to the river flow (effluent) or river may be recharging the aquifer (influent).

For estimation of effluent or influent flows, all rivers coming in the study area may be divided into a number of small reaches and computations made for each segment. For every reach, at least one observation station nearest to the middle of the reach has been selected. The hydraulic gradient is computed as the ratio of the difference between the river stage at the point where the normal from the observation well meets river and the water level in the observation well, to the distance between the points under reference. Similarly observation wells are taken on the other side of the river and the hydraulic gradients computed.
The effluent or influent seepage can now be estimated as:

$$S_e \text{ (or } S_i) = \Sigma T\, I\, \Delta L$$

where, T is transmissivity, I is the hydraulic gradient and ΔL is the length of the reach. By considering sign of the gradient the influent and effluent seepages estimated over the entire reach for all the rivers coming in the area.

5.5 Sub-surface inflow and outflow (I_g or O_g)

Sub-surface inflow and outflow is governed mainly by the hydraulic gradient and the transmissivity of the aquifer. The whole boundary is divided into small segments and the gradient of water table calculated by using the ground water levels near the boundary for each segment. Net flows are calculated for each segment by using the relationship;

I_g (or O_g) = T I ΔL in which,
T is the transmissivity, I_g (or O_g) is the discharge passing through a particular segment, I is the gradient and ΔL is the length of the segment concerned. Thus to get the total discharge

passing across the study areas boundaries, the discharge values for each segment are summed up. Thus;

I_g (or O_g) $= \Sigma \, T \, I \, \Delta L$

5.6 Recharge from canal seepage (R_c)

Seepage refers to the process of water movement from a canal into sub-surface strata. Seepage losses from surface water bodies often constitute a significant part of the total recharge to ground water system. Hence, it is important to properly estimate these losses for recharge assessment to ground water system.

Recharge from canal seepage = Seepage factor x Wetted Area x Running days

5.7 Recharge from field irrigation (R_i)

Water requirements of crops is met, in parts, by rainfall, contribution of moisture from the soil profile, and applied irrigation water. A part of the water applied to irrigated fields for growing crops is lost in consumptive use and the balance infiltrates to recharge the ground water. Infiltration from applied irrigation water, derived both from ground water and surface water sources, constitutes one of the major components of ground water recharge. For a correct assessment of the quantum of recharge by applied irrigation studies are required to be carried out on experimental plots under different crops in different seasonal conditions.

(a) Recharge from surface water irrigation (R_{rs})

Recharge from surface water irrigation =

Seepage factor x Area Irrigated x Average water depth

Generally 20 to 30 percent of water delivered for application in the field will be taken as the recharge from the surface water irrigation.

(b) Recharge from ground water irrigation (R_{rg})

Recharge from ground water irrigation normally considered as 30 to 40 percent of the water delivered (i.e 30 to 40 percent of the ground water draft).

5.8 Recharge from reservoirs and tanks (R_t)

Study have indicated that seepage from tanks varies from 9 to 20 percent of their live storage capacity. However, as data on live storage capacity of large number of tanks may not be available. The seepage from the tanks may be taken as 44 to 60 cm per year over the total water spread. If monthly water level data for tanks are available for the study period, the corresponding water spread areas may be estimated from area-elevation curves available. Then the monthly recharge values are computed by multiplying the seepage factor with the water spread areas. If there is only live capacity the tank which are present in the study area available, then 10 to 20 per cent of the total capacity of the tanks may be considered for the recharge due to tanks.

5.9 Change in ground water storage (ΔS)

The change in ground water storage is an indicator of the long term availabilities of ground water. The change in ground water storage between the beginning and end of the non-monsoon season indicates the total quantity of water withdrawn from ground water storage, while the change between the beginning and end of monsoon season indicates the volume of water gone into the reservoir. During the monsoon season, the recharge is more than the extraction and hence the ground water storage increases, which can be utilised in the subsequent non-monsoon season.

To assess the change in ground water storage, the water levels are observed through a network of observation wells spreaded over the study area,. The water levels are normally highest immediately after monsoon in the month of October or November and lowest just before monsoon in the month of May or June. The change in ground water storage can be computed from the following equation.

$$\Delta S = \quad \Sigma \Delta h \, A \, Sy$$

where

ΔS = change in ground water storage
Δh = change in water level
A = area influenced by that well and
Sy = specific yield.

Thiessen polygons have to be drawn for the observation wells and the weighted average of groundwater level has to be calculated for monsoon and non-monsoon. The change in ground water storage in monsoon and non monsoon seasons were estimated by using the above relation.

5.10 Recharge from rainfall (R_r)

Part of the rain water that falls on the ground, is infiltrated into the soil. This infiltrated water is utilised partly in filling the soil moisture deficiency and part of it is percolated down reaching the water table. This water reaching the water table is known as the recharge from rainfall to the aquifer.

For the monthly rainfall data in the study area Thiessen polygons have may be drawn and mean seasonal rainfall values are computed for the study period.

The methods for estimation of rainfall recharge involve the empirical relationships established between recharge and rainfall developed for different regions. Nuclear methods can also be employed to assess the rainfall recharge. However, in the present study, the recharge to ground water from rainfall is estimated by water balance approach. In this approach, all the components of water balance equation other than the rainfall recharge, are estimated using the relevant hydrological and meteorological information. The rainfall recharge for monsoon season is calculated by substituting these estimates in the water balance equation. Recharge coefficient i.e. recharge per unit rainfall is thus estimated. Since most of the rainfall occurs in the monsoon season only, it is assumed that in non-monsoon season all the rain water is used by crops and absorbed in the soil moisture zone with no recharge to ground water reservoir. Hence the recharge from rainfall has been taken as zero in the non-monsoon season.

6.0 Surface Water Balance

In order to allocate the surface water for various purposes, it is required to assess thesurface water balance of the study area. Surface water balance will be estimated on the basis of the impounding capacity of reservoirs or tanks. The monthly reservoir or tank water balance is caried out as follows;

6.1 Components of water balance equation of reservoir

The water balance equation states that over a time period the the sum of all inflow components are equal to some of all outflow componrnts and change in storage.

The water balance equation can be sated as

$$I_s + I_g + P - E - Q - L - \Delta S = 0$$

in which,

Is = Total surface water inflow into the reservoir during a time period

I_g = Total groundwater inflow into the reservoir during the time period

P = Total precipitation on the surface reservoir during the balance period

E = Total evaporation from the reservoir during the period

Q = Total release from the reservoir during the balance period

L = Total storage loss including seepage during the time period

ΔS = Total change of reservoir storage during the balance period

The water enters into the reservoir through surface inflow and direct precipitation. Water that leaves reservoir comprises of release through outlets, spillways, evaporation and losses due to seepage. The storage increases if the inflow exceeds outflow, and decreases if the outflow exceeds inflow. All the components of water balance equation need to be independently estimated.

If there is no tank irrigation, the monthly water that is supplied through all canals and distributories which comes under study area has to be accounted as surface water available for the crop water requirement.

7.0 Water Quality

The analysis has been carried out to identify the suitability of the Groundwater for drinking and irrigation purpose. The statistical test also conducted in order to find the present trend of the quality of the study area, variation of each parameter over year to year, for the post monsoon and premonsoon separately. The water quality parameters such as pH Electrical conductivity and Total dissolved solids may be analysed.

If we want to know the data of water quality, how big, diverse and symmetrical are they? , it can be analysed by the statistical measure mainly standard deviation and coefficient of skewness irrespectively.

7.1 pH value

The pH value of water is a measure of hydrogen in concentration of the water sample. It may be noted that the pH of natural water is 7, acidic is less than 7, and alkaline water is more than 7.

7.2 Electrical conductivity

The ability of a cube of one centimetre side water to conduct an electrical current is called specific electrical conductance or electrical conductivity. The relationship between conductivity in micromhos/cm and TDS ppm TDS = 0.64 micromhos/cm (Hart Bary T. 1974). For rainwater, conductance vary from 5 to 20 micromhos/cm for ocean water varies from 45,600 to 55,000 micromhos/cm.

7.3 Total dissolved solids

It is an indicator for the total solid present in the water. The presence of total dissolved solids in the collected samples over study period has to be estimated in PPM.

8.0 Mangagement Strategy

The two components of water resources surface and groundwater have been developed largly in isolation for irrigation. The excessive use of surface water has resulted in rise of groundwater table causing waterlogging and salinisation of fertile agriculture land. Similarly large scale groundwater exloitation has resulted in undermining accompanied with drying shallow wells and even subsidence of land. Thus for optimal use of water resource conjunctive use is essential. It is realised that in all irrigation projects the conjunctive use of both surface and groundwater should be provided. The first task would be to made a realistic assessment of the surface and groundwater resources and then plan their use in such a way that full crop water requirement are met and there is niether waterlogging nor excessive lowering of groundwater table. This can be done in a conventional manner by water balance technique and also using the modern technique of mathematical modelling with the help of computers.

9.0 Advantages

9.1 Meeting the water reuirements of crops

Timely supply of irrigation water in adequate quantities in essential for a good crop yield. It is all the more necessary in the case of high yielding verities. Surface water scheme do not have sufficient flexibility and so, the roaster of the operating channels can not be adjusted to provide timely irrigatin in the command area for various crops with different base and critical periods. The need can not also be ecconomically met from groundwater alone on account of pumping efforts required for lifting thr water. Thus conjuntive use can help to meet the requirements both in respect of quantity and time.

9.2 Control of waterlogging and Salinisation

Surface water irrigation in many command areas, without proper surface drainage and inadequte groundwater development has resulted in alarming rise of water table creating problem of waterlogging and salinisation, affecting crop growth adversely and rendering large areas unproductive. With increasing intensity of irrigation, tendency on the part of the cultivators to oversupply irrigatrion from surface water, the problem is likely to aggrevate in future. The simultaneous development of groundwater, thus can prevent waterlogging and salinisation.

9.3 Problem of salinity ingress in coastal areas

In cases of coastal areas, the excessive pumpage of groundwater in certain areas has responsible for causing gradual movement of sea water into inland aquifers. The salt water intrusion makes fresh groundwater saline rendering it unfit for many purposes. Such condition can also occur in the inland areas due to lowering of water level as a result of excessive withdrawal of fresh water in the vicinity of saline water zone. This situation can be controlled by increased application of surface water by encouraging conjunctive use.

9.4 Control on over pumping of groundwater resources

Continuous increased withdrawals from groundwater reservoir in excess of replenishable recharge has resulted in regular lowering of water table leading to mining of the groundwater. in such a situation a serious problem is created resulting in drying of shallow wells and increase in pumping head for deeper wells and tube wells. The remedy lies in providing more surface water irrigation by help of storage reservoirs, inter-basin transfer, etc.

9.5 Use of saline water

In certain areas surface water is not able to cope with the full demand of irrigation water. At the same time, groundwater being saline, direct application is not possible. In such cases,, conjunctive use can be made by construction of augmentation wells and mixing the saline water with canal water to the extent that the quality of mixed water remains with in tolerable limits by crops.