NATIONAL INSTITUTE OF HYDROLOGY
ROORKEE

WORKSHOP

ON

GROUND WATER MODELLING - TYSON-WEBER MODEL

(18 - 22 Nov.1985)

LECTURE	:	I
TOPIC	:	GROUND WATER BALANCE
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DATE AND TIME	:	18.11.85 11.45 A.M.- 12.45 P.M. 18.11.85 2.00 P.M.- 3.00 P.M.

Water Balance Methodology and Data Availability

1.0 General

Water balance is an effective tool for estimating the water resources of an area. This approach will be used to estimate the groundwater potential of Kunda and Satak commands. A brief description of the methodology is as follows :

2.0 Definition

Water balance study means the book keeping of water of a basin or region in relation to the components of the entire hydrologic cycle or part of it, done over a specified period.

3.0 Necessity of Study

The water balance study is carried out for following purposes :

i) to evaluate the available water resources; both surface and subsurface;

ii) to assess the existing water utilization pattern and practices. This information will help in planning optimal and efficient management of water resources.

4.0 Components of Study

The study includes the hydrologic water balance, ground water balance and water use balance. Thus this study involves considerations of the following equations :

i) Hydrological water balance equation

ii) Groundwater balance equation

iii) Irrigation water use equation

4.1 Hydrological Water Balance Equation

The basic concept of balance is :

(Input)		(Outflow)		Change in
(to the)	-	(from the)	=	storage in
(System)		(system)		the system

Considering the various components, the terms of this basic equation can be put as

$$P_i + Q_{Ii} + I_{Gi} + I_{RRI} = E_1 + O_{Gi} + Q_{Ti} \pm \Delta S_{Di} \pm \Delta S_{Mi} \pm \Delta S_{Gi} \quad ...(1)$$

where i refers to the decision period.

P_i = Precipitation = $P_{Ii} + P_{Ui} + P_{Si} + P_{Ri} + P_{Ci}$

Q_{Ii} = Diverted flow = $Q_{Si} + Q_{Ci}$

I_{Gi} = Inflow to ground water from other basins/aquifers

I_{RRi} = River flow downstream of storage reservoir/diversion

E_i = Evapotranspiration = $E_{Ii} + E_{Ui} + E_{Si} + E_{Ri} + E_{Ci}$

= E_{TGi}

O_{Ci} = Outflow from ground water to other basins/aquifers

O_{Ri} = Outflow from river downstream (including effluent seepage)

Q_{Ti} = Water in canal flowing out of the area

ΔS_{Di} = Change in depression storage

ΔS_{Mi} = Change in soil moisture storage

ΔS_{Ci} = Change in ground water storage

$O_{Ri} = I_{RRi} + F_i \pm S_{Ri} + P_{Ri} - E_{Ri} \mp S_{RBi}$

= Unaccounted water (discrepancy)

where,

F_i = Surface runoff to the stream

S_{Ri} = Effluent/influent seepage (-ve for influent)

ΔS_{RBi} = River bank storage

SUBSCRIPT :

I = Irrigated area

U = Unirrigated area

S = Depression storage and ponds/storage

R = River

C = Canal

4.2 Ground Water Balance Equation

$$R_{Ui} + R_{Ii} + R_{Ci} + R_{Si} + I_{Gi} = E_{TGi} + T_{Pi} + Q_{Gi} \pm S_{Ri} + \Delta S_{Gi} \quad \text{....(2)}$$

R_{Ui} = Recharge to ground water from unirrigated area

R_{Ii} = Recharge to ground water from irrigated area

$= R_{Ui} + RI_{Ci} + RT_{Pi}$

R_{Si} = Recharge to groundwater from ponds and lakes $= P_{Si}$

R_{Ci} = Seepage from canals and field channels

$= (Q_{Ii} - Q_{Ti}) - I_{Ci} - E_{Ci} + P_{Ci}$

E_{TGi} = Evapotranspiration from groundwater (potential rate)

T_{Pi} = Actual groundwater draft reaching the field

$= \beta\ T_{Pi}$

$R_{Ui} = P_i$ or $R_U = P$

4.3 Water Use Equation

$$I_{Ci} + P_{Ei} + I_{Di} + T_{Pi} = R_{Ii} + E_{Ii} + E_{Ui} + R_{Ui} \pm \Delta S_{Mi} \quad \ldots(3)$$

I_{Ci} = Water applied to the field $= a\ (Q_{Ii} - Q_{Ti})$

P_{Ei} = Effective precipitation $= (P_{Ui} - F_{Ui}) + (P_{Ii} - F_{Ii})$

I_{Di} = Irrigation from depression storage and ponds.

5.0 Methodology of Water Balance

5.1 Study Area

The drainage basin is generally taken as a unit for the surface water balance study which has well defined boundaries separated by natural divide lines from other basins. If the lithological formations are dipping towards drainage lines, the divide line for ground water as well can coincide more or less with the boundaries of the drainage basin and in such case ground water balance study can also be made for the basin area. However, in practice the study area for surface water balance study and ground water balance study seldom coincide. Sometimes the two divide lines may be separated wide apart.

Where the ground water basin can be characterised by prominent drainages it is desirable that the doab should be considered for the ground water balance study.

It will seem appropriate from the above description that where ground water may not be paramount, the study area for water balance study can be taken as drainage basin, but in areas where ground water constitutes a substantial water resource the study area should preferably be taken as doab.

5.2 Models and Period of Study

The models may be broadly classified as lumped or distributed models. In spatially lumped model, the entire area is taken as a single unit and average values of the parameters of the area are taken or assumed for study. A lumped model, therefore, does not take into account the spatial distribution of the input variable, nor the spatial variation in parameters characterising the physical process acting upon the input. For example, suppose that a network of N rain-gauges records rainfall $x_1(t)$, $x_2(t)$ ...... $x_n(t)$ during a certain time interval, then a (spatially) lumped model combine N readings into a single input variable say $\bar{x}(t)$. A geometrically distributed model, on the other hand, express spatial variability in terms of the location of the point. In such a case the area under study is sub-divided into nodal points according to geohydrological considerations. The sub-area influenced by each nodal point is marked and the equations are applied for the sub area of each nodal point.

Hydrologic balance study is mainly a lumped model study. The entire study area is taken as a single unit and average values of the parameters of the area are taken or assumed for the study.

Precipitation is the main source of supply. Although its distribution varies greatly from period to period, variance from year to year is not so marked and precipitation over the area under study generally follows a set annual pattern. The period of study for hydrologic water balance is therefore, generally taken as a year.

The figures that are obtained for consumptive use are checked by ground water balance study and water use balance study.

Ground water table is a subsurface reservoir and its level fluctuates according to inputs to it and withdrawals from it. Most of the input to the ground water reservoir is received during monsoon and withdrawal from it takes place during the non monsoon period. The water table, therefore attains maximum level of the year at the end or somewhat after the monsoon and reaches its lowest level just before the monsoon. The period between two consecutive yearly peaks of water table is termed as a water year. In case of arid regions this period may be taken from the time when water table is minimum during a year. The water year may be further subdivided into smaller periods of a year for detailed study.

In the areas where most of the rainfall occurs in a part of year, it is desirable to conduct water balance study on part year basis i.e. for monsoon period and non-monsoon period. Generally, the periods of study in such situations will be from the time of maximum water table elevation to the time of minimum water table elevation as the non-monsoon period and from the time of minimum water table to the time of maximum water table elevation as monsoon period. For Northern India, the water year can be taken as November 1 to October 31 next year (or October 16 to Oct. 15). The monsoon and non-monsoon period can be taken as June to October and November to May (May 16 to Oct 15 and Oct 16 to May 15) next year respectively.

For this study it is desirable to use the data of a number of years preferably covering one cycle of a dry and wet year. This will enable to determine the recharge for an average year, so that the ground water potential of the area is known. Any development of the area beyond this average recharge would cause 'Mining' of the area and the water table will go down and would not only be expensive due to cost of pumping but also affect the surface supply of the bounding streams. It is, therefore, necessary to limit, the exploitation of ground water reservoir to the safe yield of the aquifer.

5.3 Lumped Model of Two Seasons

This model is used to study the impact of various components of the system on the ground water reservoir. The components which are difficult to evaluate are the recharge from rain, evapotranspiration from ground water and the distribution of withdrawal from ground water. Other components could be evaluated within reasonable reliability.

6.0 Components of Water Balance Equation

Considering the ground water balance equation the various terms can be evauated as below :

6.1 Recharge from Rainfall (R_{ui})

Part of the rain water that falls on the ground is infiltrated into the soil. This water infiltrated 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.

The recharge from rain can be estimated by nuclear methods :

1. Tritium injection
2. Gamma transmission method

The tritium injection method has been found to give good results, but cannot be used for long term estimates. The Gamma transmission method is being developed and can be used without causing health hazards.

The other method of working out recharge from rainfall is an indirect one i.e. by using the watertable fluctuation in the area. Under this approach the various other factors in the equation 1 are estimated over a certain period and the net recharge estimated. In this equation the most difficult task is to estimate the inflow to and outflow from the area from upstream and downstream regions or other basins or deep percolation to other aquifers contributing to other basins further downstream.

By this method of working out rough recharge estimates from rainfall , it is required to work out the average rise in water table during the period just before and after the rainy season. If this rise is denoted by h_e and s_y, is the specific yield of the aquifer and A the area, then

$$R_r = h_e \cdot s_y \cdot A \qquad \ldots(6)$$

Here the rise in water table contributed by other factors in the equation 1 is considered negligible and rejected.

The value of specific yield can be determined by pump tests or if that is not available, the following values worked out by U.S.G.S. Hydrologic Lab. (1) can be used.

Material	Specific yield (%)
Clay	1
Silty clay	2
Sandy clay	3
Clay silt	5
Silt	7
Clay sand	7
Silty sand	20

Sandy silt	14
Fire sand	26
Medium sand	35
Coarse sand	33
Sand (undifferentiated)	32
Values from Eckis (1934)	
Fine gravel	25
Medium gravel	20
Coarse gravel	14

6.2 Recharge by Seepage from Canals and Percolation from Irrigation Fields (R_{ci})

A number of investigations have been carried out to study the seepage losses from canals. All these formulae give the seepage losses in M^3/sec per million square metre of the wetted area. In addition to the seepage losses from the main canal and branches, the seepage losses also take place from the water courses and also a certain amount of water percolates from the fields which is accounted for by irrigation efficiency. Even by lining the canal system which accounts only for lining of main canals, branches and minor canals, the losses from the water courses and fields will remain the same and would build the water table. The Punjab practice is to assume losses from lined canal as one fourth of those from unlined canals.

The following formulae are in use in North India.

In U.P. the losses in unlined channels are usually computed using the following formula :

$$\text{Losses in cumecs/km.} = \frac{C}{200} (B+D)^{2/3} \qquad \ldots(7)$$

where B and D are the bed width and depth of the channel in meters.

C is a constant, being 1.0 for intermittent running channel and 0.75 for constant running channel.

In Punjab the loss formula is a function of discharge (2) where losses in cumecs/million sq. meter of wetted perimeter

$$= 4\ Q^{0.06} \qquad \ldots(8)$$

where Q is the channel discharge in cumecs.

USBR(6) has recommended the following values for channel losses based on the channel bed material.

Material	Losses in cumecs/million sq.m. of wetted perimeter
Clay and clay loam	1.5
Sandy loam	2.4
Sandy and gravelly soil	8.03
Concrete Lining	1.2

The World Bank in their staff appraisal report for medium and Minor projects No.3260 in the month of Feb., 81 recommended the following maximum efficiencies to be used in project planning.

MAXIMUM EFFICIENCIES TO BE USED IN PROJECT PLANNING

	Kharif Crops				Rabi Crops	
	Paddy crops		Non Paddy crops		Loss (%)	Efficiency
	Loss (%)	Effi-ciency	Loss (%)	Effi-ciency		
Conveyance from dam to 8 ha.Govt. outlet	10	90	10	90	10	90
Operational losses	15	85	15	85	5	95
Field channel losses	10	90	10	90	10	90
Field appli-cation losses	20	80	40	60	25	75
Overall efficiency		55		42		58

However, the various guidelines for estimating losses in the distribution system as given above are at best approximate. Thus, the seepage losses may best be estimated by conducting actual tests in the field for which a number of tests are available. The methods most commonly adopted are (i) Parshall Flume method (ii) Current meter method and (iii) Ponding method.

The first two methods i.e. the Parshall Flume method and the current meter method are basically discharge measuring devices. Thus in these two methods discharges are measured at two differentlocations on the two sides of the test section and the difference assumed to be losses in that particular reach.

In the ponding method bunds are constructed in the canals at two locations, one upstream and the other downstream of the reach of canal with the water filled in it. The total change in storage in the reach is measured over a period of time and seepage loss computed.

The total losses from the canal and field channels generally consists of the evaporation losses (E_C) and the seepage losses (R_C). The evaporation losses are generally 10 to 15 percent of the total losses. Thus the R_C value is 85 to 90 percent of the losses from canal and water courses.

6.3 Recharge from Field Irrigation (R_{Ii})

This consists of R_{ICi}, recharge from canal irrigation on the field and R_{TOi} recharge from tubewell irrigation from the field. R_{Ii} will be calculated for the entire irrigated area whereas R_{ICi} on the canal irrigated area and R_{Tpo} on well irrigated area. The component R_{ui} mentioned earlier refers to the entire unirrigated area. In the absence of any field investigation the coefficients are given as a fraction of the water applied on the field. Generally these figures are 0.4 and 0.35 respectively. With economical use of water these figures are likely to reduce, but in the near future may be expected to reach 0.35 and 0.3 respectively.

6.4 Recharge from Depression Storage (R_{si})

The surface water may be stored in the depressions which may be fed from canals or by seepage water. The change in depression storage at the beginning and at the end of the study period can be estimated from the field survey. But in the present study, it is assumed that the change in the depression storage is inappreciable and can be neglected.

6.5 Inflow and Outflow from the Basin (I_G and O_G)

If a doab is considered for analysis, it will be bounded on two sides by two streams and on the other two sides by other aquifers or extension of the same aquifer. In such analysis it is desirable to take these boundaries as one along a water table contour. The flow into the region or out of the region will be governed mainly by the hydraulic gradient and the transmissibility of the aquifer. This gradient of the aquifer can be determined by taking the slope of the W.T. normal to water table contour. Then the inflow or outflow can be determined by the following relationship :

$$Q = \sum^{L} Ti \Delta L \qquad \ldots(10)$$

where T is the transmissibility, i is the hydraulic gradient average over a length ΔL.

L - total length of the contour line.

Also observing the hydraulic gradients the losses across the river or inflow from across the river can be worked out.

6.6 Influent and Effluent Seepage (S_R)

The flow into the rivers or the river hydrograph is composed of the surface flow component and the ground water flow component. In certain reaches of the river the ground water levels being lower than the river, the influent seepage will take place. Also during floods a certain amount of water will enter the flood plain and may raise the water table elevation reducing the contribution of the groundwater to the river. In some cases even for part of the period the river may become an influent stream and, may contribute to the ground water storage.

This water stored in the adjoining area to the river and flood plain is released as base flow during the receeding river stages. Thus, this storage will on the hand reduce the flow of ground water from storage to the river and on the other will release this temporarily stored water to the river as delayed flow making it more useful for utilisation downstream.

In order to estimate the contribution of water from the ground water aquifer to the stream as regenerated flow the following equation can be used :

$$\Sigma Q_R \Delta t = \Sigma I_{RR} \Delta t + \Sigma S_R \Delta t + \Sigma Q_t \Delta t - \Sigma Q_o \Delta t \pm \Delta S_{RB} \quad ...(11)$$

where,

Q_R = discharge at the d/s section

I_{RR} = discharge at the u/s section

S_R = ground water contribution (to be evaluated) from both banks of the river

E_R = rate of evaporation from the river water surface and flood plain

Q_t = discharge of tributaries

Q_o = discharge diverted from river

S_{RB} = change in the storage of the river bank area.

But this S_R would be contribution from aquifers on both sides of the streams. The contribution from each side can be separated by any of the following methods.

1. The contribution from both sides can be assumed to be in proporation to the areas on either sides.
2. The transmissibilities and gradients on either side are determined. The contribution from either side is then determined in proportion to the product of transmissibilities and gradient.

Contribution from left

$$= \frac{I_L \, T_L}{I_L \, T_L + I_R \, T_R} \, S_R \qquad \ldots(12)$$

and contribution from right

$$= \frac{I_R \, T_R}{I_L \, T_L + I_R \, T_R} \, S_R \qquad \ldots(13)$$

where I_L and T_L are gradient and transmissibility respectively on the left, I_R and T_R are those on the right side.

6.7 Evapotranspiration

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 watertable is close to the ground surface, the evaporation from the soil and transpiration from the plant 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 rise in the watertable 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 areas can be worked out by usual methods of computing evapotranspiration using the known data.

6.8 Crop Evapotranspiration Coefficient

Many research stations are now reporting consumptive use data by relating to evapotranspiration. Coeff. K for various crops, as recommended by Hargreaves are given in tables 1a, 1b, 1c .

6.9 Withdrawals from Groundwater (T_p)

Withdrawal is the amount of water lifted from the aquifer by means of various lifting devices. The withdrawal may be obtained by means of :

1. State tubewells
2. Private tubewells
3. Open wells

In case of State tubewells, information about the

TABLE NO. 1a

CROP CONSUMPTIVE USE COEFFICIENT

Percent of crop growing season	Consumptive use (Evapotranspiration) Coeff. k, to be multiplied by Class A Pan Evaporation or Calculated E_p							
	Group A	Group B	Group C	Group D	Group E	Group F	Group G	Rice
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	0.25	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	0.95	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	1.00
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
100	0.20	0.20	0.17	0.20	0.90	0.60	0.50	0.20

Group A - beans, maize, cotton, potatoes, sugar beets, jowar and peas.
Group B - dates, olives, walnuts, tomatoes, and hybrid jowar
Group C - melons, onions, carrots, and grapes
Group D - barely, flox, wheat, and tother small grain
Group E - pastures, orchards, and cover crops
Group F - citrus crops, oranges, limes and grape fruit
Group G - sugar and cane and Alfalfa

The evaporation from free water surface of river and from the flood plain area can also be evaluated using the pan evaporation data or the hydrometeorological data(3).

TABLE NO.1b

CONSUMPTIVE USE (EVAPO-TRANSPIRATION) COEFFICIENTS k, TO BE MULTIPLIED BY ESTIMATED OR MEASURED CLASS A PAN EVAPORATION

% of crop growing season	Sugarcane Hawaii	Rice Los Banos	Groundnut Israel	Castor Beans Hargreaves	Sugarcane Hargreaves
0	.34	1.00	.30	.16	.40
5	.37	1.02	.30	.30	.50
10	.40	1.03	.32	.50	.55
15	.44	1.05	.35	.65	.55
20	.50	1.07	.40	.74	.60
25	.60	1.09	.49	.81	.67
30	.72	1.11	.60	.87	.75
35	.86	1.13	.69	.92	.80
40	.93	1.16	.78	.96	.85
45	.98	1.18	.85	.98	.87
50	1.02	1.20	.90	1.00	.89
55	1.05	1.21	.94	1.00	.80
60	1.07	1.22	.96	.99	.90
65	1.10	1.22	.95	.97	.85
70	1.13	1.21	.94	.93	.75
75	1.16	1.19	.91	.80	.71
80	1.19	1.16	.86	.82	.60
85	1.20	1.10	.79	.72	.59
90	1.20	1.03	.72	.58	.51
95	1.19	.96	.64	.37	.50
100	1.19	.96	.55	.22	.50
* seasonal k	.89	1.10	.68	.73	.69

* Based on a 13 months crop length.

TABLE NO. 1c

CONSUMPTIVE USE (EVAPO-TRANSPIRATION) COEFFICIENTS k TO BE MULTIPLIED BY ESTIMATED OR MEASURED CLASS A PAN EVAPORATION

% of Crop Growing Season	Wheat Ludhiana	Wheat Poona	Maize Ludhiana	Maize Albama, U.S.A.	Jowar Albama, U.S.A.	Cotton Poona	Soyabean Hargreaves	Small Vegetables Hargreaves	rooted Vegetables Hargreaves
0	.14	.30	.40	.40	.42	.22	0.15	0.25	0.10
5	.17	.40	.42	.40	.44	.22	0.18	0.23	0.15
10	.20	.51	.47	.43	.46	.23	0.20	0.30	0.20
15	.23	.62	.34	.46	.48	.24	0.23	0.38	0.30
20	.45	.73	.65	.52	.50	.25	0.25	0.45	0.40
25	.60	.74	.75	.59	.32	.35	0.28	0.30	0.45
20	.22	.52	.25	.67	.56	.58	0.30	0.55	0.50
26	.31	.53	.26	.76	.59	.60	0.38	0.58	0.55

number of running hours and discharge is obtained to calculate the volume pumped in each month. The information is available with the various tubewell divisions of irrigation departments. Similar information also needed for private tubewells and open wells (including those with mechanical devices) is maintained by Minor Irrigation Department. In order to find the draft from private tubewells and open wells, sample surveys have to be conducted regarding their number, discharge and withdrawals over the year. These sample surveys will update the information about the average discharge pumped by private tubewells and open wells.

But the main problem is that the draft by wells cannot be known in different periods. For this water use equation is used to arrive at the fortnightly estimate of draft by wells ,by suitably adjusting the water application.

6.10 Changes in Ground Water Storage

Water level fluctuations in wells indicate changes in storage resulting from recharge to or discharge from the ground water reservoir. When recharge exceeds discharge, water levels rise, conversely, when recharge is less than discharge, water levels decline. The water levels are highest immediately after monsoon in the month of October or November and lowest just before rainfall in the month of May or June. The water levels are observed through a network of observation wells spread over the area. Change in storage for distribution model study can be computed from the following equation.

$$\text{Change in storage} = \Sigma\ h.\ A.\ S_Y \qquad \ldots(24)$$

in which,

h = change in water level

A = area influenced by that well

S_Y = Specific yield

In case of lumped model studies, the average (weighted) depth of change in water level over the area is found. The specific yield of the area can be estimated by long term pumping out tests in shallow wells.

7.0 Data Requirement

The data required for carrying out the water-balance study can be enumerated as follows :

7.1 Watertable data

Premonsoon and post monsoon data of sufficient number of wells should be available for a few years. The well locations should be available on a map. The wells should be adequate in number and well distributed within the area, so as to permit reasonably accurate interpolation for contour plotting. The available data should comprise

RL of watertable and depth to watertable. Piezometric data should also be available at a few points close to the river.

7.2 Rainfall Data

Monthly rainfall data of sufficient number of stations lying within or around the area should be available. The data should be of the same period as the watertable data. The number of stations should be large enough to permit computation of average rainfall. The locations of rain-gauges should be marked on a map (preferably the same map which shows observation wells).

7.3 Canal Supplies

Monthwise releases into the canal and its arteries alongwith running days each month over the entire period of water balance will be required. To account for the seepage losses, the seepage test data will be required in different canal reaches, distributing channels and water courses.

7.4 Ponded Infiltration

Field test data will be required for computing final infiltration capacity to be used to evaluate the recharge from depression storages and leakage from the tank.

7.5 Tank Data

Monthly tank gauges and releases should be available for the same period for which other data are available. In addition to this depth Vs area and depth Vs capacity curves should also be available. These will be required for computing the evaporation and the seepage losses from tanks.

7.6 Aquifer Parameters

The specific yield and transmissibility data should be available at points sufficient in number to account for the variation of these parameters within the area.

7.7 Details of draft from wells

A complete inventory of the wells operating in the area, their running each month and discharge are required for estimating groundwater withdrawals. If draft from wells is not known, this can be obtained by carrying out sample surveys. For getting the draft each month, the consumptive use of crops can be adopted for evaluating the same.

7.8 Cropping Patterns

These data are necessary for estimating the spatial and temporal distributions of the groundwater withdrawals and canal releases if required. These should be available for the same period for which other data are available.

7.9 Evapotranspiration Data

These data should be available at a few locations for estimation of consumptive use requirements of different crops.

7.10 River Data

These data are required for estimating the inter-flows between the aquifer and hydraulically connected rivers. The data required for these computations are the rivergauge data (monthly preferably) and the river cross/sections at a few locations. The river gauge data should be available for the same period for which other data are available.

7.11 Land Use Data

These data are required for estimating the ET losses from the watertable through forests and orchards.

8.0 Data Availability in Satak Command

The data has been collected from M.P. Irrigation Department and Narmada planning-Authority and other concerned departments. Some observations have been made by CE'S also the data as available is as below :

8.1 Water Table Data

All the wells that are being monitored in Satak command have been classified under the following groups :

a) Temporary observation wells being monitored by GWS.

b) Wells between dykes being monitored by CES.

c) Wells along RTL (2) left bank being monitored by CES.

d) Piezometric data of 4 piezometers installed along RTL (2) L.B.

(a) Temporary observation wells G.W.S. in Satak Command for which monthly water level data was acquired total 19. For these wells monthly water level data for a period of 13 months starting from June'82 upto June'83 is available. These are shown in Table 2.

(b) A total of 63 wells fall in this group. The following table gives the village wise distribution of wells, nomenclature and commencement of data collection.

Village	No. of wells	Nomenclature	Observed from
Balgaon	9	A01-A08	July'83
Balsamund	9	B01-B09	July'83
Ekalghariya	4	C01- C04	July'83
Balkhad	10	D01-D09	July'83
Regwa	9	E01-E09	Aug.'83
Bamandi	10	F01-F09	-do-
Salimpura	8	G01-G08	Sept.'83
Salkur	4	H01-H04	-do-

Table 3 shows the data of wells between dykes collected upto Feb.'1984.

(c) CES has monitored 52 wells along RTL (2) (Long. 75°31'20''). Recording of water levels in these wells started in April'83 and were regularly recorded upto Feb.'1984. The particular of these wells are presented in Table 4.

(d) A series of 4 piezometer have also been installed along RTL(2) left bank which were also monitored. The data of piezometers collected upto Feb.'84 are presented in Table 5.

(e) Seasonal water level data for year 1970-71 is also available for some selected wells. Table 6 gives the particular of such wells as well as pre and post monsoon water level data. These were extracted from the Geohydrological Report for parts of Rajpur, Manawar, Meheshwar and Kasaraw d.

(f) Details of the permanent observation wells at Balsamand are available and water level data for well is available season wise from May'74 upto Nov.'82 after which monthly observations are available upto Nov.'83.

This is given in Table 7.

8.2 Rainfall Data

The following rainfall data is available for one observation station at Satak tank: Daily Rainfall (in mm) from June'74 upto Oct.'1983. This data has been extracted from the M.P. Irrigation Department records. The rainfall data are presented in Table 8.

8.3 Tank Canal Data

(1) Tank gauge, surface area and capacity data for Satak tank, is available as given in Table 9. This has been used to develop the elevation Vs area and elevation Vs capacity curves as shown in Fig. 1.

(2) Tank gauge at the beginning and at the end of each month from June'69 upto May'79 is available and given in Table 10.

(3) Daily tank gauge data available from June'79 upto Nov.'83 and is shown in Table 11.

(4) Monthly water releases from tank to canal for the years 1979-80 to 1982-83 was also supplied by the office of SDC , Irrigation sub division No.1 Kasrawad. The release data are presented in Table 12.

8.4 Lift Pumping

In Satak command lift pumping has been resorted to from the tank as well as in some reaches of the canal. The details regarding lift pumping that are available include lift pumping locations e.g. reservoir, main canal etc.,the number of pumps effecting such lifts, and also the total area irrigated by each of the lift . Such data is available from 1975 upto 1978 and are given in Table 13. Monthly areas irrigated and cropwise areas irrigated are shown in Table - 14 and - 15 respectively for the period 1979-80 to 1982-83.

However, canalwise, cropwise and yearwise areas irrigated by lift pumping is available for period 1979-80 to 1982-83. These are given in Table 16.

8.5 Aquifer Parameters

The aquifer parameters namely the transmissibility and the specific yield are evaluated at specified location by conducting rest pumping and analysing the pumping data. Since no transmissibility tests have been conducted in the zone close to Narmada in Satak command area, the test pump results of Surana and Jhirvi were adopted to get the transmissibility values close to Narmada River in the Satak command area. These two wells were selected because of their similar nature of aquifers being weathered and fractured basalt. The transmissibility value for Surana is 82.85 m^2/day and that for Jhirvi as 55.67 m^2/day (Transmissibility map; fig.........). The thickness of saturated formation is around 5 metres and that in Jhirvi is about 4 metres giving a permeability figure of about 15 m/day.

In the region close to Narmada in Satak command, the thickness of the saturated aquifer during post-monsoon season is around 5 metre and during pre-monsoon period is around 4 metre. Thus transmissibility value of 80 m^2/day was adopted for rainy season and 60 m^2/day for non-rainy season.

	1 HP	Village	No. of wells	$7\frac{1}{2}$ HP sets	3 HP sets	5 HP sets		10HP
50	-	Satkur	91		25	16	-	
41	1(D)	Katkur	94		17	35	-	
9	-	Pathora	73	1	31	31	1	
16	-	Balkhad	59		17	23	3	
2	-	Pagakhed	45	1	28	14	-	
5	-	Kachhipura	23		-	16	1	1
1	-	Maharajkhedi	2		-	-	1	
6	-	Ekalghariya	28		1	21	-	
4	-	Dhamnod	10		2	1	3	
14	10	Bamandi	77		26	34	2	
5	-	Salimpura	58		30	23	-	
-	-	Roopkheda	48		6	41	1	
1	-	Sonkhedi	41		15	19	6	
3	-	Regwa	70		12	45	10	
26	-	Balsamand	109		33	49	-	1
3	-	Balgaon	34	1	6	22	2	
-	-	Akbarpura	3		-	3	-	
5	-	Majhapura	25	-	7	11	2	2
191	2			3	256	404	32	2

Table 17 gives the results of the sample survey. The table shows the wells surveyed, the draft system used and their corresponding draft.

Draft from drinking wells :

Village wise population figures as given in table 18 and adopted from the satak tank performance evaluation report for the year 1971 were scaled up by 20 percent and taken as population figures for 1981. A draft of 25 litres per capita per day was adopted to estimate the draft from wells for domestic use.

8.6 Ponded Infiltration Data

Results of Infiltration tests, conducted at 36 locations by M.P. Agriculture Department and CES (through U.P. IRI), are given in table ..... of Chapter ...... (Hydrologic soil classification). Out of these tests, three test sites fall within the command of Satak tank as listed below along with the values obtained at each site.

S.No.	Village location	Final Infiltration cap.(mm/hr)
1	Satkur	4.0
2	Balsamund	5.0
3	Balsamand	2.5 Av = 3.8 mm/hr.

8.7 River Data

These data are required for estimating effluent and influent seepage. There are a number of discharge measurement stations established along River Satak. These along with the river flow data are presented in table 19 The data available is for the period from 1.8.82 upto 10.4.83.

8.8 Seepage through Canals and Water Courses

Table 20 gives the particulars of the tests conducted by CES through UP IRI to determine losses in the canals and distributiories.

Losses in Water Courses :

Table 21 presents the particulars of wells covered by the sample survey. Also shown in the table are computed average losses in the water courses. These are used to estimate the net draft from wells.

8.9 Draft from Wells

G.W.S. conducted an inventory of all wells in Satak Command. The village wise distribution of such wells is as follows :

8.10 Evapotranspiration

Table 22 shows the average monthly potential evapotranspiration rates for Indore and Khandwa. Average monthly Class A pan evaporation data as available for Khandwa are given in table 23.

8.11 Land Use Data

For a total Geographical area of 5341 Ha. table 24 shows the land use pattern for the year 1982-83. Out of a total cropped area of 3228 Ha., 1818 Ha. is irrigated by the Canal and a total of 52.6 Ha. comes under forests.

9.0 Data Availability in Kunda Command

9.1 Water Table Data

The following is a list of wells being monitored in the Kunda Command Area.

(a) G.W.S. is monitoring 39 temporary wells distributed in and around Kunda command. For these wells, monthly water level data from Nov.'82 upto Nov.'83 is available. These are shown in Table .25. .

(b) Weekly water level data of 9 temporary observation wells in Kunda command monitored by GWS is available from Sept.'82 to April'83. Table 26. shows the details of these wells.

(c) CES is monitoring 67 wells (numbered 1 to 52) along RTL (2) Right Bank, out of which well No.51G was always found dry. A record of monthly water levels starting from April'83 upto Feb.'84 is available. These 67 wells include 10 wells that are included in the 39 wells listed in table 25 . Particulars of these wells are given in table 26. .

(d) On the periphery of Kunda command CES has selected 30 wells for which water level data has been collected. The data extends from May'83 upto Nov.'83 and are presented in Table 28.

(e) Water level data for 262 GWS wells within Kunda command area is also available from Oct.'82 to April'83.

Table 29, gives the draft system used for these wells. Based on this information drafts are found out.

(f) The old permanent observation well at Dhamnod is being monitored by GWS. The data for this well is available from May'74 to Nov.'83. The particulars are presented in Table 30

(g) A total of 4 piezometers have been installed along RTL(2), Right bank out of which 3 are located within Kunda Command area. Table 31 5 presents the details of these piezometers.

9.2 Rainfall data

(1) Daily precipitation (in inches) recorded at Kunda Tank Raingauge station is available from June'71 upto 13th March'83 and from June'83 upto Oct.'83. These data are presented in Table 32.

9.3 Tank Data

(1) Daily gauge data from March'71 upto 13th March'83 and from June'83 to Oct.'83 is available and presented in Table 32.

(2) From the data on tank gauge, capacity and reservoir surface area and presented in Table 33., , elevation vs area and elevation vs capacity curves were prepared. These are given in fig. .2.

(3) Daily canal release data is available for Nov.'72 and Jan.'73 to May,77, from April'78 to Feb.'81 and from Nov.'82 to 18th Feb.'83 .. The breaks in between are the months in which the canal was not in operation. This data is presented in table 34.

9.4 Lift Pumping Data

No lift pumping is done either in from the Kunda Reservoir or any of the canals. This factor is therefore not considered.

9.5 Aquifer Parameters

One pump test data for Eklera Khurd was available in Kunda command area but the formation in this well is weathered basalt. Since the transmissibility value close to Narmada River is needed, the value for this well cannot be representative of the formation close to river.

The test pump data for Thikri was available, the analysis of which revealed a transmissibility value of 101.9 m^2/day with saturated thickness of about 5 mts giving a permeability value of 20 m/day. This value was considered applicable to Kunda command region close to Narmada also.

In alluvial reach close to Narmada in Kunda command the saturated thickness is about 5 mts in post monsoon period and 4 mt. in pre monsoon period. Therefore, the value of transmissibility was adopted as 100 m^2/day and 80 m^2/day for rainy and non rainy period respectively.

9.6 Ponded Infiltration Data

Results of Infiltration tests conducted at 36 location by MP Agriculture Department and CES through U.P., I.R.I., are given in table ..... of Chapter ..... (Hydrologic soil classification). Out of these tests, two test sites fall within the command of Kunda tank as listed below along with the values obtained at each site.

Sl.No.	Village	Final Infiltration Capacity mm/hr.
1	Dhamnod	5 mm/hr
2	Morgadi	4.7 mm/hr

Average = 4.85 mm/hr.

9.7 River Data

No river data is available in Kunda command area.

9.8 Losses From Canals

CES has conducted tests through IRI on the different conveyance systems of Kunda command area to estimate conveyance losses. Table 35 gives the details of such tests and the values of the loss rates obtained.

9.9 Sluice Leakage Data

Data of leakage through sluices is also available from Nov.'82 upto March'83 and shown in Table 36 . For the rest of the period leakage rate of 0.941 cusecs is reported.

9.10 Cropping Pattern

Yearwise, crop wise irrigated area is available for the period 1971-72 to 1982-83.

These are presented in table 37 However, the data regarding the overall cropping pattern adopted for practice in Kunda is not available.

9.11 Evapotranspiration and Evaporation Data

Average monthly potential evapotranspiration rates for Khandwa and Indore are available and given in Table 22. Information regarding class A pan evaporation rates for Khandwa is available. Table 23 gives average monthly class A pan evaporation rates for this station.

9.12 Land Use Data

Land use figures are given in table 38. Out of a total geographical area of 2430 Ha a total of 257 Ha has been adopted as area that has been provided canal irrigation out of a total canal command of 587 Ha .