'SODEPT' A Software for Design of Percolation Tank

R. C. Srivastava · H. C. Verma · B. K. Nanda · S. Mohanty

Abstract Percolation tanks are widely used for increasing recharge of ground water resources. This has been used from centuries in arid and semi arid regions of India and is known by different indigenous name, viz. *rapat, nadi* etc. However not much work has been done on standardization of the design parameters of these tanks, and therefore most of the time, tanks are either over designed or under designed. The design parameters of the percolation tank and amount of water recharged to groundwater during different months depend upon area of catchment, hydrological cover complex characteristics of the catchment, rainfall characteristics of the area, evaporation loss and seepage rate of the tank bed. Since rainfall and evaporation are stochastic variables, their distribution should also be accounted for. Further the dimensions of the tank will vary with the level of probability of design. With this in view, a software has been developed for giving the design parameters of the percolation tank. The input data are long term daily rainfall and evaporation data, seepage rate of the tank bed which is a function of textural characteristics and hydraulic conductivity, area of catchment, hydrological complex characteristics defined by curve numbers, area available for construction of the tank (length and width) for excavated type of the percolation tank or width of the gully and slope of the drainage way for impounded type of the tank, and cost of the earthwork for different depths and lead. The output is capacity of the tank for most economic recharge per unit investment, total recharge during the year, recharge during monsoon and recharge during post monsoon months and expected storage level at the end of the monsoon.

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1 Introduction

Percolation tanks are important for the conservation of runoff and groundwater recharge, a multipurpose structure for storing water for livestock, irrigation and recharge to groundwater. They may be depression excavated to form a small reservoir (Fig. 1), an embankment across a natural ravine, or an impounded reservoir (Fig. 2) (CRIDA 1990; Sivanappan 2002). Little can be found about the design of such structures though there are guidelines : Percolation tanks should not be located in heavy, impervious soils; suitable soils should be available for the embankment; an ideal location would be a narrow stream with high ground on either side; there should be some economic advantage (Singh et al. 1990; Dhruvnarayana 1993; Tideman 1996; Yugandhar 1995). The size of the pond should be related to the catchment area and the number of filling events (Samra et al. 2002).

   Without standardization of design parameters the tanks are both over-and under-designed. Since percolation tanks are being constructed in large numbers under watershed management program in India as well as other developing countries, there is concern with poor performance and economic loss. For this purpose a methodology for design of percolation tanks has been developed and based on it 'SODEPT'-Software for Design of Percolation Tanks has been developed. This paper presents details of this software.

2 Methodology

The design parameters of the percolation tank and amount of water recharged to ground water during different months depend upon the area of the catchment of the reservoir, hydrological cover complex characteristics of the catchment, rainfall characteristics of the area, evaporation loss and seepage rate of the tank bed. Since rainfall and evaporation are stochastic variables, their distribution should also be accounted for. These factors will affect the water balance of the tank. The water balance of the tank can be divided in two parts: (a) during monsoon months (also called rainy season) when there will be inflow in the form of the runoff and direct rainfall as well as outflow in form of evaporation and percolation; and (b) during post monsoon season when there will be no inflow and only outflow in form of evaporation and percolation. The water balance of the tank on jth day of ith year during monsoon can be expressed as below:

$$S_{ij} = S_{i(j-1)} + Q_{ij} \cdot 10 \cdot \text{Area} - E_{i(j-1)} \cdot 0.7 \cdot \text{WSA}_{i(j-1)}/1,000 - \text{SP}_{i(j-1)} \cdot \text{WSA}_{i(j-1)} \\ + P_{i(j-1)} \cdot \text{WSA}_{i(j-1)}/1,000 \tag{1}$$

Where

S_{ij}	amount of water stored in tank on jth day of ith year, m^3
$S_{i(j-1)}$	amount of water stored in tank on $(j-1)$th day of ith year, m^3
$E_{i(j-1)}$	open pan evaporation on $(j-1)$th day of ith year, mm
$\text{SP}_{i(j-1)}$	seepage rate ($m\ day^{-1}$) on $(j-1)$th day of ith year corresponding to water surface area (WSA) of that day, $= a + b \cdot h_{i(j-1)}$
$\text{WSA}_{i(j-1)}$	water surface area on $(j-1)$th day of ith year, m^2
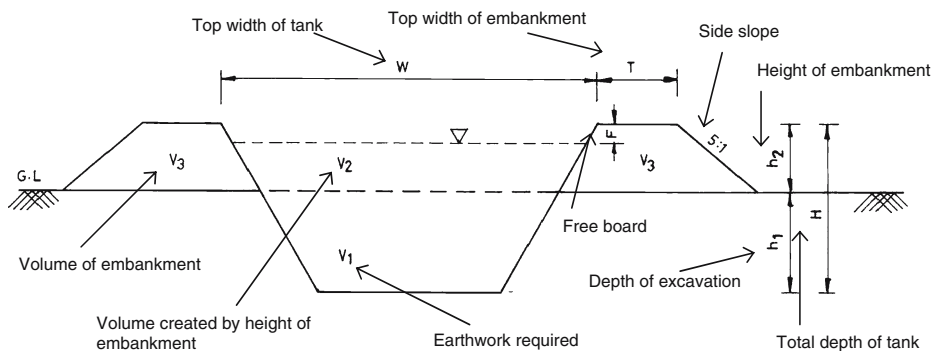
Fig. 1 Elevation of dug out tank

|	f (W, L, H, $h_{i(j-1)}$) for excavated type of the tank, or
	f(W, S_g, H, $h_{i(j-1)}$) for impounded type of the tank
Area	catchment area, ha
a, b	constants in seepage rate equation
W	top width of the tank/width of the embankment, m
L	top length of the tank, m
H	maximum possible depth of water, m
$h_{i(j-1)}$	depth of water in tank on ($j-1$)th day of ith year, a function of $S_{i(j-1)}$
Q_{ij}	runoff on jth day of ith year, $m = \left(P_{ij} - 0.2\,\mathrm{SR}\right)^2 \big/ \left(P_{ij} + 0.8\,\mathrm{SR}\right)$
P_{ij}	rainfall on jth day of ith year, mm
SR	25,400/CN-254
S_g	slope of the gulley
CN	weighted curve number for the catchment area for jth day of ith year. (Curve number is a hydrologic soil cover complex number which is dependent upon land use/cover, treatment, hydrologic condition, hydrologic soil group and antecedent moisture condition of last 5 days (U.S. Soil Conservation Service 1964)).

If the storage capacity is constrained by space available, the $S_{ij} \leq$ maximum storage capacity.
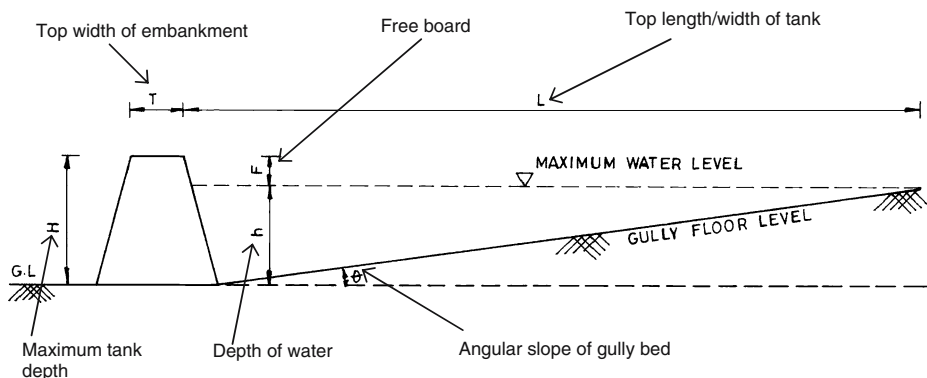
Fig. 2 Elevation of impounded type tank

The recharge to the ground water on jth day of ith year will be

Recharge$_{ij}$ = SP$_{ij}$ WSA$_{ij}$

And recharge (MR$_i$) during monsoon months in ith year will be

$$MR_i = \sum_{j=1}^{nm} \text{Recharge}_{ij} \tag{2}$$

where

nm=total number of days in monsoon period

After monsoon months, the amount of water stored can be expressed as following:

$$\text{Storage}_{ik} = \text{Storage}_{i(k-1)} - \text{montheva}_{ik}.0.7.\ \text{WSA}_{ik} - \text{SP}_{ik}.\text{WSA}_{i(k-1)} \tag{3}$$

Where

Storage$_{ik}$	volume of water in tank at the end of kth month of ith year, m^3
Storage$_{i(k-1)}$	volume of water in tank at the end of $k-1$th month of ith year, m^3
montheva$_{ik}$	monthly evaporation of kth month of ith year, m
SP$_{ik}$	seepage rate in kth month of ith year, m per month
WSA$_{i(k-1)}$	water surface area at the end of $(k-1)$th month of ith year as expressed in Eq. (1)

and recharge during post monsoon months (PMR$_i$) in ith year will be

$$PMR_i = \sum_{k=2}^{pm} \text{SP}_{ik}.\text{WSA}_{i(k-1)} \tag{4}$$

pm=number of months in post monsoon peroid + 1 and total recharge (TR$_i$) in ith year will be

$$TR_i = MR_i + PMR_i \tag{5}$$

The storage capacity required capturing all the runoff of ith year

$$VT_i = \max.\left(S_{ij}\right) \tag{6}$$

The above formulation will give a time series of total volume (VT), monsoon recharge (MR), post monsoon recharge(PMR) and total recharge(TR). To get the dependable values, these series were fitted to different distribution (normal, Pearson, extreme, lognormal, log Pearson and log extreme). It was found that all the parameters fitted to normal distribution without any transformation. The probable values of these parameters were estimated for the exceedance probability levels of 10, 20, 30, 40, 50, 60, 70, 80 and 90%. Once these values are available, the value of total recharge (TR) per unit of storage capacity (VT) was estimated for each probability level and maximum of this was selected and all values at this design level of probability were taken. Once the storage capacity is known, the design parameters of the pond can be estimated. As stated earlier, there can be two site conditions: one where the water is stored in an excavated pond, and another where the water is stored behind an embankment constructed across the stream.

For the first condition, the value of W can be obtained assuming the tank be of inverted trapezium shape with rectangular dimensions (Fig. 1). Although Helweg and Sharma (1983) have conceptualized circular shape for economizing on cost, but the commonly used shape of dugout percolation tanks is rectangular and therefore it has been used. Srivastava (1992)
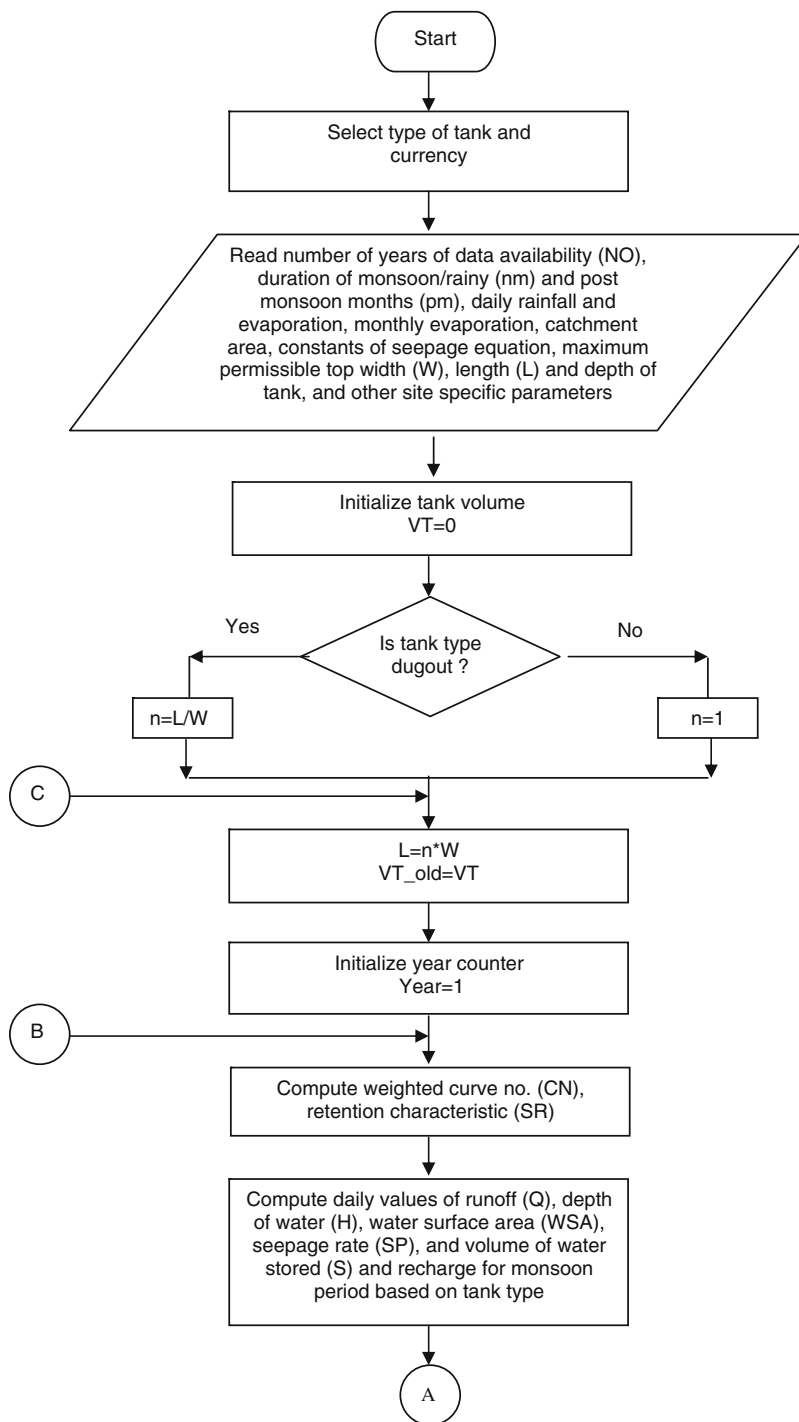
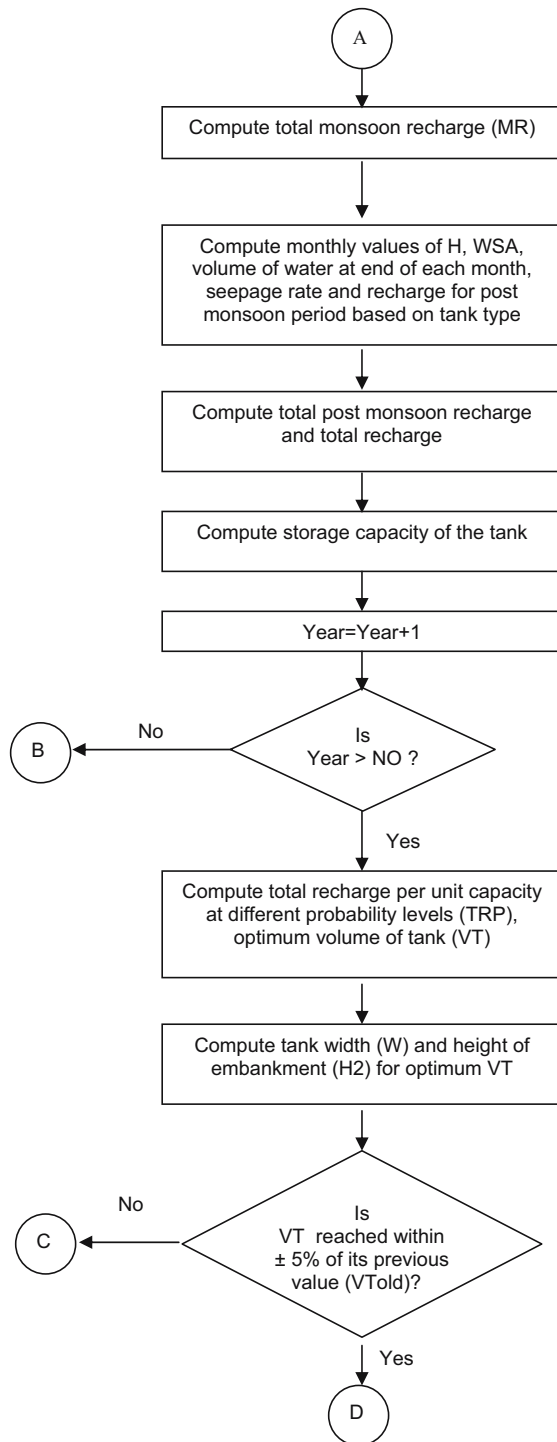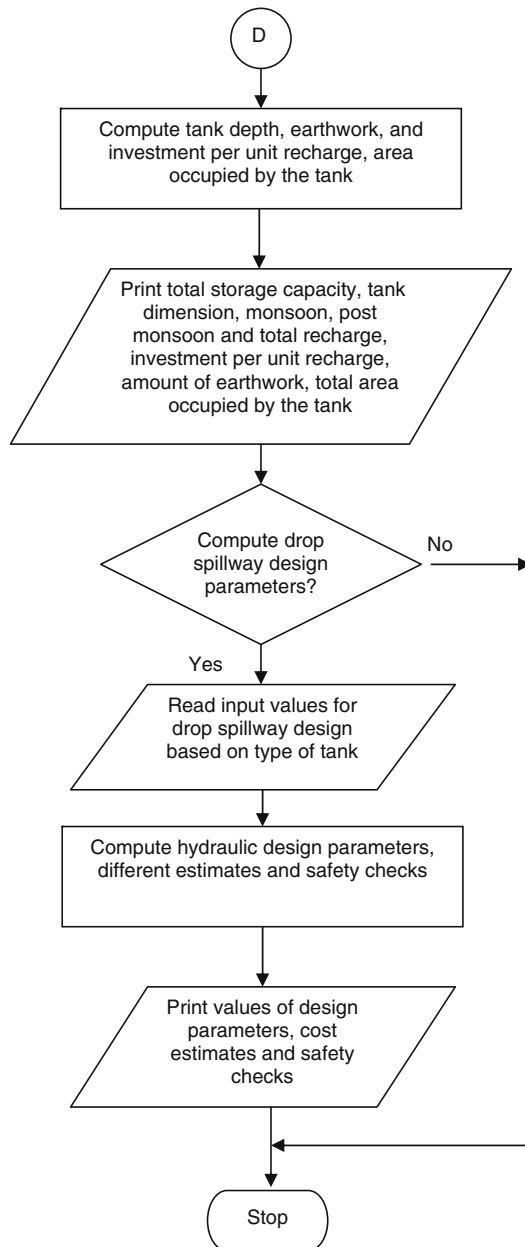**Fig. 3** Flow chart of SODEPT software program

Fig. 3 Continued

Fig. 3 Continued

```
                            ( D )
                              |
                              v
          +---------------------------------------+
          |  Compute tank depth, earthwork, and   |
          |  investment per unit recharge, area   |
          |        occupied by the tank           |
          +---------------------------------------+
                              |
                              v
          /----------------------------------------\
         /    Print total storage capacity, tank    \
        /       dimension, monsoon, post             \
        \    monsoon and total recharge,             /
         \   investment per unit recharge,          /
          \  amount of earthwork, total area       /
           \    occupied by the tank               /
            \-------------------------------------/
                              |
                              v
                        /  Compute drop  \
                       /  spillway design \-------- No ----+
                       \   parameters?    /                |
                        \                /                 |
                              |                            |
                             Yes                           |
                              v                            |
                /-----------------------------\            |
               /    Read input values for      \           |
              /     drop spillway design         \          |
              \    based on type of tank         /          |
               \-------------------------------/            |
                              |                             |
                              v                             |
          +---------------------------------------+         |
          |  Compute hydraulic design parameters, |         |
          |  different estimates and safety checks|         |
          +---------------------------------------+         |
                              |                             |
                              v                             |
                /-----------------------------\             |
               /     Print values of design    \            |
              /     parameters, cost             \           |
              \     estimates and safety         /           |
               \         checks                 /            |
                \-----------------------------/              |
                              |                              |
                              v <---------------------------+
                        (  Stop  )
```

Table 1 Sample screen to select and load pre-created data file
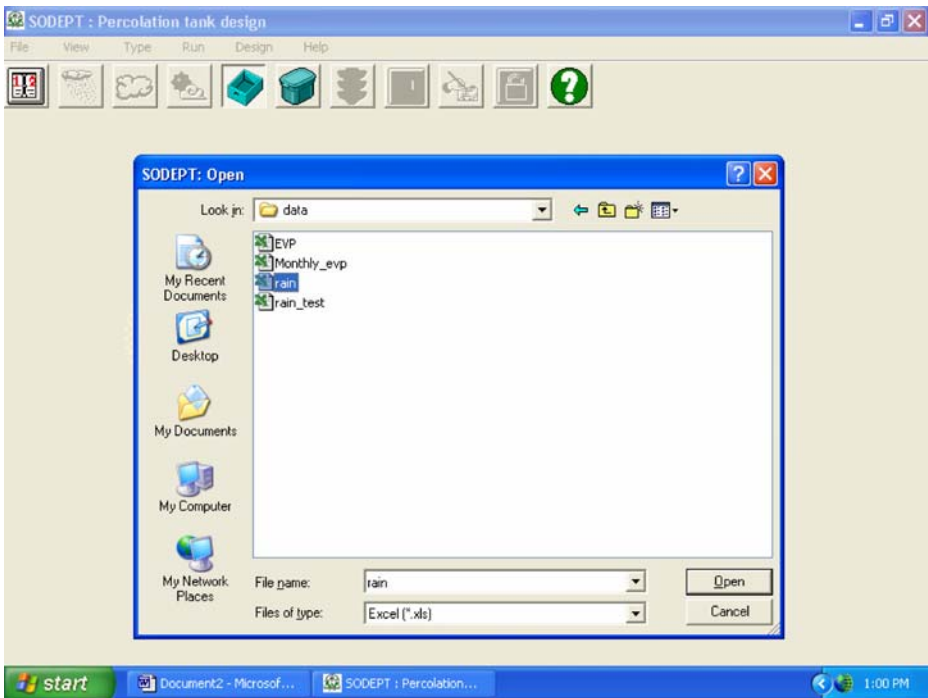
has given following relationship for estimating volume of such tank having 's' (horizontal/vertical) side slope

$$VT = W.L.H - (W + L).\, s.H^2 + 1.33\, s^2\,.\, H^3 \tag{7}$$

Where

W top width, m
L top length, m
H total depth, m

Thus from Fig. 1 when $L = n.\, W$ and $s = 1$

$$VT = (W - F)(n.\, W - F)(H - F) - (W + n.W - 4F)(H - F)^2 + 1.33\,.(H - F)^3$$
or (8)
$$n.W^2(H - F) + W(1 + n)(F^2 - H^2) + 1.33H^3 - 1.33F^3 - VT = 0$$
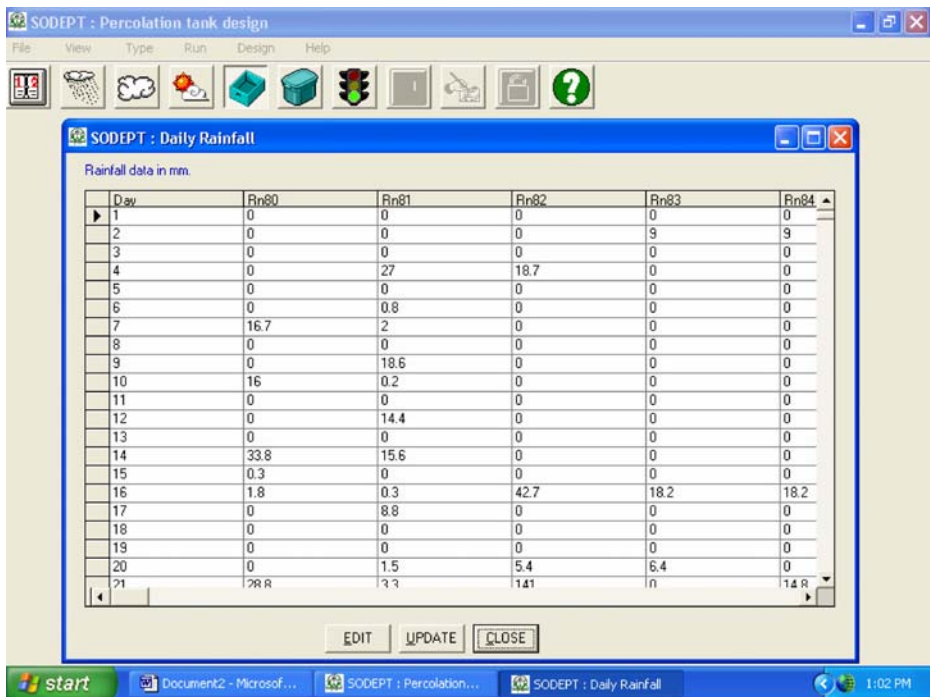
where

F freeboard, m
n ratio of the top length(L) to width(W) of the proposed site

This is quadratic equation and thus W can be calculated for a particular value of H. The value of H will be dependent upon substrata conditions, and it can vary from 4 to 5 m.

Table 2 Sample view of a loaded rainfall input file

From Fig. 1 the earthwork required will be

$$V_1 = (W - h_2)(n.W - h_2)h_1 - (W + n.W - 4h_2)h_1^2 + 1.33h_1^3$$

Where

h_1 depth of excavation, m
h_2 height of embankment, m

Volume created by height of embankment

$$V_2 = n.W.W.h_2 - (W + n.W)h_2^2 + 1.33h_2^3$$

And volume of embankment

$$V_3 = h_2^2\{2(1+n)W + 4T\} + h_2\{2(1+n)T.W + 4T^2\} \quad (9)$$

where T=top width of embankment, m.

For optimal construction, the excavated earth should be equal to volume of earth required for embankment (Helweg and Sharma 1983), i.e., $V_3 = V_1$. By solving it

$$h_2^2\{2(1+n)W + 4T - (1+n)W\}$$

$$+ h_2\{2(1+n)\text{WT} + 4\,T^2 + n.W^2) - n.W^2.H + (1+n)W.H^2 - 1.33H^3 = 0$$

Table 3 Screen to select the type of percolation tank
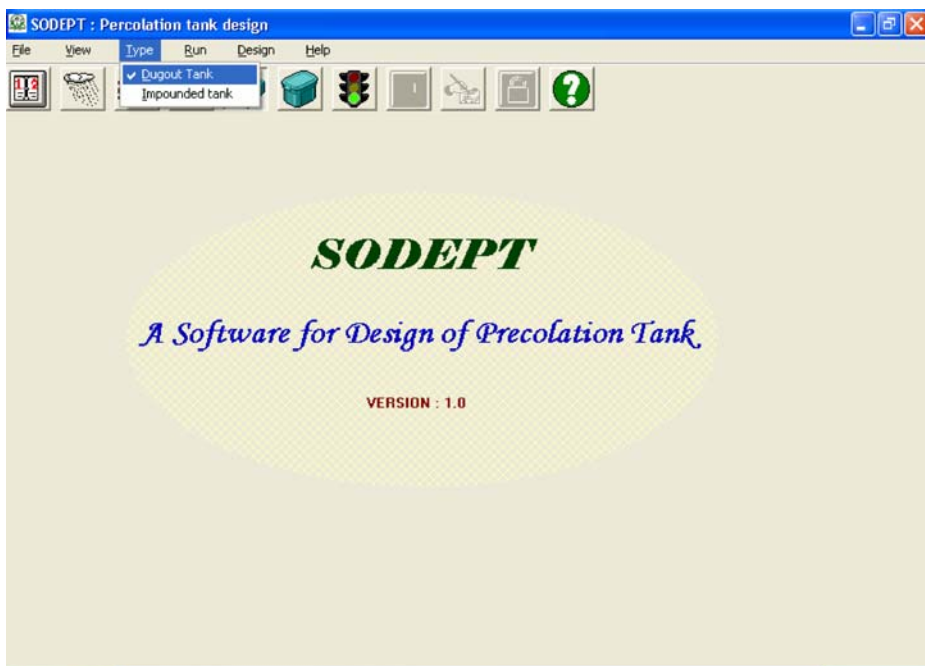
This is a quadratic equation and value of h_2 can be determined for given value of W and H. The value of W is available from solution of Eq. 8 and value of H is dependent upon sub strata conditions. Depth of excavation will be

$$h_1 = H - h_2 \qquad (10)$$

and thus all the dimensions are estimated for a particular VT.

For second condition, the water stored will be in the shape of a right-angled triangle (Fig. 2) with water surface being base, embankment being perpendicular and gully bed being hypotenuse. It has been assumed that the width is same for the submerged area. In case of this not being so, average width can be taken. The mathematical formulation for estimation of volume at maximum depth H, i.e., maximum storage capacity will be as follows:

$$\text{Max storage capacity} = H^2 \cdot \cot \theta \cdot W/2 \qquad (11)$$

where θ is angular slope of the gully bed and for any height h_i on jth day of ith year

$$S_{ij} = h_{ij}^2 \cdot \cot \theta \cdot W/2 \qquad (12)$$

i.e.,

$$\text{WSA}_{ij} = W \cdot h_{ij} \cdot \cot \theta \qquad (13)$$

and

$$\text{VT} = h^2 \cdot \cot \theta \cdot W/2 \qquad (14)$$

Table 4 Input screen for dugout tank type system

Where h=depth of water, m, with a condition that $h+F<H$

Total amount of earthwork for construction of the embankment V_1 will be

$$V_1 = \frac{1}{2}\{2T + (h + F)(S_u + S_d)\}(h + F)W \tag{15}$$

where S_u and S_d are upstream and downstream slopes of the embankment and T is the top width as stated earlier.

Assuming that the soil required for the construction of the embankment will be taken out from the gully bed, the height required for creating required storage capacity will reduce and new height will be

$$h = \sqrt{2}.(\text{VT} - V_1)\Big/W . \cot\theta \tag{16}$$

By iterating Eqs. 15 and 16, the appropriate value of 'h' can be determined and thus all dimensions are estimated for a particular VT. For further design of embankment, a module for testing the safety of the embankment was added to test the embankment against overturning, sliding, tension and compression using standard methodology. Further every percolation tank will require a surplussing structure to discharge the excess runoff and for this a drop spillway will be required. To provide complete design of the percolation tank, a module for designing a drop spillway was also added. This module was developed on the basis of standard methodology given in text books (Murthy 1985). Another module for estimating the cost of the tank and spillway was added for estimating the final cost of the system (C_T). From this cost, the investment cost of the recharged water (INV) was estimated by dividing C_T by total recharge TR, i.e., INV=C_T/TR.

Table 5 Input screen for impounded type system

Based on these mathematical formulations, computer software was developed for this simulation. The flow chart of the software is presented in Fig. 3. The input data required for the program are rainfall and evaporation data, constants of seepage equation for the tank site, catchment area, weighted curve numbers for all the three antecedent moisture conditions for the catchment area. The other parameters will vary as per the site conditions. They are width, length and maximum depth of excavation at the tank site for first type of site condition, and width, maximum permissible height of embankment, and bed slope of the drainage way/ gully for the second type of site condition. To initialize the simulation, values of W, L and H were taken as per the site condition or in such a way that total volume is equal to approximate annual runoff. After first iteration, the new values of W and H are taken and the iteration is made till convergence of $\pm 5\%$ in storage capacity 'VT' is achieved. Once convergence is achieved, the following parameters will be available in output:

(1) The total storage capacity of the tank (VT), m^3
(2) The amount of earthwork (V_1), m^3
(3) Top width of tankgully (W), m
(4) Total depth of the tank (H), m
(5) Free board (F), m
(6) Top width of embankment (T), m
(7) Depth of excavation (h_1), m
(8) Height of embankment (h_2), m
(9) Total area occupied by tank (A_t), m^2
(10) Total amount of recharge (TR), m^3
(11) Amount of recharge in monsoon season (MR), m^3

Table 6 Input screen for data required for design and estimation of the system

Table 7 Output screen for dugout type system

Table 8 Output screen for impounded type system

SODEPT - Data input screen for impounded tank		

INPUT

Catchment area, ha	20	Width of gully, m	50
No. of years of data availability	16	Bed slope of gully to be impounded	0.02
Curve no. for AMC I condition	57	Maximum permissible depth including freeboard, m	5
Curve no. of AMC II condition	75	Top width of embankment,m	3
Curve no. for AMC III condition	88	Freeboard required, m	1
Seepage equation constant , a	0.04	cost of earthwork per cubic meter, Rs.	30
Seepage equation constant, b	0.008	Upstream slope of embankment	1.5
		Downstream slope of embankment	2

DEFAULT   COMPUTE   CLOSE

Table 9 Output screen depicting hydraulic design of the spillway

SODEPT : Hydraulic Design of Drop Spillway

OUTPUT(including inputs)

Catchment Area, ha	A	20
Max. intensity of rainfall for equal to time of concentration. mm/hr	I	25
Runoff coefficient for rational formula	C	0.5
Expected highest depth of crest flow, m	h	0.28
Height of the crest wall, m	H	0.2
Depth of foundation, m	DF	0.2
Longitudinal sills	LS	2
Peak Discharge, cum/sec	Q	0.69
Length of the crest, m	L	3.00
Critical depth of the flow, m	Dc	0.18
Length of the apron, m	La	1.02
Height of wing wall/head wall extensionat junction. m	J	0.55
Length of wing wall/head wall extension, m	Lw	1.43
Height of the end sill, m	HES	0.09
Thickness of the apron floor, m	TAF	0.20
Length beyond apron, m	LBA	0.46
Height of longitudinal sills, m	HLS	0.07
Component M ,m	M	1.12
Component K, m	K	-0.01

PRINT   CLOSE

PLAN

Footing   Apron

DOWNSTREAM ELEVATION

Headwall extension   Headwall   Wing wall

SECTION ON CENTRE LINE

Table 10 Output screen depicting estimate of the spillway

Table 11 Output screen depicting the safety check of embankment for all the three conditions

Fig. 4 Variation of tank storage capacity and annual total recharge with seepage rate (for excavated tank and curve number 70 for AMC II conditions)

(12)   Amount of recharge in post monsoon season (PMR), m^3
(13)   Investment required for per unit recharge (INV), Rsm^3

To assess the effectiveness of the software in optimal design of the percolation tank, the software was test run for different seepage rates with value of '*a*' ranging from 0.01 to 0.20 and different catchment characteristics represented by curve number with value of curve number for antecedent moisture condition II ranging from 60 to 85. For these test run, all other input parameters were kept constant, and effect of these changes on different output parameters were evaluated.
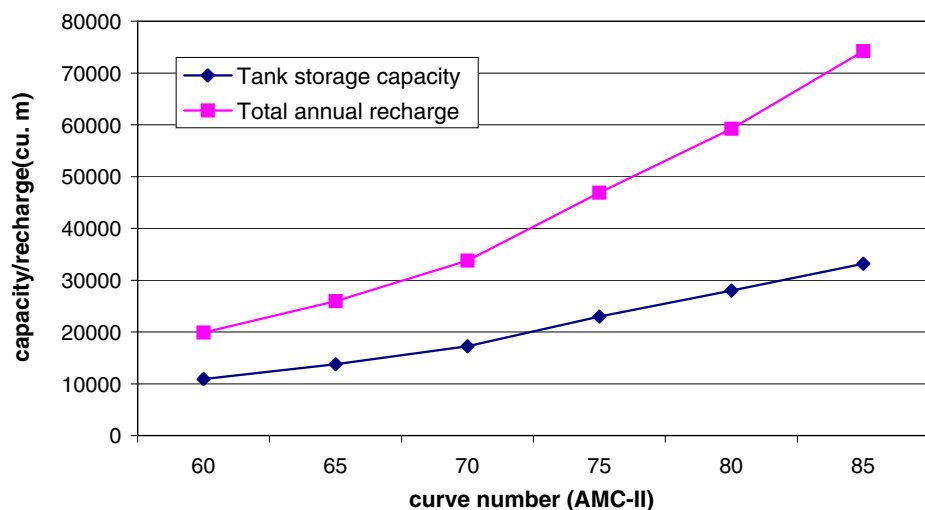
Fig. 5 Variation of tank storage capacity and total annual recharge with curve number (for excavated tank and seepage rate of 0.04 m/day)

3 Results & Discussion

The software was tested for Bhubaneswar conditions for a 16 year series of rainfall and evaporation data. It is a menu-driven system which comprises of six menu items viz., File, View, Type, Run, Design and Help. The 'File' menu provides options to load monthly evaporation, daily rainfall, and daily evaporation data from MS Excel files (Table 1). It is flexible enough to load a pre-created data file from any drive or folder selected by user. 'View' menu can be used to display data, once it is loaded, in tabular form that can be edited too (Table 2). 'Type' menu provides users with options to select either dugout or impounded type of tank (Table 3). Options from 'Run' menu can be used for entering data specific to percolation or impounded type of tank (Tables 4 & 5), depending on user selection (Table 6), and executing a module to compute all output parameters discussed in previous section (Tables 7 & 8), The 'Design' menu has three options viz., hydraulic design of drop spillway, cost estimate, and safety check for impounded tank that takes design specific parameters as input and computes different design parameters, cost estimates and safety checks (Tables 9, 10 & 11).

It is evident from tables that all required parameters for construction of the percolation tank are received from the software. All cares were taken for implementation of input validation rules in data entry forms, error free execution and avoiding system crash, and providing context sensitive user help.

Figure 4 presents the effect of change in seepage rate on total capacity of the tank, and total recharge, which indicate that the tank capacity changes sharply with seepage rate. However the change in total recharge is not that significant, which means that to achieve higher recharge at sites having less seepage rate, the capacity has to be higher. As the investment per unit recharge is directly related with capacity, investment per unit recharge will be less for higher seepage rate. Similarly it is evident from Fig. 5 that the catchment characteristics affect the size of the tank as well as the total annual recharge, which increases with increase in runoff generating capacity of the catchment. This shows that thumb rules which are prevalent for designing percolation rates either over-design or under-design the system, and this software will be helpful in overcoming this problem and optimize the investment in this sector.

4 Conclusion

'SODEPT' is a WINDOWS based menu-driven user-friendly software for optimal designing of the percolation tank. It takes in account the rainfall, evaporation, catchment area and its characteristics, seepage rate and site specifications. The output gives the total design parameters of the system along with drawing of the spillway and estimate.

References

CRIDA (1990) Field manual on watershed management. Central Institute for Dryland Agriculture, Hyderabad
Dhruvnarayana VV (1993) Soil and water conservation research in India. ICAR Publication, New Delhi, p 454

Helweg O, Sharma PN (1983) Optimal design of small reservoirs (tanks). Water Resour Res 19(4):881–885
Murthy VVN (1985) Land and water management engineering. Kalyani Publications, New Delhi, p 590
Samra JS, Sarda VK, Sikka AK (2002) Water harvesting and recycling: Indian experiences. Central Soil and
     Water Conservation Research & Training Institute, Dehradun, Uttaranchal, India
Singh G, Venkataramanan C, Sastry G, Joshi BP (1990) Manual of soil and water conservation practices.
     Oxford and IBH Publishing Pvt. Ltd, p 385
Sivanappan RK (2002) Technologies for water harvesting and soil moisture conservation in small watershed
     for small–scale irrigation. url: http://www.fao.org./docrep/W 7314E/w7314eog.htm
Srivastava RC (1992) Design of multi tank irrigation system for rolling lands using multi level multi objec-
     tive optimization. PhD thesis, Indian Institute of Technology, Kharagpur
Tideman EM (1996) Watershed management: guidelines for Indian Conditions. Omega Scientific Publishers,
     New Delhi, p 372
U.S. Soil Conservation Service (1964) Hydrology section 4, supplement A, (1957). National Engineering
     Handbook, Washington DC
Yugandhar BN (1995) Guidelines for watershed management. Department of Land Resources, Ministry of
     Rural Development, Government of India