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Study of the Hydraulic Parameters of Existing Water Storage Structures in Bhakra Main Canal Command Area of Sirsa District, Haryana

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ABSTRACT

Balancing reservoirs are extensive kind of water storage structures. They ensure the adequate quantity of water availability to fulfill the demand and maintain water quality. The major hydraulic parameters of the tank are length, width, depth, side slope, surface area and storage capacity. In this study, information about hydraulic parameters of 109 existing balancing reservoirs was collected from various sources. The storage capacity of the balancing reservoir is important for the efficient operation of the water supply system. The balancing reservoir should be large enough to store sufficient water to meet both average and peak daily demands of the crop. In the present study, balancing reservoirs of different sizes and shapes were found existing in the farmers' fields. Trapezoidal shaped tanks having a geometrical advantage over other shaped tanks can be constructed. Mostly, the B-category tanks (size between 50-100 m^2) existed in research areas and these were based on the size of landholding. Water storage through the tank is considered as an efficient tool because it improves crop productivity and minimizes risk uncertainties.

Keywords: Tank, balancing reservoir, farm pond, storage capacity, hydraulic parameters.

INTRODUCTION

Balancing reservoirs are small reservoirs which located in irrigated areas that allow farmers to capture rainfall and store surplus water from other sources (viz. canal and groundwater). It allowed users to obtain water on demand because of their capacity to store water close to users (Barker *et al.*, 2001). In a rainfed upland ecosystem, conserving rainwater in a small tank in the farm area, popularly known as the on-farm reservoir (OFR), and recycling the harvested water can mitigate the probable drought and submergence situations. However, the size of the OFR with respect to the farm area and its type (lined or unlined) plays a decisive role in the effective implementation of the technology at the field level. Because an under or over-sized structures in the crop field make the system economically unacceptable. Hence, attempts have been made to arrive at an optimum size of the tanks with respect to various cropping systems at its upstream and downstream. Panda (2010) studied the optimum sizing of OFR for various cropping systems in rainfed uplands of eastern India.

The most efficient way of storing water locally is to create reasonably sized pond consistent with the catchment area. There may be substantial water seepage in an unlined pond and it depends on soil type. The water lost through seepage from ponds is priceless, as we may not be able to find any alternate source of getting the same. The typical approach for seepage control is lining the pond. Generally, cement/concrete lining of reservoirs used for control of water seepage. The estimation of hydraulic parameters of tank played an important role in water resources management. The hydraulic parameters such as water surface elevation, flow velocity and hydraulic radius should be assessed.

The storage capacity of the tank is directly related with storage areas. The storage capacity of tanks increased with an increase in surface area at constant water depth (Jeet and Patel, 2016). The statistical or geo-statistical systems may be used to estimate the cross-section and hydraulic parameters along the canal based on scarce measured data. The SSISP model shown that an increase in the number of ponds does not always correlate with an increase in the size of the irrigated area since the available water resources, the operation, and management play a significant role (Chukalla *et al.* 2013; Ghahraman and sepaskhah 2002). These procedures are useful and cost-effective in the estimation of hydraulic parameters along the canals or rivers at locations with no measured data. A mathematical relationship can be assumed between water depth or water surface width, and other hydraulic properties such as flow area and flow velocity. Shahrokhnia *et al.* (2004) studied on the estimation of hydraulic parameters for Karoon River by cokriging and residual kriging.

The present study aims at estimating the hydraulic parameters viz. length, width, depth, surface area, and storage capacity, of existing structures, have adequate capacity to store the rainfall and another source of water supply (canal and groundwater). Such studies are needed to be promoted, as the water balancing reservoir in the riverbed is more effective both in terms of cost of the structure and the land requirement for these structures.

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MATERIAL AND METHODS

Study area

The present study was carried out in Sirsa, the north western district of Haryana State with a total geographical area of 4277 sq. km is located between the latitudes of $29^0 13'$ N and $29^0 59'$ N and longitudes of $74^0 30'$ E and $75^0 7'$ E at an altitude of 204 m above the mean sea level (Fig.1). The climate of Sirsa district can be classified as tropical desert, arid and hot which is mainly dry with very hot summer and cold winter except during monsoon season. The mean annual temperature is 25^0 C. May and June are the hottest months with 30 years normal maximum temperature is $41\text{-}46^0$ C. January is the coldest month with a mean daily maximum temperature of 21^0C and a minimum of 5^0 C. The mean annual rainfall is 300-350 mm of which as much as 80% which is received during the monsoon in the months of July to September. The district has mainly two types of soils viz. Sierozem and Desert soils and soil textures varies from sandy to sandy loam.

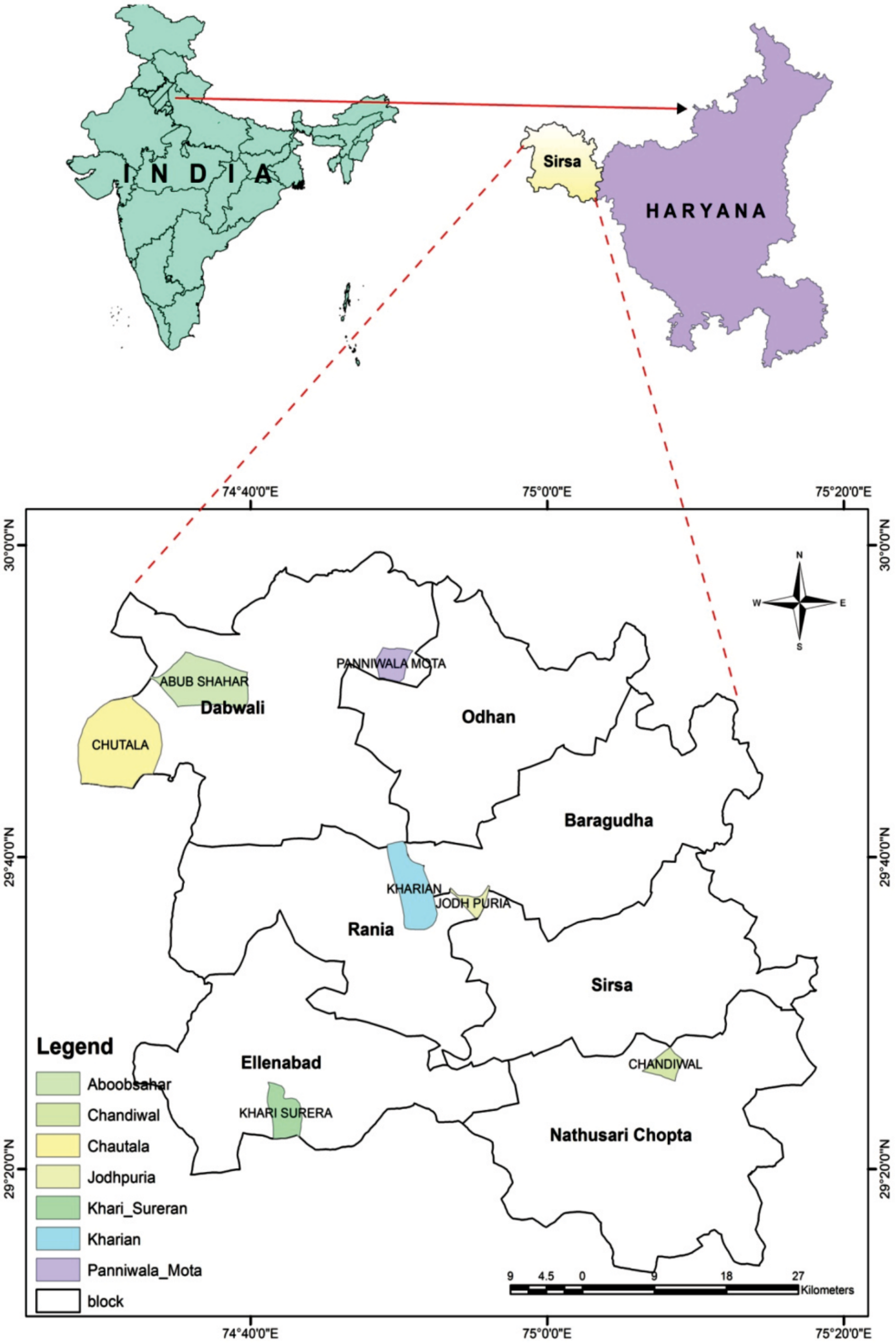

Fig. 1: Location of the study site

Data collection

Various existing balancing reservoirs hydraulic parameters data was collected from Horticulture Department of Sirsa, Haryana. A total number of existing water balancing reservoirs in Sirsa district was nine hundred ninety-nine. Out of the total balancing reservoirs, 109 balancing reservoir of 7 villages has been chosen for this study (Fig. 2).

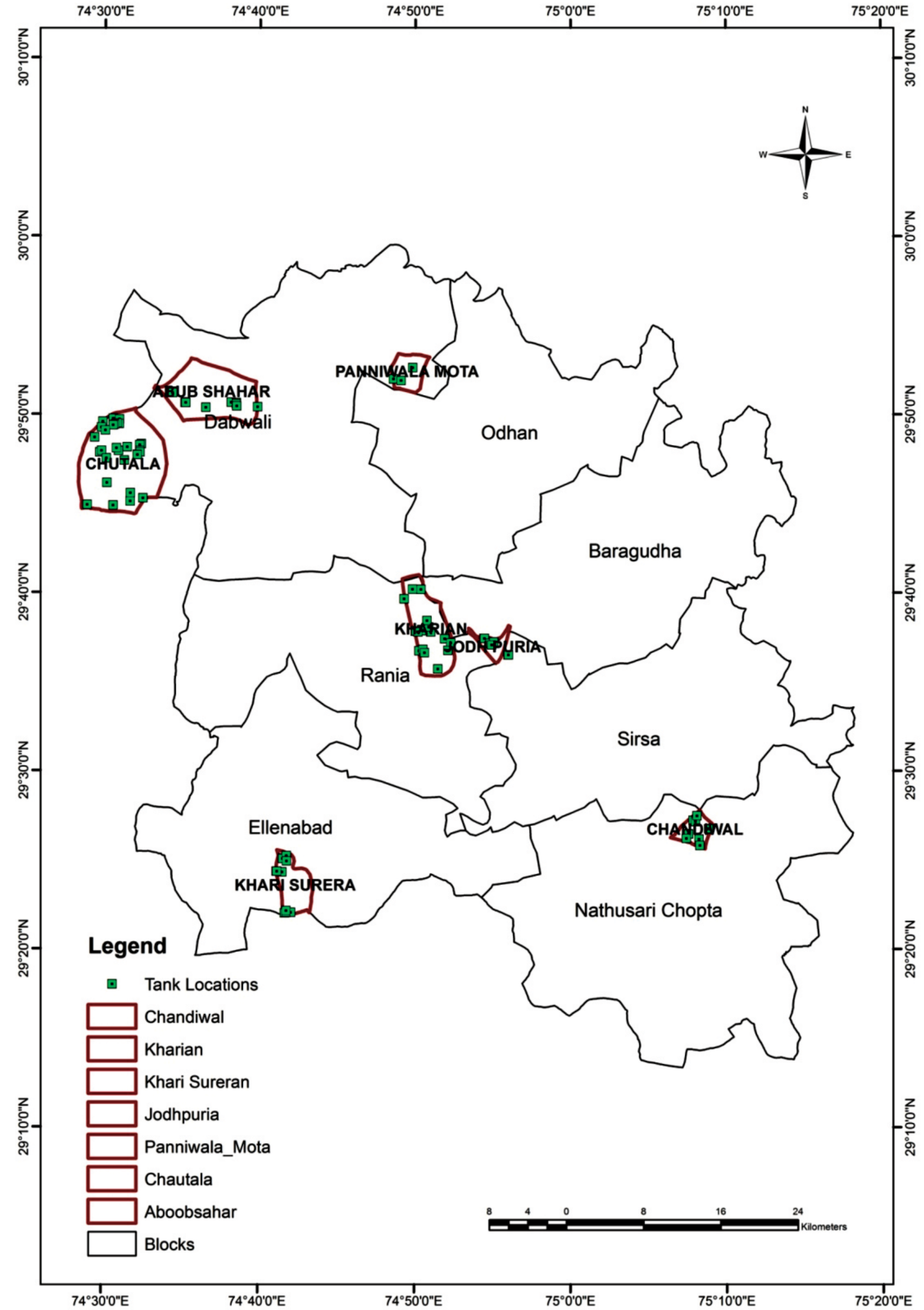

Fig. 2 : Location of selected existing balancing reservoirs in Sirsa district

Estimation of bottom width, surface area and storage capacity of tanks

There are many factors that influence the surface area and storage volume or capacity within tanks or farm pond including the intensity of the storm, the volume of precipitation, the land use, soil type and initial moisture conditions.

Water Storage volume was calculated on the basis of the maximum level of water obtained in the farm pond. Volumes of water lifted for irrigation were calculated from discharge rate of pumps. Pumping hours of lifting water from the canal to farm pond, and from pond to the farmers' cultivable field for irrigation were recorded.

Patel *et al.* (1997) reported the cost of constructing farm pond as (which will vary as per prevailing rates), cost of construction i.e. excavation + fill, cost of pipe inlet and cost of constructing main drainage canal and field channels. Top width of tanks and side slopes (2-2.5 H: 1 V) for earthen lined farm ponds were based on soil type. Vora *et al.* (2008); USDA (1992) calculated surface and storage volume of the trapezoidal tank or farm ponds by using simple mathematical equations.

Bottom width of tanks was calculated by using mathematical equation (1)

$$B = [T + 2x\,(H/V)Xd \qquad (1)$$

Cross-sectional area was calculated by using mathematical equation (2)

$$A = \frac{(T + B)}{2d} \qquad (2)$$

Storage capacity or volume were calculated by using mathematical equation (3)

$$V = A\,X\,L \qquad (3)$$

Where, B = Bottom width; T = Top width; Side slope = 2-2.5:1 (Horizontal/Vertical); d = Tank depth; A = Cross sectional area; L = length of the tank; and V = Storage volume of tank.

The dyke should be properly designed so that it can hold maximum water in the pond and withstand the hydraulic pressure. The slope of the dyke usually depends on the type of soil. As such, the height of the perimeter dike should have a free board of 0.6–0.7 meters above the desired water depth (Vora *et al.*, 2008). Free board allowance is determined from the occurrence and frequency of flood levels over a period of 5–15 years at the farm site.

Estimation of water requirement of the major crops

The reference crop evapotranspiration (ET_0) is calculated by using CROPWAT software. The water requirement of the major crop in the canal is calculated by using equation (4)

$$WR = \frac{(ETXKC)}{(effciciency)} \qquad (4)$$

Peak volume of water needed for the crop (V_{peak}) was calculated by using equation (5)

$$V_{peak} = WR\ X\ A \qquad (5)$$

Where K_c = Crop coefficient, A = Area coverage by different crops (m^2) and V_{peak} = peak volume of water needed for the crop (m^3).

Dimensions of pond

Depth of pond

Another important factor in the overall health of the pond is the depth. The depth of the pond should range from 3 to 5 m (Table 1). Greater than 1 m of depth is necessary and would require less area as well as minimum evaporation loss and maintenance hazard (Reddy *et al.*, 2012).

If space for the adequate surface area is not available, this can be offset to some degree by increasing the depth of the pond. When the construction is done with human labour, any increase in depth beyond 3.5 to 4.0 m becomes uneconomical. Generally, a depth of more than 3 m may be suitable for the construction of the pond for water storage for irrigation (Rao *et al.*, 2017).

Table 1: Average depth of pond as per climatic condition

Climate	Average depth (m)
Wet or per humid	2
Humid	2.4 - 2.8 or 2.5
Moist sub humid	2.8 - 3.15 or 3
Dry sub humid	3.15 - 4.00 or 4
Semi arid (moist)	4.00 - 4.80 or 4.5
Arid (dry or typic)	4.80 - 5.50 or 5

The slope of the pond: 1.5:1 to 3:1 slopes has been recommended for clay to sandy loam soil. The side slopes are decided by the angle of repose of the sub-soil. The constant action of standing water may require relatively flatter side slopes to avoid slippage due to saturation. Generally, side slopes of 2:1 or flatter are adopted.

The side slope ranging from 1: 1 to 1.5: 1 is generally suitable for pond construction (Reddy *et al.*, 2012; Rao *et al.*, 2017).

***Bottom side*:** When the volume of the pond is known and the depth and side slopes are fixed, the side of the bottom square can be obtained by using equation (6)

$$B = \frac{1}{3}\sqrt{\frac{3(3V - n^2D^3)}{D}} - D \times n \qquad (6)$$

Where, B = Side of bottom square (m); V = Volume of pond (m^3); D = Depth of pond (m) and n = Side slope ration (horizontal: vertical).

***Top side*:** The bottom dimensions are known, the side of the top square can be obtained by using equation (7)

$$T = B + 2D \times n \qquad (7)$$

Where, T = length of the side of farm pond at the top in the metre.

RESULTS AND DISCUSSION

Physical properties of soil

The physical properties (viz. textural class, hydraulic conductivity, bulk density, field capacity and permanent wilting point etc.) of the soil sample is analyzed in a laboratory and is presented in Table 2

Table 2: Physical properties of soil sample at different depths

Depth	Particle size distribution (%)			Textural class	Hydraulic conductivity (cm h^{-1})	Bulk density (g/cc)	FC (%)	PWP (%)
	Sand	silt	clay					
0-25	60.48	31.28	8.24	Sandy loam	3.45	1.65	25.20	10.05
25-50	68	22 .72	9.28	Sandy loam	2.45	1.54	28.05	11
50-75	61.36	30.28	8.36	Sandy loam	1.39	1.48	21.85	14.02
Avg.	63.28	28.09	8.62	Sandy loam	2.43	1.56	25.03	11.69

Size and shape of existing water storage structure

A total of nine hundred ninety-nine tanks were constructed spread over in 7 blocks of Sirsa district. Based on the survey of 109 existing water storage structures of 7 villages of Sirsa district, the number of water storage structure per village varied from 9 to 27. Number of tanks and its dimensions details are given in Table 3. Tanks depth are taken as 3.05 m (10 ft), 3.66 m (12 ft) and 4.57 m (15 ft), in which tanks depth 4.57 m (15 ft) is very common. Trapezoidal shape is the most common existing water storage structure in the study area.

Table 3: Measurement of the dimension of the existing storage structure in research areas

Length (m)	Top width (m)	Bottom width (m)	Depth (m)	Number of tanks
35.81	35.81	17.52	4.57	3
29.72	29.72	11.43	4.57	9
45.72	36.58	31.09	3.66	2
22.09	22.09	3.81	4.57	22
23.62	23.62	5.33	4.57	20
33.53	34.75	15.24	4.57	1
48.01	31.24	29.72	4.57	8
33.22	33.22	14.94	4.57	3
33.83	33.83	15.54	4.57	1
51.05	34.14	32.77	4.57	14
16.76	16.76	4.57	3.05	2
36.58	30.48	21.94	3.66	4
30.48	29.26	15.85	3.66	2
24.38	21.34	9.75	3.66	4
16	16	2.29	4.57	6
19.81	16.76	7.62	3.05	2
27.43	23.77	12.80	3.66	3
47.24	42.37	28.96	4.57	3
Total				**109**

Bottom width of water storage structure

Bottom width of existing water storage structure based on the top width and side slope of structures. The side slope of existed structure based on soil texture and types is presented in Table 4. The top and bottom width were calculated by using mathematical equation (1) and its measured value is presented in Table 3.

Table 4: Suitable side slopes for different soils

Soil type	Side Slope (Horizontal:Vertical)
Clay	1:1 to 2:1
Clay Loam	1.5 to 2:1
Sandy Loam	2:1 to 2.5:1
Sandy	3:1

The depth and side slope of the water storage structure

The depth of the pond is generally determined by soil depth, kind of material excavated and type of equipment used. The selected pond depth should have a depth equal to or greater than the minimum required for the specific location as the depth of the pond is most important dimension among the three dimensions i.e. length, width, and depth. In semi-arid regions, the evaporation losses can be reduced by deepening the pond depth for the same volume of water stored as lesser is the area occupied by the pond. The side slope of the tanks is decided on the basis soil types. The soil type of the study area is sandy loam to loamy sand and side slopes ranging from 2:1 to 2.5:1. But, the side slope ranging from 1: 1 to 1.5: 1 is generally suitable for pond construction (Reddy *et al.*, 2012;

Table 5: Surface area, perimeters and hydraulic radius of the water storage structure

Surface area (m^2)	Perimeter (m)	Hydraulic radius (m)
121.94	37.97	3.21
94.06	31.88	2.95
107.71	47.45	2.96
59.23	24.26	2.44
66.19	25.78	2.57
116.84	35.69	3.12
101.13	50.16	3.54
110.09	35.38	3.11
112.88	35.99	3.14
115.08	53.21	3.06
32.52	18.20	1.79
84.81	38.30	2.79
80.35	32.21	2.63
51.33	26.11	2.39
30.22	18.16	1.73
32.55	21.25	1.97
53.58	29.16	2.52
152.05	49.40	3.53

Rao *et al.,* 2017). The recommended side slopes for different soil are given in Table 4.

Cross section area of water storage structure

Cross section area of the trapezoidal water storage structure is based on top and bottom width, and depth of water in the storage structure. The parameters of structure i.e. perimeters and hydraulic radius for the most economical section for a given area is calculated by using mathematical equation (2) and its value is presented in Table 5. The hydraulic radius of the water storage structure is calculated with the help of surface area.

Table 6: Storage capacity of water storage structure

Length (m)	Surface area (m^2)	Storage capacity (m^3)
35.81	121.94	4291.36
29.72	94.06	2746.99
45.72	107.71	4808.41
22.09	59.23	1286.10
23.62	66. 19	1510.56
33.53	116. 84	3856.75
48.01	101.13	4766.15
33.22	110.09	3594.21
33.83	112.88	3752.82
51.05	115.08	5767.91
16.76	32.52	53 5.099
36.58	84.81	3 045.33
30.48	80.35	2404.21
24.38	51.33	1228.82
16	30.22	474.79
19.81	32.55	633.05
27.43	5 3.58	1 442.52
47.24	152.05	7051.92

The storage capacity of water storage structure

It is the most parameters of the water storage structure. The storage capacity of water storage structure is a function of storage area and water height. The storage capacity of the structure was calculated by using equation (3). The storage capacity of the most important hydraulic parameters because it decided the amount of water stored in the reservoir (Table 6).

Size analysis of water storage structure

Categorization of water storage structure was based on higher and lower value of the surface area that helped in the estimation of water storage capacity of water storage structures (Fig. 2). Mushtaq *et al.* (2007) economically evaluated the small multi-purpose ponds in the Zhanghe irrigation system, China on the basis of tanks area. The Categorization of the tank was based on the interval of the surface area of tank existed in farmers' fields (Fig. 3).

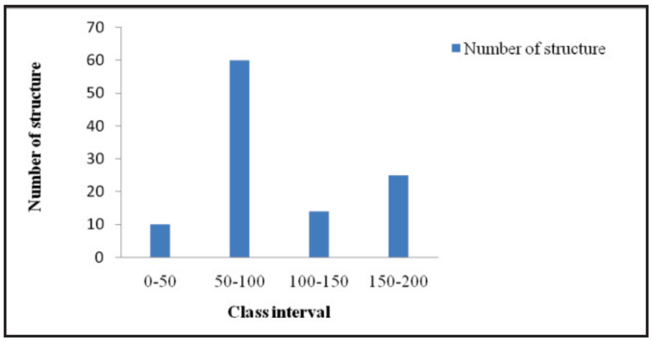

Fig. 3: Categorization of balancing reservoir

Table 7: Peak water requirements of major crops grown in Sirsa district

Crop	Cropping Season	Peak value of ET 0 (mm/day)	Peak Kc	Peak crop water requirement (m^3/month/ha)
Drip irrigation				
Kinnow	January –December	5.7	0.65	801.58
Flood irrigation				
Cotton	June –October	5.74	1.2	1489.2
Guar	July -October	4.95	1.05	1303.05
Wheat	October -March	3.54	1.15	688.79
Mustard	September -January	4.14	1.15	760.29
Gram	October -March	3.54	1.15	738.19

Required water storage structure capacity

Balancing reservoirs capacity was decided on the basis of soil type, type of crops grown in the farm areas and maximum water requirements of the crops. Side slope of balancing reservoirs was decided on the basis of soil type of the lands i.e. sandy loam of the research areas. Water Technology Centre for the eastern region, Bhubaneswar reported that, when pond construction is done with labour, any increase in depth beyond 3.5 to 4.0 m becomes uneconomical. Hence, construction views of the point, optimum depth of pond between 2.5 to 3.5 m. The depth of existed tanks in the study areas was 4.57 m. Amount of water deficit and excess was estimated using the storage capacity of existing tanks in study areas. Negative value of the difference in storage capacity showed that the existing tanks in the research area were not sufficient to meet the monthly water requirement of kinnow crops. Positive value of the difference in storage capacity showed that the existing storage structure meet the monthly water requirement of kinnow crops and left the amount of water in the tank was used for conjunctive use with tubewell to irrigate other major crops. Required capacity of balancing reservoir indicated the amount of water required by major crops grown in the command areas. Water demand met by rainfall and the possibility of mixing of ground water with canal water was also taken into consideration.

CONCLUSIONS

The balancing reservoir is a very efficient water storage structure in the limited water supply regions. It can be effectively used as an on-farm water management tool that helped in water budgeting in canal command areas of the country. The trapezoidal shape water storage structure is mostly followed by the farmers. Surface area of water balancing reservoir helped in the categorization of a number of tanks and in the recommendation of the actual storage capacity of balancing reservoirs in irrigated areas. B-category balancing reservoirs (Size between 50-100 m^2) tanks are mostly existed in command areas that were based on the size of landholding. The number of balancing reservoirs under this category was 60. Hydraulic parameters of balancing reservoirs were decided on the basis of side slope that was calculated on the basis of soil types and required storage capacity. The storage capacity of balancing reservoirs was decided on the basis of the peak water requirements of the crops grown in the field and size of land holding. The required storage capacity of balancing reservoirs was more than the existing storage capacity. This study can be helpful in stabilizing and supporting water management technology for supporting a large proportion of agriculture in the arid and semi-arid tropics.

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