APPLICATION OF A WATERSHED BASED TANK SYSTEM MODEL FOR RAINWATER HARVESTING AND IRRIGATION IN INDIA

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ABSTRACT

The SOFTANK model designs the watershed based tank system optimally by simulating field, tank and groundwater balances. This model was applied to a small watershed consisting of six tanks (small reservoirs) in the semiarid region of India. The existing tank system in this watershed was evaluated and compared with a one-tank system. The results showed that one tank at the outlet of the watershed would have been more beneficial (with benefit: cost ratio of 1.80) than the existing six-tank system (with benefit: cost ratio of 1.71). Finally the analysis was performed for obtaining the optimum tank system for the watershed and it was found that the tanks for irrigation purpose are not economical for the small watershed. The groundwater source was enough for irrigation and any additional investment in the tanks would be uneconomical. The results demonstrate the importance of the watershed based tank system approach to design.

KEY WORDS: Tank, watershed, semiarid, sub humid tropics, model, India.

INTRODUCTION

Watershed based tank systems consist of several tanks (small reservoirs) on main or secondary drainage features of the watershed. There can be several locations on the drainage features for these tanks. While designing the tanks in the watershed, the design

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needs to be based on the whole tank system instead of designing each tank as "stand alone" as is usually done. As the tanks are located in the same drainage area, the hydrology of the tanks is linked and designing the tanks to "stand alone" does not consider the interdependence of different tanks. In contrast, design of tanks on the 'tank system' concept as envisaged in this study enables the interdependence of different tanks to be considered. In addition to this, the in situ rainwater harvesting structures like terraces and trenches in the catchment of the tanks influence the inflow to the tank. The downstream water requirement that is often ignored in the development of watersheds in India needs to find a place in the design to avoid upstream-downstream conflicts and maintain downstream ecology. The design of tanks on the concept of "tank system" helps to address these issues.

The design of "stand alone" tanks has been addressed by different scientists in the past. Palmer et al. (1982) developed a simulation model combining a watershed runoff model and a corn grain model to determine the reservoir size necessary to ensure the availability of water on a probability basis for irrigation. Srivastava (1996 and 2001) developed a simulation model of a tank and a cropped area water balance for a rice based cropping system in India to determine the catchment-command area ratio and the required size of the tank. The model was run for different catchment-command area ratios (CCR) varying from 1.0 to 6.0 for different years of climatological data. It was found that a catchment command ratio of 5.0 or more and a tank with a storage capacity of 1326 m^3/ha of command area would be sufficient at a return period of five years for the midhills of Uttar Pradesh, India, and a catchment-command ratio of 3.0 and tank size of 1750 m^3/ha command area for eastern India. Panigrahi and Panda (2003) found that an on farm reservoir of depth 2 m requiring 12% of the 800 m^2 farm area with a volume of 61 m^3 is optimum size for rice fields in eastern India. All these studies performed the simulation of tank and field water balance to derive the optimum tank (or pond) size and were limited to “stand alone” tanks. However as stated above, when designing the tanks in watershed, it would be preferable to use the ‘tank system’ concept to consider all the features that influence the hydrology and hence the design of the tanks.

Some tank systems have been evaluated previously by different researchers (Grewal et al. 1989, Sur et al.1999 , Guerra et al. 1990 and Mugabe et al.2003) . These studies indicated that evaluation of the existing tank system in the watershed helps to understand its performance and the individual water balance components and system indicators like catchment-storage-command ratios. The performance of the tank system can then be improved by considering the causes of low system performance and addressing specific constraints in the performance of the system. Thus in addition to design of a new tank system it is also important for a model to be able to suggest changes in the management of an existing tank system to improve its performance.

The SOFTANK model developed by the authors designs and evaluates the watershed based tank system by considering the hydrology and demand of water in the entire watershed. The model has been developed in detail by Shinde (2006) and presented by Smout et al (submitted). This paper provides a brief description of the model and discusses the application of the model to a small research watershed at Akola in India to determine the optimum tank system for the watershed.

SOFTANK Model

The SOFTANK model designs a watershed based tank system for semiarid and subhumid regions. The methodology for optimum design of a tank system consists of following four steps.

- Field assignment to stream points
- Generation of tank strategies
- Catchment and command field assignment to tanks
- Water balance-tank, field and aquifer

The methodology of tank system design starts from the identification of ‘stream points’ i.e. possible (or actual) tank locations on the main stream(s) in the watershed. Different fields in the watershed are assigned to these stream points based on the elevations of the fields and the stream points. Tank strategies (described below) are then generated for the identified stream points. Fields are then assigned to the catchment and command areas of the tanks of a tank strategy. Simulation of field, tank and groundwater balance is then carried out on a daily basis for all the tank strategies, from which the optimum tank strategy is selected and the tank system is designed. The criterion for selection of a tank strategy is described later in this section.

Generation of tank strategies

The tank strategy in this research defines the number of tanks, their locations on the stream and their types (defined below). The number of tank strategies is a function of the number of stream points and increases exponentially as the number of stream points increases. These tank strategies are identified by 'tank strategy number' and a particular 'tank strategy number' defines one specific combination of 'number of tanks', 'tank locations' and 'tank types'.

Tank type: Water from the tank may be used for irrigation to an area downstream of the tank or may be lifted for irrigation to the upstream catchment area or may be a combination of both these cases. In the proposed methodology the tanks have been distinguished based on the utilization pattern of the stored water as stated above by introducing the concept of 'tank type'. Based on the location of its command area, a tank could be any of the following types.

Tank type 1: Tanks with the command area downstream of the tank

Tank type 2: Tanks with the command area upstream of the tank

Tank type 3: Tanks with the command area both upstream and downstream of the tank

Criterion for selection of a tank strategy

A tank strategy and design that provide maximum net benefits and satisfy the specified downstream release (DSR) are selected as explained by Smout et al. (submitted) and outlined below.

Field, tank and groundwater balances are simulated simultaneously on a daily basis for this purpose. Initial tank capacities are determined with the design runoff depth (DRD). Design runoff depth is an empirical value of minimum runoff depth for the entire watershed that is assumed at the beginning of the simulation to facilitate the computation of tank capacity. DRD multiplied by the catchment area of the tank gives the volume of runoff for which tank dimensions are optimized. At the end of the simulation, the output DSR is obtained. The output DSR is the function of tank size, water use and climate. Hence output DSR may or may not match the input DSR. Therefore the difference between the DSRs is checked for an acceptable range i.e. output DSR = input DSR ± allowable deviation (e.g. 30% ± 10%). If the output DSR is not within the allowable limit, the tank capacity is increased (or decreased) and the simulation is repeated again. The procedure is repeated till the DSR criterion is met. When the DSR criterion is met, the net benefits for the tank strategy are estimated. In this way the net benefits for all tank strategies are calculated. The tank system i.e. the tank strategy with the capacities of the tanks that produces maximum net benefits is chosen as the optimum tank system for the watershed.

In addition to this the SOFTANK model considers the effect on tank design of in-situ rainwater harvesting practices (e.g. trenches and terraces) and upstream-downstream conflict, as described by Smout et al. (submitted).

Water balance:

The SOFTANK computes the tank, field and groundwater balances while deriving the optimum tank system for the watershed. These water balances are discussed in detail in companion paper (Smout et al submitted).

THE CASE STUDY WATERSHED

The study watershed is located at Akola in the semiarid region of Maharashtra state of India (see Fig.1). It is a small research watershed of 28 ha divided into six small watersheds called herein after “subwatershed” with a tank in each subwatershed. The latitude and longitude (GPS coordinates) of boundary points of this watershed are presented in Table 1.

Figure 1: The location of the Akola watershed

Table 1 The latitude and longitude (GPS coordinates) of the boundary points for Akola watershed

Climate: The climate of the region is semi-arid monsoonal type and characterized by three distinct seasons; specifically, summer with hot and dry weather from March to May; monsoon, warm and rainy from June to October; and winter, dry and mild cold from November to February. The average rainfall (based on 30 years) is about 880 mm distributed over 48 rainy days. The annual rainfall data for Akola station for 28 years is given in Table 2.

Table 2 Rainfall data for Akola

Soil: Soil types in the watershed vary according to depth, and exhibit varying properties which are displayed in Table 3. These soils are moderately drained. These soil properties were used in the SOFTANK model for estimation of runoff, infiltration, evaporation and irrigation requirements.

Table 3 Soil properties of Akola watershed

Stream points: “Stream points” are the locations of tanks in the watershed. The tank locations are defined by the x, y coordinates as shown in Table 4 and Fig.2.

Table 4: Coordinates of stream points in the watershed

Figure 2: Overview map of the Akola watershed

Tanks: As shown in the Fig. 2, there are two streams or drainage features in the watershed. Six tanks exist on these drainage features. Tank No. 1 which is at outlet of the watershed is common to both streams. Runoff is collected in the tanks during wet spells of the monsoon and the water in the tanks is used for groundwater recharge, and irrigation. Table 5 presents the dimensions of the tanks. The shape of all the tanks is an inverted truncated pyramid.

Table: 5 Dimensions of existing tanks in the Akola watershed

Fields: Fields in the watershed are of varying sizes (Table 6). These fields are allocated to the catchment and command areas of different tanks in varying tank strategies while deriving the optimum tank strategy for the watershed. Continuous contour trenches are excavated in the catchments of tank No 2 and 3 for in situ rainwater harvesting.

Table 6 Field coordinates of Akola watershed

Land use: Land use/land cover and other hydrologic characteristics are required in the SOFTANK model for estimation of runoff in the watershed. These characteristics for Akola watershed are presented in Table 7. Land use in the watershed includes agriculture, horticulture and silvipasture system. Horticultural crops include guava, gooseberry, custard apple, pomegranate, *ber* fruit and oranges. Agricultural crops include sorghum and cotton.

Table 7 Land use details for Akola watershed

Irrigation: Drip irrigation system is used for horticultural crops. Irrigation is not provided to the silvipasture plantations. Agricultural crops are irrigated by surface methods. The source of irrigation is both tank water and groundwater and there are bore wells in the watershed for utilization of groundwater.

METHODOLOGY

The SOFTANK model was applied to Akola watershed for evaluating the existing tank system and obtaining the optimum tank system. The optimum tank system is derived based on the net benefits from crop production. SOFTANK also computes the different performance indicators (runoff, deep percolation from fields, inflow to tanks, irrigation volume applied, evaporation, seepage from tanks, seepage from trenches, groundwater flow etc). The output of the simulation of a specified tank strategy (either during simulation or optimization) includes the location, tank type and dimensions of the tanks, detailed field, tank and aquifer water balances along with the crop plan and the irrigation schedule for the derived tank system. The SOFTANK model was run in the evaluation mode to evaluate the existing tank system in the watershed. Subsequently some alternative tank strategies were compared with the existing tank strategy. The model was also run in optimization mode to find optimum tank system.

Evaluation of the existing tank system

The existing tank system consists of six tanks in the watershed. The climate, soil, field and land use data considered for the analysis are shown in Tables 2 to 7. This data was used as input to the SOFTANK model in the evaluation mode.

Simulation of alternative tank strategies

In the simulation mode of the SOFTANK model, the field, tank and aquifer water balances are simulated and different performance indicators are estimated for alternative tank strategies. The model also allows testing options for changes in the management of the tanks in the watershed. For example whether to use only tank water or both tank and groundwater for irrigation, modifications in irrigation scheduling criteria, changes in the crop etc. Alternative tank strategies that were considered for simulation were tank strategy No 1, 50, 58, 1805, 1926 and 2047. These tank strategies are described in Table 8. The climate, soil, field and crop data used for simulating the alternative tank strategies were the same as that used for evaluation of the existing tank strategy. However the allocation of fields to the catchment/command areas of the tank changed according to the relative locations of field and tank for a specified tank strategy. In simulation mode tank sizes are optimized whereas in the evaluation mode existing tank sizes are considered.

Table 8. Alternative tank strategies that were considered for comparing with existing tank strategy of Akola watershedOptimum tank strategy

The optimum tank strategy for the watershed was derived by running the 'SOFTANK' model in optimization mode. In optimization mode, for repeated input values of the downstream release (DSR), the optimum tank strategy is obtained for a specific climate year and then this optimum tank strategy is evaluated for the remaining climatic years. While in evaluation mode the net benefits and DSR for each climate year are obtained for the optimum tank strategy of a specified climatic year. The average of the net benefit and DSR values obtained for all climatic years are considered as the net benefit and DSR values of the optimum tank strategy of a specified climatic year. The process is repeated for all climatic years. However if the average DSR of the optimum tank strategy for a specified year is not within the specified range of input DSR (e.g. 30% ± 10%), the strategy with next highest maximum net benefits is considered and is evaluated for all the climatic years. The process is repeated till the output DSR is within the specified range of input DSR as shown in Fig 3. For Akola watershed, the climatic data of 28 years were available, meaning 28 climatic years. Thus SOFTANK model gave 28 optimum tank strategies for 28 climatic years. If a particular tank strategy was repeated as the optimum tank strategy for different years, it was treated as a different tank strategy for the optimization purpose since the dimensions of the tanks were different (though the strategy was the same). Subsequently the tank strategy with maximum average net benefits was selected as the optimum tank strategy for the specified DSR. The process was repeated for a range of DSR values from 10 to 90 %. The tradeoff between DSR and net benefits was then performed to determine whether the tank system is economical for the watershed and if it is economical then to know how much water will be harvested and released from the watershed. The process is explained in the flowchart presented in Fig 3.

Figure 3: Flowchart for obtaining optimum tank strategy

RESULTS AND DISCUSSION

The results of application of the SOFTANK model to Akola watershed for evaluating the existing tank system and obtaining the optimum tank system are discussed in the following paragraphs.

Evaluation of existing tank system

The components of the field, tank, groundwater and trench water balances were obtained for the existing tank system of Akola watershed. These are given in Table 9. The downstream release (DSR) was found as 65.6 % and the annual net benefits were estimated as Rs132,025 with Benefit-Cost ratio of 1.71 (Rs is the symbol for Indian currency. 1 US$ ≈ 46 Rs in August 2010).

Table 9: Performance indicators of existing and alternative tank strategies

The total storage capacity of six tanks was 4824 m^3. Irrigation was provided to 13.33 ha. Runoff was 18.9% and deep percolation 10.6% of rainfall. Tank water balance components per m^3 of tank capacity were inflow 9.41, irrigation 0.41, evaporation 0.29 and seepage 1.71 m^3. Out of the total groundwater recharge the contributions of field, tank and trench recharge were 54.0%, 23.8% and 22.2%. From groundwater storage irrigation was 25.7%, other use was 2.2% and groundwater flow was 72.1%.

Simulation of alternative tank strategies

The water balance components of field, tank, groundwater and trench were simulated and the performance parameters were estimated for different alternative tank strategies. The DSR value of 65.6 % that was obtained in the evaluation of the existing tank strategy was used as the target DSR in simulating the alternative tank strategies. The existing tank strategy thus utilizes only 34.4 % of the water generated in the watershed. Among the alternative tank strategies, tank strategy-1 gave the maximum benefit-cost (BC) ratio and hence the existing tank strategy is compared with tank strategy-1as described below. The tank strategies are illustrated in Fig 4 and performance parameters for Tank strategy-1 are presented in Table 9.

Figure 4. Illustration of existing and alternative tank strategy No.1

Under tank strategy-1, only one tank at the outlet of the watershed would be built. Table 9 shows that this would provide 5.2% more net benefits than the existing tank system of six tanks in the watershed. The cost- benefit analysis shows that the higher BC ratio for tank strategy-1 is due to the decreased cost of the project resulting from the lower excavation cost of a single tank, fewer pumps etc. In this strategy the tank storage capacity was estimated as 6691 m^3. Irrigation volume per unit tank capacity was significantly higher (1.14 m^3) in tank strategy-1 than the existing tank strategy (0.41 m^3). There was no difference in the runoff and field deep percolation losses as compared to the existing strategy. Loss due to seepage from the tank was reduced due to the single tank in tank strategy-1. As a result the contribution of tank recharge to the total groundwater recharge was reduced to 13.0% from 23.8% in the existing strategy.

Thus the SOFTANK model has shown that instead of six small tanks in the watershed, construction of one big tank at the outlet of the watershed would have been more economical. Managing one tank is easier than managing six. The alternative strategy would not have changed the downstream release of water, thereby maintaining the downstream ecology.

It is to be noted here that the analysis presented above is to show the utility of the SOFTANK model for investigating the causes of low performance of the existing tank system and finding alternative solutions. However in practice when a tank system already exists in the watershed, there are limited options (or no options at all) to make changes in the physical tank system. In such circumstances it is however possible to consider changes in the management options of the tank system. But at the initial phase of the watershed development when tanks are not yet constructed the SOFTANK model can simulate different tank strategies for different desired values of DSR. Thus the demand for water of downstream users and the water needed for ecological reasons would be considered in the simulated tank strategies. Therefore the new strategy would provide better water management and better environmental stewardship concurrently.

Optimum tank strategy for the watershed

Optimum tank strategies are the best tank strategies for the watershed under given conditions. Optimum tank strategies were derived for the existing land use and land treatment for the Akola watershed. For this purpose all possible tank strategies were evaluated for different climatic years and the tank strategy that gives maximum net benefits was selected for a particular climatic year as the optimum tank strategy as shown in Table 10. In this way the tank strategies for different climatic years for different DSR values were obtained and presented in Table 10. The final optimum tank strategy for a specified DSR value would be the one that gives maximum average net benefits for different climatic years. It is interesting to note from the table that tank strategy-1is the most frequently occurring strategy for almost all the years and for different DSR values. While simulating different tank strategies, the output DSR values do not strictly match with input DSR values hence provision is made for allowable deviation of the output DSR values from the input DSR values (e.g. 30% ± 10%). Table 11 gives the optimum tank strategies along with net benefits obtained for different DSR values for the watershed. The actual values of DSR obtained in the simulation are also shown in the table.

Table 10 Optimum tank strategies for different climatic years for different values

of DSR for Akola watershed

Table 11 Final optimum tank strategies for different DSR levels for Akola watershed

DSR vs net benefits for the watershed

The variation of net benefits with DSR level is shown in Fig. 5. From the figure it is seen that the net benefits from the watershed increases with DSR. As the DSR increases less water is stored and used in the watershed. Contrary to expectations, the results in Fig. 5 show increased net benefits from the watershed as the DSR increases. It thus indicates that tank and groundwater irrigation in combination is not economical in the Akola watershed. This can be understood by considering the particular land use of Akola watershed. Out of a total area of 28 ha, horticulture comprises of 11 ha and silvipasture 10 ha. Horticultural crops include gooseberry, custard apple, pomegranate, *ber* and guava. These are dry land horticultural crops and their water requirements are less. They are irrigated with a drip irrigation system and provided with deficit irrigation for 2 months to induce water stress for flowering. Irrigation is not provided to the silvipasture crops. Field crops are grown on 2.5 ha area for which irrigation is provided to supplement the rainfall by surface method. An area of 3.5 ha is barren.

Figure 5 Net benefits vs Down Stream Release for Akola watershed

Akola watershed is in an assured rainfall zone and the average annual rainfall is about 880 mm. Moreover there are water conservation trenches in subwatersheds 2 and 3. The horticulture land use and the trenches land treatment along with assured rainfall result in increased groundwater recharge. The demand for water is also low compared to the supply. Out of a total irrigation volume of 14767 m^3, 12787 m^3 (87%) is given through groundwater irrigation and only 1980 m^3 (13%) is given through tank irrigation. Recharge to groundwater through fields is 24504 m^3 and through trenches is 9537 m^3. About 38% of the recharge water is reused through groundwater irrigation. According to Keller et al. (2000) typically groundwater recovery under artificial recharge averages 75% of the recharge volume. The groundwater extraction in the present case for Akola watershed is much less than this average. The groundwater recharge from trenches and fields is sufficient to meet the deficit created by groundwater irrigation for the crops. About 75% recharge takes place through field and trenches, which is sufficient to meet the groundwater deficit. Construction of tanks therefore does not appear economical for the watershed. This is also supplemented with the fact that the groundwater flow is a major outflow (72%) from the groundwater. Since irrigation needs are met by groundwater, any additional investment in a tank system becomes uneconomical.

The SOFTANK model is basically developed for optimum design of a watershed based tank system for rainwater harvesting and irrigation in the watershed. It considers the total watershed water balance while designing the optimum tank system. The watershed development works in India focus on harvesting as much water as possible. But at present there are no answers as to how much water should be harvested and how much should flow downstream. How much groundwater recharge takes place? Is the construction of tanks necessary to meet the crop water requirements in the watershed? The SOFTANK model will help in finding solutions to these questions. The SOFTANK model was run here with the historical rainfall data for Akola station. If future rainfall series are generated considering the effect of climate change, these rainfall series can be used in the model to design an optimal tank system for the watershed which considers the effect of climate change in the region, thus enhancing the utility of the model for future planning.

CONCLUSION

Application of the SOFTANK model to the Akola watershed has demonstrated its value for evaluation of the existing tank system and development of an optimum system for locating and sizing tanks in a watershed. The Akola watershed has six small tanks (ponds) in the watershed for runoff harvesting in addition to the trenches in the catchments of tanks two and three. The SOFTANK model was found suitable for evaluation of the existing tank system of the watershed. The analysis for the optimum tank system for the watershed revealed that as the DSR increases, the net benefits in the watershed also increase thereby suggesting that tanks are not economical. This finding can be explained by particular features of this watershed. It demonstrates the value of considering the watershed based tank system in designing tanks, rather than following empirical methods to design individual tanks.

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Table 1 The latitude and longitude (GPS coordinates) of the boundary points for Akola watershed

Boundary point No.	Latitude	Longitude
1	$20^{0}\ 42^{'}\ 43.72^{''}$N	$77^{0}\ 2^{'}\ 54.45^{''}$E
2	$20^{0}\ 42^{'}\ 37.90^{''}$N	$77^{0}\ 2^{'}\ 58.23^{''}$E
3	$20^{0}\ 42^{'}\ 31.69^{''}$N	$77^{0}\ 2^{'}\ 57.71^{''}$E
4	$20^{0}\ 42^{'}\ 25.14^{''}$N	$77^{0}\ 3^{'}\ 7.45^{''}$E
5	$20^{0}\ 42^{'}\ 23.50^{''}$N	$77^{0}\ 3^{'}\ 9.80^{''}$E
6	$20^{0}\ 42^{'}\ 24.62^{''}$N	$77^{0}\ 3^{'}\ 11.71^{''}$E
7	$20^{0}\ 42^{'}\ 27.21^{''}$N	$77^{0}\ 3^{'}\ 11.30^{''}$E
8	$20^{0}\ 42^{'}\ 40.26^{''}$N	$77^{0}\ 3^{'}\ 8.59^{''}$E
9	$20^{0}\ 42^{'}\ 43.39^{''}$N	$77^{0}\ 2^{'}\ 59.06^{''}$E

Table 2 Rainfall data for Akola

Year	Rainfall, mm	Year	Rainfall, mm	Year	Rainfall, mm	Year	Rainfall, mm
1976-77	760.4	1983-84	842.5	1990-91	1019.3	1997-98	827.8
1977-78	1075.3	1984-85	538.0	1991-92	454.0	1998-99	870.2
1978-79	914.5	1985-86	700.5	1992-93	977.4	1999-00	976.5
1979-80	840.7	1986-87	817.4	1993-94	893.2	2000-01	646.4
1980-81	707.9	1987-88	739.3	1994-95	1011.2	2001-02	634.10
1981-82	967.7	1988-89	1372.0	1995-96	562.4	2002-03	639.10
1982-83	551.9	1989-90	747.3	1996-97	710.4	2003-04	380.80

Table 3 Soil properties of Akola watershed

Soil Id	Soil type	FC,%	WP,%	BD, gm/cm^3	Depth cm	Ks mm/h	CP mm	n	θ_s
1	SCL	32.20	15.10	1.42	118	1.5	218.5	0.40	0.43
2	SCL	32.50	19.19	1.40	117	1.5	218.5	0.40	0.43
3	SCL	32.50	15.08	1.38	74	1.5	218.5	0.40	0.43
4	LS	21.58	10.15	1.38	20	29.9	61.3	0.44	0.40
5	LS	24.34	12.2	1.34	20	29.9	61.3	0.44	0.40
6	LS	25.79	13.50	1.31	20	29.9	61.3	0.44	0.40
7	SCL	31.30	16.10	1.27	76	1.5	218.5	0.40	0.33
8	SL	29.20	15.30	1.22	81	10.9	110.1	0.45	0.41
9	LS	20.90	15.10	1.25	83	29.9	61.3	0.44	0.40
10	SCL	31.10	16.70	1.25	80	1.5	218.5	0.40	0.33
11	SL	29.10	15.20	1.32	79	10.9	110.1	0.45	0.41
12	SL	28.98	15.20	1.39	60	10.9	110.1	0.45	0.41

(SCL:= Sandy clay loam, LS= Loamy sand, SL= Sandy loam, FC= Field capacity, WP = Wilting point, BD= Bulk density, Ks = Saturated hydraulic conductivity, CP= Capillary potential, n = Porosity, , θ_s = Saturated moisture content)

Table 4: Coordinates of stream points in the watershed

Stream point No.	X-coordinate meter	Y-coordinate meter	Z-coordinate meter
1	162	25	304.00
2	158	55	305.40
3	120	135	311.30
4	125	40	306.50
5	84	55	308.30
6	52	155	313.90

Table: 5 Dimensions of existing tanks in the Akola watershed

Tank No.	Subwatershed No	Top length (m)	Top width (m)	Bottom length (m)	Bottom width (m)	Depth (m)	Capacity (m^3)
1	3	24.3	24.3	20.3	20.3	2.0	1000
2	2	23.4	23. 4	19. 4	19. 4	2.0	918
3	1	17.6	17. 6	13. 6	13. 6	2.0	488
4	4	20.1	16. 1	20. 1	16. 1	2.0	656
5	5	26.3	26.3	22.3	22.3	2.0	1186
6	6	19.0	19.0	15.0	15.0	2.0	578

Table 6 Field coordinates of Akola watershed

Field No	Subwatershed No	X-coordinate (m)	Y-coordinate (m)	Z-coordinate (m)	Area, ha
1	1	9.0	16.5	314.40	1.20
2	1	12.0	13.5	311.30	1.80
3	1	12.0	13.5	311.30	0.85
4	2	15.8	5.5	305.40	3.30
5	3	14.1	4.0	305.30	1.00
6	3	16.2	4.0	304.50	1.00
7	3	16.2	2.5	304.00	1.85
8	4	12.5	4.0	306.50	2.75
9	4	12.5	4.0	306.50	0.05
10	4	12.2	7.8	308.50	0.34
11	4	12.2	8.5	308.90	0.35
12	4	12.2	9.2	309.10	0.36
13	4	12.1	10.0	309.50	0.36
14	4	12.0	10.8	309.90	0.34
15	4	12.0	11.5	309.90	0.35
16	4	12.0	12.4	310.90	0.40
17	5	8.4	5.5	308.30	6.80
18	6	5.2	15.5	313.90	0.50
19	6	5.2	15.5	313.90	3.40

Table 7 Land use details for Akola watershed

Field No	Subwatershed No	Land use (crop)	Treatment	Hydrologic condition	Hydrologic soil group	Area ha
1	1	Horticulture	--	Good	C	1.20
2	1	Horticulture	--	Good	C	1.80
3	1	Horticulture	--	Good	C	0.85
4	2	Silvipasture	CCT[1)]	Good	C	3.30
5	3	Horticulture	CCT	Good	C	1.00
6	3	Horticulture	CCT	Good	C	1.00
7	3	Horticulture	CCT	Good	C	1.85
8	4	Horticulture	--	Good	B	2.75
9	4	Agriculture	--	Good	B	0.05
10	4	Agriculture	--	Good	C	0.34
11	4	Agriculture	--	Good	B	0.35
12	4	Agriculture	--	Good	B	0.36
13	4	Agriculture	--	Good	C	0.36
14	4	Agriculture	--	Good	B	0.34
15	4	Agriculture	--	Good	B	0.35
16	4	Agriculture	--	Good	B	0.40
17	5	Silvipasture	--	Good	B	6.80
18	6	Horticulture	--	Good	B	0.5
19	6	Bare	--	Poor	B	3.4

([1] CCT- Continuous contour trenches)

Table 8. Alternative tank strategies that were considered for comparing with existing tank strategy of Akola watershed

Tank strategy No	No. of tanks	Tank strategy details Tank No-Stream point No-Tank type	Tank strategy description
1	1	1-1-2	One tank of type 2 at stream point No 1 (at the outlet of the watershed)
50	2	1-2-1, 2-5-1	Two tanks of type 1 at stream point No 2 and 5
58	2	1-2-3, 2-5-3	Two tanks of type 3 at stream point No 2 and 5
1805	6	1-1-2, 2-2-1, 3-3-1, 4-4-1, 5-5-1, 6-6-2	One tank of type 2 at the outlet and five tanks of type 1 at other stream points
1926	6	1-1-2, 2-2-2, 3-3-2, 4-4-2, 5-5-2, 6-6-2	All six tanks of type 2 at six stream points
2047	6	1-1-2, 2-2-3, 3-3-3, 4-4-3, 5-5-3, 6-6-3	One tank of type 2 at the outlet and five tanks of type 3 at other stream points

(Note- Tank type 1- Tank with the command area downstream of the tank, Tank type 2- Tank with command area upstream of the tank and Tank type 3- Tank with command area both upstream and downstream side of the tank)

Table 9: Performance indicators of existing and alternative tank strategies

Performance indicator	Existing strategy	Tank strategy No 1
No of tanks	6	1
Total tank capacity, m^3	4824.43	6691.09
Area irrigated, ha	13.33	12.71
Irrigation volume (from tanks), m^3	14767.32	14703.30
Runoff (per cent of rainfall)	18.90	18.90
Deep percolation (per cent of rainfall)	10.62	10.70
Inflow (m^3/m^3 tank capacity)	9.41	8.02
Irrigation (m^3/m^3 tank capacity)	0.41	1.14
Evaporation (m^3/m^3 tank capacity)	0.29	0.25
Seepage (m^3/m^3 tank capacity)	1.71	1.50
Field recharge[1]	54.04	61.27
Tank recharge	23.76	12.99
Trench recharge	22.19	25.74
Irrigation (from aquifer)[2]	25.74	20.87
Other use	2.17	2.32
Groundwater flow	72.09	76.81
Incremental costs, Rs	185657	173786
Incremental benefits, Rs	317682	312656
BC Ratio	1.71	1.80
DSR,%	65.6	65 (64.11[3])

([1] Recharge components are per cent of total groundwater recharge. [2] Outflow components are per cent of total groundwater outflow, [3]Value of output DSR)

Table 10 Optimum tank strategies for different climatic years for different values of DSR for Akola watershed

Year	DSR values,%									
	10	20	30	40	50	60	70	80	90	95
1976-77	1	1	1	1	1	1	1	1	1	1
1977-78	1	1	1	1	1	1	1	1	1	13
1978-79	1	1	1	1	1	1	1	1	1	1
1979-80	1	1	26	1	1	1	1	1	1	1
1980-81	1	1	1	1	1	1	1	13	1	1
1981-82	1	1	26	26	1	1	1	13	1	1
1982-83	1	1	1	1	1	1	1	1	1	1
1983-84	1	1	1	1	1	1	1	1	1	1
1984-85	1	1	1	1	1	1	1	1	1	1
1985-86	1	1	1	26	1	1	1	1	1	1
1986-87	1	1	1	392	27	1	1	1	1	1
1987-88	1	1	1	1	1	1	1	1	1	1
1988-89	1	1	1	69	405	26	1	13	1	1
1989-90	1	1	1	1	1	1	1	1	1	1
1990-91	1	1	1	376	1	1	1	1	1	1
1991-92	1	1	1	1	1	1	1	1	1	1
1992-93	1	1	28	1	1	1	1	1	1	1
1993-94	1	1	1	1	1	1	1	13	1	13
1994-95	1	1	1	1	1	1	1	1	1	1
1995-96	1	1	1	1	1	1	1	1	1	1
1996-97	1	1	1	1	1	1	1	1	7	7
1997-98	1	1	22	1	1	1	1	1	1	1
1998-99	1	1	1	1	1	1	1	1	1	1
1999-00	1	1	29	1	1	1	1	1	1	1
2000-01	1	1	1	1	1	1	1	1	1	1
2001-02	1	1	1	1	1	1	1	1	1	1
2002-03	1	1	1	1	1	1	1	1	1	1
2003-04	1	1		1	1	1	1	1	7	7

Table 11 Final optimum tank strategies for different DSR levels for Akola watershed

Input DSR	Actual output DSR,%	Tank Strategy No.	Net benefits, Rs
10	11	1	432720
20	18	1	433952
30	26	1	435767
40	40	1	438623
50	47	1	439826
60	55	1	441095
70	68	1	442938
80	72	1	443422
90	86	1	445007
95	92	1	445682

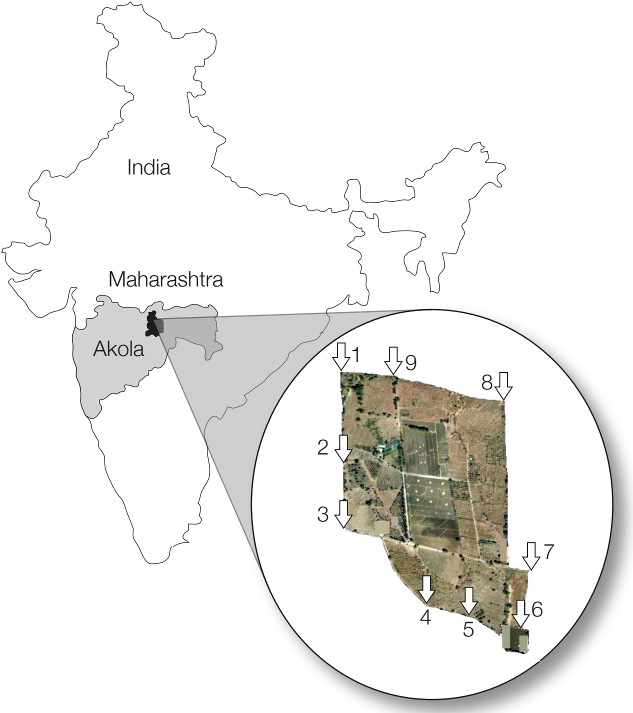
Shinde_Gorantiwar_Smout-Fig1.pdf

Shinde_Gorantiwar_Smout-Fig2.pdf

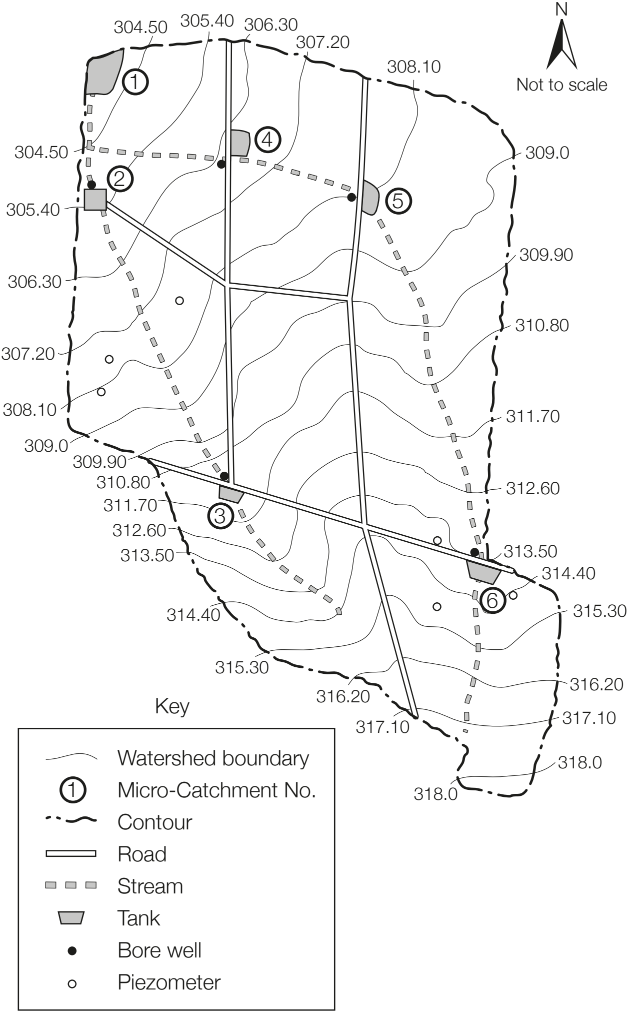
Shinde_Gorantiwar_Smout-Fig3.pdf

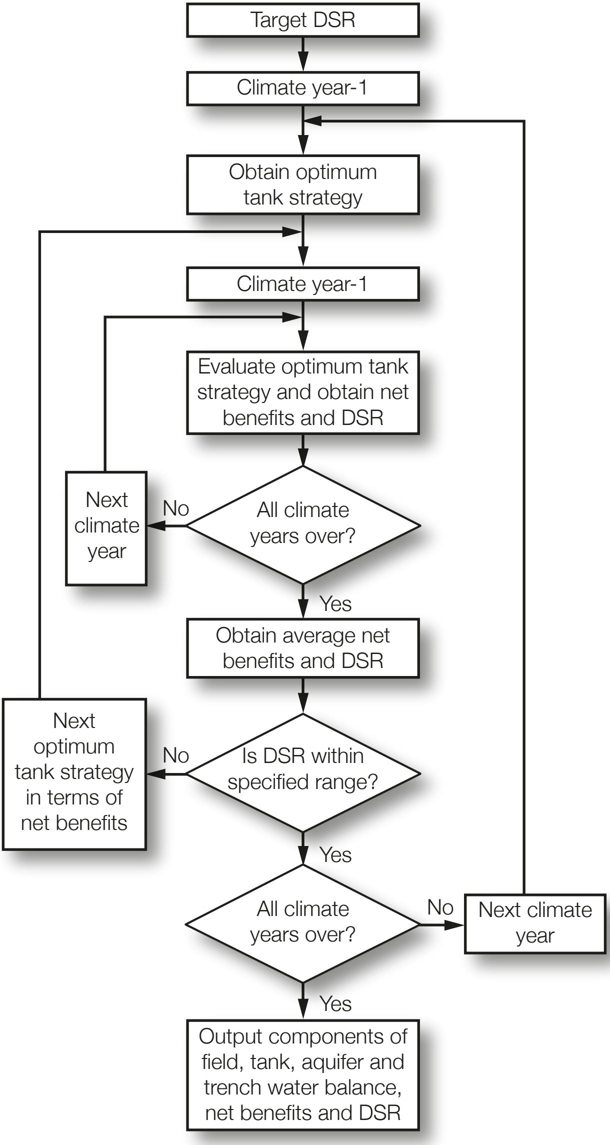
Shinde_Gorantiwar_Smout-Fig4.pdf

Shinde_Gorantiwar_Smout-Fig5.pdf

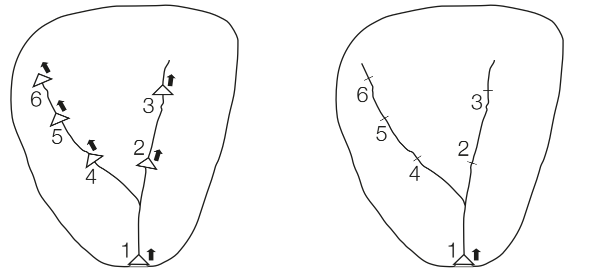


Akola watershed


N
Not to scale
304.50
305.40
306.30
307.20
308.10
309.0
309.90
310.80
311.70
312.60
313.50
314.40
315.30
316.20
317.10
318.0
1
2
3
4
5
6
Key
Watershed boundary
Micro-Catchment No.
Contour
Road
Stream
Tank
Bore well
Piezometer

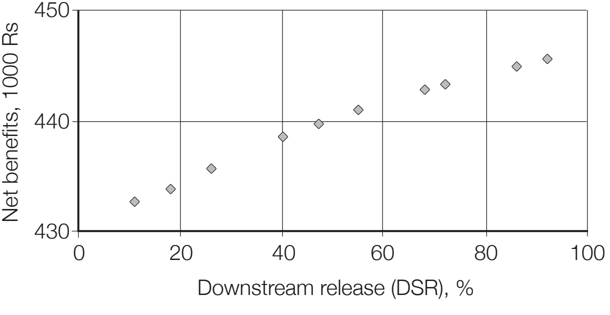


Target DSR
Climate year-1
Obtain optimum tank strategy
Climate year-1
Evaluate optimum tank strategy and obtain net benefits and DSR
All climate years over?
No
Next climate year
Yes
Obtain average net benefits and DSR
Is DSR within specified range?
No
Next optimum tank strategy in terms of net benefits
Yes
All climate years over?
No
Next climate year
Yes
Output components of field, tank, aquifer and trench water balance, net benefits and DSR



(a) Existing tank strategy

(b) Tank strategy No.1



450
440
430
Net benefits, 1000 Rs
0
20
40
60
80
100
Downstream release (DSR), %