OPTIMAL USE OF SURFACE DRAINS FOR ENHANCING GROUND WATER RECHARGE

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ABSTRACT
Growing demand for the fresh water has resulted in increased exploitation of its limited sources - the foremost of them being the groundwater. Artificial recharge through a network of surface drains can be one of the remedy to this problem. In this paper, Khepar’s model has been used to investigate the effect of drain parameter on the amount of recharge. The parameters which were kept in focus during the investigation were check dam height, number of check dams, bed slope of drain and wetted perimeter of drain. One of the key findings was that the recharge rate is found directly proportional to check dam height, bed slope of drain and wetted perimeter of drain. This formulation can lead to optimization of recharge and consequent raise in water table in addition to effective usage of surface drains.

Keywords: Groundwater, surface drains, artificial recharge, check dams, parametric study

INTRODUCTION
The total amount of water made available by the hydrologic cycle is enough to meet the demand of freshwater but most of this water is concentrated in few regions, the remaining areas face problem of water scarcity (Pimentel 1999). Because of the uneven distribution of water resources and population densities worldwide, water demands have already exceeded supplies in many countries, almost 40% population of the world is affected with the problem of water shortage (Bennett 2000). The annual rainfall, including snow, in India is about 400 M ha-m, and the estimated mean annual river flows are 186.9 M ha-m. At present, about 37 M ha-m surface water and 14 M ha-m groundwater are being utilized for irrigation. The projected demand on water resources, by 2025, are estimated to be 105 M ha-m, of which surface water constitutes 69 M ha-m and groundwater 36 M ha-m (Agriculture 2004). The Indo-Gangetic plains in India receive rainfall ranging between 650 mm and 1000 mm, most of which is concentrated within the 3 months of the monsoon period. Out of this only about 200 mm naturally recharges to the groundwater aquifers and remaining part runs off unharnessed into the ocean (IWMI 2002). The important states that are part of these plains are the state of Punjab, Haryana and Uttar Pradesh. Land in these plains is very fertile and intensive agriculture has resulted in the overexploitation of groundwater resources, leading to lowering of the water table in various parts of these plains.

It has been reported that in many areas of Punjab, the water table has gone down by 15 m (Kaushal 2009). A previous study by author has shown the situation is not any better in Haryana (Gaurav, Setia et al. 2003) (study area is shown in figure 1). The decline of the water table can be arrested by reducing the groundwater draft and/or by increasing the groundwater recharge. A reduction in groundwater draft may be difficult because of ever-increasing irrigation demands. Artificial groundwater recharge, however, offers the potential

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Manuscript No.: 1353

Fig. 1: Study area
to reduce the rate of decline subject to the availability of good quality water and favourable geohydrological conditions (CGWB 1994).

A network of surface drains constructed in Indo-Gangetic plains long time ago to control waterlogging and floods are not required now for the control of waterlogging. This can be utilized for artificial groundwater recharge. These unused drainage channels can be altered to act as temporary reservoirs. Excess water not needed for irrigation during rainy season, combined with the low crop water requirement period, can be diverted into these unused channels, where ‘check structures’ can slow down it for groundwater recharge. The research by Khepar and his colleagues (Khepar S. D. 2000a; Khepar S. D. 2000b; Khepar S. D. 2002) has established that building check structures, at suitable intervals in the drainage channel, can increase the recharge capacity of a drain by three-and-a-half times over recharge under natural flow conditions. In this paper, a parametric study is carried out to study the effect of various parameters of drain in increasing recharge rate using the Khepar’s (Khepar S. D. 2000a; Khepar S. D. 2000b; Khepar S. D. 2002) model.

MODEL DEVELOPMENT

The model is based on the principle that the amount of discharge to be released at the head end of the drain should be equal to the total loss-taking place over the entire drain length so as to avoid any outflow (Khepar S. D. 2000a; Khepar S. D. 2000b; Khepar S. D. 2002). Two cases are considered for the drain i.e. (i) natural flow condition (ii) Interrupted flow condition. Under the natural flow conditions water flows in the drain without any hindrance. While in interrupted flow condition, the drain is divided into segments by installing check dams in the drain. Check dams create reservoir of water in the segments therefore enhancing the amount of water recharged.

Natural Flow Conditions

The details regarding the geometry of the drain and the derivation of governing equations can be found in detail in the previous study (Khepar S. D. 2000b). However some sections and equations are reproduced here. Since all the water available at the head end is considered to be loss in the drain, therefore the sum of seepage loss in each segment gives the total loss in the drain. Mathematically this can be shown as below:

\[ Q = \sum_{i=1}^{n} SL_i \]  

(1)

Where, \( Q = \) canal discharge to be released at the head end of the drain, \( SL_i = \) seepage loss in the \( i^{th} \) segment of the drain and, \( n = \) total number of segments.

The seepage loss \( (SL_i) \) in the segment can be determined by equation 2. Here the drain cross section is considered to be trapezoidal and the seepage loss occur throughout the wetted perimeter

\[ SL_i = a \frac{y_i^2}{2} \left[ B_i + 2y_i \sqrt{m_i^2 + 1} \right] L_i \]

where \( L_i = \) length of \( i^{th} \) segment, \( B_i = \) bed width of the segment, \( a = \) empirical fitting parameters determined

experimentally, \( m_i = \) side slope of the segment and \( y_i = \) average depth of flow in that segment.

Considering the flow of water in last segment, the following equation can be derived

\[
\left( B_i + m_i y_i \right) y_i = \frac{Q L_i}{n_i} \left[ B_i + m_i y_i \sqrt{m_i^2 + 1} \right] y_i^2 - \frac{y_i + 0}{2} \left[ B_i + m_i y_i \left( y_i + 0 \right) \sqrt{m_i^2 + 1} \right] L_i = 0
\]

Equation 3 contains only \( y_n \) as unknown, thus the depth of flow at the upstream end of the \( n^{th} \) segment \( (y_n) \) can be calculated. The depth of flow at other segments can be calculated by advancing the calculation to them.

Interrupted flow condition

The entire length of the drain is converted into pools by providing checks at intermediate intervals in the drain.

Average depth of ponding in the pool is given by

\[ \bar{y}_i = \frac{y_i + y_{i+1}}{2} = y_{i+1} - S_i L_i \]

Substituting this value of average depth into equation 2, the seepage loss \( SL_i \) in any pool can be calculated. The discharge, \( Q_1 \) to be released at the head end of the drain can be estimated using equation 1. Flow chart for the step-by-step calculation of discharge to be released at the head end of the drain is given in figure 2.

CHECK DAMS

Check dams are constructed across small streams with mild slope and are feasible in any formations. Site selected for check dam should have sufficient thickness of permeable bed or weathered formation to facilitate recharge of stored water within short span of time. The water stored in these structures is normally contained within the streams. Check dams spans across the stream width with limited height. The excess water is allowed to flow over the check dam wall. A series of small check dams are made across selected stream sections such that the flow of surface water in the stream channel is impeded and water is retained on pervious soil/ rock surface for longer body.

Site Characteristic and Design Guidelines

For selecting a site for check dams the following conditions may be kept in mind:

i. The rainfall in the catchment should be less than 1000 mm/annum, otherwise the presence of check dams will impede the passage of storm water.

ii. The soil in the ponded area should be adequately permeable to cause ground water recharge through ponded water.

iii. Check dams should be built at sites that can produce a relatively high depth to surface area so as to minimize evaporation losses.

iv. There should not be any soil erosion in the catchment area.
PARAMETRIC STUDY

In order to find the significance of different parameters and their order of importance, the Khepar’s model was applied by varying these parameters in justified ranges. MATLAB was employed for drafting the program in accordance with the Flow chart given in Figure 2 (Khepar S. D. 2000a; Khepar S. D. 2000b; Khepar S. D. 2002). The model was applied to drain located in State of Haryana (figure 1). This drain is known as ‘Khanpur Drain’ or ‘Betan Nallah’. The drain originates from Shahbad sugar mill area and flows along G.T.Road (NH1) upto Khanpur area near Pipli where it drains into Markanda river. The various parameters used in the model are:

- Bed width of the drain, \( B = 4.876 \) m.
- Full supply depth (F.S.D.) = 0.9144 m.
- Longitudinal slope, \( s = 1 \) in 4000
- Manning’s coefficient, \( n = 0.025 \)
- Total drain length, \( L = 8.67 \) Km.
- Design discharge, \( Q = 2.83 \) m³/sec.

In order to conduct the analysis it was necessary to derive the seepage equation. To obtain this, a lithological investigation was carried out. The lithology of the bed material of Khanpur drain under study comprises a comparatively less permeable...
layer underlayed by a more permeable stratum. The study also revealed uniformity in the lithology along the drain. Based on this the seepage rates were assumed to be the same as those for the Rohti drain (Khepar S. D. 2000a; Khepar S. D. 2000b; Khepar S. D. 2002).

The input to the model includes seepage rate, wetted perimeter, longitudinal slope and length of drain. Parameters that were varied are:

- Bed width of the drain, B
- Longitudinal slope of the drain, s
- Height of check structure, h
- Number of check structures, N

The parameters that are taken into consideration are bed width of the drain B, height of check structure h, number of check structures, N and longitudinal bed slope, s. Since the wetted perimeter is a function of bed width and ponding depth in the drain, a graph (Figure 3) was plotted between ponding depth and wetted perimeter for different bed widths. It may be observed from the figure that the wetted perimeter increases with increase in both ponding depth and bed width. Also this variation is linear for the two parameters.

**RESULTS AND DISCUSSION**

As mentioned above, the results are divided into four categories. At first the effect of bed width on recharge rate is studied. Secondly the effect of bed slope on recharge rate is plotted. The third case investigates the effect of height of check structures on recharge rate. The fourth and the final case looks into the effect of number of check structures on recharge rate.

**Effect of Bed Width on Recharge Rate**

In order to study the effect of bed width of the drain, B on the recharge rate the bed width was varied from 0 to 10 m in increments of 2 m. Bed width equal to 0 m depicts a triangular channel. The height of check structures, h and longitudinal slope, s were kept constant for one set. The results are plotted in figure 4. In these figures the pink line (lowest) represent bed width of 0 m and the dark green (top most) represent bed width of 10 m. Rest of them represent the intermediate bed widths of 2m, 4m, 6m and 8m.

Referring to figure 4 (a) it may be observed that for a bed width of drain equal to 2 m the recharge rate corresponding to 2 check structures per segment is 0.0097 m$^3$/sec while for 16 check structures it is 0.013 m$^3$/sec. Hence, for an increase in 8 times the number of check structures per segment the increase in recharge rate is only 1.34 times. Similarly, for a bed width of 8 m, the computed recharge rates are 0.0274 m$^3$/sec and 0.0343 m$^3$/sec for number of check structures equal to 2 and 16, respectively thus registering an increase of only 1.25 times the recharge rate against an eight times increase of bed width. It goes to suggest that though the recharge rates increase with increase in bed width, the increment is not significant.

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**RESULTS AND DISCUSSION**

The relationship between ponding depth and recharge rate is given by, $q = 0.11d^{0.73}$, where $q$ is seepage rate in cm/hr and $d$ is ponding depth in cm. The seepage rates have been taken to be consistent for the whole work.

**Fig. 3:** Plot between the wetted perimeter, depth and bed width: bed width varies from 10 m (top most) to 0 m (lowest) in interval of 2 m.
Fig. 4 (a, b, c): Variation of recharge rate with no. of check structure (h=0.6 m, 0.8 m, 1.0 m; s=1/1000): bed width varies from 10 m (top most) to 0 m (lowest) in interval of 2 m.
Fig. 5 (a,b,c): Variation of recharge rate with no. of check structure (h=0.6 m, 0.8 m, 1.0 m; B=10 m). Dark blue line (lowest) represent bed slope of 1 in 1000 and the sea green (top most) represent bed slope of 1 in 4000.
Effect of Bed Slope On Recharge Rate

Another major factor that seems to be affecting the recharge rate through the drain is the longitudinal bed slope. Four different bed slopes ranging from 1 in 4000 to 1 in 1000 were considered and a graph (figure 5) was plotted between the check structures and the recharge rate. A constant bed width of 10 m was adopted for this set. In figure 5 the dark blue line (lowest) represent bed slope of 1 in 1000 and the sea green (top most) represent bed slope of 1 in 4000. Rest of them represent bed slope of 1 in 2000 and 1 in 3000.

From figure 5 (a) the recharge rate corresponding to bed slope of 1 in 1000 are computed as 0.0333 m³/s and 0.0414 m³/s for number of check structures equal to 2 and 16, respectively. Thus with an increase in 8 times the number of check structure, the increase in recharge rate is 1.24 times. Similarly for a bed slope of 1 in 4000 the computed recharge rates are 0.1331 m³/s and 0.1657 m³/s for number of check structure equal to 2 and 16 respectively. The increase in recharge rate for a bed slope of 1 in 1000 to 1 in 4000 is 4 times for analogous number of check structures.

In other words, number of check structures remaining the same, the recharge rate is higher for flatter slopes than steeper slopes. The increase in recharge rate follows the same ratio as that of the inverse of the slopes.

Effect of Height of Check Structure on Recharge Rate

It is expected that the depth of ponding is the predominant factor affecting the recharge rate through the drain. The depth of ponding is controlled by the height of check structures. For a slope of 1 in s, a check structure of height equal to 1 m would be sufficient for a length s m. In this case, the drain storage would be in the form of a triangle and the average depth of ponding would be (0+1)/2 m. In generalised terms it is given by equation 4. Therefore, to ascertain the effect of height of check structures a series of computations were made for height of check structures ranging from 0.6 m to 1.0 m. To study these effects in detail a graph figure 6, has been plotted for a bed width of 10 m for different check heights. The results are consonant with the theoretical considerations that with an increase in value of height of check structures (depth of ponding) the recharge rate increases.

It can be observed that for bed slope of 1 in 1000 the computed recharge rate for 4 number of check structures per segment are 0.0379 m³/s, 0.0651 m³/s and 0.0997 m³/s for the check heights of 0.6 m, 0.8 m. and 1 m. respectively. The recharge rate is found to be increased by 1.72 times for the check height from 0.6m to 0.8m and by 2.63 times for the check height varying from 0.6 m to 1 m. Thus height of check structures has significant effect on recharge rate.
Effect of Increase in Check Structures on Ground Water Recharge

The provision of check structures at intermediate intervals converts the entire length of drain into sequence of pools. The discharge at the head end of the drain so as to avoid any flow at the outfall of the drain, can be represented mathematically as equation 1. This part of the study was carried out on Khanpur drain. The drain was divided into 3, 4, 5 number of segments and heights of check structures was kept 0.723 m, 0.542 m and 0.434 m respectively. Referring to figure 6, it is easy to observe that height of check structures tends to increase the recharge rate. Providing height of check structure equal to full supply depth would result in maximum efficiency. But from a practical standpoint it was assumed to fix the height of check structure upto 0.7 – 0.75 times of full supply depth. Since the drain has larger cross-section corresponding to the top portion of the check structure, this clearance would be sufficient to allow designed peak flows over the check structures.

After selecting the check height the drain was subjected to the model (Khepar S. D. 2000a; Khepar S. D. 2000b; Khepar S. D. 2002). The input to the model included length of drain l, Manning roughness coefficient n, bed width B, side slope m, and longitudinal slope, s. The output included flow rates at the upstream end of drain segment and seepage loss from them. The evaporation loss from the drain was insignificant and was thus ignored.

The results for height of check structure h=0.723 m are plotted in figure 7 (a,b). Figure 7 (b) shows the relationship between percent increase in recharge and number of check structures. Although other results are not shown here but it was found the rate of recharge is maximum for the check structure height of 0.723 m.

It may be noted that the increase in recharge rate after 4 number of check structures goes on diminishing and after that it does not increase significantly with increase in the number of check structures.
CONCLUSION

In this work involving parametric study it has been observed the recharge rate is directly proportional to check height, bed slope and bed width. For an increase in number of check structures from 2 to 16 the recharge rate increases 3.99 to 4.02 times for a change in slope of 1 in 1000 to 1 in 4000. For an analogous number of check structures recharge rate increases from 1.69 to 1.72 times for a change in height of check structures from 0.6m to 0.8m.

For a similar change in number of check structures the change observed is 1.6 times to 2.2 times for change in bed width from 2 m to 10 m. Therefore the longitudinal bed slope, s height of check structure, h and bed width, B are observed to be affecting the recharge rate in decreasing order of importance.

REFERENCES


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