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A study on water seepage losses for ponds and reservoirs

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ABSTRACT

Irrigation is main factor for agricultural production. Our aim is to increase agricultural yield by increasing area under irrigation. It is very important to see that more water available for irrigation is completely used as far as possible to avoid water loss during conveyance through canal. Seepage loss is major water loss during transit. Rainwater harvesting is the artificial collection, storage and use of runoff or rain water. The water harvesting with tanks and ponds is one option to increase water availability and agricultural production at the household level. Rain fed agriculture can be protected by adopting farm ponds. The harvested runoff water in a farm pond creates salinization / water logging problems so; it has to be lined to control the seepage losses. The article presents a review on the type of lining materials viable and to explore for a cost effective sealant which can be adapted. In comparison to clay lining, Bentonite, polymers like HDPE, LDPE, Silpoulin, LLDPE in combination with concrete increases the durability along with the 100% seepage control with benefit cost ratio for HDPE lining in combination with concrete showed highest value of 10.4:1. Bentonite, though costly has shown significant results by reducing the seepage losses by 72% to 96% respectively, depending on the thickness of application. In vertisols, lining did not show any significant variation. Whereas alfisols, luvisols of arid and semi-arid regions require lining materials with diversified crops and conservative irrigation practices.

KEYWORDS

Water Harvesting, Farm Ponds, Lining Materials, Seepage Control, Cost Effective, Conservative Irrigation Practice

HOW TO CITE THIS ARTICLE

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Water has been said that the "oil of the 21st century": a commodity whose availability and quality may be subject to both known and unknown influences. Day by day, the scarcity of water has been felt worldwide due to ever-increasing demand for industrial, municipal and other users, besides agriculture. Agricultural use of water accounts for nearly 70% of the water used throughout the world, and the majority of this water is used for irrigation. Irrigation is main factor to boosts agricultural production. The volume of water used for irrigation by the last century was 300 BCM of surface water and 128 BCM of groundwater out of 428 BCM. The estimates indicate that by the year 2025. The water requirement for irrigation would be 561 BCM for low demand scenario and 611 BCM for high demand scenario. These requirements are likely to further increase to 628 BCM for low demand scenario and 807 BCM for high demand scenario by 2050. Therefore, in order to meet food grain requirements and to bring maximum area under cultivation, the water resources are to be managed efficiently. Global warming is evidencing the present rainfall scenarios like extreme drought or heavy showers for short duration, means though the annual rainfall is normal water will not be sufficient for rain fed agriculture. Rain fed agriculture provides subsistence to farmer which is inadequate and uncertain (Bhandarkar, 2009). The rate of infiltration of rain water depends on the texture and structure of the soil.

Though the percolated water will rejuvenate ground water storage it cannot be allowed as it takes more time where immediate irrigation requirements are to be met. Therefore on farm water conservation and storage practices (Vohland and Barry, 2010) at low cost are to be adopted depending on the local climatic conditions (Palmier *et al.,* 2010). The historical study can be used for designing the conservation practices. Runoff water can be conserved through in suite and ex suite techniques.

Heavy rains for short duration creates runoff such water can be collected in a pond and used during the prolonged dry spells (Desai *et al.,* 2007). Various studies revealed that the water stored in a farm pond without lining evidence of seepage losses and also salinity, water logging etc., which ultimately decreases the fertility of the adjacent agriculture, lands (Getaneh, 2013, Samuel, 2013 and Jayanthi, 2004). Farm pond lining is a process of installing an impervious material in a pond to reduce the permeability of the soil from insignificant or to at least to tolerable limit. The size and depth of farm pond depends on various factors like soil type, available land, farmer's requirement, possible use of excavated land (Mane *et al.,* 2015, Goyal, 2009, Desai *et al.,* 2007) and probable runoff of the region (Ambati *et al.,* 2011).

Table 1 and 2 showing the infiltration rate and seepage loss through different types of soils respectively. Infiltration properties were measured *in situ* with a disk infiltrometer in order to evaluate the saturated hydraulic conductivity of the soil under undisturbed conditions and with solutions being representative of field conditions. Water Infiltration (I) into soil is usually well described by the Philip equation (1957):

$$I = S \sqrt{t} + A\, t$$

Where,

S is the sorptivity, resulting from the flow due to capillary pressure head in dry soil.

A is the constant infiltration rate parameter, depending on the gravity flow.

Table 1. Infiltration rates of different types of soil

Soil Type	Infiltration Rate (cm/hr)
Clay	0.5
Clay loam	0.8
Silty loam	1.0
Fine sandy loam	1.2
Fine sand	1.2-2.0
Coarse sand	2.0-2.5

Table 2. Seepage losses in different soils

Soil Type	Water loss through seepage (cumec/millionm^2 of wetted area)
Heavy clay loam	1.21
Medium clay loam	1.96
Sandy clay loam	2.86
Sandy loam	5.12
Loose sandy soil	6.03
Porous gravelly soil	10.54

Seepage is defined as "the process of downward lateral movement of water into soil from source of supply such as irrigation canal". Seepage loss is depending upon permeability of soil, area and shape of canal wetted perimeter, Water depth in the canal, location of ground water table, constructions on ground water flow, location of wells, rivers, drains, impermeable boundary conditions, soil suction zone in between ground water level and ground level, viscosity of flowing water (neglected), salinity of available water, sedimentation and size distribution, life of canal.

According to different research it was observed that average seepage loss was 20-50 percentages in conveyance (Shaha, 2015). More seepage loss contributes water logging of lands and higher salt concentration in soils due to this problems crop production will be reduced. Number of methods is adopted for controlling seepage loss like soil compaction, lining of canal, replacement of canal by close conduit. Lining of irrigation canal is the simplest and most effective method for saving water and land in irrigated area (Meman *et al*., 2013). Seepage loss (S_R, mm h^{-1}) was calculated using: (Shaha, 2015).

$$S_R=(D\cdot A_R)(P\cdot A_S)^{-1}$$

Where,

D is the change in main storage tank water depth (mm).

A_R is the area of the main storage tank (mm^2).

P is the measurement period (h).

A_S is the area of the infiltration ring (mm^2).

Seepage Loss Standards

The following mean seepage rates for ponds based on the following Unified Soil Classification System groups:

SM (silty sand, sand silt mixtures) = 0.2 ft per day.

SC (clayey sands, sand clay mixtures) = 0.007 ft per day.

ML (inorganic silts - very fine sands, silts or clayey fine sands) = 0.02 ft per day.
CL (low to medium plasticity clays) = 0.003 ft per day.
CH (high plasticity clays) = 0.0003 ft per day.

These published seepage rates provide reasonable seepage loss expectations for appropriately designed small ponds and reservoirs.

Lining Materials

The suitable canal lining can reduce the seepage rate considerably. However, in some circum-stances, a high-cost lining might not decrease canal leakage greatly and a low-cost lining could have a better cost/benefit performance. For example, even without extra canal lining, canals located on compacted soil beds can compete well with the lined canals, resulting in lower overall costs. Soil hydraulic properties and soil structure below the canal can also influence canal seepage. Measurements have shown that seepage rates are influenced by the condition and composition of canal banks, and to a lesser extent by soil texture. Most canals are located in areas with complex multi-layered soil conditions. Conversion of permeability in layered profile (K) to single value as follows:

$$k_{average} = \frac{d}{\frac{D_1}{k_1} + \frac{D_2}{k_2} + \frac{D_3}{k_3}}$$

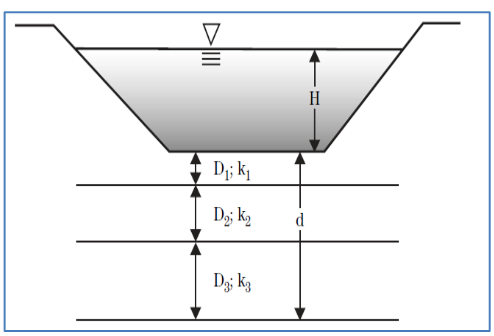

Fig 1. Layered profile (K)

Experiments indicate that the infiltration into layered soils can differ markedly from those in homogenous soils. Water losses in unlined canals are usually high. One of the most important ways to increase the efficiency of water diverted for irrigation is to reduce the amount of water lost by seepage during conveyance to farmers' fields.

Total seepage losses from main and secondary canals range from 20 to 45 percent. This article is a review on various types of lining material. Lining material is necessary where the infiltration rate of soil is more than 10mm (Srivastava, 2004). The paper presents easily adaptable various types of lining materials like clay, soil cement, concrete, chemicals like bentonite, Sodium bicarbonate, polymers like HDPE, LDPE, Silpoulin, LLDPE etc. and their major site specific annotations. In a study, on evaluation of different lining materials, the total water loss per day was maximum with soil + cement (8:1) lining while the loss per unit volume was higher with stone powder + cement (8:1) lining (54.3 lt/m^3) followed by stone slab (45.5 lt/m^3) and the loss per unit volume is minimum in brick lining (20.1 lt/m^3) (Srivastava, 2004).

There are many technical reasons for lining irrigation canals:

- Reduction of water lost by seepage
- Increase in canal discharge capacity
- Limitation of weed growth
- Reduction of water logging
- Prevention of bank erosion
- More equitable water distribution and reduction in transmission time
- Prevention of damages to adjacent land
- Reduction of drainage cost
- Reduction of canal dimensions
- Reduction in right-of-way and land acquisition cost.

Effect of Lining Materials

Clay Lining

Excessive seepage in alfisols and luvisols can be abridged through clay lining where as in vertisols soil compaction can reduce seepage losses. Impounding area should be compacted proportionately for two to three times and well graded material containing at least 20% clay can be applied evenly as liner studies conducted in various regions. Clay lining is the cost effective compared to plastic membrane, biocrete and concrete lining (Jayanthi *et al.,* 2004). Thickness of the blanket varies from 10 to 30cm depending on the depth of water impounding and type of soil.

Soil Cement

Is a highly compacted mixture of natural soil/ aggregate and portland cement, the soil material can be in any combination of sand, silt, clay and gravel which is readily available. Soil cement is a mixture of portland cement and natural soil. For best results the soil should be graded with a maximum size of 3/4th inch and contains 10 to 35% fines passing the No. 200 sieve.

Rate of application and ratio of soil cement shall be determined based on laboratory test and field situations. Depending on the depth of water stored, thickness of the lining material is fixed as 4" for water depth up to 8 feet and 6" for water depth up to 12 feet (NRCSCPS, 740-1). Various studies revealed that runoff water stored in farm pond used to irrigate crop during dry spells (Islam *et al.,* 2017, Wallace and Bailey, 2015, Subudhi and Senapathi, 2013, Dhanapal *et al.,* 2010 and Jayanthi *et al.,* 2004). On an average 93.5% seepage is reduced with 4.9 l/m^2/day. Though the seepage losses from the lined pond are increasing year after year it can be adapted where the budget is a constraint.

Polymer Lining

Waterproof lining material for pond are polyethylene, vinyl, butyl rubber and asphalt sealed liners are widely accepted in a thin film form but if not broken or punctured. Thickness of plastic films ranges from 3-20 mils. Before lying a plastic film pond area should be cleared with gravel greater than 6 inch to protect it against puncture (table 3).

Table 3. Effectiveness of different lining material for seepage control

S. N.	Lining Material	Seepage loss, l/hr/m^2
1	Control (No lining)	18.56
2	Cowdung + Paddy husk + Soil plaster (1:1:10)	16.98
3	Cementplaster at bottom (1:6)	12.99
4	Cement + Soil plaster (2:10)	0.85
5	Polythene sheet	0.32
6	Paddy husk +Ash plaster	11.6
7	Coastal saline soil plaster	5.47
8	Fly ash + Sand Plaster	2.5
9	Clay	12.07

Silpaulin

Silpaulin is durable, light weight and waterproof material. Plastic lining has great acceptance for seepage control. These sheets are made up of waterproof UV-stabilized, heat-seated, multi-layered and cross-laminated plastic materials and hence ensure high tensile strength, long life and high resistance to external pressure. Generally, trapezoidal-shaped storage tanks are constructed by excavating soil and dumping the removed soil along the four sides of the tank. Silpaulin of 200 and 500GSM is mostly used and found effective.

High Density Polyethylene

High density polyethylene tarpaulins made out of Industrial strength HDPE Woven fabric and re-in forced with lamination of LDPE on both sides. In comparison to concrete and shortcrete, HDPE and LDPE lining is cost effective as it does not require any maintenance except that it should be protected from mechanical damage by maintaining water continuously. Studies reported that 1.2 cm/month seepage, and almost 100% seepage control in case of undamaged sheet. Where as in case of LDPE sheet seepage loss reduced from 55 to 2.91 l/m^2/day showing percentage of reduction ranging from 93% - 95% (Rao, 2010; Singh, 2010; Singh, 2006).

Bentonite

Bentonite is natural clay which has the characteristic of swelling 10-12 times its dry size. It showed 92% to 96 % of efficiency in seepage control for best results, application should be done at the depth of 25-30cm. Cost incurred in this method is high due to the cost of Bentonite and the field preparation (Shehzad *et al.,* 2017).Canal lining is very expensive, adding 30 to 40 per-cent to the total cost of an unlined system. Invariably the high investment cost is justified by the value of water saved by reduction of seepage losses. This justification is usually based on research studies that show that roughly 60 to 80 percent of the water lost in unlined canals can be saved by hard-surface lining. Other Lining materials like Sodium Bicarbonate, LLDPE, Geomembrane, Concrete and Calcarious soil lining were studied by various researchers.

Riaz and Sen (2005) has taken up a project with Geobembrane lining with soil cover to control seepage, water logging and salinity and reported that it is durable for two years. Harvested water can be used for life saving irrigation furthermore to get maximum benefits diversified farming like aquaphonics, agrihorti - selvi pastoral system can be adopted (Das, 2017; Samule, 2013). A study revealed the benefit cost ratio of HDPE is the best also with maximum seepage reduction along with B: C ratio of 10.43, compared to IITD + shortcrete, geotextile cover + shortcrete, geotextile cover + concrete and IITD + concrete showed the B: C ratio 9.59, 6.83, 5.4, 6.95, 6.83 respectively (Kadu *et al.,* 2017). Therefore considering the geological conditions HDPE lining if effective as lining material in polymers (Mohan *et al.,* 2013; Mathew *et al.,* 2008). Cost involved in silpouline lining ranged from Rs.0.14 per liter to Rs.0.71per liter (Das *et al.,* 2017; Samule, 2013).

Extensive review concludes that field experiments at various regions using different combinations of lining materials shows that polymer based lining has good effect on seepage control. Provided, depending on the type of soil, lining material can be selected. Where the durability is matter of concern like canal lining or big farm ponds planning to conserve water to cover large areas than HDPE in combination with concrete showed 100% seepage control as the concrete alone has not proved to be efficient due to thermal expansion and contractions. Bentonite, though costly has shown significant results by reducing the seepage losses by 72% to 96% respectively, depending on the thickness of application.

Clay lining and soil compaction is the cheapest lining method provided the ponds should be erected in vertisols. In case of alfisols, luvisols of arid and semi-arid regions require lining materials with diversified crops and conservative irrigation practice to get maximum benefits and minimum payback period. Benefit cost ratio for HDPE lining in combination with concrete showed highest value of 10.4:1.

Recommendations

The main factors influencing canal seepage are the canal linings, the soil hydraulic properties and their spatial variations, the canal cross-sectional profile and water level, the groundwater table location, and the amount of sediment inside the canal. The choice of lining material depends primarily on local costs, availability of materials and availability of local skills. Some advanced techniques like Bentonite, polymer spray and geo-membrane in combination with protector cover can be undertaken for studies. Region specific recommendations are to be developed to adopt by the farmers individually or as a community or group. Government is encouraging the water harvesting structures in few parts of the country by providing subsidies for the cost of construction. In addition to this, farm ponds along with the suitable lining material can be provided for agriculture lands by providing subsidy. Advanced techniques and technicians like polymer spray and sprayers are to made available in local markets.

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