

## Adoption of Offset manifold design in Hillside Drip Irrigation system – An Appropriate Design concept

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### Abstract

*This paper deals with how best the underutilized resource of treated sewage water can be utilized productively for nearby hillside irrigation with drip irrigation avoiding environmental degradation. Design analysis was performed to adopt the offset and split manifold designs for drip irrigation system in different land slopes to achieve better uniformity of application. For land with slopes of 5, 8, 10 and 12 percent, the offset manifold design is recommended for having uniform manifold diameter. Split manifold design is feasible up to 5 percent land slope with manifold mainline junction at the centre and beyond this slope the junction should be located other than midpoint. Rainfall analysis, crop water demand and sewage water availability reveal exciting opportunities for water productivity enhancements in rainfed agriculture by integrating components of water management within the context of rainfed farming through sewage water harvesting and supplemental irrigation for dry spell mitigation.*

**Key words:** crop water, Drip irrigation, hill side irrigation, manifold design, rainfall, sewage water

### Introduction

Against the background of the rapid decline in irrigation water potential due to climate change and low water-use efficiency in the flood (conventional) method of irrigation, drip irrigation becomes a feasible choice. Besides saving a substantial amount of water, it also helps to increase the productivity of crops. The issue of rainfall variability is more critical for agricultural lands located on hills that, unlike the marshlands, lack water storage and for which reason support only limited farming during dry seasons. Ethiopia's cultivable land is about 13.2 million hectare. But the actual cultivated land is about 6 million hectare, which is 45% of the cultivable area. Dynamic

and innovative action is needed to increase the actual cultivated area by transforming swamps and hill side lands into cultivable round the year. To achieve this goal, new land management technologies are to be adopted. Irrigation is kept as one of top priority area by Government of Ethiopia. From the existing cultivated area, only about 4 to 5 percent is irrigated (Sileshi, 2010). This is very low compared to other developing countries.

Continuous application of waste water on agricultural land affects soil hydraulic properties (Mustafa and Manon, 2012). But this impact is more on flat lands rather than hillside lands. Waste water and the adjoining hillside land have been taken as a research subject for

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effective resource utilisation in order to improve land productivity and environmental conditions. In hill side lands, drip irrigation system has to be designed considering the land slope in order to eliminate high pressure variation which results non uniform application of irrigation water. Normally on hill side lands, drip laterals are to be laid along the contour lines and obviously, the manifolds should run across the land slope leading to high pressure variation in the manifold and this leads to limitation of manifold length to achieve water application uniformity. To find a solution for this problem appropriate design concepts of drip irrigation are analysed with reference to the study area.

The main objective of the study is to adopt the offset and split manifold designs for drip irrigation system in different land slopes for sugarcane cultivation using waste water.

## **Materials and Methods**

### **Climate and topography**

Hawassa has warm temperature which varies between 10°C in winter and 30°C in summer. The mean annual precipitation is 958mm. Hawassa is situated at the Eastern shore of Lake Hawassa close to the eastern fault belt of the central part of the Main Ethiopian Rift Valley in a large volcano-tectonic collapse. It lies on the plain between Lake Hawassa and Chelelaka wetland with general slope towards Lake Hawassa. The average elevation at is 1700m and that of the lake surface is 1680m. Rain is more intensive during the four rainy months of June to September such

that more than 80% of the rain falls during this period.

### **Design of lateral**

The lateral length is chosen by dividing the field into two parts, as the manifold passes in the middle of the land. Discharge into this pipe depends on the number of dripper operating on it and their operating discharge. The diameter of lateral pipe is selected so that the difference in discharge between emitters operating simultaneously will not exceed 10 percent (Israelsen, and Hansen, 1962). Normally a head of only 0.5 to 1m is used for bucket kits (Sijali, 2001). Using a head of between 0.5 and 1.5 m, and 10m long laterals results in an average emitter discharge of approximately 0.2 to 3.0 l/h depending on the drip system (Chigerwe et al., 2004). This figure can be compared with flow rates under conventional drip of approximately 2.0 to 8.0 l/h (Dasberg and Or, 1999) irrespective of the length of the laterals.

### **Manifold design**

It is commonly accepted practice to orient the pipe network so that the laterals traverse the minimum slope possible (on the contour). The manifolds, therefore, are likely to lie along maximum slopes and thereby necessitate special consideration during the design procedure. Two basic manifold design strategies can be employed. The first maintains the manifold pipe to single diameter by offsetting the main or submain-manifold junction uphill. The objective of this design is to keep the minimum pressure in both

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directions equal so the design standard or allowable pressure variation is satisfied. The second approach is to locate the main or submain-manifold junction at the manifold mid-point and use two pipe diameters to achieve the same objective.

### Offset manifold design

The auxiliary will be connected to the manifold at a point where the minimum pressure in both sections of the manifold will be the same. For instance, if the manifold is lying on level ground, the connection point will be midway along the manifold. For manifolds on a slope, the connection point will be somewhat towards the manifold end with the highest elevation (Keller and Karmeli, 1975). The location of the connection point and the manifold pipe diameter involve a series of trial and error calculations. The first step is to divide the manifold length into the reach flowing uphill  $L_1$  and the reach flowing downhill  $L_2$  ( $= L_m - L_1$ ) where  $L_m$  is the total manifold length (Fig 1). The discharge diverted into both pipes is estimated by assuming the average lateral discharge. The number of intervals in both directions is:

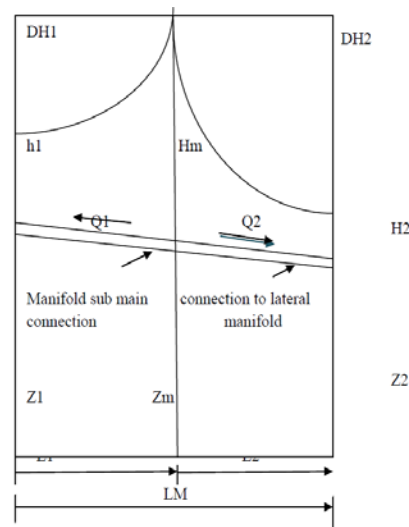


Fig 1 Lateral inlet pressure heads along a sloping manifold

Setting the pressure heads at the two ends of the manifold to be equal ( $h_1 = h_2$ ), the difference between the uphill and downhill head losses must be equal to the difference in elevation between the ends of the manifolds.

$$\Delta H_1 + Z_1 = \Delta H_2 + Z_2 \quad (1)$$

The allowable head loss for horizontal manifolds can be taken as 45% of the allowable pressure variation in the network which is usually taken as  $0.2 H_o$  where  $H_o$  is design system operating pressure.

$$\text{Hence, } H_{f \text{ allowable}} = 0.45(0.20H_o) = 0.09H_o \quad (2)$$

For pipes running uphill:

$$hf_{\text{allow}} \geq \Delta H_1 + \Delta Z_1 \quad (3)$$

In which  $S_m$  is the uniform manifold slope.

For pipes running down hill:

$$hf_{\text{allow}} \geq \Delta H_2 - \Delta Z_1 \quad (4)$$

After setting  $L_1$  and  $L_2$ , knowing  $H_o$  and uniform manifold slope, allowable head loss ( $hf_{\text{allowable}}$ ) and  $\Delta H_1$  are calculated. Manifold diameter  $D_m$  to produce friction  $\Delta H_1$ , is calculated as below

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$$D_m = \left[ \left( \frac{1}{\Delta H_1} \right) 1.21 \times 10^{10} \left( \frac{Q_1}{C} \right)^{1.852} \times L_1 \cdot F_1 \right]^{0.2063} \leq hf_{\text{allowable}} - L_1 \cdot S_m \quad (5)$$

In which  $\Delta H_1$  - friction head loss uphill reach in meter  
 $Q_1$  - uphill reach discharge, lit/sec,

Knowing  $\Delta H_1$ ,  $Z_1$  and  $Z_2$  determine the friction head loss in the down slope reach  $\Delta H_2$ . Using equation (5), determine the manifold diameter which will produce  $\Delta H_2$ . If the manifold diameters computed for the uphill and downhill sections are different, the value of  $L_1$  and  $L_2$  are modified until the difference between the iterations for diameter is negligible.

#### **Split manifold design**

The total manifold length is divided by two to get  $L_1$  and  $L_2$ . The friction head loss in the uphill and downhill reaches is obtained from equation:

#### **Impact of planting season**

For 5 year average of climate data, according to the time of planting of sugarcane irrigation demand varies. Being a perennial crop, water demand of each crop stage interacts differently with rainfall and results typical irrigation demand. Two cases are analysed,

$0.2063 \leq hf_{\text{allowable}} - L_1 \cdot S_m$   
 In which  $S_m$  is the uniform manifold slope.

Setting the pressure heads at the two ends of the manifold to be equal ( $h_1 = h_2$ ), the difference between the uphill and downhill head losses must be equal to the difference in elevation between the ends of the manifolds. The manifold diameter for the uphill reach and downhill reach can be calculated separately using Hazen - William formula.

#### **Results and Discussion**

The concept of offset and split manifold design, is applied on a field measuring 0.8 ha area with different slopes available on the farm land adjoining the oxidation ponds of Hawassa university sewage treatment system. Both the designs are analysed and discussed under different slopes regarding their applicability.

one is planting in February and another planting in June. Figure 4 shows monthly irrigation demand for planting in February with 5 year average data. For both 5 year and 20 year average climate data, peak crop water demand is atleast 47% more than that of planting in June.

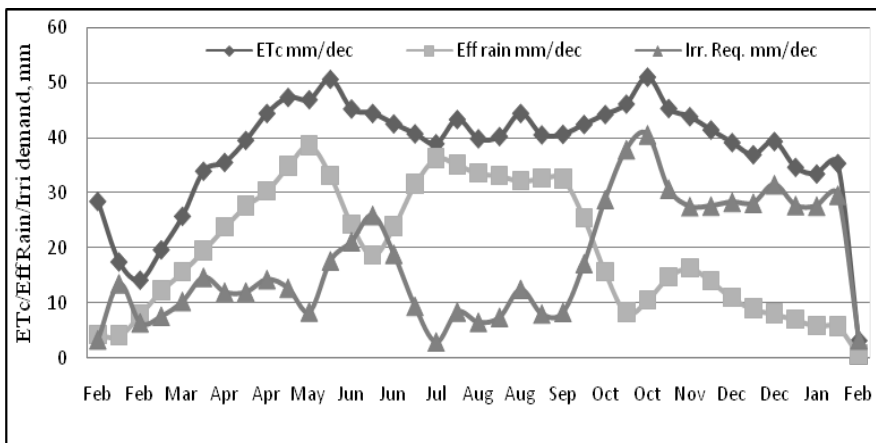


Fig 2 Monthly Crop water and irrigation demand

Main pipe design discharge requirement is 12 l/s/ha for planting in June whereas it is 14.7 l/s/ha for planting in Feb. So, planting in June is more affordable and favourable for crop and irrigation economy. Due to less water consumption during initial crop stages and reasonable rainfall, irrigation demand is nil during June, July and August. This happens if planting is done in June (Fig 3). Whereas in case of planting done in February, irrigation is to be supplied during most months of the year resulting higher irrigation system and

operating costs. Shifting of planting date due to effects of climate change will result in increased irrigation demand. For timely planting farmers need to have independent water source for irrigation. This demands intervention of ground water or other new water resources which are not tapped so far. In the present area of study, sewage water which is ineffectively utilised can be converted into more productive by adopting innovative water management techniques.

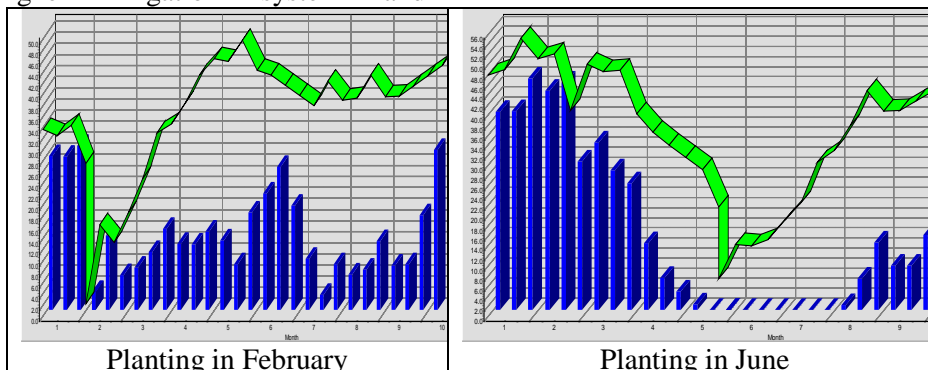


Fig 3 Seasonal Variation of crop water demand and irrigation demand

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### **Irrigation demand of Sugarcane**

Being a long duration crop, it needs total crop water demand of 1400mm for Hawassa climate conditions. Both 5 year and 20 year average monthly rainfall data are analysed to estimate effective rainfall and irrigation demand. Considering medium sandy loam soil, the net irrigation water to be applied in the root zone to replenish 30% depletion is calculated as 48.6mm. For 90% irrigation efficiency, gross irrigation depth of 54mm is to be applied. Considering peak crop water demand of 5.5mm/day for the case of 5 year average climate data, the root zone can retain moisture to favour 9 days irrigation interval. But to be more efficient, drip irrigation needs more frequency of water application. So, 3 days of irrigation interval is selected for the design of the drip irrigation system. Peak irrigation demand of 2.7mm/day is observed for 20 year average data with planting date in January whereas 4.6mm/day is observed when planting is in June. Maximum irrigation demand of 795mm is needed for 5 year average data whereas it is 7.5% less for 20 year climate data. This clearly reveals

recent climate conditions demand increased irrigation as compared to the past years. Considering the effect of climate change, designing the irrigation system to match recent average climate data of atleast 5 years will be a more appropriate. This will equip our irrigation system better adapted to climate changes.

### **Sewage water**

From the effluent treatment plant of Hawassa university student's residential buildings, average treated effluent discharge of 10litres/sec is currently underutilized. Prospective of using effluent water for irrigation is well justified by low biological oxygen demand and suspended solids which are well within the permissible limit of 20 and 30ppm. Since the sewage is subjected to septic tank for sedimentation and anaerobic preliminary treatment to reduce the biological and suspended impurities. After this, the effluent is further treated with sedimentation, oxidation and polishing tanks for natural process of sedimentation and anaerobic biological treatment. The treated water is found as clear and odorless and found as suitable for irrigation purpose. Since the water availability is limited, high efficient irrigation method of drip irrigation system is selected. This will envisage irrigation of 5.5 hectares of nearby hill side lands with addition of water treatment by disc/pressure sand filter of 200 micron. The suspended solids of treated effluent are rich in readily available nutrients essential for plant growth and increased yield. According to Bates et al. 2008, observational records and climate projections provide abundant evidence that freshwater resources are vulnerable and have the potential to be strongly impacted by climate change, with wide-ranging consequences on human societies and ecosystems" e.g. devastating floods and droughts of increasing frequency and magnitude in different regions, with severe

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damages to agriculture, livelihoods of poor farmers and food security of nations. To cope with very low Storage-Drought Deficit Index (i.e. how much of the long-term annual hydrological drought deficit is satisfied by the existing storage capacity in a county) of 0.05 % for Ethiopia (Eriyagama et al. 2009), utilization of sewage water becomes inevitable to mitigate vulnerabilities due to climate change. The proposed strategy of using sewage water for irrigation will not only use water farmer-friendly but also environment friendly and reduces vulnerability of food production system to climate change.

### **Drip Irrigation**

#### ***Emitters and Laterals***

For sugarcane drip irrigation system is designed with single row inline drip laterals with 1.2m spacing. Wider lateral spacing is not considered despite its access to farm implements. Since the study area is hill side land, possibility of application of farm mechanization is limited particularly in un-terraced hill side lands. Inline dripper of 4lph is selected with operating pressure of 1.5bar. This can meet 3 days peak irrigation demand of sugarcane in 3 hrs 45 minutes irrigation duration. In case of hill side lands where normally steep slopes are expected, the laterals are to be laid along the contour and obviously the manifolds run along the slope gradient. Required number of laterals needed is 42 with lateral spacing of 1.2m. Considering the field of 160m x 50m in which the length is equal to the length of one lateral and the width has been chosen as the length

of manifold. The number of plants irrigated by one lateral is 200 plants. Accordingly lateral discharge is calculated as 0.22lps. Always the manifold is placed at the predominant slope so that laterals are perpendicular to this to reduce the head loss. With 20mm diameter of lateral pipe, the head loss is 1.43m which is within the allowable limit of 1.65m. Since pressure variation in lateral is found as 9.5% which is less than the allowable limit of 10%, the selected diameter is acceptable.

Since the lateral is laid along the contour zero slope is considered. But this may not be the case always. Many times the laterals will be laid along the slope and depending on the degree of the slope, design decision will be taken. Under such conditions the slopes are to be verified whether it is steep or not based on land elevation and operating pressure. Steep slope occurs when the change in land elevation is more than 30% of the operating pressure of the emitter. Under steep slope conditions normally the laterals should be laid down hill in such a way that the friction loss with a particular pipe diameter should compensate the increase in pressure due to land elevation. Laying the laterals in uphill direction should not be practiced provided the land is steep slope. Laying the lateral in the uphill direction if at all needed under specific circumstances, it should be done only when the slope is mild.

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### ***Design of Manifold***

Since the manifold of hill side irrigation system needs to be laid along the existing land slope, location of main pipe-manifold junction decides the pressure distribution in manifold pipe which ultimately influence the distribution uniformity. But its influence depends on the degree of land slope. As presented in the methodology section both offset and split manifold designs can be practiced in manifold design. Considering 45% of total allowable friction loss, for manifold it come to 1.35m. With 90mm PVC pipe under manifold discharge of 8.4lps, actual friction loss comes to 0.37mm which is less than allowable limit. It also shows that the pipe size still can be reduced since the available head loss is far more than the actual. Under flat land conditions no matter where is the location of main pipe – manifold junction.

### ***Offset manifold design***

The main pipe will be connected to the manifold at a point where the minimum pressure in both sections of the manifold will be the same. The diameter of the uphill and downhill reach comes to 46 and 44mm respectively. The location of the connection point and the manifold pipe diameter involve a series of trial and error calculations. For the previous trials taken at different distances from the uphill(at 8th lateral,12th ) the diameters found were not the same i.e no inlet position can give the equal diameters at the uphill end and downhill end. For the last trial the inlet position taken at 10th lateral

from the uphill end gives the approximately same diameters at the uphill and downhill ends (46mm,44m) when the connection point is 12m from uphill. No other trial can be made beyond 12m from the uphill end, if it is performed beyond this distance the friction loss will be negative for uphill manifold indicating pressure variation going beyond the acceptable limit and needs pressure regulator.

For different slopes viz. 12%, 8% 5% with suitable junction positions, the offset design is performed. It indicates that the appropriate diameters found for 12%, 8% and 5% were 40 & 42mm, 43 & 44mm and 44 & 44.5mm respectively for uphill and downhill pipes. The objective of offset design is to keep the minimum pressure in both directions equal. For more accurate calculations, a computer program can be written since it involves much iteration. It is observed that for higher land slope, the junction approaches the uphill end. Under higher slope conditions, the downhill length will be more than the uphill length and beyond certain level pressure regulator is must to have same pipe diameters on both sides. Since pressure regulators are expensive, it is suggested to go for different diameters in both uphill and downhill sides. The manifold diameters computed for the uphill and downhill sections are different, and no other trial can be made beyond 6m from the uphill end. If it is performed, the friction loss will be negative for uphill manifold. The objective of offset design is to keep the minimum pressure in both directions equal but in this case the

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design standard or allowable pressure variation is not satisfied. So the offset manifold design should not be utilized for the slope of 22% and split manifold design is recommended for this slope and utilization two different diameter of 45mm and 30mm respectively for uphill and downhill manifold sections. Location of main pipe – manifold junction from uphill for 5, 8, 10 and 12% are 16.8, 13.2, 12 and 9.6m respectively.

#### ***Split manifold design***

The manifold length is divided into two equal parts to get L1 and L2 and two different diameters are used so that the design standard or allowable pressure variation is satisfied. For our case, the inlet position is at 25m from uphill end, at 21st lateral. If the slope is 12%, 10%, 8% the allowable head loss in the uphill reach is negative; the variation of the pressure will be high for supplying water from the mainline manifold junction to the uphill end. At 5% slope it is found that the allowable head loss in the uphill is positive and the uphill and downhill pipe diameters are 75 and 40mm respectively. Beyond this slope the allowable head loss at uphill end is negative indicating that the main pipe - manifold junction cannot be at midpoint of the manifold.

#### ***System capacity***

To supply 8.4lps to the irrigation system, main pipe of 110mm diameter is needed resulting 0.9m friction loss in 150m length. With total pressure head requirement of 32.5m, power of 4.5KW is needed to lift water and

feed to the irrigation system. Based on elevation head, the energy cost varies making the pressure irrigation system to perform uniquely with different crops. Deep rooted crops can tolerate more than shallow rooted crops which demands irrigation more frequently. Type of crop, land elevation and planting period all together controls the feasibility of drip irrigation system in hill side agriculture.

#### **Conclusion**

Prevailing climate conditions in Hawassa needs supplemental irrigation particularly for cultivation of annual crop like sugarcane. Irrigation demand is influenced by planting season. Sugarcane planting in June demands less irrigation compared to February. Analysis of climate data reveals that in the past 5 years rainfall is in decreasing trend and supports positively to consider the design of irrigation system based on 5 years data rather than 20 years data. Sewage water from Hawassa University can be effectively utilized for irrigating sugarcane in the adjoining hill side lands near effluent treatment plant. By using drip irrigation about 5 hectares can be irrigated to meet the peak irrigation demand of sugarcane. Both offset and split manifold design practices can be adopted with different limitations. For land with slopes of 5, 8, 10 and 12 percent, the offset manifold design is recommended for having uniform manifold diameter. Split manifold design is feasible up to 5 percent land slope with manifold mainline junction at the centre and beyond this slope the junction

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should be located other than midpoint. Analysis of rainfall, crop water demand and sewage water availability reveals exciting opportunities for water productivity enhancements in rainfed agriculture by integrating components of water management. Detailed analysis is needed for feasibility of lift irrigation with different crops under different altitudes to derive suitable solution for hill side irrigation.

To strengthen water availability in addition to sewage water, it is recommended to construct rainwater harvesting ponds to collect runoff from the adjoining hillsides for combined use of both rainwater and sewage water adopting lift irrigation to support hill land agriculture. This needs further detailed studies on water exploration to ensure its availability. Elevation difference of more than 50 m between the low lying flat land and hillside lands in most of the cases questions feasibility of lift irrigation. Detailed analysis is needed for feasibility of lift irrigation with different crops under different altitudes to derive suitable policy for hill land irrigation and cropping pattern. Feasible zones of altitudes for different crops should be demarcated on hill land based on its economical viability. It is recommended to go for commercial crops in higher altitudes of hill to make the irrigation system feasible. Beyond the feasible altitude, runoff harvesting in farm ponds using micro catchment should be practiced for supplemental irrigation.

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