TRAINING MANUAL

Household and Micro Irrigation Technology (HHMI-TM)

Small-Scale Irrigation Development Directorate

January 2019
Addis Ababa, Ethiopia

Small-Scale Irrigation Development Directorate Ministry of Agriculture

Household and Micro Irrigation Technology Training Manual (HHMI-TM)

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HOUSEHOLD AND MICRO IRRIGATION TECHNOLOGY TRAINING MANUAL

A training manual for woreda experts and development agents in Ethiopia
First Edition

January 2019

MINISTRY OF AGRICULTURE SMALL-SCALE IRRIGATION DEVELOPMENT DIRECTORATE

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About this Edition:

This HHMI training manual is the first edition containing 10 modules designed to meet the technical need of Ethiopian woreda experts and DAs that are working in the area of water and irrigation development.

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Picture on front cover: Some selected household and micro irrigation technologies considered in this training manual

Picture on inside front cover: Manual Pump and motor pump photo

Picture on back cover: Solar pump and Sprinkler photo

Picture on inside back cover: Spring, Manual Tube Well and Roof Water Harvesting pictures

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List of Household and Micro-Irrigation Technology Traning Manual

First Edition January 2019

FORWARD

Intensifying productivity in smallholder farming is a high priority for Ethiopian Government because of the high occurrence of rural poverty and the large productivity gap in the smallholder subsector. Ensuring water availability and access for the vast majority of farmers, effective and sustainable water management for agricultural production and productivity, and resilience against weather shocks and climate change, will however require overcoming a number of critical challenges.

Household level irrigation schemes are promoted with a broader objective of minimizing the vulnerability of smallholder crop production systems to rainfall fluctuation and thereby enhancing food security. For wider development of small scale and household irrigation, different technologies are used for irrigation water development, irrigation water abstraction or water lifting and irrigation applications. These technology options are presented in ten manuals as part of first vision of household and micro irrigation development training package.

The presentation of the 10 training manuals is tailor-made in order to provide easy self-learning of the trainees during and after training period, and serve to foster knowledgeable and highly effective human capital in Irrigation sub-sector. Concerning its content, strong effort in order to fit the widely practiced and recommended training manual standards is taken into considerations. The trainee can go through the training manuals for future use in their working environment. In general, this training manual will serve in all regions as a training material to woreda experts and kebele agricultural development agents. Regions are expected to translate the manual from English language to regional languages for better understanding of each technology presented at different training manuals.

Elias Awol
Director, Small Scale Irrigation Development Directorate
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ACKNOWLEDGEMENT

Ministry of Agriculture (MoA), based on the national strategic directions is striving to achieve its commitments in which modernizing agriculture is on top of its highest priorities to sustain the rapid, broad based and equitable economic growth and development of the country. To date, major efforts have been made to realize the Agricultural Transformation Agenda of the country that is changing smallholder agriculture from subsistence oriented, low input-low output agriculture to a high performing sector well integrated into the national and global economy and to do so in an environmentally sustainable and inclusive manner. The Ministry under its Natural Resource Sector, Small Scale Irrigation Development Directorate developed and implemented several important strategies and national guidelines by its major programs and projects.

These training manuals on household and micro irrigation, which comprises ten areas from water abstraction to efficient resources utilization, have been one of the key outputs of Small Scale and Micro Irrigation Support Project (SMIS), a bilateral project implemented by Agriteam Canada Consulting Ltd, jointly financed by the Government of the Kingdom of the Netherlands and the Government of Global Affair Canada (GAC). In the process of developing these manuals, concerned sectors of the regions are involved. In this regard, we highly recognize the technical inputs delivered from the four regions, specifically from Bureau Agriculture and Bureau of Water from Amhara and Tigray and OIDA in Oromia and ICSSA in SNNPR.

We would like to extend our appreciation and thanks to all contributors and editors for their support in developing and editing of these very important training manuals. Moreover, sincere regards and thanks, goes to the Small Scale and Micro Irrigation Support (SMIS) project for its technical and financial support in developing this training manual through organizing write shop for team of experts and review and validation workshop for federal and regional partner institutions.

Finally, we acknowledge the support of the Kingdom of the Netherlands and the Government of Canada in providing financial and technical support through the SMIS project for all capacity development works particularly for preparation of this training material.

PRESENTATION OF THIS TRAINING MANUAL

This manual is presented in ten modules in three categories. The first four deals with water resource development technologies (spring, hand dug well, manual tube well, roof top rainwater harvesting, farm pond) while the second categories composed of water-lifting technologies (manual pump, motor pump, solar pump) and the third category includes water saving application technologies (drip and sprinkler).

Accordingly, the first module deals with spring development. The second module describes about, Hand Dug Well Development while the third module deals with Manual Tube Well Drilling. The fourth module presents Rooftop Rainwater harvesting (RWH). Farm Pond and Manual Pumps and Motor Pumps are presented in module five, six and seven, respectively. Solar Pump and Drip irrigation are presented in module 8 and 9 and the last module 10 presents about micro is Sprinkler irrigation.

TABLE OF CONTENTS

Module 6: Manual Pump 138

Module 7: Small Engine/Motor Pump 151

I. LSIT OF FIGURES

LIST OF TABLES

ACRONYMS

ATA	Ethiopian Agricultural Transformation Agency
DA's	Development Agents
E pan	Pan Evaporation
FAO	Food and Agricultural Organization
FB	Free Board
GW	Ground Water
HDW	Hund Dug Well
HHMI	House Hold and Micro-Irrigation
HHMIS	House Hold and Micro Irrigation Schemes
KC	Crop coefficient
K pan	Pan Coefficient
MoALR	Ministry of Agriculture and Livestock Resource
NGOS	Non-Governmental Organizations
O & M	Operation and Maintenance
Q	Discharge
SGW	Shallow Groundwater Water
SMIS	Small Scale and Micro Irrigation Support Project
SSI	Small Scale Irrigation
SSID	Small Scale Irrigation Development Directorate
TDS	Total Dissolved solid
WUA	Water User Association

Module-1

Spring Development

1. INTRODUCTION

This module is one of the materials among the HHMI Training manual. It outlines how to successfully select site and develop for House Hold and Micro Irrigation schemes (HHMIS).

By highlighting the purpose of spring development, it explains types and components of springs, spring development techniques, planning spring development, design and construction procedures, management of spring development, operation and maintenance, gender aspects, environmental and social issues.

1.1 Purpose and Scope

The module helps as a training material and to enhance the knowledge and skill of woreda experts and DA's on spring development. It can also be used as a field manual. The material describes in-depth planning, design, construction, operation and maintenance techniques for spring development on HHMI.

1.2 Why Spring Development is Important

Springs have been traditionally used by allowing people and livestock direct access to the water and spring site. As a result, springs has been quickly become contaminated with livestock manure and become mud holes from livestock traffic.

Proper spring development protects both the spring and its water quality from environmental damage and contamination. It improves also spring discharge and access to water for all its intended uses. Moreover, springs are less costly to develop than wells and dugouts.

1.3 Potential indicators for sustainable spring development

- The indicators for spring can be obtained by having physical observation and secondary information. Potential indicators for the availability of spring water include:
- Growth of lush vegetation i.e. trees, wildflowers and shrubbery especially in low-lying or valley areas
- Animal footprints or signs of wildlife activity (grass burrows, crayfish mud holes, and animal feces) and animal tracks
- Information about wells operating in the area
- Furthermore, asking questions like: Is there an area where the grass grows longer and greener than the rest of the grass? Does this area tend to stay wetter and softer longer after it rains?

2. TYPES OF SPRINGS

Based on their location and source, there are three main common types of springs .Each type is described in the following section.

2.1 Artesian Springs

Artesian springs are confined by two layers of impervious material. Water from artesian springs is likely to have been sufficiently filtered naturally through the ground and typically has little to no chance of being contaminated with surface water that may infiltrate into the spring. Artesian springs are less common than gravity springs.

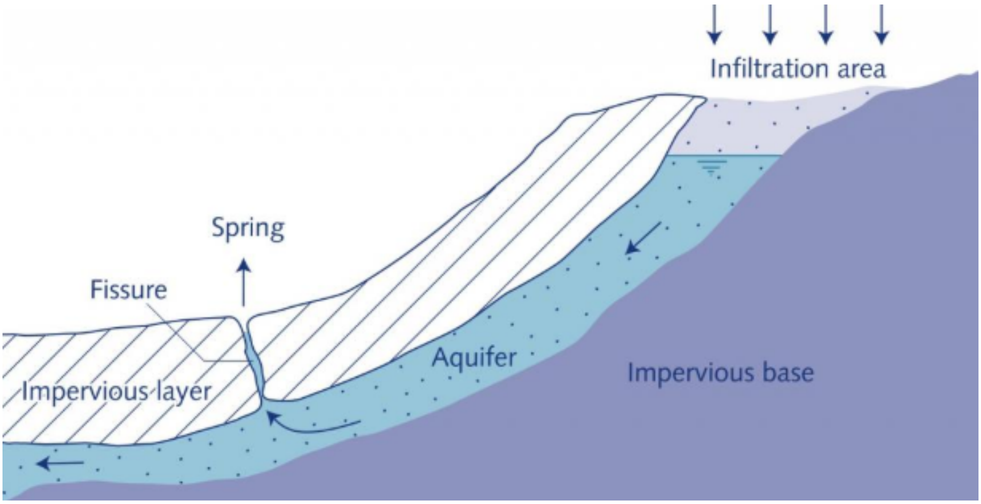

Figure 2- 1 Artesian Spring

2.2 Gravity Springs

Gravity springs rests on a single impervious layer, and can be thought of as an underground river. The unconfined aquifer will add many "tributaries" or input from local water and rain that seeps into the ground. Any contaminated water that flows into the ground will

only have the short flow distance before reaching the spring, giving the input water much less time to be filtered naturally.

[1]There are also other forms known as Mountain slide; Fracture and tubular; and Back-stowing springs etc which are not common.

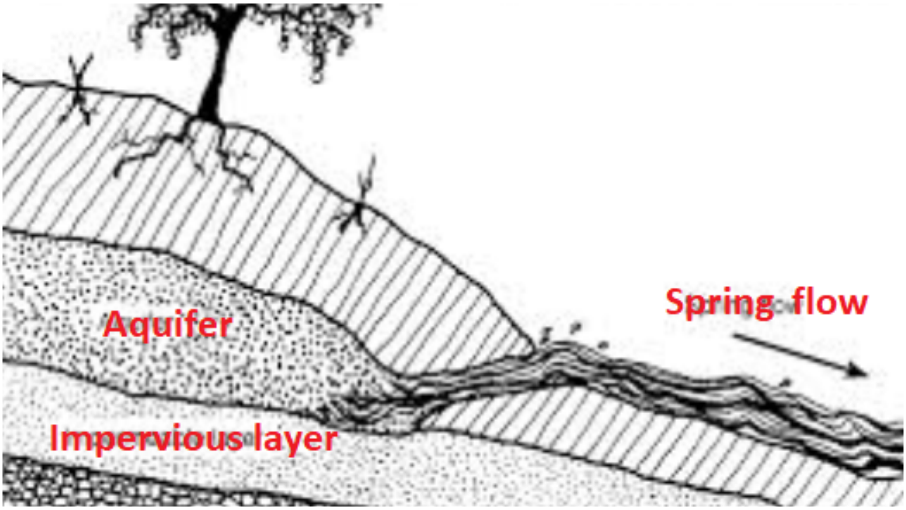

Figure 2- 2 Gravity Spring

2.3 Seepage Springs

Seepage springs occur where water simply seeps out of sand, gravel, and other porous material. Opposed to artesian and gravity springs where flow is directed to one point, seepage springs result from a somewhat unconfined aquifer, where an underground reservoir simply leaches out in different places. This gives seepage springs the highest susceptibility to contamination. Therefore, seepage springs need periodic treatment, if the intention is to use for domestic water supply.

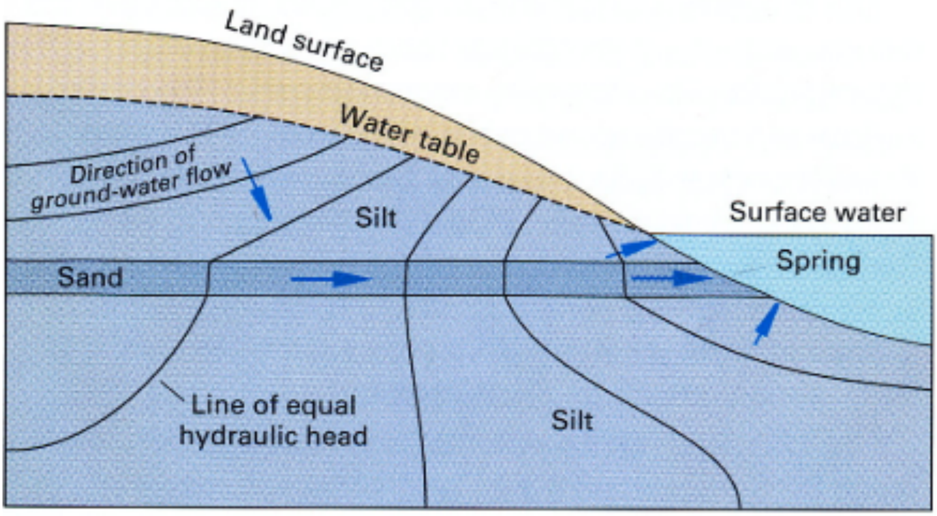

Figure 2- 3 Seepage spring

3. COMPONENTS OF SPRING DEVELOPMENT

The main components of spring water development are:

- **Collection box or spring box:** A box made of concrete, Masonry, fibre glass, galvanized steel or other material that collects spring water. It may be sealed and buried, or it may extend above ground and may have access for inspection and treatment.
- **Collector pipe:** A perforated or slotted pipe that collects spring water
- **Collection system:** A system of gravel, collector pipe, and a trench or spring box and/or cut-off wall used to contain the spring eye
- **Cut-off ditch:** An excavated trench extending below the water-bearing formation and into an impervious layer. It is used in place of a spring box. It is used to avoid water leaking away through the porous strata.
- **Cut-off wall:** A well-tamped impervious wing shaped wall of clay, concrete, masonry or other material that ensures the spring flow enters the collection system
- **Diversion ditch:** A ditch above the spring box that diverts the surface flow around the spring development
- **Overflow:** Plumbing that prevents excess spring water from undercutting the spring box
- **Vent:** A screened opening that prevents a vacuum in the spring box
- **Outlet/ Inlet:** water tap point or intake for the storage tanker.
- Drain: to drain the spring box during maitence and cleaning.

4. SPRING DEVELOPMENT TECHNIQUES

There are three main methods of spring development. The methods are presented in the following subsequent section.

4.1 Spring Boxes

There are two basic types of intakes for spring development and collecting water from springs and seeps. The first, and easiest to install, is the spring box. A small area is dug out around the spring and lined with gravel. A concrete box with a removable cover is placed over the spring to collect and store the water. The cover prevents contamination and should be heavy enough to keep people from removing it to dip buckets and cups into the collection box. A tap and an overflow to prevent a back-up in the aquifer should be installed. For springs that flow from one spot on level ground, an open-bottomed spring box should be placed over the opening to capture all available flow.

For spring development on a hillside, a box with an open back should be placed against the hillside and the water should be channeled into the collection box. Intakes for seeps and some springs can be perforated plastic or concrete pipe placed in trenches or collection ditches. The trenches are deep enough so that the saturated ground above them acts as a storage reservoir during times of dry weather. Collection pipes are placed in the trenches which are lined with gravel and fine sand so that sediment is filtered out of the water as it flows into the pipes. Clean and clear water flows from the collection pipes to the storage or collection box. For spring flows that cover a wide area, a concrete wall should be installed to collect all flow.

4.2 Horizontal Wells

Where a spring has a steeply sloping water table (steep hydraulic gradient), horizontal wells may be used for spring development. Horizontal well intakes must be located in an area with a sloping water table in order to have adequate discharge. Pipes with open ends or with perforated drive points or well screens can be driven, jetted, or augured into an aquifer horizontally or at a shallow slope to tap it at a point higher than the natural discharge.

The pipe must also enter the aquifer deep enough to ensure the required minimum flow (safe yield) throughout the year. The water supply reaches the surface by flowing from the tapped aquifer through the installed pipe. Horizontal wells are installed in a manner similar to driven and jetted wells except that care must be taken to prevent water from flowing through the annular space outside the pipe. Any leaking flow can be stopped by grouting or by constructing a concrete cut-off wall packed with clay backfill.

4.3 Seep Development

In case of water seeping from the ground and covers an area of several square meters, a third method may be used. Pipes can be laid to collect the underground water and transport it to a collection box. A poured concrete wall just down slope of the pipes can trap the water for more efficient collection. With this seep water collection method; maintenance costs are higher as pipes often clog with soil or rocks. Also, the expense and difficulty of construction may prohibit its use. Unless the seep supplies abundant quantities of water, this method should not be considered.

5. PLANNING FOR SPRING DEVELOPMENT

5.1 Spring Site Selection

Sites for spring development are selected at a place where the natural flow of groundwater emerges at the earth's surface, usually at hillsides or low-lying areas (Figure 5-1). The water that flows from springs is usually safe from contaminants, due to the fact that groundwater is naturally filtered as it flows through the earth. Therefore, spring water is generally safe for human consumption in addition to irrigation, requiring little to no treatment. This makes springs relatively inexpensive yet safe as water sources.

Figure 5- 1 Spring Site Selection (Toke kutaye, Guder

5.2 Spring Reliability and Quality

It is also necessary to determine the reliability, quality, and the average/ minimum flow of the spring. Ask local elderly residents about the history of the spring. Determine if the spring is seasonal or fairly constant all year round.

Check the quality of the spring water especially if it is also required for potable water supply. If you have no equipment to do this, look at the turbidity and check how the water smells. Collect a sample for physical and chemical analysis. If there is a strong odor, or the water is very turbid, it will probably need additional treatment which include settling, filtering, and disinfecting.

Determine the discharge of the spring in dry season. This can be done by constructing a temporary dike to retain the spring flow. Insert a pipe through the clay dike, and measure the time it takes to fill a container with a known volume. It is advisable to perform this test several times, and at least three times during the dry season. The goal is to determine average and minimum flows in order to predict if the spring will be sufficient for the needs of the community or to fix the size of irrigable land.

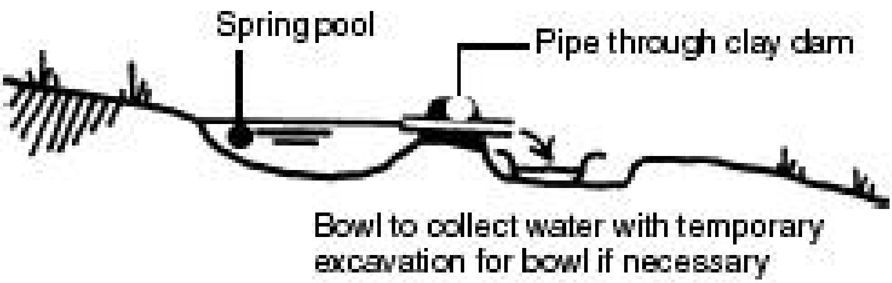

Figure 5- 2 Spring Discharge Estimation

Procedures:

- Arrange a container with known volume (V) , stop watch and pipe
- Direct the water to one small outlet that has fall/drop to facilitate collection.
- Set the stop watch and start collecting the water
- Fill the container and record the starting and finishing time
- Stop the timer when the bucket is full and record the time.
- Repeat this measurement 3 to 5 times
- Average the time (Tavg).
- Add estimated loss to the bucket volume, if there is any.
- Determine discharge (Q) by dividing the volume by average time (Q= V/ Tavg)

5.3 Locating Spring Eyes and Development

To develop a spring, one must first find the source of the water called the "eye" of the spring. Locate the eye by carefully excavating the area surrounding the highest wet elevation of the spring and looking for surface flow and/or bubbling ground water. Once you locate the eye, clear the surrounding area of excess soil and small rocks. This makes it easier to locate and expose the bedrock formation below the spring, where the foundation for the dam and collection area will be constructed (Figure 5-2).

After you locate the eye, consider the watering tank location. The difference in elevation of the spring and the watering tank must be enough to allow gravity to provide water flow. If there is not an adequate difference in elevation, pumps will be needed to transfer the water from the spring to the tank. In that case, solar-powered pumps may be able to supply the water effectively, eliminating the need for electric utilities.

Figure 5- 3 longitudinal section of Developed spring

6. DESIGN CONSIDERATIONS

6.1 Spring Box

Both the type of spring and its location will determine the type of spring box to be built. There are three basic design types, related to the three types of springs. These are described below.

6.1.1 Artesian springs

Spring, which is naturally occurring on relatively flat ground is likely to be an artesian spring. Water flows vertically out of the ground due to the pressure that is accumulated within a confined aquifer. For this type of spring, a spring box with an open bottom is used, as illustrated in Figure 6-1.

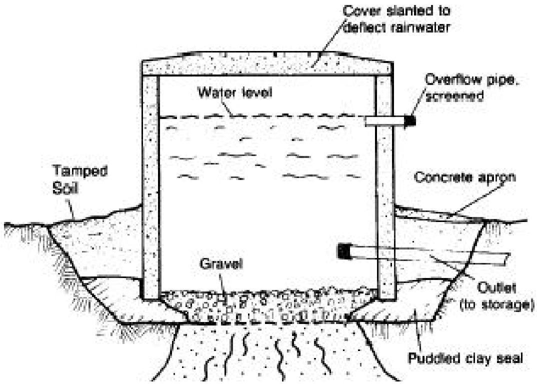

Figure 6- 1 typical feature of artisan spring box

6.1.2 Gravity Springs

For the spring occurs at the base of a slope or hillside, the flow is likely to be gravity driven. Unlike an artesian spring, a gravity spring will most likely have just one impermeable layer at the bottom. In this case, much less pressure will exist in the system. Due to the nature of the horizontal flow, and low water pressure, a gravity spring in a hillside will require a spring box with a side entrance for the water. The design will most likely be similar to the structure presented in Figure 6-2 below.

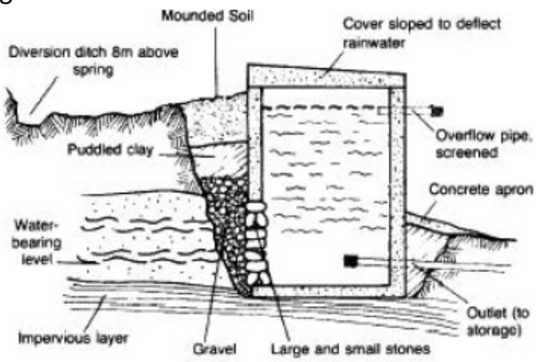

Figure 6- 2 typical feature of a gravity spring box

6.1.3 Seepage Springs

A spring box for a seepage spring may be constructed in two ways, depending on the spring characteristics. The ideal design is to dig far enough back into the hill to reach the single source of all of the spring flow. In this case, the seepage spring would simply be a gravity spring covered by a small amount of porous media. If a single line of water flow cannot be found, it may still be possible to dig far enough back to ensure all of the water flows into the side opening of the spring box.However,if the lines of spring flow are too separated and cannot be channeled into one spring box structure, then a different approach is needed. Rather than a spring box, one should construct what is known as a Seep Collection System as shown in Figure 6-3.

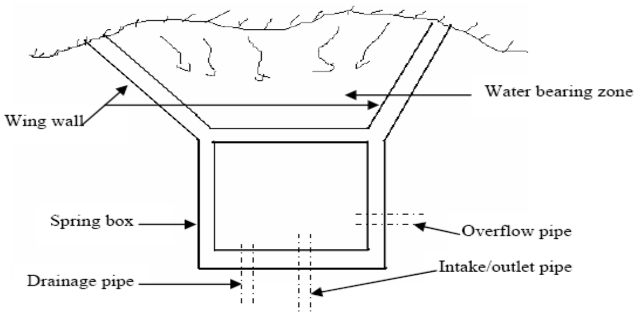

Figure 6- 3 typical feature of a seepage spring box

6.2 SPRING YIELD DETERMINATION

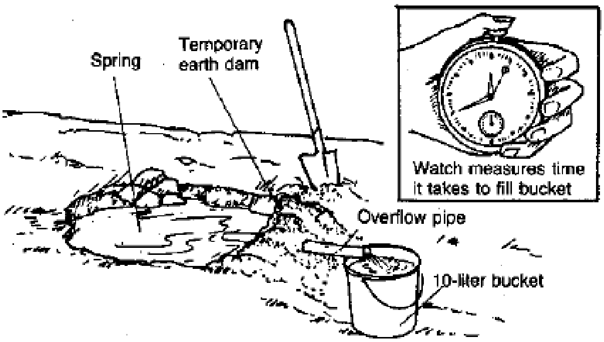

Figure 6- 4 Measuring spring discharge (volumetric method)

Flow rate (discharge) is the volume of water coming out from the spring per unit of time. It should be measured during a low flow period, usually in the early fall (ending of dry season). For small springs, the flow rate can be measured by damming the spring's flow, inserting a pipe to collect the water, and measuring the time it takes to fill a container of known volume (i.e. jar, bucket, etc…) as shown in Figure 6-4, the procedure stated under 5.2 will be adapted.

6.3 Reservoir

Reservoir in irrigation or rural water supply is required when the yield of the spring is very low and causes excessive queuing time. Overnight spring flows can be easily collected, stored and made ready for day time use that would otherwise have drained down the drainage in the absence of reservoir.

- To determine how big, the storage reservoir should be, calculate how much water will flow into the reservoir during the night or non-irrigation hours.
- Volume (liters) = flow rate (liters per minute) x number of minutes
- Volume (cubic meters) = Volume (liters) ÷ 1000
- It is generally a good idea to have some extra capacity in the tank, so multiply the volume calculated by 1.2.
- Storage Reservoir volume = Volume (cubic meters) x 1.2

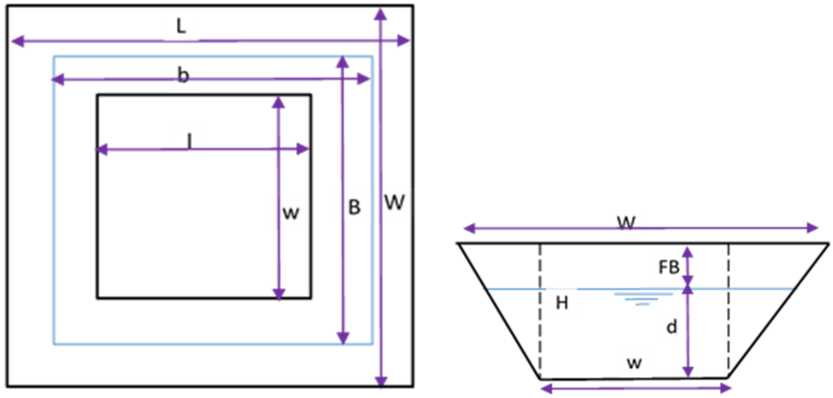

Figure 6- 5 Plan and section of Trapezoidal Reservoir

The following trapezium equation can be used for uniform height.

$$V = \frac{H}{3}\left[A_t + A_b + \sqrt{A_t + A_b}\right]$$

Where, V = Total storage capacity including free board, m3

d = Water storage depth at height, d, m

H = Total tank depth = d+FB, m

At = Top surface area of storage = Lx W, m2

Ab = Base area of storage = lx w, m2

For water volume calculation, the top surface area (At) will be reduced to level d and H=d

Shape, dimensions, slopes and other factors of storage area is fixed based on the actual site condition. Depending on the construction method and site condition, the shape of the chamber can be trapezoidal, square, circular or rectangular.

Figure 6-6 Night storage Reservoir (Embaguhalit-Tsegedie)

Example:

Flow rate = 3 liters per minute

Spring closed at 7pm and opened at 6am

Number of hours closed overnight is 11 hours and number of minutes closed is 11 x 60 = 660 min.

Volume (liters) = 660 x 3 = 1980 liters or 1.98 cubic meters

Storage Reservoir Volume = 1.98 x 1.2 = 2.4 cubic meters

Once you know the volume, you can calculate the dimension of the reservoir using the formula

Volume = width x breadth x height

For instance, a trapezoidal shape below ground reservoir with 8m x 8m top width, 5m x 5m bottom width and 3m depth can store 129 m3 of water and can be constructed with available low cost construction materials i.e. geo membrane plastic sheet for lining; grass for roof cover; local wood for fencing and above ground tanks constructed with masonry.

6.4 Water Demand Estimation

Water demand in general is the sum of irrigation water requirement, drinking water for livestock and domestic uses and losses. It is important to account for water losses through seepage and evaporation from storage reservoirs and during distribution and application of water.

6.4.1 Irrigation Water Requirement

Important data including climate, irrigable (command) area and crop type is required for computing irrigation water requirement.
Crop water needs can be fully or partly met by rainfall and therefore reliable rainfall of the area should be deducted from the calculated crop water requirement.

$$Ir = \frac{10[ETcrop - Rainfall] \times Ca}{Ef}$$

I_r Irrigation water requirements in cubic meters for the whole dry period.

ET_{crop} Crop water requirement in mm during the dry period.

C_a Area irrigated in ha.

E_f Overall water application efficiency

For detail calculation of irrigation water requirements refer Agronomy guideline, for manual calculation see Annex-1

6.4.2 Domestic and Livestock Water Use

It can be calculated using the expression:

$$Wd = N \times q \times t$$

Where, Wd is the volume of water required for domestic purposes

N is number of people and livestock

q is daily water consumption and

t is number of days' water consumed

Note that 20 % of the total water demand is considered as various losses

6.4.3 Total water demand

It includes all water requirements depending on the area required for irrigation, livestock and domestic water supply. Hence,

Total Demand= Irrigation requirements + Domestic water use+ Water for Livestock + Losses

See Annex-I, for sample calculation (Example).

7. CONSTRUCTION PROCEDURE

7.1 Site Preparation

The site needs to be properly prepared before excavation and construction begins. If you prepare the site well and have a good layout for tools, materials and other construction equipment, the process of developing the spring will go smoothly and easily. The main steps required for site preparation are clearing the site, fencing the site, plan the site layout, and construction materials and equipment and storage facilities. A working area roughly 15 m radius from the spring should be cleared of all vegetation, loose stones, dead wood etc, after the aforementioned steps have been completed, excavation and construction will begin.

7.2 Construction Period

Construction of spring should be carried out during dry seasons to ensure that only the most reliable springs are protected.

7.3 Mobilization

The construction team in consultation with the community should prepare a time schedule for all activities to be carried out and all the required materials and tools should be delivered to the site accordingly.

7.4 Site Clearing

Clearing the vegetation and removing minimum top layer of soil to enable spring flows clearly to be seen for safe excavation works.

7.5 Excavation

Digging out the spring until the flow is concentrated from a single source. If the spring is located in a hillside, it may be necessary to dig into the hillside far enough to locate the eye of the spring. Look to see if flow from major openings increases, or if flow from minor openings decrease or stop. These are signs that the flow is becoming concentrated from a single eye. Remember that the objective is to collect as much water as possible from the spring. Once a single eye is located, dig down until it reaches an impervious soil layer. This will make a good, waterproof foundation for the spring box.

- Place 5cm lean concrete (1:3:6) in to the foundation trench with a 50cm thick (1:3) masonry wall fitted with delivery, wash out and overflow pipes on its top. The masonry wall shall be well plastered and pointed.
- The elevation of the overflow pipe should not be higher than the natural elevation of the spring. If subjected to back pressure from the stored spring water in the box, there is a possibility to change flow direction.
- The delivery (outlet) pipe should be placed below the overflow pipe and the drainage pipe should be placed near to the spring box floor. The levels depend on the size, location and elevation of peculiar points (spring eye, water taping point, command level etc)
- During construction of spring capping, reservoir and water point, the pieces of pipes which are installed in the structure for the purpose of delivery, overflow, drainage and water point should be anchored to maintain proper

bondage with the concrete/masonry structures. This can be done, by welding other pieces of bars crossing on their external surface at which their part is buried in the concrete or masonry wall.

- Proper space and direction has to be kept among the pipes for easy assembly, maitence, and use.
- It is more advisable to place a well compacted concrete sandwich with 1:2:4 mix ratio and thickness of 7-10cm between the 50cm thick masonry wall in order to prevent seepage flow through the masonry wall.
- There should be an air vent pipe installed with the spring capping cover slab. The vent pipe should have threads in one end to connect two elbows with one nipple which will help to prevent the entrance of dust and pieces of wood by children.
- The overflow should have elbow directed to down wards and drainage pipe should have coupling for plug installation.
- 7cm thick lean concrete should be placed in the spring eye box floor to easily convey water coming from the filtration chamber to the delivery pipe and seep underneath the front wall.
- The interior of the wall of spring box shall be filled with river gravel (2mm - 40mm) and boulders in order to filter the flow. The smaller size river gravel should be placed near to the spring eye and its size increase towards the inlet pipe until it reaches to the wall of spring box.
- Finally, over the filter pack 10cm thick concrete (1:2:4) cover slab shall be placed. The cover should be provided a manhole with a dimension of 50cm x 50cm so as to make inspection and cleaning easier.
- Construction materials, tools, equipment, and sample list of materials and labour is given in Annex II and III.

Other design aspects specific to the particular spring site should be taken in to account, factors such as flood and catchment area protection requirements. Whenever flood is anticipated, it is recommended to construct a flood protection wall.

8. MANAGEMENT OF SPRING DEVELOPMENT

8.1 Groundwater Recharge

In order to maintain the safe yield of springs, implementation of groundwater recharging techniques in the vicinity is crucial. These methods include but not limited to:

- Construction of series of percolation ponds
- Flooding in flat region where water can be spread as a thin layer with higher rate of infiltration in a region having thin vegetation cover or sand soil cover

- Stream augmentation: Seepage from natural stream or river is artificially increased by putting some series of check dams across the river or stream
- Ditch and Furrow system: A system of closely spaced flat bottom ditch or furrow is used to carry the water from the source. It provides more opportunity to percolate the water into the ground.
- Contour bund: Small embankment constructed along the contour in hilly region to retain the surface runoff.
- Recharge well: used to recharge water directly to the aquifer

8.2 Spring Protection

Spring protection refers to the modification of a spring source to capture the available water before it becomes exposed to surface contaminants. A well protected spring has the following indispensable elements i.e. Spring box, Cover, Overflow pipe, Outlet pipe (distribution pipe), Drainage (cleaning) pipe, Diversion ditch, Manhole and Fence.

8.3 Spring Maintenance

Classification of Maintenance

i. **Regular:** The regular or routine maintenance is carried out on regular basis at daily, weekly, monthly, or end of each crop season interval and beginning of the new crop season. Such work may include de silting, vegetation removal, greasing of tools and gates, etc.

ii. **Periodic:** This includes activities that are carried out from time to time depending on the need of the specific components of the system. Such activities are mainly related to the repair of structure, waterway shaping, equipment, gates and pumps. Such maintenance may be carried out within a given period of time after inception of the system. It is commonly done once a year, before water harvesting and also at the end of irrigation and is done during non-crop season.

iii. **Special Maintenance:** This is done when extra ordinary repair is needed such as changing of gates, mesh wire, renovation of the structures, guiding channel from the catchment, etc. Special maintenance requires additional cost in addition to the normal maintenance cost.

iv. **Emergency:** This is done in connection with emergent problems, like pump failure, pipe lines closing, etc…

8.4 Drinking Water Treatment

It is very important to test and treat spring water before using it as a drinking water source. Tests to assess the safety and quality of the water supply should include coliform bacteria, nitrate, lead, iron, hardness, pH, sulfate, total dissolved solids (TDS), and the corrosion index. If the test results indicate one or more contaminants are present in the water sample, try to locate the source of contamination and if at all possible, reduce or eliminate the contaminant source. Inspect the spring box and its components for defects and correct these problems. If the water test shows presence of contaminants even after the above steps have been taken, then water treatment system will be necessary.

9. GENDER EQUALITY BOX

What are the issues of gender inequality?

The module helps as a training material and to enhance the knowledge and skill of woreda experts and DA's on Spring development, to meet its purpose, at chapter 5,6,7 and 8 it is stated community consultation is required, therefore, female and male beneficiaries may not consulted equally during potential identification and water demand estimation, experts may not consider the relevancy of female beneficiary's knowledge on spring development, and the available time of both female and male to mobilize for spring construction

How can the gender inequalities be addressed?

Consult female and male farmers as source of local knowledge to develop reliable spring and get relatively actual water demand estimation and construction team should consider the different roles and responsibilities during scheduling for activities

What will be the benefits when gender inequalities are addressed?

Farmer's (female and male) will benefit from sustainable spring and quality water availability

10. ENVIRONMENT AND SOCIAL FREINDLYNESS OF SPRING DEVELOPMENT

Spring development can have a major impact on village water supply for domestic and livestock needs and promotion of small scale irrigation. To maintain sustainable spring discharge treatment of its upper catchment / landscape with good land and water management practices is essential. Furthermore, any contamination approaching the developed spring should be watched out. Proper fencing and protection of the spring capping point, collection box, and water take-off point is essential.

Spring development can:

- Mitigate the impacts of climate change
- Reduce the carbon footprint by enhancing biomass growth and maintaining healthy soil
- Lessen the effects of wet and dry spells

Springs development and placement of its various structures such as the collection box and water collection points, canals for irrigation, should not interfere with spiritual areas such as churches, mosques, grave yards, etc. Site selection and placement of related infrastructures should be well discussed with the surrounding community. Spring development should not affect upstream and downstream users and they should be consulted and consensus reached (or mechanism should be devised to make them beneficiary of the scheme). Socially spring development is a resource to be managed by group of people and community members thus encourages communal resource /asset management and encourages group work and the culture of working together.

Provided there are developable springs in many rural areas lack of technical and economic capacity to develop them remains a challenge and this need to be addressed by both the government and development partners.

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ANNEX- I. WATER DEMAND ESTIMATION

A. Irrigation water Requirements

Step 1: Reference Evapo-transpiration (ETo)

It is also called potential evapo- transpiration. The highest value of ETo is found in areas which are hot, dry, windy and sunny; whereas the lowest values are observed in cold, humid and cloudy areas with little or no wind. In many cases, it will be possible to obtain estimates of ETo for the area from a nearby Meteorological Service. However, where this is not possible, the values for ETo should be calculated. Methods to estimate reference evapo-transpiration (ETo) are Blane-criddle, Pan Evaporation, Penman, and FAO-Penman-monteith. Out of these methods Pan Evaporation (ETo = Epan × Kpan) is the easiest, which needs pan evaporation (Epan) and pan coefficient (Kpan) data only.

FAO-Penman-monteith (recommended) as the sole method to determine ETo (see FAO Irrigation and Drainage Paper No. 24 and FAO Irrigation and drainage paper 56). Basic Data required are monthly mean rainfall (mm), monthly mean temperature (Oc), relative humidity (%), daily sunshine hour (h/day) and wind speed (Km/hr). Though this method gives reliable estimate of ETo, it is not widely utilized because of its data intensive nature except in fewer research areas.

Step 2: Crop Evapo-transpiration (ETc) or Crop Water Requirement

ETc= ETo x Kc

Where, Kc = crop coefficient, which varies for different crops, with growing stages and climate. For details on how to estimate ETc, Woreda experts can review FAO Paper 24.

Step 3: Irrigation Water Requirement

Crop water needs can be fully or partly met by rainfall and therefore reliable rainfall of the area should be deducted from the calculated crop water requirement.

$$Ir = \frac{10[ETcrop - Rainfall] \times Ca}{Ef}$$

Where Ir Irrigation water requirements in cubic meters for the whole dry period.

ETcrop Crop water requirement in mm during the dry period.

Ca Area irrigated in ha.

Ef Overall water application efficiency

B. Domestic and Livestock Water Use

It can be calculated using the expression:

$$Wd = N \times q \times t$$

Where, Wd is the volume of water required for domestic purposes

N is number of people and livestock

q is daily water consumption and

t is number of days' water consumed

Note that 20 % of the total water demand is considered as various losses.

Figure 1 Cattle trough

C. Total water demand

It includes all water requirements depending on the area required for irrigation, livestock and human water supply. Hence,

Total water demand= Irrigation requirement +domestic water use+water for livestock+losses

Example: Computation of Gross water demand

Crop data: Selected crop is Sorghum; Average Kc is 0.7 (from FAO books)
Livestock data: Total livestock number (NL) 500, water consumption (Ac) is 50 l/day/animal. Population data: Number of users (Po) is 400, water

consumption (Dc) 40 l/day/person

General data: Average reference crop evapo-transpiration during the dry period is 6mm/d, Irrigated area (Ca) is 2ha, overall water application efficiency is 40%, dry period (t) is 90 days, rainfall is 78mm per total growing season of 120 days, seepage loss is assumed to be equal to ETo losses, reservoir surface area is 1000 m², bottom and side walls area is 1500 m²

Estimate irrigation water demand: -

ET crop = Kc x Eto = 0.7 x 6mm/d = 4.2mm/d

ET crop (dry period) = ET crop (day) x dry period = 4.2mm/d x 90d = 378mm

Irrigation water requirement = ET crop – rainfall = 378 – 78 = 300 mm.

Finally, it will be calculated for the proposed crop area

→ $\mathbf{Ir = \dfrac{10 \times (ETcrop - rainfall) \times Ca}{Ef} = \dfrac{10 \times 300 \times 2}{0.4} = 15{,}000\ m3}$

Estimate livestock water demand: -

$WL = \dfrac{NL \times Ac \times t}{1000} = \dfrac{500 \times 50 \times 90}{1000} = 2250\ m3$

Estimate domestic water demand

$WD = \dfrac{Po \times Dc \times t}{1000} = \dfrac{400 \times 40 \times 90}{1000} = 1440\ m3$

→ **Total water demand = Ir + WL + WD**
= 15,000 + 2,250 + 1,440 = 18,690m3

→ **Losses = Evaporation losses + Seepage losses**

Evaporation losses = ETo × Surface area of reservoir
= 6mm/d ×1000 m² = 6 m³ /d

Seepage losses assumed equal to 6mm/d

Total seepage losses = Seepage loss × Bottom and side wall areas
= 6mm/d × 1500 m² = 9 m³ /d

→ **Total losses = (Evaporation losses + Seepage losses) × Dry period**

= (6 + 9 m³ /d) × 90d = 1350 m³

Estimate Gross water demand = Total water demand + Losses

= 18,690 + 1,350 = 20,040m3 for 90 days
= (20,040 m3 *1000 litres/m3)/ 90 days = 222,667 liters/day

Note that the yield of the spring should be sufficient enough to satisfy the demand (222,667 liters/day). If the supply is below the requirement, storage tank can be designed to store water at night or during non-irrigation hours.

ANNEX-II. CONSTRUCTION MATERIALS, TOOLS, AND EQUIPMENT

The following is a list of the most commonly used materials needed for construction of spring developments and storage tanks/ponds. Some of these are locally available and others need to be procured and transported to the site. Whether they are bought or provided by the community, all materials have value and should be handled properly during transportation, storage and use. If you do not handle and store materials correctly, they will deteriorate and the quality of your construction will become poor. You should make an estimate of the quantity of materials you will need to develop the spring, and arrange to have as much of the material as possible on site before you begin. This will ensure that work is not held up whilst materials are being procured, transported or collected.

i. Cement

Comes in 50kg; must be transported and stored dry; never leave bags of cement sitting on the ground, even in storage sheds or shelters; opened bags should be stored in water and air tight containers; avoid contact with skin; use shovels to handle; if direct handling is necessary, use gloves; quality of cement has an effect on the strength of mortar (cement + sand + water) and concrete (cement + sand + gravel + water).

ii. Fine aggregate (Sand)

Can be available locally or transported to site using trucks. Clean river sand is generally the most suitable sand for concrete and mortar. Sand used in mortar and concrete mixes must be clean and free of soil and organic materials such as sticks, leaves, etc. Sand that is contaminated should be washed and sieved, or discarded. Store sand on a clean dry surface, and cover with plastic sheeting or Hessian sacking to prevent contamination.

iii. Coarse aggregate (Gravel)

Can be available or made locally or transported to site using trucks. Coarse aggregates should be comprised of small stones between 6mm and 19mm across. This should be checked by passing the aggregate through sieves with 6mm and 19mm diameter holes. River gravel is generally suitable for concrete. Alternatively outcrop rock can be broken down with hammers to form a suitable aggregate. Coarse aggregate should be free from dust, soil and organic matter. If sieving fails to remove these contaminates then the aggregate should be washed. Store coarse aggregate on a clean surface and cover it to protect it from contamination.

iv. Stone

Stone is generally available locally and is used as a lining material. It should be clean and not fractured. It should be of a size that is able to be handled without too much difficulty.

v. Water

Water is needed for making cement-mortar, concrete and for washing tools, equipment and curing the structures. Water used for cement-mortar and concrete should be clean. Generally, water from the well during construction is not suitable. Spring water generally can be used. It is a good idea to have a barrel or other container on site to store enough water for the daily activities.

vi. Geo-membrane plastic sheet (GPS)

Check its thickness and quality of the material. Fold up it properly and store in good storage. Compact & make it smooth the internal surface of the pond before lining the GPS.

vii. Tools and Equipment

The following tools and equipment are needed to develop springs.

Measuring tools:- Plump bob, sprit level, measuring tape (5 meters), Set Square (quadra), and nylon string.

Construction tools:- shovel, pickaxe, digging hoe, mattock, crow bar, bucket, hammer, chisel, wheelbarrow, nylon rope, trowel, float, sieves, gauging boxes, axe, wood saw, dewatering pump and work gloves.

ANNEX-III. SAMPLE LIST FOR ESTIMATION OF MATERIALS AND LABOR

S.№	Activities description	Unit	Quantity	Rate	Amount	Remark
1	**Earth work**					
1.1	Site clearing to an average depth of 20 cm.	m^2				
1.2	Excavation of spring box floor area, wing walls strip foundation& retaining walls.	m^3				
1.3	Back-filling the external faces of the foundation wall with good quality soil.	m^3				
1.4	Spread and Cart away surplus excavated material from the site to a distance of 50 m to spoil tips.	m^3				
1.5	Filling the spring eye area with clean and graded river Gravel	m^3				
1.6	Placing 20cm thick hard core for flooring above the graded gravel to protect the spring.	m^3				
2	**Concrete work**					
2.1	Construction of reinforced concrete collection box adjacent to Spring Eye to collect filtered water and guide to the out let, drainage &over flow system.	LS				
2.2	Casting 10cm thick mass concrete above the hard core to cover and protect the spring eye.	m^2				
2.3	Construction of 15cm thick reinforced concrete roof slab with manhole opening of 60 x 60cm.	m^3				
2.4	Construction of manhole cover made of reinforced concrete having a thickness of 20 cm and 75 x 75 cm dimension & Plastered smoothly.	No				
2.5	Plastering the internal wall surfaces of the collection box & wing walls with 30 mm thick cement mortar mix 1:3.	m^2				
2.6	Pointing all the external face of exposed masonry wall.	m^2				
2.7	Provide cut & fix in positions sawn wooden from work.	m^2				
2.8	Provide ,cut, bend & fix reinforcement bar Diameter of 10 mm placed at 150 mm c/c.	Kg				
3	**Masonry**					
3.1	Construction of 50 cm thick above ground stone masonry wall and retaining wall with cement mortar ratio of 1:3 as per the design drawing.	m^3				
3.2	Construction of 25cm thick stone pavement and foot Steps around the spring collection box.	m^3				
4	Pipe work					
4.1	Supply & install all necessary class "B" pipes and fittings for out let, drainage and over flow system with all necessary gate valves & control.	LS				
	Total					

ANNEX-IV. CASESTUDYONSPRINGWATERDEVELOPMENT

Mai-Kot spring water is located in Debretsion Kushet /Gott which is located some 27 Km West of Wukro town, the capital of Kilte-Awlaelo wereda, and is neighboring to Abraha-We-Atsbeha Tabia /Kebele in the west. Abraha-We-Atsbeha is a renowned area in eastern Tigray for its extra ordinary achievement in changing the highly degraded area into an array of green oasis by applying appropriate and sustainable methods of watershed management. Debretsion Kushet has 480 households out of which the majority is women.

The main sources of water in Debretsion Kushet are springs, communal water storage check dams, community and private owned hand dug shallow groundwater wells and ponds. According to Ato H/Mariam Berhe, Water Resources Engineer from Kilte-Awlaelo Woreda office of water resources, and Ato G/Hiywet Tsegay, a member of the Tabia cabinet and inhabitant of Debretsion Kushet, ground water depth in the village vary from 3 meters at the elevated areas to 30 meters at the lower localities. Those farmers who settled at the elevated part of Debretsion Kushet, where the ground water table is close to the ground surface, have one or more hand dug shallow well in their backyards and /or own farms and are utilizing for irrigation as well as livestock purpose.

Figure 2 Mai-Kot spring domestic water point

Figure 3 Mai-kot spring night storage , cattel trough and Irrigation canal

As far as domestic water supply is concerned, the entire population of Debretsion Kushet is reliant on Mai-Kot spring water which is located at the elevated portion of the village. Owing to improper utilization by the community and the cattle, the spring has been suffering from erosion and sedimentation during the rainy season and gets contaminated. To reduce the aforementioned problems, two decades ago, Relief Society of Tigray (REST), an indigenous non-governmental organization (NGO), has taken responsibility to develop the spring water. REST was in charge of supplying industrial materials such as cement, reinforcement bar, steel pipes, transportation of sand and finance for laying and fixing of pipes erected from the collection box to the distribution tap/outlet. The community contributed labor force for crushing, collecting and transporting stone for construction of masonry works thereby creating sense of ownership. Similarly, as part of Mai-Kot spring water development, REST together with the community have constructed cattle trough for livestock for periods where other water sources get depleted.

Unlike majority of the settlements which are situated in close proximity to the spring water, some are located approximately 1 Km far from the spring water point. In the driest period of every year, as it is the sole source of water for domestic purpose, these people are forced to travel such long distances to fetch, carry on their backs and/or using donkeys. Each household is entitled to have only two Jerrycan i.e. 40 – 50 liters of water because of the lower yield of the spring water in the driest period.

Figure 4 Cultivation by Mai-kot spring

In addition, by collecting water in a storage reservoir at night and in times where the spring water is unutilized during day time, six households are able to irrigate 2.5 hectare of farm land. The reservoir together with the lined canal system has been constructed by the Woreda office of Water Resources and helped to reduce conveyance losses. Several crops (Maize, Teff , Wheat and Rhamnus prinoides/ Gesho), fruits (Mango, Apple-Mango, Orange and Guava /Zeytoni) and vegetables (Onion, Garlic, Green Pepper, Tomatoes, Potatoes and Lettuce) are cultivated two to three times per year. Apart from household consumption, the farmers are transporting plenty of their produces to Wukro town so that it can be sold and used for buying clothes, shoes and to cover other expenses of their families. As a result, the farmers are protecting and maintaining the reservoir and canal infrastructure and properly operating the irrigation system so as to maintain their benefits.

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Module-2

Hand Dug Well Development

1. INTRODUCTION

This module on Hand Dug Well Development is the first version and is a series of other modules in the HHMI competencies area such as, Manual Tube Well, Spring Development, Rooftop Rainwater Harvesting, Farm Pond Constructions, Manual Water Lifting Pumps, Solar Pumps, Engine Pump, Drip Irrigation, and Sprinkler Irrigation. This professional development series supports the application of the Small scale Irrigation Development programs and projects in the country.

Groundwater is one of the best alternative sources for irrigation development, and domestic water supply because of several benefits. It is a reliable water source (if renewably and safely exploited). Typically, GW is readily available on-demand water and not trans-boundary, well distributed and available in many places. Besides, it is less institutional prerequisites for managing, buffer to manage variability of surface resources and can be developed with simple technologies, needs drilling if too deep. Household irrigation is a technology with highest potential for tapping groundwater resources.

The level at which the groundwater becomes continuous is called groundwater table/GWT/ and is represented by the water surface elevation in a well or in other excavations. The level of the water table fluctuates up and down according to the seasons as the inflows and outflows vary with the seasons of the year and the utilization by humans. Hence, it has high variability depending on season and weather conditions and only farmers located close to surface-water sources benefit. There are efforts going on the sector through ATA, to provide accurate information on availability of Shallow Groundwater Water (SGW) potential to allow rational well drilling decision, reducing unnecessary labour and cost. Currently, over 100 thousand Km2 area has been mapped at national level and potential irrigation command area identified at four regions; yet it need building national capacity to regulate SGW development and protect against SGW depletion.

1.1. Purpose and Scope

The module helps as a training material and to enhance the knowledge and skill of woreda experts and DA's on HDW development. It can also be used as field manual. The material describes in-depth planning, design, construction, operation, operation and maintenance techniques for HDW development on HHMI.

The major purpose and scope of the module concentrates in design and development of hand dug wells for the main purpose of upgrading the technical capacity of experts working in the area of irrigation development. After all, this module will serve as guideline to the experts for design and development of hand dug wells taking into consideration the required maximum offset distances. This manual contains many points, which enables the woreda non-geologist experts to select sites, design and construction for hand dug wells confidently.

1.2. Why and Where Hand dug well is required?

Hand Dug Wells are preferred since they are free from bacteria/micro organisms problems compared to surface water, it is used for irrigation and domestic and livestock water supply. The scheme can be easily constructed and maintained by the rural communities. If there is no sufficient amount and easily accessible water source, development of Hand Dug Well (HDW) for satisfying water requirements is essential. HDWs are constructed in areas where local circumstances permit. Most of the hand dug wells have depth in the range of 3 to 15 meter usually the average depth is assumed to be 3m under manual digging condition.

1.3. Indicators for Potential HDW Development

a) Existing water points or sources and possible on-going construction Check/ record the depth and their location, static water level, rock nature, water level rise in meters /12hours of the HDW, yields of the HDWs, etc. for all available functional water sources and their present condition. Most of the Dug wells are concentrated around the major water divides. Information from springs, HDW, and deep wells can indicate the availability of shallow sub surface water resource.

b) Abandoned Hand Dug wells: Check the existing irrigation wells, which were abandoned and reasons for abandoning. The failure of hand-dug wells is high because of climatic changes and ground water depletion. Poor workmanship and lack of close follow up and lack of timely maintenance is one other factor for higher degree of its failure.

c) Topography and nature of the area
Since ground-water flows from high topography to low topography, therefore, the higher topography is the recharge area to the lowland area. This is the reason why all water points are recommended at the lower area in order to get a recharge from the elevated land. On the other hand, a saturated flat land in rainy season is another potential indictor. Besides, to topography, catchment size is another criterion, which should supply enough amount of water to the area of well site.

d) Vegetation Pattern
The most useful indicators of ground-water are the perennial plants (which are present year round). Annual plants, such as, grasses, are not good indicators since they come and go depending on rains and seasons of the year. Generally survey of vegetation to help find shallow groundwater is most effective if carried out in the dry seasons.

e) Geological formation of the selected area

Study of the subsurface geology is an important indicator for availability of water. Subsurface geology can also be known by close observation of the area along:

- Along stream course and buried river valleys, gullies, seasonal floods, etc.
- Rivers - are also other indicators along their embankments

Majority of dug wells get their water from the alluvial and alluvial soils as well as lacustrine sediments. Moreover, the highly weathered top part of sandstones and meta-volcanic rock, weathered basalts and residual soils and sediments are also the major water bearing layers for dug wells. Thus, select weathered and fractured rocks because of more water bearing formations than fresh and massive rocks.

2. TYPES OF HAND DUG WELLS

In general, there are two types of wells known as dug wells and drilled wells. The obvious difference between the two is the size of the holes. In both categories, there are many different specific sinking techniques.

a) Drilled wells: are sunk by using special tools, which are lowered into the ground and worked from the surface. These wells are normally less than one meter in diameter, see figure 1 bellow. This system is an advanced type of hand-dug well which is constructed in accessible area by a medium drilling rig which can reach greater depth than hand digging. The major advantage of using drilled wells over hand-dug wells is: 1) they can be reaching up to 60 meters depth, 2) they are not risky during the dry season, and 3) they cannot be polluted easily. Shallow drilled wells are wells, which have been drilled with drilling machine and lined with uPVC or steel casing. This type of wells could be fitted with Village Level Operation and Maintenance (VLOM) type hand pumps and the diameter of the wells is usually 4 to 6 inch. Cleaning of such well is not done manually but with the use of pumps, surging and or bailing. Thus, it requires drilling machine, pumps and accessories and trained personnel.

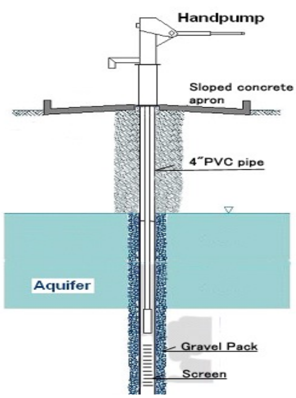


Figure 1 Typical Drilled well fitted with Hand Pump

b) Dug wells: are sunk by people working down in the hole to loosen and remove the soil. They need to be at least 1 meter wide to give people room to work. If you double the diameter of the well, you increase the amount of soil and rock that must be dug by four times and the water yield (see Table 1). The size of the well is a measure of how wide it is. Some holes are very large, and some are very small. The size will be largely determined by: the way it is excavated, geological formation, materials used to line it, and the purpose of the well.

Designs vary according to local preferences and conditions. Generally, hand-dug wells are 10–15 metres deep. For deeper wells, drilling is more appropriate. Wells should only be dug in suitable places where good supplies of clean ground water are likely to be available. There are dangers in building hand-dug wells. Skill, knowledge and expertise are essential to ensure the safety of workers during the construction process. A communal hand-dug well can give long-lasting service if it is well designed and constructed.

If the soil formation is easy for excavation and required amount of water is sufficient for the demand, then small diameter HDW can be excavated. Large diameter (greater than 1m of HDW is recommended for previous that have caving problems indicating that there is a need to use large diameter cylinder and carry out digging by using the sinking method. For example, as indicated in the table below, a 1meter diameter well 20 meters deep requires removal of 15.7 cubic meters (m^3) of debris while a 2 meter diameter well 20 meters deep will require the removal of 62.8 m^3.

Volume = Diameter x Diameter x 0.7854 = Area; and Area x Depth

Table 1 Example for determination of storage volume

Diameter	Area, m^2	Depth, m	Volume, m^3
1.0 m	0.79	20	15.7
1.5	1.77	20	35.4
1.8	2.54	20	50.8
2.0	3.14	20	62.8

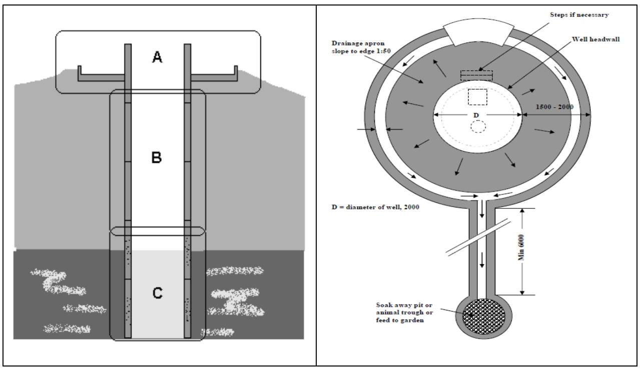


Figure 2 Components and Layout of Hand Dug Well

The major components of hand dug well are A) The Well Head, B) The well shaft and C) The intake as illustrated in Figure 2 above; the following its decryptions:

i) **Head wall:** The headwall is simply the continuation of the well lining above the ground level. It should be at least 250mm high. Sometimes headwalls can be up to a meter high, however if a Hand pump is to be installed this is not recommended.

ii) **Apron and Drainage:** The apron is a concrete platform around the well. It creates a clean smooth surface from which to collect water. It is sloped so that spills away water from the well. At the lowest point, a drainage channel takes any spill water (or rainwater) away from the apron to a soakage pit, garden or animal trough. The apron can be square in shape, or round. Square aprons are 4.75m x 4.75m, and round aprons are 5 meters in diameter.

Figure 3 Traditional HDW - head not capped

Figure 4 Traditional HDW - head capped

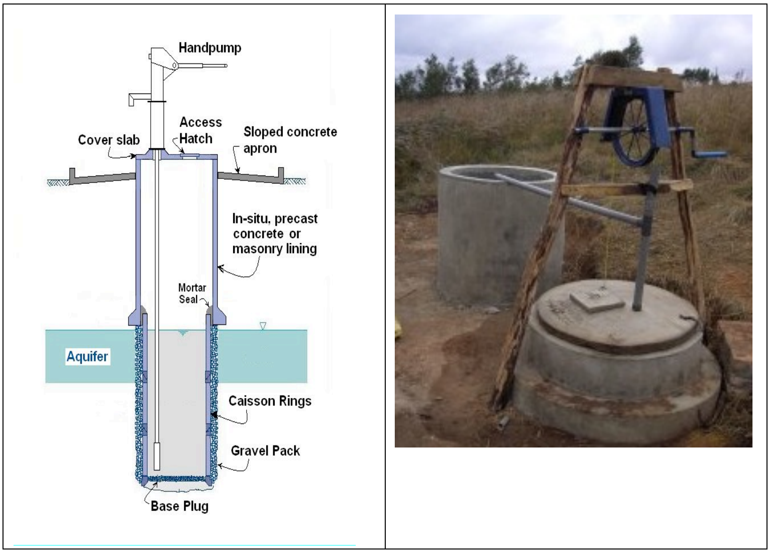


Figure 5 Hand Dug Well fitted with Hand and Rope Pumps

3. HDW DEVELOPMENT TECHNIQUES

3.1 Unlined Wells

Unlined wells have no lining. The well sides are unprotected. These wells are of a temporary nature. Unlined well is of limited depth. It caters to only small, local demands. This type of well is sometimes constructed where the water table is at a shallow depth, and where the subsoil formation is relatively, hard and compact so that it can stand vertically at the sides of the well.

3.2 Well with Pervious Lining

In this type of well, the sides are lined with dry bricks or stone masonry (without mortar) so that the lining is pervious. To give structural stability, a portion of the lining above the water table is constructed in cement mortar. Generally, a band of lining in cement mortar, about 0.3m deep, is also provided at 1.25m vertical interval below the water table.

The water enters the well from the sides only, and therefore the flow is radial. This type of well is suitable for construction in the formations consisting of gravel or coarse sand deposits. For sand formations, brick ballast (gravel) up to 20 mm size is packed behind the lining to form a sort of filter which prevents the fine sand from coming in to the well with flowing water. This type of well is quite suitable and economical for the limited rate of water withdrawal.

3.3 Well with Impervious Lining

This is the most common type of well and suitable for all types of formations. This is a permanent type of well commonly constructed for well irrigation of small farms. It provides a dependable source of supply so long as the ground water conditions are favourable. In sandy soils, the impervious lining is essential from structural stability consideration. These wells are fairly deep, but the depth is usually limited to 30m from the point of view consideration of an efficient and economical lifting of water.

The lining of such wells is in brick or stone masonry in cement (or lime) mortar or concrete. The thickness of lining generally varies from 30cm to 70cm, depending on the depth of the well for stone or brick lining. Bottom of the well is not plugged so that the water can enter the well from its bottom. In this type of well the flow is not radial.

4. PLANNING AND DESIGN PROCEDURES

4.1 Planning

At the beginning of the planning, the site should be selected at appropriate place with full participation of the beneficiaries. As it is mentioned in detail under potential indicator; hand dug well sites can be located considering the following points:-

i) Alluvial /deposition areas
ii) Highly weathered and permeable rock with enough recharges area
iii) Up stream of the spring eye
iv) At the foot of the mountain
v) River bank
vi) Location of the irrigable land and village of the community
vii) Sites with community acceptance and with no environmental impacts

The planning and design shall be based on the above information, its environmental impact, and technical and economical feasibility of the project.

Spacing between the wells should be located at a distance as much as possible away from each other depending on the ground-water condition of the area; and toilet site.

4.2 Design Consideration

Size of the well: The size and depth of the well depends on the water requirement calculated. It is the sum of irrigation, livestock and domestic water demand. Irrigation water requirement is calculated considering the type of crop, size of command area and climate data.

Estimation of typical quantities of materials needed to construct the HDW: quantity of materials needed to construct the HDW and arrangement to have as much of the material on the site.

During construction of a hand-dug well

- Ensure the well is deep enough to provide water through the dry season
- Use precast concrete rings installed below the water level which allow water to enter (permeable)
- Place a layer gravel in the bottom of the well to avoid silting up
- Use properly mixed concrete and reinforcements and allow them to' cure' to ensure long life
- Build a manhole cover to allow continued access to water if the pump breaks down.

[1]Alluvial is a fine-grained fertile soil deposited by water flowing over flood plains or in river beds.

5. DISTANCE DETERMINATION BETWEEN WELLS

When two or more wells are located close to each other, then their draw down curve will intersect and the discharge of one well will interfere with the discharge of the other. This is known as wells interference. Due to interference, the discharge of each well will be decreased. For this reason, well should be located at a distance as much as possible away from each other depending on the groundwater condition of the area. The number of well recommended for a given catchments can be determined by different reasons. Among them, the main ones are the following.

- The reserve of groundwater within the catchment
- Pumping rate
- Level of groundwater table
- Type of aquifer

On the other hand when the discharge of groundwater exceeds the recharge of the system, several adverse effects can occur. Most common is lowering of the water table, resulting in increasing the depth of drilling.
Well spacing roles are designed to reduce the interference between wells when pumped. Table 2 shows possible limits of radius of influence in unconfined aquifer. Radius of influence is the radial distance from the centre of a wellbore to the point where there is no lowering of the water table or potentiometric surface (the edge of the cone of depression). A potentiometric surface is based on hydraulic principles. For example, we know that two connected storage tanks with one full and one empty will gradually fill/drain to the same level. This is because of atmospheric pressure and gravity. A potentiometric surface is the imaginary line where a given reservoir of fluid will "equalize out to" if allowed to flow.

Table 2 Possible radius of influence in different unconsolidated deposit

No	Soil formation and texture	Radius of influence (m)
1	Fine sand layers with some silt and clay	30 - 90
2	Fine to medium sand layers, fairly clean and free from silt and clay	90 - 180
3	Coarse sand and fine gravel layers free from silt and clay	180 - 300
4	Coarse sand and gravel without silt and clay	300 - 600

From Table 2 above, one can understand that the spacing between wells in coarse sand and gravel soil formation free from silt and clay should be even over 600 meter apart while in fines and layers with silt and clay texture, the spacing between wells could be as low as 30m.

6. HAND DUG WELL CONSTRUCTION

Before the construction started, type of well to be constructed should be known on depth, water source, and designed lining materials at the time of the study period.

6.1. Social, Environment and Safety Issues

- Consider social issues (if any), don't dig at boarder, grave area, religious places and other socially respected area
- Make sure that the well is located upstream of potential pollution sources such as pit latrines, petrol stations, rubbish pits or burial grounds.
- Problem of nitrate pollution from septic pits happens when the formation has a relatively high permeability and when the septic pit is quite near the water well, on the upslope side. Prevent surface pollution at the well site. Ensure any spaces between concrete rings, the slab and well cover are filled in with concrete. Fit a pump on a raised pedestal.
- The ownership issue should be clear from the start as wells can be constructed and utilized by individual or group member (see Chapter 9). Individuals can also pull labour during digging.
- Consult experts on well sitting, well spacing and groundwater recharge
- The well should have cover (lockable)
- Digging deep wells can be dangerous, both for the diggers and for observers.
- The dangers include:
    - o Collapse of the sides (dig inside precast concrete rings if soil is unstable)
    - o Objects or buckets falling from the surface
    - o People or animals falling in the well (use fences or covers)
    - o Lack of oxygen in the well
    - o Poison exhaust gases from a generator used to pump out water
    - o Unsafe entering and climbing out of the well (use a safety harness and tripod and at least two helpers at the surface)
    - o Electric shock due to poor isolation of the electric pump or cutting of power cable
    - o Worker collapse due to exhaustion
    - o Unhygienic conditions in the well (do not allow the well to be used as a toilet during digging).
    - o If the completed well will not have a cover and hand pump, build a protection wall at least 70cm high to prevent children and animals falling in.

6.2. Site Preparation

Arrange to have as much of the material as possible on site before you begin. This will ensure that work is not held up whilst materials are being procured, transported or collected.

If you plan and prepare your site properly, then the processes for constructing a hand dug well (digging, cement mixing, ring casting, equipment storage and so on) will go smoothly and will not interfere with each other. The steps for site preparation are as follows:

6.3. Digging /Drilling

It is done when a well has dried up in the dry season or in a drought. The aim is to penetrate further into the aquifer so that the well will not dry up in future years. Water well drilling method (hand-digging, human-powered drilling or 'conventional' drilling) is used.

Figure 6 Different types of soil (substratum) conditions for well digging

Drilling tools must break, cut or penetrate the solid formation to be drilled. In the case of unconsolidated materials such as sand and silt, this does not require much energy; in the case of stiffer materials such as clays, or consolidated materials such as sandstone, limestone, or granite more energy is required. While doing the digging it should be checked that:

1. Is the well likely to collapse or be unsafe because of the near-exposure of one side and uneven earth pressures?

2. Is the whole well at risk of bursting out of the hillside below?
Then one should consult experienced well digging expert to plan for well rings or other means of HDW reinforcements. Wall reinforcement can be carried out by: stone masonry works or well rings (see Figure 3 and Figure 4, respectively).

Figure 7 Stone masonry lining of HDWs and staged entrance (Humera area, Ethiopia)

Figure 8 Lining of the collapsing loose walls (such as in sandy soils) using ring walls in the construction of HDWs

Figure 9 Head capping using metal barrel (left) and concrete (right)

6.4. Steps for Construction

This will be done after digging

i. Mark out the apron using wooden pegs

ii. Select the lowest point around the edge of the apron. If the ground is flat, then one side will have to be built up using stones, sand and aggregate to create a slope to a lowest point (chosen for convenience in this instance).

iii. Measure 6 m from this point to the location of the soakage pit, trough or garden

iv. Mark the corners of the drainage channel with pegs

v. Using wooden boards, make shuttering around the edge of the apron and drainage channel. Shuttering should be 150mm high and create a gap 100mm wide. Secure the shuttering with pegs and baton braces.

vi. Using a 1:2:4 (cement: sand: aggregate) mix, fill shuttering with concrete, tamping thoroughly to remove air

vii. The next day, carefully remove the inner shuttering, making sure you do not disturb the outer shuttering

viii. If available, lay a 50mm thick bed of clean sand within the apron walls

ix. Wet the bed of sand or ground thoroughly.

x. Lay a 75mm concrete slab within the apron walls, smoothing and grading it to ensure that there is a 2-5% slope away from the well, and the lowest point is where the drainage channel starts

xi. Cover and keep moist for 7 days. The remaining shuttering can be removed after 24 hours

6.5. Bill of Quantities

Make an estimate of the quantities of materials (Annex-1) needed to construct the HDW and arrange to have as much of the material as possible on site before beginning.

The most commonly used materials needed for construction of Hand Dug Wells will be locally available (sand, gravel, stone, water, wood, local labor) and others (cement, industrial material, skilled labor) will need to be procured and transported to the site.

6.6. Construction Equipments and Materials

All necessary equipment required for study, site clearing, excavation, and construction should be available before starting the activities. The common tools and materials are listed below.

a) Some of the common equipment are: measuring tapes, shovel, pickaxe, digging hoe, bucket, hammer, chisel, wheelbarrow, rope, shovel, and other carpenter and masonry tools, nylon rope, pipe tripod (morsa), trowel, float, sieves, gauge boxes, cement mixer, etc.

b) Some of the construction materials are: cement, sand, aggregate (gravel), reinforcing bars, wire, stone, water, timber planks, timber poles, etc.

7. CONSTRUCTION SUPERVISION AND TESTING PROCEDURE

7.1. Supervision

Checking the progress of the scheme should focus on the quantity and quality of the works in accordance with specifications and plan. Prior to the start of the construction adequate training and demonstration has to be carried out for the construction crew including safety. For items to check on supervision during site visits are given in Annex 2.

7.2. Measuring Yield of Well

The yield of a well is the amount of water that can be removed from the well (by pumping or bucket) without the well running dry. You must know how to measure and calculate the yield of a well because this is how you know that you have dug the well shaft deep enough. The yield of the well should be measured to confirm that you can stop excavating and start finalizing the well and constructing the headwork.

The yield of the well can be measured using the following methods:

a) Bucketing method

- Get a bucket of known volume and a stop watch or clock that measures seconds
- Place the end of the hose in the bucket and at the same time start the stop watch or read the seconds on the clock
- When the bucket is full, stop the stop watch or read the seconds on the

clock

- Calculate the number of seconds to fill the bucket
- Flow rate (litres per second) = Volume of bucket (litres) / number of seconds. Yield (litres per minute) = Flow rate x 60

b) Pumping test method

In this method, water is drawn from the well by dewatering pipe to have heavy draw down in its water level. The rate of pumping is changed and so adjusted that the water level in the well becomes constant. In this condition of equilibrium, the rate of pumping will be equal to the rate of yield, and hence the rate of pumping will directly give as the yield of the well at a particular draw down.

8. FINAL SITE INSPECTION AND TESTING OF THE WELL

The final inspection and tests dictate that excavation can cease and that the well is complete. As a general rule, the two tests that determine whether the well is complete or not are quantity and quality of the water (quality is if water is required for water supply).

The yield measurements and detailed target in the specification should be meeting the nominal targets, which are a combination of static depth of water in the well, and inflow when water is removed (see Table 3). These targets are as follows:

Table 3 Nominal Targets for Hand Dug Well Yield

Depth	Inflow
2.0 metres	20 litres per minute
2.5 metres	15 litres per minute
3.0 metres	10 litres per minute

Under certain circumstances, the HDW may be considered to be complete even if these nominal targets are not met. It depends on the water requirement planned from the well.

It is also important to note that the well is also designated as "Provisionally Complete", even if the nominal yield targets are met, until the first dry season has passed, to ascertain whether the HDW needs to be deepened.

9. OPERATION AND MAINTENANCE

- The planned irrigation schedule and water supply determines the operation of the scheme. The schedule for operation of the scheme depends on irrigation interval, and volume of water required per day for water supply. At the beginning of the operation, working condition of each component of the well and water lifting equipment should be checked (Figure 6).

- It needs to prepare maintenance program and follows the program during operation period.

Types of maintenance are:

- Routine /regular maintenance that can be managed by the farmers at the time of starting and finishing irrigation
- Periodic maintenance which is done weekly, monthly, quarterly, six months and annually
- Emergency works, done if any technical problems created that needs urgent maintenance works

Figure 10 HDW equipped with manual pulley system changed to roller fitted with bearings attached with livestock cattle trough.

10. MANAGEMENT OF HAND DUG WELLS

For sustainability of a scheme proper management of the hand dug well by the beneficiaries is necessary. Inspect the hand dug well for safety against the entrance of animas and children into the hand dug well. Construction of roof and fence are good measures.

Safety: is an essential aspect of management in HDWs. For safety, HDWs can be protected from the reach of animals and children by installing head capping with concrete works or metal barrel and both fixed with lockable gate. Other HDWs that are wide and difficult to fix the head capping then fencing and fixing the gate with lockable key is essential. If the HDW is on communal lands there should be agreed bylaw developed and enforced by the beneficiaries. Prior to the start of the construction adequate training and demonstration has to be carried out for the construction crew including safety.

Groundwater recharging: for the HDW to be sustainable it is necessary that all the proper groundwater-recharging practices should be applied. These include terracing (slope correction) of the catchment including trenches, percolation pits, percolation ponds, recharging wells. Consult and get coordinated with the natural resources experts. See also Section 5.1.

11. GENDER EQUALITY BOX

What are the issues of gender inequality?

Household micro-irrigation is undertaken on small plots of land which comprise the homestead garden which is a women farmer's domain but women farmers have faced different problems to use HMMI technologies like motor pump: lack of information, capital constrained and lack of maintenance services.
Women farmers like technologies that save their time and labour at the same time enhancing productivity.

How can the gender inequality be addressed?

Train motor pump maintenance jobless youth girls to make the service women friendly. Improving the financial management status of women and introducing community level credit and loan services is important to purchase and use motor pumps.
Arrange training for women farmers to check oil level, to remove the dipstick and to clean it. Women centred trainings shall be organized for women-only groups, in local languages and with practical demonstrations and experience sharing visits to model sites.
Technical knowledge regarding the operation and management of motor pump technologies must be arranged for women farmer's as part of the extension service.
By promoting women friendly micro irrigation technologies

What will be the benefits when gender inequalities are addressed?

By using women friendly technology like motor pump irrigation can boost agricultural productivity and contribute to household food security, nutrition, health, and income.

Case Study

Construction of Improved HDW for HHMI the case of Merab Abaya Woreda of SNNPR

1. Introduction

Hand-dug well with one meter in diameter and 10 - 30 m in depth is commonly used for micro irrigation in SNNPR. Well construction is cheap and there are experienced local artisans to dig wells. However, there are challenges including declines in water level during the dry season, low well yields, silting-up of wells, and caving-in or collapsing of well walls.

Well yield can be improved by using perforated concrete rings to screen the aquifer. An improved type of perforated concrete ring has been designed for use in the screened portion of the well. Non-perforated concrete rings are used in the non-productive portions of the aquifers or above the water table, to prevent caving or collapsing of well walls. A convex cover forms a protective rim extending beyond the circumference of the well, to prevent the entrance of surface contaminants. Water from the dug-wells is pumped through to the field to irrigate vegetables. All of these designs are suggested to improve the efficiency of the wells, to provide stability to the wells and better well yield, and to lessen the incidence of pollution/contamination within the well and its surrounding environment.

2. Site Selection and Construction of HDW

2.1 Site Selection

The site for construction of the well was selected with PIs (Partner Institutions) and the local people with the assistance of a qualified person (geologist from Gamo Gofa Zone water and Mining department).

Geographic location

- Zone:- Gamo Gofa
- District/Woreda:- Mirab Abaya
- Name of the FTC/Kebele :- Omo Lantie
- Coordinates - North:- 60 10’ East:- 370 39’
- Distance from zone town (Arba Minch):- 33Km
- Distance from district town (Birbir) :- 17KM
- Total demonstration area:- 0.75ha
- Topographic of the FTC demonstration plot: - Flat (less than 5% Slope)

Climate of FTC Site

- Annual average rainfall:- 800mm
- Altitude:- 1197 masl
- First round irrigation time:- September to January
- Second round irrigation time:- January to June
- Agro climatic condition of the demonstration area:- Wet Kolla

Soil texture and physical properties (type, soil moisture holding capacity, depth, intake rate):- Silty clay loam /alluvial soil
Soil color:- Light brown
Water source :- Shafie spring

FTC/kebele irrigation Beneficiaries:- Male - 530, Female – 60; Total – 590 Households
Major rainfed crops growing around the FTC:- Maize, Teff, Chick pea, Sweet potato, Sorghum and Cotton
Major irrigated crops growing around the FTC:- Onion, Tomato, Pepper and Cabbage

Current Challenges of irrigation activities

Shortage of irrigation water and water use conflict
Inputs supply problem (Chemicals, and improved varieties of seeds)
Weak irrigation agronomic practices (spacing, weeding, fertilizer application, poor pest control)
Poor market linkage
Variety selection problem
Poor identification of pests and usage of chemical
SMIS SNNPR entered into contract agreement with local artisans to dig the well with close follow up of Zonal and Woreda PIs. Accordingly, the digging process was started in April 2018.

2.2 Site Preparation

A working area of 15 meter radius from the well centre was cleared of all vegetation, loose stones, dead wood and the area around the well of about 6 meters diameters was levelled.

2.3 Site Planning and Setting out

The site layout is planned to facilitate flow of materials and people through and around the site to prevent interference of handling materials.
Mark the position of the well center peg exactly in the middle.
Using a piece of string tied to the peg draw a circle on the ground of radius 900 mm.
Assemble the head frame:- wooden head frame with a pulley that sits over the well shaft during construction for raising and lowering items such as buckets, equipment and workers.

2.4 Excavation

Excavation is the main activity of constructing the hand dug well. As the lining method adopted is precast concrete rings the diameter of excavation is 1300 mm.

Excavation techniques

The tools used for hand excavation are:

Purpose	Tools
Digging the center of the well	Pickaxe
Shaping the side of the well	Mattock, wide blade hoe (gesso)
Digging out the spoil	Shorthanded shovel
Removing spoil from well	Buckets, rope, pulley and head frame
Checking for verticality	Plum line, top plumb rod and trimming rods

The pattern of excavation followed:

Dig in 10 - 20 cm keeping the bottom as level as possible

First dig one half of the well, removing the soil in buckets

Then dig the other half in the same way

Excavate slightly less than the correct diameter initially all the way around.

Then trim the shaft to the correct diameter.

Every meter of excavation check the verticality of the shaft using plum bob

For efficiency, two buckets were used. One is being emptied while the other is filled. All excavated soil dumped at a distance of 5 meters from the edge of the well shaft.

2.5 Dewatering

One of the main features that distinguish the traditional HDWs from improved HDWs is the ability to provide water all year round, even in the dry season and times of drought. Therefore, the well penetrated 1.8 meter below the static water level.

To excavate 1.8 meters in to the aquifer adequate de-watering was done by bucket and rope. De-watering is the process of removing enough water from the well during excavation so that workers can continue digging without being submerged.

3. Lining the Well with Perforated Concrete Rings

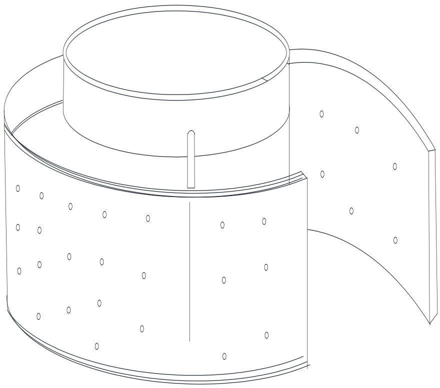
Perforated concrete rings are normal precast concrete except that they have small holes cast into them through which water flows into the well. The holes are 10 mm in diameter.

Steps to make perforated rings

The process for making perforated pre-cast concrete rings is the same as solid concrete rings except the following steps. The inner and outer ring moulds with holes to take weep hole dowels. Prepare the dowels for the weep holes. Make sure they are covered in oil or a similar lubricant.

As the concrete is being placed, the weep holes dowels should be placed as the level of the concrete reaches them. Weep holes should angle up towards the middle of the ring at about 300.

Remove the dowels after the concrete has been setting for an hour or two



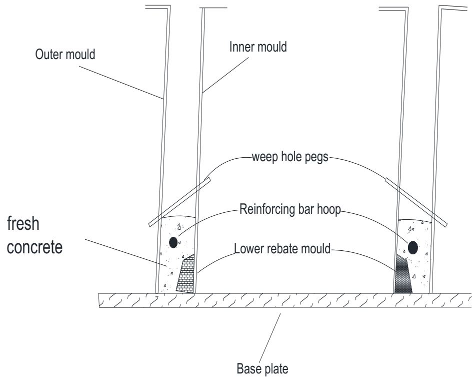


Figure 11 Mould ring (left) and its cross sectional view (right)

4. Finalizing the Well Shaft

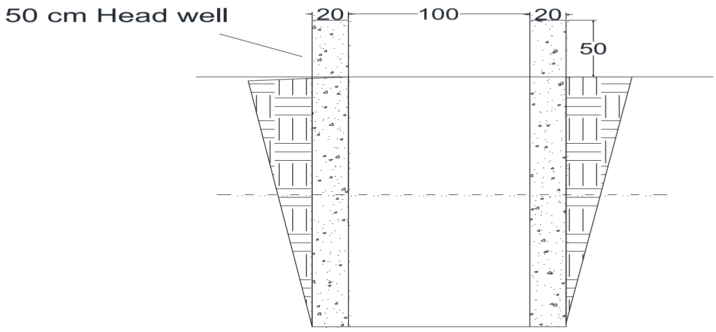
Once enough depth was excavated and it has been fully lined the well should be finalized. There are some activities to be done:

4.1 Gravel Pack and Sealing

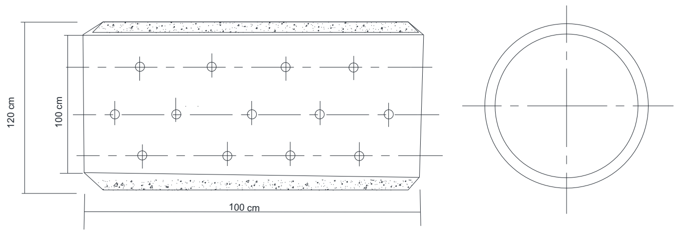
The void between the concrete rings and the surrounding ground was packed with gravel. This helps to stabilize the surrounding ground and control the flow of sand, silt and water into the well.

4.2 Apron and Drainage

Concrete platform around the well was constructed which sloped outward so that spilt water or rain water flows away from the well.



Cross section of the well



Concrete grade of the perforated casing is C20
# of Holes on the casing wall by which water can enter the well 24
diameter of the holes are 10 mm to prevent passing of sand

Figure 12 Cross section of the well head (top) and perforated concrete casing for HDW (Bottom)

Figure 13 Perforated concrete casing

Figure 14 Installation concrete casing

Figure 15 Excavated well before lining

Figure 16 The well lined with concrete

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ANNEX 1. BILL OF QUANTITIES FOR HAND DUG WELLS

Item	Description	Unit	Qty	Rate	Total
I	**Mobilisation/Demobilisation**				
1	To site for well construction	each	1		
2	To site for well deepening	each	1		
3	From site after well construction	each	1		
4	From site after well deepening	each	1		
5	Hiring of expensive equipment	each	1		
	Sub-Total I				
II	**Setting up / Excavation (1.5 metre diameter hole)**				
1	Site Preparation	each	1		
2	Excavation at different depths	m			
	Sub-Total II				
III	**Well Lining (Concrete – in-situ cast or pre-cast)**				
a	Well lining at different depths	m			
	Sub-Total III				
IV	**Well Lining (Masonry)**				
a	Well lining at different depths	m			
	Sub-Total IV				
V	**Works Below Water Table**				
a	Caisson lining below the water table	m			
b	Caisson lining for well deepening (Provisional payment)	m			
	Sub-Total V				
VI	**Head works**				
a	Headwall	each	1		
c	Access Extension	each	1		
d	Access Hatch Cover	each	1		
e	Apron with Raised Lip	each	1		
f	Drainage Channel	each	1		
	Sub-Total VI				
VII	**Completion**				
a	Construction of Fence	each	1		
b	Operation and Maintenance Training	each	1		
	Sub-Total VII				
	Total				

ANNEX 2. ITEMS TO CHECK ON SUPERVISION/SITE VISITS

Item	Observation or Measurement to be made
General site conditions	Fencing to keep animals and children away General cleanliness of the site Storage of tools, equipment and materials Evidence of safe work practices Storage of spoil from excavation
Excavation	Verticality (allowable limit of 10mm non verticality for every metre of depth) Depth left unlined and stability of surrounding ground
Precast Concrete Rings	Dimensions (ID 0.95 m, OD 1.1 m, wall thickness 75mm) Quality of concrete mix (strength, compaction, finish) Reinforcing Steel (quantity, type and placement before placement of concrete; visibility of steel after concrete placement) Placement, including gravel packing and mortar seal between rings
In-situ Lining	Dimensions (ID 1.3 m, roundness) Joints between lifts Reinforcement (quantity, type and placement, and visibility after formwork removed) Quality and mix of mortar used for masonry lining Quality and mix of concrete blocks if used for lining or joints
Materials	Uniformity of size and cleanliness of gravel/aggregate Cleanliness of sand Quality of stones used for masonry lining Cleanliness of water for concrete and mortar
Head works	Height of headwall (minimum 250mm above ground) Hardness of apron foundation material (no soft ground etc) Drainage slope (2 – 5%, no ponding of water) Soakage pit (no ponding or stagnant water).
Finishing	Final fencing (ability to keep animals out, and to prevent unauthorized access) Cleanliness of well (see below) General cleanliness of site, including removal of building materials and restoration of any damage caused by construction

Module-3

Tube Well Drilling

1. INTRODUCTION

This module, manual tube well drilling is one of the HHMI training manual. In this module brief but basic information on manual tube well drilling related to its purpose, where it can be applied, types of manual drilling methods, drilling steps and measures for sustainability are presented.

1.1. Purpose and Scope

This module is a training material and aims at enhancing the knowledge and skill of woreda experts and DA's on manual tube well drilling technology for household and micro irrigation. It can also be used as field manual for both woreda experts and DAs.

1.2. Types and Classifications of Water Well Drilling techniques

Methods for accessing groundwater fall into four broad categories. These are:

- hand-digging
- manual/human-powered drilling
- small 'conventional' drilling rigs
- large 'conventional' drilling rigs

In this module, human/manual powered drilling techniques is presented. Accordingly, widely available existing manual drilling techniques can be divided into four main drilling principles: Percussion, well jetting, auger and Simple sludge. Within these four main drilling principles, a whole range of versions has been developed in different countries of the world. However, in this module, commonly practiced in Ethiopia which is a simple sludge drilling method in combination with percussion tool is considered.

2. TECHNICAL DESCRIPTION OF MANUAL TUBE WELL DRILLING

Manual tube well drilling technology is a technology, operated by human power to drill shallow ground water, up to 40-50 meters drilling depth for productive uses, such as for household micro irrigation, for domestic and livestock water supply. Manual tube well drilling technique uses different tools. Simple sludge in combination with percussion tool is the most common techniques used in Ethiopia (Fig 1). Manual tube well drilling technique using simple sludge and percussion is suitable for drilling in unconsolidated and consolidated formations: sand, silt, stiff clays, gravel, sandstone, laterite, weathered rock and fractured granite. It is also appropriate to shallow groundwater depths in which its static water depth not more than 30 meter deep.

The problem of well collapse in hand dug wells, especially in sandy and clays soil conditions can be improved by using tube well drilling techniques. Using manual tube well drilling techniques can solve the problem of well collapse in hand dug wells especially in sandy and clayey soil condition.

Figure 1 Percussion and simple sludge tools

3. ADVANTAGE AND DISADVANTAGES OF MANUAL TUBE WELL DRILLING

Drilling of shallow groundwater depth using tube well (simple sludge in combination with percussion) is cost effective when compared with hand dug well as well as drilling machine. In the case of hand dug wells, beyond the cost, collapse of the well and frequent maintenance requirement is the critical problem. It is therefore, in the area where the ground water depth is shallow and the soil profile is fragile or loose, manual tube drilling well technology could be considered as an alternative water source for various multiple uses including household irrigation. Simple sludge in combination with percussion tool is one method of manual drilling where the weight of series connected drilling pipes are used to penetrate the upper levels of the soil until the aquifer is reached. The advantage and some limitations are described below:

Advantages:

- Drilling equipment, tools and materials are easily available at local markets, even at woreda level.
- Drilling equipment is a low cost option and is simple to use by local people.
- The techniques can be handled by the local people and would be more sustainable.
- Drilling tools and equipment can be easily transported to any village where simple sludge method is technically feasible to be practiced.
- Suitable for a wide variety of fractured rocks

Disadvantages:

- Large quantity of water is required while drilling.

- The technique is limited only in areas where the subsoil condition is not hard rock or boulder. The existence of any hard stone or rock at the b drilling point greater than the diameter of the drilling pipe (1½ “) can stop the drilling work.
- If the sub soil formation is fine sand or high silt content and are thick in depth, drilling could be interrupted due to well collapse problem.
- When combined with percussion, slow, compared with other methods
- Percussion tool can be heavy

4. PERIOD OF IMPLEMENTATION

Tube well drilling is done during the dry season where the groundwater depth (static label) is believed to be at its lower depth. This means during the highest dry month/s in a given locality. If the well is drilled during the rainy season, it is difficult to determine how much the groundwater level could drop during the dry season and how deep the well would need to be drilled to ensure an adequate yield.

5. GEOGRAPHICAL EXTENT OF USE, WHERE TO USE?

Manual tube well drilling techniques can be applied in all agro ecology where groundwater resources are shallow, the soil formation is not hard and where water is a problem and developing groundwater resources is relatively Simple and cheaper when compared to developing surface water resources.

6. PLANNING AND MOBILIZATION REQUIREMENT

During planning of manual tube well drilling in a given area, the following technical requirements must be considered:

- Based on need assessment (full community participation), water shortage is a critical challenge in the area,
- Check development of shallow groundwater water is relatively simple and cost effective
- Check its requirement (fulfilling) the required technical specification? Soil formation, water table depth, available water lifting device, available command area size, drilling tools availability in the locality, knowledge and skill in the locality, etc
- Determine its future use (identify best commodities), irrigation, livestock water supply, domestic water supply, or multiple use
- Availability of optimum size of irrigable area, for household micro irrigation.
- Ease access for manual or engine pumps with the required accessories and technical knowhow in the area.
- The existence of groundwater with static water level (SWL) up 20 m for using lift pumps.

- Static water level not deeper than 12 m (if suction pump is proposed).
- Availability of basic drilling tools, equipment and materials at local market.
- Availability of sufficient labor, minimum 6 people per well.
- Approved go-ahead permission from responsible government institution

7. MANUAL TUBE WELL DRILLING STEPS

Step 1: Drilling site selection

The location of a well is determined by the well's purpose, for example, for human or livestock water supply, irrigation, or any other industrial purposes. However other factors such groundwater quality, long term groundwater supply of the wells, etc. should be also considered. Moreover, the site selection criteria depend on the geology, hydrogeology conditions, and geophysical properties of the area. The quality and quantity of groundwater can be governed by the local groundwater system, adverse arrays of information's such as: land surface topography, groundwater chemistry, existing well data and local vegetation.

The following are Simple parameters that indicate the presence of groundwater nearby:

- layers of gravel and sand
- weathered and fractured rock zones
- Springs nearby
- valleys and river beds
- aligned indigenous vegetation
- Boreholes or traditional hand dug wells

Local knowledge from traditional well diggers and others is a very useful source of information regarding good and bad well sites. Moreover, wells should be carefully sited so that drilling only occurs where there is a high probability of successfully penetrating into water-bearing formations and the wells can be effectively used, maintained, and protected. Every well will not result in a good yield; however, advanced planning with the community can maximize the number of successful wells and minimize drilling costs.

Even though, the technology discussed in this module is designed for irrigation purposes, in some places due to the scarcity of drinking water, people or animal may use from this water source. Therefore, when locating a well, one should also consider the proximity to these potential sources of contamination such as fuel or chemical storage areas, toilet, and leach fields or septic tanks. The presence of a significant barrier between such potential sources and the well itself is very important for the protection of the well (Table 1)

Table 1 Allowable Distance from Polluted Sources

Distance (m)	Possible Sources of Contamination
100	Garbage dumps/refuse piles, car repair or fuel (petrol) sales outlets, industrial operations/storage facilities etc.
50	Seepage pit or cesspool
30	Pit toilets, animal pens, barns, fields fertilized with dung
15	Septic tank, surface water body
7	Drain, ditch, house

Step 2: Determine the distance between two wells (how far should a well be apart if there exist a water well in the proposed site?)

Knowing the distance between wells either from the existing that is close to the proposed site or any well that will probably be drilled in the future is critical.

When two wells are located close to each other, then their draw down curve will intersect and the discharge of one well will interfere with the discharge of the other. This is known as wells interference. Due to interference, the discharge of each well will be decreased. For this reason, wells should be located at a distance as much as possible away from each other depending on the groundwater condition of the area. The number of wells recommend for a given catchment can be determined by different reasons. Among them, the main ones are the following:

- the reserve of groundwater with in the catchment
- Pumping rate
- Level of groundwater table
- Type of Aquifer

On the other hand, when the discharge of groundwater exceeds the recharge of the system, several adverse effects can occur. Most common is lowering of the water table, resulting in increasing the depth of drilling.

Well spacing rules are designed to reduce the interference between wells when pumped. Table 2 shows possible limits of radius of influence in unconfined aquifer. Radius of Influence is the radial distance from the center of a wellbore to the point where there is no lowering of the water table or potentiometric surface (the edge of the cone of depression). A potentiometric surface is based on hydraulic principles. For example, we know that two connected storage tanks with one full and one empty will gradually fill/drain to the same level. This is because of atmospheric pressure and gravity.

Table 2 Possible Radius of Influence in Different Unconsolidated Deposit

No.	Soil Formation and Texture	Radius of Influence (m)
1	Fine sand layers with some silt and clay	30 – 90
2	Fine to medium sand layers, fairly clean and free from silt and clay	90 – 180
3	Coarse sand and fine gravel layers free from silt and clay	180 – 300
4	Coarse sand and gravel without silt and clay	300 – 600

From table --- above, one can understand that the spacing between wells in coarse sand and gravel soil formation free from silt and clay should be even over 600 m apart while in fines and layers with silt and clay texture, the spacing between wells could be as low as 100 m.

Step 3: Know the static water table

From wordea office or from observation (if exist) in the area, try to know how deep is the static water table in the area especially during the dries month of the year. If the static water table is up to 20 -30 meter the simple sludge with percussion too can be considered.

Step 4: determine the type of pump to be installed

A suction type water pump like treadle pump, diesel engine pump, etc can be considered if the static water table is not deeper than 4 meter from the ground surface. Otherwise, though the depth is beyond 4 meter and suction pumps are preferred, pump house excavation to lower the position of the pump is required. The pump hose need to be excavated to the shape of trapezoid (Fig 2).

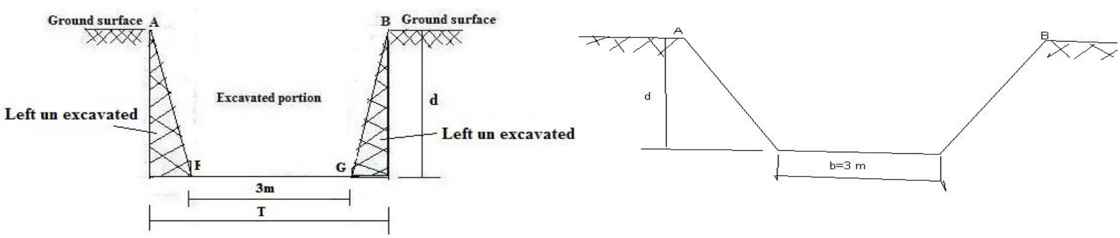


Figure 2 Pump house in trapezoid shape

This will avoid colapese of the structure specially in heavy clay and sandy soils. The dimension of pump house is given in Table 3. The detailed design of pump house is available in the tube well guideline ((MoALR, 2018).

Table 3 Dimension of pump house

Static Water	**Stable Soil, Side Slope (V:H) = 1:0.5**			**Unstable Soil , Slope = 1:1**		
Level	D1	B1	T1	D2	B2	T2
[1]	[2]	[3]	[4]	[5]	[6]	[7]
3	0.5	3	3.5	0.5	3	4
4	1.5	3	4.5	1.5	3	6
5	2.5	3	5.5	2.5	3	8
6	3.5	3	6.5	3.5	3	10
7	4.5	3	7.5	4.5	3	12
8	5.5	3	8.5	5.5	3	14
9	6.5	3	9.5	6.5	3	16
10	7.5	3	10.5	7.5	3	18
11	8.5	3	11.5	8.5	3	20
12	9.5	3	12.5	9.5	3	22

$D_{1=}D_2$= Depth of excavation = [Col.1]-[2.5], $B_{=,}$ B_2 = Bottom width = proposed value = 3 m (square in shape), T_1 = Top width=[Col. 3]+(2*[Col. 2]*0.5, T_2 = Top width = [Col 6]+(2*[Col 5]*1)

As a rule, the depth of the pump house excavation will be equal to the vertical height (depth) difference between the center of the pump position and the static water level. This depth difference should not be over 4 meters. Then drilling will start at bottom floor of the pump house.

However, pump house is recommended if the SWL is not lower than 10 meters from the surface.
If the SWL is lower than 10 meter, it is recommended to consider lift pumps such as rope and washer pump, submersible pumps, etc (3 inch diameter).

In addition to the water table depth, pump selection, will be decided based on the diameter of the casing, the well yield, the purpose (crop, water supply, etc) and the area to be irrigated.

Step 5: get Approval

Approved go-ahead permission from responsible government institution and local community is required

Step 6: Organize basic drilling tools and equipment

Tools and equipment required for simple sludge with percussion method can be categorized in to the following three parts:

Part one: Tools and equipment required for layout and pump house excavation (if pump house is required)

Part two: Tools and equipment required for Drill crews (6 person per team)

Part three: Tools and equipment required for well development (after drilling)

Detail list of tools and equipment needed are given in Annex 1

Step 7: Prepare all hand tools and equipment required for drilling work. For example, preparing GIP for cutting and tread making for use as a drilling tool (Fig. 3).

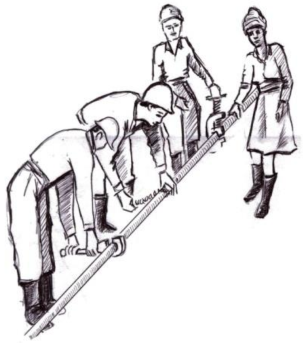


Figure 3: Preparation of Drilling Tools and Equipment

Step 8: Make ready four pieces of 1½ " GIP of length 0.5 m, 1 m, 1.5 m and 3 m by cutting from 6 m long 1 ½ ' GIP (Figure 4).

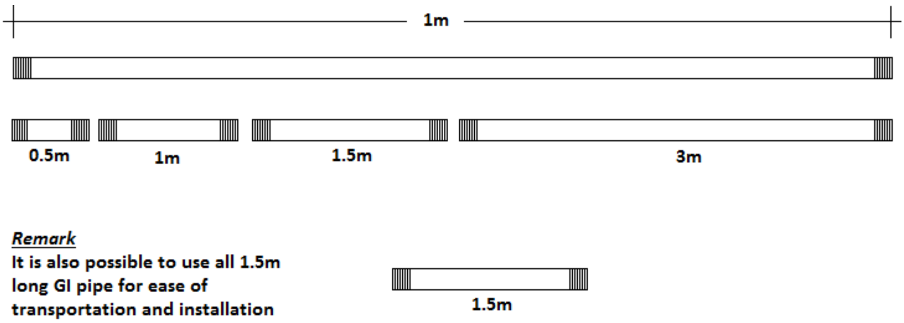


Figure 4: Basic Drilling Tools (1½" GIP)

Step 9: Using the pipe thread maker, make a thread to each cut pieces of 1½" GIP and fix coupling (Figure 5)

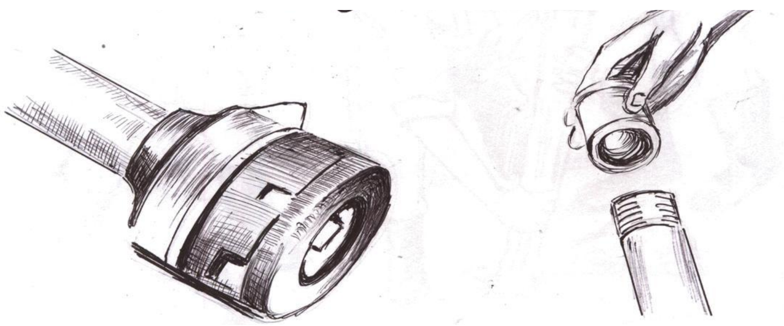


Figure 5: Pipe Tread Making

Step 10: Use hammer and puncher or any metal to remove the bottom part of the metal bucket (Figure 6).

Figure 6: Preparing Guide Bucket

Step 11: Dig a well guide hole to with the same diameter and height of metal bucket where the well is to be drilled. The well guide hole should be located at 1 m away from one corner of the pump house. Then, embed the metal bucket into the well guide hole by putting straw or leaf material at the space between the hole and metal bucket (Figure 7).

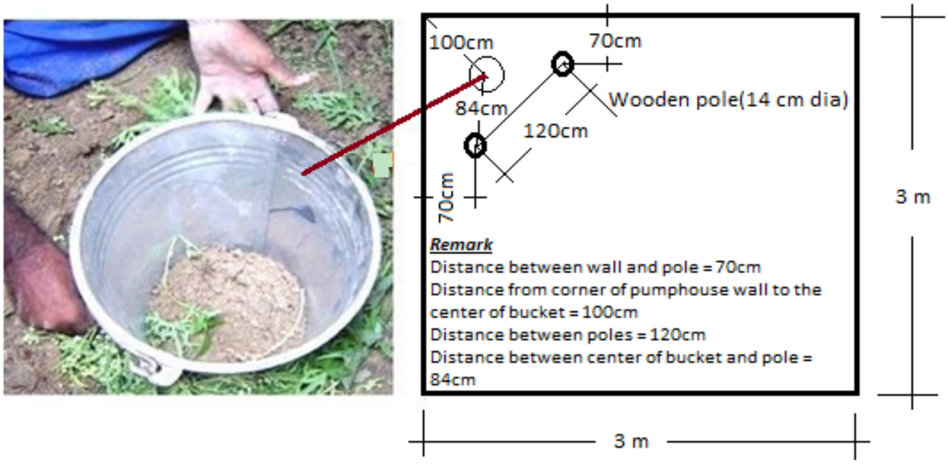


Figure 7: Location of Guide Bucket

Step 12: Dig two holes each 70 cm deep and 20 cm wide at a distance of 84 cm from the center of the metal bucket and erect two vertical wooden poles (14 cm diameter and 300 cm long) at a distance of 120 cm between them (Figure 8). Place flat stones (15 cm thick) under the poles to prevent sinking in while drilling. In clay and loam soil, fill-space around poles with compacted stones and soil.

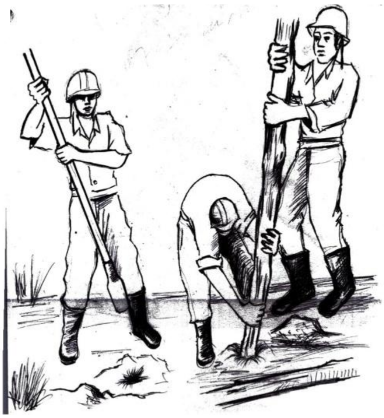


Figure 8: Erecting Wooden Poles

Step 13: Put one horizontal wooden pole (12 cm diameter and 180 cm long) across the two vertical wooden poles at height of 220 cm from the bottom surface of the pump house and tie both ends of he horizontal wooden pole with nylon rope (6 mm) to the vertical bottom surface of the pump house and tie both ends of the horizontal wooden pole with nylon rope (6 mm) to the vertical wooden poles. Then. Prepare one wooden pole of 10 cm diameter and 280 cm long (sludge lever) and tie it at 180 cm of its length with 12 mm diameter chain to the center of the horizontal wooden pole. Knot a 6 mm chain or 6 mm nylon rope on the sludge lever wooden pole at its end (270 cm) towards the metal bucket and check the fastened nylon rope or chain touches the top surface of the metal bucket when the lever is at horizontal position and it must be exactly at the center of the bucket (Figure 9).

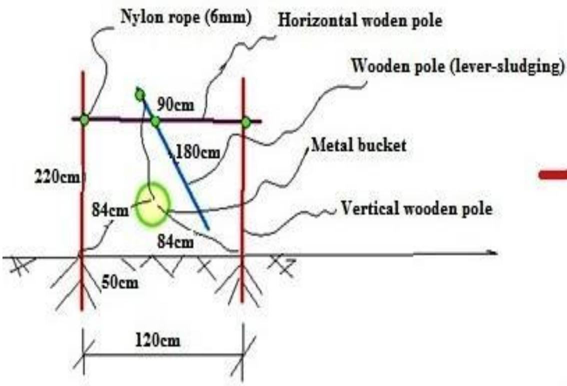


Figure 9 Fixing Drilling poles, Pipe with Simple Sludge

Step 14: Make ready the drilling fluid. Fill 30-40 cm depth of (drilling fluid) to the pump house. The drilling water can be obtained from the following three alternative sources Dig a small diameter of hand dug well within the pump house, and then use this water by bucket lifting

Step 15: Start drilling by placing a 1 m long 1½" GIP at the center of the metal bucket. The drilling work consists of the following basic tasks:

- The driller who controls the water flow with his hand and rotates the drill pipe using pipe wrench (one person).
- The lever operator who pull the drill pipe up and down (two people at the beginning and maximum three when the depth of drilling is over 12 m) (Fig. 10)

Figure 10 Start the Drilling Work

Step 16: Collecting soil sample (cuttings)

Collecting soil cut material for every 1 m depth during drilling is important to decide where to fix the casing, select screen type, and where to stop drilling. Therefore, collecting soil samples and knowing their types (gravel, sand, clay, silt, and loam) is an important area that deserves attention during water well drilling work. Soil sampling can be done by collecting the soil cuttings that comes out mixed with overflows drilling fluid (water) through the drilling pipe. To collect the overflow fluid a metal bucket or any available container can be used. Cuttings (sample) from the container or metal bucket should be displayed properly on for example plastic sheet, prepared on level surface (Figure 11-)

Figure 11 Sample Cuttings

Step 17: The drilling process with 1 m long galvanized pipe will continue until all its length sinks into the drilled hole. Then, the drilling pipe should be raised to the level of the metal bucket. This can be done when the lever operators pull down the lever. The 1 m long pipe is then removed and replaced by 150 cm (1 m long) drilling pipe (Figure 12).

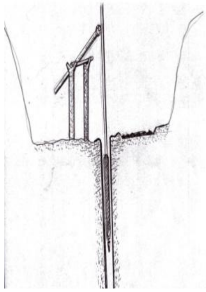


Figure 12 Removing Process of Drilling Pipe (1 m long pipe)

Step 18: After drilling with 1.50 m long drilling pipe, raise it and attach the 1 m long drilling pipe to make the total length of the drilling pipe 2.50 m. Then, continue drilling until it reached to the top surface of the metal bucket. For quick reference, Table 4 shows how pipes are connected and disconnected using simple sludge water well drilling technique.

Table 4 Connecting and Disconnecting Drilling Pipes

Steps	Connect (pipe length, m)	Disconnect (pipe length, m)	Replace with pipe size (m)	Depth to drill (m)	Cumulative depth of drilling (pipe length, m)
1	1*	X	x	1	1
2	x	1	1.5	0.5	1.5
3	1	X	x	1	2.5
4	x	1,1.5	3	0.5	3
5	1	X	x	1	4
6		1	1.5	0.5	4.5
7	1	X	x	1	5.5
9		1,1.5,3	6	0.5	6
10	1	X	x	1	7
11		1	1.5	0.5	7.5
12	1	X	x	1	8.5
13		1,1.5	3	0.5	9
14	1	X	x	1	10
15		1	1.5	0.5	10.5
16	1	X	x	1	11.5
17		1, 1.5, 3	6	0.5	12
18	1	X	x	1	13
19		1	1.5	0.5	13.5
20	1	X	x	1	14.5
21		1,1.5	3	0.5	15
22	1	X	x	1	16
23		1	1.5	0.5	16.5
24	1	X	x	1	17.5
25		1,1.5,3	6	0.5	18
26	Continue the same procedure until the required drilling depth is reached				

* drilling work begins with this GI pipe length (1 m long)
X No pipe connected, disconnected or replaced. The following are important activities that should be done together with the drilling work:

Step 19: Well Washing and Flushing

When drilling is interrupted due to various reasons (at the end of working hour, connecting and disconnecting pipes, drillers are tired, etc.) well flushing should be done at the beginning and end of drilling (Box below).

What is flushing?

Flushing is cleaning of a tube well (borehole) using the same pipe used for drilling. The work is performed by moving the drilling pipes up and down only without bringing new cuttings and allowing the drilling fluids to circulate for not less than 10 minutes to remove as much cuttings as possible from the tube well.

The need for flushing

The process will help in removing the mud and/or cuttings out of the borehole by replacing it with clean (fresh) water. Flushing prevents the sludge (drilling water with soil particles) from becoming too heavy. When regular flushing is "forgotten" then the sludge will become too heavy preventing the water from being pumped around. Drilling becomes now more difficult

When to flush?

In principle, flushing should take place every time when the drilling work is interrupted. An interruption is considered to be a pause of longer than 10 minutes. Thus certainly at the end of the working day, but also for example, when connecting a new drilling pipe. In general, it may be necessary to flush in between times, before stopping and beginning drilling.

How long to flush?

The driller feels how long to flush through the pressure on his hand. The greater the suction pressure on his hand, the heavier the sludge (wet mud) will be. This can also be determined by the volume of water squirting out, which decreases with heavier sludge. It means that the volume of water ejected from the pipe will decrease as the drilling fluid contains more mud or cuttings. Thus the driller instructs the lever operators to wash and washing takes place until he feels a reduction in the concentration of sludge.

When the drilling has reached to the required depth, the well should be washed before the drilling pipes are removed. During the removal of the drilling pipes, the drilling hole should be filled with water by doing so the water pressure will prevent the well walls from collapsing.

Step 20: Use of Additional Drilling Tool and Extra Weights

In hard and compact ground, for example, tuff stone and sandstone, it may be necessary to connect a strong and sharp tool to the simple sludge-drilling pipe. This tool can be fabricated in any local metal workshop from leaf springs (Fig. 13).

Figure 13 Use of Additional Tools with simple sludge method

Step 21: Use of percussion tool

When drilling with simple sludge and with additional tool is becoming difficult because of stone or rock underneath, percussion tool can be used. With percussion drilling a heavy cutting or hammering bit attached (4 inch diameter and 50-70 kg weight) to a rope or cable and is lowered in the borehole. Usually a tripod is used to support the tools. By moving the rope or cable up and down, the bit loosens the hard soil formation or breaks consolidated rock in the borehole (Fig. 14). Water is added to the hole and it plasters the wall of the borehole and lifts up small rock chips that have been broken. The mud (cuttings and rock chips) is then extracted by using a simple sludge drilling technique. Then the bit is lowered into the borehole and the drilling process begins again.

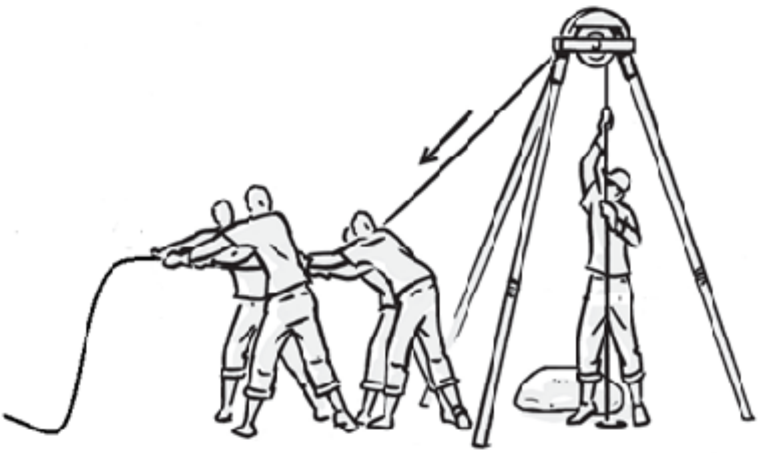


Figure 14 Drilling using Percussion

Step 22: Measures for Preventing Well Collapse

Tube wells drilling in soils with poor cohesion such as silt and very fine sandy soils are susceptible to collapsing. A high drilling speed in combination with these soil types often results an increased risk for well collapsing. Therefore, in such situation, to prevent wall collapsing cow dung is added to the borehole. In a very loose soil condition, use 16 liters of cow dung (2 kg mixed with water) per m depth of drilling (Figure 15).

Figure 15 Use of Cow Dung (if required)

Step 23: Hanging the Drilling Pipes

Whenever the drilling work is interrupted due to for example, lunch break time or end of day time working hours, the drilling pipes should be left hanging and firmly tied with vertical poles. By doing so, it is possible to prevent the possibility of drilling pipes being stuck with borehole wall. While doing this, the drilling hole should be filled with water since the water pressure can prevent the well wall from collapsing (Figure 16).

Figure 16 Hanging the Drilling Tools while at Rest

Step 24: Reaming

In order to install the well casing and perforated screen, the borehole which has been drilled using 1½" GIP must be enlarged by using 3-6" diameter (Fig. 17).

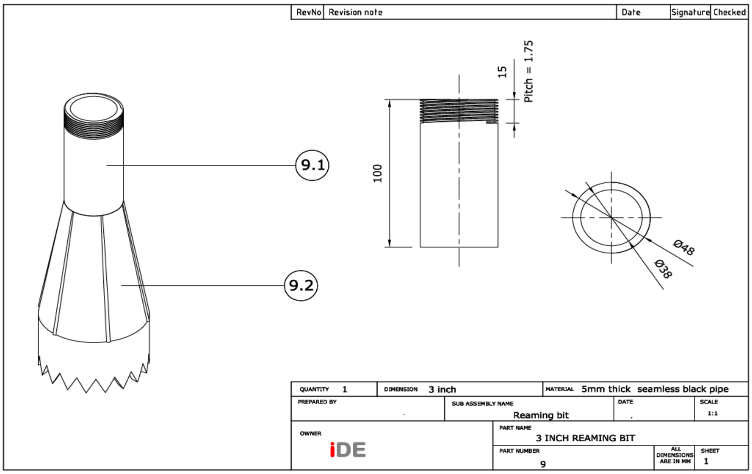


Figure 17 Reaming Bit (3-6")

Step 25: Installation of Well Casing,

To keep loose sand and gravel from collapsing into the borehole, it is necessary to use well casing. The screen supports the borehole walls and allows water to enter the well; and is the most important component that affects the efficiency of a well. The casing can be blind or with slot or perforated (Fig 18). The well casings; blind and screens shall be made of either corrosion resistant material or steel pipes having sufficient thickness to guard against the effect of corrosion and to ensure reasonable life of tube well.

Figure 18 Slot and Perforated Screens (left to right)

Step 26: Flushing and gravel Filter Pack

After the casing has been installed, try to flush the well by pouring water into the casing. The dirty water present in borehole will be flushed out through the screen and up through the space between the casing pipe and borehole wall.

Then, slowly pour the river gravel into the annular space (the space between the casing and the well wall) and let it settle into the upward flowing water (Figure 19). This is done by hand so that it is distributed evenly. At the same time there is a need of shaking the casing in order the filter pack materials reached to the foot of the casing and completely fill the open space between the casing pipe and the drilling wall (Figure 19).

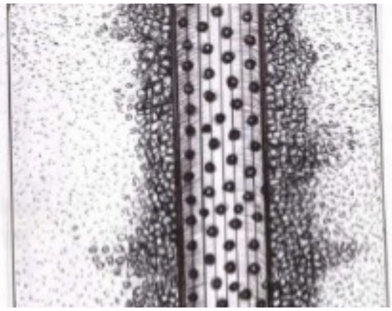
 

Figure 19: Gravel Pack filter

Step 27: Pump installation

As decided during planning of the tube well drilling, the right water lifting devices can be installed. Rope and washer pump, diesel/petrol pumps, and solar pumps are common examples of water lifting devices installed for wells drilled by using tube well technology in Ethiopia (Fig. 20)

Figure 20 manually drilled tube well installed with diesel engine pump

Step 28: Well Development

Following completion of well drilling and installation, well development is necessary to increase its specific capacity, prevent sanding, and obtain maximum economic well life. These results are accomplished by removing the finer materials from the natural formations surrounding the perforated sections of the casing. The purposes of well development are to:

- Increases the rate of water movement from the aquifer into the well.
- Stabilizes the aquifer to prevent sand pumping, thereby producing better quality water and increasing the service life of the pump cylinder and well.
- Remove organic and inorganic material from the well screen and the gravel pack and then to improve the flow condition to the manual tube well.

Over pumping (continuous or interrupted over pumping) is commonly used well development method.

Step 29: Pumping Test

In hydrogeology, a pumping test is a controlled field experiment in which a well is pumped at a controlled rate and water-level response (drawdown) is measured.

Pumping test can be done as follows:

i. Measure the distance to the water level in the well.

ii. Then turn on and operate the pump at about one-third its capacity for 1 to 4 hours.

iii. During the pumping, measure the yield of the pump by filling a container of known volume and recording the length of time it takes to fill it. For small containers, the flow rate in litres per minute (lpm) can be calculated using Equation 4:

Q=V/time

$$Q = \frac{V}{t} * 60 ----------------(4)$$

Where:

Q pump flow rate in lpm

V volume of container (litres)

T time taken to fill the given container (se)

60 constant used to change the time taken from second to minute

Example: 2
The diesel pump installed in one tube well site took 30 second to fill 220 litre oil drum. Then what will be the pumping rate in lpm?
Solution
Q= 220/7=7.33 lit/s or
Q= 7.33*60= 440 lpm---Answer

iv. At the end of the pumping period, measure the water level as soon as the pump is turned off.

v. Calculate the drawdown by subtracting the original depth of the static level from the new depth after pumping.

vi. Calculate the "specific capacity" of this one-third drawdown point by dividing the yield (how many litters collected in the barrel in one minute) by the drawdown.

vii. Repeat this process pumping at two-thirds of the pumps capacity and then again at full capacity.

viii. If water level measurements are frequently taken during drawdown and recovery, hydro geologists can use the information to calculate aquifer characteristics (transmissivity and storativity) which can be used to help develop local groundwater development plans.

ix. A trench should be prepared ahead of time to carry this water away from the measuring container so that it does not pond around the well.

Step 30: Estimating Specific Capacity of a Tube Well

The Specific Capacity of a well is simply the pumping rate (yield) divided by the drawdown (Fig. 21).

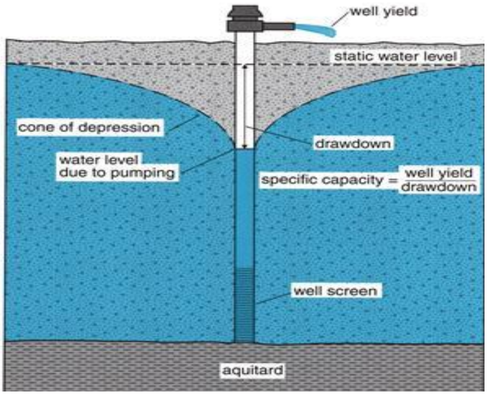


Figure 21 Groundwater Situation during Pumping

It is a very important parameter that can be used to provide the design pumping rate or maximum yield for the well. It can be used to identify potential well, pump, or aquifer problems, and accordingly to develop a proper well maintenance schedule.

Example: 3
From a typical well driller's log the pumping test was run for 8 hr when the yield (480 lpm) and the drawdown (1.5 m) were measured. The Specific Capacity can be calculated as 320 lpm/m (see also the example given for drillers log):
$Specific\ capacity = \frac{Q}{S}$
Where Q=Flow rate (lpm)
S=Draw down (m)
Driller's log: Example
Water level and yield of completed well
Depth of static water level from the ground surface = 8 m
Depth of static water level from pump house base = 2 m
Calculated yield = 8 lps = 480 lpm
Test type = diesel pump
Test length = 8 hour
Total draw down = 1.5 m

Step 31: Potential Well Yield Estimation

Specific capacity can be used to estimate well yield potential. The pumped rate on the well log may not be the pump rate of the planned system. The question is, "What is the maximum yield expected from this well?

Example 4: (note: the calculation given in this example should be verified with a real test, but this procedure helps determine whether the real test is likely to succeed or fail).

- Well yield from well log = 4 lps=240 lpm
- Drawdown from well log = 1.2 m
- Calculate specific capacity = 240/1.2 = 200 lpm/m
- Water level (static) from well log = 8.35 from the ground surface, or = 2.35 from the pump house base (pump house depth =6 m)
- Total well depth from well log = 57 m from the ground surface
- Calculate available drawdown = 57 m – 8.35 m= 48.65 m. However, this will be true for other types of pumps for example submersible pumps, where the pump is installed inside the well at the bottom. Therefore, for diesel pump where having maximum lift of 6 m, the available draw down will be = (depth of pump house + 6 m = 12 m) minus water level (static) = 12 m – 8.35 m= 3.65 m
- Then, the estimated potential yield with diesel pump will be = specific yield divided by available draw down depth = 200 lpm /m * 3.65 = 730 lpm

Step 32: Estimating Well Recovery

Well recovery can be estimated by turning off the pump and measuring how long it takes for the water in the well to return to the pre-pumping level. For this purpose, measure the water level every minute for 10 minutes, then every 5 minutes for half an hour, then every 15 minutes for an hour and then every half hour until recovery is complete. These readings can be used by hydro geologists to analyze the aquifer.

8. POSSIBLE PROBLEMS AND CHALLENGES TO TUBE WELL DRILLING MANUAL

Possible problems or challenges and measures that should be taken during tube well drilling and installation of pump are discussed as follows:

- Excessive Drilling Fluid requirement
- Drilling Pipe Jamming
- Objects Dropped into Well

- ➢ Encountered Hard Rock Bed
- ➢ Decreased Well Yield

9. WELL CONSTRUCTION RECORD

A manual tube water well construction record should be prepared for each well that is drilled. The record is used to guide future drilling, to ensure that the well casing and screen extends across the appropriate thickness of the aquifer. The recorded data is useful if maintenance and repair need arises in the future. Well records should include the information on the following parameters (Annex 1):

- Well location
- Client (owners) information
- Drillers information
- Pump house excavation
- The geologic character of each formation;
- Drilling description
- Reaming
- Well casing and Screen
- Screen mesh wire
- Pump and pumping
- Well development
- Well yield (lpm)
- Estimating well recovery (hr)
- Potential well yield estimation
- Water quality
- Drilling fluid
- Drilling performance and cost

10. REQUIREMENTS FOR SUSTAINABILITY

Groundwater is one of the water source found in a natural reservoir in which if not wisely used could be finished or depleted or its depth become deeper and deeper in which it could not accessible for the majority of people using low cost tools. In this regard, for sustainable use of groundwater resources, groundwater-development must be implement with appropriate groundwater recharge technique and groundwater recharge techniques should be considered as mandatory prerequisite.

Any development plan should be environmental friendly. Human activities often affect environmental values by degrading the environment or by discharging contaminants into water. Gender equality box

11. GENDER BOX

What are the issues of gender inequality?

This module is designed to help experts and development agents to assist trained local people and to train people with no spring development experience, to meet its purpose, at chapter 5,6 and 7 it is stated community consultation is required, therefore, female and male beneficiaries may not consulted equally during potential identification and water demand estimation, experts may not consider the relevancy of female beneficiary's knowledge on spring development, and the available time of both female and male to mobilize for spring construction

How can the gender inequalities be addressed?

Consult female and male farmers as source of local knowledge to develop reliable spring and get relatively actual water demand estimation and construction team should consider the different roles and responsibilities during scheduling for activities

What will be the benefits when gender inequalities are addressed?

Farmer's (female and male) will benefit from sustainable spring and quality water availability

1. Limitation

Promotion of manual tube well techniques will be difficult in the area where the soil formation is hard (granite, basalt,, etc) and the groundwater depth is as deep as over 30 meters

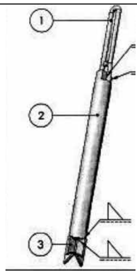
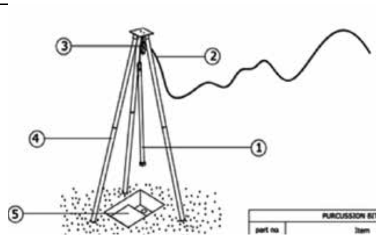
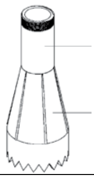
REFERENCE

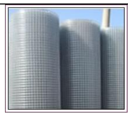
MOANR, (2018). Guideline for manual tube well drilling and installation for household irrigation in Ethiopia. A practical guideline for woreda experts and development agents in Ethiopia second edition (Hune, et al (Ed), 2018). Addis Ababa, Ethiopia.

Annex 1: Tools and Equipment required for drilling using simple sludge and percussion method

S/N	Items with Specification	Unit	Qty	Responsibility for Provision of Tools and Equipment	Image
1	**Layout and Pump House Excavation (if required)**				
1.1	Measuring tape(30 m)	Pcs	1	Beneficiaries	
1.2	Measuring tape (5 m)	Pcs	1	Beneficiaries	
1.3	Nylon rope (thin-layout)-3 mm	Roll	1	Beneficiaries	
1.4	Spade	Pcs	5	Beneficiaries	
1.5	hoe	Pcs	5	Beneficiaries	
1.6	Wooden ladder (7 m long)	Pcs	2	Beneficiaries	
2	**Drilling**				
2.1	Measuring tape(30 m)	Pcs	1	Driller	
2.2	Measuring tape (5 m)	Pcs	1	Driller	
2.3	Working cloth, boots and helmet	Set	1	Driller	
2.4	First aid kit (for 25 people)	kit	1	Driller	
2.5	Pipe wrench, 36'' , 24" and 18"	Set	1	Driller	

2.6	Chain pipe wrench	Pcs	1	Driller	
2.7	Pipe cutter (½ – 4")	Pcs	1	Driller	
2.8	Pipe thread maker (½ – 4 ")	Pcs	1	Driller	
2.9	Metal hack saw frame with blade	Pcs	1	Driller	
2.15	Mason hammer (1kg)	Pcs	1	Driller	
2.10	File (flat)	Pcs	1	Driller	
2.11	Metal bucket (16 lit)	Pcs		Driller	
2.13	Chain (12mm)	m	12	Driller	
2.14	Nylon rope (thick)- 12 mm	m	20	Driller	
2.15	shovel	Pcs	1	Driller	
2.16	Metal bucket (16 lit)	Pcs	2	Driller	
2.17	Wood poles (14 cm diameter and 3.10 m long – 2 Pcs), (10 cm diameter and 1.80 m long, 1 Pcs), 8 cm diameter and 2.8 m long, 1 Pcs)	Pcs	4	Driller	
2.18	GIP (1½"diameter and 0.5 m long)	Pcs	1	Driller	
2.19	GIP (1½"diameter and 1 m long)	Pcs	1	Driller	Same as image under S/N
2.20	GIP (1½"diameter and 1.5 m long)	Pcs	1	Driller	
2.21	GIP (1½"diameter and 3 m long)	Pcs	1	Driller	

2.22	GIP (1½"diameter and 6 m long)	Pcs	9	Driller	
2.23	Coupling (1 ½")	Pcs	15	Driller	
2.24	Percussion tool (50-70kg)	Pcs	2	Driller	
2.25	Percussion bit accessories	Set	1	Driller	
2.26	Different drilling bits (3-5)	Set	1	Driller	
3	**Reaming**				
3.1	GIP (20 cm long 3"GIP welded with 1½ " coupling)	Pcs	1	Driller	
3.2	GIP (20 cm long 4" GIP welded with 20 cm long 3" GIP welded with 1½" coupling)	Pcs	1	Driller	
3.3	GIP (20 cm long 5" GIP welded with 20 cm long 3" GIP welded with 1½ " coupling)	Pcs	1	Driller	

4	**Casing and screening and gravel pack**				
4.1	GIP (3" diameter and 6 m long B-Class, 42 kg)	Pcs	2	Beneficiary	
4.2	Perforated GIP (3" diameter and 6 m long) 12 mm hole diameter	Pcs	1	Beneficiary	
4.3	Coupling (3")	Pcs	3	Beneficiary	
4.4	galvanized mesh wire screen (1mmx1mm hole size and 1mm wire diameter) 1 m wide and 3 m long	Pcs	1	Beneficiary	
4.5	River gravel (1 – 2 mm diameter)	m^3	1	Beneficiary	
5	**Pump Installation**				
5.1	Diesel pump (3", 5hp, 30 m total head, 16 l/s)	Pcs	1	Beneficiary	
5.2	PVC reinforced flexible suction hose (5 mm thickness)	m	25	Beneficiary	
5.3	20 cm long 2½" galvanized pipe welded with 3" galvanized pipe coupling	Pcs	1	Beneficiary	
5.4	PVC reinforced flexible suction hose (5 mm thickness)	m	1.5	Beneficiary	
5.5	Hose clap, 3"	Pcs	3	Beneficiary	

5.6	Hose connector (aluminum), 3"	Pcs	1	Beneficiary	
5.7	Screw driver (flat and Philips)-one each	Pcs	1	Beneficiary	
5.8	Teflon, medium	roll	3	Beneficiary	
5.9	Diesel fuel for pump test	lit	10	Beneficiary	
5.10	Oil for diesel pump	lit	2	Beneficiary	

Module-4

Rooftop Rainwater Harvesting

1. INTRODUCTION

1.1 Background

This module is in a series of the ten modules in the House Hold and Micro Irrigation (HHMI) competencies in Ministry of Agriculture (MoA). It is believed to support the development and implementation of household micro irrigation initiative in Ethiopia.

1.2 Purpose and Scope of the Training Module

The module help us as a training material and enhance the knowledge and skill of woreda experts and Development Agents (DA's) on Rooftop Water Harvesting techniques. It can also be used as a field manual. This Module focuses on key aspects of Rooftop Water Harvesting techniques which includes; definition, where to apply, advantages, basic components, planning and design aspects, construction steps, common problems and solutions and operation and maintenance on HHMI.

1.3 Concept and Definition of Rooftop Rain Water Harvesting

Definition: Rooftop Catchment Rainwater Harvesting is a system of catching rainwater where it falls. In rooftop harvesting, the roof becomes the catchments, and the rainwater is collected from the roof of the house/building. It is the process or technique of collecting and storing rainwater for future productive use. It can either be stored in a tank or diverted to artificial recharge system. This method is less expensive and very effective and if implemented properly helps in augmenting the groundwater level of the area.

Roof Top Rainwater harvesting (RTRWH) is a technology used for collecting and storing rainwater from rooftops, the land surface or rock catchments using simple techniques such as jars and pots as well as more complex techniques. Commonly used systems are constructed of three principal components; namely, the catchment area, the collection device, and the conveyance.

1.4 Benefits of Rainwater Harvesting

- Can provide domestic water supply
- Reduces the cost for pumping as the storage tank is in most cases is above ground
- Provides high quality RAIN water, which is soft and low in minerals
- When recharged to ground water it improves the quality of groundwater through dilution
- When applied to significant scales in urban areas reduces soil erosion and flooding

- Compared to groundwater abstraction and piping through long distances the rooftop rainwater harvesting is less expensive
- Rainwater harvesting systems are simple and divisible which can be adopted by individuals
- Rooftop rainwater harvesting systems are easy to construct, operate and maintain
- Relatively cheap materials can be used for construction of containers and collecting surfaces
- Construction methods are relatively straightforward
- Once fixed with relatively high capital costs it has low maintenance costs and requirements
- Collected rainwater can be consumed without treatment provided a clean collecting surface is used
- Provides a supply of safe water close to homes, schools or clinics, encourages increased consumption, reduces the time women and children spent to collect water, reduces back strain or injuries from carrying heavy water containers

2. BASIC COMPONENTS OF ROOFTOP RWH SYSTEMS

Each rainwater harvesting system consists of three basic components:

- Catchment or roof surface to collect rainwater
- Delivery system to transport the water from the roof to the storage reservoir (gutters and drainpipes)
- Storage reservoir or tank to store the water until it is used
- First flush or rain separator or washout pipe as it is called, has a valve or an end cap to allow the little amount of rainwater to be collected
- Filter is very important in keeping the rainwater in the storage tank clean. It removes silt, dust, leaves, and other organic matter from entering the storage tank.

Below: different parts of rooftop RWH systems parts are described and also in Figure 1.

2.1 Rooftop (Catchment)

a) Rooftop is the part of an rain water harvesting (RWH) system that receives rainfall and drains the water into a storage facility through a conveyance system Roofs have to be impervious, durable and clean, to make them free from contamination/bacteria, dissolved material and debris. The smoother and more impermeable the collection surface, the less debris will accumulate, keeping the stored water cleaner.

b) Types of roofing materials: roofing material used for domestic RWH are such as corrugated iron sheets, corrugated plastics and tiles. All are suitable to serve as catchment surfaces; however, corrugated iron sheets are the most ideal and the most rapidly expanding as they are smoother, and the high temperatures help in sterilizing bacteria.

c) Factors to be considered: There are some important factors about the roof to consider when planning for rooftop RWH system:

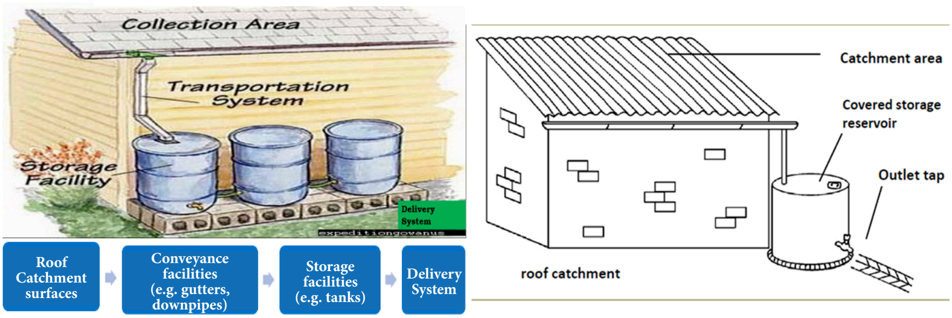


Figure 1: Basic components of rooftop RWH systems

- The material the roof is made of: a metal roof it easily sheds contaminants. Though, asbestos is not common in Ethiopia and should not be used - it is a contaminant by itself.
- Rooftop water harvesting systems are best suited where the roofing material is smooth and coated with chemically neutral substances or should not be painted
- Roof materials suitable for this purpose can be of many sorts, depending on technology, natural conditions and affordability
- The most commonly used roofing materials are galvanized corrugated iron (noncorrosive sheet metals) and aluminum as they are less prone to build-up contamination from dust, leaves, animal droppings and other debris. The corrugated iron sheets are available on markets and affordable by average farmers and very common in rural areas.

Slope: The slope of the roof affects how quickly water will runoff during a rain event. A steep roof will shed runoff quickly and more easily clean the roof of contamination. A less-steep, flatter roof will cause the water to move more slowly, raising the potential for contamination to remain on the catchment surface. The roof on the right has a steep slope followed by a more gradual slope.

Sizing a Catchment Area: The size of the catchment area or roof will determine how much rainwater that you can harvest. The area is based on the "footprint" of the roof, which can be calculated by finding the area of the building and adding the area of the roof's overhang.

Conveyance Systems

a) Conveyance systems: components of RWH systems that collect water from catchment surfaces and transport it to the inlets of storage facilities. In roof catchment conveyance systems gutters and down pipes constitute the most common roof catchment conveyance systems. These are fixed on roofs (even without RWH systems) to protect walls and to safely dispose away water without causing erosion on the ground next to buildings (Figures 2, 3 and 4).

b) Design Considerations of Conveyance Systems: this part will mainly look into considerations for the planning and design of gutters and downpipes

Gutters: are channels all around the edge of a sloping roof to collect and transport rainwater to the storage tank. Gutters can be semi-circular, square, rectangular, V-shape/triangular and can be made using:

- Locally available material such as plain galvanized iron sheet (20 to 22 gauge), folded to required shapes
- Semi-circular gutters of PVC material can be readily prepared by cutting those pipes into two equal semi-circular channels
- Bamboo trunks cut vertically in half

Materials for conveyance system

- Plain galvanized iron (GI) sheet that can be folded to required shapes
- Semi-circular gutters of PVC material that can be prepared by cutting those pipes in to two equal semi-circular channels
- Bamboo trunks by cutting vertically in half

Figure 2: Semicircular (from PVC) and angular (GI) shapes of gutters in sequence

Figure 3: Rooftops fitted with conveyance systems

The size of the gutter should be according to the flow during the highest intensity rain. It is advisable to make them 10 to 15 per cent oversized Gutters need to be supported with brackets so they do not sag or fall off when loaded with water. The way in which gutters are fixed depends on the construction of the house. It is possible to fix iron or timber brackets into the walls, but for houses having wider eaves, some method of attachment to the rafters is necessary

The usual problems include the following:

- ➢ Gutters clogged with debris and not cleaned,
- ➢ Not properly sloping,
- ➢ Not intercepting runoff properly,

- Overflowing, making use of only part of the roof area, twisted, leaking, broken and not repaired.

Down pipes: are pipelines or drains that carry rainwater from the catchment or rooftop area to the harvesting system. It can be of any material like polyvinyl chloride (PVC) or galvanized iron (GI), materials that are commonly available.

Materials of downpipes:

- Polyvinyl chloride (PVC) pipes are available on market with various sizes
- Low cost local materials can also be used for down pipe

Shapes

Round down pipe	
Square downpipe	
Contour downpipe	

Figure 4: Materials for gutter and downpipe

Table 1: Guiding to sizing of gutter-downpipe relationship for a given roof area (Source: WWW: sopac.org)

Roof area (m2)	Gutter width (mm)	Minimum diameter of downpipe (mm)
17	60	40
25	70	50
34	80	50
46	90	63
66	100	63
128	125	75
208	150	90

Rainwater Storage Facilities

Storage facilities: are facilities used to receive collected water from the conveyance system. It is the most expensive component of RWH system, which sometimes leads to direct use of rainwater. It is therefore, necessary to pay due attention to selection, design and construction of reservoirs, always keeping in mind cost aspects along with other considerations.

Types of Storage Facilities: There are three broad categories of storage facilities; Surface tanks or above ground tanks, Sub-surface tanks or underground tanks and in ground tanks (combinations of the first two)

Table 2: Storage facilities

No	Storage facilities	Descriptions	Advantages	Disadvantages
1	Surface tanks or above ground tanks	Surface tanks are used for harvesting water from elevated catchment surfaces, e.g. large roofs. The materials used for construction are ferrocement, blocks (of concrete, brick and rubble stone), concrete in situ, plastic, metals and wood. The tanks should be watertight, durable, affordable, and non-contaminant	➢ Water can easily be abstracted by gravity; ➢ Allow for easy inspection of cracks and leakages; and ➢ Smaller sizes render themselves for central production and transportation, which is good for the quality control of certain tank types such as plastic or ferrocement	➢ They are relatively expensive when compared with subsurface storage tanks; and ➢ Required space, generally a problem in urban areas ➢ During construction, there is a need of formwork (mold) to keep the right shaped
2	Sub-surface tanks or under ground tanks	Subsurface tanks are mostly associated with the purpose-built ground catchment surfaces; they are however, used for roof catchments as well. They share much of the features of surface tanks regarding construction material and methods. Sub-surface tanks are built in excavated ground where the soil is backfilled upon completion.	➢ The costs are cheaper than surface tanks. This is due to cheaper designs resulting from tanks benefited by the support of the surrounding ground; ➢ They are appropriate in places where space above ground is limited; and ➢ The water is cooler.	➢ Pump or some kind of abstraction device (such as rope and bucket) is required to access water. An alternative to this is to construct steps (access ramps) to a tap stand from where the water can be abstracted by gravity. ➢ When they use ground catchments, they suffer from contamination and sediment inflow. ➢ Leakages and failure is difficult to detect; and ➢ They cannot be easily drained for cleaning.

Sizing the storage facility

The proper sizes for your catchment surface and your water storage tank depends on how often and how hard it rains at your home, as well as on how much water you and your family use.

Step 1. Determine Your Annual Water Demand. The first thing that you need to do is to figure out how much potable water you and your family need each day

Step 2. Determine the Amount of Rainfall You Can Capture

Step 3. Determine How Big Your Storage Tank Needs to Be

The storage capacity should be at least double the total water requirement to take care of evaporation and seepage losses. As a rough guide, 10% extra storage may be provided for sediment deposition. For example, if the total annual water requirement is 10,000 cum and pond /tank will have only one filling, its gross capacity should be 22000 cum (2 x 10,000 + 10%).

Water Application Methods (for irrigation)

- Depending on the timing of the growing crops, quantity of stored water and type of crop, either supplementary or full irrigation is possible

- Water application methods with the maximum water saving can be used. For instance, manual (Can or bucket), drip, or manual sprinkling methods are recommended in order to maximize the water efficiency (See Figure 5 and 6).

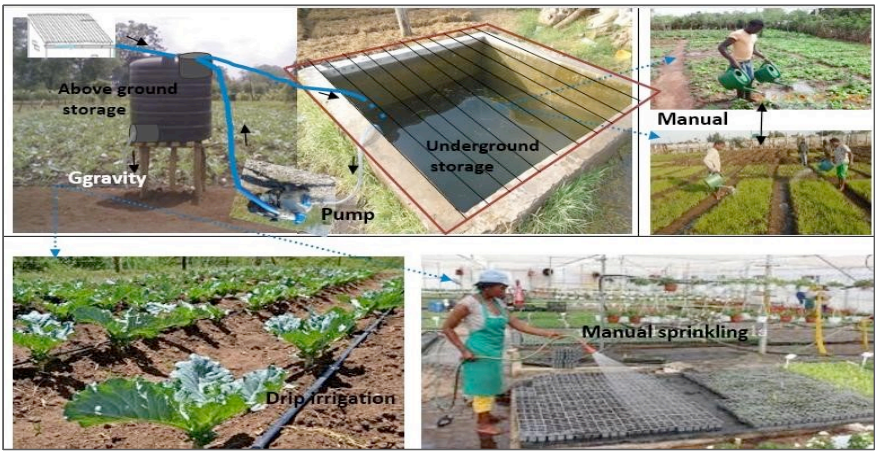


Figure 5: Recommended water abstraction methods in roof-top water harvesting practices

photo: taken at Melkassa Research Institute

Figure 6: Water distribution systems

3. PLANNING AND DESIGN CONSIDERATIONS FOR ROOFTOP RWH SYSTEMS - MULTIPURPOSE USE

3.1 Planning Rooftop Water Harvesting Systems

The basic planning of rooftop water harvesting should consider the multipurpose use of the collected water for irrigation of vegetables in backyard, seedling plantation, and domestic uses, drinking for house hold and animals, and groundwater recharge. An example of a simple planning of rooftop water harvesting for multipurpose water uses is shown below (Figure 7).

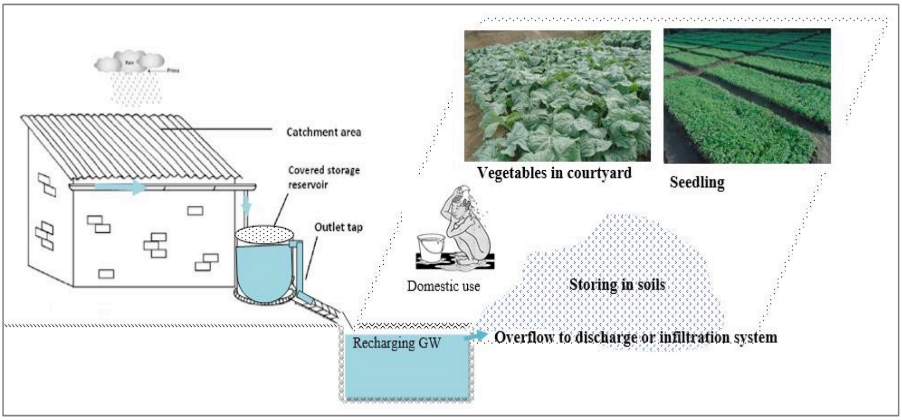


Figure 7: Multipurpose use of rainfall harvesred on rooftop

3.2 Design of Rooftop Rainwater Harvesting Systems

3.2.1 Estimation of runoff amount from a given catchment area

How much water is collected from a given catchments area is the key consideration in the design of water tanks. Rainwater yield varies with the size and texture of the catchments area. A smoother, cleaner, and more impervious catchments area contributes greater quantity of runoff water. In general, the amount of runoff from a catchment depends on the following things:

- The size of the catchment: large areas produce more runoff.
- The type of the surface the rain falls on: sand and grass absorb more water than compacted and rock surfaces.
- The intensity of the rain: light shower has a chance to sink into the ground. Heavy or continuous rains produce more runoff, especially late in the rainy season when the soil is already wet.
- The slope and length of the catchment: the steeper and shorter in length, the more runoff will be generated. Steep slops with long length however, will produce less runoff. The flat the area, the less will be the runoff.

To estimate the amount of runoff from a catchment, one must know the size of the catchment and the average amount of monthly or annual rainfall. Then multiply by the percentage of runoff (amount of runoff generated from the seasonal or the annual rainfall amount), which is termed as runoff coefficient (K), (Equation 1).

$$K = \frac{R}{P} \text{ -}(1)$$

Where,

R=Runoff amount (mm)

K=Runoff coefficient (%)

P= Long term annual or monthly rainfall depth (mm)

In principle, **1mm of rainfall on an impervious catchment area, can generate 1 liter of runoff water per square meter.** However, due to several factors, the rainfall that falls on a particular catchment area may not be totally resulted as runoff. The expected runoff volume is therefore, the expected design rainfall multiplied by the runoff coefficient and the area of the catchment (Equation 2).

$$Runoff\,(mm) = K * Ra\inf all\ depth(mm) * catchment\ area \text{ - - - - - -}(2)$$

In rural catchment where no or only small parts of the area are impervious, the runoff coefficient (K), which describes the percentage of runoff (R) resulting from a rain storm (P), is however not a constant factor. Instead its value is highly variable and depends on the catchment specific factors and the rainstorm characteristics (total rainfall and rainfall intensity).

There is limited information on coefficients for various soil, surface conditions and slopes. However, the most comprehensive information available is summarized in table 3 and 4.

Table 3: value of runoff coefficient, K for various materials under different rainfall regime

No.	Surface type	Rainfall Regime		
		250 to 500 mm	**500 to 1000 mm**	**1000 to 1500mm**
1	Corrugated iron sheet	0.80 - 0.90	0.80 - 0.90	0.80 - 0.90
2	Tile	0.65 -0.80	0.70 - 0.85	0.80 - 0.90
3	Asbestos sheets	0.8 0- 0.90	0.80 - 0.90	0.80 - 0.90
4	Organic (thatch)	0.20	0.20	0.20
5	Concrete floor	0.75 - 0.85	0.75 - 0.90	0.80 - 0.90
6	Bricks	0.30 - 0.40	0.35 - 0.45	0.45 - 0.60
7	Rock/ stone floor	0.70 - 0.80	0.70 - 0.85	0.70 - 0.85
8	Agricultural field	0.15 - 0.30	0.25 - 0.40	0.35 - 0.55

9	Soil compacted	0.40 - 0.55	0.40 - 0.60	0.50 - 0.65
10	Plastic floor / roof	0.85 -0.92	0.85 - 0.95	0.85 - 0.90
11	Grass covering – sparse	0.08 - 0.15	0.15 - 0.30	0.30 - 0.50
12	Grass covering – dense	0.06 - 0.15	0.15 - 0.25	0.25 - 0.45

Source: Hudson (1981)

Table 4: value of runoff coefficient, K for different topography and land use

Topography and Vegetation	**Soil Texture**		
	Sandy Loam	**Clay and silt loam**	**Clay**
Wood land			
Flat (0-5%)	0.1	0.3	0.4
Rolling (5-10%)	0.25	0.35	0.5
Hilly (10-30%)	0.3	0.5	0.6
Pasture			
Flat 0.1	0.3	0.4	
Rolling	0.16	0.36	0.55
Hilly 0.22	0.42	0.66	
Cultivated			
Flat 0.3	0.5	0.6	
Rolling	0.4	0.6	0.7
Hilly 0.52	0.72	0.82	
Urban	30% of the area is impervious	50% of the area is impervious	70% of the area is impervious
Flat 0.4	0.55	0.65	
Rolling	0.5	0.62	0.8

To estimate the volume of runoff (how much of the rain becomes runoff-R) from a give catchment area, it is necessary to determine the frequency and duration of rainfall.

Total annual runoff is referred to as water yield. The minimum water yield should be used to determine the catchment area needed to ensure that the storage fills even in dry year. If water needs equal to storage capacity, then, shortage of water will occur when the annual water yield is not sufficient to fill the storage. If storage is greater than water needs, then some water can be carried over to a dry year. Estimates of runoff depend on the availability of rainfall and stream flow records, and the longer and more reliable the records the more reliable will be the estimates.

Equation 3 can be used to estimate the amount of runoff (Q)

$$Q = \frac{K*P*A}{1000} \text{ - } (3)$$

Where; Q = Runoff (m3)

A = Catchment size (m2)

K = Runoff coefficient (R/P)

P = Seasonal or annual rainfall (design) mm

1000= conversion factor millimeter to meter

Example 1

Suppose a farmer in rainfall regime receiving annual design rainfall of 700mm has 40m2 corrugated iron sheet roof, 60m2 dense grazing plot and 50m2 soil compacted yard, estimate the total volume of runoff generated from the catchment surfaces.

Solution

From Table 3 The value of runoff coefficients (average) for the available catchment types are:

- Corrugated iron sheet roof = 0.85
- dense grazing plot = 0.20
- soil compacted yard= 0.30

Then, the volume of runoff (Q)amount from each catchment area can be computed as follows:

$$Q1 = \frac{P \times A1 \times K1}{1000} = \frac{700mm \times 40m2 \times 0.85}{1000}$$

$$= 23.8 \text{ m3}$$

$$Q2 = \frac{P \times A2 \times K2}{1000} = \frac{700mm \times 60m2 \times 0.2}{1000}$$

$$= 8.4 \text{ m3}$$

$$Q3 = \frac{P \times A3 \times K3}{1000} = \frac{700mm \times 50m2 \times 0.3}{1000}$$

$$= 10.5 \text{ m3}$$

The total volume of runoff that can be generated from the total catchment areas will be:

QT = Q1 + Q2 + Q3

= 23.8 m3 + 8.4 m3 +10.5 m3

= 42.7 m3

3.3 Estimating household and livestock water demand

Since the amount of household water consumption varies according to the living condition, it is very difficult to precisely assess the quantity of household water demand. Household water demand includes the water required for drinking, cooking, bathing, sanitary purpose, and water supply for small animals, etc.

There are wide variations in the use of water in different seasons, months of the year, days of the month, and hours of the day. The normal variation in demand should be assessed and known in order to design water tanks. The volume of water-stored will not only relate to available runoff that can be harvested but so also to the cost of the storage. Other important considerations in a household context that relates to storage provided are:

- Season (dry seasons)
- Family members
- Livestock number in the household
- Distance from the existing water sources
- Availability of donkeys or other transport facilities
- Type and availability of water containers
- Activities at home/ other demands on time
- Amount and quality of water at sources
- Travel time and waiting time at water sources
- Health and age

The per capital domestic demand defined as the annual average amount of daily water requirement by one person and it can be expressed as Equation 4:

$$Per\ capital\ demand\ (lit\ /\ day) = \frac{Total\ yearly\ water\ requirement\ per\ person\ (lit)}{365} ------(4)$$

The objective in designing of water tanks must be therefore to reduce the burden on the rural households in a pre-determined number of years in such a way that the farmer can achieve the benefit and can also replicate the system. In determining the household consumptive use, the standard developed by World Health Organization (WHO) and adapted to local conditions is given in Table 5.

Table 5: Water demand for various types of consumer (liter/day)

S/N	Category	Demand/survival (liter/day)
1	Domestic use	
	Water source > 1000 m distant	10
	Water source 500-1000 meter	15
	Water source < 250 meter	20
2	Cattle	25
3	Equine	20
4	Sheep and goat	10
5	Donkey	20
6	Camel	50
7	Poultry (liter/100 birds/day)	15
8	Pigs	15

To get the total water demand by the household each day, multiply the above figures by the number of people, (or by each type of animal).

Depending on the estimated water consumption figure for people and livestock in a certain area, the water demand for a month or year can be estimated using the Equation 5.

$$D = \left[(N*Q)+(n*q)\right] * T * 1.2 ------------------(5)$$

Where; D= domestic and livestock water demand in liters per year

N= average number of people in a household

Q= average daily water consumption per person in the area

n= average number of livestock in a household

q= average daily consumption per livestock per day

T= number of days per year/month for which the stored water supply is needed

1.2=20% = extra allowance for number of people and number of livestock in a household and increased consumption due to ease access

Example 2

A household of five people keeps two goats, two oxen, one cow and one donkey. How much water do they need in a day and a month? How much in a year?

Solution

Use equation below to calculate the daily demand:

N = number of people in the household
Q = daily consumption (people)
n = number of animals
q = daily consumption (animals)
T = number of days for which the stored water supply is needed
1.2 = allowance for water losses (20% plus the demand)

Therefore;

People =5*15=75 liters per day
Oxen =2*25 =50 liters per day
Cow =1*25 =25 liters per day
Goat =2*10 =20 liters per day
Donkey=1*20=20 liters per day
Total water needs per day=75+50+25+20+20=190 liters per day
Total water needs per month=190*30=5700 liters per day
Total water needs per year=5700*12= 68400 liter per year, or about 69m3 per year.

4. CONSTRUCTION OF ROOFTOP STORAGE FACILITY SYSTEMS

4.1 Selection of Materials

Materials for Storage: Selection of the type of storage facility ultimately depends on purpose of use, affordability, availability of supplies and materials, and know-how in design and installation. Some of the recommended storage tanks are the following:

4.2 Types of Tanks

Ferrocement tanks:

- Ferro-cement consists of a thin sheet of cement mortar which is reinforced with a cage made of wire mesh and steel bars (Figure 8)
- Ferro-cement tanks constitute a comparatively inexpensive technology, which requires little maintenance and can last long
- Step by step construction of ferrocement

Masonry tanks

- It can be constructed locally available backed bricks, cut stones, compressed-soil blocks, solid cast concrete and quarry (Figure 9)

- A bar of steel is also placed vertically in alternating holes of the blocks
- The insides of cisterns should be finished first with a carefully applied mortar mix and then coated additionally with a non-toxic sealant

Plastic tanks

- Light-weight, easily installed, water-tight and do not corrode
- The cost can vary depending on the volume capacity
- Provide adequate shading (light penetration through the tank wall will result in algal growth and other biological activity thereby degrading the water quality (Figure 10)

Drum tanks / oil drums

- Tanks are simple and cheap
- Suitable for use in crowded settlements, where space is limited and roofs are small

Warning: wash before use as most drums have previously contained oil

4.3 Construction Procedures

In this section, commonly known and widely used small-rainwater ex-situ storage structures in Ethiopia (10-100m3 capacity) are presented. Step by step construction procedures supported with the pictures, diagrams and sketch are also presented.

4.4 Ferro-cement rainwater tank (10m3)- Rooftop rainwater harvesting

1. Select appropriate site, which is 3 meters away from the wall of the building /the house (Fig. 7).

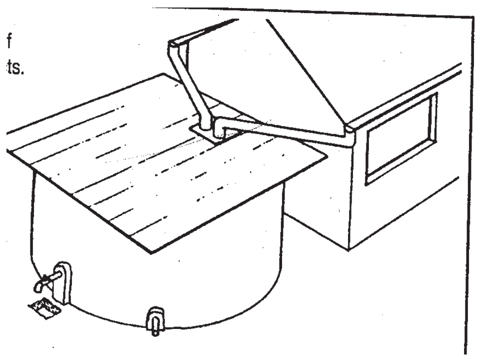


Figure 8: Step 1- Fero cement rainwater tank construction

2. Clear soft-top soils of the site so that the tank is constructed on firm ground.

3. At the center of the cleared site, hammer one wooden peg. Tie a rope to the center peg equal to 1.75-meter-long (1.5 m radius, 20 cm foundation footing and 5 cm wall thickness (Fig. 8)

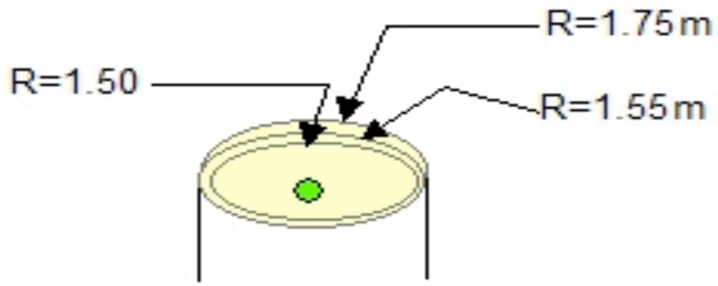


Figure 9: Step 3-Fero cement rain water tank construction

4. Draw a circle using the tied rope (1.75 m long)-Fig 9

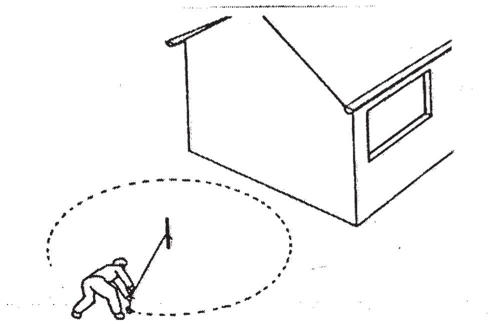


Figure 10: step 4-Fero cement rain water tank construction

5. Remove the soil inside the marked circle to a depth of 50 cm (if the soil is stable, otherwise the depth can be increased) (Fig 10).

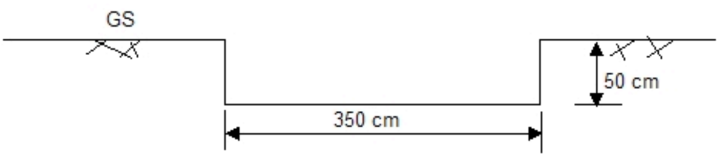


Figure 11: Fero-cement rain water tank construction

6. Fill stone foundation to the depth of 35 cm (Fig 12).

Figure 12: step 6-Fero cement rain water construction

7. Put 5 cm thick lean concrete on the top of stone fill (1:3:4).
8. On the top of the lean concrete lay horizontal steel reinforcement (10 mm diameter) at 20 cm spacing with the same diameter of vertical steel at 40 cm interval. Bend the horizontal steel as shown in Fig. 14.

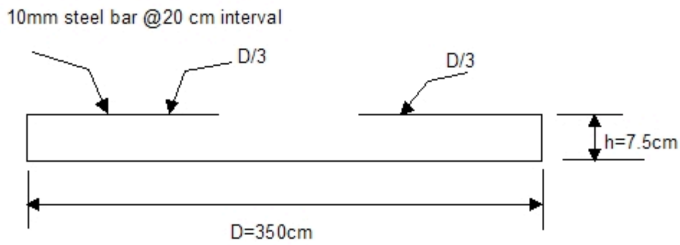


Figure 13: Step 8-Fero cement rainwater tank construction

9. Fix vertical and horizontal steel bars as shown in Fig. 14.

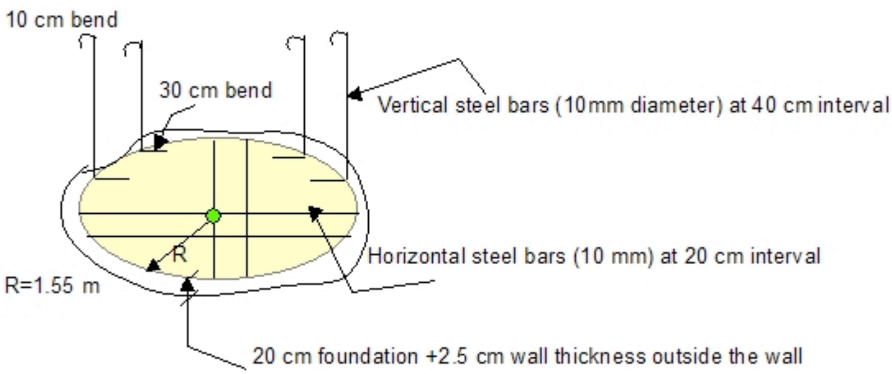


Figure 14: step 9-Fero cement rain water tank construction

10. Then fill 10 cm thick concrete (1:3:4) on the top of steel reinforcement bar (Fig. 15)

Figure 15: step 10-Fero cement rain water tank construction

11. Install galvanized pipe 3/4” for delivery and drainage. The delivery galvanized pipe should be fitted with elbow and nipple while the drainage is without nipple but with elbow and the elbow fixed leveled with the final concrete floor.

12. The vertical steel bars need to remain vertical and make sure that they are very firm.

13. Spread 25 mm of cement mortar across the floor of the tank. Make the surface of the mortar flat, but roughen it by scratching or brushing it. Work as quickly as you can.

14. Before the cement hardens, carefully lay one layer of wire mesh across the floor of the tank. Bend it up wards at least 300 mm between the vertical steel bars so it can be cast into the wall formed outside the bars. Tie the meshes together using black wire. Stand or kneel on planks of wood to spread your weight and not to damage the first layer of mortar. Sprinkle water on the first mortar surface if it has begun to dry out (Fig. 16).

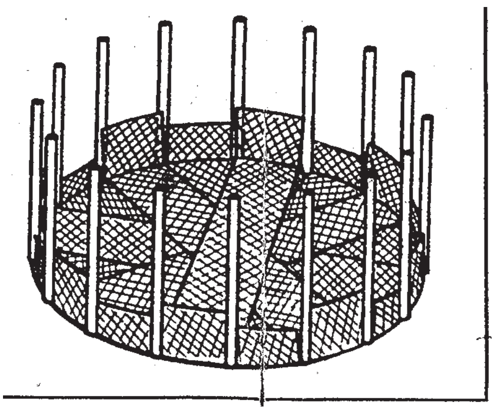


Figure 16: Step 14-Fero cement rain water construction

15. Then quickly add another 25 mm layer of mortar. You must now keep the surface for the new mortar damp until the whole tank is finished.

16. Wrap the inside of the tank wall with bamboo mat held in place with a spiral of string (Fig. 16).

Figure 17: Step 16-Fero cement rain water construction

17. Extend the wire mesh (step 14) up to the top of the bamboo formwork and vertical steel bars and tie it to the steel bars with black wire.

18. Strengthen the mesh by winding a continuous spiral of wire (diameter 6 mm) around the wall of the tank. The rings of wire should be 15 cm apart near the bottom of the wall, increasing to about 30 cm apart at the top. An extra ring of wire should be used right at the top of the wall. Place a pipe and tap through the wall 10 cm above the floor and hold the pipe firmly in place by tying it to a strong pole driven into the ground (Fig 18).

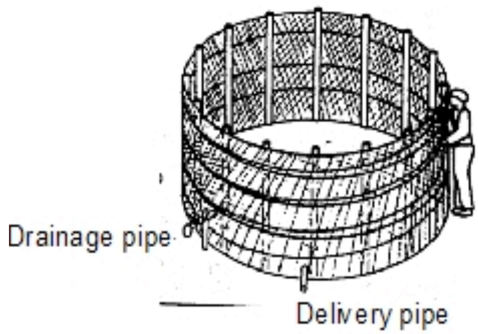


Figure 18: Step 18-Fero cement rain water tank construction

19. Begin plastering the tank walls from the outside with cement-sand (1:2) mortar to a thickness of 1.5 cm. If available, use gravel 10mm for 1:2:3 mix. Scratch or brush the surfaces to make them rough. After a day, add

a second layer of 1.0 cm thick mortar to the dampened outside surface of the tank, giving it a smooth finish (Fig 19).

Figure 19: Step 19-Fero cement rain water tank construction

20. Three days later remove the bamboo mat and plaster the inside part of the tank as the same thickness done for the outside part of the tank. Now add a final smooth layer of the tank and to the floor.

21. For waterproofing, apply a coat of cement and water slurry (nil) on the same day as the final coat of plaster for the walls (inside and outside) and the floor. Again, keep surface damp all the time. Support the delivery pipe on the outside. Make a small pit under the faucet so that a bucket can fit under it.

22. Make the whole tank damp for at least three weeks before filling. Leave some water in the tank to prevent from drying. The tank should be watered three times a day for about 21 days.

23. Cover the tank with appropriate roofing material to keep out dirt and insects and also to prevent water losses through evaporates. You can use corrugated iron or a deemed Ferro cement roof. The roofing should have a manhole (60x 60 cm) and an inlet (20x20 cm) and screen ventilation. Fill the tank very slowly with water (Fig. 19).

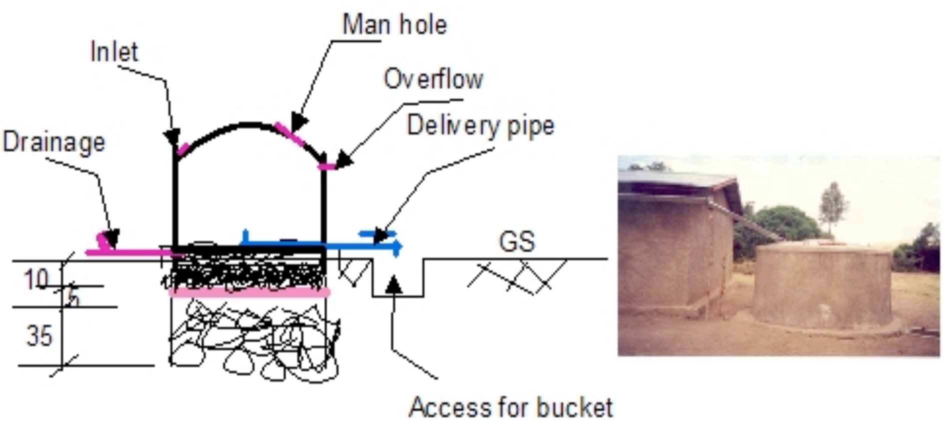


Figure 20: Step 23-Fero cement rain water tank construction

24. If you find any cracks, you can repair them when the tank is empty by chipping away the mortar from the mesh and then filling the hole with fresh mortar. Keep this repair damp for at least two weeks.

5. MANAGEMENT OF ROOFTOP RAINWATER HARVESTING SYSTEMS

5.1 Operation and Maintenance

Once a roof catchment rainwater harvesting system is in place, it requires certain management system/mechanism that is capable of ensuring the proper operation, maintenance and repair of the RWH system. The users themselves, unlike design and construction, which in many cases are initiated and implemented by experts, do the management of Roof RWH systems. The users of Roof RWH systems could be individual households, institutions such as schools, or communities for whom the RWH systems are built for communal use.

The management of RWH systems needs to lay out clear duties and responsibilities in respect of the following items.

- ➢ The management arrangement/system and responsibilities;
- ➢ Physical safety and protection of the RWH system;
- ➢ Maintenance and control of water quality;
- ➢ Operation, maintenance and repair of the system; in any case, proper maintenance is an important aspect in the management of RWH systems and needs to include, among others, the following activities;

- Inspection, regular cleaning and minor repair of the whole RWH system; the catchment, the conveyance, the tank and the various tank components such as tap
- Removal of branches of trees over hanging on roofs. Not only leaves and debris, but also the droppings of birds and small animals contaminate rainwater. Dust and other such dirt also need to be cleaned regularly from the catchment/roof
- Supplies can be contaminated by bird/animal droppings on catchment surfaces and guttering structures unless they are cleaned /flushed before use – disconnection of first rain wash from the system and need of reconnecting after
- Poorly constructed and maintained water jars/containers can suffer from algal growth and invasion by insects, lizards and rodents and need of cleaning
- They can act as a breeding ground for disease vectors if they are not

properly maintained

- Cleaning and minor repair of the conveyance system (gutters and downpipes/gutters) at least once a year
- Inspection of water quality in the tank, testing from time to time and treating/disinfecting regularly
- There should be no opening that allows small animals to enter into the tank
- There should be no tree growing within 10 m from the tank to protect the foundation from damage/crack by roots searching for moisture underneath
- The harvested water may not be used efficiently and if consumed luxuriously using it for various purposes, such as; household water use, livestock water use, and small-scale irrigation there will not be water for critical dry times. Therefore, inspect regularly the amount of water in the tank, and compare with demand and abstraction rates

Repair of Rainwater Tanks

The repair of RWH tanks, unlike maintenance, it is one of the most important tasks in the management of RWH systems. The repair of tanks normally involves locating leakage points and making them water tight.

(a) Leakage between wall and foundation (joints)

(b) Leakage through a cracked foundation

(c) Leakage through walls without cracks

(d) Leakage through cracked walls

(e) Repair of leaking ferrocement tank walls

(f) Plastic and metal tanks

5.2 Treatment of Stored Rainwater

The aim of water treatment is to make water safe (from harmful substances/ chemicals and organisms); to make it good in appearance and attractive for human consumption. There are various methods and stages of water treatment which include screening, sedimentation, filtration (with fine granular materials such as sand and gravel), disinfection, and miscellaneous other treatments to reduce chemical levels, improve taste, hardness etc. The treatment of rainwater is done in the tank itself or after it is drawn and taken home. Various treatment methods are mentioned as follows:

(a) **Chlorination:-** Chlorination either is done in the tank or after the water is collected and taken home. Chlorine is very effective in killing microorganisms, but requires care because it can affect the taste of water and over application may cause certain problems.

(b) **Use of filters:-** Sand filters are simple to use and cheap to acquire. They filter fine suspended material and much of the bacteria, and improve physical qualities such as color, taste and odor.

(c) **Boiling:-** Boiling for two to three minutes makes water free from any harmful bacteria. However, it is not always a practical option, as it requires of fuel, and needs waiting for the water to cool.

(d) **Sunlight:-** Putting water in clear glass or plastic bottles, and placing it in direct sunlight for several hours kills both bacteria and other microorganisms.

6. GENDER EQUALITY BOX

What are the issues of gender inequity?

Water scarcity especially for domestic and agriculture purposes compromises the role of women in food production. Though women are mostly responsible for water at household level decisions for investment in major rain water harvesting technologies are made by men. Men might overlook its importance for domestic purpose and only focus on its agricultural purposes. Provision of water using technologies like rooftop rain water harvesting reduces the burden on women and increases their production, but women might lack enough knowledge about the impact of the technology on their life and might not participate on the planning, designing, construction and management of the technology.

How can the gender issues be addressed?

The water collected is used by both men and women and the whole family. So, there could be a joint decision between men and women on how to invest on the technology and how to use the water. Facilitate an inclusive planning and design process in which women and men articulate their domestic and productive water needs as equal opportunities for improved livelihood. Responsible bodies have to give training to both men and women farmers on the technology and its impact on their life to know its pros and cons before deciding to use them.

What will be the benefits when gender issues are addressed?

Reduction of women fatigue and time required for fetching water will enhance their involvement in productive works, household micro irrigation and other productive works. They start producing vegetables which reduces expenses for buying vegetable for household consumption and the family members will able to eat different fresh and nutritious food varieties. Adoption rate of farming households will increase recognizing the benefit.

7. ENVIRONMENT AND SOCIAL FREINDLYNESS OF ROOFTOP RWH

Rainwater can have a major impact on water supply and has been shown to be able to reduce household water demand enough that large in areas where new public water sourcing projects are impossible or become unnecessary. Rainwater harvesting systems counteract storm water runoff and thereby reduce flooding, erosion and ground water contamination.

Further rooftop rainwater harvesting can:

- Protect homestead area and local watershed
- Be means to drought-proof, flood-proof
- Restore the hydrologic cycle by recharging the groundwater
- Reduce the carbon footprint by enhancing biomass growth and maintaining healthy soil
- Lessen the effects of wet and dry spells
- Mitigate the impacts of climate change

Socially rooftop rainwater lessons the drudgery work on women and children. It can also stimulate the culture of working together if individual households are organized in groups for labor sharing system.

Lack of economic capacity to materialize rooftop rainwater harvesting remains a challenge to be addressed by both the government and development partners.

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ANNEX CASE STUDY

Rooftop Rainwater Harvesting Initiatives in Minjar Shenkora Woreda

Story by Hune Nega and Aschalew Demie

Minjar Shednkora Woreda is located in Noth Shoa zone of the Amhara Regional State of Ethiopia. The Woreda capital town is known as Arerti and is at a distance of 60 km from Mojo Town on the main road Mojo to Debre Birhan. Mojo town is the seat for Lome Woreda in East Shoa zone of Oromia regional State and is located 70 km from Addis Ababa on the Adama Addis main Road.

The majority (about 90-95%) of the people in Minjar Shenkora Woreda are residing in a rural village, dense settlement mosaic, while the settlement pattern of few households is scattered. About 75% of the households in the woreda have simple wooden and corrugated roof houses without compartments. In Minjar Shenkora Woreda there are only 3 perennial rivers, and are far from villages. The main sources of drinking water for rural people of the Woreda are community pond. Few households own plastic lined (geomembrane) ponds (Figure 15 and 16).

Figure 21: Plastic lined household pond

Figure 22: Clay lined community pond

According to information collected from the Woreda, the groundwater condition is very poor and its depth on average is about 241 meters. Water shortage for human and livestock as well as irrigation is the major development constraint in the Woreda. In the critical months of February to June, when community and household ponds are completely dry due to high evaporation, seepage and over consumption, women and children from various rural Kebeles travel as far as 15-25 Kms to Arerti town and Kesem River to collect water for domestic needs and livestock watering. On average, 8-10 Jerrycan, of 20 liters capacity, is collected by each household per day using donkeys and camels from distant locations (Figure 17).

Figure 23: Collecting domestic water from distance

To improve the problem of water in the Woreda, a Water Cellar installation project financed by China Foundation for Poverty Alleviation (CFPA) and Xuzhou Construction Machinery Group (XCMG) was initiated in 2016/17. The project was implemented by Ethiopian Rainwater Harvesting Association (ERHA). The Water Cellar project was implemented at household level (farm level). A total of 40 households (about 200 people) from Kiticha (15) and Chele (25) Kebeles were able to benefit from the project. The structures were of two types i.e. below and above ground tanks. Below ground tanks are 19 and above ground tanks are 21 in number.

According to the information from the local community, the project is successful and the intervention would be sustainable and beneficial and can be considered as a learning ground for future implementation of similar projects in Ethiopia. The main reason as to why it is believed to be sustainable is connected with modality of implementation approach followed. The project was implemented at household level and there was full participation from beneficiary farmers at all stages of planning and construction of the structures.

The project is envisaged to address water shortage problem and improve the access of water for human, livestock, and home irrigated gardening. From this project, large numbers of women and children living in the two Kebeles have started reaping the benefit and will continue to benefit from reduced drudgery work of traveling long distances as far as 6000 km every year. This is assuming 20 km per day travel and considering 300 dry days per year.

Abebayehu Tarekegn is 35 years old and is one of the project beneficiaries of the project. Abebayehu lives in Chele Kebele and Geyed village /Gott of Minjar Shenkora Woreda. The Kebele is located at 15 Km from Arerti town towards North East direction. Abebayehu is married and has a daughter and a son. Including two of Abebayehu's relatives, they are six in the family. As part of the project beneficiary /participant, he was selected to construct underground dome shaped rainwater tank of 32m3 capacity. The roof area of the family is about 50m2. During construction, Abebayehu with his family fully participated in digging the dome shaped pit (See Figure 18). The pit is 3.2 m diameter and 5 m depth (See Figure 19).

Figure 24: Above ground and below ground water cellars from roof top

Figure 25: Underground dome shaped tank of 32 m3 capacity

In addition, the entire family provided support for technicians during masonry work, steel fixing, gutter fixing as well as transportation of construction materials from common points to the place where their structure was constructed. Costs related to excavation of the whole dome shaped tank and assistance to technicians during construction was fully covered by Abebayehu's family.

Industrial construction materials like cement, steel, PVC and other local materials such as sand which are transported from distance places were supported by the project. In addition, all technical supports like masonry, steel fixing, gutter fixing and carpentry work was supported by the project. According to the project document, the unit cost of the roof top rainwater harvesting system including material, labor and administration was about 2000 USD.

Abebayehu and his family are happy now because they have easy access to an important commodity; water, which is very scarce resource in the area where they live. Previously, Abebayehu and his family members were traveling every day about 5 km to fetch water for domestic and livestock use. To this particular village, the challenge was not the distance, but so also the water source in which it is very narrow underground pit (locally know as Ela) where only a group of men together go inside the well for abstracting from the depth 15-20-meter-deep by making a line.

Currently, the family is benefiting from harvested water at its homestead. The water in the tank is used for various uses such as household use including drinking, watering of livestock including sheep and growing of few fruit trees at the homestead garden. The Health Extension Agent is closely working with households having rainwater harvesting structures for her/his guidance on the use of stored water for various uses including drinking. The extension support includes how to treat stored water with different treatment techniques commonly known and advised by the Woreda Health office.

Moreover, because of the rainwater harvesting facility, Abebayehu's family has engaged in fattening of sheep (about 70 in number), small poultry farm (See Figure 20). On average the family is using 5-6 Jerry cans per day (each Jerry can 20 liters) to run the sheep fattening and poultry. From the sales of sheep, he gets 11,000 Birr net profit after fattening for 5 months.

Figure 26: Scene of sheep fattening in the barren and small poultry farm by Abebayehu

Additionally, using about 6-8 Jerry cans per week, the harvested water is applied for fruit trees growing such as Mango (4), papaya (15), guava (1), lemon (2) and Hopes /Gesho - planted on a 20*20m plot. Realizing the importance of the limited stored water, Abebayehu is trying to use various water saving technologies such as, plastic water container, watering cane and soil improvement with micro basin, and mulching (See Figures 21 and 22). Moreover, Abebayehu's family water demand for household and livestock use is improved through these rainwater harvesting initiatives.

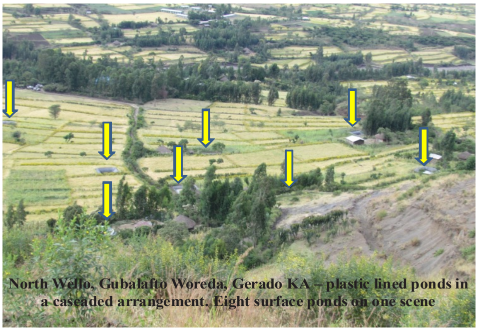
In general, because of the ease access for water at the homestead, one can read from Abebayehu's face that he is happy showing confidence on his life. His income is expected to increase in the future from the sales of various fruit tree and the sales of livestock commodities.

Figure 27: Homestead fruit tree and hopes cultivated including water saving techniques

Figure 28: Bucket lifting that result in drudgery and less quality water still remains a challenge

Module-5

Farm Pond Water Harvesting



1. INTRODUCTION

1.1 Background

This module on Farm Pond Water Harvesting Techniques is in a series of the ten modules in the HHMI competencies in Ministry of Agriculture (MoA). It is believed to support the development and implementation of household micro irrigation initiative in Ethiopia.

1.2 Purpose and Scope of the Module

The module helps as a training material and to enhance the knowledge and skill of woreda experts and SA's on farm pond construction. It can also be used as a field manual. This Module focuses on key aspects of farm pond which includes; definition, where to apply, advantages, basic components, planning and design aspects, construction steps, common problems and solutions and operation and maintenance on HHMI.

2. CONCEPT AND DEFINITION OF WATER HARVESTING FARM POND

Water harvesting is the collection and concentration of rainwater and runoff and its productive use for:

- The irrigation of annual crops, pastures and trees
- Domestic consumption
- Livestock consumption
- Fish and duck ponds

Farm pond is a dug-out structure with definite shape and size having proper inlet and outlet structures for collecting the surface runoff flowing from the farm area. It is one of the most important rainwater harvesting structures constructed at the lowest portion of the farm area. A farm pond must be located within a farm drawing the maximum runoff possible in a given rainfall event.

2.1 Where to use Farm Ponds

Farm ponds are used:

- In areas where there are no natural or permanent water sources
- In areas where rainfall is not sufficient to meet the demand by crops
- In areas where there is shortage of water for livestock
- In areas where water is needed for domestic use

2.2 Classification of Farm Ponds

Farm ponds can be classified by: their site or location, shape, ownership, and lining materials

Pond classification by site of construction or location:

Dug-out pond: these ponds are usually constructed on gently sloping or flat areas. The whole pond volume is excavated by digging the soil needed for water storage. Here the volume of water to be harvested is almost equal to the volume of soil /debris that needs to be excavated. Sometimes these ponds are referred as subsurface. The photo of the pond on the cover page is dug-out pond. At times, the ponds are considered to collect surface runoff from farm area into a local depression or the lowest portion of the farm so that the excavation is minimum except to construct the earthen bund surrounding the water body. Such farm ponds do not require inlet provision but is should have outlet provision in the earthen bund to remove the excess flow.

Embankment pond: These are earth dam type ponds by partial excavation and filling /constructing the embankment on the lower side where /when the topography permits. They are mostly carried out within natural cricks, depressions or valleys. Contrary to dug-out ponds these are referred as surface storage ponds. In this case, compared to the dug-out ponds, there is a potential advantage of gravity supplying water by gravity the target (i.e. irrigated area) – See figure 4.

Shape: ponds can be square, trapezoidal or circular. When trapezoidal, as a rule of thumb, the longer side divided by the shorter side should not be greater than 1.5. Circular can be hemispherical or frustum of a cone.

Ownership: ponds can be constructed by individual households or communities. Based on the ownership it is usually common to understand them as household or community.

Lining materials:

a) Clay lining – is when earthen clay soil is used as a lining material with compaction to control seepage. The clay can be found from site or brought in from other clay rich sites (See Figure 1).

b) Soil and cement mixed lined pond – for sandy and high seepage soils surface of the pond is lined with soil mixed with cement. Usually this mix of cement to soil is like 1:6.

c) Masonry lining – is when stone masonry work is used (See Figure 2).

Figure 1:Clay lined pond in Jama, Wello, Ethiopia

Figure 2: Farm pond in the Hararghe Highlands with stone masonry lining

d) Concrete lined pond – these are expensive lining materials as both iron and cement works are needed. In stable and non-cracking soils then reinforcement with chicken mesh and plastering with cement mortar can work (See Photo 3).

e) Plastic or geomembrane lining – these are factory made impermeable materials /liner for retention of water. They are used in areas where the soil is sandy, high permeability, vertic soils

Figure 3: reinforced concrete lined pond under construction

Figure 4: Embankment type of pond (Source: ICARDA 2001, Sirya)

2.3 Advantages of Farm Ponds

- They provide water over the dry season to grow crops. Also, they provide irrigation water during dry spells between rainfalls. This increases the yield of crops in one year, and the diversity of crops that can be grown.

- Water can be harvested in farm ponds to raise seedlings of vegetables and fruit trees so that time would not be lost as the raised and ready seedling can be planted immediately at the setting in of the Belg or Keremt rains

- Can be used to raise, thus supplying the farm household with an additional source of income and of nutritious food

- They check soil erosion and minimize siltation of waterways and reservoirs

- They supply water for livestock and domestic purposes

- They promote fish rearing

- They recharge the groundwater when not lined

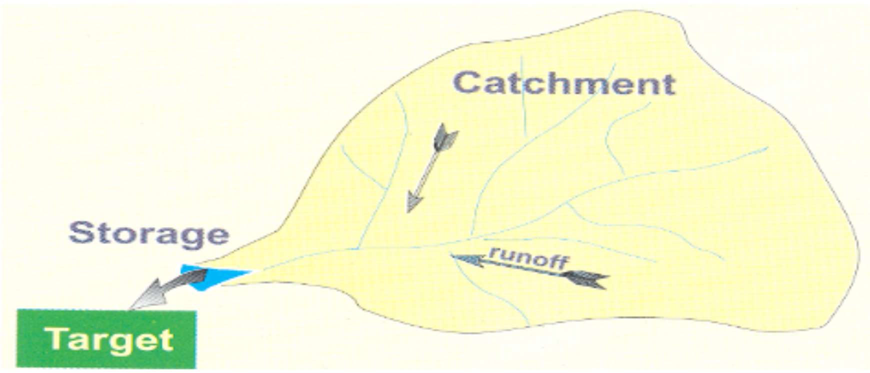


Figure 5: Catchment delineated for rain water / runoff harvesting system

3. COMPONENTS OF WATER HARVESTING SYSTEM

3.1 Catchment

Catchment is an area where the water /runoff collected from. Rainwater / runoff from catchment is made to concentrate and contributes some or all its share of to a target area. It can be an agricultural area or purposely prepared for runoff harvesting (degraded /marginal area, stony area, bench terraced area, etc.). Sometimes paved grounds such as roads, school grounds, and home yards can be used as catchment. These are at times referred as borrowed catchments. The catchment area can be as small as a few square meters or as large as large as a square kilometre.

3.2 Runoff delivery/Conveyance Systems

Delivery system/Conveyance system – is the means how the runoff is channeled /directed to the silt trap or pond (e.g. open ditches, pipes). Ditches are made of compacted earth, or lined with cement or other materials. Sometimes the delivery system includes temporary diversion from natural waterways and in this case, ponds are sited at the end of waterways or cut-off drains.

3.3 Silt Trap or Sediment Pond

Silt trap is a structure used to separate /filter out suspended materials and silt from entering the pond. It is used to allow the sediment to settle which is being carried by the runoff from the ground catchment area. It is dug at least 3m away from the storage pond to prevent water from over topping during heavy rains and damaging the pond. If the runoff has no sediment, the structure may not be necessary.

It is important to properly select the location of the pond to easily collect the runoff. In case of ground catchments, sometimes it is necessary to build interception ditches on the slope to guide the water to the diversion channel. Depressions or primary sediment pits are used along the diversion channel or flow way to settle sediment as much as possible before entering silt trap.

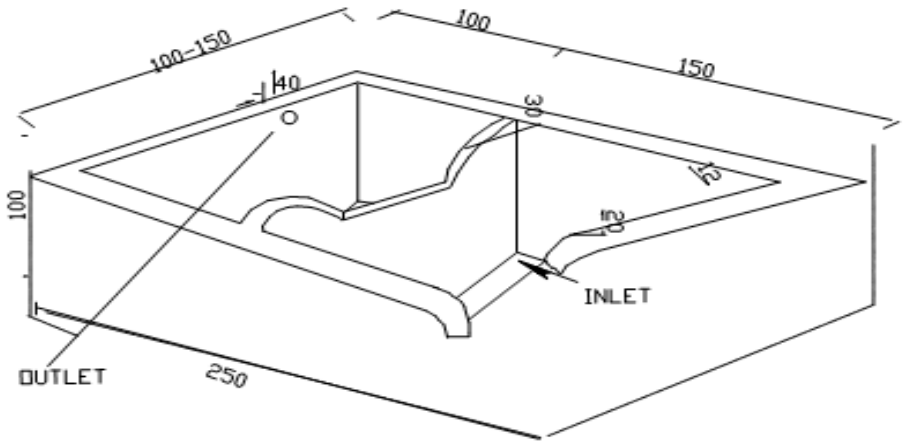


Figure 6: Design / layout silt trap or sediment stilling basin

Designing Silt trap/sediment pond: Its size is determined according to sediment characteristics and flow discharge. If a lot of sediment is expected, a two-chamber silt trap is recommended - one chamber to catch sand, and the second one to trap finer material. A filter mesh is used to trap leaves, twigs and other debris before the water drains into the pond. From the experience of Ethiopian condition, the recommended size of silt trap is 100cm deep, 250cm long and 100-150cm wide. The compartment is made at a distance of 150 cm from the inlet and the spillway is made on the compartment at 30cm depth and 40cm width. The channel from the catchment to the silt trap is connected at a depth of 20 cm and width of 40cm. The outlet from the silt trap to the storage tank is made with 10-15 cm pipe laid at a depth of 40 cm and a filter is provided at the mouth of the outlet.

3.4 Storage Facility

It is the place where runoff water is stored from the time it is collected until it is used. Different size and shape of surface and sub-surface storage structures are available. The water storage pond usually represents the biggest capital investment element of a system. It therefore, usually requires the most careful design to provide optimal storage capacity and structural strength while keeping the costs as low as possible. It should be noted that in excavated ponds the volume of excavation equals the storage volume. So, it means water: soil (storage: excavation) ratio is 1:1. In the case of embankment ponds this should be minimum 3:1. Generally Water: Soil Ratio of <2 is said to be Poor; 2-4 Moderate; 4-6 High; and >6 is Very High.

3.5 Water Abstraction System

It is the means used to deliver the stored water to the command area. This abstraction could be gravity system where the storage area has sufficient head to deliver the water; or pumps may be used. The pumps can be manual or engine.

3.6 Command Area

It is the land area where the harvested water is beneficially used for crop production. The size of the irrigable area depends upon the amount of water harvested from the runoff area. The harvested water can also be used for other water needs such as domestic and livestock consumption.

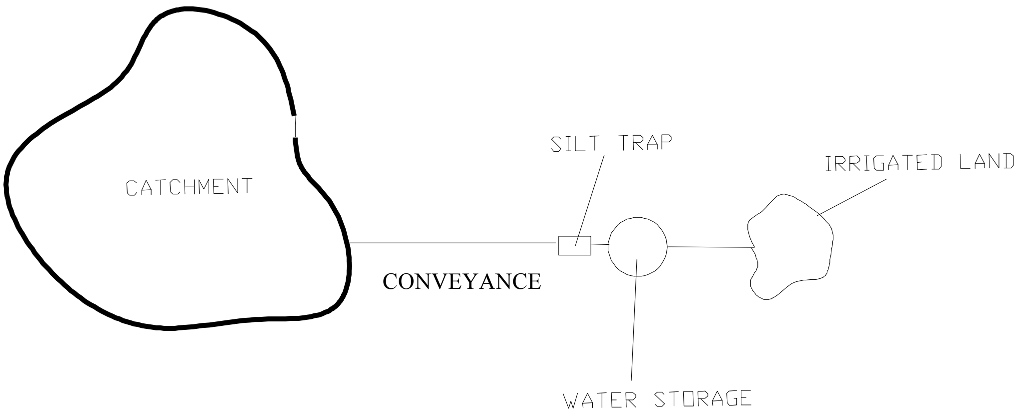


Figure 7: Relative position of catchment, conveyance, silt-trap and irrigation area

4. SITE SELECTION ASPECT OF FARM POND

Sitting of farm pond considers the following by also involving key and experienced experts:

- Presence or absence of other easily accessible alternative permanent water sources should be explored first
- The critical criteria to be considered are sufficient size and suitability of the land for catchment, pond site and command area
- The site selected should not create upstream and downstream conflict
- The soil survey should be conducted so as to determine whether the soil textures at the selected site are suitable (clay, silty clay or sandy clay) and have a low permeability and a friable nature to a depth of at least 3 m
- If the soil has a clay content of less than 30%, especially below the top 1m, it will have high permeability and the site should be rejected because water losses by seepage will be excessive
- A hardened layer or soil with very high clay content (more than 60%), will reduce the workability of the soil and significantly reduce the excavation rate
- After the site selection and pond dimensions decided, the pond site should be cleared of all stones and woody vegetation
- Before construction of farm pond, proper layout should be made for proper construction
- The design drawings for farm pond with silt trap, inlet and outlet construction should be properly laid down (for the various options in site selection see Figures 8, 9, and 10).

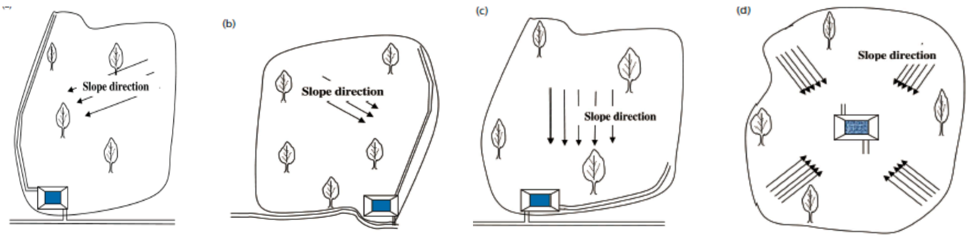


Figure 8: Runoff collection methods depending slope direction of catchment

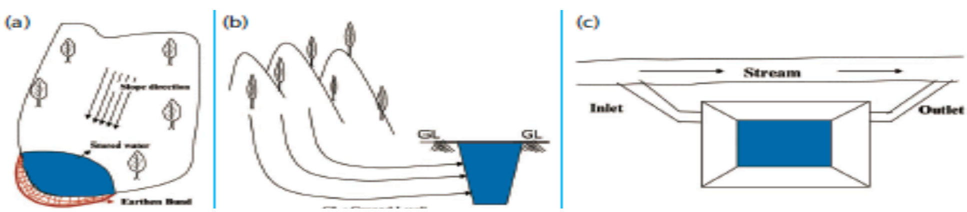


Figure 9: Type of storages

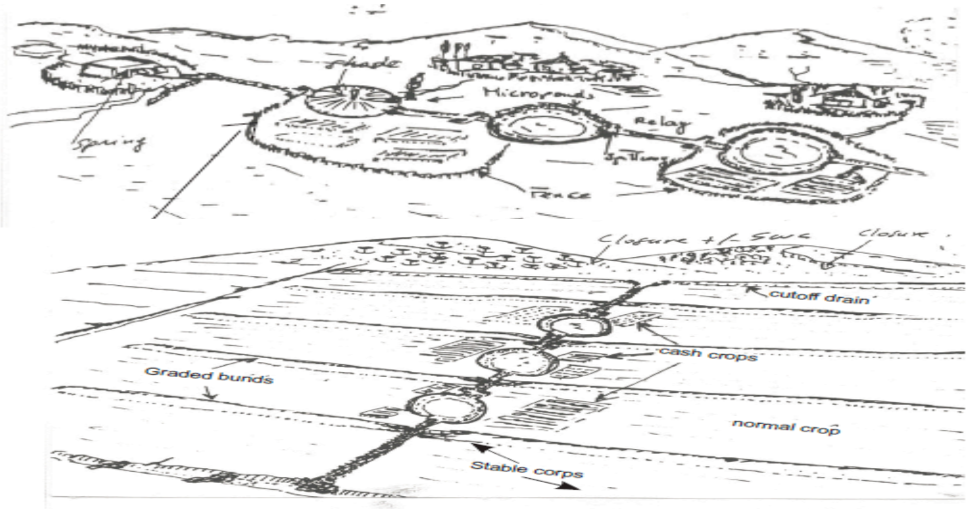


Figure 10: Relay / series ponds strong high overnight flow - linked by stone paved waterways

5. DESIGN CONSIDERATIONS

5.1 Estimating Runoff

In low rainfall areas or areas where the rainfall is of uneven distribution, more care has to be taken to size the storage properly. The amount of runoff harvested or rainfall, size of catchment area and its characteristics determines the storage capacity. The factors affecting surface runoff are rainfall characteristics, topography, vegetation, soil type, and antecedent soil moisture. In order to determine the potential rainwater supply for a given catchment, reliable rainfall data is required, preferably for a period of at least 10 years. The volume of water that can be collected from the catchment can be calculated using the standard formula developed. An estimate of the approximate mean annual runoff (water harvested) from a small catchment can be obtained using the following equation.

Annual Runoff = Mean annual rainfall x Catchment area x Runoff coefficient (See Table 1)
On the other hand, the required size of the catchment area can be determined by using the following equation (Gould and Peterson, 1999 and MOA, 2002).

$$A = \frac{1000V}{PK}$$

Where, A: catchment area (m2)

V: Water storage capacity, m3

P: Annual rain fall (mm) and

K: Rainwater collection efficiency for a given catchment

Table 1: Runoff Coefficients

	FLAT	ROLLING	HILLY
Pavement & Roofs	**0.90**	**0.90**	**0.90**
Earth Shoulders	0.50	0.50	0.50
Drives & Walks	0.75	0.80	**0.85**
Gravel Pavement	**0.85**	**0.85**	**0.85**
City Business Areas	0.80	**0.85**	**0.85**
Apartment Dwelling Areas	0.50	0.60	0.70
Light Residential: 1 to 3 units/acre	0.35	0.40	0.45
Normal Residential: 3 to 6 units/acre	0.50	0.55	0.60
Dense Residential: 6 to 15 units/acre	0.70	0.75	0.80
Lawns	0.17	0.22	0.35
Grass Shoulders	0.25	0.25	0.25
Side Slopes, Earth	0.60	0.60	0.60
Side Slopes, Turf	0.30	0.30	0.30
Median Areas, Turf	0.25	0.30	0.30
Cultivated Land, Clay & Loam	0.50	0.55	0.60
Cultivated Land, Sand & Gravel	0.25	0.30	0.35
Industrial Areas, Light	0.50	0.70	0.80
Industrial Areas, Heavy	0.60	0.80	**0.90**
Parks & Cemeteries	0.10	0.15	0.25
Playgrounds	0.20	0.25	0.30
Woodland & Forests	0.10	0.15	0.20
Meadows & Pasture Land	0.25	0.30	0.35
Unimproved Areas	0.10	0.20	0.30

Note:

- *Imperviou surfaces in bold*
- *Rolling+ ground slope between 2 percent to 10 percent*
- *Hilly+ ground slope greater than 10 perc*

Spillway

- The spillway is the most important outlet and has to be designed to accommodate the anticipated maximum flood. It has to be a permanent structure that will not erode and is located at a level that allows for the required water depth and freeboard ascertained at the site selection and investigations stage.
- Natural spillways are generally best for ponds but often some degree of cut is required to obtain the necessary design slopes
- For grass spillways, the erosion hazard is an important consideration. Therefore, this type of spillway should be horizontal at its entrance, ideally with a concrete or masonry sill to level the entrance and control velocities and erosion. It can have a slight cross fall (but no more than 5o) across the spillway and must have a safe outfall to return floodwaters to the stream. Allowable flow velocities will depend upon depth of flow (and in turn affect the freeboard) and the floor material of the spillway.
- Guidelines to follow are presented in Table 2. The guidelines assume that an earth spillway is level and grassed with good, mat-forming creeping grass.
- Any movement of machinery over the spillway area should be minimized to avoid over compacting the existing soil, establishing track ways (which

could lead to erosion later) and destroying any existing grass cover.

- Where a cut is required it should be kept to a minimum and, unless unavoidable, should not involve complete removal of the topsoil. If the latter does occur, over cut will be necessary, the additional depth being required because good quality topsoil and grass cover will have to be placed once the desired profile has been attained.

Table 2: Guideline discharge and velocities for conveyance and spillways

Type of surface materials	**Sand to sandy loam**	**Sandy loam to sandy clay loam**	**Sandy clay loam**	**Light clay**	**Heavy clay gravel friable rock**	**Hard rock**
Max velocity (m/s)	0.30	0.60	0.75	1.00	1.25	1.50
Flow depth (m) at spillway entrance	0.15	0.30	0.50	0.60	0.75	1.50
Discharge (m3/s per m width)	0.05	0.20	0.35	0.60	1.00	2.50

5.2 Estimating Water Demand and Losses

Water demand (water requirement) in general is the sum of irrigation water requirement, drinking water for livestock and humans and losses (see Figure 10). It is important to account for water losses (20% efficiency factor in Ethiopia) during the storage by seepage and/or evaporation and during distribution and application of water. Therefore, after calculating the demand, the availability of the supply should be checked from the proposed catchment. At least the supply must be greater than the demand including losses.

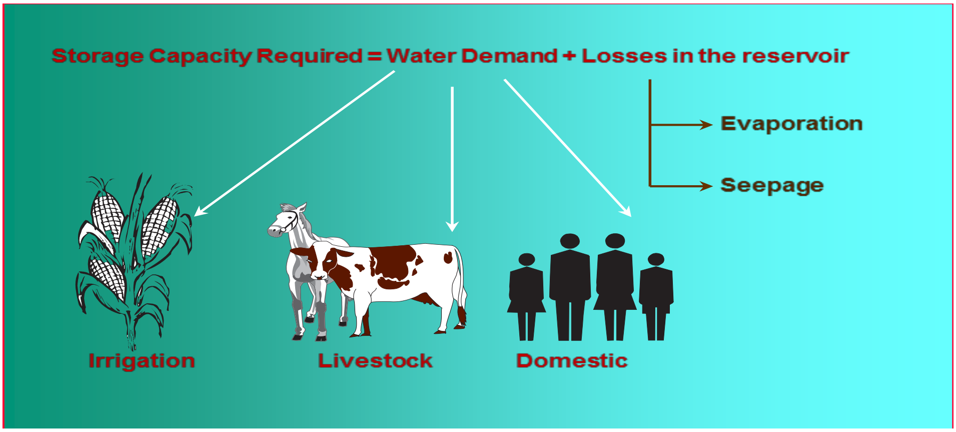


Figure 11: Multiple water demand and loss

5.2.1 Irrigation water demand

The irrigation water requirement is computed based on the crop water requirement for evapotranspiration (ETcrop), the irrigated area and overall water application efficiency. The efficiency is adopted in order to account for the water losses during water conveyance and application.

Irrigation water demand can be calculated using the following formula:-

$$Ir = \frac{10 \times ETcrop \times Ca}{Eff}$$

Where, Ir : Irrigation water requirements in cubic meters for the whole dry period

ETcrop : Crop water requirement in mm during the dry period

Ca : Area irrigated with water from the reservoir in ha

Eff : Overall water application efficiency

Crop water requirement, ETcrop

$$ET_{Crop} = K_C \times ET_O$$

Where, ETcrop : Crop water requirement in mm per unit of time

Kc : Crop factor (crop coefficient)

ETo : Reference crop evapotranspiration in mm per unit of time

ETo, reference crop evapotranspiration (potential evapotranspiration, PET) is the rate of evapotranspiraion from a large area covered by green grass which grows actively, completely shades the ground and which is not short of water. The rate of water which evapotranspirates depends on the climate. The highest value of ETo is found in areas which are hot, dry, windy and sunny whereas the lowest values are observed in areas where it is cool, humid and cloudy with little or no wind. The following are commonly used methods of computing ETo.

Example 1:

- Crop to be grown: Sorghum
- length of total growing season: 120 days (sum of all 4 crop stages)
- ETo: average of 6.0 mm/day over the total growing season (from measurement, calculation or given)
- Rainfall is 150mm for total growing season of 120 days

Based on the data given above, calculate ETcrop and irrigation water requirement.

→ **Crop water Requirement:**

ET crop = kc x ETo
ET crop = 0.78 x 6 = 4.68 mm per day
ET crop = 4.68 x 120 days = approx. 560 mm per total growing season.

Irrigation water requirement = Etc – rainfall = 562 – 150 = 412mm. Finally, it will be calculated for the proposed crop area.

Twenty percent of the water demand is usually considered as various losses; then Total water demand = Total Irrigation requirement + Domestic water requirement + 20% loss

Example 2: A household plans to harvest roadside runoff water and to construct underground water tank to irrigate a 300m2 onion crop for five months. The average annual rainfall of the area is 600 mm.

Given:
- The total irrigation water demand for onion crop for five months, if ETO is 6mm/day, Ef is 70%, and Kc is 0.7
- The required storage size, if the water loss is assumed 20%
- Catchments size, to meet the irrigation water demand. Assume runoff coefficient (K) for the catchments type is 30%.

Solution

→ **Irrigation Water demand**

ET crop or CWR = Kc x ETO x Dry period (days)
= 0.7 x 6 x 150 (days)
= 630 mm per unit area for five months

Then, IR = CA x CWR/ Ef
= 300x630 / 0.7x1000
= 270 m^3

→ The required water tank size = IRx1.2 or = IR+(IRx20%) = 324m^3

5.2.2 Water demand for livestock

The water demand for livestock is computed by considering average rates of animal water consumption per day per animal. The rate is assumed in the range of 25 to 60 liters according to the availability of water and the type of animal.The constant 1000 appears in the equation below to take care of the unit conversion from liter to cubic meter.

$$WL = \frac{NL * AC * T}{1000}$$

WL: Water needed for livestock during the critical period in cubic meters

NL : Number of animals to be watered from the reservoir

Ac : Average rate of animal water consumption in liters per day per animal (see Table 1)

T : Duration of the critical period in days

Table 3: Average daily water consumption of selected animals

Animal	Consumption (l/d)
Camel	50
Cattle	25 – 35
Sheep	5 – 15
Goat	5 – 15
Donkey	16 – 20
Chicken	15 - 20/100 heads

5.2.3 Water demand for domestic use

Domestic water supply is calculated by adopting a suitable rate of consumption. In rural areas , the domestic water consumption is assumed to be 40 liters per day per person. The rate depends on the availability of water.

$$Wd = \frac{Po * Dc * T}{1000}$$

Where, Wd : Domestic water supply during a critical period in cubic meters

Po : Users of the reservoir

Dc : Average rate of water consumption in liters per day per person

T : Duration of the critical period in days

5.2.4 Evaporation and Seepage losses

Losses in the reservoir comprise of evaporation from the surface of the reservoir and seepage losses through the walls and bottom of the reservoir. Evaporation losses can be easily calculated or measured using evaporation pan (see Figure 12). However, seepage is the most difficult factor to evaluate since it must be estimated indirectly from measurements of ground water levels, permeability, etc.

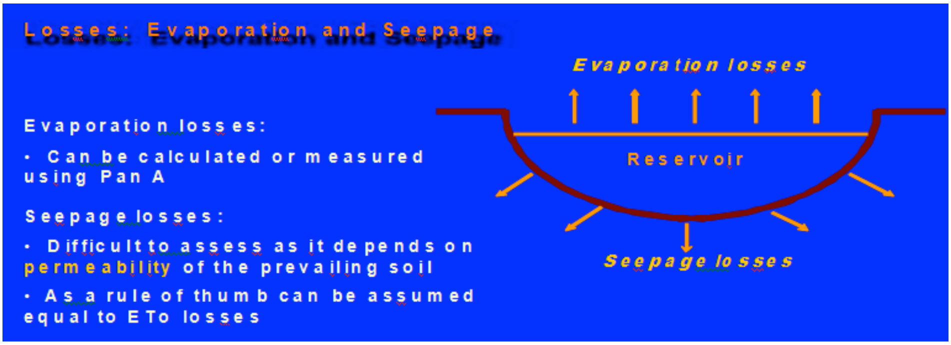


Figure 12: Evaporation and Seepage Losses

6. DESIGNING STORAGE PONDS AND DETERMINATION OF STORAGE CAPACITY/VOLUME OF THE POND

The shape, size and depth depend on the amount of land available, the type of soil, the farmer’s water requirements, the cost of excavation, and the possible uses of the excavated earth. Water from the farm pond is conveyed to the fields manually, by pumping, or by both methods.

6.1 Design of Circular Ponds

- Volume of a circular pond can be calculated by multiplying the average area of the pond by its depth.
- To avoid collapsing or sliding of the sides of ponds, it should have a

certain permissible side slope (in most cases 1:1)

- The volume of the sloping sides therefore should be deducted from the total volume of the pond
- The average area of a circular pond is calculated using the following formula π = 22 / 7 = 3.1428

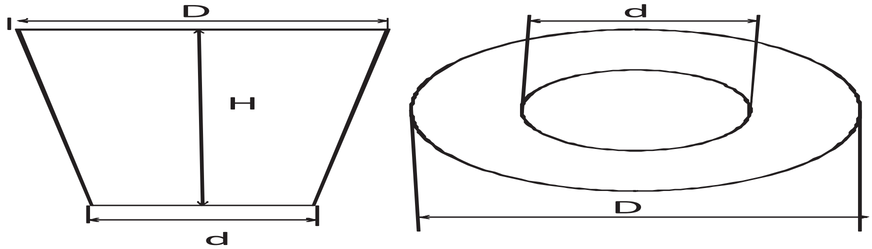


Figure 13: Design of Circular Farm Ponds

AP = Average Area of Pond (M2); $A_p = (\pi\frac{D^2}{4} + \pi\frac{d^2}{4})/2 = \frac{\pi}{8}(D^2 + d^2)$

VP = Average Volume of Pond (M3); $V_p = A_p H = \frac{\pi}{8}(D^2 + d^2)H$

H = Depth of Pond (M)

D = Larger (Top) Diameter (m)

D = Bottom Diameter (m)

6.2 Designing of Trapezoidal Ponds

Volume of a rectangular pond can be calculated by multiplying the average area of the pond by its depth. The surface area (A1) and area at the bottom of the pond (A2) is calculated as follows:

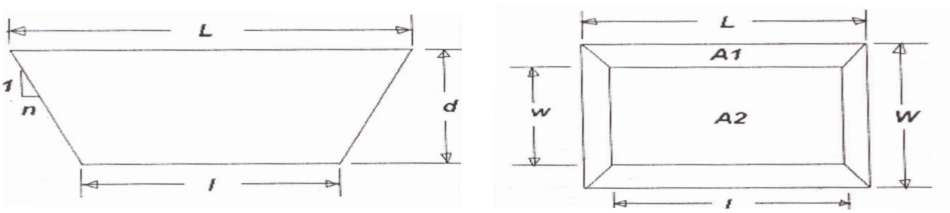


Figure 14: Design of Circular and Trapezoidal Farm Ponds

$$A_P = \frac{(A1+A2)}{2} = \frac{(WL+wl)}{2}$$

$A_2 = wl$

$$V = A_{av} d = \frac{(WL+wl)}{2} d$$

AP = Average area of the pond, m2

V = Volume of the pond, m3

To determine the volume of water to be stored in the pond, the volume of expected water use should be calculated. Volume of a pond is calculated based on the shape of the pond and formulae (as above).

Example 3: Computation of required water storage capacity

Crop data: Selected crop is Sorghum; Average Kc is 0.7

Livestock data: Total livestock number (using the reservoir) 500, water consumption is 50l/day/animal

Population data: Number of users are 400, water consumption 40l/day/person

General data: Average reference crop evapo transpiration during the dry period is 6mm/d, Irrigated area is 2ha, overall water application efficiency is 40%, dry period is 90 days, seepage loss is assumed to be equal to ETo losses. Reservoir: Surface area is 1000 m², bottom and side walls area are 1500 m²

→ **Irrigation water demand:-**

ET crop = Kc x Eto= 0.7 x 6mm/d = 4.2mm/d

ET crop (dry period) = ET crop (day) x dry period

= 4.2mm/d x 90d = 378mm

Ir = CWR X CA / 1000 x Ef (for full irrigation)

$$Ir = \frac{10 \times Etcrop \times Ca}{Ef} = \frac{10 \times 378 \times 2}{0.4} = 18900m3$$

→ **Livestock water demand:-**

$$WL = \frac{NL \times Ac \times T}{1000} = \frac{500 \times 50 \times 90}{1000} = 2250 \text{ m3}$$

→ **Domestic water demand:-**

$$Wd = \frac{Po \times Dc \times T}{1000} = \frac{400 \times 40 \times 90}{1000} = 1440 \text{ m3}$$

→ **Total water demand** = Ir + WL + Wd

= 18,900 + 2,250 + 1,440 = 22,590m3

→ **Losses** = Evaporation losses + Seepage losses

Evaporation losses = ETo × Surface area of reservoir
= 6mm/d ×1000 m² = 6 m³ /d

Seepage losses assumed equal to 6mm/d

Total seepage losses = Seepage loss × Bottom and side wall areas
= 6mm/d × 1500 m² = 9 m³ /d

Total losses = (Evaporation losses + Seepage losses) × Dry period
= (6 + 9 m³ /d) × 90d = 1350 m³

→ Required Storage Capacity = Total water demand + Losses
= 22,590 + 1,350 = 23,940 m3

7. STEPWISE CONSTRUCTION OF FARM POND

1. Clear the site from unnecessary debris and twigs and make it level
2. Arrange wooden pegs, measuring tape or marked string, sledge hammers, crow bars, shovels, pick axes, wheel barrows and barilla (to carry out soil), buckets, and workers or labourers
3. Mark the pond on the ground
4. Consider point O as the center of the pond and start digging the pond
5. If the side slopes are considered to be same in both sides, the distance of points AC and BD are equal. Similarly, distances of points OA and OB are as well equal.
6. Start excavating or digging AMNB first and then shape CAM and DBN as shown above
7. Excavate similar dimensions on the width wise direction
8. Keep the soil 3m away from the edge of the pond
9. Following this logic, the whole depth can be divided into equal segments and digging can continue similarly until the final depth is reached. See Figure 15 and 16

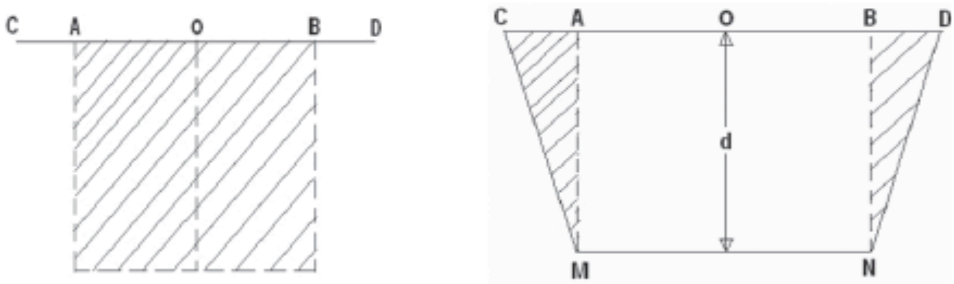


Figure 15: Construction procedure of farm ponds

Figure 16: Stepwise construction on-going based on the layout made

Figure 17: Stepwise digging, deepening and shaping the inner side of the pond surface

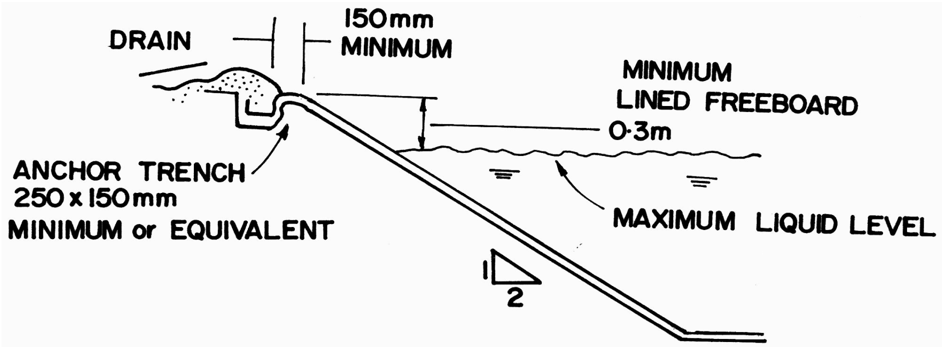


Figure 18: Crowning details of geomembrane lining to overcome seepage loss

Figure 19: Plastic lined pond, in Bichena area of Gojam

8. OPERATION, MAINTENANCE AND MANAGEMENT

Poor management and lack of maintenance are the main causes for the failure of most water harvesting projects. To ensure the success of any water-harvesting project, it is essential to involve the community in all aspects of planning, project design, implementation, operation and maintenance.

When construction or excavation of the pond is finished the embankment (dumped soil) must be sown with suitable vegetation to prevent the loose soil from being washed back into the pond.

Finally, fencing the completed ponds is generally recommended, where livestock are allowed for grazing in adjacent areas of the farm pond and to protect it from the reach of children. Every un unattended entrance should be controlled by fencing with lockable gate. The fencing provides the protection and also helps in maintaining the vegetative cover over the embankment section.

Preventative maintenance is the key to ensuring a long life for a pond. Regular monitoring of the embankments, reservoir and catchment area should be carried out to make sure that maintenance needs are identified early enough to act. At large, the following operation and maintenance procedure should be followed.

- A complete inspection should always be taken before the season of storing water comes
- In addition, during the operation, it is proposed to monitor water level and make recording
- Caution should be taken to check if there is any abnormal lowering of the water level
- If it is found that the water level drops down very fast or even the tank is unable to store any water, it means there are serious problem happening
- When water is flowing in but the water level can be raised only to certain depth then it indicates seepage is happening in the wall near the water level
- In case of minor leakage, only small cracks happen on the surface of concrete or masonry, the crack can be filled with sealing materials without treating the subsoil
- If large leakage occurs, it should be carefully inspected for any cavity behind the concrete or masonry
- For the collection and conveyance ditch (channel), silts and weeds should be cleared regularly. Maintenance for the scoured portion of the ditch should be done on time. Particularly, the entry gate and spillway of the water cellar should be inspected carefully

N.B: See also additional checklists in Annex 1 and Annex 2 for surveying the performance of proposed and existing ponds. Further, related to this technology additional references are listed and the reader is advised to consult.

9. GENDER EQUALITY BOX

What are the issues of gender inequity?

Women farmers, especially female headed households might not engage in farm pond water harvesting due to economic and manpower problems to dig the ponds individually and even to lift up and apply water from the pond. They might not be trained on how to dig, how to cover, how to keep water clean, how to maintain the pond and selecting appropriate site.

How can the gender issues be addressed?

Graft development of farm pond water harvesting up on the existing community based social supporting systems like 'debo', 'jigi', 'wenfel' etc to support FHH dig ponds. Women farmers, both females headed and married have to be targeted during technology introduction and promotion activities and provided with the required capacity development extension services. It will be good to link the technology with other simple water lifting technologies or create access to simple machines like pulley to foster sustainable impact.

What will be the benefits when gender issues are addressed?

FHH technology adoption rate increased and by using the technology they produce more and their livelihood improved. The water in the pond will also support for multiple uses that generate economic benefits.

ANNEX CASE STUDY SURFACE WATER POND

Story by Hune Nega and Aschalew Demie

1. Background

The case study was conducted by interviewing the beneficiaries on 05 May, 2018 Minjar Shednkora Woreda, Arerti town which is found in Noth Shoa zone of the Amhara Region. Arerti, the Woreda capital, is located at a distance of 60 km from Mojo Town on the main road from Mojo to Debre Birhan.

In the Woreda there are only 3 perennial rivers, which are very far away from where the larger community of the Woreda people are residing. The main sources of water for the majority of the people in the rural area is community pond and few numbers of household own geomembrane lined farm ponds. In the urban area also, there is water shortage problem. During the visit it was observed people with long queue to fetch water for drinking from communal water tap in Bolo Selassie Kebele which is located by the side of the main road to (see Figure 8).

Figure 20: Array of plastic vessel “Jerycan” for drinking water

2. Owner Information

Demrew Mulu Kassa, 55 years old, lives in Minjar Shekora Woreda, Bolo Selassie Kebele, Aletamengot village. He is married and has six children (5M/1F). Including him and his wife Demerew has 8 family members. His pond farming is located about 1km from his house.

It was possible to learn about Demrew from the WoA and went directly to his house to get firsthand information, unfortunately he was not at home and his baby boy who is 10th grade complete, lead us to the pond farming. When we reached there, we found his elder brother who is working on the farm. And he told us that his father has gone for market.

After watching the seedling and horticulture development we started our interviewing him. He gave us all information that he knows and more by mobile calling his father. As a labor division in the family, he usually works on rain fed farming and came to support his father. His father works on seedling and horticultural crops to support the

Figure 21: Collecting information from Woreda Agricultural expert

Figure 22: Brothers, Sons of Ato Demrew, Student and farmer from left to right (Wondwessen and Sisay)

All family members are engaged in the household farming practices. Rain fed farming is the main means of existence for the family. In this area, after rainfed crop harvesting and threshing, the farmers are spending idle, the long dry season, until the next rainy season comes. But for Ato Demrew, this is not the case, he and his family has created another job opportunity during long dry season. They constructed two water harvesting ponds which collect run-off during rainy season and use it during long dry winter.

3. Technical Information

The source of water for this HHMI is from two geomembrane lined surface water harvesting ponds, which were constructed in 2004 and 2006, respectively, by family labor with technical and credit support from WoA and used to purchase geomembrane and treadle pump. The shape of these ponds is trapezoidal with capacity of 624 barrel (124.8m3) each. They use treadle pump (overflow type) to abstract water from the pond and watering can for water application. Two ponds are used to harvest surface water during rainy season. They are aligned parallel and run-off led to the ponds alternatively.

Figure 23: Geomembrane lined pond and treadle pump

Figure 24: Seedling and fruit trees

4. The Plot

The plot under development is estimated to be 25mx50m (1250m2). It has seedling block and scattered fruit trees. The seedling consists of avocado, mango, orange, lemon, coffee, gravlia and acacia (Girar). The fruit trees are mango (12), orange (5), avocado (8), lemon (4), guava (3), papaya (1), kazmirno (3) and coffee (50)

5. Gender Responsiveness

The woman in the house (mother and daughter) is working on the seedlingplot and gets a chance to select for family use and marketable crops. They enjoy also working under the shade of the trees.

6. Other use of Water

The water is also used for livestock, which saves their time and energy in searching for water.

7. Adoption

Many farmers in the village frequently visit this farm and it is adopted in other villages by three farmers.

8. Operation and Maintenance

Maintenance involves clearing and repair of diversion/ drainage canal leading to the pond and removing sediment entering the pond to keep its maximum holding capacity. The routine maintenance work is done by the family labor with technical support from WoA.

9. Limitations

The limitation is watershed/ catchment flow is becoming less and less as it is shared among the local community.

10. Key Benefits

Financial: Increased family earning, 10,000.00 birr per season. The family can purchase agricultural inputs like fertilizer and selected seed varieties for rain-fed farming and saves subsistence crops from market spell. They are on upper hand on family life and sending babies to school.

Social: Good working opportunity is crated for the family, they are working in all seasons irrespective of the rain stops and water shortage. They make also available different seedling variety for urban and rural community. It is also a learning ground and activators for other farmers.

Time: They don’t travel long distance in search of water for livestock, which is the common and routine activity of the community. They manage to use their time for other family businesses within house or on the field.

Environmental: Creates local climate for surrounding and home for birds.

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Module-6

Manual Pump

1. INTRODUCTION

This is module 6 of the HHMI Manual. It deals with different manual lifting devices like treadle rope, and hip pumps. Manual pumps are labour intensive and requires minimum capital investment. Manual pump is mechanical equipment that serves for lifting water from a lower level to a higher level using human labour. Introducing the technology and comparing to others considering its low cost, requires low labor requirement and its women friendly and low environmental impact makes it preferable. These pumps has their own selection criteria, installation, operation, and maintenance.

2. PURPOSE AND SCOPE OF THE MANUAL

The module helps as a training material and to enhance the knowledge and skill of woreda experts and DA's on Manual lifting devices development. It can also be used as afield manual. The material describes in-depth planning, selection criteria, operation and maintenance.

There is a dire need to delivery alternative water resource and access (for irrigation system) to each farmer as much as possible. One of the solutions to achieve this task is reinforcement operation and maintenance of irrigation pumps in each region. However, there is a shortage of person power to fulfill the daily maintenance activities.

Hence, there is a great demand to train Woreda technicians who obtain adequate knowledge and practical skills. Using this training muddle, the irrigation-qualified engineers (technicians) would be able to cover the lack of adequate personnel to train farmers who are using irrigation pumps.

3. WHY MANUAL PUMP IS REQUIRED?

- It is low cost water lifting technology and important tool for resource poor farmers
- It can easily be maintained by local technicians and trained farmers
- It is a "gender friendly" technology in that it can provide increased economic opportunities for women farmer
- Manual pump is applied in the area where shallow ground water or surface water is available; and no possibility of gravity irrigation
- It is environmentally friendly
- It can be linked to rural job opportunity by both directly benefiting from irrigation and also by involving in the production, distribution, and maintenance of its replaceable parts

4. PLANNING CONSIDERATION

During the planning period, selecting the irrigation pump site requires complete investigation of the site and conditions under which the pump will be used. The investigation of the site must include:

- Willingness of the beneficiaries to install on the selected land and apply irrigation.
- The source of water (well, river, pond, etc.)
- The required pumping flow rate (q)
- Suction and delivery head
- Size of command area and its distance from the water source
- Suitability of the topography of the land for installing the pump

5. TYPES OF MANUAL WATER LIFTING PUMPS

There are different types of manual pumps. The main points considered in selection of the pump type are total head, cost, availability of spare parts, and ease of operation and maintenance, preferably by the farmers. Commonly used, Rope, Treadle and Hip pumps are described in this module.

5.1. ROPE PUMP

It is a kind of pump where a loose hanging rope is lowered down into a well and drawn up through a long pipe with the bottom immersed in water. On the rope, round disks or knots matching the diameter of the pipe are attached which pull the water to the surface. Rope pump can be installed on a hand-dug-well or manual tube well (bore hole) – See Figure 1.

Figure 1 Rope and washer pump in Sekela woreda

Main components of the pump are the following:

a) Head work for fixing the rope to rotate the pump
b) Hand dug well cover for the purpose of care for the operator and protects entrance of other materials. There is also an opening for monitoring and minor maintenance made out of concrete or wood with a size of 40 cm width and 40cm length covered with appropriate cover.
c) Rope: the thickness of the rope is estimated 5mm and strong, durable, smooth and safe from water damage.
d) Piston: made out of plastic materials used for pushing the pipe to lift the water through the plastic pipe or hose with a diameter of from 0.5 to 1mm.
e) Pipe: is plastic hose serves as a conduit suction pipe; its diameter is less that the diameter of the hand dug well.

According to the type of water source, user interest and position of the collecting tank or irrigable plot, the pump can be installed in a front or back forth position (See Figure 2).
Installation procedures:

1. Attach the rubber washers on the selected rope based on the specification; and insert the rope that hold a series of washers inside the pipe and tie the two ends together
2. Put wooden poles at a rescannable distance from the water source so as to fix the pulley wheel; and fixing the pulley wheel on the shaft, fix on the poles with wooden bearing.
3. Insert the bottom of the pipe in to the water. Put poles at an appropriate distance and bind the pipe to avoid bending or breakage due to water load
4. Put collecting tank at the outlet

Table 1 General data on rope pump

Discharge	Water level	up to 10m depth: 35 liter/min
		up to 20m depth: 20 liter/min
		up to 35m depth: 10 liter/min
Maximum depth	35 meter (water level)	
Input power	Approximately: 50 Watt – the discharge is based on an input power of 50 Watt, which is the power that women and children can deliver for longer periods	
Discharge level	1 m above ground level (no pressure condition) and with an additional wheel and structure up to 6m above ground level is possible	
Application	1 – 10 households (approximately 50 users maximum)	
Cost	Variable (e.g. by the support of Sustainable Land Management Project – SLMP it is distributed at the cost of Birr 3500 for the hand dug well excluding the head work)	

5.1.1. ROPE PUMP INSTALLATION

A rope pump is a kind of pump where a loose hanging rope is lowered down into a well and drawn up through a long pipe with the bottom immersed in water. On the rope, round disks or knots matching the diameter of the pipe are attached which pull the water to the surface.

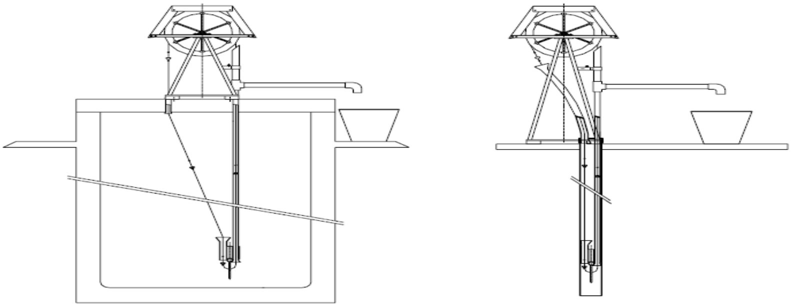


Figure 2 Rope pump fixed on the hand-dug-well (left) and manual on tube-well (right)

This pump is often used by farmers due to low cost; ease maintenance by local technicians/workshop; and ease transport. The rope pump consists of a wheel and an endless rope with pistons made out of tire. The pistons are attached to the rope at intervals of 1 meter. The pistons fit with a clearance of 1 millimeter in a PVC-pipe (called raising pipe or raising main). The wheel and handle are mounted on a structure on top of the well. Rope pumps can be used on hand dug with a diameter as small as a 2 inch. Even for children it is easy to fill a bucket (See Figure 1).

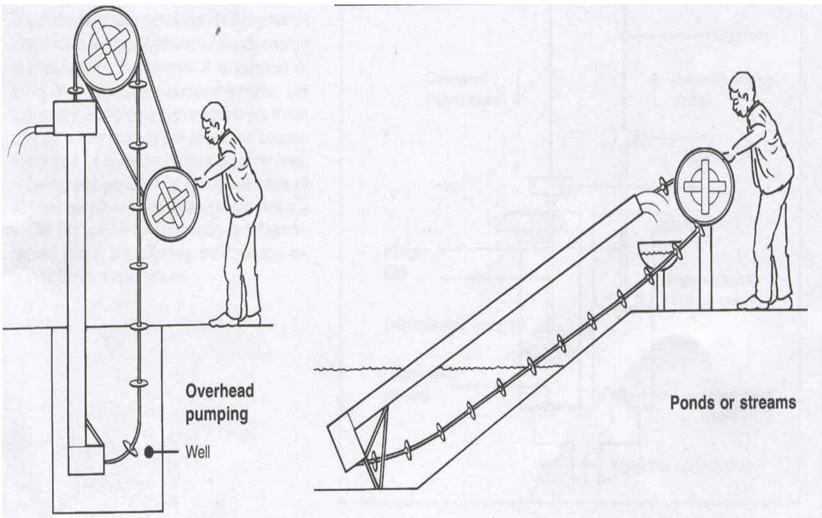


Figure 2 Rope pump fixed on the hand-dug-well (left) and manual on tube-well (right)

5.1.2. ROPE PUMP OPERATION

The pump consists of a continuous rope, with rubber washers attached, which is pulled up through a pipe by means of a pulley wheel. The diameter of rubber washer is slightly small than the inside diameter of the pipe. When the bottom of the pipe is immersed in water, the rubber washers, moving up wards to draw the water. As they emerge at the top of the pipe, the water falls in to the collecting tank or irrigable plot. One person operates it at a time.

Table 2 Pumping Capacity of the Rope pump according to depth

Depth (m)	Adult (li/min)	Child (li/min)	Time needed for an adult to fill a barrel (minutes)
5	70	39	3
10	41	19	5
15	27	13	8
20	20	10	10
25	16	8	13
30	14	6.5	15
35	12	5.5	18
40	10	4.8	20

5.1.3. MAINTENANCE OF ROPE PUMP

It might be necessary to correct the tension in the rope during the first weeks of use, as the knots tend to lengthen the rope. Lack of tension in the rope can cause the rope to slip over the pulley wheel. To alter the tension in the rope, remove the rope and untie the knot. Put the rope back on the pulley wheel with the desired tension to measure where the new knot must be made, and repeat the process.

Greasing oil or grease the bushings of the axle and the handle as required. Additionally:

- Fastening of the wheel should be revised periodically, checking the screws
- Cleaning and painting to prevent corrosion, clean and paint the wheel every year is required

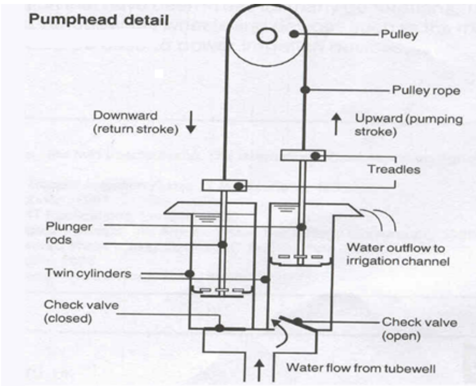
5.2. TREADLE PUMP

A treadle pump is a human-powered suction pump that sits on top of a well and is used for irrigation and other domestic use. It is designed to lift water from a depth of seven meters or less. The pumping is activated by stepping up and down on a treadle, which is levers, which drive pistons, creating cylinder suction that draws groundwater to the surface.

5.2.1. OPERATING PRINCIPLE OF TREADLE PUMP

The principle of treadle pumps is based on suction lift using a cylinder and piston to draw water from a source below ground level, for example a river or shallow groundwater. Two pistons are used, each connected to a treadle. They can be about 1-meter-long, hinged at one end and supported at the other by a rope or chain running over a pulley. Treadles can be made from steel, wood or bamboo. Treadles need to be strong enough to take the forces applied by the weight of the operator. The treadle pump is ideal for areas where the water table is high, ranging from 3 m to 7.5 m below the ground. Besides, most of the models of the treadle pump can be used for drawing surface water, such as from ponds, canals, streams and dug wells (See Figure 4 and 5).

The pressure treadle pump is a modification of this design which also uses suction to draw water to the surface but then can force the water out of the pump under pressure. This allows water to be moved a distance of up to 50 meters across the ground, or to a height of 6 meters above the pump.



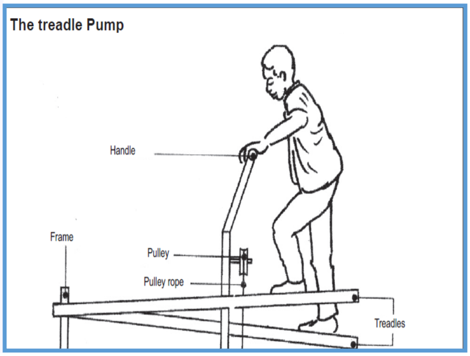


Figure 4 Operation and Parts of treadle pump   Figure 5 Layout and Parts of Treadle pump

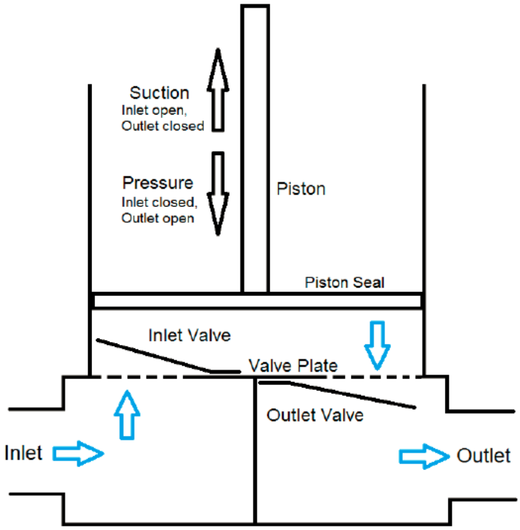


Figure 6 Treadle Pump operating principle (top) and water flow (bottom)

5.2.2. VOLUME OF WATER VS AREA TO IRRIGATE

The amount of water pumped will depends on:

- The strength, weight and stamina of the operator

- The distance of the water below the pump intake
- The height the water is raised from the pump to the end of the delivery pipe
- The duration of pumping

In turn, the area to be irrigated is dependent on the amount of water that can be lifted within a given time.

If the owner farmer is willing to pump about 5 hours every day, and the water source is adequate, 18,000 liters per day is available. Assuming the peak water requirement for irrigated crops grown in the Rift Valley system of Ethiopia is about 6 mm/day in November. At this time, 18,000 liters is enough water to maintain a crop on approximately 0.25 ha.

5.2.3. TREADLE PUMP INSTALLATION

Before installation, level the ground for placing the pump on the selected site. A completely installed treadle pump has essentially the following parts:

a) Cylinder and valve assembly: used for conveying water from the well and store until deliver to the irrigated land or other place. Valve box assembly helps filling the water in the cylinder and delivers it.
b) Piston and chain assembly: This section transfers person power to the pump for suction.
c) Treadles: The operator stands on the treadles and pushes them up and down to work the pump.
d) T-hand: The operator uses this component to use as handle during operation time.
e) Suction and delivery hoses: - These hoses are for conveying the water from the water source to the command area.
f) Foot valve with strainer: - For the water to pass only in one direction and serves as silt trap

5.2.4. TREADLE PUMP OPERATION

The pulley wheel and rope / rocking bar connect the two treadles and enable the operator to work the treadles up and down in a reciprocating movement. This pump can produce a discharge of 2 liters/second.

When a pump is first used, it must be primed. This is a process of removing all the air from the suction pipe and the cylinders. If this is not properly done, pockets of air left in the system will impair the performance of the pump. Priming can be achieved in a number of ways. The simplest way is to draw the air out by normal pumping action. Some pumps have a non-return valve at the entrance to the suction pipe, so that it does not drain when it is not in use. When the pump starts up again, it is already primed and ready to go. Unfortunately, very few treadle pumps have this feature. Another approach is to fill the pump and the suction pipe with water prior to pumping. Whichever way priming is achieved; the main objective is to get all the air out of the system.

At the time of proper operation of the pump, the following results are obtained.

Table 3 Area irrigated using proper operation of treadle pump

Head(m)	1	2	3	4
Discharge (liters/sec)	3.6	1.8	1.2	0.9
Volume pumped in 8 hours(m3)	102.75	51.38	34.25	25.69
Irrigation capacity(ha) in highland	1.28	0.64	0.43	0.32
Irrigation capacity(ha) lowland	0.93	0.47	0.31	0.23

5.2.5. TREADLE PUMP MAINTENANCE

Table 4 . Pump problems and possible causes

Problem	**Causes**
No Flow	- Failure to prime the pump - A loose impeller - Faulty coupling
Insufficient Flow and/or Pressure	- Insufficient suction head - Suction strainer plugged or partially obstructed - Air and/or gas in media, usually through faulty or improperly installed gasket in the suction line - Electric motor wired wrong, causing the pump to run in reverse - Suction lift higher than estimated - Damaged impeller - Suction piping not correct.
Power Demand Increase	Drop in pump efficiency. As the efficiency drops,horsepower requirements increase. This may be as result of: - Pump misalignment - Damaged bearings
Cavitation	- Insufficient net positive suction head available - Air and/or gases are trapped in the pump or are entering the pump or suction piping. - Leaking casing gaskets may cause this problem. - Pump operates close to minimum flow, where the pump manufacturer may have stated suction head available incorrectly

The treadle pump has been designed and manufactured in such a way that it is easy to maintain and repair by an average user at village level. While the pump can last up to seven years, the internal movable parts (rubber cups) can last between 9-18 months, depending on the use and source of water. It has been established that sandy and muddy water will wear out the rubber cups in just few week time.

In order to increase the lifespan of the internal movable parts, it is recommended to use a strainer at the intake to prevent debris coming into the pump. The foot valve can last as long as the pump itself, except the rubber flap which allows water one-way into the pump by opening and closing. However, this movable part can easily be replaced by making one from disused bicycle or motor vehicle tube. The rope, which moves over the pulley, may also break easily but animal skin hides, old bicycle chain and old fan belts easily replace this.

When the pump is not in use, it should be stored in a cool storage place and protected against corrosion by greasing the internal metallic parts of the cylinder.

5.3. HIP PUMP

The Hip Pump is unique lifting device developed to create a lower cost and lighter weight, portable pump. The weight of hip pump is about 4.5kg. It can irrigate about 4000m2. Hip pump is super-efficient valve box, but the genius of the design is a simple pivot hinge by attaching a “Hand Pump” to a hinged platform, it changed the body mechanics-- allowing users to use their leg, body weight, and momentum, rather than the small muscles of the upper back and shoulders. This allows the pump be easily used to irrigate more than a quarter hector.

The Hip Pump can pull water from 7 meters, transporting the water at ground level through a hose approximately 18m in length and pumping water up into a tank of 3m in height.

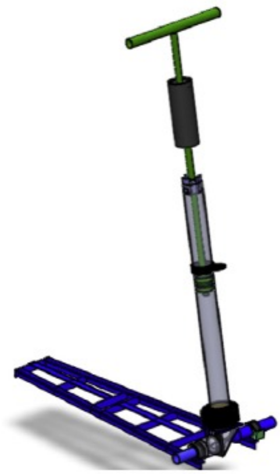


Figure 7 Hip Pump

Hip pump is for operation. It does not need unique installation. It is like a hand bicycle or football air pump.

Photo 1 HIP pump demonstration in Oromia

6. MANAGEMENT OF MANUAL PUMPS

Since the famers/ beneficiaries are fully participating; the management of the pumps can be easily managed. The following activities shall be undertaken for a sustainable use of the pump.

- Keep in dry and safe place when not in use
- Keep out of the reach of children when not in use
- The training on daily maintenance and operation
- All members of the family shall participate in keeping it from any damage
- Do not operate the pump unless water is required for the intended purpose

7. ENVIRONMENT AND SOCIAL FREINDLYNESS OF MANUAL PUMPS

Key rainwater harvesting structures manual pumps can affect the environment positively in a number of ways:

1. Greening the environment through promotion of climate smart agriculture

   i.e. keeping the area green has a direct impact on the water cycle, ecosystems, and our ability to maintain balance with our surroundings
2. Mitigate the impacts of climate change
3. Reduce the carbon footprint by enhancing biomass growth and maintaining healthy soil
4. It is a divisible technology that can be applied at every household and can be scaled up /out easily

8. GENDER EQUALITY BOX

What are the issues of gender inequality?

Women are usually not having information about water lifting micro irrigation technologies like pulley, rope and washer treadle pumps before they are introduced to the community. Once they have been introduced, women are often left out of decision-making and other processes. They may not have enough information and skills to operate manual pumps to produce to their optimal potential. Also, the technologies may not be women-friendly but majority of activities pertaining to vegetable farming under manual pumps carried out by women.

There is a gap in provision of updated information, training and continuous extension services to women which results in reduce women effectiveness in adopting new technologies.

How can the gender issues be addressed?

Women should be informed, trained, operation and maintenance of manual pumps for optimal use. Different stakeholders must invest more effort to reach women with information and ensure and understanding the time and location convenient for women. There is a need to extend invitation to women directly for information sharing events and meetings, one should not rely on spouses or men in the community to inform women.

Provision of adequate women friendly technologies and gender sensitive training on irrigation farming, agronomy practice and technology operation is important to the capacity development of women farmers

What will be the benefits when gender issues are addressed?

Technologies to be introduces have to be gender responsive based on the needs and preferences of women and which are appropriate business models that can boost micro irrigation development by saving water, reducing costs, and manage natural resources more sustainably. A gender-sensitive manual pumps contributes to promoting gender equality as a component or a facilitating variable for food security and poverty alleviation.

Hip pump require less labour, easy to carry, simple to operate. Women in any age can operate it.

Rope and washer can save women time in lifting water from deep well.

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Module-7

Small Engine Pump

1. INTRODUCTION

This module 7 is about Motor Pumps. It is the part of the HHMI manual. The HHMI manual consists Farm Pond Constructions, Manual Water Lifting Pumps, Rooftop Rainwater Harvesting, Spring Development, Hand Dug Wells, and Drip Irrigation modules. This module supports the application of the household irrigation in the country.

Water pumping is required in situations where site conditions do not favor the use of gravity supply. This may occur in irrigation or water supply projects. In either case, gravity systems tend to involve high capital costs but low operating costs. On the other hand, pumping systems tend to require lower capital costs but high operating costs. In addition to the technical variables, the choice between gravity supply, and pump fed supply is therefore, an economic one. When the economic case is not obvious, then the economic viability of each alternative must be established, and the economically superior alternative chosen.

1.1 PURPOSE AND SCOPE

The module helps as a training material and to enhance the knowledge and skill of woreda experts and DA's on Motor Pump development. It can also be used as afield manual. The material describes in-depth planning, design, selection criteria, operation and maintenance.

There is a dire need to delivery alternative water resource and access (for irrigation system) to each farmer as much as possible. One of the solutions to achieve this task is reinforcement operation and maintenance of irrigation pumps in each region. However, there is a shortage of person power to fulfill the daily maintenance activities.

Hence, there is a great demand to train Woreda technicians who obtain adequate knowledge and practical skills. Using this training muddle, the irrigation-qualified engineers (technicians) would be able to cover the lack of adequate personnel to train farmers who are using irrigation pumps.

1.2 TYPES OF ENGINE PUMPS

1.2.1 CENTRIFUGAL PUMPS

Almost all irrigation pumps fall into the category of centrifugal pump. Centrifugal Pumps are machines for moving fluid by accelerating the fluid radially outward. A centrifugal pump uses an "impeller" (sort of like a propeller, but a little different) to spin the water rapidly in a "casing", "chamber", or "housing". This spinning action moves the water through the pump by means of centrifugal force. Centrifugal pumps may be "multi-stage", which means they have more than one impeller and casing, and the water is passed from one impeller to another with an increase in pressure occurring each time. Each impeller/casing combination is referred to as a “stage”. Centrifugal pumps must be “primed” by adding water to the intake pipe and case before the first use. To prime them you simply fill the intake pipe with water and then quickly turn on the pump.

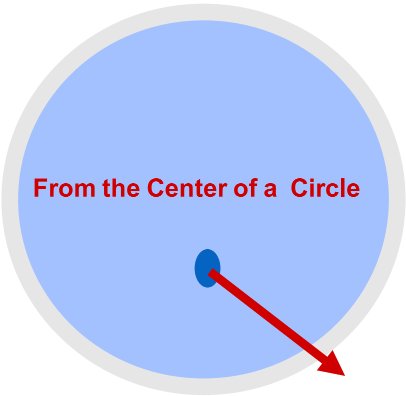

Figure 1 RADIAL DIRECTION - to the outside of a circle

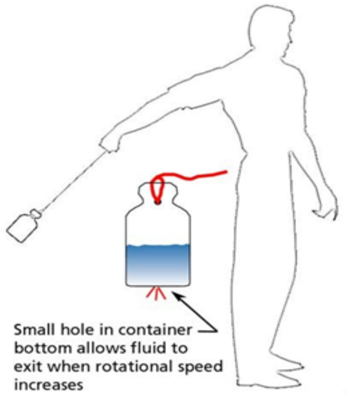

Figure 2 a spinning bottle to demonstrate centrifugal force

This machine consists of an IMPELLER rotating within a case (diffuser). Liquid directed into the center of the rotating impeller is picked up by the impeller’s vanes, accelerated to a higher velocity by the rotation of the impeller, and discharged by centrifugal force into the case (diffuser).

A collection chamber in the casing converts much of the Kinetic Energy (energy due to velocity) into Head or Pressure.

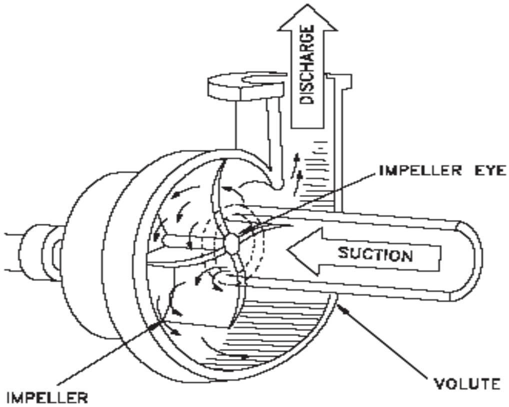

Figure 3 Schematic view of a centrifugal pump

1.2.2 TURBINES AND JET PUMPS

A turbine pump is basically a centrifugal pump mounted underwater and attached by a shaft to a motor mounted above the water. The shaft usually extends down the center of a large pipe. The water is pumped up through the pipe and exits directly under the motor. Turbine pumps are very efficient and are used primarily for larger pump applications. Often they consist of multiple stages, each stage is essentially another pump stacked on top of the one below. It works as if a train with multiple engines hitched together pulling it, each stage would be an engine.

Turbine pumps are typically the type of pumps you see on farms. When you see, a huge motor mounted on its end and a pipe coming out sideways below the motor that is most likely the motor for a turbine pump down inside the well. The turbine pump is mounted in a large concrete vault with a pipe connecting it to the lake. The water flows by gravity into the vault where it enters the pump. The pump motors are suspended over the vault on a frame. Usually it is common to use two or three different sized pumps side-by-side to handle different flow combinations. A jet pump is similar to a turbine pump but it works by redirecting water back down to the intake to help lift the water.

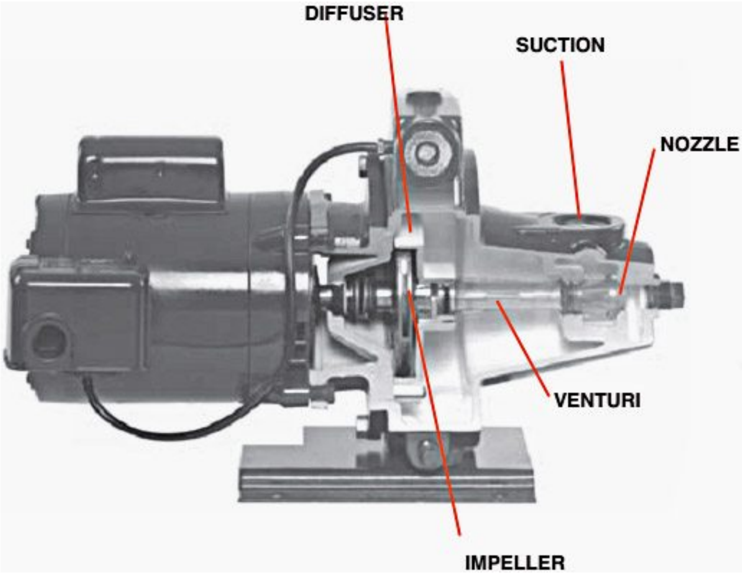

Figure 4 Jet Pump section

1.2.3 DISPLACEMENT PUMPS

Displacement pumps force the water to move by displacement; such pumps include piston pumps, diaphragm pumps, roller-tubes, and rotary pumps. Displacement pumps are used not only for water but also for moving very thick liquids, creating very precise flow volumes, or creating very high pressures. In addition to oil wells, they are also used for fertilizer injectors, spray pumps, air compressors, and hydraulic systems for machinery. With the exception of fertilizer injectors (used for mixing fertilizer into irrigation water), you will not see them typically used for irrigation systems.

1.2.4 SUBMERSIBLE PUMPS

Submersible pumps are installed completely underwater, including the motor. The pump consists of an electric motor and pump combined in a single unit. Typically, the pump will be shaped like a long cylinder so that it can fit down inside of a well casing. Although most submersible pumps are designed to be installed in a well, many can also be laid on their side on the bottom of a lake or stream. Another common installation method for lakes and rivers is to mount the submersible pump underwater to the side of a pier pile (post).

Submersible pumps do not need to be primed since they are already under water. They also tend to be more efficient because they only push the water. Most submersible pumps must be installed in a special sleeve if they are not installed in a well, and sometimes they need a sleeve even when installed in a well. The sleeve forces water coming into the pump to flow over the surface of the pump motor to keep the motor cool. Without the sleeve, the pump will burn up. Because the power cord runs down to the pump through the water it is very important protect that it from accidental damage. Submersible pumps should not run outside water even for test purpose, as water is the only means for cooling.

2. ENGINE

2.1 DIESEL ENGINE

This is also called a compression ignition engine. Those for various purposes are manufactured in a wide output ranging from small sized diesel engines of the output of about 3 to 10 Horse Power (HP - also (PS) to the large output diesel engines with the outputs of 1000 HP or more. They are also classified by the speed of the engine. Those of lower speed less than 600 revolutions per minutes (RPM) are called the low speed diesel engines, those of 600 to 1200 RPM are called the medium speed diesel engines those of 600 to 1200 min-1 are called the medium speed diesel engines and those of higher speed than 1200 RPM are called the high speed diesel engines. From the medium and low speed diesel engines, heavy oil is used as the fuel and light oil is used for the high-speed diesel engines. In the following, diesel engines related with the pumps are described.

2.2 GASOLINE ENGINE

This is a spark-ignited engine for which gasoline is used as the fuel. This kind of engines can be classified to the small sized gasoline engines and the gasoline engines for automobiles remodeled as a power plant for general purposes. As the former type, those of 5 HP (horse power) output or less are produced and most of them are air cooled. The latter types are with the output of 15 to 50 HP output or less is produced. Most engines of this type are 4 – cycle water- cooled type and are usually provided with a radiator.

They are low in price and provide high speed generally in the range of 1500 to 2600 RPM. They are widely used for high head volute pumps which can be run being directly coupled with the engine.

2.3 ELECTRIC MOTORS

An electric motor seems almost the ideal prime mover for a water pump. Power is supplied “at the flick of a switch”, and water is produced at a constant rate until the motor is turned off. Electric motors have relatively long service lives and generally need little or no servicing. The application of electric motors /engine as a prime mover in rural areas is not as wide as that of diesel and gasoline engines. However, its use can be expanded for the future.

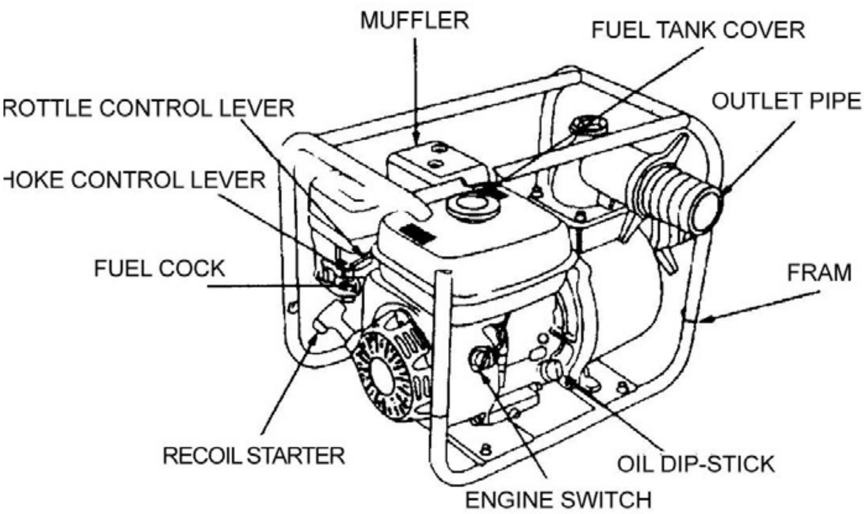

Figure 5 Electric motor connection to a Centrifugal Pump and its component parts

3. BASIC CHARACTERISTICS OF ENGINE PUMP

3.1 BASIC PUMP OPERATING CHARACTERISTICS

“Head” is a term commonly used with pumps. Head refers to the height of a vertical column of water. Pressure and head are interchangeable concepts in irrigation, because a column of water 2.31 feet high is equivalent to 1 pound per square inch (PSI) of pressure. The total head of a pump is composed of several types of head that help define the pump’s operating characteristics.

3.2 TOTAL DYNAMIC HEAD

The Total Dynamic Head (TDH) of a pump is the sum of the total static head, the pressure head, the friction head, and the velocity head.

3.3 TOTAL STATIC HEAD

The total static head is the total vertical distance the pump must lift the water. When pumping from a well, it would be the distance from the pumping water level in the well to the ground surface plus the vertical distance the water is lifted from the ground surface to the discharge point. When pumping from an open water surface it would be the total vertical distance from the water surface to the discharge point.

3.4 PRESSURE HEAD

Sprinkler and drip irrigation systems require pressure to operate. Center pivot systems require a certain pressure at the pivot point to distribute the water properly. The pressure head at any point where a pressure gage is located can be converted from Atmosphere or bar meter of head. A fall of 1 m in elevation is equivalent to an increase in pressure of about 0.1 bar.

3.5 FRICTION HEAD

Friction head is the energy loss or pressure decrease due to friction when water flows through pipe networks. The velocity of the water has a significant effect on friction loss. Loss of head due to friction occurs when water flows through straight pipe sections, fittings, valves, around corners, and where pipes increase or decrease in size. Values for these losses can be calculated or obtained from friction loss tables. The friction head for a piping system is the sum of all the friction losses.

3.6 VELOCITY HEAD

Velocity head is the energy of the water due to its velocity. This is a very small amount of energy and is usually negligible when computing losses in an irrigation system.

3.7 SUCTION HEAD

A pump operating above a water surface is working with a suction head. The suction head includes not only the vertical suction lift, but also the friction losses through the pipe, elbows, foot valves and other fittings on the suction side of the pump. There is an allowable limit to the suction head on a pump and the net positive suction head (NPSH) of a pump sets that limit.

Operating a pump with suction lift greater than it was designed for, or under conditions with excessive vacuum at some point in the impeller, may cause cavitation. Cavitation is the implosion of bubbles of air and water vapor and makes a very distinct noise like gravel in the pump. The implosion of numerous bubbles will eat away at an impeller and it eventually will be filled with holes.

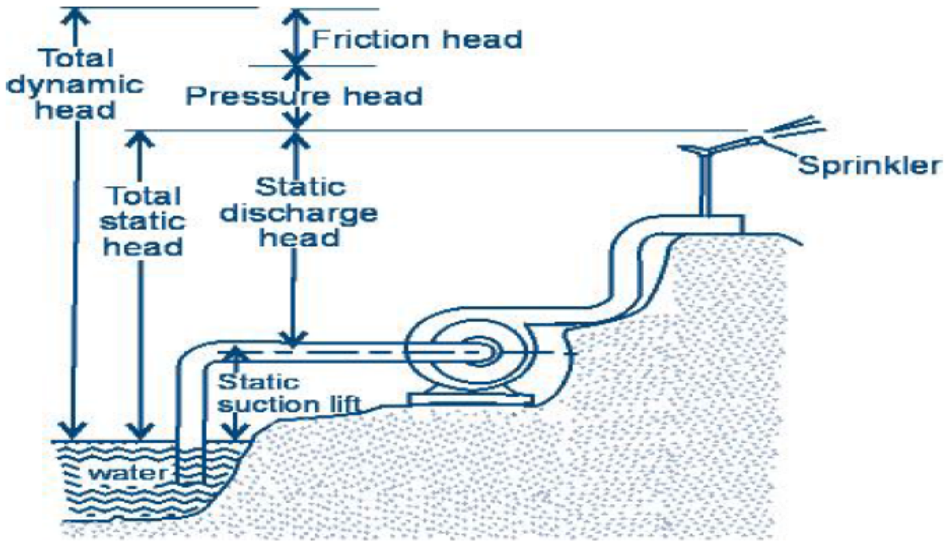

Figure 6 . Parts of a Total Dynamic Head (TDH) when the pump is placed above the water level

4. PUMP SELECTION

4.1 BASIC SELECTION CRITERIA

Here is the basic procedure to follow if you are selecting a pump for a new irrigation system. This is presented here as an overview to help you see where we are going with all of this:

1. Estimate your flow (Liter per minute) and pressure (Meter of head) requirements and select a preliminary pump model to use
2. Using your preliminary pump information, create a first draft irrigation design
3. Once you have a first draft of your irrigation design you may be able to fine-tune your pump selection based on that design. Return to the pump selection process and re-evaluate your pump selection. Make your final pump selection.
4. Return once again to your irrigation design. Can it be fine-tuned to better match your final pump selection? Make any necessary adjustments.

4.2 PUMP PERFORMANCE CURVE

It is a graph, which shows the performance characteristics of a particular pump. The pump manufacturer creates pump curves and the manufacturer should be able to provide you with performance curves for the pumps you are considering /ordering. Remember, there is always an inverse relationship between pressures and flow (discharge). Higher pressures mean lower flows. Lower pressure means higher flow (discharge).

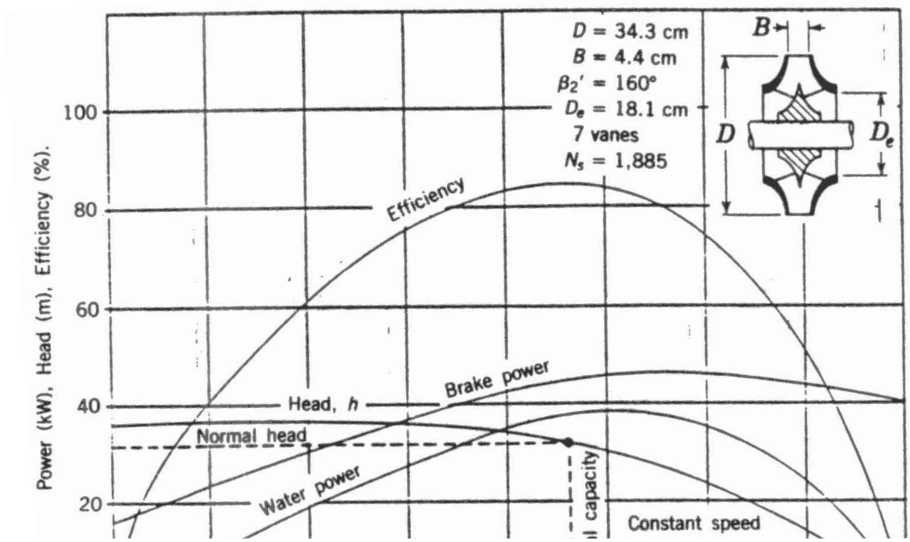

Figure 7 Pump characteristics curve at constant speed

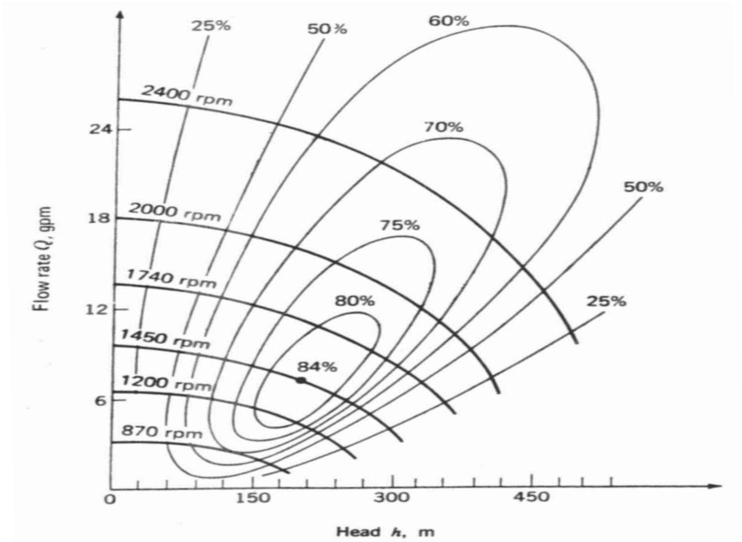

Figure 8 Characteristics of a centrifugal at various speeds

Example on how to estimate total dynamic head:

- Measured suction lift between water and pump is 3m
- Total discharge for irrigating 2ha in 24hr is 2.5liter per second (i.e. 5liter per 2ha)
- Since the pump cannot be made to operate 24 hours we plan for 12 hours
- To irrigate the two hectares, we should pump at 5x24/12 = 10liters per second
- Economical diameter of the pipe is D = 0.97x(Q)0.5 up to 1.22x(Q)0.5

=0.97x(0.01)0.5 up to1.22x(0.01)0.5

=0.097 up to 0.122m

= 97mm up to 122mm (3.28 up to 4.8 inch)

- For this design we can fix at the pipe size of 4inch (which is 0.1016m)
- The velocity of water flow in the pipe would be V = Q/A = 0.01x4/(3.14x0.10162) = 1.2m/s
- Head loss between pump and field or tanker and using Hazan William's formula, head loss due to friction (hf):

$$\text{hf} = \frac{10.675x(\frac{Q}{C}(\frac{Q}{C})^{1.85}}{1!}xL = \frac{10.675x(\frac{0.01}{150})}{0.1016^{4.87}}x100 = 1.4m$$

Head loss between pump and field or tanker and using Darcy Weisbach formula, head loss due to friction (hf):

$$h_f = f * \frac{L}{D} * \frac{V^2}{2g}$$

hf=friction loss (ft /m of head)

f= friction loss factor (from Moody Diagram)

0.02, for cast iron/could be used available flexible pipes

0.01, for cast iron/could be used available flexible pipes

l=length of pipe or tube (ft/m)

V= velocity of flow in tube (ft/sec – m/sec)

D= diameter of pipe (ft/m)

g= gravitational constant = 32.2 ft/sec – 9.81m/sec

$$h_f = f * \frac{L}{D} * \frac{V^2}{2g}$$

$$h_f = 0.02 * \frac{100}{0.101} * \frac{1.2\ m/sec^2}{2\ X\ 9.81} = 1.4\text{ m}$$

- Head loss due to fittings, hff = 10% of hf = 0.1x1.4 = 0.14m
- Therefore, head loss due to friction and fittings = hf + hff = 1.4 + 0.14 = 1.54m
- Then, if the measured head difference between the center of the pump and the field to be irrigated or the tank to be filled is (he) = 5m
- The height of the tanker above the ground is (h) = 1m
- Compensation for any other losses (l) = 5m
- Then total head (H) = s+hf+he+h+l = 3+1.4+5+1+5 = 15.4m.
- Therefore, the head capacity of the pump to be selected and purchased should be 15.4m

Power of the pump - the power of the pump is estimated as follows:

$$P_P = \frac{RQH}{102xE_P} = \frac{1000x0.01x15.4}{102x0.65} = 2.4$$

Where; PP = Power of pump in kilowatt

Q = 10 liters/second = 0.01M3/sec

R = Density of water in kilogram per cubic meter

H = Total Dynamic Head in meter

EP = Efficiency of the pump in fraction

Power of the engine

- Total power of the engine should be 10-30% higher than the power of the pump
- The engine, for every 100m operating above sea level, efficiency of the engine drops by 1% (Pt)
- Above 300C atmospheric temperature, for every 5.60C temperature increase, the efficiency of the engine drops /reduces by 1% (Pa)

Therefore, by considering the above factors the power of the engine can be estimated as follows

Pr = from 10-30% taking 20% on average

Pa = 2000x1%/100 = 20%

Pt = ((Tmax - Tmin) x 1%)/Tmin = ((31.2-30) x1%)/5.6 = 0.2% (Note! 31.20C is a measured T0C of the operating area).

Total increment or de-rating = 20% + 20% + 0.2% = 40.2%

Therefore, power of the engine = 40.2%PP + PP = (40.2 x 2.4/100) + 2.4 = 3.4kw

Therefore, since the selected pump is centrifugal and the total dynamic head is 15.4m power of the pump is 2.4 kilowatt. To operate this pump the power of the engine would be 3.4 kilowatt (this is then the power of the engine is about 42% higher than the power of the pump).

Demand assessment and flow rate

The discharge flow rate required is stated in liters per second (l/s), or cubic meter per second (m3 s). It is determined by a study of water demand.

Water demand is determined by segregating the total demand into categories such as:

1) Irrigation demand;
2) Domestic demand;
3) Industrial demand;
4) Commercial demand;
5) Institutional demand.

For irrigation, the water demand is derived from the total area to be irrigated and the water required per unit of area irrigation. The water demand required per unit area irrigated depends on the crop, the climatic conditions, and the soil conditions.

For categories of demand except irrigation, the population to be served and its per capita water consumption is estimated, and from this data, the aggregated water demand is computed. The water quality for categories of demand other than irrigation will generally be to human health standards.

In practice, demand for irrigation will usually be isolated and designed for separately, because the location where it occurs and the water quality demanded is often different.

Estimating pump and power capacity

Water Horsepower

Power required to pump water is determined by the flow rate, and the total head generated as shown below:

Water Horsepower Pw = rgQH, in watts,

Where, r = Density of water in Kg/ m3;

g = Gravity constant m./ s2 ;

Q = Flow rate in m3 /s;

H =Total pumping head in metres of water moW.

Taking r = 1000 Kg m3 and transforming into kilowatts;

Pw = gQH, in kilo watts

Pw = 9.81*QH Kw.

The water horse-power that the pump must inject into the water is therefore fixed once the design specifications of the pumping system are determined.

5. SUCTION AND DELIVERY PIPE (HOSES)

5.1 PIPELINE SELECTION

The pressure loss due to fluid friction in a pipeline depends on several factors: pipe size, material, length, fittings, and flow velocity. The total (dynamic) pressure head that the pump must overcome partly depends on the pressure loss due to fluid friction in pipeline and hence on the pipeline data.

The selection of the pipeline should therefore be done before that of the pump, because pipeline data will influence the selection of the pump.

A preliminary selection of the pipeline is therefore made using a recommended flow velocity for water pipelines. This flow velocity recommended for preliminary design of water pipelines is chosen such that pressure losses due to fluid friction in pipeline are kept within acceptable limits. This ensures that pumping equipment size and costs are also kept within certain limits.

The recommended range of flow velocities for water pipelines, to be applied during preliminary design, is between 1 and 3 m/s. After this preliminary stage, the design specifications should guide further decisions.

5.2 SELECTION OF PIPE SIZE

The selection of pipe size is the first step in system design. The pipe size is selected such that the flow velocity, when the pipeline delivers the design flow rate, remains within a specified range.

The flow velocity recommendation is an empirical guide, aimed at the compromise of ensuring that the pressure loss due to fluid friction in the pipeline is not too high, while the discharge flow rate through the pipeline is also not too low.

The trade-off (balancing) is therefore between the size of pump, and the size of pipe. The total head to be overcome dictates the size of pump. The size of pump therefore depends on the friction loss in pipe; and this in turn varies inversely with the size of pipe. The size of pump therefore varies inversely with the size of pipe. For a given set of design specifications therefore, the smaller the pipe selected, the larger the pump required, and vice versa, all else being equal.

5.3 SELECTION OF PIPE MATERIAL

The pressure loss due to fluid friction in pipeline depends on the pipe size, material, length, fittings, and flow velocity. The second step in the selection of pipeline is therefore to select the pipe material. The available pipe materials for water pipelines are: UPVC (plastic), steel, cast iron, and ductile iron.

6. OPERATION AND MANAGEMENT OF ENGINE PUMP

6.1 OPERATION

6.1.1 PRE-OPERATIONAL CHECKS

- Before starting the engine, perform inspections according to the procedures described on pre-operation inspections to avoid accidents and damage to the machine.

- For safety, never attempt using this GEP (gasoline engine powered) water pump to deliver inflammable or corrosive liquids (such as gasoline and acids). Likewise, corrosive mediums, seawater, chemical solvents, alkaline liquids (such as used gasoline, liquor and honey) should be avoided.

- Place the water pump on a solid, level position surface to avoid tilting or turnover that may give rise to spilling of fuel.

- To prevent fire hazards, keep the pump well ventilated during operation and maintain a distance of at least l meter between the machine and the wall or other machines. Keep away from inflammable substances.

- Do not allow children and pets to enter the working area as this may increase the chance of their getting burned by hot surfaces of the operating parts.

- Know how to stop the water pump quickly how to operate the controls. Do not use the pump against the prescribed operating rules

Connecting the water inlet

Connect the water inlet with a commercially available hose, connector and fastener clip. The inlet hose must be a continuous non-foldable structure with a length not more than required length. It should be placed near to the source of water so as to achieve the pump should be fitted to the end of the hose with the hose connector.

CAUTION: Before pumping water, attach the filter to the end of the hose to filter out foreign matters in the water, the presence of which may cause clogging and damage to the wane wheel.

NOTE: The hose connector and fastener clip should be securely fastened to prevent air leaks and reduction in suction power. A loose hose will reduce the pump performance and self-suction capacity.

Connecting the water outlet

Connect the water outlet with a commercially available hose, hose connector and fastener clip. Large diameter hoses are the most effective while small ones will increase the flow resistance and reduce the output power of the pump.

Due to differential thermal expansion rates between metal and plastic, transmittal of pipe vibration, and pipe loading forces DIRECT INSTALLATION OF METAL PIPE INTO PLASTIC CONNECTIONS IS NOT RECOMMENDED. Wherever installation of a plastic duplex strainer into a metal piping systems is necessary, it is recommended that at least 10 pipe diameter in length of plastic pipe be installed upstream and downstream of the plastic duplex strainer to compensate for the factors mentioned above .

6.1.2 ENGINE OIL

Use 4-stroke engine oil, API Service classification SE class or equivalent. Check the API service label on the container to be sure it includes the letters SE class or equivalent. SAE 1oW -30 recommended for general use. Other viscosities shown in the chart may be used when the average temperature in your area is within the indicated range.

Oil level Check method are:

1. Remove the dipstick and clean it.
2. Reinsert the dipstick into the oil filling hole without screwing it, and check oil level.
3. If the oil level is too low, add the recommended engine oil up to the oil filling neck.
4. Reinstall the dipstick.
5. Lubrication oil capacity K180 -3 0.6 L
6. Running with insufficient oil may damage the engine severely.

6.1.3 AIR CLEANER

Dismantle the air cleaner cover and check the element to make sure it is clean and complete and clean or replace it as necessary. Never run the engine without an air cleaner or severe wear of the engine may be resulted in.

Fuel recommendation

1) Remove the fuel tank cap and check the fuel level
2) If the level is too low, refuel the tank. Remember adding fuel not over the fuel filter shoulder

6.2 STARTING AND STOPPING PROCEDURES

6.2.1 STARTING ENGINE

1.Turn on the fuel tap (by setting it to the ON position)

2. Close the choke NOTE: The choke is not required when starting the engine warm or the ambient temperature is rather high, (i.e. keep the choke open when starting the engine).

3. Set the engine switch to the ON position
4. Turn the throttle control lever slowly to the left
5. Gently pull up the starter lever until a resistance is felt and then quickly pull it up
6. CAUTION: Do not allow the starter lever to retract quickly into the engine. Let it go back gently to avoid damaging the starter.

6.2.2 OPERATION OF THE WATER PUMP (SAFETY PRECAUTIONS)

i. The gasoline fuel is highly inflammable and may explode under certain conditions.

ii. Do the fueling with the engine shut down and in a well-ventilated environment. No smoking is allowed and no open fire or sparks allowed to exist in areas where fueling is carried out or the fuel is stored.

iii. Do not allow the fuel to overflow the fuel tank. Be sure to recap the tank and tighten it after refueling.

iv. When fueling, take care not to spill the gasoline about as the gasoline vapor may easily get ignited to cause a fire hazard. Be sure to remove the spilled gasoline as by wiping before starting the engine.

v. Do not run the engine indoors or in a poorly ventilated space as the exhaust gas produced by the running engine contains toxic carbon monoxide that may cause the loss of personal consciousness or even death. Below chapter is on Diagnosing pump and Seal Problems in Field.

7. MAINTENANCE

7.1 DAILY INSPECTION

Before running the engine, check the following service items

- Enough fuel
- Enough clean oil
- Not leakage of oil or fuel
- Clean air cleaner elements
- Loose or broken bolts and nuts
- Excessive vibration noise

7.2 REPLACING THE ENGINE OIL

Oil drains easily and quickly while the engine is warm

1. Remove the oil dipstick and drain bolt to let out the oil
2. Screw the drain bolt back in place and tighten it
3. Pour in clean oil until the desired level is reached

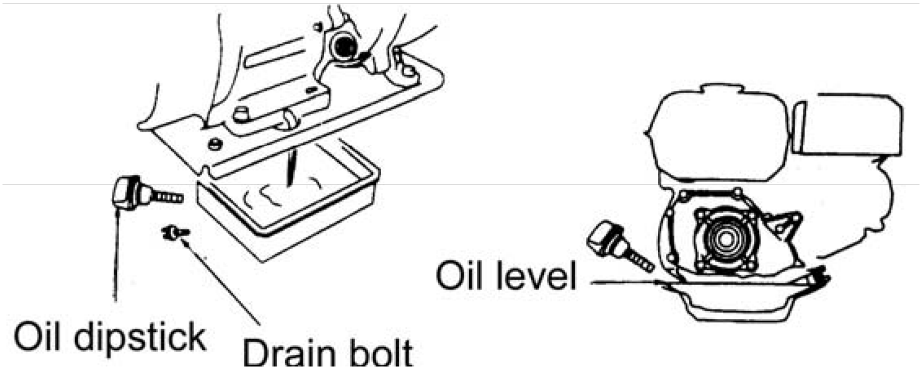

Figure 9 Engine oil parts to be replaced

Clean the hands with soap if stained with the engine oil.
NOTE: Be sure to keep the environment clean when disposing used engine oil. We suggest you collect the waste oil in a container to be sent to a waste disposal site or a recycling service center or spill it in the garbage or on the ground.

7.3 MAINTAINING THE AIR CLEANER

A dirty air cleaner will let less air into the carburetor. To prevent carburetor malfunctions, be sure to maintain the air cleaner periodically. If the pump is working in an extremely dirty environment, more frequent maintenance of the air cleaner will be necessary.

DO not clean the air cleaner with a low ignition point solvent because it may get enflamed or even explode under certain circumstances.

CAUTION: Do not use the water pump without an air cleaner. The dirt or dust if sucked into the engine may quicken engine wear.

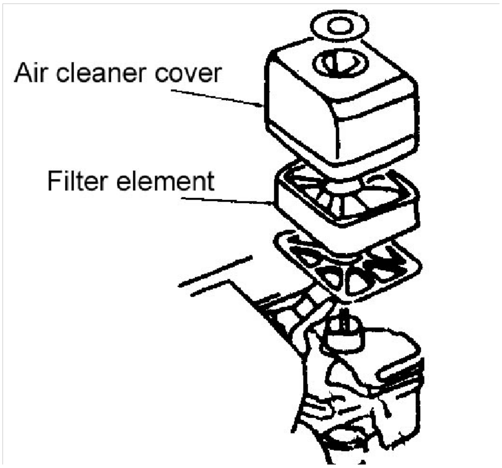

Figure 10 Air cleaner parts of an engine

1. Unscrew the wing nut and remove the air cleaner cover and filter element
2. Clean the filter element with a detergent solution inflammable or with a high ignition point and let it dry thoroughly after cleaning
3. Immerse the filter element into clean oil and then squeeze out the excessive amount of oil
4. Put the filter element as well as the air cleaner back in place

7.4 MAINTAINING THE SPARK PLUG

The recommended type of spark plug is NHSP LD P6RTCU. To ensure normal operation of the engine, the spark plug should have a correct gap and should remain free of carbon deposits.

1. Remove the plug cap. The muffler may be very hot if the engine is still running. Take care not to touch the muffler.
2. Check the spark plug visually. Discard the spark plug if it is obviously worn out or the insulation ring on it is broken or cracked. Clean the spark plug with a brush when putting it back in place.
3. Check the plug gap with a feeler gauge. Vary the gap by moving the side electrode.

   Normal plug gap: 0.70~0.80mm
4. Check the plug O-ring for normal condition. Screw it in with the plug wrench to protect the plug thread

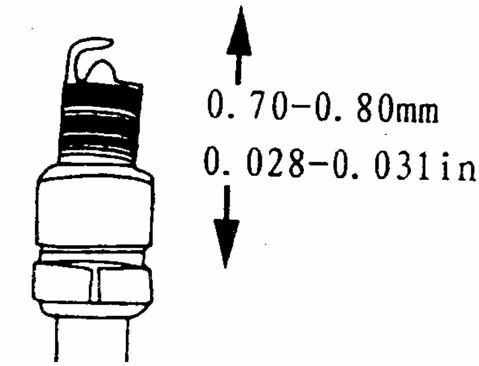

Figure 11 The spark plug clearance

7.5 TRANSPORTATION AND STORAGE

To avoid causing a fire hazard, let the engine cool down before transportation or indoor storage of the pump.

Before transporting the pump, set the fuel tap to the OFF position and place the pump body in a level position to prevent the fuel from spilling out. The spilled gasoline or the gasoline vapor may get ignited.

Note and do the following before storing pump for an extended period of time:

1. Make sure the storage area is free of moisture or dust
2. Clean the inside of the pump.

The pump may get clogged if it is used to suck up water containing such matters as earth, sand or heavy fragments.

Before storing, clean the pump by sucking up clean water or otherwise the wane wheel may be damaged when the pump is put to use again. After cleaning, unscrew the water drain plug to drain off the water from inside the pump casing as much as possible. Then screw the drain plug back into place.

3. Drain off the fuel. To drain off the fuel:
   a. Turn off the fuel tap (OFF position), unscrew the drain screw from the carburetor float chamber to drain off the fuel from inside the carburetor and collect the gasoline in a suitable container
   b. Turn on the fuel tap (ON position) and collect the gasoline in a suitable container
   c. Screw the carburetor fuel drain screw back into place

7.6 TROUBLESHOOTING

Engine unable to get started:

i. Is there enough fuel? Is the fuel tap turned on?

ii. Has the fuel reached the carburetor? Make the check by unscrewing the oil drain screw from under the carburetor with the fuel tap turned on.

WARNING:

Should there be a spill of fuel, be sure to clean it before checking the spark plug and start the engine or otherwise the spilled fuel or fuel vapor may get ignited

iii. Is the engine switch set to the ON position?

iv. Is there enough oil in the crankcase?

v. Is the spark plug generating sparks?

   a. Uncap the spark plug, clear off the dirt from around the plug and remove the spark plug
   b. Fit the spark plug into the plug cap
   c. Turn on the engine with the side electrode and pull up the starter lever to see if there is sparks generated
   d. Ground the engine with the side electrode and pull up the starter lever

to see if there is sparks generated

e. Replace the spark plug if no spark is found

vi. Start the engine as directed in the operation manual if sparks are generated

vii. If the engine still refuses to get started, send the pump to authorized dealers

7.7 THE PUMP UNABLE TO SUCK UP WATER

1) Is it filled with enough amount of water?
2) Is the filter clogged?
3) Is the hose fastener clip tightened?
4) Is the hose damaged?
5) Is the suction head too high?
6) If the pump still fails to work, send it to any of the authorized dealers

Figure 12 Small pump sitted at the right suction head

8 GENDER EQUALITY BOX

What are the issues of gender inequality?

Household micro-irrigation is undertaken on small plots of land which comprise the homestead garden which is a women farmer's domain but women farmers have faced different problems to use HMMI technologies like motor pump: lack of information, capital constrained and lack of maintenance services. Women farmers like technologies that saves their time and labor at the same time enhancing productivity.

How can the gender inequality be addressed?

Consider women labour and time in pump selection in weight, operation and simplicity.

Train motor pump maintenance jobless youth girls to make the service women friendly. Improving the financial management status of women and introducing community level credit and loan services is important to purchase and use motor pumps.

Arrange training for women farmers to check and change oil level. Women centered trainings shall be organized for women-only groups, in local languages and with practical demonstrations and experience sharing visits to model sites.

Technical knowledge regarding the operation and management of motor pump technologies must be arranged for women farmer's as part of the extension service.

By promoting women friendly micro irrigation technologies.

What will be the benefits when gender inequalities are addressed?

By using women friendly technology like motor pump irrigation can boost agricultural productivity and contribute to household food security, nutrition, health, and income. It empowers the women significantly in decision making in family life and on her own destiny.

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CASE STUDY

MOTOR PUMPS

Story by Ato Esubalew Erkie who is Irrigation Agronomist from Woreda Office of Agriculture and also Focal Person for SMIS and Ato Agegn Abebe, Kebele Agricultural Office Head

1. BACKGROUND

Jegna Kebele is one of irrigation potential Kebele out of the total 36 Kebeles located in Dera Woreda, South Gonder Zone of Amhara Region. This case study was collected from Jegna Kebele located 47km from Bahir Dar, 12km from Hamusit town from three farmers (2M and 1F) involved in irrigation development.

The major water source used for irrigation is known as Abagenen river. The river is a perennial and serves for irrigating large size land in as well as outside the Kebele. There are also runoff storage ponds, manual tube wells, and HDWs owned by individual and group of farmers. Three hundred water lifting pumps are also available in the Woreda in addition to some bucket pumps used by local farmers. Nowadays, in the Woreda, the number of bucket and manual water lifting pumps has decreasing due to the fact that income of farmers involved in irrigation has increased and farmers shifted their lifting to motor pumps. Because of this dynamics: "What is appropriate technology today is not an appropriate technology tomorrow at a given place and time". Related to this fact the area under irrigation also increased from time to time and presently, in Jegna Kebele alone, out of 1162ha irrigated in the Kebele is irrigated by using motor pumps by 1436 farming households of which 210 are female headed.

Even though there is water resource potential in the area, technologies were not introduced adequately to the farmers through the Woreda and Kebele agricultural experts. Except very minor differences irrigation practices within the Kebele are of similar nature in terms of crops, water source, water abstraction and water application methods. Related to this the irrigation practice by the following farmers is presented here.

1.1 ATO BAYLEGN ADDIS

General background information: He is 56 years old and has seven family members. His farm is located 2km from Hamusit town and 500m from the main road. The water source of the farm land is Abagenen, which is high flow Perennial River. Robin brand pump is used for water lifting from the river to the command area. Ato Baylegn, started irrigation before 6 years on 0.25ha, and now has reached irrigating 0.75ha of land (Photo 1). Major crops under his irrigation are onion, shallot, maize, tomato, pepper, and potatoes. The crops are as per the recommendation by the Woreda Office of Agriculture (WoA).

Major benefits as perceived by Ato Baylegn are:

- Increment of agricultural production and productivity that has resulted in increment of household income
- There is no upstream and downstream social conflict because of availability of sufficient amount of water source
- Because of the presence of the perennial river direct pumping of the water from river to command area without the need for additional investment on water harvesting

Adoption: His family members and other neighbouring farmers have taken a good experience from his best practices indicating a sign of adoption of best practices

Major problems as perceived by Ato Baylegn are:

- The existing manufactured pump and its spare parts are not of good quality
- He need a better quality pump, but not available at local market
- Practical training on repair and maintenance has not been given to the farmers and also not accessible at Woreda level
- Price of fuel and spare parts is very high and not available at local market
- It cannot be easily managed by women because of its location are somehow far from their home

1.2 ATO TILAHUN MEKUANINT

General background information: He is 54 years old with 10 family members living in Atreko village, Jegna Kebele located at equal distance with that of Ato

Baylegn Addis. Using water from Gumara River, he irrigates 1.25ha (Photo 2). He started practicing irrigation before 16 years on 0.25ha and now has expanded it to five fold. He is one of the top model farmers recognized at the Woreda level. He uses the two water pumps (Haomax and Robin) depending on different periods and based on the existing unit price of the diesel and benzene; and also the size of irrigated land. He is also cultivating additional irrigable land rented from two neighbouring farmers with 50% of payment rate to the owner of the land. The major crops planted are tomato (0.25ha), teff (0.63ha) and onion (0.37ha). The main market center for procurement of pumps, diesel/benzene and spare parts is from Woreta and Hamusit towns.

Major benefits as perceived by Ato Tilahun are:

- High agricultural crop productivity results better income to Tilahun, and procured one more irrigation motor pump
- No need of credit support from Amhara Credit Service Support local organization due to his good income from his farm land

Adoption:

- Ato Tilahun has excellent acceptance than all model farmers in the Kebele and even at the Woreda
- His site serves as a demonstration (learning laboratory) center to Kebele Agricultural office and following that other farmers are procuring motor pumps for micro irrigation

Major problems as perceived by Ato Tilahun are:

- Incidence of pest and diseases on the vegetables production
- High unit price of diesel/benzene and spare parts

Figure 13 Photo 2 Ato Tilahun Mekuanint irrigating using motor pump - Photo on 29/6/2018

1.3 W/O YERBALEM AYELE

General background information: Her farm is located in Gerargie village on the right side of the main road at about 500 meter. She is one of the many farmers practicing irrigation. The construction of water harvesting structures was done in 2016/17 E.C by team of youth contractor trained by Agricultural Growth Program (AG) project. The source of water is Manual Tube Well (MTW) with a depth of 30m; and its minimum water storage depth is 20meter. in month of February to May. Water sources for irrigation are from Manual Tube Well (MTW), hand Dug Well (HDW), rivers and ponds (Photo 3). More than 40 Robin type motor pumps exist in the Kebele however 17 pumps are not functional.

Advantages:

- One MTW is constructed/drilled at her own full cost
- One of her son has graduated from university and three children have enrolled in private Colleges
- She has constructed one additional house

Adoption:

- Techniques particularly on development of MTW, HDW and irrigation water management are fully adopted by her relatives and neighboring farmers who have shallow ground water

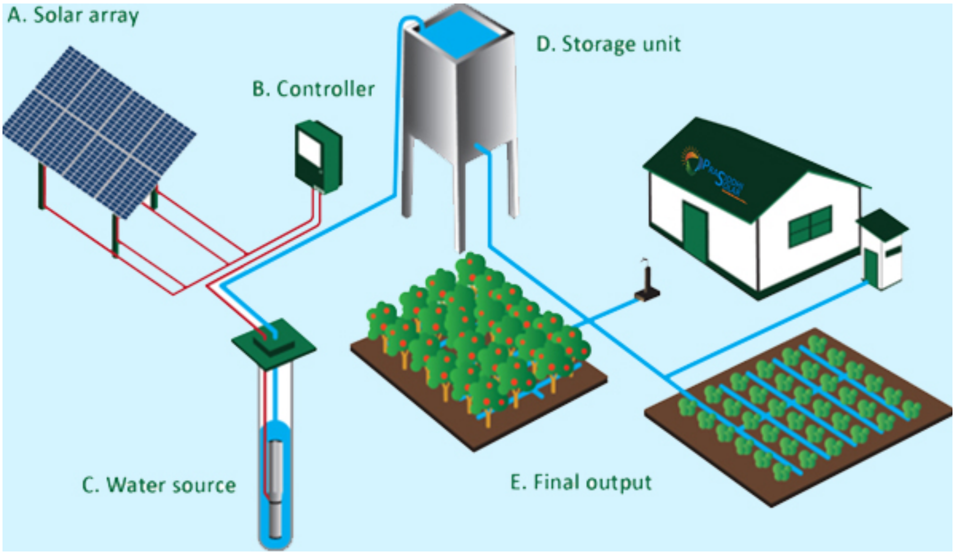
Major problems forwarded by w/o Aynalem Ayele:

- Repeated failures of the pump
- No appropriate personnel on repair and maintenance
- No spare parts at local market and high unit price reaching to birr 8500 per year
- Size of irrigated land is also decreasing because of absence of fertilizers, onion and tomato seed, chemical (for rust disease), existing tomato variety is not good
- Absence of market for tomato and onion
- Adoption of the technology faces difficult by some farmers because of high price of pumps

Figure 14 Photo 3 W/o Aynalem Ayele, in her irrigated field with the pump - Photo on 29/6/2018

Module-8

Solar Water Pumps



1. INTRODUCTION

This module on Solar Water Pumps is the first version and is a series of other modules in the HHMI competencies area such as, Hand Dug Well Development, Manual Tube Well Development, Spring Development, Rooftop Rainwater Harvesting, Farm Ponds, Manual Water Lifting Pumps, Engine Pumps, Drip Irrigation, and Sprinkler Irrigation. The module outlines on how to understand solar water pumps, selection, installation, operation and maintenances for micro and/or small-scale irrigation schemes. This professional development series supports the application of national household micro irrigation development program interventions. Solar-powered pumps offer a low-cost and environmentally-friendly alternative to electric irrigation technologies and motor pumps. Research suggests that investing in solar irrigation can profit smallholders irrigation agriculture, although the level of profit depends on the type of crops under cultivation, water delivery and application systems, and the size of the cultivated area.

The solar water pump is well suited to cover the needs of those smallholder farmers as it is an affordable irrigation technology for individual use that combines environment- friendliness and low maintenance costs with income, productivity and labor-saving benefits in the rural areas of Ethiopia.

1.1 PURPOSE AND SCOPE

This module is help us a training material and to enhance the knowledge and skill of wereda experts and DA's on solar water pumps (SWP). It can also be used as a field manual. This material gives a clue for; planning, designing, installation, operation and maintenance of SWP pump.

1.2 WHAT IS SOLAR WATER PUMP

Solar pumps utilize the photovoltaic effect to produce free electricity used for water pumping. Photons of light hit a collection of solar cells, exciting electrons into a higher state of energy, making them act as charge carriers an electric current. This is how Photovoltaic (PV) cells produce electricity. Solar water pump is a pumping device powered by solar energy, consists of solar panels, solar pumping inverter and pump, can be used for irrigation in agriculture, domestic water supply and water for livestock. A solar-powered water pump is a pump running on electricity generated by photovoltaic panels or the radiated thermal energy available from collected sunlight as opposed to grid electricity or diesel run water pumps. Solar water pump is cost-effective and easy to operate and sustainable energy solution to irrigation farmers.

A photovoltaic solar panel can power a pump, which can move some liters per hour based on the solar panel power and pump capacity. For example, a 50-watt photovoltaic solar panel can power a 12-volt pump, which can move 1,300–2,600 liters per hour.

Currently, solar water pump is widely promoted in Ethiopia for irrigation and domestic water supply. Solar water pump can play significant role in household irrigation. This manual briefly explains about solar water pump selection, parts, installation, operation and maintenance. Sunlight in Ethiopia is very reliable and very predictable as a country close to the equator having a long sun shine hour.

1.3 SUITABILITY OF SOLAR WATER PUMP TECHNOLOGY

The capacity of solar pumps is better when compared to treadle, hip, and other manual pumps. Additionally, it is not labor intensive, has no energy cost, easy operation, time saving, gender responsive and above all is climate smart. Solar power is pollution free and causes no greenhouse gases to be emitted after installation. It is a renewable clean power that is available every day of the year and even cloudy days produces some power. By using it there is reduced dependence on foreign oil and fossil fuels. A study conducted in Ethiopia, comparing with the suitability maps with available land use data showed that on average 9% (96 103 ha) of Ethiopian irrigated and 18% (3,739 103 ha) of rainfed land would be suitable for solar PV pump irrigation. Furthermore, small solar PV pumps could be an alternative water-lifting technology for 11% of the current and future small motorized hydrocarbon fuel pumps on smallholder farms (2,166 103 ha).

2. ADVANTAGES AND LIMITATION OF SOLAR POWER

2.1 ADVANTAGES

- Capital costs increasingly competitive with diesel power
- Low operating cost: one of the important advantages is the negligible operating cost of the pump.
- Low maintenance-a well-designed solar system requires little maintenance beyond cleaning of the panels.
- Harmonious with nature: another important advantage is that it gives maximum water output when it is most needed, that is, in hot and dry months.
- Flexibility: the panels need not be right beside the well. They can be anywhere up to 20 m away from the well, or anywhere you need the water.
- Environmentally friendly

2.2 LIMITATIONS

- Limited power (at current stage of development)
- Technology may not be well understood by beneficiaries (compared with diesel) – risk of damage to sensitive electronic components

- Solar arrays may be attractive to thieves and vandals
- Technical expertise/support limited outside in rural areas
- Variable yield: The water yield of the solar pump changes according to the sunlight.

3. SYSTEM PARTS AND LAYOUT OF SOLAR PUMPS

3.1 SYSTEM PARTS

For understanding solar water pump systems, it is important to understand what a photovoltaic (PV) panels are. Panels are often used for agricultural operations, especially in remote areas or where the use of an alternative energy source is desired. In particular, they have been demonstrated to reliably produce sufficient electricity directly from solar radiation (sunlight) to power livestock and irrigation watering systems. By this there is a benefit of increased water requirements for irrigation, domestic and livestock needs are satisfied.

A solar water pump system is fairly simple structure and typically consists of a water pump (submersible or surface pump), control electronics, solar panels and tubes. Most solar water pump systems do not use batteries. The following parts can be mentioned with some elaborations as shown in the figure-1.

I. Water source: the configuration of the water system will be defined primarily by the type of water source used, as well as by the local topography and the location (s) of the delivery point (s). The water source may be either subsurface (a well) or surface (a pond, stream, or spring).

II. Photovoltaic (PV) solar panels: absorb sunlight as a source of energy to generate electricity. A photovoltaic (PV) module is a packaged, connected assembly of typically 6x10 photovoltaic solar cells. Photovoltaic modules constitute the photovoltaic array of a PV system that generates and supplies solar electricity to drive the motor pump.

III. Inverter: a power inverter, or inverter, is an electronic device or circuitry that changes direct current (DC) to alternating current (AC). This is because the PV produces DC and this has to be changed to AC for driving the motor pump, for most of the water pumps.

IV. Solar panels and direction controller: a frame need to be constructed to support the panels. The frame could be pointed North or South as required to receive the direct sunlight (i.e. maximum irradiance). To improve the efficiency of the system, it can be designed /adjustable in such a way that it can point South or North depending on seasons (for example North for October – March and South for April – September).

The structures for mounting the solar panels could be so designed, auto adjusted for optimal tilt throughout the year (Figure-1).

V. Submersible or surface pump: submersible pump is a device which is air tight (excludes the passage of air) close-coupled to the pump body. The whole assembly is submerged in the fluid to be pumped. The main advantage of this type of pump is that it prevents pump cavitations - a problem associated with a high elevation difference between pump and the fluid surface. Submersible pumps push fluid to the surface.

VI. Pipe mains: rising mains and surface pipes with specified diameter and lengths as this is related to friction loss and cost.

VII. Fitting the pump: fittings for the pump must be connected to a pipe and the wires. Pump and pipe to be dropped down the well or the bore-hole (for submersible pumps).

VIII. Tanks: solar only produces water when it is sunny or bright. The systems should always include an adequately sized storage tank, to match supply to demand both for domestic water supply, livestock and irrigation water use.

IX. Float Switch (Full Tank Shut-off): it is recommended to use a float switch or other means to prevent overflow of the tank. This will stop the pump when the tank is full, then reset when the level drops. This conserves ground water, prevents overflow, and eliminates unnecessary pump wear. Finally, a float switch in the upper tank turns off the pump once the tank is full (Figure-1).

3.2 SYSTEM LAYOUT

In general, there are five parts to be laid out i.e. i) solar array, ii) controller, iii) source of water, iv) storage unit, and v) final out put (See picture in the front cover). The cell panel should be laid over the ground by metal pole and with accurate angle to absorb the suitable amount of solar radiation (Figures-1). Other accessories and elevated water tank for domestic water supply or use of irrigation should be installed adjacent to the panels and surrounding by protected fence. Provide firm and fixed ladder up to the reach of the tank and module for servicing and cleaning. Wash outlet at the bottom of the tank on the ladder side. Barbed wire fencing at the ground is also required to protect the system from unintended entrance.

Solar Dual Pumps: The solar dual pumps is an innovative pump designed to utilize the power of the sun during the day and act as a normal hand pump when the solar energy is not available, hence assuring uninterrupted water supply for drinking, sanitation, personal hygiene etc. The system consists of a submersible pump which runs on power generated from the photo-voltaic solar cells and is suitable for use on bore-wells with 100 mm (and above) diameter up to 80-90 meters depth. In practice a solar array is installed near the bore-well, a submersible pump powered with DC motor is installed below the hand pump cylinder. The pump is connected to a storage tank and the collected water is dispensed through a stand post. This system can also be used on other water sources such as open wells or tanks.

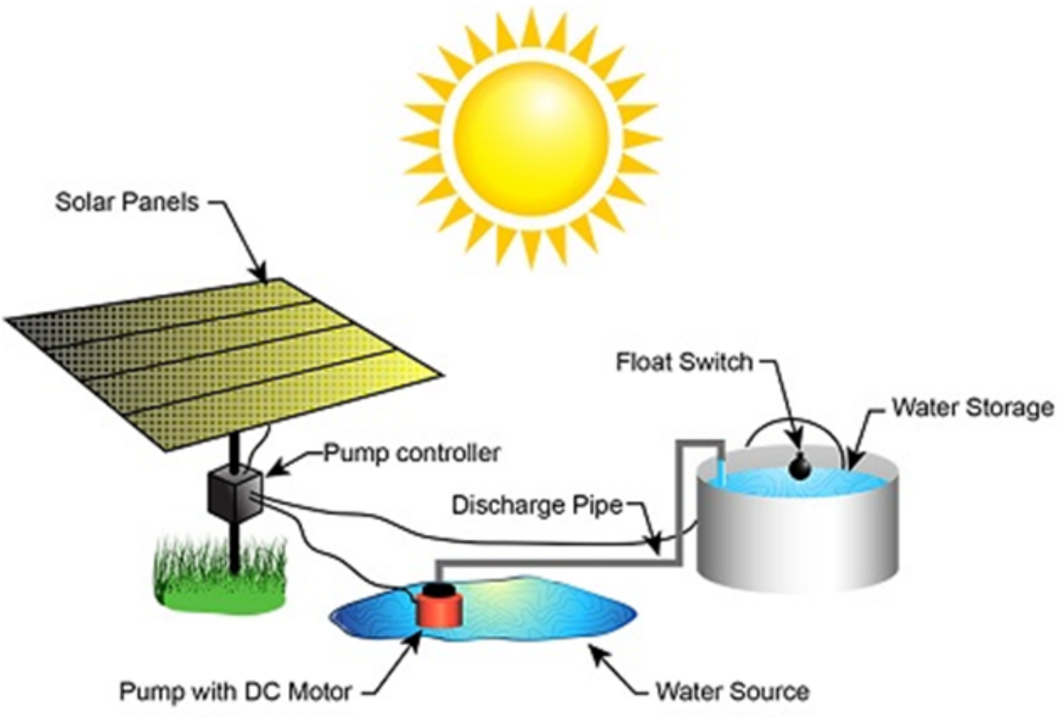


FIGURE 1 SIMPLIFIED SOLAR PUMP SYSTEM PARTS

4. EFFECTIVNESS OF SOLAR WATER PUMP TECHNOLOGY

Water is usually pumped whenever the sun is shining and delivered to the irrigated area. Some applications store water in elevated tanks that can keep water from one season to another. Solar pumping is most effective with application requiring low flow and pressure, which keeps open channels and drip irrigation as the most efficient methods when coupled with solar PV pumping (Table-1).

TABLE 1 EFFECTIVENESS OF SOLAR PUMP

Irrigation Method	Application Efficiency	Typical Head	Suitability with solar
Open channels	50-60%	0.5-1	Ok
Sprinklers	70%	10-20	X
Drip	85%	1-2	Ok
Flood	40-50%	0.5	X

5. SOLAR WATER PUMP SYSTEM DESIGN PROCESS

5.1 ELECTRICITY BASICS

It is important to be familiar with fundamental electrical concepts, such as energy, voltage, amperage, and resistance, before one begins to design a solar-powered water pumps system.

Voltage: is the electrical potential (i.e. the pressure) in the solar-powered system. It is measured in units of volts (V).

Amperage: refers to the movement of flow of electrons (i.e. the electrical current) though the system. It is measured in units of Amps (A). Voltage multiplied by amperage is the power produced. It is measured in units of watts (Pw), as:

Equation-1: Watts = Volts x Amps

Electrical energy: is the amount of power generated over a period of time. Energy is typically measured in kilowatt-hours (kWh). Lastly, resistance is a measure of a material's resistance to the flow of electrons across it. It is measured in Ohms (Ω). A good analogy to help describe the flow of electrons in a wire is the flow of water through a pressurized line. In order to illustrate this analogy, see Table-2.

TABLE 2 ELECTRICITY FOR NONE-ELECTRICAL ENGINEERS

Electricity in a Wire	**Water in a Pipe**
Amp (flow of electrons)	Q (flow rate of water)
Volts (energy potential)	Pressure (energy potential)
Watts (power) = Amps x Volts	Hydraulic /Water Power = Q x Pressure
Resistance	Friction + Minor Losses
High Voltage, Small Wire = High Amps, High Resistive losses, Heat and Fires	High Pressure, Small Pipe = High Velocity, High Friction Losses, Blown Pipe

As with water flowing through a pipe, resistance (friction, in the case of water) in the electrical line results in an energy loss in the system. It is influenced by the length, size, and type of wire conductor. Specifically, resistance is proportional to the length of the wire and inversely proportional to the cross-sectional area of the wire. In other words, the longer the wire the greater is the loss and the larger the wire diameter, the less is the loss. The wire material also influences the energy loss: a good conductor, such as copper, has a low resistance and will result in less energy loss.

Another effective way to reduce electrical losses in a system is to decrease the current flow. Power losses in an electrical circuit are proportional the square of the current, as shown below;

Equation-2: Power Loss = Current2 x Resistance

Consequently, as indicated in Equations-1 and 2, increasing the voltage while reducing the current will result in the same power transmission, but with less power loss. Therefore, higher voltage pumps tend to be more efficient than lower voltage pumps, assuming all other properties are similar.

5.2 SOLAR WATER PUMP SYSTEM DESIGN

In order to select the best possible pumps using tables listed in this text; selecting the best alternative and supporting PV energy power supply selection should be reviewed with the following checklists.

- Water requirement – demand calculation
- Water source – surface /well, depth of water source /static water level (SWL)
- System layout - determining the layout of the proposed system, identification of all necessary distances and elevations for the intake point, pump, PV panels, water tank, and water troughs
- Water storage i.e. determine the volume of storage and head
- The site-specific solar energy (Solar insolation) and PV Panel location - average daily sun-hours
- Design flow rate for the pump - the pump's design flow rate is based on the operation's estimated water needs (Step 1) divided by the number of peak sun hours (Step 5)
- Total dynamic head (TDH) for the pump
- Pump selection and associated power requirement
- PV panel selection and array layout
- PV array mounting and foundation requirement
- Water flow rated and delivery point pressure – estimated pump flow in lit /sec, recovery rate for well/ drawdown, to ensure there is adequate pressure to operate
- Summary description of the system i.e. system layout

5.3 SOLAR WATER PUMP CAPACITY

The water pumping amount requirements (m^3/d), electricity supply and sun irradiance conditions determine the overall size of the PV system. The capacity of the pump depends not only on the size of the solar panels, but also it depends on the depth of the water source and the delivery head (Table 3). Some solar pumps can extract water from 7meters deep (suction), but it is advisable to minimize the suction depth to 3-4m. Small solar pumps can discharge above 15m head based on the solar power, for example 80-120W solar water pump can deliver water at 15m vertical lift and horizontally can convey up to 500m.

TABLE 3 EXAMPLE OF CAPACITY OF SOLAR PUMP

Power	1-meter lift	6-meter lift
80W	2200 lit/hr	2000 lit/hr
120W	3600 lit/hr	2500 lit/hr

Detail online Solar water pump calculator can also be used for best fit pump purchase (such as the following characteristics listed in Table-4 below).

TABLE 4 EXAMPLE OF SOLAR WATER PUMP CHARACTERISTICS

Storage (lit/sec)	SWL (m)	Delivery head (m)	Total loss (m)	TDH (m)	Area (Ha)
10,000	3	6	1	10	0.25

6. PV SOLAR WATER PUMP CAPACITY

6.1 GENERAL

The volume of water pumped by a solar-powered system in a given interval depends on the total amount of solar energy available in that time period. Specifically, the flow rate of the water pumped is determined by both the intensity of the solar energy available and the size of the PV array used to convert that solar energy into direct current (DC) electricity.

It is important that the components be designed as part of an integrated system to ensure that all the equipment is compatible and that the system operates as intended. It is therefore recommended that all components be obtained from a single supplier to ensure their compatibility. The following information is required to design a PV-powered pump.

6.2 SOLAR PV SYSTEM DESIGN FOR WATER PUMPING

6.2.1 WATER REQUIREMENT OF THE PLANT

The water requirement of the plant varies with time and depends on the season and growth of the plants. It is essential to irrigate optimally during the stage of flowering to fruit maturity. The type of soil and the climatic parameters are other factors that need to be considered.

6.2.2 EXAMPLE ON PV SIZING

Different size of PV modules will produce different amount of power. To find out the sizing of PV module, the total peak watt produced should be known. The peak watt (WP) produced depends on the size of the PV module and climate of site location. To determine the sizing of the PV modules, calculated as follows:

- Given Example: Load requirement = 25000 liters of water every day from a depth of 5m

Amount of water to be pumped /day = 25000 liters /day = 25m3

i. To determine Total Dynamic Head (TDH)

- Possible max elevation of piping unit inlet = 3m
- Possible max elevation of piping unit inlet = 3m
- Total vertical lift = 3m + 2m = 5m
- Possible frictional losses = 5% of total vertical lift = 5x0.05 = 0.25
- TDH = 5m + 0.25m = 5.25m

ii. To determine estimate load requirement with selected DC pump (assume maximum head = 7m)

- Selected DC pump max flow = 5m3 /hour
- Supplied Voltage = 12V
- No load current = 3A
- Loading current = 14A
- Power consumption, P = VI = 12 x 14 = 168 Watt
- Required running hour /day = (Amount of running hour /day) /DC pump max flow = ((25m3 /day)/(5m3 /hour)) = 5 hour /day
- Required electrical every /day = Power consumption x Running hour /day = 168Watt x 5 hour /day = 840-Watt hour /day

iii. To determine Ampere hour requirement of DC load

- System voltage = 12 V
- Load Current = 14A
- Required running hour /day = Load current x Running hour /day = 14A x 5 hour/day = 70A-hour /day

Battery sizing and PV module sizing can continue as required. Having gone through the system design in Section 5.2 for the selection of Solar water pump Table-5 could also be used.

TABLE 5 BEXAMPLE OF SOLAR WATER PUMP RECOMMENDATION

Solar power (Wp)	Voltage (V)	Lift height (m)	Max Flow rate (m^3/h)	Max Flow rate (lit/min)
100-300	24-48	0-50	0.8	13.3
100-300	24-48	0-30	1.2	20.0
100-300	24-48	0-20	2.7	45.0
300-500	48-72	0-140	0.5	8.3
400-900	48-72	140-180	0.5	8.3
300-500	48-72	0-80	0.8	13.3
400-900	48-72	80-140	0.8	13.3
400-900	48-72	40-90	1.2	20.0
400-900	48-72	30-60	1.9	31.7
300-900	48-72	0-50	2.7	45.0
400-900	48-72	0-30	3.6	60.0
350-500	72-96	0-140	0.5	8.3
400-900	72-96	140-240	0.5	8.3
350-400	72-96	0-80	0.8	13.3
400-1200	72-96	80-160	0.8	13.3
400-1200	72-96	40-120	1.2	20.0
400-1200	72-96	30-80	1.9	31.7
350-1200	72-96	0-60	2.7	45.0
500-1200	72-96	0-40	3.6	60.0
100-450	12--24	2--22	5	83.3
300-900	48-72	0-25	7.5	125.0
300-900	48-72	0-18	11	183.3
350-1200	72-96	0-40	7.5	125.0
350-1200	72-96	0-24	11	183.3
350-1200	72-96	0-15	21	350.0
350-1200	72-96	30-60	6	100.0
300-1800	72-96	12--40	11	183.3
300-1800	72-96	25--12	16	266.7
300-1800	72-96	2--12	22	366.7

7. SOLAR WATER PUMP OPERATION

7.1 PUMP CHARACTERISTICS CURVE

When installing a solar pump, keep a few things in mind. Solar panels operate more efficiently when pointed in direction sun’s rays. Set the solar panel at allowable distance, considering the suction length and depth. The delivery or the collector should fit with the delivery head of the pump, for this one needs to refer the pump characteristics curve (Figure-2). Distance between the pump and the PV panels should be kept to a minimum to reduce voltage drop in the cables. Consider mounting solar collectors on polls to avoid damage from children or animals, and to keep the cells from being covered by dust or other debris.

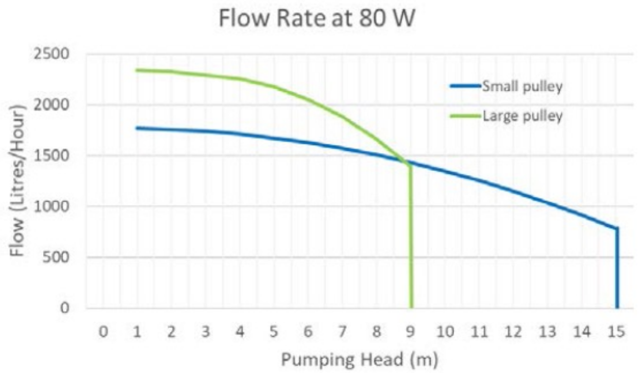


FIGURE 2 TYPICAL SOLAR WATER PUMP CHARACTERISTICS CURVE

7.2 OPERATION GUIDELINES

Panel Cleaning: Clean the panels regularly to avoid particles, feces, leaves, and other residues from blocking the sun. Panels can be cleaned with a plain piece of cloth with the use of some water when available.

Panel Inspection: Inspect the PV panels to make sure there are no cracks or damages
Shadow Prevention: Check the panels for any shadow and perform necessary trimming of trees if necessary.

Wiring inspection: Check wires regularly for fraying (decaying), splitting, or damage

FIGURE 3 SOLAR WATER PUMP OPERATION

Because the power required for pumping water is a product of flow and head. The greater the head the smaller will be the discharge and also should be seen the population that can be served. The cost of solar has decreased over the year and the higher initial cost will be offset in the long term by the lower running costs.

The “Mounting Structure” should have the following features:
Preparation of Scheme: on the basis of water quality and yield, engineer should consider the following basic things;

- ✓ He /she should decide the location of solar unit
- ✓ It should not be located under a tree or in shadow area
- ✓ It should have space for fencing for protection
- ✓ It should have proper foundation as the steel structure of solar panel has to withstand wind of up to 200 km/hr velocities
- ✓ Hence it should not be located on exposed rocks

FIGURE 4 TYPICAL FEILED OPERATION SYSTEM OF SOLAR WATER PUMPS

8. ENVIRONMENT AND SOCIAL FREINDLYNESS OF SOLAR PUMPS

Solar powers have distinct environmental advantages for generating energy over conventional technologies. Solar pumps use solar energy as driving forces. The operation of solar pumps systems does not produce any noise, toxic-gas emissions, or greenhouse gases. Solar water pump is a proven climate smart water lifting system for irrigation with no or minimum negative impact of environment, energy saving and women favored technology.

A benefit of using solar energy to power agricultural water pump systems for irrigation, domestic, and livestock needs is those increased water requirements tend to coincide with the seasonal increase of incoming solar energy. When properly designed, these PV systems can also result in long-term cost savings and a smaller environmental footprint compared to conventional power systems.

9. GENDER EQUALITY BOX

What are the issues of gender inequality?

A case study conducted by International Water Management Institute (IWMI) shows that women preferred solar pumps than other irrigation water lifting technologies when the pumps are located nearby and can be used for multiple purposes, such as irrigating household gardens and providing water for the home (Nigussie et al. 2017). Women and girls often spend hours each day hauling water from the closest water source. A water supply near the home would save them significant time and effort, as well as providing an opportunity to earn extra income by supplying water to neighbors. In addition, using solar pumps increases yields and diversifies the family diet. However, women face barriers to adopting solar pump irrigation. They traditionally control water use for domestic activities, rather than for productive purposes such as irrigation. Women farmers also have significantly less access to agricultural information than men, which limits their capacity to obtain credit, make decisions about technology adoption and strengthen irrigation practices.

What will be the benefits when gender inequalities are addressed?

This could limit their ability to benefit equally from the use of solar water pump technologies.

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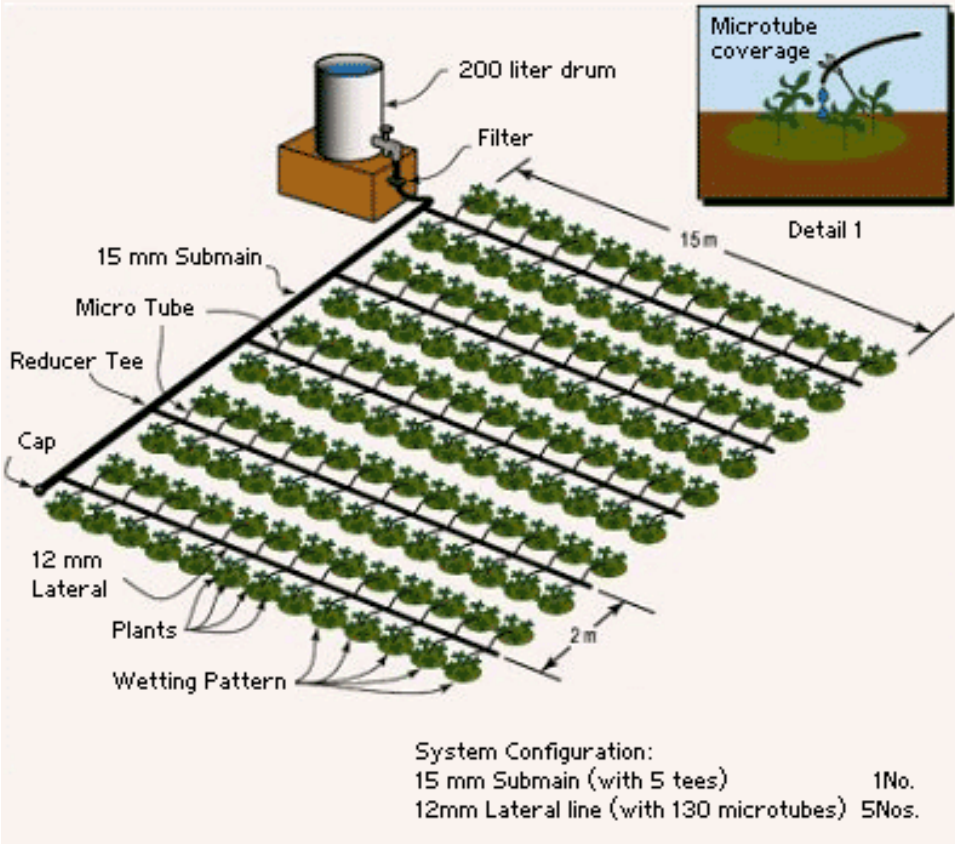
Module-9

Low Head Family Drip Irrigation System



1. INTRODUCTION

This module on Family Drip Irrigation is the first version and is a series of other modules in the HHMI competencies area such as Hand Dug well, Manual Tube Well, Spring Development, Rooftop Rainwater Harvesting, Farm Pond Constructions, Manual Water Lifting Pumps, Solar Pump, Engine Pump, and Sprinkler Irrigation. This professional development series supports the application of MoAL, (SSID) other development interventions.

1.1 PURPOSE AND SCOPE

This module help us as a training material and enhance the knowledge and skill wereda experts Development agents on family drip system. It can also be used as a field manual. The material describes in depth planning, design, construction, operation and maintenance together for family drip development on HHM

1.2 WHAT IS DRIP IRRIGATION SYSTEM?

Drip or trickle irrigation is a process of slow application of water to the soil through a mechanical device called emitter, located at selected point along the delivery line. In drip irrigation, water is applied to each plant separately in small, frequent, precise quantities through dripper emitters. It is the most advanced irrigation method with the highest application efficiency. The water is delivered continuously in drops at the same point, moves into the soil, and wets the root zone vertically by gravity and laterally by capillary action. The planted area is only partially wetted.

There are two types of drip irrigation systems: high pressurized drip irrigation system which is mainly developed for commercial farming on open fields or greenhouses; and non-pressurized or low-head drip systems for small-scale agriculture. The low-head family drip irrigation system requires much less skills and is simple to operate and maintain by a farming family.

This family Drip technology frees the farmer from the limitations of rain-fed farming, enabling him/her to cultivate year round, grows a wider variety of crops, and has higher cropping intensity.

1.3 WHY AND WHERE DRIP IRRIGATION SYSTEM IS IMPORTANT

The focus of this module is on low-cost micro-irrigation systems that may include simple family drip systems, which are relevant to suitable crops, slopes, soils and irrigation water.

Suitable crops: - Drip irrigation is most suitable for row crops (vegetables, soft fruit), tree and vine (grape) crops where one or more emitters can be provided for each plant. Generally, only high value crops are considered because of the high capital costs of installing a drip system.

Suitable slopes:- Drip irrigation is adaptable to any farmable slope. Normally the crop would be planted along contour lines and the water supply pipes (laterals) would be laid along the contour also. This is done to minimize changes in emitter discharge as a result of land elevation changes.

Suitable soils:- Drip irrigation is suitable for most soils. On clay soils water must be applied slowly to avoid surface water ponding and runoff. On sandy soils higher emitter discharge rates will be needed to ensure adequate lateral wetting of the soil.

Different soil types will also have an effect on which type of drip emitters will work best on your drip system. While all soils contain the same elements, different types of soils will contain different proportions of these given elements.

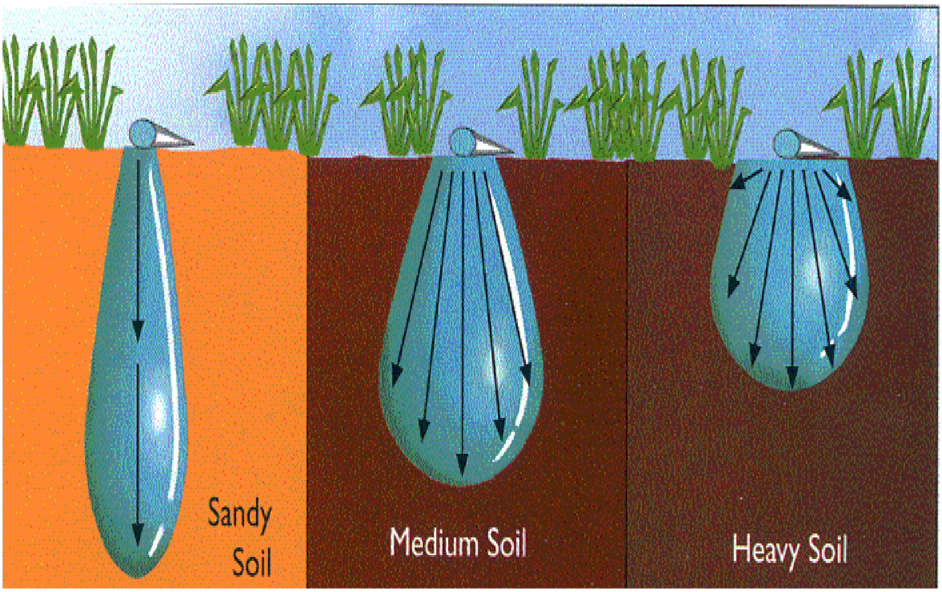


Figure 1 Different types of soil for Drip Irrigation System

- **Clay soils**:- have densely packed particles that have little space for water or air. Water is absorbed very slowly and runoff can occur if water is applied to quickly. When wet, water tends to move outward, away from the drip emitter. Clay soils will hold water very well and can stay wet for several days. Choose 2 ½ & 4LPH GPH (litter per hour) drip emitters when planting in clay soils. Drip emitter spacing tends to be further apart.

- **Sandy soils**:- are very loose and have plenty of spaces for water or air. Water is absorbed very quickly and runoff usually doesn't occur. When wet, water tends to move straight down through the soil. Sandy soils do not hold water very well and can dry out very quickly. Choose 8 & 16 LPH drip emitters when planting in sandy soils. Drip emitter spacing tends to be closer together.

- **Loam soils**: - are ideal in-between mixes of clay and sandy soils. Its absorption rate is greater than that of clay soil but not as fast as sandy soil. When wet, water will move outward and down more evenly. Loam soils will hold water well and dry out at a medium rate. Choose 4 & 8 LPH drip emitters when planting in loamy soils.

Suitable irrigation water: - One of the main problems with drip irrigation is blockage of the emitters. All emitters have very small waterways ranging from 0.2-2.0 mm in diameter and these can become blocked if the water is not clean. Thus it is essential for irrigation water to be free of sediments. If this is not so then filtration of the irrigation water will be needed. Blockage may also occur if the water contains algae, fertilizer deposits and dissolved chemicals which precipitate such as calcium and iron. Filtration may remove some of the materials but the problem may be complex to solve and requires an experienced engineer or consultation with the equipment dealer.

1.4 ADVANTAGES AND LIMITATION OF DRIP SYSTEM

The following advantages are accompanied with the use of drip irrigation (Kadyampakeni 2004):

More efficient use of water: Compared to surface irrigation and sprinkler methods (with efficiencies of 50–75% in high-management systems), drip irrigation can achieve 90–95% efficiency. This is because percolation losses are minimal and direct evaporation from the soil surface and water uptake by weeds are reduced by not wetting the entire soil surface between plants.

1. **Reduced cost for fertilizers**: Precise application of nutrients is possible using drip irrigation. Fertilizer costs and nitrate losses can be reduced considerably when the fertilizers are applied through the irrigation water (termed as fertigation). Nutrient applications can be better timed to coincide with plant needs since dressing can be carried out frequently in small amounts and fertilizers are brought to the immediate vicinity of the active roots.

2. **Reduced labor demand**: Water application is less labour demanding compared to surface or bucket irrigation. Cultural practices such as weeding can be performed when the plants are being irrigated.

3. **Low energy requirement**: A drip irrigation system requires less energy than a conventional pressurized system as it increases irrigation efficiency and therefore requires less water to be pumped. Compared to other pressurized systems, savings are also made because of the lower operational water pressure required for drip systems.

4. **Reduced salinity risk**: Compared to surface irrigation, the drip lines are placed close to a row of plants and the root zone tends to be relatively free

of salt accumulations as the salts always accumulate towards the edge of the wetted soil bulb. The accumulation of salts on a surface-irrigated field tends to be right in the middle of the root zone.

5. **Improved yield**: Slow and regular applications of water and nutrients uniformly to all crop-plants give improved quality and increase in total produce

6. **Difficult terrain**: It can be used on undulated terrain (hilly area) where irrigation by traditional method is difficult

7. **Improved crop and disease control**: Regular irrigation ensures timely inter-culturing operations and spraying etc. which gives better crop control and prevents spread of diseases caused due to flooding

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8. **Uniform application of water**: Since water is applied uniformly to all the plants, there is uniformity in growth and quality of yield

9. **Reduced cultivation cost**: Slow and regular application of water keeps optimum soil-water-air ratio in the soil, which is essential for healthy plant growth. It also reduces need for frequent inter-culturing, weeding etc. Combined with above saving it gives reduced cost of cultivation.

10. **Application to variety of crops**: Number of crops can be irrigated using this method - vegetable crops, fruit crops, commercial cash crops, flowers etc.

11. **More cultivated area**: reduction in area under surface distribution system thereby increasing the potential cultivated area

Limitations of Drip System

1. Breakage of the filter plug due to brittleness of the plastic used
2. Less flexibility in terms of emitter spacing and lateral length
3. Easily punctured by sharp objects if poorly handled
4. Clogging of some emitters
5. Non-uniformity of emitter discharge along the lateral especially where land is not well leveled
6. Lack of spare parts and inadequate extension services
7. Leakage, especially at bucket connections, if fittings are not done properly. i.e., if the hole is bigger than the adapter; other causes of leakage are punctures, cracks.
8. Insecurity; fear of theft if the system is installed far from the house
9. Pest attraction- being the only green spot, especially during the prolonged dry spells, insects, rodents, aphids, etc., find refuge in the drip gardens.

2. COMPONENTS OF DRIP IRRIGATION SYSTEM

2.1 WATER SOURCE

Stored and Elevated Tank: - This is to provide the amount of water required at the necessary pressure to push water out of the drip emitters. A water-holding tank, ranging from a simple bucket to a large permanent tank is the first component. Systems irrigating 250 to 500 m2 areas would require a tank size of about 400 to 500 liter. Black plastic tankers are more preferable than the white tankers as they inhibit algae growth for smallholder uses in marginal areas of the region. Two oil barrels or locally made barrels have been found to be effective for use by connecting them using 2.54 cm diameter and 50 cm length of steel pipe.

A well-built support stands usually made of timber or sturdy (strong and healthy) posts is placed near the cultivated area. The most important point when putting up the stand is to get the correct height from the ground to the bottom of the tank. If it is higher, it will make it hard for filling, especially for younger people and if mounted lower, it will not provide sufficient pressure to the drip tapes. The recommended stand height for a drip system usually ranges from 0.5 to 2m.

Water Availability and Quality

In micro-irrigation systems, the source of water may include, among others: rainfall-runoff harvested water, surface water and ground water. Clean water is especially important to successful drip irrigation. The small orifices found in the trickle emission devices can be clogged easily by physical and chemical contaminants found in the water. Groundwater from wells is generally of good quality and should be used when possible however Groundwater may contain sand or chemical precipitates. Surface water can be used but often contains bacteria, algae, and other aquatic life. Therefore, the water must be cleaned or filtered to the extent possible.

2.2 WATER LIFTING

Hand-pumps, treadle pumps, small diesel pumps and solar pumps are often used to avail the water or to fill the tank regularly. The designed flow of the Family drip irrigation systems offered is around, 1.1 m3/h at 1.5m head. Refer module 6, 7 and 8 of this Training manual.

2.3 WATER DISTRIBUTION AND APPLICATION SYSTEM

Drip irrigation systems convey and emit water to the crop root zone. Including the delivery /distribution system, it consists of the following basic components:

Delivery/Distribution System

Mainline: Poly Vinyl Chloride (PVC) or Polyethylene (PE) pipe to convey water from source to sub mainline and laterals

Sub-mainline: PVC or PE pipe to supply water to the lateral pipes

Drip lines/laterals: Pipes placed along the rows of the crop on which emitters are connected to provide water to the emitters. Lateral pipe size in most systems range from 12mm to 16mm. The difference between 'line-source' and 'point-source' lateral is based on the material used for the lateral line. Line-source laterals come in the form of tapes or thin walled flat hoses with built-in emission devices, whereas the point-source drip designs are thick walled with emission devices that could be created by the user when required (Figure 2). Most FDS (family drip systems) have line source (inline) lateral lines running parallel to each other with flexible spacing from 0.5 to 1m.

Figure 3: Mainline, Sub-mainline, and Drip lines/laterals

Emitters:- Device through which water is emitted at the root zone of the plant with required discharge. The main division is between: On-line Drippers / emitters and In-line Drippers /emitters also known as integral Drip lines (Figure 3).

Figure 4: Example of on line emitter (left) inline emitter

Filters: - help to ensure clean water enters into the drip system. Depending on the type of the drip system used there are different types of filters such as screen, media and disc filter types (figure 4). Screen filter is the most commonly used type of filter for smallholder family drip systems. This is an essential component of FDS, because it keeps away solid materials – sand particles, algae, small insects, and other materials from entering into the drip lines and clogging the emitters.

Figure 5: different types of filter

For regular cleaning, it is always installed at the outlet pipe of the water tank and should be very easy to remove. It is important to check the filter every time the tank or bucket is filled and to rinse off collected material. (DO NOT RUB CLOTH ON THE FILTER). It shall be noted that water from rivers, shallow wells; etc should always be poured into a cloth placed over the bucket inlet to remove large particles which would quickly clog the screen of the in-line filter.

Fittings:-The various fittings commonly required in FDS are described below:

Figure 6: Different types of fittings

Tee connectors: Tee connectors of various sizes are required in FDS to connect a branch to the main pipe, main pipe to the sub main pipe, lateral pipe to the sub main pipe etc. Tee connectors can be equal Tee or reducing Tee type (Figure 5).

Take off: It is used to connect lateral pipes to the sub main pipe in large systems. It is fixed in the wall of sub main pipe with the help of a rubber washer called Gromate.

Lateral end stop: The lateral pipes are closed at the other end with the help of plastic ring or barbed endcap.

Pegs: Small plastic or wooden pegs used to place the lateral pipe in place.

Valves/gauges

Valves are made of plastic or metallic materials used to regulate required pressure and flow of water into the system. There are valves of various sizes depending on flow rate of water in the system (Figure 6). The most commonly used valve type in FDS is the barb valve fitting.

Figure 7: different types of valves

3. PLANNING AND DESIGN OF FAMILY DRIP SYSTEMS

3.1 PLANNING

Setting up a new irrigation system has two phases: Planning and Design. Planning is the preliminary stage and consists of collecting data, taking decisions about the irrigation regime, choosing the layout and the components of the system, especially the emitter type and flow rate.

Planning has to do with which crops to choose, on what types of soils, what pressure, deciding on the frequency of watering of vegetable garden, cost of installation, assessing the advantages and limitations of drip systems are some of the areas that one should cruise through. The hydraulic design is the next stage and comprises of mapping the irrigation system layout, locating control units, mains and laterals, calculating and determining the pressure-flow regime. For example we need to use 2 liters per hour drippers in clay soil, 4 liters per hour drippers in loam and 8 liter drippers in sandy soil.

3.2 BASIC PRE DESIGN DATA

- Plot boundaries and topography: plot borders, crop spacing, row direction and partition into sub-units, if applicable. Intervals between elevation contours will not exceed 1 m.

- Soil properties: Soil depth, Soil texture and structure, Bulk density, Saturation Percentage, Field Capacity, Wilting Point, Infiltration rate and Hydraulic conductivity data, if available, Presence of stratified layers and cracks, Soil salinity.

- Climate data: Rainfall (amount and seasonal distribution), Reference Evapo-transpiration (ET0) (calculated from climatic parameters), (Penman-Monteith method) or measured in Class A pan

- Cropping technology: Growth season, Phonological stages (dates, time-length, foliage coverage, root-zone depth, sensitivity to water stress), In-row and between row spacing, Peak season Crop coefficient (kc).

- Water supply capacity and quality: Water source characteristics (under /above ground tank, surface pond, hand dug well, etc.). Water quality (physical contamination) should be considered.

3.3 LAYOUT OF THE AREA

The layout of the area or plot to be irrigated is determined by the field geometry and size of the drip system. Moreover, the quantity of irrigation water, the types of crops grown and crop water requirement are important. Because the size of the drip system cannot be changed after the procurement, it is important that the selection of plot size and spacing of emitters should be carefully evaluated. The Following points should be carefully considered:

Plot to be irrigated should be close to the water source: a plot located at a distance from the water source would require a long hose to convey water either to the storage tank or to the field causing loss of available head. Attempts should be made to select a plot that is close to the water source to the extent possible.

Plot size should be regular in shape: an irregular shaped plot such as triangular or trapezoidal will make it difficult to install a drip system and achieve higher efficiency. Attempts should be made to select a plot shape that is relatively uniform. A regular shape such as square or rectangle is preferable.

The plot ground surface should be relatively uniform: highly undulating ground surface should be avoided to the extent possible. Although drip system can be installed on undulating ground and can work, the uniformity of irrigation cannot be always achieved due to variability in pressure head of emitters located at different elevations. Similarly plot land with excessive slope greater than 7% (a drop of 7m in 100m) should be avoided.

Draw a sketch or map of the plot: mark the area on the ground by placing wooden pegs. Measure all sides using a measuring tape and record length and width on a paper. From observations, mark the highest and lowest point on the map and note an estimated elevation difference.

The plot sketch or map should be used to orient the drip irrigation system on the ground and to estimate the length of mainline; sub-mainlines and laterals as discussed above.

3.4 OBSERVE SOIL TYPE IN THE PLOT AREA

Soil type determines the types of crops that can be grown and irrigation interval or cycle at which water should be applied to the plant. Observe the details of the soil type such as heavy soil, light soil as well as visible color such as black, brown, red or reddish brown. Based on soil type and color, the infiltration capacity of the soil or time taken to absorb a given quantity of water in the soils can be estimated. Heavy or black soils have a low infiltration rate and lighter soils such as red or brown have a higher infiltration rate. This information is required to prepare emitters design specification/emitters flow rate or discharge rate in relation to the soil infiltration rate. If the emitter discharge is higher than the soil infiltration rate, water will begin to pond over the surface causing loss of water. Similarly, if the emitter discharge is lower than the infiltration rate, more time will be required to irrigate at the desired depth. Attempt should be made to match the emitter discharge with the soil infiltration rate. In Ethiopia, emitters of two types (micro tube and drip tape) are commercially available for smallholder drip irrigation systems with flow rate of 1 lt/hr at about 1.5 m head. Both of these emitters are suitable for medium and low infiltration soils including clay, loam, clay loam, silty clay. Soil infiltration values are important to select appropriate emitter types and discharge rates.

4. INSTALLATION

Installation of FDS is a very simple process. The drip kit components or materials delivered at site should be checked with the plot sketch map and orientation of drip system on the ground before installation. Drip system installation could be divided into two stages:

1. Installing water source (bucket, barrel, tank, pump etc.)
2. Laying of pipes and emitters/micro-tubes

4.1 INSTALLING WATER STORAGE /TANK

The water source and the choice of storage tank have been determined in the planning, study and design Section of the manual. Generally, a bucket or a barrel is used in the family drip systems. In case of barrels, it is recommended that two barrels are interconnected using a 2.54 cm steel or galvanized iron pipe and separated by a distance of about 50 cm. The fitting or welding of pipes into the barrels should be checked for leakage. The inside of barrel should be painted with a black paint and outside with an anti-rust paint. It would increase the life of barrels.

The location of placing barrels or bucket should be placed at the highest point close to the edge of the cultivated area. On level land, the barrels could be placed in the middle of the field but would require additional fittings such as a tee or a cross to connect the main line or sub-mainlines.

The barrels or buckets should be mounted on a sturdy platform about 1 to 1.5 m height above the ground as per the design. The platform could be made out of wooden poles and other locally available materials.

4.2 LAYING OF PIPES

The drip system installation starts from the storage tank or barrels to the drip lines. The control valve and filter is connected to the barrel outlet pipe and installation procedure continues by connecting elbows, standpipe and required fittings up to the mainline. For smooth operation, pipe from barrel should join drip main at the middle.

The mainline, sub-mainlines and the manufacturer supplies laterals in a roll. It is very important that the plot sketch and orientation map is studied to determine the correct length of mainline, sub-mainlines and laterals. The drip system orientation should be checked on the ground before cutting the pipes. Following procedure should be used:

- Measure correct length of main line, sub-mainlines and laterals on the orientation map and reconfirm on the ground
- Spread pipe rolls on the ground as straight as possible
- Measure correct length of pipes
- Cut pipes as per required length and smooth out edges of cut pipes.

Lateral pipes are laid on the ground in straight line or along the plant rows. In-line emitters are prefixed on the lateral. On-line emitters are placed in the field. Following procedure should be used for on-line emitters (Figure 7):

- Layout laterals on the ground as per designed orientation or along the plant rows. Use wooden stakes to place them properly and to keep them straight
- Mark equal spacing as per desired plant spacing on the laterals
- Punch holes on the lateral pipes with the help of manufacturer supplied punch at given spacing
- Insert micro-tubes or emitters gently into the hole up to the specified depth.

A pipe cutter or a sharp scissor should be used to cut pipes. Similarly, the punch used for making holes in the lateral pipes should conform to the specified diameter of emitters. Care should be taken so that dirt, sand and any foreign material does not enter into the holes or pipes while making connections.

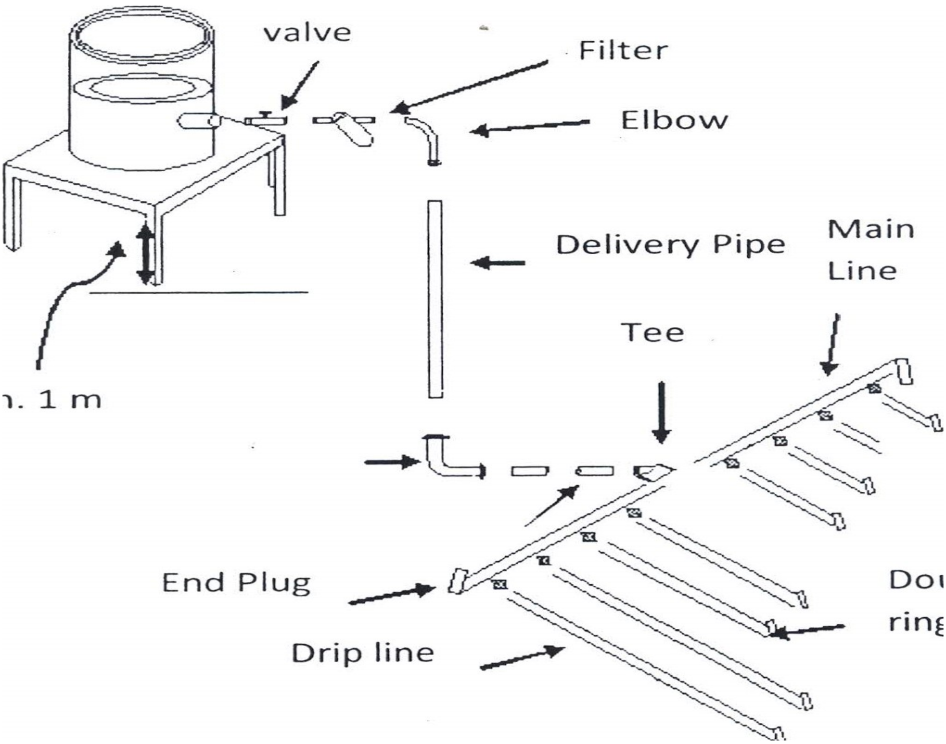

Figure 8: Parts in the laying out of pipes and emitters/micro tubes along the line

More drip irrigation layout for 500M2 is presented on Figure 8 next page as an example.

Make an appropriate hole in the water container (size of the valve)

Insert the valve into the hole of the water container

Connect the screen filter with the female threaded side of the valve

Make sure that the arrow on the filter shows to the opposite direction from the valve

Connect the socket and elbow nipple to the screen filter

Cut the delivery pipe (appropriate length) and insert it on the other side of the elbow

Connect the other side of the delivery pipe into the tee (25x25x25mm)

Cut the main line into two equal parts and insert them with the tee on both directions

Use the punch to make a hole at 1m intervals on the main line and insert the off takes (start connectors) into the holes. One shall give 0.5m spacing at both ends of the PE pipes

Cut the drip line into equal length and connect them with the start connectors

Insert the end plugs at the end of the lateral and main lines

Note:

Use the Teflon tape when connecting the different parts of the components to make leak proof connections whenever it is necessary

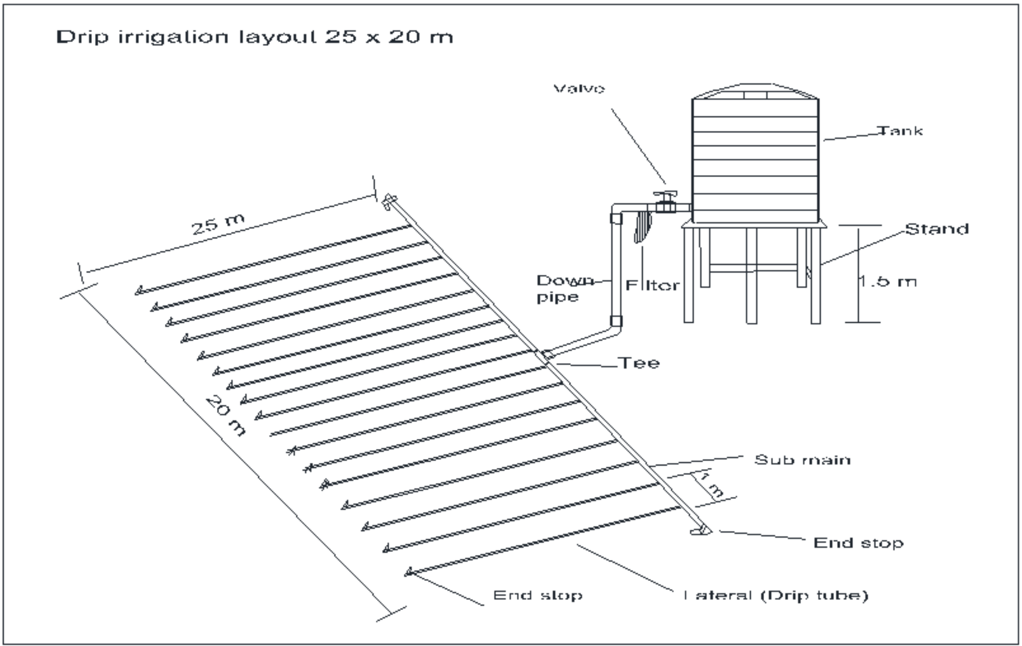

Figure 9: Example of drip irrigation layout on 500m2

The water container should be mounted on a stand so that the bottom of the barrel is at least one meter above the ground in order to get enough pressure to irrigate the whole area. The water container can be located at the middle of the field (if the tee is used).

The bed should be quite level

The drip lines shall be laid on top of the soil, with outlets up

Usually one fill of the water container per day provides enough moisture

Common setup mistakes include; not installing a filter or pressure reducer, use of overly long lengths of main line, and adding too many drip emitters.

5. OPERATION AND MAINTENANCE OF DRIP IRRIGATION

Lack of attention to operation and maintenance procedures can result in the malfunctioning of one or more component of the system and thus to serious water stress. Therefore, the success of a localized irrigation system is based on proper operation and a programmed regular maintenance.

5.1 OPERATION

The operation of a family drip system is virtually automatic. The planned operation scheduling should be properly implemented with the duration of application and volume of irrigation required at each growth stage throughout the growing season. During operation all drip system components should be checked for proper functioning and efficiency. Following procedure is recommended during operation of the system:

- Close the control valve located at the outlet pipe of the storage tank or barrels
- Fill the storage tank or barrels to full capacity
- Open the control valve
- Check flow through emitters to ensure uniform coverage

At the same time, the farmer shall make sure the functioning of all drip systems to convey and emit water to the crop root zone (drip pipes, filters, valves and fittings); and should make check for proper connection before starting the operation.

Checking of system components: Regular inspection of filters, pipes, end of laterals and other components

Checking pressure and flow: Pressure checks at filter, inlet of block, end of lateral, and identify leaks, pipe breakages, and blockage. Pressure checks at the filtering system help to decide on the frequency of cleaning the filters.

Additionally, pressure checks at critical points of the system (inlet of block and end of lateral) help to identify possible leaks or pipe breakages or blockage in the system.

A water meter or a flow meter, located after the filters, can assist in checking the proper operation of the system. If the flow rate is higher than the designed flow, it is an indication of pipe breakage or the end of a number of laterals being open. On the other hand, if the flow is lower than envisaged, it is a sign of clogging in the system, reduced performance of the pump, or overloaded filters.

Back-washing of main filters and cleaning of line filters: Most mesh filters are cleaned manually by removing the element from the case. As the filters remove water impurities, the pressure difference will increase. If left unchecked, the load inside the filter will consume unreasonable levels of pressure, resulting in the substantial reduction of the pressure available for the operation of the system.

Protection against insects and rodents: prone to insect and rodent damage; and standard crop hygiene practices by applying the necessary agronomic and integrated pest management (IPM) and rodent control practices should be applied.

Flushing of manifolds and emitter laterals

Not all impurities are removed from the filtered water. Most of the silt and clay particles pass through the filtering system. Some is deposited in low areas of the distribution system, at the end of the manifold and in the lateral pipe. It is therefore advisable to have flushing points at the end of each manifold that can be opened periodically to flush out the impurities. The same process should be applied to the laterals by opening the end of each lateral (one at a time) and flushing out the impurities.

It should be pointed out that flushing should be more frequent during warm weather, which promotes the growth of bacteria and the precipitation of carbonates. Fertigation should be practiced in such a way that all nutrients are out of the system before irrigation is completed. To ensure this process, fertigation should be completed 20-30 minutes before the system is turned off.

When liquid fertilizer is applied together with water, flushing of the laterals should be taken within 10~20 minutes after irrigation is finished to minimize the precipitation of chemicals on inner wall of the pipe.

5.2 MAINTENANCE OF FAMILY DRIP SYSTEM

The biggest problem in any drip system is clogging of emitters. FDS kits use very simple emitters, which are less prone to clogging due to wider flow path. Therefore, it requires less maintenance as compared to other drippers. However periodic and preventive maintenance is essential for smooth working of the system. Following general checks should be carried out periodically depending on the local condition and water quality.

- Clogging of emitters /wetting pattern
- Placement of emitters /micro-tubes
- Leakages in pipes, valves, filter, fittings, etc
- Flushing and cleaning of filter by opening and cleaning the screen
- Flushing of sub main and laterals by releasing the end caps

Apart from physical impurities that can be separated by using screen filter, there are dissolved chemical (mainly salts) impurities and also biological impurities like algae, bacteria etc. present in some water sources. If the dissolved salts are in high concentration, they can accumulate and clog the emitters. Various chemicals can be applied to the emitters to flush the salts; however the application of chemicals should be carried out by skilled technicians. In case of clogging by bacteria or algae, bleaching powder (2 mg per liter) can be used to clean the emitters and inhibit slime (muddy) growth.

- Ensure only clean water is used
- Tie a piece of cloth over the top of the barrel / tanker when filling it
- Clean the filter on each irrigation day
- Flush the system at least once a month (see flushing instructions)
- Check leaks frequently, repair immediately
- Take extra care during field operation to avoid cutting drip lines
- Take precaution to minimize destruction by termites or rats.
- At the end of the season, flush the system and store the components in a safe place

Trouble Shooting

Drum Problems

- Cracks — give to the local artisan to repair or use epoxy glue.
- Algae growing inside bucket - this occurs only when a white drum is used. Therefore, colored drums are recommended.

Drum not well rinsed

- Pre-filter using a piece of cloth and always pour out the remaining water from previous irrigation before filling again

Filter

Clogging with dirt — rinse daily in remaining water and before refilling the bucket. Do not rub by hand, finger nails, cloth or try to clear it using pins or any other sharp objects. Always pre-filter the water using a piece of cloth.

Cracking — handle the filter carefully and DO NOT force it too far into the outlet
Broken — replace from the supplier

Drip lines

- Flush the system thoroughly with water more frequently (weekly) and if clogging is due to mineral deposits at hole, then scrap off with fingernail.

Preventing leaks

- Leakage in the drip lines is one of the most common problems farmers experience
- To prevent this, connect all fittings firmly and clear away all thorny branches and twigs from the garden area
- Small rodents chew holes in the drip lines to get to the water, especially in more arid, bushy places. A very good fence (chicken wire) may be the only option if such pests are numerous in an area.

Repairing leaks

- If there are leaks at the connectors, remove tape to make a new, clean cut on the end, re-insert and tighten. If in lines, use the spare connector or leave it to dry then apply PVC glue or quick-curing epoxy.

- If these are not available, several wraps of ordinary masking tape around the drip line will do the job. But the line must be dry for good adhesion. If the holes are too many or very large, the line should be replaced.

Flushing instructions

- Clean water tank and fill it to the top
- Clean filter (with water from the tank) and return to place. Open the valve
- Open end of the main line and flush it for 10 minutes, until clean water comes out, close end of main line
- To flush drip lines, first open the drip lines at the ends, pour water in the drum and let it flow through the drip line. Then squeeze the line starting from the start connections up-to the end. The water from the drip line will have some sediment. Ensure that the water coming through the tapes is clear of sediments before closing the ends.

6. GENDER EQUALITY BOX

What are the issues of gender inequality?

Given the efforts to promote drip irrigation technologies and its benefit, initial investment, proximity and availability of the technology may affect FHH's adoption rate

How can the gender inequalities be addressed?

Encouraging private sectors who are involved in production of the technologies to create linkage to the ground demand of HHMI and facilitation of loan service to trained female farmer may help to address the issue

What will be the benefits when gender inequalities are addressed?

Improve adoption rate of FDK by FHHs, women economic status/ generate family income, family nutrition improved and reduce women work load.

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ANNEX

CASE STUDY

FAMILY DRIP KIT (FDK)

1. OVERVIEW

In years, particularly from 2007/8-2014/15 (in 8 years) Tigray BoARD had supplied thousands of Family Drip Kit (FDK) to farmers. It has also continued the introduction of this technology in a highly reduced amount. This time few numbers of farmers are using this irrigation system whilst most farmers stopped using it due to several reasons.

The major problems of assessment findings are:

- Clogging of drippers that could be created due to:
  - o Poor management (e.g. no or inadequate flushing)
  - o Lack of maintenance
  - o Poor quality of irrigation water (salty or silted/dirty)
- Tedious to refill the water tank that can be related with lack of integrated system with water lifting technologies
- Lack of knowhow and awareness in the value of irrigation water related to lack of knowledge and skill on irrigation and on-farm water management / OFWM
- Lack of knowledge and skill on operation and maintenance of drip irrigation system and poor handling of the drip materials that could be related with inadequate training
- Inadequate extension services that could be related to lack of on farm demonstrations and introduction of the system where there is adequate irrigation water using surface irrigation
- Affordability problem by the subsistence farmers: FDK is mostly recommended to small holder food insecure farmers that have shortage of income to buy these technologies. This is related to shortage of access to credits and other means of financing.

However, there are some farmers who are using family drip irrigation system successfully.

1.1. SUCCESSFUL CASE ON FAMILY DRIP IRRIGATION SYSTEM

Keshi Hailu Gebre with his wife Mulu Girmay is living in Atsbi Wonberta Woreda, Dibab-Akerien Tabia /Kebele, Sudah Kushet /village cluster, and in Beitmara - specific village. The family size of the household is 10 including 4 daughters, 3 sons, the mother, and wife and husband. He do not own land; but he is farming his mother's 0.25 ha land near their house and also yearly he ploughs about 0.5 ha rain fed farm by renting to pay half of the produce. He raised one cow with her calve, 8 goats, 6 sheep, and has 5 beehives. He does not have off-farm activity that supports the family subsistence.

He constructed a cemented tanker of about 62 m3 volume in 2013/14 and started utilization after it is filled in the immediate summer rainfall. He has been using the source of water to irrigate the homestead 0.25 ha mother's land using drip irrigation from the tanker for about 4 years since 2014/15 up to June 2018 (2017/18 production year). The whole area of 0.25 ha can't be irrigated by one FDK which covers only 500m2. However, he produces three times by rotating /shifting the system into three locations. The remaining area is also irrigated manually by fetching from the tanker.

The prominent future of the tanker is that it is built at higher elevation of the command area and has pipe outlet inserted at nearly half depth of the tanker. The farmer's innovation here is that the drip reservoirs /barrels are filled by gravity using plastic hose. Even when the water level is below the outlet pipe he used mouth suck (siphoning) to initiate the water flow through the plastic hose based on the hydraulic water movement principles.

Figure 10 Keshi Hailu Gebre's water harvesting structures and irrigation set up

By doing this all efforts the farmer produces tomato, Swiss-chard, lettuce and pepper. In 2018 production year his family earned Birr 3,300 from sold product of tomato harvested from drip system irrigated area; and about 1/3 of the produce is used for home consumption. Similarly, the elder daughter studying 11th grade in Wukro (town a bit far from residence) cover her expenses by selling the leafy vegetables (Swiss-chard, lettuce) and used about 700.00 birr from the sold leafy vegetables in this year only. Since the family sells the produce every market day and any time they went to the town, they express their product in terms of earned money, not in volume/ weight. Most of the pepper product is used for home consumption both in green and ripened. For rough estimation we can use the average productivity of the Woreda which is tomato 250 ql/ha, Swiss-chard 220 ql/ha, lettuce 200ql/ha and green pepper 200ql/ha.

Figure 11: Keshi Hailu Gebre's irrigated plots and layout of drip lines

Figure 12: Keshi Hailu Gebre's tomato crop stand from drip irrigation

In general, the major source of income and consumption of the family is generated from the irrigated plot. The farmer and his family have great consciousness on the importance of this water saving technology.

To mention one more success story is that from support by REST: a FHH farmer could able to gain 2010 birr in a year 2013 from an area of 135 m2 micro-garden drip irrigation system with a total expense for water being 420 birr only.

Figure 13: W/ro Letegebriel, in G/makeda Wored, managing Swiss chard plot

Module-10

Micro Sprinkler

1. INTRODUCTION

This module on Sprinkler Irrigation is the first version and is a series of other modules in the HHMI competencies area such as Hand Dug well, Manual Tube Well, Spring Development, Rooftop Rainwater Harvesting, Farm Pond Constructions, Manual Water Lifting Pumps, Solar Pump, Engine Pump, Drip Irrigation, and Sprinkler Irrigation. This professional development series supports the application of the AGP Program and other development interventions.

1.1 WHAT IS SPRINKLER IRRIGATION?

Sprinkler irrigation method distributes water to crops by spraying it over the crop area like a natural rainfall. The water under pressure flows through perforations or nozzles and sprays over the area. The pressure is provided by a pump of suitable capacity and horsepower. With careful selection of nozzle size, operating pressure and spacing, the actual water required for maintaining the soil moisture at field capacity is applied uniformly at a rate to suit the infiltration rate of soil thereby obtaining efficient water application. It is estimated that the sprinkler irrigation system substantially reduces the use of water and the crop productivity increases

Micro sprinklers are low capacity water emitters, sprinkler in type, but smaller in size than the conventional sprinklers and with flow rates of up to 250 liters per hour. They are placed on a relatively close rectangular or triangular spacing for the maximum overlap to irrigate potatoes, carrots, leafy vegetables, groundnuts and other densely planted field crops. This method is reliable, highly efficient, and easy to apply, operate and handle by small holder farmers. The system is a seasonal, low pressure, micro-irrigation solid installation which can be easily placed in the field and quickly removed (collected) at the end of the season.

1.2 WHY AND WHERE SPRINKLER IRRIGATION SYSTEM IS IMPORTANT?

The sprinkler irrigation system is a very suitable method for irrigation on sloppy lands and on shallow soils. It is best suited to coarse sandy terrain where the percolation loss is more and where as a consequence, the frequency of irrigation required is more. The sprinkler irrigation system is also suitable in undulating terrain where land shaping is expensive or technically not feasible. The removal of fertile soil cover by land shaping is not advisable. Sprinkler irrigation system can also be adopted in hilly regions where plantation crops are grown.

1.3 CLASSIFICATION OF SPRINKLER SYSTEMS

Sprinkler systems can be divided into portable, semi-portable and permanent types.

a) Portable systems are made entirely of movable pipe from the water source to the lateral. The pipes have manual couplers for ease of set up and disassembly. These systems can be further divided into continuous mechanical move, intermittent mechanical move, and hand move. Examples of portable systems are the Center pivot and straight-line continuous move. For this type of sprinkler system, see Figure 8.

Figure 1 Mini-Center Pivot Irrigation Systems

Figure 2 Mini-gun Irrigation Systems

b) The semi-portable systems have permanent mains and sub mains and portable laterals. Examples of the semi-permanent are the side roll wheel move, drag line or trailer line move. Hand move lateral systems are one of the oldest types. They are supplied with quick coupling joints and rotary head sprinklers. They are supplied with quick coupling joints and rotary head sprinklers.

Figure 3 Periodic move sprinkler system

c) The permanent solid set system has pipes permanently installed below ground and risers permanently in place. These systems are characterized by a high initial cost but low labor requirement. The permanent solid set system has pipes permanently installed below ground and risers permanently in place. For this type of sprinkler system see Figure 7.

Figure 4 Sprinkler system clearly showing tripod supported riser pipes

1.4 SUITABLE CROPS FOR SPRINKLER SYSTEMS

Nearly all crops are suitable for sprinkler irrigation system except crops like paddy rice, sisal, etc.. The dry crops, vegetables, flowering crops, orchards, plantation crops like tea, coffee are all suitable and can be irrigated through sprinklers.

2. ADVANTAGES AND LIMITATIONS OF SPRINKLER SYSTEMS

2.1 ADVANTAGES

- Suitable for wide range of soils, topography and field dimensions,
- It is suited to irrigate most row, field and tree crops as well as for shallow rooted crops, and germination of new plants
- Rain imitation (mimic nature) – high uniformity and efficiency performance
- Accurate water application even with small dose
- Effects on micro climate, frost protection
- It delivers water uniformly throughout the field and at high water use efficiency.
- Effective use of water from various sources such as small, and continuous streams of water, such as from springs and small tube or dug wells.

- Simple to operate, maintain, and labour requirement is low.
- Fertilizers and pesticides can be effectively applied in split doses through sprinklers at little extra cost. This facilitates uniform fertilizer application and effective pest control.
- The overall cost of labor is generally reduced
- Erosion of soil cover which is common in surface irrigation can be eliminated
- Since water is transported through pipes, no contamination of the irrigation water during transport and avoids water losses.
- The system is also known to modify the micro climate (hot and freezing conditions)

2.2 DISADVANTAGES OR LIMITATIONS

- System installation cost is relatively high.
- Pump is required for the system if sufficient head is not available. This will be extra cost of the energy consumed for creation of water pressure.
- Distribution Uniformity is sensitive to wind and pressure, they are easily drifted away under high wind conditions
- Improved conditions for disease and insects development
- Interference in other farm agro technical activities like cultivation
- Loss of water from block marginal
- Since the whole area is wetted, it promotes weed growth.
- Overhead application may induce leaf diseases, as some crops are sensitive to wet conditions.
- As sprinkler nozzles are small, suspended sediments might block it.

Planning and design of the system requires good technical expertise and its operation needs great attention.

3. COMPONENTS OF SPRINKLER IRRIGATION SYSTEM

- A pump unit
- Tubing's- main/sub-mains and laterals
- Couplers
- Sprinkler head
- Other accessories such as pump controller, pressure gauge, control valves, bends, plugs, risers, and sprinklers

See Figure 1 below for the different system components.

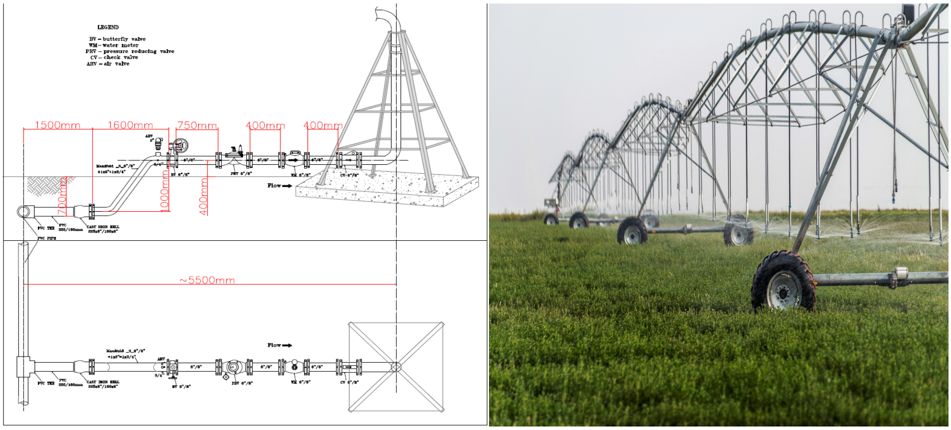

Figure 5 The inlet to the Center Pivot –Dimension 1

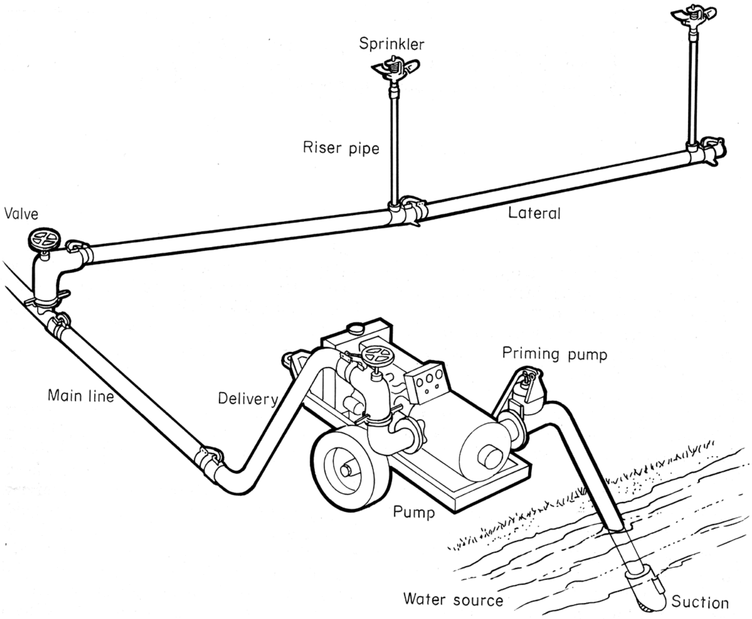

Figure 6 Sprinkler irrigation system components and layout-– see also picture on cover page

3.1 PUMPING UNIT

Sprinkler irrigation systems distribute water by spraying it over the fields. The water is pumped under pressure to the fields. The pressure forces the water through sprinklers or through perforations or nozzles in pipelines and then forms a spray. A high-speed centrifugal pump can be used for operating sprinkler irrigation for individual fields. Centrifugal pump is used when the distance from the pump inlet to the water surface is less than eight meters.

3.2 TUBING: MAINS/SUB-MAINS

The Tubing's consist of mainline, sub-mains. Main line conveys water from the source and distributes it to the sub-mains. The sub-mains convey water to the laterals, which in turn supply water to the sprinklers. HDPE (HIGH DESITY POLY ETHYLENE) pipes are used for sub-mains, PVC pipe usually used for main lines.

- Durable and light weight – lasts for more than 50 years
- Smooth external and internal finish – flow is almost frictionless, so energy savings are up to 33.50%
- Corrosion resistant – inert to most acids and alkalis
- Comprehensive range – available from DN 20 to DN 500
- Joins easily and is leak proof
- Strong enough to last uneven static and dynamic loads
- Flexibility ensures smooth installation and trouble free functioning

Table 1 Pipe selection guideline

Pipe Size [mm]	Pipe Type
≤ 50	Polyethylene
50-150	uPVC
>150	Fiber Cement, Steel and Concrete

3.3 COUPLERS

Are used for connecting two pipes and uncoupling quickly and easily. Essentially a coupler should provide

(a) A reuse and flexible connection

(b) Not leak at the joint

(c) Be simple and easy to couple and uncouple

(d) Be light, non-corrosive, durable

3.4 SPRINKLER HEAD

Sprinkler head distribute water uniformly over the field without runoff or excessive loss due to deep percolation. Different types of sprinklers are available. They are either rotating or fixed type. The rotating type can be adapted for a wide range of application rates and spacing. They are effective with pressure of about 10 to 70 m head at the sprinkler. Pressures ranging from 16 to 40 m head are considered the most practical for most farmers.

Fixed head sprinklers are commonly used to irrigate small gardens. Perforated lateral lines are sometimes used as sprinklers. They require less pressure than rotating sprinklers. They release more water per unit area than rotating sprinklers. Hence, fixed head sprinklers are adaptable for soils with high intake rate.

3.5 FITTINGS AND ACCESSORIES

The following are some of the important fittings and accessories used in sprinkler system.

a) **Water meters**: used to measure the volume of water delivered. This is necessary to operate the system to give the required quantity of water

b) **Flange, couplings** and **nipple**: used for proper connection to the pump, suction and delivery

c) **Pressure gauge**: It is necessary to know whether the sprinkler system is working with desired pressure to ensure application uniformity

d) **Tees, reducers, elbows, hydrants, valve** and **plugs**

HDPE pipe offers a number of techno commercial advantages over the conventional piping system.

- The smooth interior surface provides a high flow factor that does not decrease over time
- Longer lengths, which reduces the number of unions (smaller cost) and the possibilities of human errors in the installation
- Corrosion resistant
- Easy transport
- Flexibility, longevity
- It doesn’t maintain permanent deformations
- Light weight, cost effective installation
- Bacteria and chemical resistant

Risers

- The sprinkler is attached to the lateral by a riser. For low growing crops, the minimum height of the sprinklers above ground should be 60cm. For high rowing corps, the height should be adjusted accordingly.
- The riser is under canopy in orchards and citrus and will be as short as possible
- In field crops the sprinkler must be over the canopy all the time

4. PLANNING AND DESIGN OF SPRINKLER IRRIGATION SYSTEMS

4.1 GENERAL GUIDE TO MAKE AN INVENTORY OF AVAILABLE RESOURCES

The following guideline can be used:

Soil: Area available, quality, depth, infiltration rate and water holding capacity

Water: Amount available, at what rate and quality

Crop: Farming practice and water requirements

Management: Working hours per day and number of days per week

○ **Design specifications**

Calculate the irrigation requirement (mm/day), gross application, cycle, stand time and determine what areas with available water can be irrigated

○ **Layout of the system**

Try to fit in machine and main line as economically in the land

○ **Choice of sprinkler**

Choose spacing and discharge to fit in with infiltration rate and wind conditions

○ **System capacity**

Calculate the number of sprinklers per machine, number of machines, and test system capacity against water availability

○ **Pressure**

Calculate friction and test if pressure is within the normal ± 20 % maximum range. The following equation can be used to determine the inlet pressure at the beginning of the lateral. See also Figure for the different pressure components.

$hm = hc + hs + hf$

Where hm = Inlet pressure at the beginning of lateral (m)

hc = Sprinkler pressure (m)

hs = Static height difference to highest point (m)

hf = friction through machine (m)

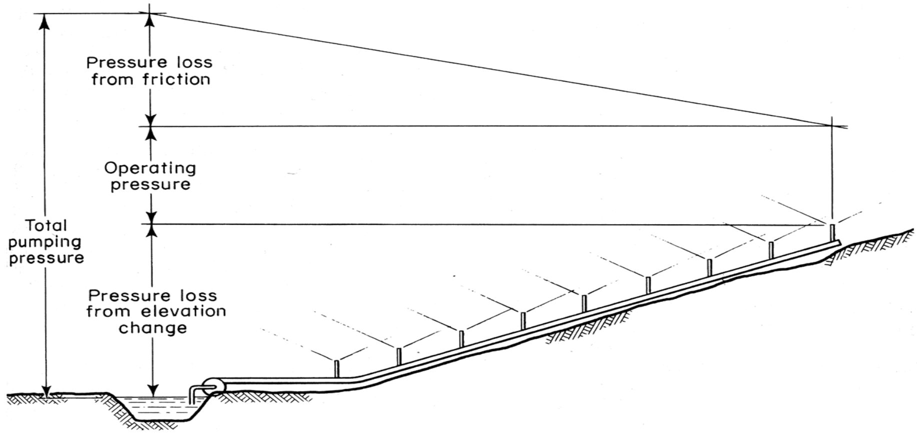

Figure 7 Sprinkler irrigation: Variation in pressure

The power input required by the pump

$$N = \frac{QXH}{270X\mu}$$

Where N= required input power - HP

Q = pump discharge - m3/h

H = total dynamic head – m

μ = pump efficiency - expressed as a decimal fraction

In addition to the standard design criteria, such as area, crop, water supply, soil and climate, it is important to examine the system's special features and characteristics as these parameters influence the final decision.

4.2 SPRINKLER SPACING

The water discharged from a single sprinkler is not uniformly distributed over the entire area; a greater quantity falls near the sprinkler and less in the periphery. To ensure a uniform precipitation over the entire area under irrigation, the sprinklers are always placed so that they overlap each other from both directions. This setting is termed sprinkler spacing. The spacing of the sprinklers along the lateral lines is known as SL, and the spacing between two lines as Sm. The spacing pattern is square, rectangular or triangular, with SL = Sm.

In order to obtain good distribution uniformity by overlapping, the sprinkler spacing (Sm) should not exceed 65 percent of the sprinkler diameter coverage under light to moderate wind conditions in the square and rectangular patterns. In the triangular pattern, the spacing can be extended up to 70 percent of the diameter coverage. In strong wind conditions, the spacing should be 50 percent of the diameter coverage with the lateral direction perpendicular to the wind direction. With wind strength of over 3.5 m/s, sprinkling is not recommended . Furthermore, to mitigate the adverse effects of the wind, a relatively large number of sprinklers per unit area should be operated simultaneously. The operation shifts should be arranged so that the area irrigated at the same time is as compact as possible.

The average application (precipitation) rate is a function of the sprinkler discharge and the spacing of the sprinklers: Precipitation rate (mm/h) = sprinkler discharge (liters/h) ÷ SL x Sm (m). The rate of precipitation should not exceed the soil intake (infiltration) rate (25 mm/h in light soils, 8–16 mm/h in loams and 2–8 mm/h in clays) – see Figure 3 and 4.

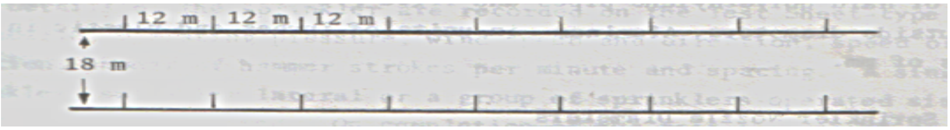

Figure 8 Distance between the sprinklers along the laterals and between the laterals

Example: Distance between the sprinklers along the laterals = 12m. Distance between the laterals = 18m.

<u>Spacing</u>: 12m * 18m = 216m^2

<u>In this case how many sprinklers are stationed in one hectare?</u>

10000 m2/216m2 = 46.3 = 46 sprinklers/hectare.

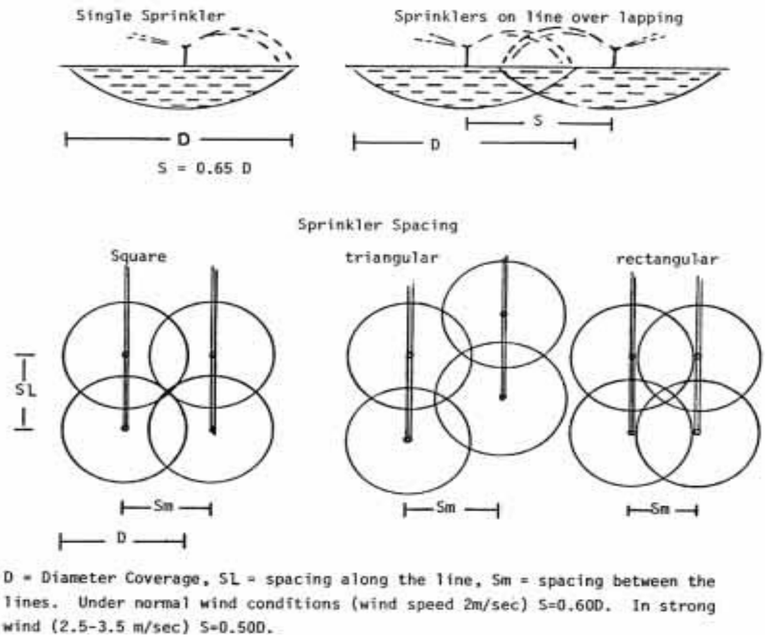

Figure 9 Sprinkler spacing

Wind directions and velocities must be recorded and classified accordingly, (0 - 0.7 m/sec Nil wind, 0.7-2.5 m/sec Light, 2.5 – 3.5 m/sec Moderate to Strong, and >3.5 m/sec very Strong).

4.3 APPLICATION RATE

Quantity of water applied to a given area in a given time. The application rate depends on the size of nozzles, operating pressure, and the distance between the sprinklers. When selecting sprinklers and designing the irrigation system it is important to make sure that the application rate is less than the basic infiltration rate.

$$\text{Application rate mm/ hour} = \frac{\textit{Sprinkler discharge l/hour}}{\textit{Sprinkler spacing (m*m)}}$$

Example:

Sprinkler discharge = 1560 l/hour

Sprinklers spacing = 12m x 18m

$$\text{Application rate} = \frac{\textit{1560 l/hour}}{\textit{12 m*18 m}} = \text{7.2mm= 72m3/hour/hectare}$$

Irrigation Duration

Irrigation duration: The time in hours that is needed to supply the required amount of water

$$\text{Time in hours} = \frac{\textit{The gross water required,mm}}{\textit{precipitation rate,mm/hour}}$$

Irrigation Efficiency (IE)

The relation between the volume of water absorbed by the soil to the total amount of water supplied to a given field.

$$\text{IE (\%)} = \frac{\textit{volume of water absorbed by the soil}}{\textit{amount of water supplied to a given field}} \text{x 100}$$

Reasons for the reducing of Irrigation efficiency

- Surface run-off
- Penetration of water below the root zone
- Poor distribution uniformity
- Water losses in margins
- Water losses due to soil and foliage evaporation
- Equipment leakages

4.4 PRECIPITATION INTENSITY

The force of water drops exerted on the soil surface during application – Figure 5 and Table 1.

- The intensity depends on:
- Drop size distribution
- Dropping velocity
- The impact angle at which they hit the soil

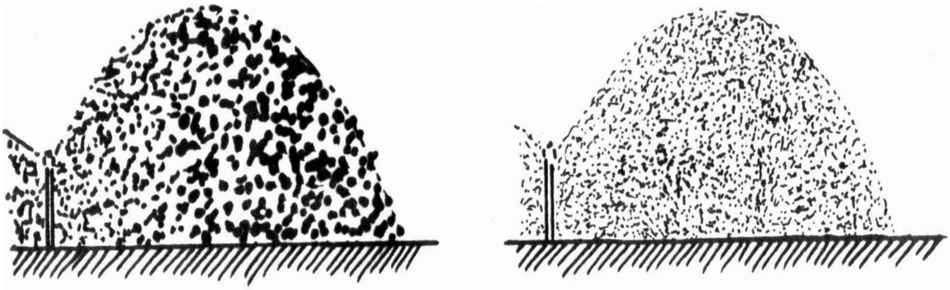

Figure 10 Irrigation intensity

Table 2 The same application rate and different intensity

Sprinkler type	A	B
Spacing (m*m)	24*24	12*12
Nozzle size (mm)	7 and 4.2	4 and 2.5
Pressure (atm)	4.5	2.5
Discharge (m3/h)	4.8	1.2
Application rate (mm/h)	8.2	8.3

The Influence of Pressure on Drop Size

The water gets out from the sprinkler and breaks to small drops due to the pressure. The small drops fall close to the sprinkler whereas the larger ones fall close to the edge of the wetted circle. (Impulse and Momentum)

Drop size is controlled by pressure and nozzle size. When the pressure is lower than is recommended, drops tend to be much larger. When the pressure is higher than the recommended more small drops are created

4.5 UNIFORMITY OF THE WETTED ZONE

- A good designing of sprinkler irrigation is achieved when the wetted profile reaches the desirable depth and the wetted zone is uniform
- In order to achieve it the following parameters must be taken in account: spacing, nozzle size, wind speed, trajectory angle, and type of soil
- Those means are important in order to get a good overlapping of the wetted profiles see Figure 6.

The 20% Rule

- In order to maintain up to 10% difference in the flow rate between the first sprinkler to the last sprinkler placed on the same lateral, the difference in pressure along the line should not be more than 20%
- Therefore if the average design pressure was 4 atmosphere the total friction loss in the line should not exceed 0.8 atmosphere

Coefficient of Uniformity (% CU)

- The CU is a measurement of uniformity, expressed as percentage, comparing the average deviation of values from the overall average
- A perfectly uniform application is represented by a CU of 100%. A lower uniformity application is represented by a lower percentage

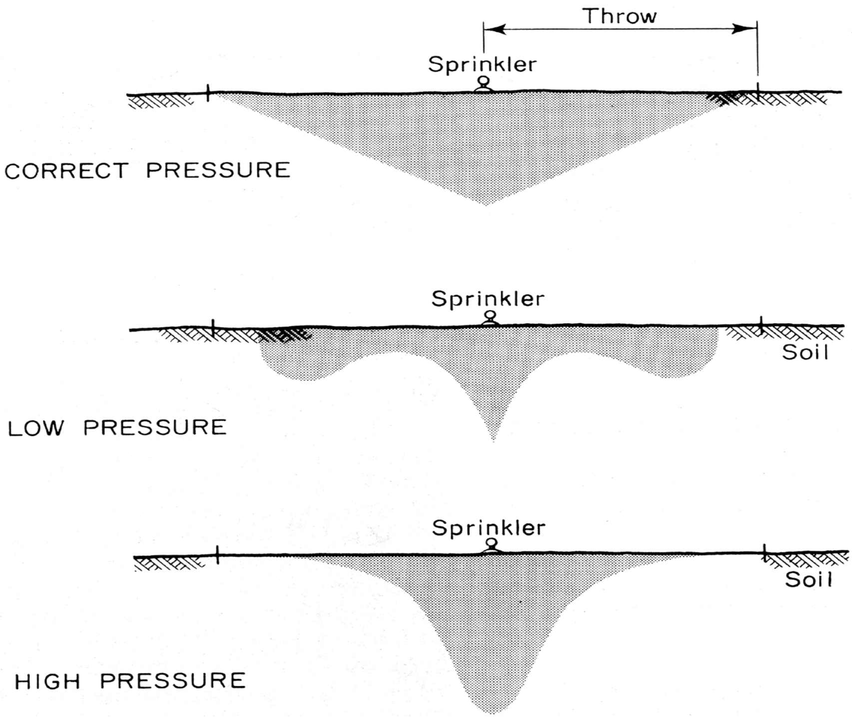

Figure 11 Distribution pattern of pressure in sprinkler irrigation

4.6 SELECTING SPRINKLER SYSTEM CAPACITY

A sprinkler system must be designed to apply water uniformly without runoff or erosion. The application rate of the sprinkler system must be matched to the infiltration rate of the most restrictive soil in the field. If the application rate exceeds the soil intake rate, the water will run off the field or relocates within the field resulting in over and under watered areas, see Tables 2, 3, and 4.

Table 3 Estimation of the total available water capacity (TWAC) also termed as Water retention

Soil type	TWAC limits max and min (mm/m)	Avg. limits
Fine sand	20-40	30
Sandy loam	40-110	75
Silt loam	60-130	95
Clay loam	100-180	140
Clay	160-300	230

Table 4 Estimation of design TWAC

Plant type zone	Effective root zone depth (m)	Plant type	Effective root depth (m)
Cotton	90	Water melon	60
Sugar beet	90	Tomato	60
Sunflower seed	80	Tobacco	70
Potato	60	Soya beans	60
Spinach	60	Strawberry	35
Cucumber	50	Pepper	60
Onion	60	Beans	60

Hence, design TWAC = TWAC (mm) x DZR (cm) /100.

Estimation of design Net Water Requirement (NWR):

NWR (mm) = Design TWAC x MAD (%) / 100.

Where, MAD is Management Allowed Deficit, generally MAD should be considered as 50%.

Estimation of Gross Water Requirement (GWR):

$$GWR = \frac{NWR\ (mm) \times 100}{Design\ efficiency\ (\%)}$$

Design efficiency for sprinkler may consider as 80-85%.
Calculation of design irrigation interval:

$$Design\ irrigation\ interval\ (days) = \frac{NWR\ (mm) \times 100}{Design\ efficiency\ (\%)}$$

Table 5 Infiltration rate of soil

Soil Structure	Infiltration rate limit (mm/hr)	Avg. Rate (mm/hr)
Sandy	12-250	50
Sandy loam	13-76	25
Loamy	8-20	13
Clay loam	2.5-15	8
Clay	0.3-5	2

Calculation of irrigation hours:

$$Duration\ of\ application\ (hours) = \frac{GWR\ (mm)}{Ppt.rate\ of\ sprinkler\ system\ (mm/hr)}$$

$$Precipitation\ rate\ of\ sprinkler\ system\ (mm/hr) = \frac{Discharge\ of\ one\ sprinkler\ (lph)}{S1 \times S2}$$

S1 = Spacing between Sprinklers (m)

S2 = Spacing between Lateral line (m)

Example on crop water requirements and irrigation scheduling

Area and Crop: An area of approximately 2ha planted with cotton at the beginning of August. The field is square and level.

Soil, water and climate: Medium texture soil of good structure, with good infiltration and internal drainage. The soil available moisture (Sa) is 110 mm/m depth. The water is of good quality with no salinity or toxicity hazards; the source is a tube-well equipped with a pumping unit delivering 36 m3/h. The peak irrigation demand is in October, at the mid season growth stage of the corp.

Solution:

The pan average readings in October are 5.6 mm/d. This figure multiplied by 0.66 (pan correction factor) gives an ETo of 3.7 mm/d. The crop factor kc for cotton at this stage is taken as 1.05, the root depth 1.0 m and the moisture depletion 50 percent. Then, Etc. cotton = 3.7 x 1.05 = 3.88 mm/d. The net application depth is Sa 110 mm x root depth 1.0 m x depletion 0.5 = 55 mm. The maximum permissible irrigation interval in October is 55 mm ÷ 3.88 mm/d = 14 days. The irrigation frequency depends on many factors and in no case should exceed the maximum permissible irrigation interval. The system's application efficiency is 75 percent, therefore, the gross application depth at peak is: 55 mm ÷ 0.75 = 73.3 mm. The gross irrigation dose is: 73.3mm x 10 x 2.0 ha = 1,466 M3.

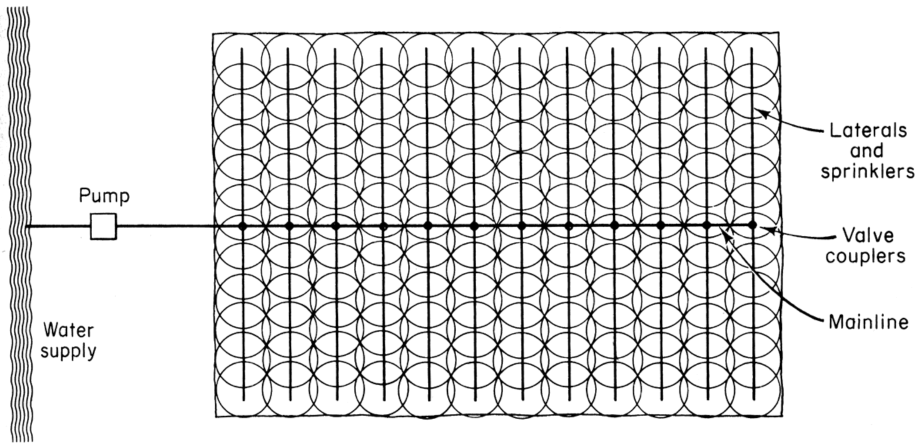

Figure 12 Sprinkler irrigation: Solid set system

5. GENERAL RULES FOR SPRINKLER SYSTEM LAYOUT

- Main should be laid up and down hill
- Lateral should be laid across the slope or nearly on the contour
- For multiple lateral operation, lateral pipe sizes should be more than two diameter

- Water supply source should be nearest to the center of the area
- Layout should facilitate and minimize lateral movement during the season

Layout should be modified to apply different rates and amount of water. Soils are greatly different in the design area. Selecting the most appropriate sprinkler system:

While selecting a sprinkler system, the most important physical parameters to be considered are:

1) The crop or crops to be cultivated.
2) The shape and size of the field.
3) The topography of the field.
4) The amount of time and labor to operate the system.

The layout of the system consists of a head control equipped only with the regulating valves (shut-off, non-return, air) and a filter of about 40-60 mesh (200-300 microns). No injectors are needed as fertigation through this system is not a common practice among farmers.

The arrangement of the main and submain lines, hydrants and manifolds is the same as in other micro-irrigation piping networks.

The size of the manifold feeder lines should be 50-63 mm and in no case exceed 75 mm. Pipelines of 50-63 mm are recommended for flows of approximately 12-18 m3/h when the water is distributed in route continuously.

Figure 13 Sprinkler irrigation technique

The pipes used for the system's distribution network are mainly in rigid PVC (buried) or black HDPE (normally laid on the surface). Other kinds of pipes are used also, such as lay flat hoses and quick coupling galvanized light steel pipes.

6. OPERATION AND MAINTENANCE OF SPRINKLER SYSTEM

6.1 OPERATION

Proper design of a sprinkler system does not in itself ensure success. The system should be operated in keeping with good irrigation practices. It should be ensured that the prime mover and the pump are in alignment. For these the drive shaft as well as the pump shaft should lie at nearly the same height to prevent too great an angle on the universal shaft. Service and installation procedures in respect of the pump and power units should be strictly observed. While laying the main and lateral pipes, always begin laying at the pump. This necessarily gives the correct connection of all quick coupling pipes. While joining couplings, it is ensured that both the couplings and the rubber seal rings are clean.

In starting the sprinkler system, the motor or engine is started with the valves closed. The pump must attain the pressure stated on type-plate or otherwise there is a fault in the suction line. After the pump reaches the regulation pressure, the delivery valve is opened slowly. Similarly, the delivery valve is closed after stopping the power unit.

The pipes and sprinkler-lines are shifted as required after stopping. Dismantling of the installation takes place in the reverse order to the assembly described above.

6.2 MAINTENANCE

A sprinkler system, like any other farm equipment, needs maintenance to keep it operating at peak efficiency. Parts of the system subject to the most wear are the rotating sprinkler heads, the pumping set, the couplers and the pipeline. General principles regarding the maintenance of the pipes and fittings and sprinkler heads are given below:

I. PIPES AND FITTINGS

The pipes and fittings require virtually no maintenance but attention must be given to the following procedures:

a) Occasionally clean any dirt or sand out of the groove in the coupler in which the rubber sealing ring fits. Any accumulation of dirt or sand will affect the performance of the rubber sealing ring.

b) Keep all nuts and bolts tight

c) Do not lay pipes on new damp concrete or on piles of fertilizer. Do not lay fertilizer sacks on the pipe.

II. SPRINKLER HEADS

The sprinkler heads should be given the following attention:

a) When moving the sprinkler lines, make sure that the sprinklers are not damaged or pushed into the soil.

b) Do not apply oil, grease or any lubricant to the sprinklers. They are water lubricated and using oil, grease or any other lubricant may stop them from working.

c) Sprinklers usually have a sealed bearing and at the bottom of the bearing there are washers. Usually it is the washers that wear and not the more expensive metal parts. Check the washers for wear once a season or every six months - this is especially important where water is sandy. Replace the washers if worn.

d) After several seasons operation the swing arm spring may need tightening. This is done by pulling out the spring end at the top and rebending it. This will increase the spring tension.

In general, check all equipment at the end of the season and make any repairs and adjustments and order the spare parts immediately so that the equipment is in perfect condition to start in the next season.

III. STORAGE

The following points are to be observed while storing the sprinkler equipment during the off season:

a) Remove the sprinklers and store in a cool, dry place

b) Remove the rubber sealing rings from the couplers and fittings and store them in a cool, dark place

c) The pipes can be stored outdoors in which case they should be placed in racks with one end higher than the other. Do not store pipes along with fertilizer.

d) Disconnect the suction and delivery pipe-work from the pump and pour in a small quantity of medium grade oil. Rotate the pump for a few minutes. Blank off the suction and delivery branches. This will prevent the pump from rusting.

7. GENDER EQUALITY BOX

What are the issues of gender inequality?

Women are usually not having information about water lifting micro irrigation technologies like pulley, rope and washer treadle pumps before they are introduced to the community. Once they have been introduced, women are often left out of decision-making and other processes. They may not have enough information and skills to operate manual pumps to produce to their optimal potential. Also, the technologies may not be women-friendly but majority of activities pertaining to vegetable farming under manual pumps carried out by women.

There is a gap in provision of updated information, training and continuous extension services to women which results in reduce women effectiveness in adopting new technologies.

How can the gender issues be addressed?

Women should be informed, trained, operation and maintenance of manual pumps for optimal use. Different stakeholders must invest more effort to reach women with information and ensure and understanding the time and location convenient for women. There is a need to extend invitation to women directly for information sharing events and meetings, one should not rely on spouses or men in the community to inform women.

Provision of adequate women friendly technologies and gender sensitive training on irrigation farming, agronomy practice and technology operation is important to the capacity development of women farmers

What will be the benefits when gender issues are addressed?

Technologies to be introduces have to be gender responsive based on the needs and preferences of women and which are appropriate business models that can boost micro irrigation development by saving water, reducing costs, and manage natural resources more sustainably. A gender-sensitive manual pumps contributes to promoting gender equality as a component or a facilitating variable for food security and poverty alleviation.

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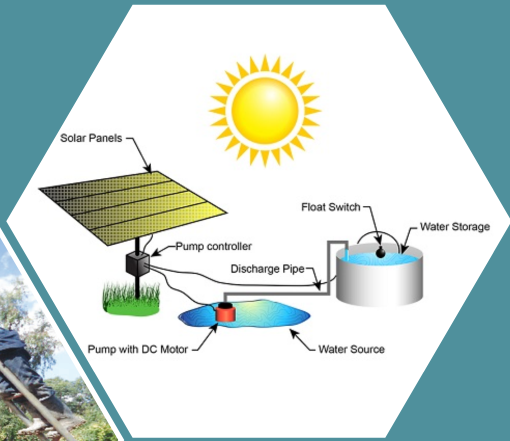

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