MINISTRY OF AGRICULTURE AND NATURAL RESOURCES

Small-Scale Irrigation Development Directorate

GUIDELINE

FOR MANUAL TUBE WELL DRILLING AND INSTALLATION FOR HOUSEHOLD IRRIGATION IN ETHIOPIA





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April 2018

Addis Ababa, Ethiopia

MANUAL TUBE WELL DRILLING AND INSTALLATION FOR HOUSEHOLD IRRIGATION IN ETHIOPIA

A practical guideline for woreda experts and development agents in Ethiopia

Second Edition

March 2018

Ministry of Agriculture and Natural Resources, Small Scale Irrigation Development Directorate

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About the Second Edition:

A first version of this guideline was developed by the Ministry of Agriculture in 2012. During the course of application, it became apparent that the guideline needed updating and should include a manual on well drilling technology in hard formations. This updated second edition takes into account state-of-art technology for manual well drilling and installation in soft and hard formations.

The updating of the guideline was supported by the Small Scale and Micro Irrigation SupportProject (SMIS)[1], while the publication has been supported by the Agricultural Growth Program (AGP), Ministry of Agriculture and Natural Resources (MoANR).

Photo Credits: Zereay Kassahun and Other Contributors

Picture on front cover: Basic steps in shallow groundwater drilling and development with simple sludge and percussion manual well drilling technique and groundwater use for small scale and household micro irrigation.

Picture on inside front cover: Manual tube well drilling technics training session picture during Oromiya region of woliso town training prepared for regions.

Picture on back cover: Manual well drilling with percussion method while giving training for hard formation by MoANR,SSID in collaboration with International Development Enterprise (IDE) experts in Oromiya region of Tulu bolo.

Picture on inside back cover: vegetable production by well drilling in Southern nations nationalities peoples regional state of Meskan Woreda.

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1 *SMIS is a five-year project of the Ministry of Agriculture with financial support from the Embassy of the Kingdom of the Netherlands as well as the Government of Canada through Global Affairs Canada.*

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ACRONYMS

ADPs	Agricultural Development Projects
AGP	Agricultural Growth Program
A-TVET	Agricultural Technical, Vocational and Education Training College
BHP	Brake Horsepower
DA	Development Agent
DAP	Diammonium phosphate
EIAR	Ethiopian Institute for Agricultural Research
EIGS	Ethiopian Institute for Geological Surveys
ETo	Reference Evapotranspiration
ETB	Ethiopian Birr
ETcrop	Crop water requirement
FHH	Female-Headed Household
FTC	Farmer Training Center
FYM	Farm Yard Manure
GDP	Gross Domestic Product
GIP	Galvanized Iron Pipe
GoE	Government of Ethiopia
gpm	Gallon per minute
ha	Hectare
HDW	Hand Dug Wells
IDE	International Development Enterprise

IWMI	International Water Management Institute
Kc	Crop Coefficient
l/s	litre per second
lpm	Litre per minute (flow rate)
m	Meter
m/s	Meter per second
MoA	Ministry of Agriculture
MoANR	Ministry of Agriculture and Natural Resources
m.a.s.l	meter above sea level
NGO	Non-Government Organization
PA	Peasant Association
Pcs	Pieces
PE	Poly Ethylene
Psi	Pounds per Square inch
PVC	Poly Vinyl Chloride
SSID	Small Scale Irrigation Directorate
SWL	Static Water Level
t/ha	Ton per Hectare
TDH	Total Dynamic Head
ToT	Training of Trainers
US$	US currency
UPVC	Unplasticized polyvinyl chloride
UN WFP	United Nations World Food Program

FOREWORD

Small scale irrigation development is a key strategy of the Government of Ethiopia (GoE) to achieve their development goals. Irrigation development is one of the many interventions specified in the agricultural development investment framework as a means to sustain agricultural growth. Within this framework, household irrigation has been identified as a key opportunity to transform the lives of smallholder farmers, increasing incomes and achieving food security objectives at the household and national level.

Ethiopia has a large proven surface and groundwater potential. The MoANR has placed high emphasis on the efficient development and utilization of water potential. Development of shallow and very shallow groundwater opens an opportunity to provide at least one source of irrigation water to every smallholder household. Several initiatives and projects are working together to realize this goal. Despite the advantages that the groundwater offers, it is not effectively exploited, primarily due to its requirement for specialized equipment, well-trained human resources and high investment cost.

A key initiative is to build the capacity and skills of experts at all levels to efficiently and cost-effectively develop groundwater potential and assist smallholders in maximizing the productivity and income from small scale irrigation. Development of practical guidelines and hands-on tools is one-step in building the capacity of woreda/district experts and development agents who are at the forefront of assisting smallholder farmers in irrigation development and improved irrigated agricultural production.

It gives me a great pleasure to introduce the Manual Tube Well Drilling and Installation Guideline for small-scale irrigation in Ethiopia. The guideline is expected to be a practical resource for woreda/district experts, development agents and irrigation technicians to assist smallholder farmers and pastoralists in efficient development and use of shallow groundwater potential. It takes into account varied geological formation, altitude and rainfall, differences in groundwater depth, soil formation and presents practical manual well drilling techniques that have been field tested.

The development of this guideline is a manifestation of the MoANR efforts to support smallholder farmers in utilizing available shallow groundwater for boosting agricultural production and increasing their capacity of and resilience to climate change. I encourage all stakeholders to make utmost efforts to adopt and use this guideline for efficient and effective development of shallow groundwater potential in Ethiopia.

Kaba Urgesa (Dr.)

State Minister, Ministry of Agriculture and Natural Resources

ACKNOWLEDGEMENTS

The preparation of the second edition of the Manual Tube Well Drilling and Installation Guideline is a timely decision by the MoANR to promote and expand groundwater development for small-scale irrigation in the country as a means to achieve food security. It is expected that the guideline will become a valuable resource for use by woreda/district agriculture and water offices and other stakeholders involved in developing shallow groundwater potential. The preparation of this guideline would not have been possible without the contribution and efforts of many individuals and institutions for which we are very grateful. We would like to thank all partner institutions and experts who found time out of their busy schedules to contribute to the production of this important guideline.

In particular, we are indebted to the efforts made by Mr. Hune Nega, National Chief Technical Advisor of the SMIS Project, Mussie Alemayehu, Senior Irrigation and Drainage Engineer in Small Scale Irrigation Directorate (SSID) of MoANR and Dr. Dev Sharma, International Chief Technical Advisor of the SMIS project for their contribution, editing and further enriching the guideline. We would like also to extend our great appreciation to Mr. Zereay Kassahun, Senior Irrigation Agronomist and Mr. Mulugeta Melese ,Junior Irrigation and Drainage engineer from SSID of MoANR for their full participation and contribution in organizing and coordinating meetings, conferences and training programs during the course of updating this guideline.

We are equally indebted to the SMIS project for its technical, financial and logistic support for field testing well drilling equipment and methods in fractured and hard rock formations, for supporting the update of this second edition of the guidelines and for supporting the training of trainers (ToT) training program on this updated manual well drilling guideline. Our thanks also go to IDE for its support in conducting field test for hard formation in Oromia and Amhara regional states. We are also very grateful to the AGP for its support in materializing the publication of this second edition guideline.

We are confident that all contributors and supporters would share with us the reward of this effort to realize manual tube well drilling technology for irrigation development in Ethiopia as an important means in eradicating poverty from Ethiopia.

Elias Awol

Director, Small Scale Irrigation Development Directorate

Ministry of Agriculture and Natural Resources

PRESENTATION OF THE GUIDELINE BOOK

This guideline is presented in ten chapters. The first chapter deals with a general introduction to the guideline preparation. The second chapter presents about groundwater investigation methodologies. The third chapter describes site selection guidelines for water well drilling.

The fourth chapter provides a description of water well drilling techniques with and followed by drilling procedures for tube well drilling (simple sludge and percussion method) described in chapter five. Water lifting and irrigation system designs and irrigation agronomy are presented in chapter six and seven, respectively. Artificial recharge techniques to groundwater and irrigation extension services for smallholder farmers are presented in chapter eight and nine. The economics of manual well drilling is presented in chapter ten.

CHAPTER 1

INTRODUCTION

1.1 Background

Ethiopia has a number of rivers and streams with enormous amounts of water flowing in all directions. The country has also huge potential of groundwater resources that can be utilized for irrigation.

The groundwater potential of the country is variable from place to place based on several factors such as geographical diversity, variation in geology, nature of structures, recharge condition, nature and duration of precipitation, hydrology and other factors. Proper and integrated groundwater (both shallow and deep) resource assessment, development and management enhance and promote all national efforts towards the efficient, equitable, and optimum utilization of the available groundwater resources of Ethiopia for significant socio-economic development on sustainable basis.

However, the use of groundwater for irrigation in the country is low. The existing irrigation development in Ethiopia, as compared to the groundwater resources the country has, is not significant. In order to ensure food security at the household level for the fast growing population of the country groundwater potential has to be developed to ensure optimum productivity of irrigated agriculture.

Moreover, Ethiopia has huge groundwater resources at shallow levels to be developed for the purpose of household irrigation. Development of shallow groundwater resource for household level irrigation is a transformative opportunity for smallholder farmers.

However, despite the advantages that the groundwater offers, it is not widely exploited in Ethiopia for irrigation primarily due to its requirement for specialized equipment, trained staff and high cost. Mobilization of water resources and its associated high initial cost is the most outstanding constraint in irrigation development in Ethiopia. At large, these costs become extremely high, especially when groundwater is tapped for irrigation with machine drilling.

In this regard, manual well drilling is a great step forward to develop the country's shallow groundwater resource efficiently and cost effectively than machinery drilling. Machine drilling in addition to its high investment cost and drilling cost per meter depth; it requires additional resources for mobilization and demobilization of drilling machine.

This guideline is therefore prepared to introduce and provide users guidelines on low cost manual well drilling methods, simple sludge and percussion, which are widely practiced in many parts of the world for various uses including for small-scale and micro irrigation purpose.

1.2 How this Guideline Manual was Prepared?

This second edition guideline manual was prepared based on the demand for a manual well drilling technology which can be used for hard rock formation.

In this regard, manual percussion techniques in combination with simple sludge techniques were tested by IDE at field level at selected fractured and hard rock formation sites in Amhara and Oromia regions. The two sites which were selected as field testing were initially tried with simple sludge techniques but it was not possible to drill and finally abandoned because of the hard soil or rock formation.

However, during the field test, simple sludge in combination with percussion techniques shows better performance in improving the concern of manual well drilling in hard formation.

Following the field test, the MoANR decided to update the guideline by including percussion method, economics aspects of manual well drilling as well as revising others topics which are part of the first edition.

As was the case with the earlier agricultural package books, it was decided that this guideline book should be designed for woreda experts and development agents who work directly with small-scale farmers. The second edition guideline was updated by a task force composed of eight experts who had participated at various times in the capacity building training programs on tube well drilling held in Ethiopia.

1.3 Rationale and Justification of Manual Tube Well Drilling

There are various techniques for drilling a drinking water or irrigation tube well. The choice of drilling method depends on geo-hydrological condition of a given area the financial means available. In general, drilling techniques can be divided into two categories i.e. drilling with a machine or manually.

The greatest difference between the two methods is that drilling with a machine is much more expensive than drilling by hand. The manual method is thus the preferred choice for low-cost wells but it obviously has its limitations. If the ground is too hard like for instance solid rock, manual drilling is often not feasible and only machine drilling can be considered. In certain circumstances, digging the well by hand may be an option. However, there are certain disadvantages regarding the so-called ‘hand dug wells’ (HDW): the dangers while undertaking the work, the difficulty of penetrating deep enough into the aquifer, the relatively high costs and the poor hygienic conditions.

Shallow tube wells contribute to diversification of cropping systems and improve economic and social conditions. Problems arise, however, if tube wells overexploit the groundwater supply or contribute to salinization of groundwater. Evaluation of groundwater supply and quality, regulation of tube well establishment, and technical support to farmers are essential for sustainable tube well systems to contribute to poverty reduction.

Manually drilled shallow tube wells are a cost-effective source of irrigation water for many small-scale farmers, where groundwater is close to the surface (less than 20 m deep) and soils are productive. These wells can irrigate up to 3 to 5 hectares, depending on the soil, crop, and water conveyance system. The technology is not complicated, and acceptance by farmers and poor rural communities is rapid. Tube wells can be one of the better investments for poverty reduction, and they are already common in many parts of the world, particularly in Asia and Africa.

The high cost of developing water sources is a major impediment to water access for many rural people. Increasing water supply in a rate that can sustain population growth can only be achieved through a realistic consideration of appropriate alternatives to expensive water technologies. The manual drilling technique has proven to be a successful, lower-cost approach with great potential scope of application for both water supply and irrigation.

Machine drilled tube wells are high in quality, but also very expensive. The cost of a machine drilled well varies between countries but is generally being in the range of Ethiopian Birr (ETB) 80,000 – 90,000 for 70– 80 m deep well.

Traditional HDW are also useful when low permeable formations exist. However, the total yield/day is often quite low; as it is difficult to hand dig deep into good water-bearing aquifers. When a hand dug well is put in a permeable layer lined with concrete rings, the yield will be higher, but the cost will come close to that of a machine drilled well. However, manually drilled tube wells can solve such problems, for example, tube well drilling experience in Ethiopian shows that, with simple sludge tube well drilling, it was possible to drill up to 50mdeep (in soft soil formation) within 3– 5 days and drilling cost varies in the range of 92– 200 ETB per m depth. However, in the case of hard rock formation in which simple sludge combined with percussion, the cost per m depth could be in the range of 800–1000 ETcrop/m depth (July 2016). Possible potential sites for manual tube well drilling in Ethiopia are given in Annex A, however, this data need to be supported with detailed geo-hydrological information.

1.4 Experience of Tube Well Irrigation in Other Countries

Shallow tube well irrigation generally results in some form of crop diversification for home or local consumption or for export. Niger, for example, has developed a good export market for green beans shipped by air to Europe, with much of the production related to shallow tube wells.

About one-half of the total irrigated area in India depends on groundwater wells, and about 60 percent of irrigated food production is based on groundwater. In 1994, there were 10.5 million dug wells and 6.7 million shallow tube wells in India. The number of shallow tube wells roughly doubled every 3.7 years between 1951 and 1991. Groundwater irrigation results in at least a doubling of yield compared to surface-watered crops. However, some states in India are facing severely declining water levels due to overexploitation.

Traditionally, farmers lift water from shallow dug-wells for i

ndividually-managed micro scale irrigation in the dry season. Discharge is low and can only allow small irrigated areas. However, in Nigeria, the introduction of low-cost shallow tube well technology combined with small engine-driven water pumps triggered off the development of fadama irrigation. The total number of shallow tube wells drilled by the bank funded Agricultural Development Projects (ADPs) in Bauchi, Kano and Sokoto State between 1983 and 1990 was over 15,000. In the same country, the cost of constructing shallow tube wells was reduced by about two-thirds, with a commensurate increased return on tube well investment. In 1992 the bank prepared a new project which would construct about 50000 shallow tube wells in Nigeria, would privatize drilling, and simplify drilling technology for shallow tube. The project simplified drilling technology, privatize drilling operations, conduct aquifer studies, upgrade irrigation technologies and organize fadama farmers for irrigation management. The tube well technology for small-scale irrigation has proven to be very successful in Nigeria. It is much cheaper than large-scale irrigation.

Other countries in West Africa benefited from the Nigerian experience in formulating tube well irrigation projects, which includes 300 shallow tube wells in Niger, 100 in Burkina Faso and in Ghana, more than 2000 shallow wells and some 100 deep wells. The technology has also reached Chad and the northern zone of the Republic of Benin.

Traditional manual tube wells installation for irrigation purposes in Northern Sudan have been used for over 50 years and are constructed manually by local artisans. Most wells are potentially constructed along Nile River and are located on average 2 to 3 kms away from the river coarse. For manual well drilling up to 50 m, the most important tool required is an ordinary "1½ and 3" galvanized pipe and some plumber hand tools which can be purchased from local market.

In most cases, the depth of tube wells varies from 10 to 50 m (32– 170 feet). In Sudan, tube well installation is carried out in areas where the static water level is not deeper than 20 to 30 m and where the soil is deep and not stony. According to Sudanese experience, four people are required for tube well installation and the work can be accomplished 3 to 7 days for tube wells up to 50 m deep.

In Tanzania, 25 m – deep 4inch wells are drilled in 2 – 3 days with the Rota-sludge method at a cost of around US$350. The Rota-sludge method is an adaptation of the Indian hand sludge method

In Bolivia, the Baptist drilling methods is used. In Santa Cruz, families that want a well form a "water club" and take turns to assist the well driller. In this way, it takes 2 – 5 days to drill a well and install a pump. Families pay for their own water systems; demand for the Baptist wells is still growing. With the Baptist, drilling technique, clay and sand layers can be penetrated to depths of 60 m or more.

The introduction of irrigation without drainage in arid and semi-arid regions, as in Pakistan, automatically leads to a rise of the water table. Due to conveyance losses in canals and percolation losses from irrigated fields, groundwater gets an extra recharge compared to the former natural conditions. Irrigation water, even the best quality, contains salts. In Pakistan, deep tube wells have been installed primarily to lower groundwater tables and secondly to provide supplemental irrigation water.

1.5 Tube Well Drilling Requirements

Prior to tube well drilling for small-scale irrigation, obtaining drilling permit from woreda (district) Water and Energy Office is required. In this regard, the woreda Water and Energy office will provide an application form to individual households, group of farmers or licensed well drillers. Then, a completed permit application form may be submitted to the woreda Water and Energy Office. The application will be reviewed by the office and if accepted, the application form shall be returned to the applicant with go ahead information. Once the well has been installed, the well owner shall notify the Agriculture Development Office for water quality inspection. If the well is intended for water supply purpose, the owner of the well shall notify the Office of Water and Sanitation for drinking water quality approval.

1.6 Scope of the Guideline

This guideline outlines how to successfully site, drill and construct manual tube wells for small-scale irrigation. The guideline describes in-depth drilling instruction on simple sludge drilling techniques and installation of diesel pump for lifting irrigation water. In the guideline, important irrigated crops, irrigation methods and extension approaches are also included.

The guideline is designed to help development agents to assist trained local people and to train people with no well construction experience and to be used as a reference when problems arise later in the field. The guideline is most useful when used in conjunction with on-job training.

The guiding principle is based on simple sludge tube well drilling method. There is plenty of water to obtain from shallow depths without employing the mechanical integrity or engineering design of well drilling methods. Hard rock drilling or drilling in stony area should be left to experienced drillers with more suitable drilling equipment. Experience in developing countries has shown that the construction of manual drilled wells must be simple and efficient. This keeps the technology affordable, simple to maintain and use local resources including drilling tools and local knowledge and skill.

CHAPTER 2

INTRODUCTION TO GROUNDWATER

2.1 Introduction

Groundwater is water that exists in the pore spaces and fractures in rock and sediment beneath the Earth's surface. It originates as rainfall and then moves through the soil into the groundwater system, where it eventually makes its way back to surface streams, lakes, or oceans. The depth at which soil pore spaces or fractures and voids in rock become completely saturated with water is called the water table. Groundwater is recharged from, and eventually flows to, the surface naturally; natural discharge often occurs at springs and seeps, and can form oases or wetlands.

Groundwater is often cheaper, more convenient and less vulnerable to pollution than surface water. Therefore, it is commonly used for water supplies, irrigation and industry. Underground reservoirs contain far more water than the capacity of all surface reservoirs and lakes.

2.2 Hydrologic Cycle

From the time the earth was formed, water has been endlessly circulating in various reservoirs in the ocean, sky, and soil. This unending circulation of the Earth's moisture is called the water cycle or hydrologic cycle (Figure 1). As with all cycles, the hydrologic cycle is ongoing and continuous, with no specific start or end point; however, by far, the greatest reservoir of water is the ocean, covering about three fourth of the Earth's surface. Water from the oceans evaporates into the atmosphere. The atmosphere then releases this water vapor primarily as precipitation in the form of rain, snow, sleet, or hail. During precipitation, some of the moisture evaporates back to the atmosphere before reaching the ground, some water is intercepted by vegetation, a portion infiltrates to the ground, and the remainder flows off the land into lakes, rivers, or back to the ocean. Groundwater is part of this continuous cycle as water evaporates, forms clouds, and returns to earth as precipitation. The processes in the hydrologic cycle are described as follows:

Precipitationis the process by which water, in the form of rain, snow, sleet, and hail, falls from the atmosphere to the Earth's surface.

Evaporation is the return of water from bare soil or open bodies of water (mainly the ocean surface) to the atmosphere. The source of energy for evaporation is primarily solar radiation. Evaporation often implicitly includes transpiration from plants, though together they are specifically referred to as **evapotranspiration**.

Transpiration is the transfer of water to the atmosphere through the stomata of vegetation.

Runoff is the over land flow of water or rainfall that does not soak into the soil.

Infiltration is the flow of water through the soil surface into a porous medium under the gravity action and the pressure effects.

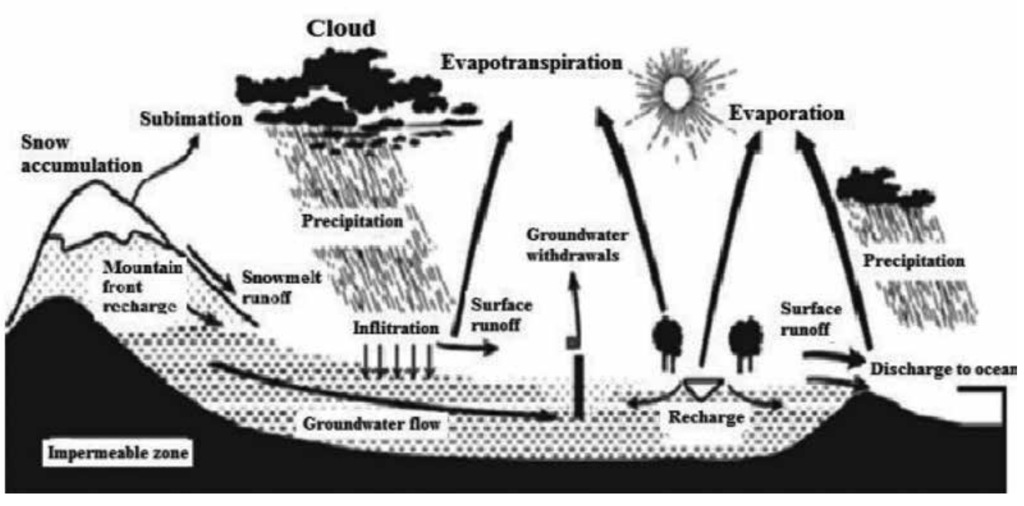


Figure 1: Hydrological Cycle

2.3 Groundwater Occurrence

Groundwater occurs almost everywhere beneath the land surface. The widespread occurrence of groundwater is a major reason why it is used as a source of water supply and irrigation in a worldwide base. Groundwater also plays a crucial role in sustaining stream flow during dry periods and is vital to many lakes and wetlands. Moreover, many plants and aquatic animals depend greatly upon the groundwater that discharges to streams, lakes, and wetlands.

The occurrence of groundwater in a given area is influenced by different factors such as geology, hydrology and hydrogeology of the area. The variability of the above stated factors influences the quantity and the quality of groundwater in different parts of the country. Geology is the study of the earth. It describes the origins, mode of formation and properties of earth material (rock and soil) on or under the surface of the earth. Hydrology studies the occurrence, circulation, distribution, and property of the waters of the earth and its atmosphere. The important components of hydrology are precipitation, evapotranspiration, and runoff. On the other hand hydrogeology dells with the rock and water interaction, groundwater recharge and discharge mechanisms, and groundwater flow system as a general.

2.4 Groundwater Zones

Rain that falls on the surface seeps down through the soil and into a zone called the zone of aeration or unsaturated zone where most of the pore spaces are filled with air. As it penetrates deeper it eventually enters a zone where all pore spaces and fractures are filled with water. This zone is called the saturated zone. The surface below which all openings in the rock are filled with water (the top of the saturated zone) is called the water table (Figure 2).

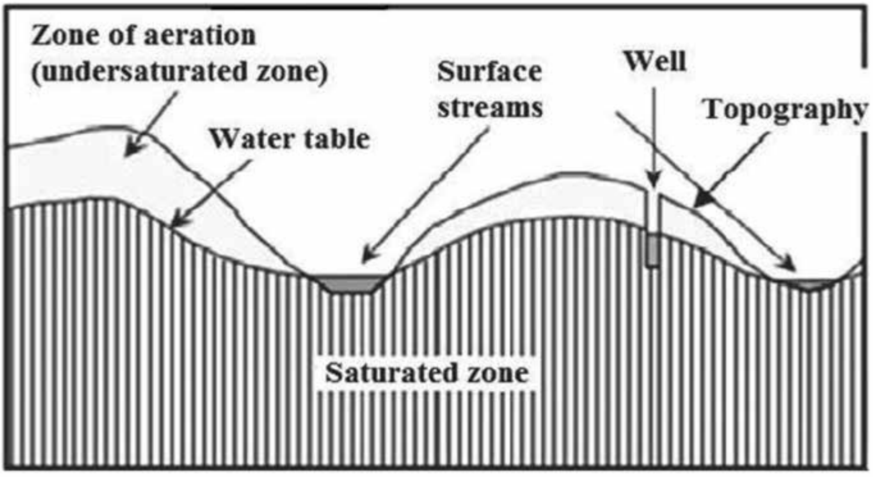


Figure 2: Groundwater and Water Table

2.5 Water Bearing Formation

Geological formations (rocks and soils) classified into different types based on water holding capacity and permeability. These are: aquifers, aquicludes, aquifuges and aquitard.

2.5.1 Aquifers

Aquifers are formation (rock or soil) that can store and transmit water easily. A good aquifer is a permeable layer (layer that can transmit water easily)below the groundwater table. Based on the presence or absence of a confining layer (impermeable layer overlying permeable layer) aquifers further divided into two, unconfined and confined aquifers. Unconfined aquifers are aquifers which have continuous permeable layers from land surface to the base of the aquifer. Whereas, confined aquifers are aquifers overlain by a confining layers (Figure 3). Perched aquifers are unconfined aquifers which are separated from the main water table by shallow impervious strata that are limited in lateral continuity and hence, water storage capacities of perched aquifers are very low.

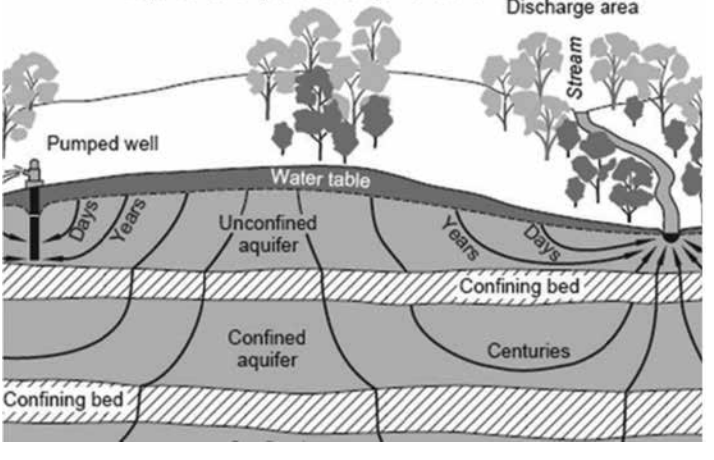


Figure 3: Groundwater Movements in Confined and Unconfined Aquifers

2.5.2 Aquitards

Aquitards are poor permeable formations, which contain water but obstruct groundwater movement, (e.g. sandy clay).

2.5.3 Aquicludes

Aquicludes are impermeable formations, which may contain water, but these are not capable of transmitting water through them. (e.g. clay).

2.5.4 Aquifuges

Aquifugesare impervious formations, which neither contain nor can transmit water (e.g. impermeable rocks).

2.6 Groundwater Movement

Groundwater is in constant motion, although the rate at which it moves is generally slower than it would move in a stream. First the groundwater moves through permeable formation downward due to the pull of gravity. But it can also move upward because it will flow from higher pressure areas to lower pressure areas, as can be shown in Figure 4.

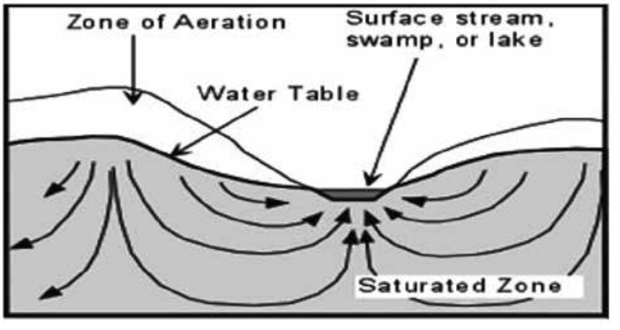


Figure 4: Groundwater Movement

The rate of groundwater flow is controlled by two properties of the rock: porosity and permeability. Porosity (n) is the percentage of the volume of the rock that is open space (pore space). It is calculated from volume of void space to total volume of the material (Eq. 1). This determines the amount of water that a rock can contain. Permeability is the ability of soil or rock to transmit or allow water to move through the layer. Permeability is a measure of the degree to which the pore spaces or fractures are interconnected, and the size of the interconnections (Figure 5)

$$n = \frac{V_v}{V_T} * 100\% \text{.......................................} (1)$$

Where:

n= porosity

V_v = volume of voids,

V_T= total volume.

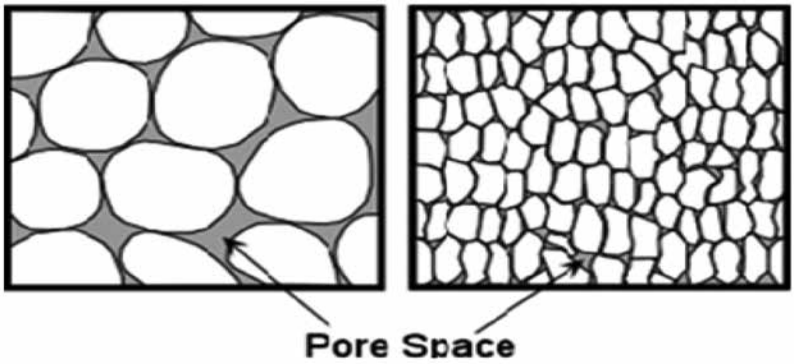


Figure 5: Porosity within Granular Materials

In sediments, the porosity depends on grain size, the shapes of the grains, and the degree of sorting, and the degree of cementation. Well-rounded coarse-grained sediments usually have higher porosity than fine-grained sediments (e.g. clay soil), because the grains do not fit together well. Low porosity usually results in low permeability, but high porosity does not necessarily imply high permeability. It is possible to have a highly porous rock with little or no interconnections between pores.

2.7 Groundwater Recharge

The Earth's surface can be divided into areas where some of the water falling on the surface seeps into the saturated zone and other areas where water flows out of the saturated zone onto the surface.

Areas where water enters the saturated zone are called recharge areas, because the saturated zone is recharged with groundwater beneath these areas. Areas where groundwater reaches the surface (lakes, streams, swamps, & springs) are called discharge areas, because the water is discharged from the saturated zone. Generally, recharge areas are greater than discharge areas.

2.8 Groundwater Discharge

Groundwater discharge is the term used to describe the movement of groundwater from the subsurface to the surface. There is natural discharge which occurs into lakes, streams and springs as well as human discharge, which is generally referred to as pumping. The natural discharge is controlled by the topography and geology, with groundwater discharging in topographically low areas (for example, valley floors).

2.9 Groundwater Resource in Ethiopia

Groundwater resource occurs in different environmental conditions and unevenly distributed in Ethiopia. Groundwater resource occurrence and distribution is highly dependent to topography, climate, hydrology, geology, hydrogeology, shallow groundwater development, the hydrological cycle, water bearing strata's, water movement in groundwater and the need of groundwater recharge are presents briefly.

2.9.1 Topography

Ethiopia has great topographic diversity which is composed of massive highland mountains and dissected plateaus divided by the Great Rift Valley running generally southwest to northeast. High rugged mountains, flat-topped plateaus, deep gorges, incised rivers, lowland and rolling plains are the predominant physiographical features. The Ethiopian plateau is an upheld block limited on the east by the rift System and declining on the west. The highlands include many subdivisions separated by the deep, steep sided valleys of the major rivers. Gorges are found along the upper courses of the big rivers, which flow, in deep canyons but widen out to broad and shallow valleys in their lower courses. The general area of the central highlands and the northern central massifs has rugged surfaces with high elevation.

The south eastern highlands include the highlands of Sidama, Bale, Arsi, and Harerge. The Afar Hills are limited in area and altitude but form a different region because they are at a higher altitude than the adjacent Afar lowlands. The Afar hills have steep sides and deep valleys and rise to an elevation of about 2500 meters. The lower rift valley is generally of low altitude (300 – 700 meters) being mainly large plains (Figure 6).

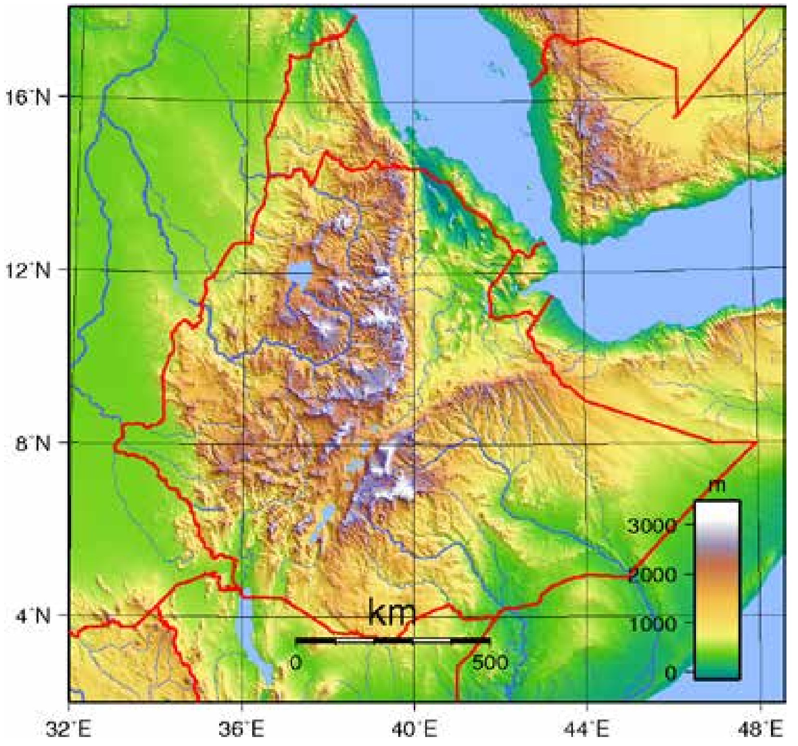


Figure 6: Topographic Setting of Ethiopia

2.9.2 Climate

Since the country is located in the tropics, the physical conditions and variations in altitude have resulted in a great diversity of climate, soil and vegetation. Altitude is the most important factor influencing the climatic condition of the country. There are considerable differences between Ethiopian Highlands and Lowlands in the average monthly and annual temperatures and rainfall. Major factors influencing rainfall are the inter-tropical convergence zone (ITCZ) the northern trade winds, and southern monsoon. The main climatic regions of Ethiopia are: dry climate, tropical rainy climate, and temperate rainy climate. Even though climate conditions are classified into generalized areas of specific types of climate, there are significant microclimatic variations over relatively small areas due to micro-relief variations.

Based on Global Precipitation Climatology Centre (GPCC http://gpcc.dwd.de) data, the mean annual rainfall is 812.4 mm, with a minimum of 50 mm and a maximum of 2,350 mm; with a highest rainfall ranging from 1,600–2,350 mm in the highlands of the western part of the country, and a lowest rainfall from 50 – 600 mm in the eastern lowlands of the country. The mean annual temperature is 22.2 °C. The lowest temperature ranges from 3 – 15 °C in the highlands, and the highest mean temperature is 35 °C in the lowlands at the Denakil Depression (Figure 7).

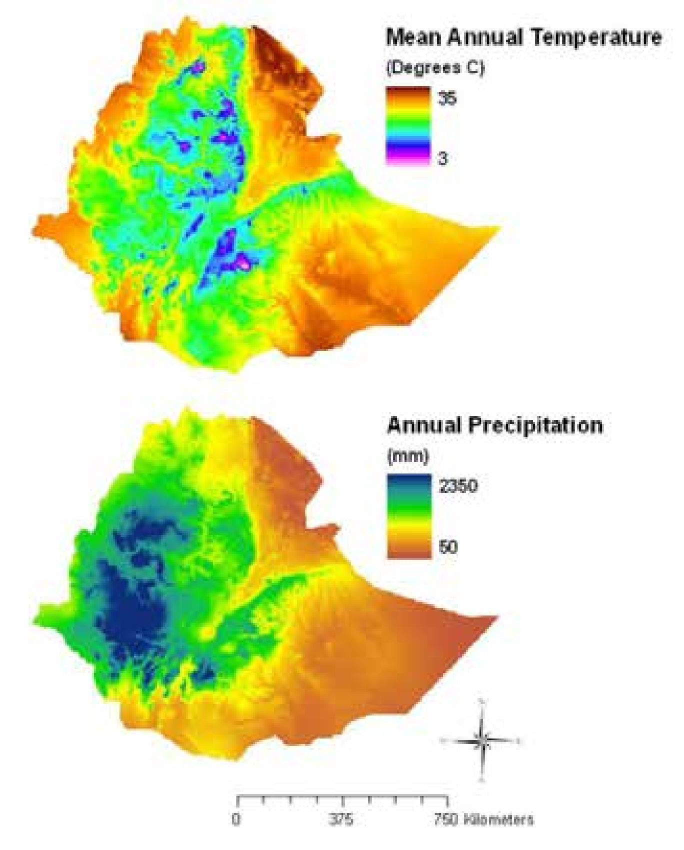


Figure 7: Spatial Mean Annual Temperature and Precipitation Distribution over Ethiopia

2.9.3 Hydrology

Ethiopia is endowed with huge water resources. The overall land mass of the country is hydrologically divided into **12** basins. These include (see also Table 1).

- **8** of these are River Basins
- **1** Lake Basin and
- **3** Dry Basins

Table 1: Major River Basins and Flow Directions

Basin Type	Flow Direction	Basin
Nile River System	flowing generally in the Western direction toward Sudan eventually terminating in the Mediterranean Sea	Abbay, Baro-Akobo, Mereb and Tekeze
Rift-Valley System	drain their water in the Great East African Rift-valley	Omo-Ghibe, Awash, Rift-valley Lakes, Denakil and Aysha
Eastern Ethiopia Basin System	generally flows in the South-easterly direction toward the Somali Republic and then to the Indian Ocean	Genale-Dawa, Wabi Shebelle and Ogaden

2.9.4 Geology

General geology of Ethiopia comprises the following three groups of country rocks:

- Cenozoic sediments and volcanic rocks
- Upper Paleozoic and Mesozoic sediments
- Precambrian lower, middle and upper complexes

Brief Summary of Geological Succession in Ethiopia is give in table 2

Table 2: A Brief Summary of Geological Succession in Ethiopia

Period	Age	Rock Formation
Cenozoic	1.Tertiary volcanics	Alkaline granite and syenite, Megdala group, trap series
	2. Tertiary sediments	Dogali formation, desert formation. Dunishub Formation, Red Sea series, Jessoma sandstone, Auradu series, Teleh series, kalakah series
	3. Quaternary volcanics	Basaltic flows and related spatter cones. Basaltic intermediate and flesic Volcanics. Quaternary sediments.
Mesozoic	1.Southern Sidamo sediments	Mount Fikkyu formation, Dibigia & Ganale Doria formation
	2. Eastern and Western Ogaden sediments	Hamanlei series, Urandab series, Gabredere series, main gypsum
	3. Central plateau sediments	Amba Aradam Formation, Antalo Group. Adgirat Sandstone, Gumburo series

Paleozoic	Pre-Cambrian	Post–tectonic granitoids, syntectonic granitoids, various grades and types of schist, gneiss, unaltered sedimentary rocks and igneous intrusions referred to as basement complex.
		Upper Paleozoic Triassic sandstone, shale, glacial deposits.

Source: V. Kazmin, 1973

2.9.5 Hydrogeology

The distribution of groundwater is mainly identified by two factors, rechargeable rainfall and the nature of geological formations. The geological formations that store and transmit groundwater (the recharge) are called aquifers. The aquifers of the country are grouped into three categories based on their regional extent, lithological homogeneity and hydrologic properties. The three categories, described below are hard rock aquifers, consolidated sedimentary rock aquifers and unconsolidated aquifers.

(WAPCOS, 1990 – see complete reference in Reference Section of this document).

a) Hard Rock aquifers

These aquifers with no primary porosity are capable of storing water within their weathered, jointed and fractured zones. They are often recharged from overlaying alluvium and weathered zones. The groundwater occurs in free dynamic condition (water table aquifers). Hydraulic conductivity is in the range of 1 to 40 meters per day. The yield is limited. Approximate area of such aquifers is 358,000 km2. *(See complete reference in Reference Section of this document).*

b) Consolidated Sedimentary rock aquifers

Consolidated sedimentary rock aquifers have moderate primary porosity and interangular permeability. The aquifers are regionally extensive and capable of yielding considerable discharge. The exploitation of aquifers is constrained by the recharge rate and chemical quality of the water. Generally, the rock types are limestone (karstic type) and sandstone. The hydraulic conductivity is less than 100 m/day. These aquifers occupy an area of most 456,000 km2. *(See complete reference in Reference Section of this document).*

c) Unconsolidated Aquifers

Unconsolidated aquifers are comprised of valley sediments with unconsolidated sand, gravel and river alluvium. They are fairly extensive in river valleys and flood plains along abandoned river channels, river terraces and delta regions. The groundwater is partly under pressure and their recharge is associated with stream flows. The river valleys of Awash, Barka, Mereb Gash and Tekeze Angereb have considerable flood deposits consisting of sand, gravel and silt. The area occupied by such aquifers is 432,000 km2. The hydraulic conductivity is greater than 100 m/day.

(See full reference in Reference Section of this document).

Table 3: Aquifer Characteristics of the Country

Aquifer system	Average Depth to Tap Water(m)	Average Specific Yield (lit/sec)	Location	Aquifer Description
In situ developed soils	5 – 20	0.1 – 1	Throughout the country but especially in the highlands and midlands	• These are soils developed within micro catchments where the rainfall directly infiltrates and stores in the saturated zone. • These types of soils are found to be useful sources of water especially in the highlands of Ethiopia where traditional and improved hand dug wells HDWs are the major sources of water supply. • Seepage springs are also common whenever there is a break in slope and/or a lower contact of the soil is exposed to the surface. Springs from these types of soils have an average yield of most 0.1 lit/sec.
Unconsolidated sediments (alluvial, colluvial, in situ developed soils, lacustrine sediments)	20 – 100	1 – 5	Mostly in the Rift Valley, western low lands, river valleys, isolated depressions throughout the country	• These are lacustrine and alluvium deposits of the flood plains and valley fills. • They are very important hydrogeological formations that are used to be very good sources of groundwater in Ethiopia. • The grain sizes of the alluvial deposits vary from fine grains of clay to gravel with horizontal and vertical variation in grain sizes. • As they are located exposed to the surface seasonal recharge by direct rainfall is occurring and as a result they are good sources of groundwater. • Due to their nature of deposit, these sediments are not homogenous and isotropic. • Besides, the extent and depth varies within a short distance as they are deposited on the existing irregular surfaces of an old topography. • The average yield of the wells dug or drilled in these formations have a yield of 1 – 5 litres/sec and the depth to abstract groundwater is between 20 to 100 meters. • These types of aquifers exist in the rift valley, in the river valleys and isolated grabens.
Quaternary Volcanics	100 – 250	2 – 5	Rift valley	• These are young volcanic of the rift floor where high tectonic activity is occurring which has resulted highly fractured rocks and as a result a favourable situation for groundwater recharge and occurrence exist.
The tertiary volcanics (having primary and secondary porosity)	50 – 250	2 – 6	Central, eastern and western highlands	• These types of aquifers have both primary and secondary porosity with a well tapping groundwater to a depth extending to 250 meters. • There are successive layers of aquifer systems and the upper most part, if tapped, is yielding smaller amount of water (0.5 to 1 lit/sec). If drilled deeper, the occurrence of groundwater increases. • These aquifers exist extensively throughout the country especially in the western, central and eastern highlands. • The water quality in this type of aquifers is generally good.

Aquifer system	Average Depth to Tap Water(m)	Average Specific Yield (lit/sec)	Location	Aquifer Description
Sedimentary rocks (Mesozoic sandstone, karstic limestone,)etc.	200 – 300	2 – 5	Eastern, southeastern	• These are thick layers of Mesozoic sedimentary rocks (only in some areas Paleozoic rocks exist) that have different layers of sand stone, marl, limestone, shale and conglomerate2. • The primary porosity developed is very poor for some of the layers (limestone) while secondary porosity and karistification is very common in the limestone. • Therefore, good yield of water is extracted from the karstified limestone and the sand stone. • However, due to the location of these layers deep underground, wells striking these aquifers are very deep to as much as 400 meters while the average depth being 250 meters.
Weathered and fractures intrusive and old Precambrian rocks (granite, metamorphose rocks, etc.)	30 – 60	1 – 2	Western, southwestern	• These types of rocks have very low fracture permeability while the depth of fracturing is shallow and accordingly groundwater in this type of aquifer is also shallow. • However, if thick layer of weathered over burden exists, relatively good potential of groundwater occurs. • In general the depth of groundwater tapping this aquifer system is between 15 to 60 meters and most wells drilled in this aquifer do have an average yield of 1 – 2 lit/sec whenever thick weathered part exists on a fractured mother rock.

Source: WAPCOS aquifer classifications originate from the hydrogeological map of Ethiopia produced by the Ethiopian Institute of Geological Survey (EIGS, 1988).

2.9.6 Shallow Groundwater Hydrogeology

A shallow groundwater maybe defined as a groundwater body that has a static water level at ranging from zero to 30 meters below ground surface (A Shallow Groundwater Mapping Pilot Project in Central Ethiopia, ATA, 2014). A shallow water level that may result from drilling of very deep confined aquifers is excluded from this definition.

Shallow groundwater is important in supporting the domestic water supply and household irrigation. The shallow groundwater table play a key role in providing base flow augmentation to the mainstream rivers. In rainy season surface water percolated into shallow groundwater aquifers and also shallow aquifers provide an important groundwater contribution to rivers.

Groundwater pumping, has withdrawn large volumes of water from both the semi-confined shallow aquifer and the deeper confined aquifer. Groundwater-pumping affects shallow groundwater flow and water quality. These human-induced changes to the shallow groundwater table and need to be impaired with restoration efforts. Shallow groundwater could be found in valleys, plains, near dams, wetlands, rivers and lakes. It is usually developed by means of hand dug wells, auger and hand driven wells, water holes and boreholes.

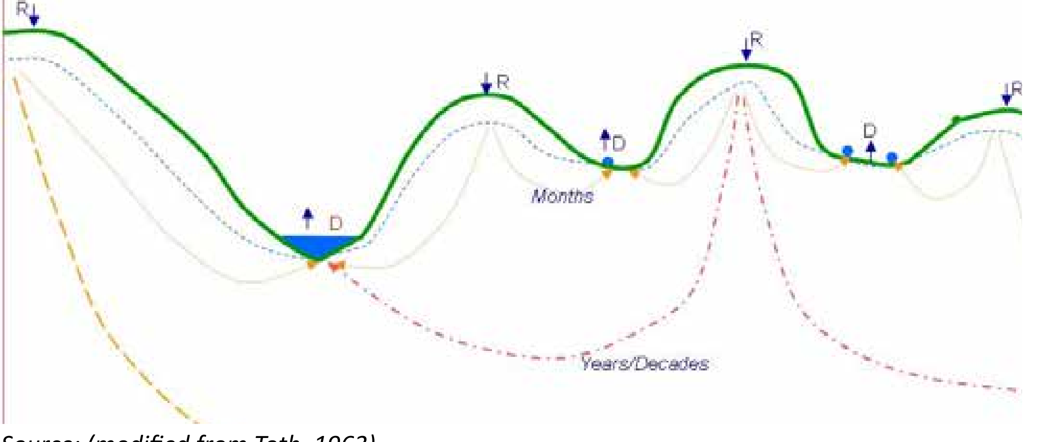
2.9.7 Shallow Groundwater Environments

Important environments where shallow groundwater can be found are:

- Groundwater discharges zones
- Shallow perched aquifers
- Unconfined aquifers filled to shallow depths
- Confined aquifer with high artesian pressure (may not be suitable for irrigation)

Favourable geological formations are:

- Loose sediments, weathered layers and volcanic ejects
- Geomorphological units (valleys , plains and foot of elevated areas)
- Near rivers, lakes, dames ,wetlands, valleys , and plains
- Wades and buried river channels
- Lake and riverine flood plains



Source: (modified from Toth, 1963)

Figure 8: Groundwater Flow System and Occurrence of Shallow Groundwater in Valleys

CHAPTER 3

SITE SELECTION FOR WATER WELL DRILLING

3.1 Introduction

In this chapter, technical, social and environmental factors that should be considered in selecting manual water well drilling sites are presented. These include mapping, topography, soil type, vegetation, etc. Criteria in determining well spacing, well location and preliminary well design are also discussed in this chapter.

3.2 Technical Consideration for 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. Don't site the well at places which are water logged or low and may get flooded in the wet season. Also avoid rocky places, which will make digging difficult.

Get advice from appropriate technical people on the sitting of the wells so that they are located on good aquifers that can supply sufficient water for the intended demand. Parameters that indicate the presence of groundwater may include the presence of:

- layers of gravel and sand
- weathered and fractured rock zones
- Springs nearby
- valleys and river beds
- aligned indigenous vegetation
- Boreholes or traditional HDW in area

Local knowledge from traditional well sinkers 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. Everywell will not result in a good yield; however, advanced planning with the community can maximize the number of successful wells and minimize drilling costs. Therefore, the following technical measures and indicators are important in deciding where to drill for water wells.

3.2.1 Maps

The Information that can be obtained from different maps such as geologic map, hydro geologic topographic maps, etc. can help in deciding the location of water well drilling. Geologic maps indicate the nature of the soil or rock materials comprising the area being investigated. Hydro geological maps gives information on groundwater occurrence, aquifer types, water points, and groundwater flow directions. Topographic maps also provide information on the size, shape, and distribution of features on the land surface, the location of lakes, swamps, springs, and streams.

3.2.2 Existing well conditions

Where dug wells exist, it is possible to determine the depth to water, geology and expected water quantity and quality. The history of old wells will indicate how far down the water table drops during dry seasons and will indicate how deep new wells must be. If the existing dug wells continue to be used, or one or more new well should be drilled in the same area; the spacing between two HDW should be kept at minimum of 500 m to ensure that both wells will produce sufficient amounts of water without interfering each other

3.2.3 Topography

The topography of the earth's surface influences the occurrence of groundwater. For example, groundwater will generally exist near the surface and in larger quantities in valleys rather than in upland areas. Similarly, the water table commonly follows the land surface (Figure 9). While the lowest areas (valley bottoms or depressions where water accumulates after rains) are generally the best places to drill (Dijon, 1981), however, ensure that the site has good access for irrigation and the area is not swampy because of high flooding.

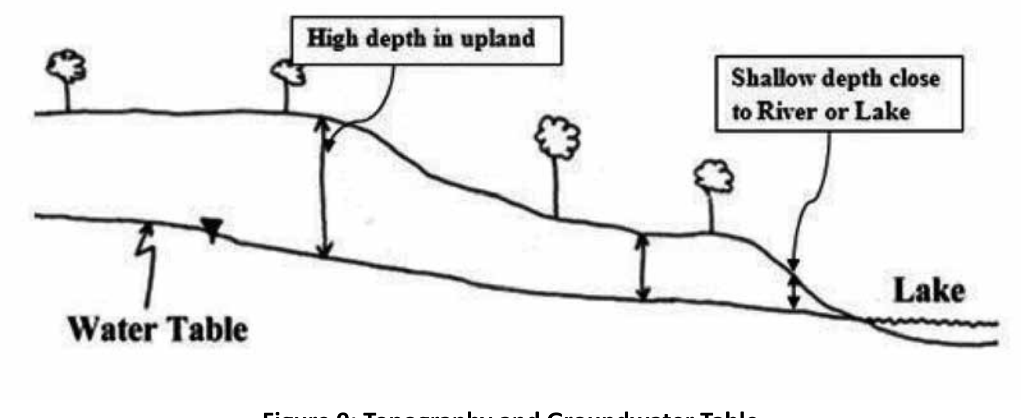


Figure 9: Topography and Groundwater Table

3.2.4 Soil Type

The occurrence of subsurface water can vary according to soil type, the nature of the underlying parent material and the depth of weathering. Water bearing capacity of different soil depends on the type of soil and grain size distribution (Figure 10).

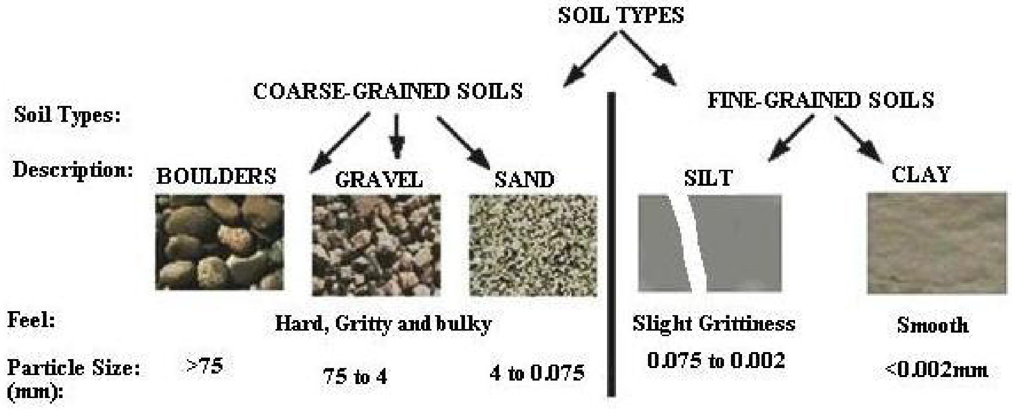


Figure 10: Soil Texture Classification

The texture of a soil is defined by the relative proportions of sand, silt, and clay present in the particle-size analysis. This is presented in the soil-textural triangle shown on Figure11 (soil samples composed of 30 percent clay, 60 percent silt, and 10 percent sand are classified as silt, clay and loam.

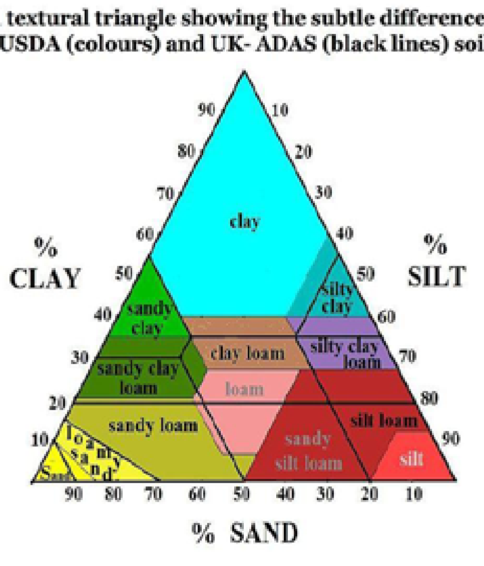


Figure 11: Soil Texture Classification

Clayey soil even though they have high water holding capacity, they have low permeability and used as aquicludes. On the other hand sandy and gravelly soils have high permeability which commonly known as the best aquifers in alluvial terrain. Based on mode of formation there are three major superficial (soil) deposits in tropical area. These include:

Residual soils: Residual soils are soils formed at the site from weathering of pre-existing rock. Weathering is change in physical and/or chemical composition of rock, which results in soil formation. Apart from highly swelling clay (vertisoil), residual soils are very stiff to collapse during well drilling. The productivity of a well located in this area is relatively low.

- **Alluvial soils:** Alluvial soils are soils formed along flood plain due to river deposition. The alluvial deposits are of two types: those spread out in alluvial plains and those strips along rivers and streams. The water holding capacity and permeability of these soils depends on the grain size of the sediment.
- **Lacustrine soils:** Lacustrine soils are lake deposits. The lacustrine deposits are of purely lake or swamp deposits. The most extensive lacustrine sediments are located around existing lakes. Because of collapsing nature of the soil deposit, high challenge in drilling expected in lacustrine sediment area.

Sand and gravel deposits usually yield large quantities of water. Water wells constructed in silt or clay soils will have very low yields regardless of how they are constructed However, the amount of water which can actually be pumped from these deposits depends on their thickness and permeability (how easy it is for water to flow through it). In general, the larger the grain size and the thicker the deposit is the higher the yield of the aquifer.

The hydraulic conductivity (permeability) of a soil and/or rock depends on a variety of physical factors, including porosity, particle size and distribution, shape of particles, arrangement of particles, and other factors. In general, for unconsolidated porous media, hydraulic conductivity varies with particle size; clayey materials exhibit low values of hydraulic conductivity, whereas sands and gravel display high values (Table 4)

Table 4: Specific Yield, Permeability and Porosity Values

S/N	Formation	Specific Yield (%)	Permeability (m/s)	Porosity (%)
1	Gravel, coarse	23	10^{-3} to 10^{-1}	25 – 40
2	Gravel, medium	24		
3	Gravel, fine	25		
4	Sand, coarse	27	10^{-6} to 10^{-3}	25 – 50
5	Sand, medium	28		
6	Sand, fine	23		
7	Silt	8	10^{-8} to 10^{-6}	35 – 50
8	Clay	3	10^{-10} to 10^{-8}	40 – 70

3.2.5 Vegetation

By investigating and looking for green vegetation in any given locality, it is possible to judge the depth of groundwater (shallow, intermediate or deep). Annual plants, such as grasses and ferns, are not good indicators because they come and go with the seasons. However, some year-round trees and shrubs are to grow where water is close to the surface. Since information on some water indicators trees in Ethiopia can be obtained from local people, the indigenous knowledge should not be ignored. Generally, baobab, mango, neem tree, etc. indicate that groundwater is deep while banana, sugar cane, and evergreen areas indicate shallow groundwater.

3.2.6 Surface water

Streams interact with groundwater in various ways. A stream may gain water from inflow of groundwater through the streambed-gaining stream or lose water to groundwater by outflow through the streambed-losing stream. Springs typically are present where the water table intersects the land surface. They may form at topographic depressions; where permeable rocks overlie rocks of much lower permeability; along joints, fractures, or faults (Fetter, 1988). The availability of springs indicates the presence of a water bearing formation (aquifer). A well can often be successfully if drilled just uphill of the spring (Figure 12).

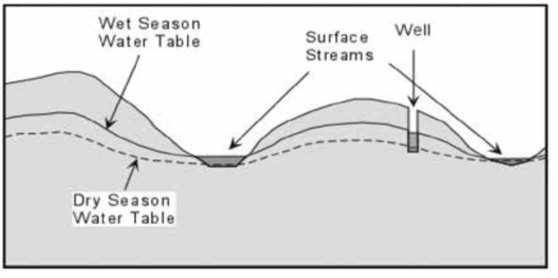


Figure 12: Surface Water Indicates the Existence of Groundwater

Groundwater development can lead to reductions in spring flow or elimination of springs altogether. Springs typically represent points on the landscape where groundwater-flow paths from different sources come together. Groundwater development may affect the amount of flow from these different sources to varying extents. For sustainable use of groundwater resources, along with the effort of groundwater development, technical measures that can enhance groundwater recharge should be done.

Moreover, successful wells are often drilled near lakes, large dams and rivers; groundwater may be available even if the river is temporarily dry (Figure 13). Water taken from wells located at least 15 m from a river is usually cleaner and cooler than water taken from the river(Dijon, 1981).

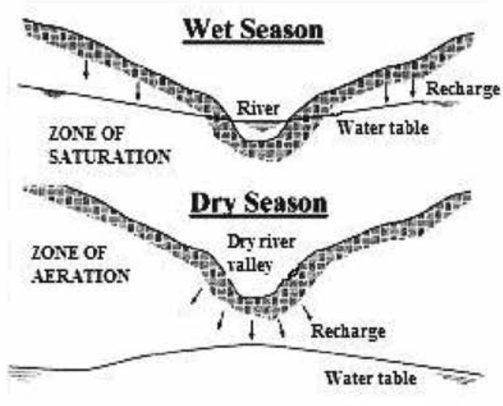


Figure 13: Seasonal Groundwater Fluctuation

The relation of lakes and wetlands to groundwater can be viewed as occurring in three different ways:

(i) lakes and wetlands may recharge groundwater without receiving groundwater input

(ii) they may both recharge groundwater and receive discharge water from groundwater

(iii) they may receive groundwater discharge, but not discharge water to groundwater (Sloan, 1972; Winter, 1976; Boyle, 1994) sited in Encyclopedia of Hydrology

3.2.7 Accessibility

Accessibility of the site is very important to minimize transportation of the pumped groundwater and to limit access restrictions for the drilling equipment. During site selection, the accessibility of the well site to the beneficiary shall be checked. The distance between the well site and irrigation field should be not more than 30 or maximum 50 m. Since women expected to fully involve in water management, along with the domestic chores, accessibility need to consider role of women and men on the process of production and harvesting

3.3 Social Aspect

The site selection process should involve the community participation. The most important factor for the community is ease accessibility of the system. It is important to consider the dynamics of men and women roles and responsibilities within the household in order to bind the range of different domestic and productive demands around water source. This demands genuine consultation with male and female-headed households (FHH) and married women farmers to more realistically identify the location fully accepted by end users of the technology. If possible, the wells should be centrally located to the area to be irrigated. Accordingly, male and female beneficiary communities need to be involved in every step from site selection to monitoring and evaluation of the scheme.

Important points to accounted equitable male and female farmer's consultation:

- employment of appropriate approaches which fits to male and female farmer's condition
- ensuring convince of schedule and venue to male and female
- attention to both FHH and married involvement and active participation

3.4 Environmental Aspect

Any development plan should be environmental friendly. Human activities often affect environmental values by degrading the environment or by discharging contaminants into water. Contaminants can enter water possibly from point and non-point source (diffuse) discharges. Point source discharges come from a single discrete point, like wastewater containing community sewage and fuel hydrocarbons and heavy metal like lead, copper, and mercury. Whereas non-point source discharges are from widespread or diffuse sources via runoff across land such as pesticides and nitrate from agricultural field.

Even though, the technology discussed in this guideline 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 5).

Table 5: 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

3.5 Determination Distance between Wells

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 6 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. A potentiometric surface is the imaginary line where a given reservoir of fluid will "equalize out to" if allowed to flow. This idea is heavily used in city water supplies − a tall tower containing the water supply has a great enough potentiometric surface to provide flowing water at a decent pressure to the houses it supplies.

Table 6: 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 6 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.

CHAPTER 4

WATER WELL DRILLING TECHNIQUES

4.1 Introduction

In this chapter, types and classification of water well drilling techniques commonly categorized into human powered and conventional machine drilling (rigs) are discussed. Water well drilling principles and processes are also presented. For simplicity and clear understanding, merit and demerit of water well drilling methods are also discussed. Moreover, in this chapter, human-powered technologies designed to construct small diameter wells with local material and local knowledge with low-cost closer to hand digging than to conventional machine drilling are discussed.

4.2 Water Well Drilling Principles

Any water well drilling method (hand-digging, human-powered drilling or 'conventional' drilling) requires various processes such as:

- 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.
- Water well drilling methods use one or more of the following methods to break or penetrate the formation:
  - percussion (striking the formation with pick, chisel, end of pipe, or drill-bit)
  - rotary action (grinding/tearing at the surface of the formation)
  - high energy percussion with rotation (as in down-the-hole hammer drilling)
  - Loosening by a water jet directed at the bottom of the hole
- The broken/loose material must be removed from the hole. This may be done by one of two methods:

- ➢ Alternating with breaking (that is; break some, clean some, break again)
- ➢ By the use of a flushing medium (water, “mud”, or compressed air)

- The drilled hole must be supported to prevent collapse during or immediately after drilling. This may be done in one of the following two ways:
  - ➢ by lining the hole as excavation progresses (with temporary casing, or permanent casing)
  - ➢ By maintaining a sufficient hydraulic head of fluid (water or mud) in the hole at all times. Drill mud is water thickened with a natural or man-made powder or liquid, to increase its viscosity (and hence its ability to carry cut rock fragments up the hole)

4.3 Types and Classifications of Water Well Drilling

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

- hand-digging
- human-powered drilling
- small ‘conventional’ drilling rigs
- large ‘conventional’ drilling rigs

The first two categories include both ‘traditional’ methods (i.e. long established, practiced by skilled practitioners, but without the benefits of modern materials and ideas) and ‘improved’ technologies. ‘Conventional’ drilling means the standard ‘modern’ techniques of cable-tool percussion, rotary and down-the-hole hammer, as used on small and large mechanical drill rigs. These human-powered technologies are designed to construct small diameter wells, at costs closer to hand digging than to conventional drilling.

4.3.1 Hand Dug Wells

Dug wells are common throughout the world and, since biblical times, have provided countless water supply points. They range from a simple unprotected hole in the ground to a properly constructed facility equipped with a hand pump. Dug wells are sunk by people working down in the hole to loosen and remove the soil. HDW need to be at least 1 m wide to give people room to work. A sinking method is a specific way of sinking a well.

Digging is relatively easy in unconsolidated formation (alluvial deposits). After digging or blasting, loose material is hauled to the surface in a container by means of pulleys and lines. As digging proceeds casing can be inserted forming a permanent lining to prevent caving in. Casing can be of wood, brick, metal, or concrete (pre-cast rings) and should contain openings for the entry of water. Dug wells must extend several m below the water table, although it cannot be too far because, even in a moderately permeable rock, dewatering needs to take place to enable digging to continue, thus limiting the depth attained. In extended drought years, shallow dug wells frequently dry up. Rural communities have frequently employed hand-dug wells to increase the supply of water available for individual use. Using simple construction techniques and suitable materials, hand-dug wells can provide reliable sources of water.

Advantages

- The level of community involvement is very high.
- Skilled labor is not required.
- Most of the construction materials are available locally.
- Water can continue to be drawn from a well equipped with a hand pump, even if the pump fails.
- Reliable maintenance of a well requires little technical skill.
- Because the resulting well is wide-mouthed, it is easily adaptable to simple water-lifting techniques, if pumps are not available or appropriate.
- Storage capacity allows wells to produce sufficient water even when aquifer permeability is extremely low, i.e. it provides a reservoir, which is useful for accumulating water from ground formations, which yield water slowly.
- Because the community can be involved in the actual construction, it is “their” well, which they are more likely to maintain.
- The equipment needed is light, simple, and thus suitable for use in remote areas.
- The construction techniques are easily taught to unskilled workers, thus cutting supervision time.
- The necessary materials are usually locally available, making it one of the cheapest methods of wells construction in a rural community.

Disadvantages

- Collapse of structure especially in areas where the soil is heavy clay and too sandy soils.
- The technology is only suitable for soft geological formations and shallow water tables thus restricting it to specific areas.
- Wells are susceptible to bacteriological contamination.
- A shallow water table generally means large water level fluctuations and the possibility of the well drying up, especially during drought periods.
- Construction speed is very slow.
- In most cases, extracting large quantities of water with motorized pumps is not feasible.
- Because it is difficult to penetrate very far into the aquifer, slight fluctuations in the water table often make hand-dug wells unpredictable and unreliable.

- Compared to other well sinking methods, digging a well by hand takes longer time.

If HDW are constructed for water supply purposes, for sanitation reasons a hand pump is desirable. If installed on a hand-dug well with a full cover, a pump will help reduce chances of contamination significantly. In rural areas where pump maintenance and repair can be a real problem, large diameter wells are often the best solution to water supply problems. Pumps can be installed while leaving an access way through which water can be drawn by rope and bucket if the pump should break down (Figure 14).

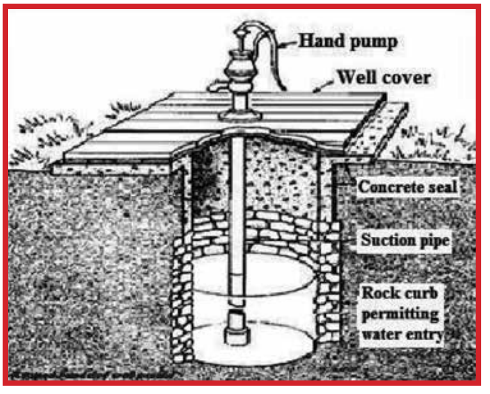


Figure 14: Section View of Hand Dug Well

An experienced team sinking a 20 m well and installing pulleys on the top structure could easily take 5 weeks, including occasional days off (this, of course, assumes no major delays). A new or inexperienced group would be expected to take twice that time.

Hand-dug wells should be dug during the dry season when the water table is likely to be at or near its lowest point. The well can be sunk deeper with less interference from water flowing into it. The greater depth should also ensure a year-round supply of water. If the well cannot be dug during the dry season, plan to go back to it at the end of the dry season to deepen it.

4.3.2 Tube Well Drilling Techniques

When a borehole is drilled, different types of geological formations can be encountered. To drill through all these different types of formation, a range of different manual drilling techniques have been developed. Therefore, it may be possible that two different drilling techniques have to be used to drill a borehole if different formations are encountered on top of each other. All existing drilling techniques can be divided into four main drilling principles: Hand percussion, well jetting, hand auger and Simple sludge. Within these four main drilling principles, a whole range of versions has been developed in different countries around the globe. There are large varieties of simple, low-cost well drilling techniques. These techniques tend to be low capital and labor intensive. While each of them has its advantages and disadvantages, good combination of two or more techniques has proven very effective in overcoming some of the limitations imposed by internal or external factors as may relate respectively to the technique itself or the lithology of the well sites. Brief description for each type of manual drilling technique is discussed in this section as follows:

4.3.2.1 Hand Percussion

Percussion method works by repeatedly raising and dropping a chisel-edged bit to break loose and pulverize material from the bottom of the hole, this consists of the alternating breaking of formation and cleaning of hole, often with separate down-hole tools (e.g. chisel alternating with bailer), but sometimes with the same tool (for instance clay-cutting tools). Usually weight is supplied over the cutting tool. The tool string (weights, drilling tools) is suspended from rope or steel cable, which is reciprocated through a stroke of 1 – 3 m. A small amount of water is kept in the hole, so that the excavated material will be mixed with it to form slurry. A bailer is lowered to remove the slurry containing the excavated material. The bailer or bailing bucket consists of a tube with a check valve at the bottom and a bail for attaching a cable or rope to the top. When it has been raised and dropped a number of times to fill it with the slurry it is brought to the surface for emptying (Figure 15)

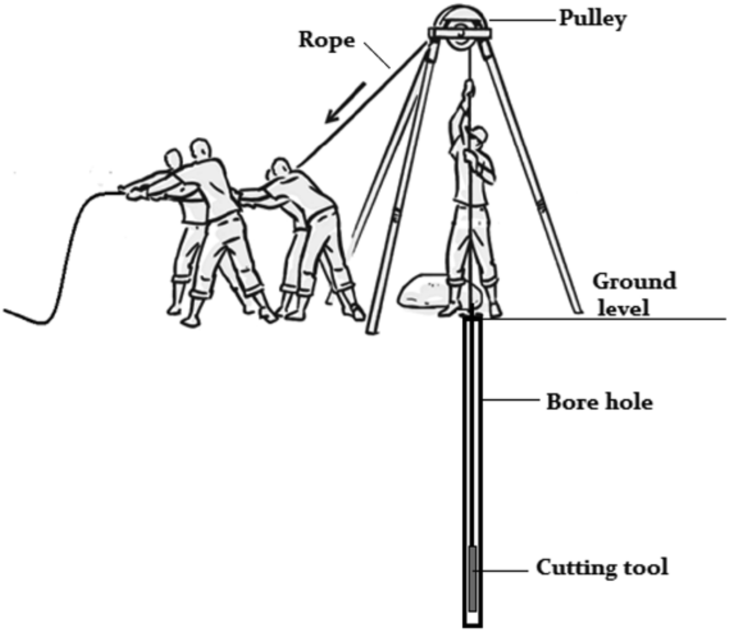


Figure 15: Hand Percussion Manual Well Drilling Method

Bailing is repeated until the hole has been adequately cleaned at which drilling is resumed; drilling and bailing are then alternated. In cases bailer is not effective it is possible to combine percussion with simple sludge to remove broken pieces from bore hole. It is frequently necessary to line the hole with temporary steel casing to prevent collapse. (Percussion drilling technique discussed in Chapter 5 in detail)

Advantages

- Simple to operate and maintain
- Suitable for a wide variety of rocks
- Operation is possible above and below the water-table
- It is possible to drill to considerable depths

Disadvantages

- Slow, compared with other methods
- Equipment can be heavy
- Problems can occur with unstable rock formations
- Water is needed for dry holes to help remove cuttings

4.3.2.2 Well Jetting

In this technique, as the name implies, a jet of water is used to increase the penetration rate of drilling. This requires specialized equipment and a plentiful supply of water, so the possibilities for application may be limited if water is scare in the area. When appropriate, depths of up to 80 m can be reached.

A drill bit with nozzles is attached to the drill pipes at its bottom and through which water is pumped at high pressure. The water on its return flow through the annular space between the bore and the drill pipe brings out the cutting along with it to the surface. Casing pipe simultaneously used to avoid caving-in. The method is suitable for drilling shallow wells in loose sandy formations (Figure 16).

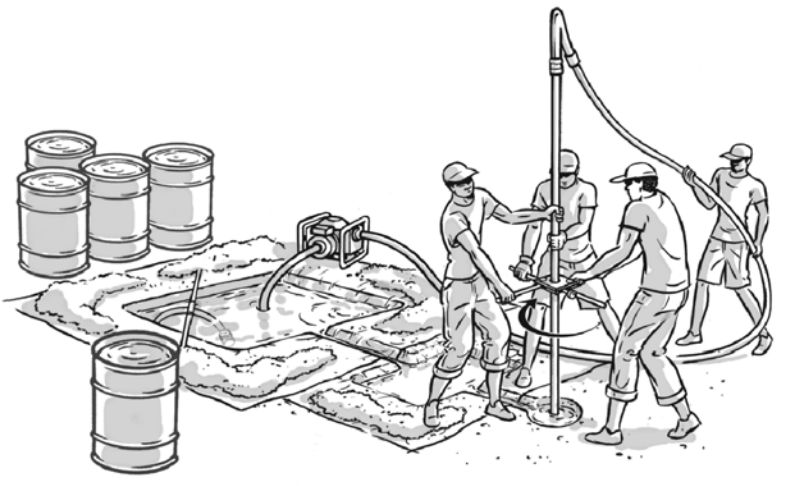


Figure 16: Well Jetting Manual – Well Drilling Method

Out of all the human-powered drilling techniques, jetting or wash boring is the only one using mechanical power, in the form of a pump. Water is delivered by hand pump or centrifugal motor-pump through an open-ended pipe (usually up to 50 mm), held vertically, and part rotated and/or reciprocated. The washing action of the water creates a hole larger in diameter than the pipe (100–150 mm). Suitable ground conditions are weakly cohesive sands and silts. Anything too hard will render the method ineffective, clay will be penetrated only very slowly, and gravels or other highly permeable deposits will result in lost circulation.

4.3.2.3 Hand Auger Drilling

The hand auger drilling is done with a spiral or worm auger connected to square rods turned manually with rod tillers, the cuttings produced as a result of drilling are removed with a sand shell. Steel casing pipes with drive shoes at the bottom are lowered as the drilling progresses. This method is employed where very shallow drilling in alluvium formation is involved.

The method is usually carried out with a heavy tripod fitted with a hand winch, using 100 – 150 mm (exceptionally up to 250 mm) diameter augers and 25 – 50 mm drill rod (threaded or quick coupling). Drilling is achieved by rotating the auger into the ground, and adding additional drill pipe as necessary from the top (Figure 17).

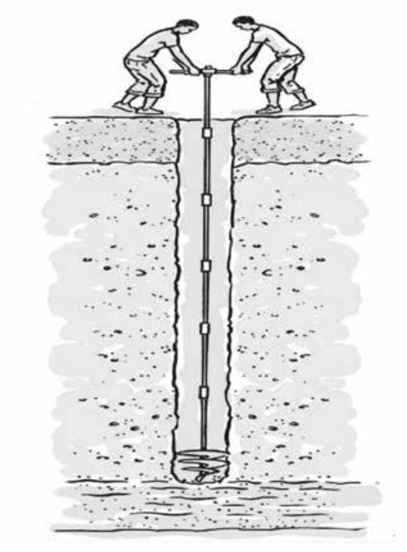


Figure 17: Hand Auger Well Drilling

Hand auguring is suitable for a limited range of unconsolidated formations such as non-collapsing sands and silts. Stiff clays, hard materials and gravels are difficult or impossible to remove unless auguring is combined with some form of percussion. In collapsing formations, it is possible to use temporary casing with some equipment. Depth is restricted by the time taken to raise and dismantle drill rods to remove from an ever-increasing depth. In practice, about 20 m is the limit.

Advantages

- Inexpensive
- Simple to operate and maintain

Disadvantages

- Slow, compared with other methods
- Equipment can be heavy
- Problems can occur with unstable rock formations
- Water is needed for dry holes

4.3.2.4 Simple Sludge Drilling Method

Galvanized Iron Pipe (GIP) is moved. This method has been developed and used extensively in Bangladesh, Sudan, Nepal and India. A hollow up-and-down in the borehole while a one-way valve; the driller hand can be used to provide a pumping action.

Figure 18: Simple Sludge Well Drilling Method

Simple sludge 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. Simple sludge is cheap and effective method of sinking small-diameter tube wells to a great depth where unconsolidated alluvial sediments are found.

The drilling pipe rests initially in a shallow pit filled with water. If the subsoil condition is lose, silt, water mixed with cow dung (2 kg of cow dung mixed with 20 litre water per 5 – 6 m drilling depth) is poured into the drilled hole to prevent the drilled hole from collapsing. If the subsoil condition is stable, use of cow dung will not be required. The drilling principle in simple sludge method is, drilling is done with 1½” GIP and the drilling fluid/liquid (water) flows down the borehole annulus (ring) and back up the drill pipe, bringing cut materials (slurry) with it. A small reservoir is needed at the top of the borehole for recirculation of the drilling liquid (water). Using a lever, two men (as the depth goes deep the number of men increases) raise and drop the pipe successively. For the duration of each upstroke, another man seals the open top of the pipe with his hand, creating a partial vacuum inside it, so that the water within the pipe rises with it. He removes his hand for the down stroke, during which the pipe drops faster than the water inside it. As this hand-on / hand-off cycle repeats, water starts to splash from the top of the pipe and the whole assembly begins to work as an elementary force pump. Additional lengths of boring pipe are attached successively until the required depth is reached.

The reciprocating action is achieved by use of a lever attached to a wooden frame. One operator uses his hand over the top open end of the pipe to act as a valve, while the other operates the lever. On the up-stroke, the hand seals the top of the drill pipe, and on the down-stroke, the operator releases his hand, allowing the cuttings to flow out of the pipe. Water from the pit moves down the annulus, and returns up the drilling pipe, carrying the spoil as sludge. The drilling GIP is open at both bottom (drilling) and top (function as valve) parts. Thickeners or stabilizers can be added to the water in the pit in order to prevent well collapse and reduce loss of circulation. Cow dung is commonly used, and sawdust is an alternative.

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.

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.

4.3.3 Large (High Capacity) ‘Conventional’ Drilling Rigs

Most deep wells are constructed by cable-tool percussion drilling or by one of the several rotary methods. These methods are now briefly described as follows:

4.3.3.1 Cable-Tool Percussion Drilling

Cable tool drilling machines also called percussion rigs operate by repeatedly lifting and dropping a heavy string of drilling tools into the borehole. The drill bit breaks or crushes consolidated rock into small fragments, whereas the bit primarily loosens the material when drilling in unconsolidated formations. In both instances, the reciprocating action of the tools mixes the crushed or loosened particles with water to form slurry at the bottom of the borehole. If little or no water is present in the penetrated formations, water is added to form slurry. Slurry accumulation increases as drilling proceeds and eventually it reduces the impact of the tools. When the penetration rate becomes unacceptable, slurry is removed at intervals from the borehole by a sand pump or bailer. In water well drilling, the depth capability for cable tool rigs ranges from 100 to 1500 m (Figure 19).

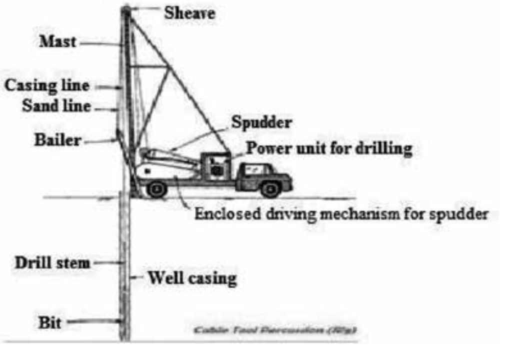


Figure 19: Cable Tool Percussion Drilling Method

4.3.3.2 Direct Rotary Drilling

Direct rotary drilling method is used to increase drilling speeds and to reach greater depth in most sub soil formations. The borehole is drilled by rotating a bit and cuttings are removed by continuous circulation of a drilling fluid as the bit penetrates the formation. The bit is attached to the lower end of a string of drill pipe which transmits the rotating action from the rig to the bit (Figure 20). In the direct rotary system, drilling fluid is pumped down through the drill pipe and out through the ports or jets in the bit; the fluid then flows upward in the annular space between the hole and drill pipe, carrying the cuttings in suspension to the surface. The fluid is cleaned in a settling pit before it is re-circulated. Drilling fluids include air, clean water, and others mixtures of special drilling fluids.

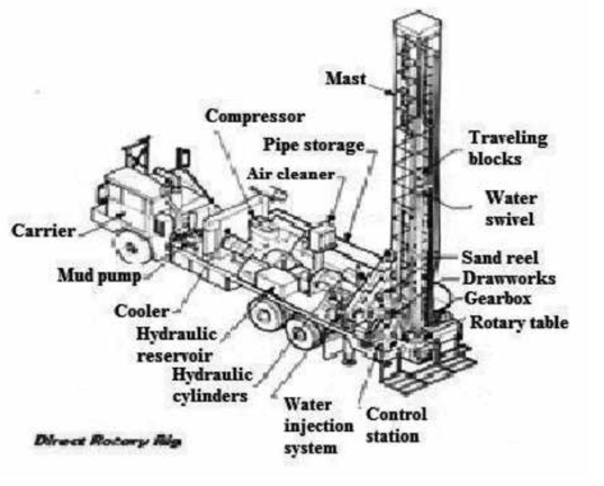


Figure 20: Direct Rotary Water Well Drilling Method

Because of limitations in pump capacity and therefore effective cuttings removals, most direct rotary machines used to drill water wells are limited to boreholes with a maximum diameter of around 600 mm. This size may not be sufficient for high-capacity wells, especially those that are to be filter packed. Also, as well diameters increase past 600 mm, the rate of penetration by direct rotary machines becomes less satisfactory.

Rotary drillings can also be accomplished with compressed air instead of drilling mud. The technique is rapid and convenient for small-diameter holes in consolidated formations where a clay lining is unnecessary to support the wall against caving in. An important advantage of the air rotary method is its ability to drill through fissured rocks with little or no water.

Moreover, in all drilling methods, it should be noted that the depth, diameter, and yield of wells as presented in this section are all only indications of the order of magnitude of what can be expected. In reality, larger diameters and depth may be obtained, whereas the yield depends primarily on the actual geology and availability of groundwater.

CHAPTER 5

MANUAL TUBE WELL (SIMPLE SLUDGE WITH PERCUSSION) DRILLING and INSTALLATION

5.1 Introduction

In this chapter, step-wise procedure how to drill and install tube well by simple sludge and percussion drilling method for small-scale irrigation up to 2.5 ha of land is discussed. Pre-drilling requirements, tube well drilling technique for simple sludge and percussion and installation approach, tools and equipment required for drilling and installation are also discussed. Other topics such as well development techniques and well yield test are also presented.

5.2 Pre-Drilling Requirements

5.2.1 Drilling and Installation Approach

The Simple sludge tube well for small-scale irrigation purpose is expected to be implemented in individual level or in small group of farmers where members are not more than 6 people and the total irrigated are not more than 2.5 ha.

5.2.2 Simple Sludge with Percussion Well Drilling Method; where to Apply?

A given location proposed for installation of tube well for small-scale irrigation with simple sludge drilling technique should satisfy the following requirements:

- Development of groundwater is relatively simple and cheap as compared to the development of surface water.
- 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).
- The demand for irrigation water and water supply is high.

- Availability of basic drilling tools, equipment and materials at local market.
- Availability of sufficient labor, minimum 6 people per well.
- Ease access for getting drilling water close to the proposed drilling site.
- Subsoil condition is not too hard rock formation like granite and the hard rock thickness not more than 2 m otherwise drillers need to have suitable percussion tools.
- Approved go-ahead permission from responsible government institution and local community.

5.2.3 Preliminary Water Well Design

Once the well location has been determined, a preliminary well design shall be completed. Final design is subjected to site-specific observations made during the well drilling. The overall objective of the design is to create a structurally stable, long-lasting, efficient well that has enough space to house proper pump or other extraction devices, allows groundwater to move easily and sediment-free from the aquifer into the well at the desired volume and quality.

At this stage the type of manual drilling method should be determined based on the sub surface condition of the specific site identified. If the site selected found to be stony or with boulder another drilling method rather than simple sludge method should be considered, however, this is beyond the scope of this guideline. Therefore, if the subsurface condition of area is free of stone or rock layer go for using simple sludge method.

Once the simple sludge drilling method is appropriate for the area, the type of pump shall be selected based on the groundwater level in the proposed site. The static water level is the most important groundwater parameter that governs in selection of water pumps. Before being pumped, the level of water in a well is the same as the level of the water table in the water-bearing formation in which the well is completed. This is called the static water level in the well and in the water bearing formations foundation (Figure 21).

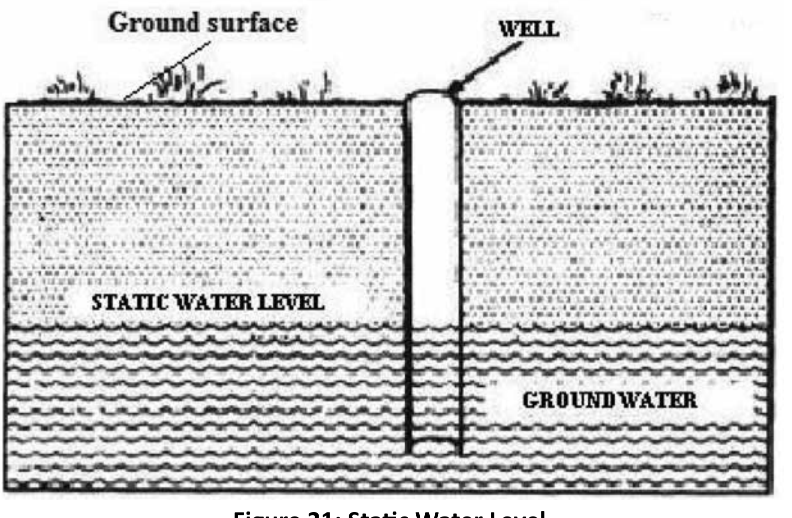


Figure 21: Static Water Level

The depth from the ground surface to the static water level should be measured and this distance used to describe its position. Thus if the water in the well is25feet(6.5 m) below ground, the static water level is saidtobe25feetforthiswell. Elevation of the static water level above mean sea level can also be used to describe its position. When a well is pumped, the water level drops. After several hours of pumping at a constant rate, it stabilizes itself in a lower position.

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This is called the pumping level or dynamic water level for this rate of pumping (Figure 22).

The distance that of water is lowered by pumping is called the drawdown. It is the difference between the static water level and the pumping water level. The drawdown in the well, resulting from pumping, lowers the water pressure in the well, but the surrounding water-bearing formation retains its original pressure.

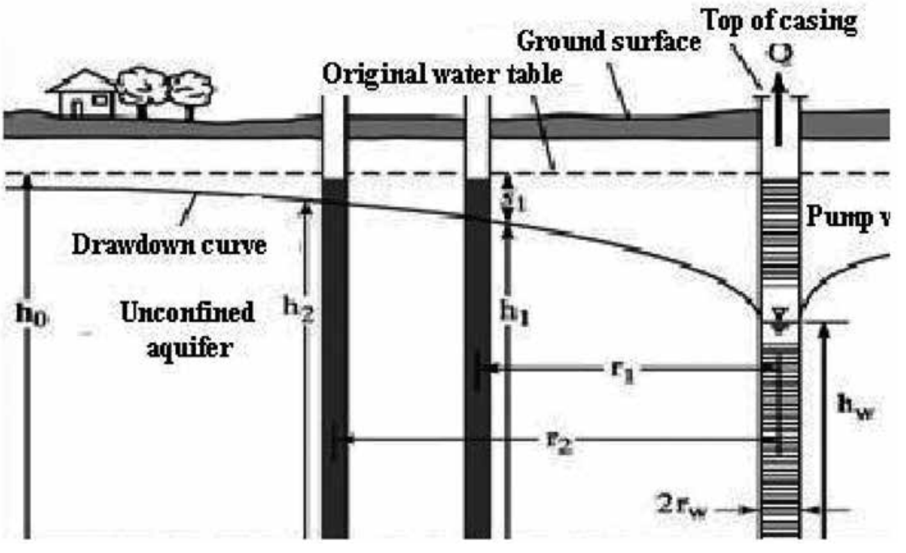

Figure 22: Radial Flow to a Well Penetrating an Unconfined Aquifer

Therefore, where the static water level is found at shallow depth that is less than 12 m, looking for surface pumps such as a diesel pump (with maximum suction head of 6 m) is appropriate. However, while using suction pumps (diesel/petrol) the pump unit should be installed below the ground surface in order to maintain the allowable suction head taking in to consideration the drawdown head during pumping.

In the area where the groundwater table found at relatively deeper (static water level greater than 12 m), use of lifting pump types such as hand pumps (rope and washer pump, Afridev , Indian Mark 2, etc.) or submersible pumps (electric, solar or generator), etc. can be considered. However, the use of other water lifting devices other than suction pump (diesel/petrol) is beyond the scope of this guideline manual.

A well consists of well screen, and well casing (pipe) surrounded by a gravel pack and appropriate surface and borehole seals. Water enters the well through perforations or openings in the well screen. Wells can be screened continuously along the bore well or at specific depth intervals. The latter is necessary when a well taps multiple aquifer zones, to ensure that screened zones match the aquifer zones from which water will be drawn. In alluvial aquifers, which commonly contain alternating sequences of coarse material (sand and gravel) and fine material, the latter construction method is much more likely to provide clean, sediment-free water and is more energy efficient than the installation of a continuous screen.

5.2.4 Tools, Equipment and Materials Required for Tube Well Installation

Important tools, equipment and materials required for pump house excavation, drilling, casing and pumping are presented in this section.

5.2.4.1 Preparation of Tools and Equipment for Pump House Excavation

Important tools and equipment for pump house excavation are given in table 7. Detailed descriptions of these items are given in Annex B.

Table 7: Tools and Equipment Required for Pump House Excavation

S/N	Items	Unit– Pieces (Pcs)	Quantity
1	**Pump house excavation**		
1.1	Measuring tape(30 m)	Pcs	1
1.2	Measuring tape (5 m)	Pcs	1
1.3	Nylon rope (thin-for layout) – 3 mm	Roll	1
1.4	Spade	Pcs	5
1.5	Hoe	Pcs	5
1.6	Wooden or metal ladder (7 – 8 m long)	Pcs	1

5.2.4.2 Preparation of Drilling Tools and Equipment by Drill Crews

Drill crews should have basic tools and equipment as given in table 8 prior to heading out to drill a well with simple sludge water well drilling method. These items are used to complete the construction of a tube well including drilling, reaming, well casing installation and diesel pump installation. Detail descriptions of these items are given in Annex B.

Table 8: Tools and Equipment Required by Drill Crews

S/N	Item	Unit– Pieces (Pcs)	Quantity
2	**Drilling**		
2.1	Measuring tape(5 m)	Pcs	1
2.2	Working cloth, boots and helmet	Set	6
2.3	First aid kit (for 25 people)	Kit	1
2.4	Pipe wrench, 36’, 24” and 18”	Set	1
2.5	Chain pipe wrench	Pcs	2
2.6	Pipe cutter (½ – 4”)	Pcs	1
2.7	Pipe thread maker (½ – 2’’)	Pcs	1
2.8	Metal hack saw frame with blade	Pcs	1

S/N	Item	Unit– Pieces (Pcs)	Quantity
2.9	Mason hammer (1 kg)	Pcs	1
2.10	File (flat)	Pcs	1
2.11	Metal bucket (16 lit)	Pcs	2
2.12	Chain (12 mm)	m	12
2.13	Chain (6 mm)	m	5
2.14	Nylon rope (thick) – 12 mm	m	25
2.15	shovel	Pcs	1
2.16	GIP (1½ "diameter and 6 m long)	Pcs	10
2.17	Coupling (1 ½")	Pcs	6
3.0	**Reaming**		
3.1	GIP (20 cm long 3" GIP welded with 1½" coupling)	Pcs	1
3.2	GIP (20 cm long 4" GIP welded with 20 cmlong3" GIP welded with 1½" coupling)	Pcs	1
3.3	GIP (20 cm long 5" GIP welded with 20 cmlong3" GIP welded with 1½" coupling)	Pcs	1

5.2.4.3 Preparation of Drilling Materials by the User or Client

Table 9 shows the list of materials required for installation of casing and screening for tube well. It includes also materials required for installation of diesel pump. These items are expected to be supplied by the owner or client of the tube well to be installed.

Table 9: Materials Required by the User (Client) for Tube Well Installation

S/N	Item	Unit– Pieces (Pcs)	Quantity
4.0	**Casing and screening and gravel pack**		
4.1	Wood poles (14 cm diameter and 3.10 m long– 2 pieces), (10 cm diameter and 1.80 m long, 1 piece), 8 cm diameter and 2.8 m long, 1 piece)	Set	4
4.2	GIP –3" diameter and 6 m long B-Class, 42 kg). Based on the aquifer characteristics, some portion of this material could be perforated at local workshop.	Set	2 – 3
4.3	Coupling (3")	Pcs	3
4.4	Galvanized mesh wire screen (coffee mesh size), if required	m	1 – 3
4.5	River gravel (1– 2 mm diameter), if re-quired	m^3	1
5.0	**Pump installation**		

S/N	Item	Unit– Pieces (Pcs)	Quantity
5.1	Diesel pump (3”, 5 hp, 30 m total head, 15litre per second(l/s)	Pcs	1
5.2	Poly Vinyl Chloride PVC reinforced flexible suction hose (5 mm thickness)	m	25
5.3	20 cm long 2½” galvanized pipe welded with 3” galvanized pipe coupling	Pcs	1
5.4	PVC reinforced flexible suction hose (5 mm thickness)	m	1.5
5.5	Hose clap, 3”	Pcs	3
5.6	Hose connector (aluminum), 3”	Pcs	1
5.7	Screw driver (flat and Philips)	Set	1
5.8	Teflon, medium	Roll	3
5.9	Diesel fuel for pump test	Litre	20
5.10	Oil for diesel pump	Litre	2

5.3 Steps for Pump House Excavation

For extracting water from manually drilled tube wells, different types of pumps can be used based on the intended use and farmers’ interest in combination with technical and economic aspects. Therefore, the type of water lifting device intended to be used will decide whether there is a need for pump house excavation or not. For example, if the tube well drilling is designed for drinking water supply purpose by installing hand pumps such as rope and washer pump, AFRIDEV types, etc., or submersible pumps, the drilling work can be done from the surface and there is no need of pump house excavation. In this case, a pit of 2mlong by 2 m wide and 0.5m deep is only required to hold water for drilling purpose. However, in this guideline document, the main water lifting device considered for lifting water from simple sludge drilling method is centrifugal diesel pump and detail discussion on other types of water lifting devices is beyond the scope of this guideline.

Centrifugal suction pumps are widely utilized to pump water from surface and groundwater sources with their practical suction lift capacity not more than 6 m. For practical adoption of centrifugal suction pumps in tube wells for irrigation purposes, an effective suction head of 2.5 m is suggested in this guideline. Therefore, if the static water level in an area is greater than 2.5 m deep from the surface then we need to construct a pump house. The static water level should be checked from any existing HDW available in the area. The site investigation for checking the static water level should be done during the dry period since water level fluctuation is inevitable towards the dry period when rain ceases. If HDW are not available in the area, consult the local people and/or relevant offices who are directly involved in water development works. In addition, the site to be selected for pump house excavation should be free from boulders or rock and should be as close as possible to the land to be irrigated (say in the range of 10 to 20 m).

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Moreover, for easy operation of the drilling work as well as for better aeration of the diesel pump intended to be installed, the base of the pump house should have a minimum area of 9 m^2 or (3 m long and 3 m wide). The side slope of the pit (pump house) will be determined based on the soil type of the site. Accordingly, for the purpose of this guideline, a vertical to horizontal side slopes of 1:0.5 for stable soils (sandy loam) and 1:1 for unstable soils (too sandy and clayey) are recommended. Once the specific site is located, the base of the pump house dimension and side slope are decided, the following are stepwise procedures to excavate the pump house:

Step 1: Know the SWL from any available information

Step 2: Once you know the SWL determine the depth of pump house excavation (d) using Equation 2:

$$d = SWL - 2.5 - - - - - - - - -(2)$$

Where:

D	Depth of excavation, m
SWL	Static water level, m
2.5	constant value, m

Step 3: Determine the side slope (Z) of the pit (pump house) based on the observed soil type:

i) If the sub soil is stable, example sandy loam, Z= 0.5

ii) If the sub soil is unstable, e.g. sandy or clayey, Z= 1

Step 4: Determine the top width of the pit (T) using Equation 3:

$$T = 2dZ + b - - - - - - - - - - - -(3)$$

Where:

T	Top width of the excavation pit, m
D	as stated earlier, m
Z	side slope of the pump house (vertical: horizontal), ratio
B	Bottom width of the pit. M

Step 5: Determine the required dimension of the pump house.

Example: 1

Find the dimensions of excavation pit if the SWL is 8.5 m?

a) Assume the soil is stable and where z= 0.5 and bottom width is 3 m long

<u>Solution</u>

d = 8.5 m − 2.5 m= 6 m

b = 3 m (given)

T= 2*0.5*6 m +3 m=9 m

b) Assume the soil is unstable and where z= 1 and bottom width is 3 m long

Solution

d= 8.5 m – 2.5 m= 6 m

b= 3 m (given)

T= 2*1*6 m +3M=15 m

Table 10 shows the required dimensions of the excavation pit based on the depth of static water level and soil type (stable and unstable)

Table 10: Pump House Dimension

Static Water Level	Stable Soil, Side Slope (V:H)=1:0.5			Unstable Soil , Slope=1:1		
	D_1	B_1	T_1	D_2	B_2	T_2
[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)

Step 6: Prepare hand tools and equipment required for pump house excavation

Step 7: Select the appropriate site for excavation and do site clearing

Step 8: Prepare four wooden pegs and fix them at equal interval with dimension equal to top width of the pump house (T). Then, tie a rope to each peg (A, B, C, D) and check each corner measure 90^0. From any direction towards to the land to be irrigated, mark a rectangular loop measuring W (width) and L (length) that will be excavated for accessing into the pump house (Figure 23).

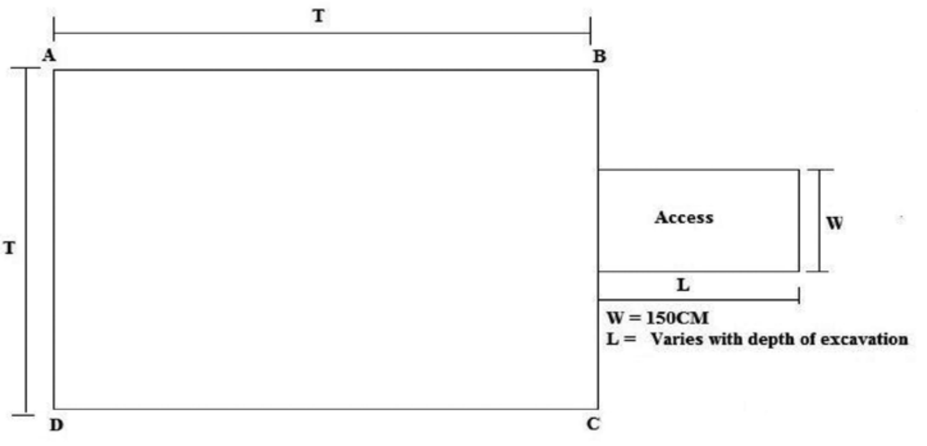


Figure 23: Pump House Layout Step 1

Step 9: Inside the rectangle ABCD, measure 3 m by 3 m and fix pegs at point L, M, N, O, P, Q, R and S. Then tie a rope to make a line LQ, MP, NS, OR (Figure 24)

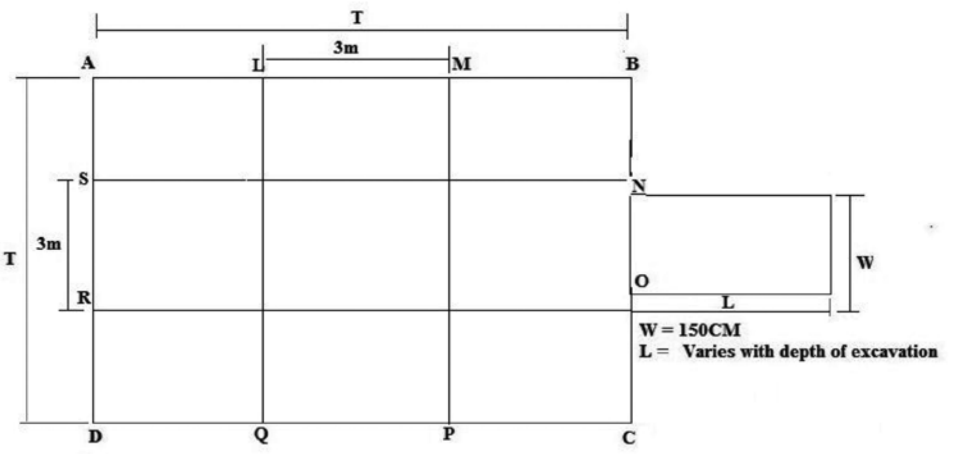


Figure 24:Pump House Layout Step 2

Step 10: Hammer 4 pegs each at point F, where line LQ and NS intercept, at point G, where MP and NS intercept, at point H, where line MP and OR intercept and at point I, where line LQ and OR intercept. Then tie a plastic rope to each peg and make a loop, FGHI, (Figure 25).

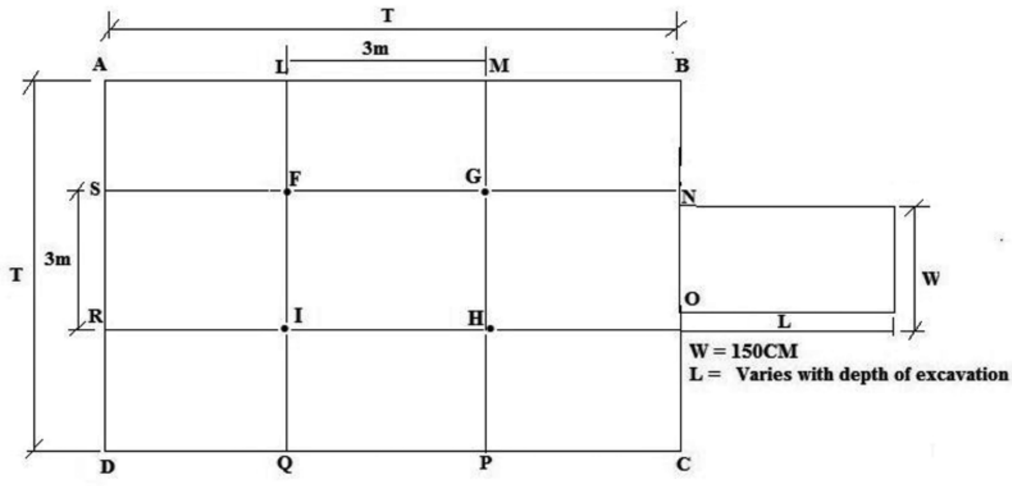


Figure 25: Pump House Layout Step 3

Step 11: Excavate the soil inside the rectangular pit (FGHI) to the depth equal to d m (Figure 26).

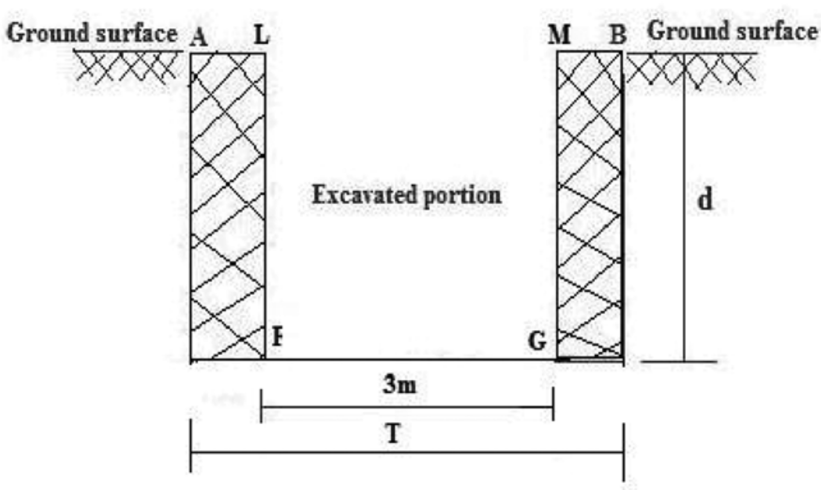


Figure 26: Method of Excavation

Step 12: Tie a rope on each pegs to make a curved line AF, BG, CH and DI. Then remove all the soil inside each curved line to make a straight line AF, BG, CH and DI (Figure 27).

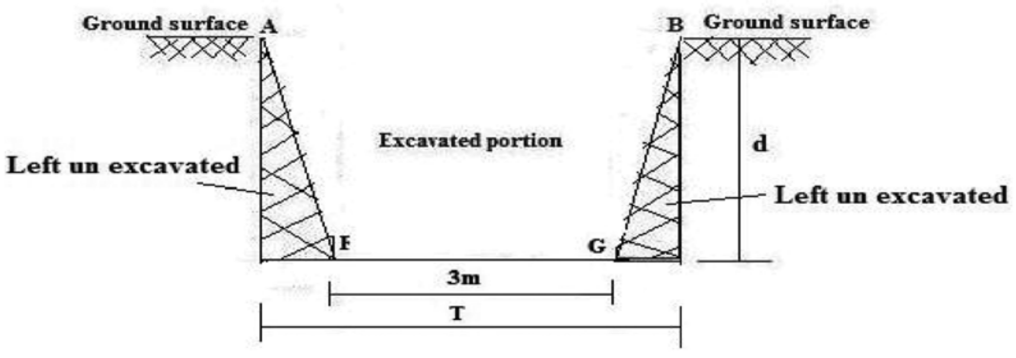


Figure 27: Excavation of Pump House with Required Side Slope

Step 13: Check the final shape of the pump house with the given depth and side slope is the same as shown in Figure 28.

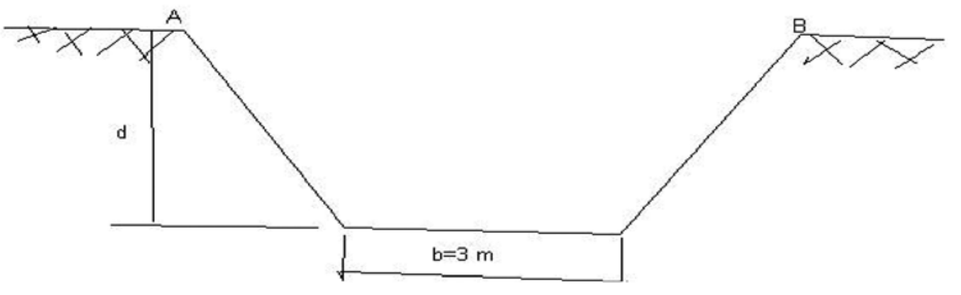


Figure 28: Final Shape of Pump House before Construction of Access Trench

Step 14: Excavate a trench (150 cm wide) towards the direction of the land to be irrigated for accessing the pump house with steps having a dimension of vertical 50 cm high and horizontal 70 cm wide (Figure 29)

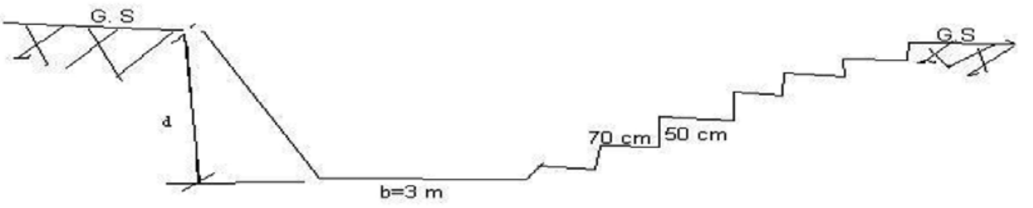


Figure 29:Final Shape of Pump House with Access Trench

5.4 Pre-Drilling Activities

Once the pump house excavation work is completed, the pre drilling works are explained under the following steps:

Step 1: 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 (Figure 30).

Figure 30: Preparation of Drilling Tools and Equipment

Step 2: 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 31).

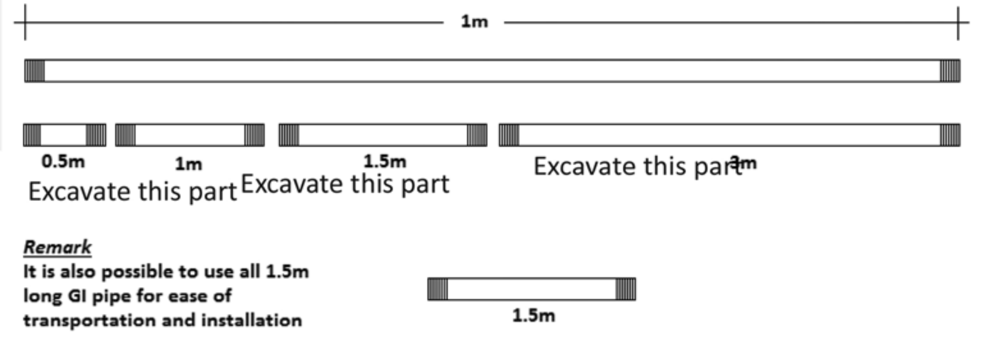


Figure 31: Basic Drilling Tools (1½" GIP)

Step 3: Using the pipe thread maker, make a thread to each cut pieces of 1½" GIP and fix coupling (Figure 32)

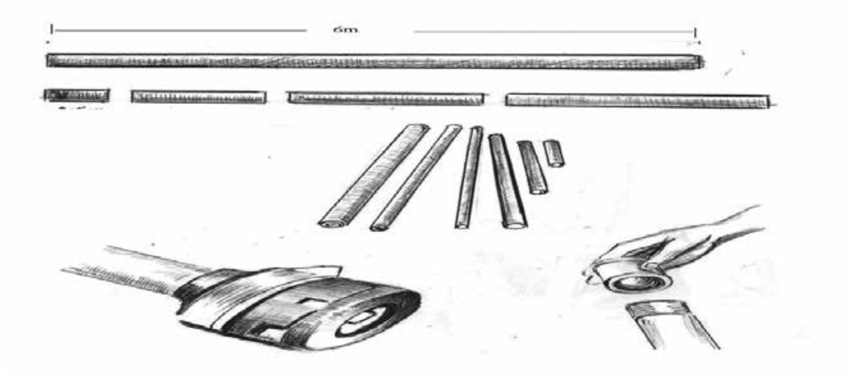


Figure 32: Pipe Tread Making

Step 4: Use hammer and puncher or any metal to remove the bottom part of the metal bucket (Figure 33).

Figure 33: Preparing Guide Bucket

Step 5: 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 34).

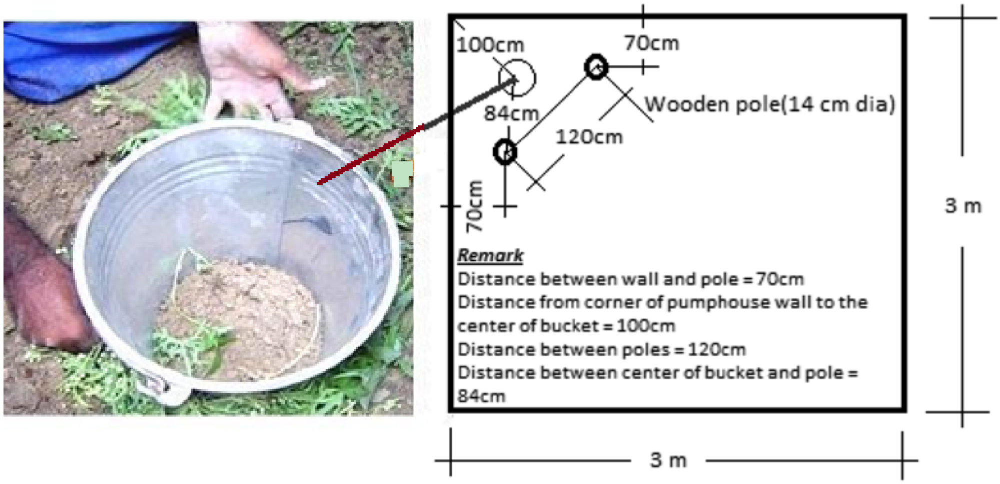


Figure 34: Location of Guide Bucket

Step 6: 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 35). 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 35: Erecting Wooden Poles

Step 7: 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 the 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 (Figure 36).

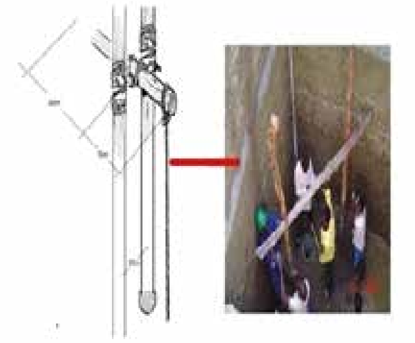


Figure 36: Erecting Wooden Poles

Step 8: 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 37).

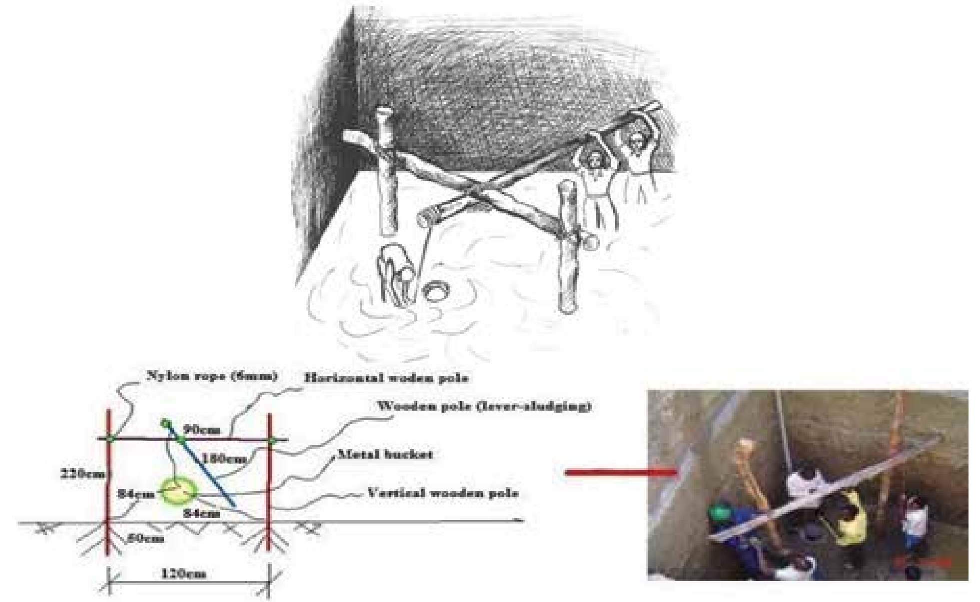


Figure 37: Fixing Drilling Pipe with Simple Sludge

Step 9: 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 (Figure 38).
  - ➢ Pumping from nearby HDW
  - ➢ Collect from any other available water sources in the area and store

it in any reservoir (about six 200 litre drums every morning until the drilling work is completed)

- Dig a small diameter of hand dug well within the pump house, and then use this water by bucket lifting

Figure 38: Possible Sources of Drilling Water

> **Important:**
>
> **How to prevent loss of drilling fluid at drilling surface?**
>
> If the soil of the drilling surface is too sandy or water (as drilling fluid) is scarce in the area, minimize the water loss by covering the drilling surface with any plastic material.
>
> **How to prevent loss of drilling fluid (water) inside the borehole**
>
> Adding fresh cow dung (about 10 kg cow dung per 200 litre of water per about 6 m depth) to the working water prevents water loss through drilling hole wall.
>
> It also serves to thicken up the water so that the soil particles are carried with it more easily. Clay or loamy soils can be drilled without cow dung, but cow dung must be added when water loss is believed to happen through pore spaces inside the borehole.

5.5 Start Drilling

A simple GIP (1½ “) is repeatedly lifted and dropped into well guide metal bucket on the base of the pump house. The hole drilled with GIP (1½ “) is kept full of water until the drilling work is completed.

On the down stroke, the impact on the ground loosens the soil and on the up stroke, the top of the pipe is closed by hand, drawing up the water through the pipe and transporting the soil cuttings to the surface. On the next down stroke, the hand opens the top of the pipe and the water flows out from the small opening pipe added into the drilling fluid. In this way there is a continuous drilling and removal of cuttings. As the drilling progresses, more pipes are added. The wooden poles installed inside the pump house (two vertical poles and one horizontal wooden beam) serves as a support for the lever that moves the pipes up and down. A pipe wrench is clamped on the top drilling pipe which permits the pipe to be partly rotated at the moment it hits the ground. For simple sludge tube well drilling method, water is an important component used to transport cuttings. Therefore, the following are basic steps in water well drilling using simple sludge manual drilling method:

Step 1: Drilling will be started 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) (Figure 39).

Figure 39: Start the Drilling Work

Important

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 (Annex C).
- 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. Cut-tings(sample) from the container or metal bucket should be displayed properly on for example plastic sheet, prepared on level surface (Figure 40)

Figure 40: Sample Cuttings

Step 2: Place the 1 m long 1½ "GIP at the center of the drilling guide metal bucket and connect it to the extended plastic rope (Figure 41).

Figure 41: Tying Drilling Pipe and Sludge Lever with Nylon Rope or Chain (6 mm)

Step 3: Before drilling is started, one must be sure that the drilling pipe is filled with water (Figure42).

Figure 42: Priming the Drilling Pipe

Step 4: 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 1mlong pipe is then removed and replaced by 150 cm (1 m long) drilling pipe (Figure 43).

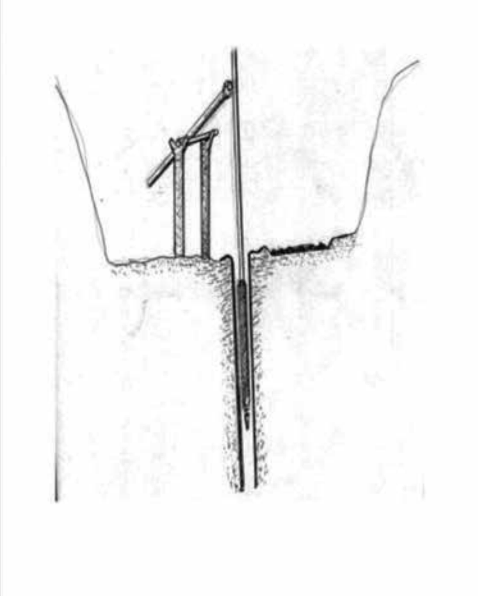


Figure 43: Removing Process of Drilling Pipe (1 m long pipe)

Step 5: After drilling with 1.50mlong drilling pipe, raise it and attach the 1mlong 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 (Figure 44).

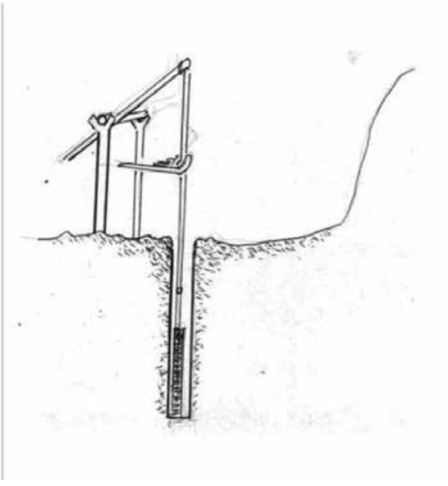


Figure 44: Connecting Extra Drilling Pipe

Step 6: Once drilling of 2.50m depth is completed, remove the two pipes (1 and 1.5 m long pipes), and replace them with one 3mlong pipe. Connecting or disconnecting the drilling pipes from the socket (coupling) should be done using two pipe wrenches, which are usually, called holding wrench (for holding the pipe) and working wrench (for fastening and unfastening from the socket). However, if it is easily available in the local market, pipe chain wrench can perform as holding wrench better than pipe wrench (Box below).

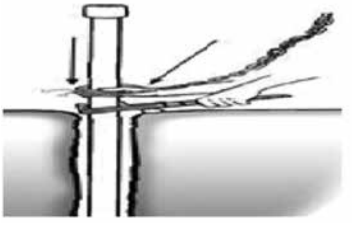
Important

How to use pipe wrench

- The holding pipe wrench or chain wrench works at the lowest possible position and is supported by a pipe or pole. The holding wrench keeps the drill pipe at the required height and prevents it from turning. The drilling pipe actually hangs on the holding wrench. If the wrench functions badly, there is the danger that the pipe will slide out of the wrench
- The drilling pipe which has to be connected or disconnected is screwed on or off using the working pipe wrench
- Always ensure that the drilling pipe is secured by the chain before connecting and disconnecting.
- While the driller is trying to move the chain to the bottom of the socket and disconnect the upper pipe, with the help of working wrench, the lever operators must ensure that the chain is not stretched or pulled tight.

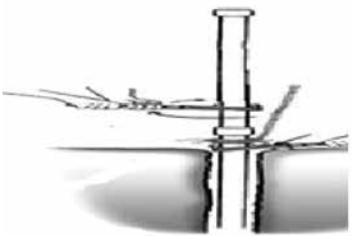
Raised and lowered drilling pipes using pipe wrenches

- When raising the pipes, the lever operator will move the lever as far as possible downwards so that the chain will lift the pipe. At the highest point the holding wrench will be attached. The chain will now be released due to the wrench automatically clamping onto the pipe with its weight. Because there is no tension on the chain, the chain will slide downwards along the drilling pipe. At the same time, the lever will be moved upwards.



The lever operator can now make the following stroke.

- When the end of the first pipe has been reached, the chain should pass the socket because the pipe should be secured.
- The supporting rope is loosened and the chain will be able to pass the socket more easily
- Now that the chain has passed the socket, the pipe can be safely unscrewed. The moment the socket is passed is the moment which carries the greatest risk. After all, everything now depends on the holding wrench. Therefore, ensure that the holding wrench is in a good position and let the chain pass the socket as quickly as possible.
- Lowering the pipes works the same way but in reverse



Step 7: Connecting and disconnecting drilling pipes

When the drilling work by 3m long drilling pipe is completed, connect to it the 1 m long pipe and continue drilling to make the total drilling depth of 4 m. Then, disconnect the 1 m long and replace it with 1.5mlong drilling pipe to make the total drilling depth of 4.5 m. Then, connect to it 1 m long drilling pipe to make the total drilling depth of 5.5 m. Then, remove all the drilling pipes, 1, 1.5 and 3 m long drilling pipe and replace them with the 6 m long drilling depth to make the total depth of 6 m. Then, connect 1m long drilling pipe to make total drilling depth of 7 m. Then, remove the 1 m long pipe and replace it with 1.5 m to make total drilling depth of 7.5 m. Then, connect 1 m long drilling pipe to drill total depth of 8.5 m. Then remove 1 and 1.5 m long drilling pipe and replace them with 3mlong pipe to make the total drilling depth of 9 m. Then, connect 1 m long drilling pipe to drill total depth of 10 m. Then, replace the 1mlong with 1.5 m to make the total drilling depth of 10.5 m. Then, connect 1 m long drilling pipe to make the depth of drilling 11.5 m. Then, disconnect the 1, 1.5 and 3 m long drilling pipe and connect the 6m drilling pipe to make the total drilling depth of 12 m. The cycle is then repeated until the required depth for installation of casing and the overall drilling work is completed and if you want to drill with 1.5 m long uniformly cut pipe it will be easier and it is just connecting the pipes without any order. For quick reference, Table 11shows how pipes are connected and disconnected using simple sludge water well drilling technique.

Table 11: 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 8: 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 (bore hole) 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 9: Use of Additional Drilling Tool and Extra Weights

In hard and compact ground such as, for example, tuff stone and sandstone, it may be necessary to connect a strong and sharp tool to the drilling pipe. This tool can be fabricated in any local metal workshop from leaf springs. The leaf spring which is normally available in a flat shape has to be modified to make it circular and fit to 1½"GIP by welding. Then, the tool needs to be further modified to have sharp spikes for example by grinding (Figure 45). The tool is then connected to the drilling pipe, which was used to the same drilling depth. While drilling with the attached modified drill bit, the driller should rotate the drilling pipe with the help of pipe wrench otherwise; the bit will be stuck to the hard rock, which could result in drudgery and waste of time in bringing back to normal drilling condition.

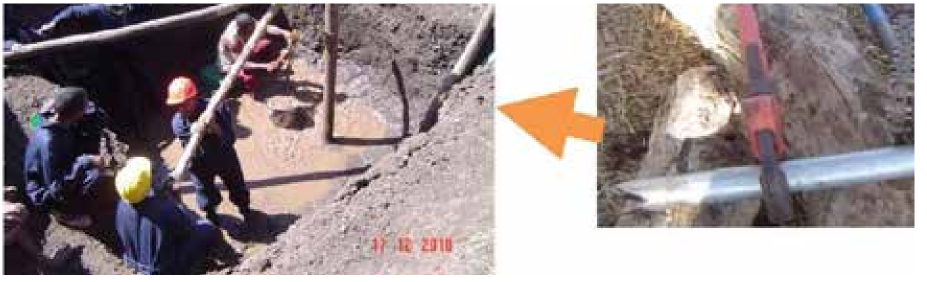


Figure 45: Use of Additional Tools for Hard Formation

In general, this tool should be used only when such difficult situation is happening otherwise it is not advisable due to its high energy and labor requirements.

While drilling at deeper depths moving the lever arm requires more energy, in such situation to minimize the load exerts on the people who are operating the lever, additional weights (assigning one or more people to sit on the lever) on the lever is required (Figure 46).

Figure 46: The Need of Extra Weight at Deeper Depth

Step 10: 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 litres of cow dung (2 kg mixed with water) per m depth of drilling (Figure 47).

Figure 47: Use of Cow Dung (if required)

Step 11: 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 48).

Figure 48: Hanging the Drilling Tools while at Rest

5.6 Installation of Well Casing, Screen and Gravel Pack

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. If submersible or hand pumps are selected as water lifting device in the borehole, the casing should be extended to the whole depth of the borehole. However, as learnt from the manual tube well drillers from Sudan, installation of casing for suction centrifugal pumps, is not necessary extend to the whole depth of the borehole. Next to pump facility, well casing is the most important and expensive component in tube well development. Hence, by minimizing the length of casing material, the cost of well drilling per m depth could be small and affordable for smallholder farmers in Ethiopia. Accordingly, the well casing in simple sludge tube well drilling will not extend to the whole depth but up to a depth where the soil is identified as loose and fragile. Moreover, some portion of the casing will be perforated by machine drilling (Figure 49) to serve as a screen. Based on the soil sample record, in conjunction with perforated screen on the casing, mesh wire could be used.

Figure 49: Preparation of Perforated Screen at Local

The following are important steps in the process of installation of casing, screen and gravel pack:

Step 12: Determine Type of Casing Material and Required Diameter

The well casings 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. For example, low carbon steel or mild steel, unplasticized polyvinyl chloride (UPVC), etc.

In general, tube well casing could be made of steel or UPVC. However, in simple sludge tube well drilling, PVC casing of 4” having a wall thickness of at least 2.5 mm is recommended for the following reasons:

- The majority of smallholder farmers who are engaged in lift irrigation owned a 3” diesel or petrol pump.
- Thicker PVC casing can resist the shock while pump engine is running.
- It is available in local market with reasonable price.

Step 13: Determine the Length of Well Casing

The well casing length will be determined based on the soil samples collected during well drilling. Therefore, the casing should be extended up to a depth where no or less fine sand or silt is recorded. So fix the casing at the point where compacted clay, hard core or stone sample is collected. The length of the casing will be therefore equal to the depth of drilling where these samples are located.

5.6.1 Type of casing

There are three types of casing, namely, blind casing, screen casing and in combination of blind and screen casing on a single casing material. Blind casing is a type of casing inserted to the well without being perforated on its surface (Figure 50).

Figure 50: Blind Casing

Screen casing is a type of casing having perforation or slot on its surface to allow the entrance of water through the pores/perforation (Figure 51).

Figure 51: Slot and Perforated Screens (left to right)

Combination of blind casing and screen casing on a single pipe is the type of casing in which some part of the GIP pipe is left blind and some part is screened (slotted or perforated). The third option is advantageous in minimizing the number of sockets to be used in connecting the blind and screen casings. For example, if the total length of well casing identified only 6 m, it will be possible to have both blind and screen casing on a single GIP with standard length of 6 m (Figure 52).

Figure 52: Blind and Screen Combined in one Casing

5.6.2 Purpose of Screen Casing

Well screens serve as intake section of a well that allows water to flow freely into the well, prevents sand from entering with water and acts as a structural retainer to support the borehole in unconsolidated material. To accomplish its intended purposes, the well screen must be of efficient design i.e. it should allow the designed quantity of sand-free water into the well with minimum head loss.

Step 14: Determine Length of Well Screen

The length of screen shall be governed by the thickness of the water bearing strata (aquifer) and shall be sufficient to obtain the specified yield from tube well. To decide the length of screen (length of GIP to be perforated), the driller must know the thickness of aquifer with good water bearing materials, such as coarse sand or gravel. Then, the length of the screen (to be perforated) shall be 70% of the total thickness of aquifer. The thickness of aquifer can be obtained from litho logical log. Litho logical log is successive arrangement of each soil or cutting materials sampled during drilling.

For example, if 5 m depth was recorded with coarse sand mixed with gravel and the other 5.5m depth was fine sand, clay and silt from the total length of 10.5 m well casing, the length of the perforated screen shall be 3.5 m (=5 m*70%). Screening 6– 7 m beneath the water table in confined aquifer generally assures adequate year-round yield.

Step 15: Determine Perforated Screen Size (opening diameter)

The size of the openings (perforated) shall be such that the gravel or aquifer material is not allowed to block the open spaces. The size of the perforated screen openings shall be determined in such a way that finer fractions remain outside the screen. The perforated screen shall not be too wide to cause entry of the gravel and resulting in plugging. In most cases it is recommended that the diameter of perforations shall be 10 to 12 mm in diameter and the distance between the two adjacent holes shall be between 25 to 40 mm (Figure 53).

Figure 53: Type of Perforated Screen Casing

The perforated screen shall be installed by wrapping steel mesh over perforated steel pipe. Wire meshis flat structured interwoven wire that screens fine material that passes the gravel pack and could result clogging of the perforated casing. Use of wire mesh as screen for perforated casing is recommended especially when the soil in the potential water bearing aquifer is found containing fine materials (Figure 54).

Figure 54: Perforated Screen with Screen Wire Mesh

When you are using 4" PVC casing first refer to your drilling log and use a hacksaw to make slots in the pipe. For a 4inch screen, 6 parallel lines are drawn along the full length of the pipe. The spaces between the alternate lines should be about 4 – 5 and 6 – 7 cm (see drawing). The slots are sawn between 6 – 7 cm lines. The distance between the slots should be about one centimeter. Guideline: the length of the filter screen should be at least 3 m. The last 1 m of pipe has no slots. This is called the sump in which fine particles that enter the well screen can settle, without blocking the filter screen. The bottom is closed with a PVC cap or by cutting and bending the bottom of the PVC pipe.

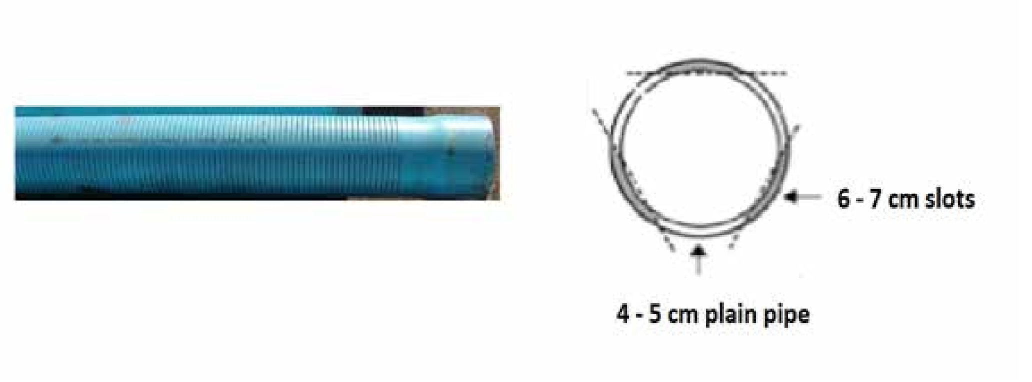


Figure 55: How to Make PVC Screen

After you prepare the filter screen, the sump and the casing, Lower the filter screen into the borehole. Then bell and glue the first PVC casing pipe to the screen, Lower the casing further into the borehole and More PVC pipes are added one by one depending on well depth.

5.6.3 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" diameter. The process of this borehole enlargement is commonly called reaming. Therefore, before installing the well screen the borehole shall be enlarged using appropriate reaming tools. For a tube wells drilled using 1½' " GIP and planned to install a 3" diesel pump, the following two reaming tools shall be prepared before starting reaming. Enlarging the diameter of the borehole is thus will help to install the casing easily and provide more space for gravel pack.

i) **Reaming Tool No. 1**

Cut 20 cm long GIP from 3" GIP. Then weld this piece of pipe to a 1½" GIP coupling/socket. This reaming tool will be connected to 1½" GI drilling pipe and used to enlarge the 1½" borehole to 3" borehole (Figures 56 and 57). The reaming steps will be the same as the drilling steps give in table 11.

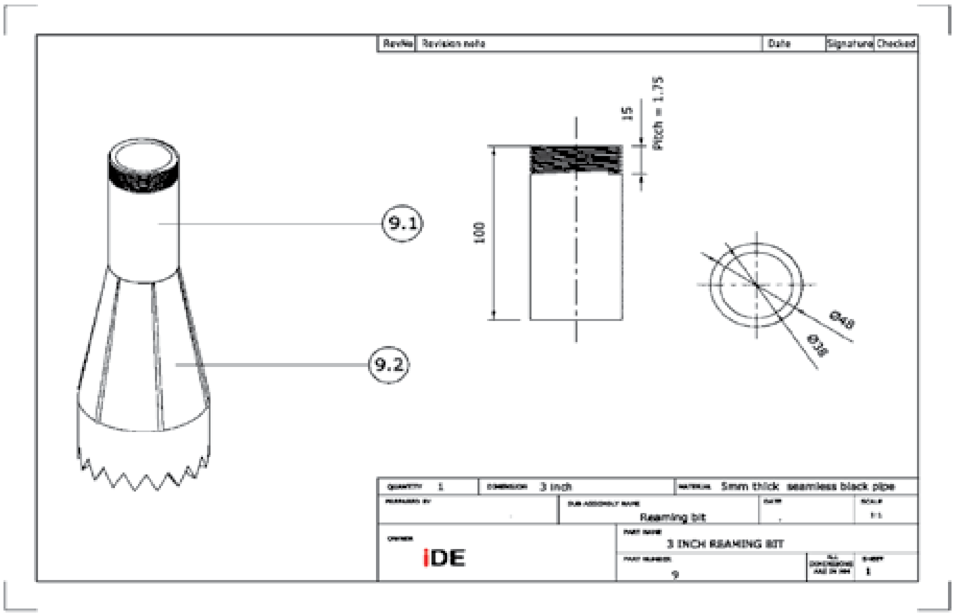


Figure 56: Reaming Bit (3")

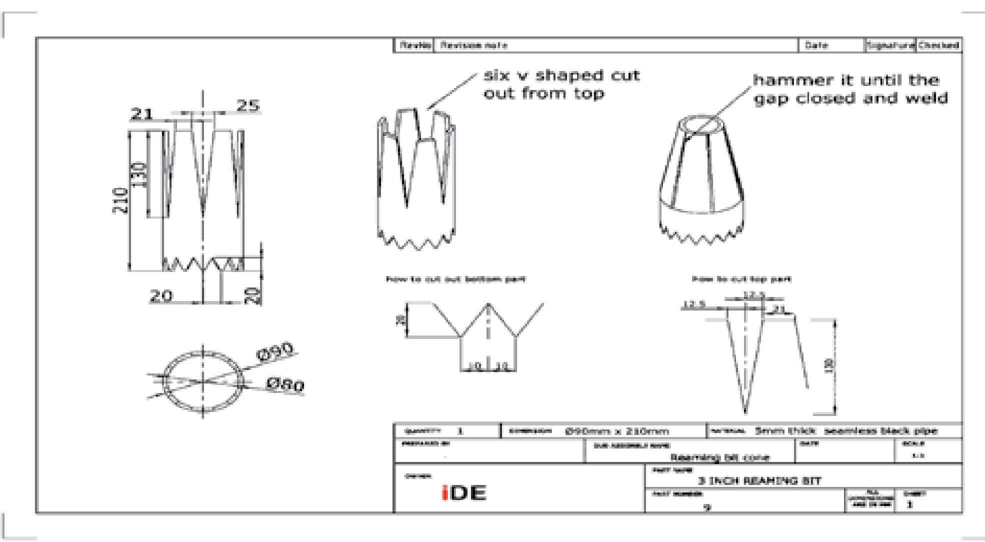


Figure 57: Detail Drawing (3" Reaming Bit)

ii) **Reaming Tool No. 2**

Cut 20 cm long GIP from 3" and 5" GIP and connect these two pieces by welding. Then, weld a 1½' GIP coupling with the 3" GIP. The tool welding arrangement from left to right will be: 5" pipe with 3" pipe and 3" pipe with 1½' Coupling. Then, connect the drilling pipe to the 1½' coupling and continue reaming until you reach to the required well casing depth (Figures 58 and 59).

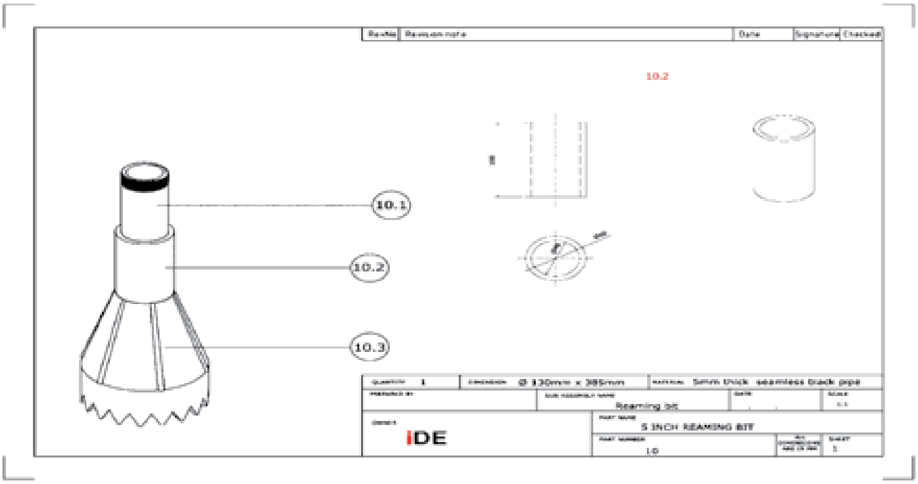


Figure 58: Reaming Bit (5”)

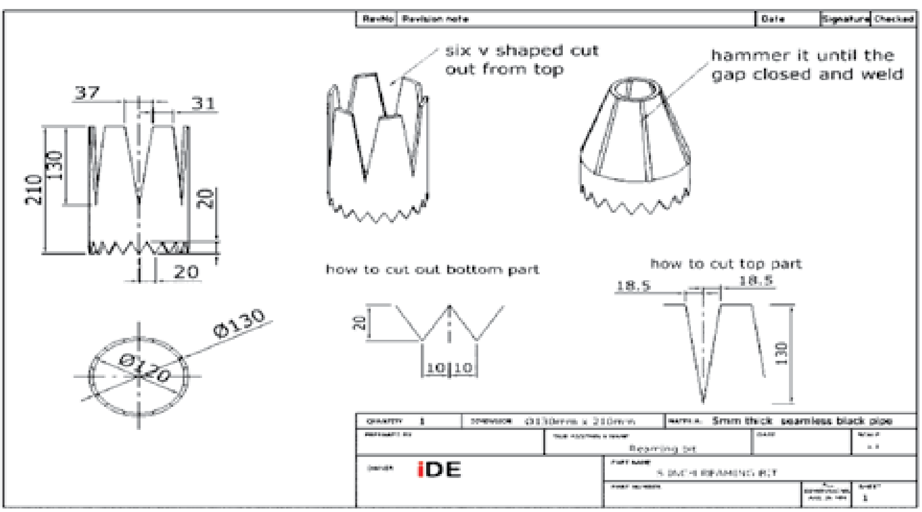


Figure 59: Detail Drawing (5” Reaming Bit)

If the tube well drilling is designed to use other water lifting devices other than diesel pump, for example hand pumps (Afridev, rope and washer pumps, etc.), submersible pumps, the reaming work shall be extended to the whole drilling depth since casing is also installed to the whole drilling depth. However, reaming with 5” diameter size over 20m depth might be difficult.

Step 16: Installation of Well Casing

Insure that the GIP casing pipes have standard thickness. Insure also that some portion of the GIP casing pipe is perforated and if required, wrapped with steel mesh wire.

Once the preparation of well casing is completed, the next step is installation. Since the tube well diameter is wider than the casing diameter (3”), the movement of the casing down wards will be high. Therefore, while installing the casing (inserting into the tube well) it has to be carefully tied to the drilling chain or rope and the drillers (may be two this time) have to firmly hold it with both chain and pipe wrenches. The lever operators should also pull down and push upwards the lever very slowly (Figure 60).

While installing 3" GIP casing

3" GIP casing prepared for diesel pump iistallation

Figure 60: Installation of Casing

Step 17: Flushing and Pouring Gravel Filter Pack

After the casing has been installed, try to flush the well by pouring water into the GIP 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 to the surface where it flows into the pump house floor. Then, remove all the mud and dirty water out of the pump house. Once it is observed that clean water is coming out to the surface, the washing can stop. Then, slowly pour the gravel into the annular space (the space between the casing and the well wall) and let it settle into the upward flowing water (Figure61). This is done by hand so that it is distributed evenly. At the same time there is a need of shaking the GIP 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 61).

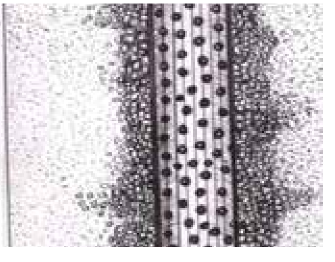


Figure 61: Pouring Gravel Pack

Gravel filter pack is the filling of the annulus space between the casing and opening of the well. The size of the gravel to be added depends on sample size of the material in the aquifer. If the size of the material in the aquifer is very fine one can use fine gravel, 4 – 6 mm. If the sample in the aquifer is medium to coarser you can use gravel with a sizes between 6 – 12 mm. The right grain size of the gravel pack is obtained by sieving the sand.

The gravel pack functions as a primary screen and prevents fine sand particles from being drawn in which could block the screen. A filter pack should be installed in all wells except those completed in rock, coarse sand or gravel. The gravel should be of a uniform size and shall be larger than the size of mesh wire openings. This is basically required to control the possibility of filter pack pumping. Well-rounded and uniform gravel from river deposits should be used as gravel pack since they will increase yield and allow for more effective well development

(Driscoll, 1986). Moreover, the gravel for use as pack shall be free from impurities, such as shale, mica, clay, sand, dirt, loam and organic materials.

Step 18: Deciding to Continue or Stop the Well Drilling Work

Once the well casing installation and gravel pack is completed, drilling work using the 1½" drilling GIP shall be continued according to the drilling steps given in table 11. However, the following two important questions shall be answered before continuing the drilling work:

Question 1: Why installation of casing is necessary before completing the well drilling work? Or why drilling is continued after installation of casing?

At many places of Ethiopia, the top 10 to 15 m depth of subsoil profile is mostly loose and fragile. It means that, if there is any disturbance for example well drilling in this zone, wall collapsing is inevitable. Therefore, installation of casing the top fragile portion is necessary and the well drilling work to deeper depth after installing the casing will be simple and consequently much labor and time could be saved. In general, where clay soils are found, it is often important to drill down and slightly into underlying rock to find significant quantities of water. A practical example is given in the box below.

Practical Case

The tube well drilling work (November 2010) in Adami Tulu Jido Combolcha Woreda, at Edo Gojela Peasant Association (PA), Oromia Regional State owned by individual household; Ato Tadele Tiko:

- The static water level was found at 8.5 m. A pump house 6 m depth having 3 by 3 m at the bottom and 4 by 4 m at the surface was excavated. Then 0.65 m perforated and 10.35m blind, total of 11mlong 3" GIP well casing was installed. The soil samples collected from this 11 m drilling depth was not sufficient for irrigation. Then after installing the casing, the drilling work was continued to a total depth of 37 m from the bottom surface of the pump house or 43 m from the ground surface. Then, diesel pump was installed and well discharge of 5.6 l/s was recorded.

Question 2: Is it always necessary to continue drilling after installation of casing?

Continuing drilling after installation of casing is not always necessary, if:

- the subsoil condition is found stable (not loose and fragile).
- 75% of the soil sample within 15 to 20 m drilling depth from the ground surface are found to be coarse sand, gravel or coarse sand with gravel mix, etc. (an indication for good aquifer –water bearing strata). A practical example is given in the box below.

Practical case

The well drilling in Shinile Kebele, Somali Region, the total depth of drilling was 10.5 m from the bottom of the pump house or 15.5 m from the ground surface (the depth of the pump house was 5 m). Drilling stopped at 10.5 m because 6mthick potential water bearing aquifer was recorded and after 10.5 m drilling depth the sub soil condition was hard rock. Hence, well drilling was completely stopped at 10.5 depths and finally a 10.5 long GIP casing (1.20 m perforated and 9.3 m blind) was installed. At this situation since the casing will stop at the foot of tube well, there is a need of closing the casing with available material such as wooden or plastic. For example, here was closed with the available cut material from a plastic bottle.

Moreover, careful soil sampling and observation to the drilling process can reveals one or more of the following signs indicating that a good water-bearing layer has been reached and drilling can be stopped:

- The cuttings may indicate that the drill bit has hit a zone of coarse sand and/or gravel (formations that usually produce abundant volumes of water if they are saturated). This is the most widely useful indicator and requires continuous, careful sampling of drill cuttings.
- Significant increase in the speed of the drilling pipes when a permeable sand aquifer is reached.
- When drilling into a gravel aquifer (which usually produce high volume of water), the gravel will often cause the drilling pipe to bounce (move or jump up and down repeatedly).
- Sometimes the drilling fluid (working water) suddenly starts to thin (containing less mud) and clear.
- There may be a noticeable drop in the level of drilling fluid. If a sub-surface formation is permeable (that can allow water to pass) enough to take water, it may also yield enough water for a well.
- The temperature of the drilling fluid in the drilling pipe becoming relatively cool.

5.7 Percussion Drilling

5.7.1 How Does It Work?

With percussion drilling a heavy cutting or hammering bit attached to a rope or cable 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. 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. A column of mud or a temporary casing is used to prevent the hole from collapsing in places where the top soil is not stable.

Manual percussion drilling technique is more effective up to depths of 25 m, but deeper wells are possible. Usually the weight of drilling bits can vary from 30 – 75 kg depending on the hard formation encountered. Percussion drilling can be combined with other manual drilling techniques such as simple sludge for better performance. This technique rapidly drills the first m(s) in soft formations until harder formations are found which require the use of the percussion technique and help to easily extract broken rock chips.

5.7.2 Where Does It Work?

Manual percussion is suitable for drilling in unconsolidated and consolidated formations: sand, silt, stiff clays, gravel, sandstone, laterite, weathered rock and fractured granite. Unlike any other manual drilling technique, it can drill through several types of rocks. Although percussion drills through hard or fractured rock formations, it is recommended to check your chances of success and do a few simple tests. If you find rocks in the drilling area, observe if they have a layered structure. A rock with layers, that breaks easily or crumbles when hit by a hammer, is a rock that you can drill through. Rocks that are solid and that will not chip may be difficult to drill through. This is the same for larger stones, or boulders. If there are many very large and solid rocks in an area, you can probably not drill. If you are not sure, try to drill the rock for at least a full day. If you can drill 30 to 50 centimeters a day, you are making excellent progress and it is worth continuing. If you encounter a large boulder, you can move your drilling a few m(s) in any direction and drill right past the buried boulder. In soil, the drill bit may only need to be raised 30 centimetres during drilling; in harder material a full m may be required. You do not need to lift and drop the bit very far to cut rock or soil. For example: a worker who is breaking stone is using a 7kg sledge hammer only lifts and drops it 1m. So when you are using a 45kg drill bit, you only need to lift the bit less than a m to cut stone.

5.7.3 How to Drill a Borehole by Combining Percussion with Simple Sludge

Step 1 Selecting and Preparing the Site

Select the site as per the site selection procedure indicated in Chapter 3 and clean the working area.

Figure 62: Site Preparation

Step 2 Drilling through Soft Formation using Simple Sludge

Set simple sludge drilling equipment as shown in section 5.3 and start drilling through soft soil formation until you will face hard formation. To avoid problem of well inclination use properly made drilling pipes and make sure that all your drilling pipes are straight and threads are made properly.

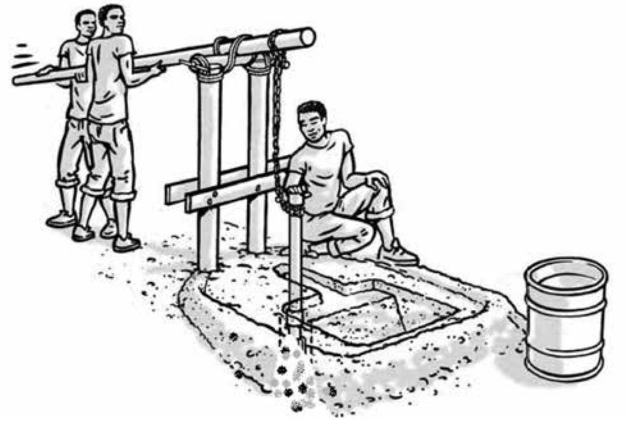


Figure 63: Drilling through Soft Formation

The following points may be indications for hard soil formation.

i) ***Bouncing pipe***

When your drill pipe starts to 'bounce' (jump) you have hit a hard consolidated formations, stone or a big boulder that is difficult or impossible to drill. You can recognize this by a change in sound (higher 'ping' sound) and less resistance during the rotation of the arm.

ii) ***No drilled material coming to surface***

Check if there is drilling material coming to the surface. If this is not the case, just keep drilling for a while and check the progress. If drilling deeper is not possible, it is better to try it with percussion.

Step 3 Reaming the Bore Hole

Percussion drilling bits have a diameter of 4 inch. As a result, a bore hole should be reamed to a diameter of 5 inch before we are using percussion and this will help the drilling bit to move up and down smoothly. Drillers should use 3 inch and 5 inch reaming bits step by step to come up with appropriate bore hole diameter for percussion.

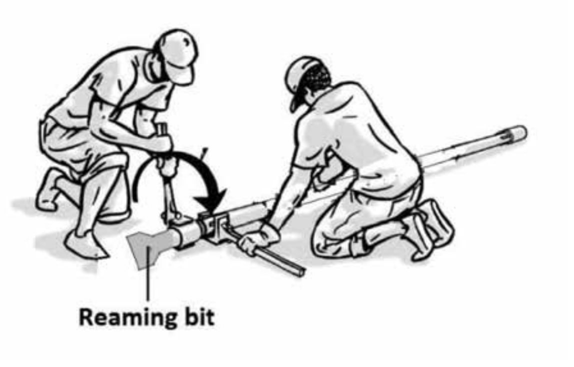


Figure 64: Reaming the Bore Hole

Step 4 Setup the Tripod

Connect the post to the upper plate having pulley on it and secure this pin. Put the rope through the pulley, Dig a hole and place the front post in the hole. Lift up the pulley and the front post and attach the 2 other poles to make a tripod. Dig 2 other holes and place the 2 poles in the holes. The tripod is now ready to use. Make sure that the distance between the 3 poles is equal to make the tripod stable.

Figure 65: Set-up Tripod

Step 5 Connect the Rope to the Percussion Drill Bit

Make sure that the tripod is centered and aligned with started hole by hanging small piece of metal rod having weight of at least 500g on the pulley. Properly tie a rope having a diameter of at least 18mm and length of 30m on a hook welded on the percussion drilling bit.

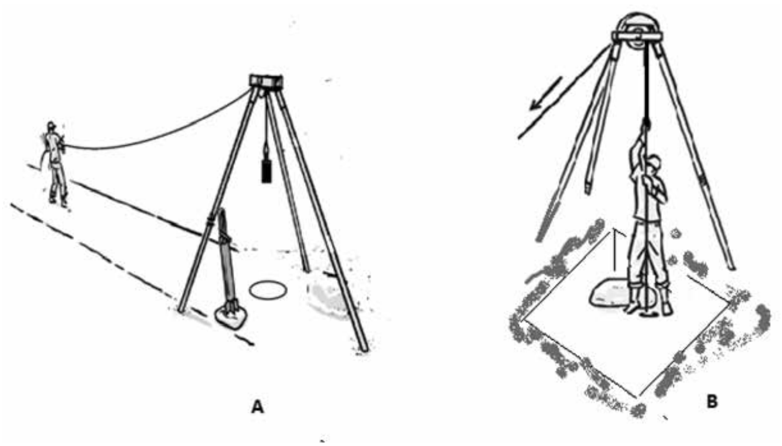


Figure 66: Centering Tripod

Step 6 Preparing to Drill

The team consists of 1 lead driller and 4 to 5 pullers (the number of pullers may increase depending on the weight of percussion and hard formation). The lead driller's job is to direct the pullers and gently guide the drill bit. The driller is standing under the tripod, facing the pullers. The pullers lift and drop the drill bit under supervision of the lead driller.

Remark

- Never let go of the rope and release it gently until it touches the bottom.
- If the drill bit is swinging, the bit can damage the edges of the hole. The driller needs to guide the bit gently back to the center of the hole.
- Walk towards the tripod until you feel a change in weight and the driller calls, "OK".
- Keep tension on the rope to prevent the bit to fall sideways. This can damage the walls of the hole and may cause well collapse.

Step 7 Starting to Drill

i) ***The drilling movement of the pullers***

Start with your arms in front of you, pull the rope until your arms are behind your waist and return your arms quickly to the start position so that the weight of the drill bit causes it to fall easily to the bottom of the hole. Repeat this cycle until the driller gives the signal to stop. Pull and release together at exact the same time and make sure that the drill bit is not slowed down by the weight of all the arms.

ii) ***The movement of the lead driller***

The lead driller should use both hands to gently guide the rope and keep the drill bit centered and not lifting or dropping the bit, which is the job of the pullers. Agree with the team on short 'commands' that you can give during drilling. For example: "Up" to lift the tool, "Down" to lower the tool, "Again" to lift and drop the bit or bailer, "Go easy" to reduce how high they lift the bit before dropping it, "All the way" to pull until the bit is out of the hole, "Stop" to tell that the bit has reached the surface.

iii) ***Drilling strokes***

A formation that is hard and compact needs more drilling strokes to drill through than fractured formations. Sometimes the bit may only have to be lifted and dropped 12 times, but in hard rock over 100 strokes may be required. As a result, the number of stroke can be adjusted by observing the progress and the recommended stroke height about 1m.

iv) ***Watch the progress***

It is advisable to make a mark on the rope before you do the first drilling stroke to watch the progress of drilling. Feel the impact and listen to the sound of the impact. If the impact is being absorbed and no more progress is made, you need to wash the borehole using simple sledging technique. Be careful that the drill bit does not get stuck in the soil at the bottom of the hole. If that happens it is better to use shorter strokes.

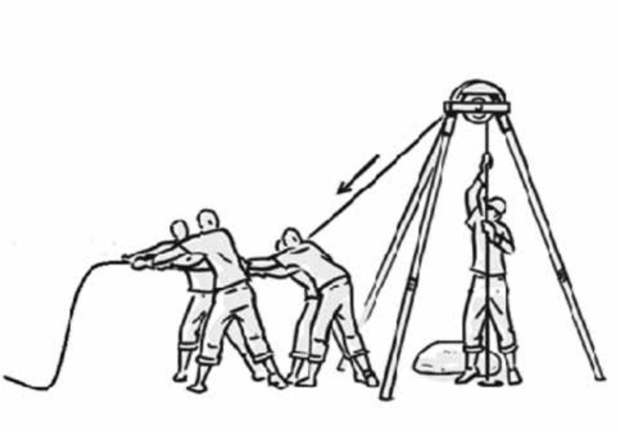


Figure 67: Drilling using Percussion

Step 8 Removing the Drill Bit and Extract Broken Rock Chips

Pull the rope slowly and watch the bit come up the hole. When you pull too fast, there is a risk that the drill bit can damage the tripod and pulley or injure the driller and remove the drill bit. After removing the drill bit insert the simple sludge drilling equipment into the bore hole and wash the broken pieces until you feel water without chips on your hand. Repeat this cycle (drilling and washing) until your reach the water table.

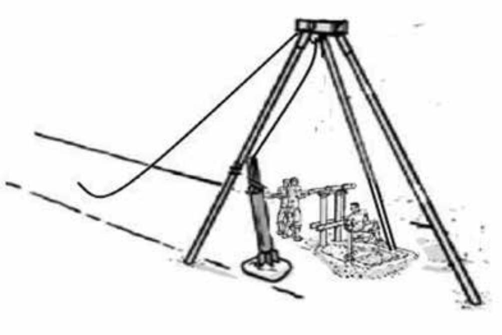


Figure 68: Drilling using Simple Sludge and Percussion in Combination

Remark

Don't forget to take a sample of the drilled soil, every time you washed the bore hole.

Figure 69: Taking Samples

Step 9 The Final Steps

i) Measure the depth of drilling

Generally, the final depth of drilling is reached when you have drilled at least 4 m into a coarse layer of sand/ gravel. Only continue with the next steps if you have reached the final depth of drilling and Measure the exact depth of your borehole. This gives you information on the total length of casing pipes needed.

Figure 70: Measuring Depth

ii) Making screen and installation of the PVC casing

Refer to your drilling log and use a hacksaw to make slots in the pipe. For a 4 inch screen, 6 parallel lines are drawn along the full length of the pipe. The spaces between the alternate lines should be about 4 – 5 and 6 – 7 cm (see drawing). The slots are sawn between 6 – 7 cm lines. The distance between the slots should be about one centimetre. Guideline: the length of the filter screen should be at least 3 m. The last 1 m of pipe has no slots. This is called the sump in which fine particles that enter the well screen can settle, without blocking the filter screen. The bottom is closed with a PVC cap or by cutting and bending the bottom of the PVC pipe.

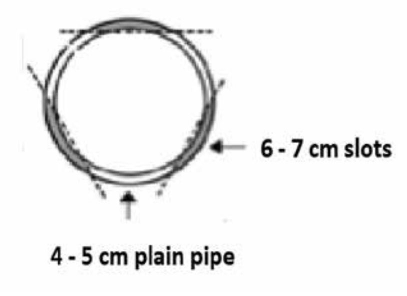


Figure 71: PVC Casing

After you prepare the filter screen, the sump and the casing, Lower the filter screen into the borehole. Then bell and glue the first PVC casing pipe to the screen, Lower the casing further into the borehole and More PVC pipes are added one by one depending on well depth.

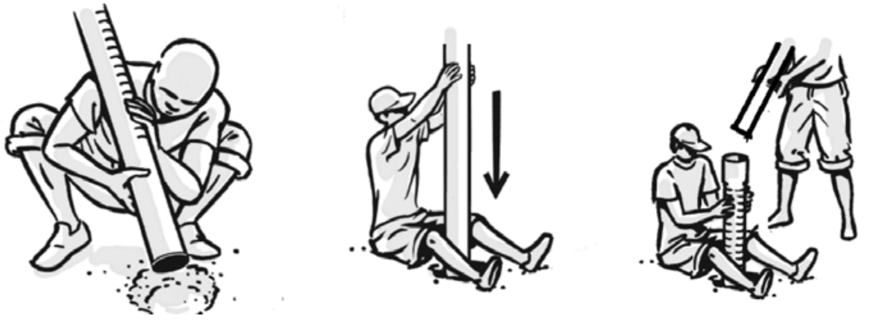


Figure 72: Installation of PVC Casing

Remark

Always make sure that one person is holding the casing to prevent it from dropping into the borehole.

iii) Cleaning the well and the screen

When the casing and screen is installed, the borehole and screen are now further cleaned: Drain the dirty water away from the mud pits. Then pour clean water into the casing and allow dirty water to overflow the borehole. Only when clean water comes out of the borehole, the cleaning is finished and the gravel packing can start.

Figure 73: Cleaning Well and Flushing

iv) Gravel packing

Coarse river sand in the range 1.5 – 3 mm is used as a gravel pack. The gravel pack fills the space between the borehole wall and the filter screen. It may also serve to filter some of the fine sand particles from entering the well. Use a minimum and a maximum sized sieve to prepare the 'gravel'. The gravel pack is now poured in the annular space around the pipe. At the same time the PVC pipe is moved from side to side to guarantee an easy passage for the gravel down to the screen. Pour in the gravel slowly, to prevent bridging (gravel getting stuck at the wrong level). Use the measurement tape or tool to measure the depth to the top of the gravel and fill to 1 – 2 m above the top of the well-screen. In fluid drilled holes, water will overflow from the PVC casing pipe, as the gravel is dropped around the well-screen. Water will stop overflowing the PVC casing pipe when the entire length of the well-screen has been backfilled.

Figure 74: Gravel Packing

v) Well development

'Well development' is necessary to maximize the yield of the well and optimize the filter capacity of the gravel pack. This is achieved by removing the fines and drilling fluid additives, and settlement of the gravel pack. Therefore it very important to develop well before installation as discussed in section 5.9.

vi) Leaving the well behind

When the drilling is finished and you are leaving the site, remember to cover the PVC casing. This can be done with a PVC cap or plastic bag tightly wrapped with inner tube. It is needed to assure that nothing can be dropped into the well.

Figure 75: Covering PVC Casing

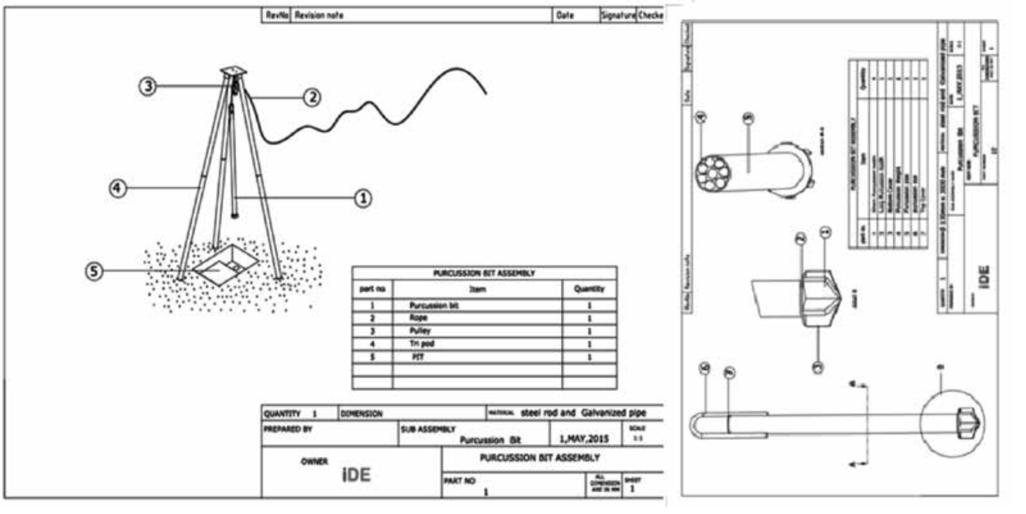


Figure 76: Percussion System Drawing

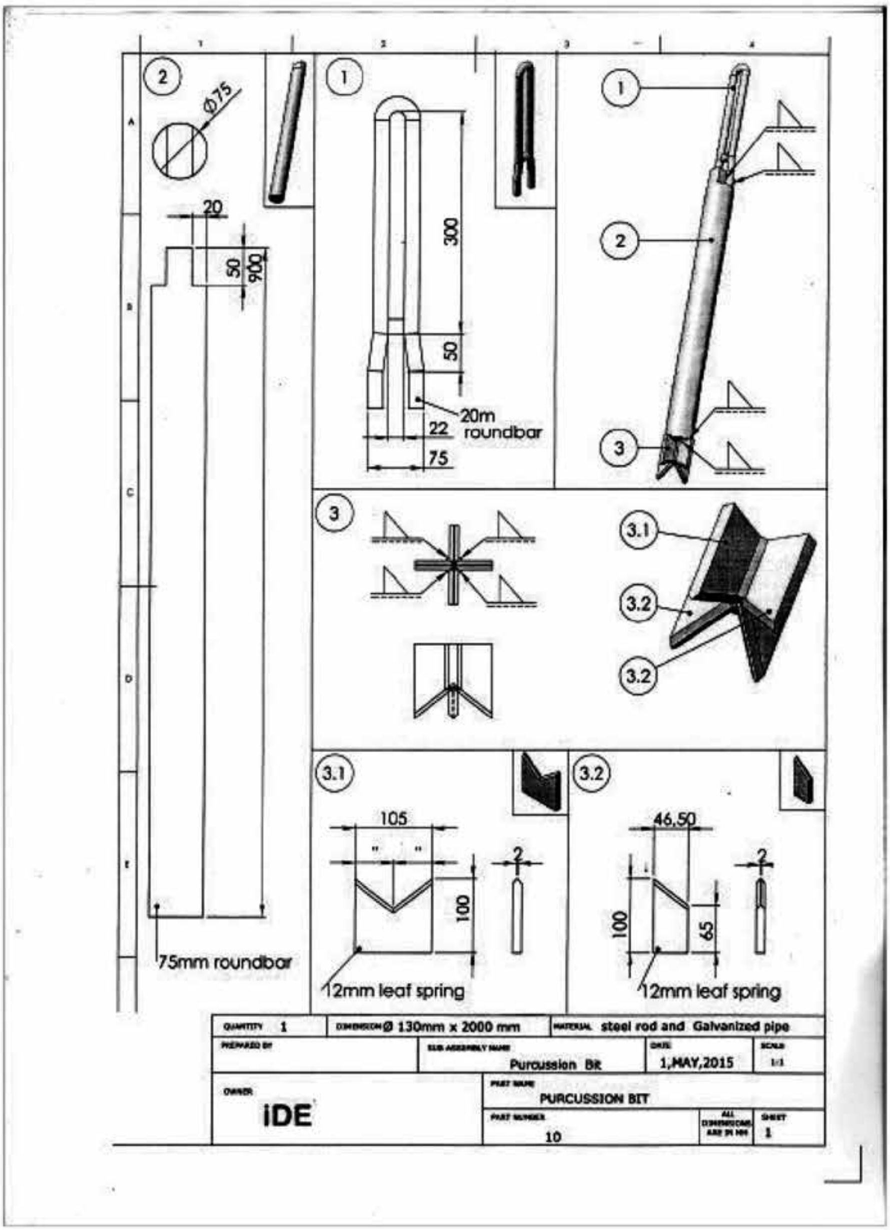


Figure 77: Detail Drawing of Percussion Drilling Bit

5.8 Installation of Centrifugal Suction Diesel Pump

5.8.1 Description

Centrifugal suction pumps are widely used by farmers in Ethiopia. Centrifugal pumps usually give efficient operation over a relatively wide range of operating conditions; because of its relative simplicity for maintenance and relative low cost as compared to pumps with the same discharge rate. The centrifugal pumps are suction pumps operating on the principle of centrifugal action. In a centrifugal pump, a motor or other driver rotates an impeller fitted with vanes immersed in water and enclosed in a casing (Figure 78). Water enters the case at the center and is immediately engaged by the impeller which is in rapid rotation; this rotation causes a flow from the center of the impeller to its rim or the outside of the case where pressure head is rapidly built up. To relieve this pressure, the water escapes through the discharge pipe. The centrifugal pump will not operate until the case is entirely full of water or primed. The need of priming is one of the disadvantages of the horizontal centrifugal pump.

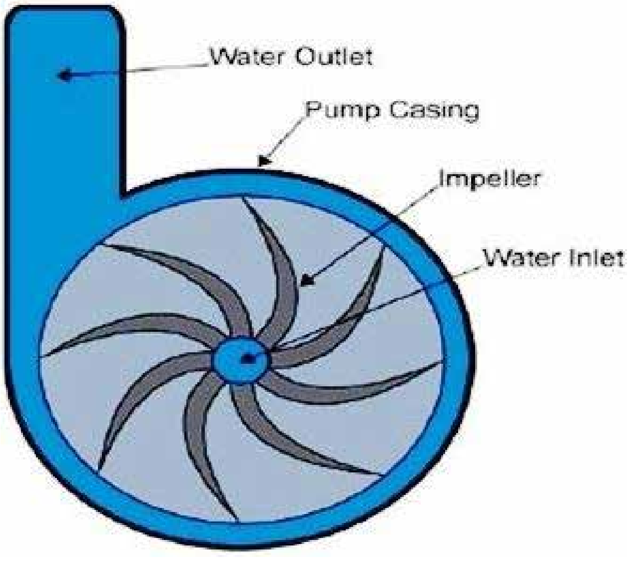


Figure 78: Horizontal Centrifugal Suction Pump

Suction lifts head of centrifugal pumps is theoretically 10 m but practically it is not greater than 6 m which depend on altitude, temperature, friction in the suction hose. However, for the purpose of this guideline, a net 2.5 m suction head from the bottom surface of the pump house is recommended. It means that, the static water depth from the center of the pump should be about 2.5 m or less.

5.8.2 Pump Installation

The 3” GIP installed as a casing will be used as suction pipe. However, unless modification is made, connecting this casing with the pump will be difficult. Connecting using a 3” elbow can make the work simple but there will be more head loss due to the friction that will be exerted on the curved elbow. A short elbow should never be bolted directly to the suction opening of a pump. Sharp bend so near the pump inlet causes a disturbance in the water flow and may result in noisy operation, loss of efficiency, and heavy end thrusts. This is particularly true when the suction lift is high, Therefore, to avoid this problem, prepare from any metal workshop the following material to enable connect the pump safely to the well casing.

Cut 20 cm long GI reducer pipe from 2” GIP pipe. Then, weld this 2” and 20 cm long GIP inside one side of the 3” GIP coupling. While welding, care should be taken not to damage the teeth of the coupling (Figure 79).

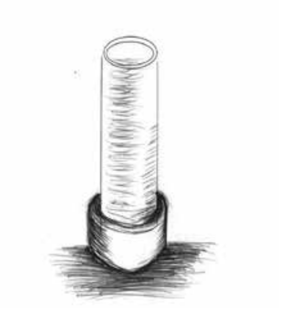


Figure 79: Hose Connector (Reducer)

Figure 80: Process of Pump Installation (heating PVC for ease connection)

Prepare 1 m long flexible 3” suction pipe and insert the reducer (2” GIP hose connector) to one end of the pipe. Fix the suction hose coupling to the other end of 1 m long flexible suction hose. It is advisable to heat the hose and force fit into the 2.5” GIP (Figure80). If farmers owned for example a 4” diesel pump, the pump connector (reducer) can be prepared from 3.5” GIP and welded to the same 3” GIP coupling. Tighten both sides with hose clamp so that air will not leak and form cavitation.

In order to make the pumping system air and watertight during pumping, any pump part with thread shall be sealed with Teflon (Figure 81).

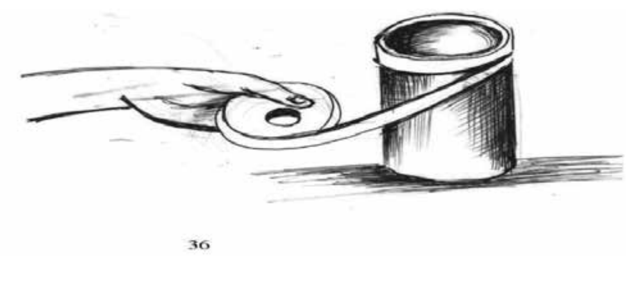


Figure 81: Use of Teflon for Sealing

Connect the 1 m long flexible pipe with reducer to the pump inlet and the delivery pipe to pump outlet (Figure 82). Use the same material for suction (1 m long with reducer) and delivery purposes. The length of the delivery pipe is recommended not to be less than 20 m. To avoid any water and air leakage though this connection, fasten firmly the 3” coupling using pipe wrench.

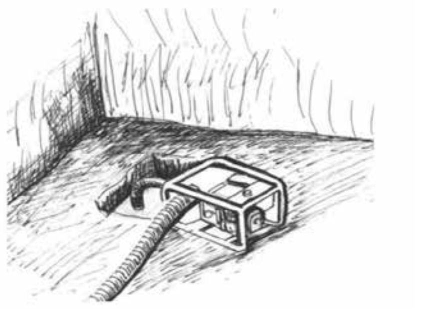


Figure 82: Pump Connected to In-Situ Casing

While installing the pump, check that the pump out let (delivery pipe) is in the direction of the access provided in the pump house and to the land to be irrigated (Figure 83).

Figure 83: Direction of Delivery Hose/Pipe

Whatever the pump is new or has been used before, don't start the pump before checking the level of fuel and motor oil.

5.8.3 Prime the Pump

It has to be remembered that starting a pump dry will cause seizing or destructive wear between the pump components. Therefore, pumps that are not self-priming or those with a positive suction lift should be primed before they are started. While deep well pumps, such as submersible pumps, are submerged into the water and have no need for priming, the well-known horizontal centrifugal pump usually needs priming. Priming is the process of removing sufficient air from the pump and the suction pipe so that the atmospheric pressure can cause the flow of water inside the pump.

The simplest way of doing this is to displace the air in the system by filling the pump and suction pipe with water. For this purpose, the pump casing is connected to the well casing (which serves as a suction pipe). The pump casing is filled with water when the system is operating. Before the system is switched on, the water from the tank is diverted to the pump and suction pipe via a valve. The pump must not be run unless it is completely filled with water; otherwise there is danger of damaging some of the pump components. Wearing rings, bushings, seals or packing and internal sleeve bearings all need liquid for lubrication and may seize if the pump is run dry.

5.8.4 Starting the Pump

Start the pump by closing the gate vale. This is because the pump operates at only 30 – 50% of full load when the discharge gate valve is closed. To avoid water hammer, the gate valve has to be opened gradually until it is fully open. Put the start plug on and pull the starting rope. By opening and closing the pump casing cover, try to remove air and/or gases trapped in the pump or entering the suction pipe. While doing so, one person should be assigned to close the outlet of the delivery pipe with his hand until he fills water is coming. If you succeed, record pump starting time and measure the discharge every 30 minutes for 8 hr per day for five days (Figure 84).

Figure 84: Pumping Test

5.8.5 Pump Malfunctions, Causes and Remedies (troubleshooting)

Following are some general causes of pump malfunctioning and their remedies that can be used for on-spot trouble-shooting when pump problems are encountered

Table 12: Pump Troubleshooting

Symptoms	Causes	Corrections
Failure to pump	Pump not properly primed	Prime pump correctly
	Speed too low or high	Check speed, check calculations, consult with manufacturer
	Not enough head to open check valve	Check speed, check calculations, consult with manufacture
	Air leak	Check and rework suction line
	Plugged section	Unplug section
Reduced perfor-mance	Air pockets or small air leaks in suction line	Locate and correct
	Obstruction in suction line or impeller	Remove obstruction
	Insufficient submergence of suction pipe	Check water level in the well
Drive overloaded	Speed higher than planned	Reduce speed
	Water too muddy	Raise suction
	Stress in pipe connection to pump	Support piping properly

5.8.6 Stopping the Pump

The first step is to close the gate valve. This eliminates surges that may occur in case of an abrupt closure. When this has been done, the prime mover is then closed or shut down. If the pump remains idle for a long time after it is stopped, it gradually loses its priming. Thus, the operator should re-prime the pump every time before start-up.

5.9 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.
- To alter the physical characteristics of the aquifer near the borehole and to enable the pore spaces and fractures to pass the water so smoothly to the well.
- To repair damages done to the formation by the drilling operation and improve the natural hydraulic properties.
- To create a graded zone of sediment around the screen in a naturally developed well thereby stabilizing the formation so that the well can yield sand free water.
- To increase permeability and storage.

The effective way to remove clay smear is to generate a strong back-and-forth flow of water between the well and the formation. Several development methods generate a back-and-forth flow. Method of well development is influenced by; the type of formation material, drilling method used, well recovery rate, well depth, depth to water, contaminants, purpose of the well, and other factors that only an experienced professional can determine. Commonly used well development methods include:

- Over pumping (continuous or interrupted over pumping)
- Surging
- Use of compressed air
- Hydraulic jetting
- Hydraulic fracturing
- Use of explosives

All methods listed above are important in the process of well development. However, in this guideline it is only recommended over pumping and back washing well development methods since others require more sophisticated commercial equipment, specialized training and are usually used in developing large capacity wells.

5.9.1 Over Pumping

The continuous over pumping method of well development is accomplished by uninterrupted pumping at pumping rates up to 1½ times the design capacity of the well, while, the interrupted over pumping method of well development is done with a pump capable of pumping at rates up to 2 times the design capacity. The pumping should be carried out in at least 5 steps. These steps should include pumping rates of 1/4, 1/2, 1, 1½ and 2 times the well design capacity, with no check valve nor foot valve present. Pumping should be conducted in 5 minute cycles, and should continue a minimum of 2 hours or until such time as acceptable standards are attained.

During over pumping, the groundwater moves from the aquifer into the well in order to replace the pumped water in the meantime, the water would bring undesired finer materials from the aquifer through the gravel pack and the screen which can be removed from the well by repeating the over pumping. The method is more appropriate to wells that produces small amount or water since it is easier to remove most of the water by over pumping. For wells that produce higher amount of water, high capacity pump required to apply this technique.

5.9.2 Back Washing

It is a development technique applied by filling the well with water and forcing it to flow back out of the well through the screen by any appropriate method. The basic of all well development method is to carry activities that will make it easier for water to reach the pump suction (Figure 85).

Figure 85: Well Casing Situation at Well Development Time

5.10 Pumping Test

5.10.1 Principle and Procedure

In hydrogeology, a pumping testis a controlled field experiment in which a well is pumped at a controlled rate and water-level response (drawdown) is measured in one or more surrounding observation wells and optionally in the pumped well (control well) itself. Aquifer test and aquifer performance test (APT) are alternate designations for a pumping test.

Pumping test or pump test? Although pumping test and pump test are often used interchangeably, pumping test is the preferred term (Anderson and Woessner, 2002). If you are testing the performance of a pump, use pump test; if you're testing the performance of an aquifer through the action of pumping a well, use pumping test

Pumping test can be doneas 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:

= /

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

Where:

Q	pump flow rate in lpm
V	volume of container (litres)
T	time taken to fill the given container
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.

5.10.2 Estimating Specific Capacity of a Tube Well

The Specific Capacity of a well is simply the pumping rate (yield) divided by the drawdown (Figure 86). It is a very valuable 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.

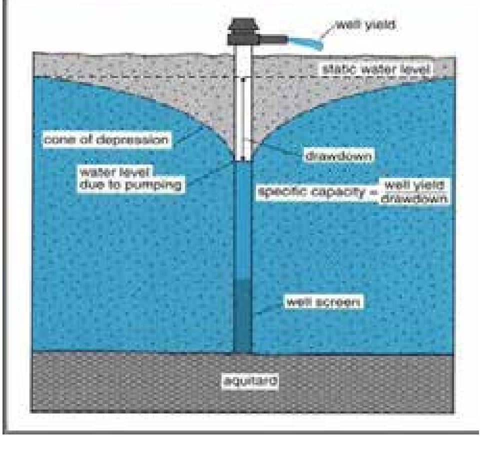


Figure 86: Groundwater Situation during Pumping

It can also be used to estimate the transmissivity of the aquifer(s) tapped by the well's perforations. Transmissivity is the rate water is transmitted through an aquifer under a unit width and a unit hydraulic gradient. It equals the aquifer's hydraulic conductivity (permeability) times the aquifer thickness. The higher the transmissivity, the more prolific the aquifer and the less drawdown observed in the well.

Typically, a well should run continuously for at least 24 hours at a constant yield before recording the drawdown (Driscoll, 1986). Shorter periods are sometimes used example 1 – 4 hour test for pump efficiency tests or step-drawdown tests, but these shorter times may not sufficiently allow the water levels to stabilize for a reliable specific capacity calculation, see example below.

Example: 3: Calculate the Specific Capacity
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):
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

Example: 3: Calculate the Specific Capacity
Test type = diesel pump
Test length = 8 hour
Total draw down = 1.5 m

The Specific Capacity obtained just after a well is drilled and properly developed is typically the highest value that will be produced and is the benchmark with which to compare all future values. As time goes by, the specific capacity will decline as plugging of the well's perforations or filter pack occurs, as the pump starts to fail, or as static water levels change. Specific capacity tests should be performed at least twice a year and water levels (static and pumping) should be recorded monthly to provide early detection of potential well problems. Rehabilitation work should be done when specific capacity drops by 25% (Driscoll, 1986).

5.10.3 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

The following shows the yield and SWL in Precambrian aquifers in some parts of Ethiopia (Tamiru, 2006) (Table 13).

Table 13: Groundwater Yield and Static Water Level in some parts of Ethiopia

S/N	Locality	Yield (l/s)	Static Water Level
1	Moyale	14	15
2	Mega	2	17
3	Between Mega and Moyale	3.3	40
4	Yabello	0.8	36
5	Between Mega and Yabello	1.1	21
6	Konso	6.0	42
7	Negele	3.1	4
8	Between Yabello and Negele	1.4	5.2
9	Harekelo	0.8	34
10	Kibre Mengist	5	3
11	Metu	2	28
12	Between Nejo and Mendi	10	5.5
13	Mankussa	2	15
14	Harar	1.8	7.3
15	Babile	3	9
16	Humera	5	30
17	Shehet	0.3	28
18	Turmi (dug well)	-	12
19	Weyto (dug well)	0.9	-
20	Jinka (dug well)	-	5
21	Sawla	5	50

5.10.4 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.

5.11 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 centrifugal suction pump are discussed as follows:

5.11.1 Excessive Drilling Fluid Loss

A large amount of drilling fluid is usually required every day before starting drilling work. This is important because drilling fluid sometimes suddenly flows into permeable formations inside the drilled hole and results in low volume of water used for conveying cutting to the surface through the drilling pipes. Therefore, if return circulation is suddenly lost, immediately pull-up the drill pipe 1– 2 m from the bottom of the borehole so that it is less likely to become jammed if the bottom portion of the hole collapses.

Then, add more water mixed with cow dung or clay and allow it to settle inside the wall of the borehole for some minutes. For thickening the drilling fluid, bentonite (6 – 7 kg/l) instead of cow dung or clay can be used, however, the accessibility is a limitation for not to be recommended in this guideline. When you think the mix is ready to circulate back down the hole, start the drilling work rapidly and try to pass that depth where wall collapse (caving) is expected to happen.

If thickening the drilling fluid by adding cow dung or clay and waiting some minutes to settle the drilling fluid do not solve the problem of drilling fluid circulation, ask yourself why the circulation is lost. The possible reason could be you have reached to highly permeable saturation formation, and it may be possible to get a well with high yield. Therefore, install your diesel pump and test the well yield. If the problem is not solved, consult specialists.

5.11.2 Drilling Pipe Jamming

The drill pipe may become jammed when the drilling fluid is not allowed to thoroughly clean the borehole prior to stopping to add another joint of drilling pipe or the fluid is too thin to lift gravel from the bottom of the borehole. Therefore, if the drilling pipe starts to catch when drilling, stop further drilling and allow the drilling fluid to circulate and remove accumulated cuttings from the borehole. Then continue to drill at a slower rate. If it continues to catch, thicken the drilling fluid as it was discussed earlier.

5.11.3 Objects Dropped into Well

If care has not taken in advance during drilling, rocks, drilling pipe, working tools such as pipe wrenches, etc. could dropped into the borehole.

If objects are dropped into the borehole after the final depth has been reached, it may be possible to leave them there and still complete the well. If this is before reaching to the final depth of drilling, it may be possible to make a “fishing” tool to set-up on the lost gear. However, for “fishing” exercises there is no single right way of doing this work, but require innovation to solve the problem in the right way on the right time.

Even if the lost tools or drill pipes are important and the effort of fishing is not succeed, just move over and start drilling a new hole. By doing so considerable time can be saved since there is a low likelihood of success in fishing.

5.11.4 Encountered Hard Rock Bed

This problem would be much serious problem in the case of manual tube well construction with centrifugal diesel pump water lifting device. This is because additional labor and time has been spent in the excavation of pump house. Therefore, while selecting site for this type of manual drilling method care should be taken to understand the subsoil condition and should be able to identify the right drilling tool or tools in combination.

Moreover, if the subsoil condition found hard or rock formation and the drilling pipe starts bouncing and the rate at which the drill pipes penetrating the formation drops dramatically, decide on one of the following options:

i) Prepare a drill bit from strong material and try again the drilling process. If this work takes too much time with no or very small drilling depth, go for the second option.
ii) Try the drilling work by locating one or more points inside the pump hose.
iii) If second option similarly fails and however, the construction of tube well by manual drilling (simple sludge) method is recommended, abandoned the pump house and try it outside the pump house in another site.
iv) Then, if not succeed in both cases as explained above, try the drilling work with simple sludge in combination with percussion tools.

5.11.5 Fishing when the Bit has dropped

Sometimes the drill bit has dropped in the hole because the rope around the rope was broken or the driller was not paying attention when tying the bit. When the drill bit has fallen back into the borehole, it needs to be recovered very quickly to overcome problem of serous stacking due to silt. In such case Buy a chain hook or bend a hook (make it so that the hook will fit the inside of the top of the bailer) out of 12mm round bar. Attach the hook to a rope. Lower the hook in the borehole to 1 m above the bottom of the hole and try to find the bit. In case it is difficult to pull the bit using human labor it is advisable to use three Ton chain block.

5.11.6 Artesian (flowing well) Well Encountered

Water in a confined aquifer is under so much pressure that it will flow out the top of a well which is drilled into it. Special precautions and construction techniques must be used to control the water pressure and flow or serious environmental problems can result.

The free flow of excess water can result in the depletion of a valuable water resource and free flow from the well casing can cause serious soil erosion and flooding problems on the adjacent farm fields. Extending the well casing above the ground surface into the air by estimating the piezometric head can improve the problem and a pump can be installed after if the pressure in the pipe drops over time.

5.11.7 Marginal Aquifer Encountered

The possibility of getting a very thin or relatively impermeable aquifer is high in some parts of the country, for example, Libo Kemkem woreda, Amhara regional state. In this situation, ensure that the borehole penetrates the full thickness of the aquifer, extending as far below it as possible. Install the well screen adjacent to the entire aquifer thickness with blind casing installed above and below it. After developing the well, install a hand pump instead of motor pumps.

If a well is being completed in a fine sand/silt aquifer within 15−22 m (50 −75 ft) of ground surface, use larger size reamer say 6− 8” . This will help to install a better filter pack and reduces entrance velocities and passage of fine silt, clay and sand particles into the well. In this case larger capacity pumps such us motor pumps can be installed.

5.11.8 Decreased Well Yield

A well can suddenly no longer provide the same amount of water as it did before. If you start the pump and water is flowing at low rate or no water comes out, the well may be dry. Confirm this by measuring the water level in the well and try to determine which of the following causes are responsible:

- Natural lowering of the water table: Water levels experience large fluctuations due to climatic conditions.
- Well interference: The construction of water and sewer mains, drainage ditches and

highways (road cuts) can occasionally affect ground-water levels and interfere with nearby shallow wells. In addition, the static water level in a well may be affected by large withdrawals of groundwater from nearby large capacity pumping wells.

- Screen blockage: the well screen might be blocked with fine sand and silt particles.

5.12 Safety issues on Manual Water Well Drilling WorK

Attention and good working habits during tube well drilling can reduce errors that lead to accidents and/or injury. The following errors can be mentioned as a cause for many injuries and/or accidents during manual tube well installation period:

- Excavating the pump house with wrong side slope may result collapse of pump house while people are engaged in drilling work.
- Mismanagement of drilling fluid and cause slippery on the access provided in the pump house and the drilling crew may fall and broken.
- Miscommunication between the driller and people working on the lever may cause injury to the driller while the driller is connecting and disconnecting drilling pipes.
- Worn loose clothes and prone to catch sharp or moving drilling tools and equipment.
- Working without protective clothing, helmet, glove, working cloth and boots, etc.

5.13 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 C):

- 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

CHAPTER 6

WATER LIFTING AND IRRIGATION SYSTEM DESIGN

6.1 Water Lifting Devices

Water-lifting device are used to withdraw water from surface (lakes, rivers or reservoirs), groundwater sources (HDW or drilled wells) and underground reservoirs, or to pump water in irrigation systems.

According to International Center for Irrigation Development, Lift irrigation is a method of irrigation in which water instead of being transported by natural flow (as in gravity-fed canal systems) requires external energy through animal, fuel based or electric power using pumps or other mechanical means.

The heart of most lift irrigation systems is a pump. To make an irrigation system as efficient as possible, the pump must be selected to match the requirements of the water source, the pumping system and the irrigation equipment. This section is therefore, presents classification, selection, installation, operation and maintenance of pumps more suitable for lifting water from tube wells.

6.1.1 Definition and Classification of Water Pumps

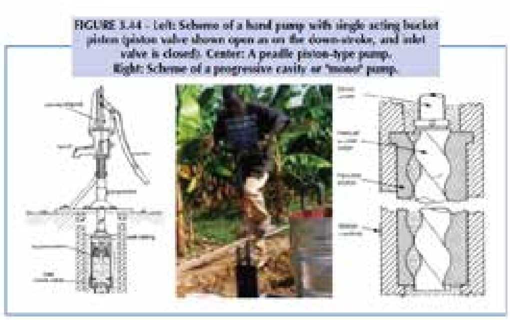
Pumps are mechanical devices which convert mechanical energy supplied to them into hydraulic energy, thus lifting liquid from a lower level to a higher level. Almost all pumps increase the pressure energy of the liquid which is subsequently converted into potential energy as the liquid is lifted from a lower level to a higher level.

FAO, Technical handbook on pressurized irrigation techniques (A. Phocaides, FAO Consultant, ROME, 2000) classifies Pumps and lifting/propelling devices on the basis of the mechanical principle used to lift the water: direct lift, displacement, creating a velocity head, using the buoyancy of a gas or gravity. Most categories sub-divide into further classifications “reciprocating/cyclic” and “rotary”. The first of these relates to devices that are cycled through a water-lifting operation (for example, a bucket on a rope is lowered into the water, dipped to fill it up, lifted, emptied and then the cycle is repeated); in such cases the water output is usually intermittent, or at best pulsating rather than continuous. Rotary devices were generally developed to allow a greater throughput of water, and they also are easier to couple to engines or other mechanical drive.

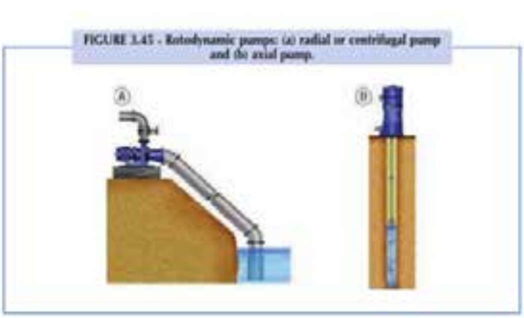
Virtually all water lifting devices can best be characterized for practical purposes by measuring their output at different heads and speeds. Normally the performance of a pump is presented on a graph of head versus flow (an H-Q graph) and in most cases curves can be defined for the relationship between H and Q at different speeds of operation. Invariably there is a certain head, flow and speed of operation that represents the optimum efficiency of the device, i.e. where the output is maximized in relation to the power input. Some devices and pumps are more sensitive to variations in these factors than others; i.e. some only function well close to a certain design condition of speed, flow and head, while others can tolerate a wide range of operating conditions with little loss of efficiency.

A. Direct-lift devices

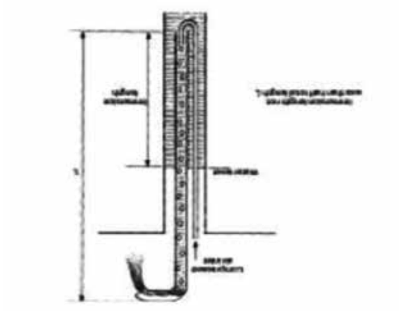
B. Displacement Pumps (Hand/Pedal Type)



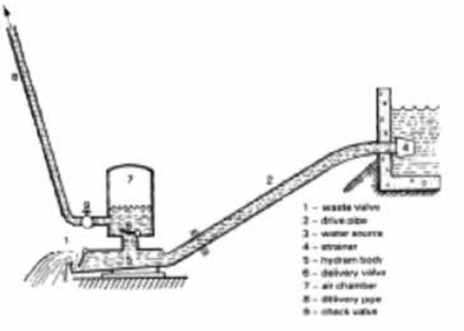
C. Velocity Pumps (Roto Dynamic Pump in Parallel– Centrifugal and Axial)



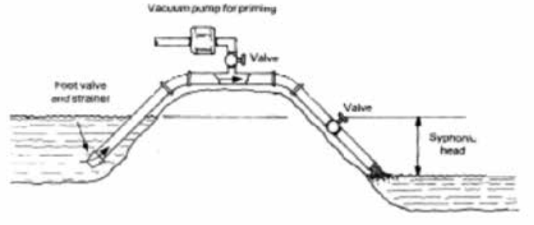
D. Air-Lift Pumps



E. Impulse (water hammer) pumps – e.g. hydraulic ram pump or “hydram”



F. Gravity Devices e.g. Syphons



6.1.2 Pump Selection

For extracting water from tube wells different type of pumps can be used based on farmers’ interest in combination with some technical and economical aspects. Before selecting an irrigation pump, a careful and complete investigation of the conditions under which the pump will operate must take place. The investigation must include:

- The source of water (well, river, pond, etc.)
- The required pumping flow rate and command area
- The total suction head
- The total dynamic head

Thus a pump must be selected to match the requirements of the water source, the water piping system and the irrigation equipment. Various source of power for the pump are used like wind energy, solar energy, human, animal, diesel, gasoline and electric. The kind of power or drivers used to pump or lift water depends on cost, availability and the amount of water to be pumped.

By considering farmers' interest and capacity, farmers that do not have, or cannot afford an adequate supply of mechanical energy or if their well yield is very small (up to 0.5 l/s) they may use human powered pumps such as hip pump, rope and washer pump, AFRIDIV, etc. The discharge of hand pumps is however; low thus require efficient irrigation systems like use of drip irrigation that save water and labor. On the other hand if the yield of well is good or more water is going to be pumped to higher elevations, then motor pumps can be chosen. Gasoline, diesel, or electric driven engines might be used as source of power. For extracting water from tube wells 5 hp or less capacity motor pumps are recommended for use in small groups or at the household level.

Accordingly, hand pumps (AFRIDEV or Rope pump), suction diesel/petrol/gasoline or submersible pumps driven by electric/solar/generator can be considered as option for use in tube well irrigation.

6.1.2.1 Rope and Washer Pump

Rope and washer pumps are lift pump types used to lift small quantities of water manually. It consists of PVC pipe and rope with knots or a chain fitted with discs, spaced at regular 1 m intervals. The diameter of the knots and discs is nearly the same as that of the delivery pipe in which the rope or chain travels. The lower end of this pipe is immersed in the water to be pumped. The chain is driven by a wheel and a crank. As each knot or disc rises, it traps a little water in the pipe. For tube well they can be installed at the ground surface i.e. no need for excavating pump house. The water is discharged into a channel placed at the top of the delivery pipe to a container or with some special modification; the water might be delivered in to reservoirs. These pumps can be made by local people at local metal workshop (Figure 87). Installation, operation and maintenance of rope and washer pump are given in Annex I.

Figure 87: Rope and Washer Pump

During Rope pump PVC size determination, consider the depth of the water level in the well.

Table 14: PVC Diameter vs. Static Head

Static Head (m)	PVC Inner Diameter (mm)	Practical Case Recommendation (inch)
5 – 10	32	1
10 – 20	25	¾
20 – 35	20	½

* *Recommended by PRACTICA Foundation (2010)*

6.1.2.2 AFRIDEV Type Hand Pump

The AFRIDEV Pump is a conventional lever action hand pump. The configuration includes an open top cylinder, i.e. the piston can be removed from the cylinder without dismantling the rising main. The foot valve is retractable with a fishing tool. The riser pipes are made of u-PVC. The pump rods are stainless or mild steel with hook and eye connectors, allowing removal without tools. This pump is corrosion resistant in the stainless steel rod configuration (Figure88).

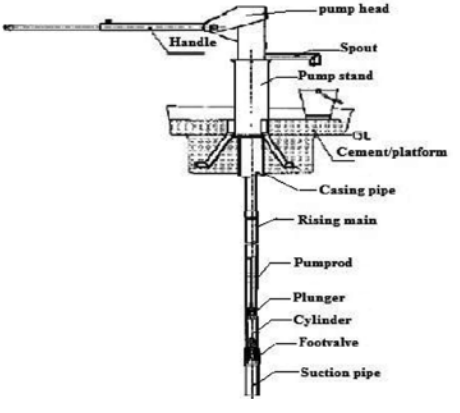


Figure 88: AFRIDEV Type Pump

6.1.2.3 Solar Pump

Solar well pump is water lifting device that uses solar as its driving energy, it is climate smart technology and less operation cost compared to other lifting devices. In addition, it saves labor and it gender responsive: It can be installed at vicinity of residence (Figure 89).

Figure 89: Solar Panel

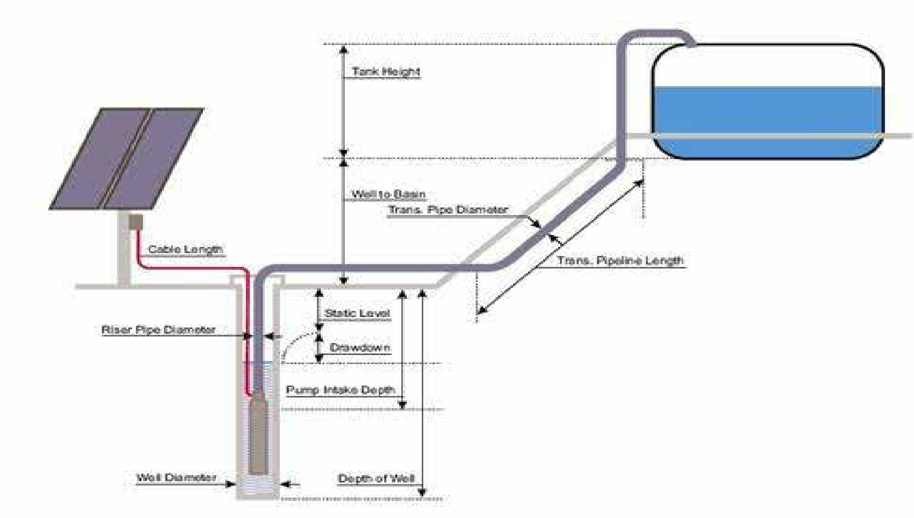


Figure 90: Solar Pump with Complete Set

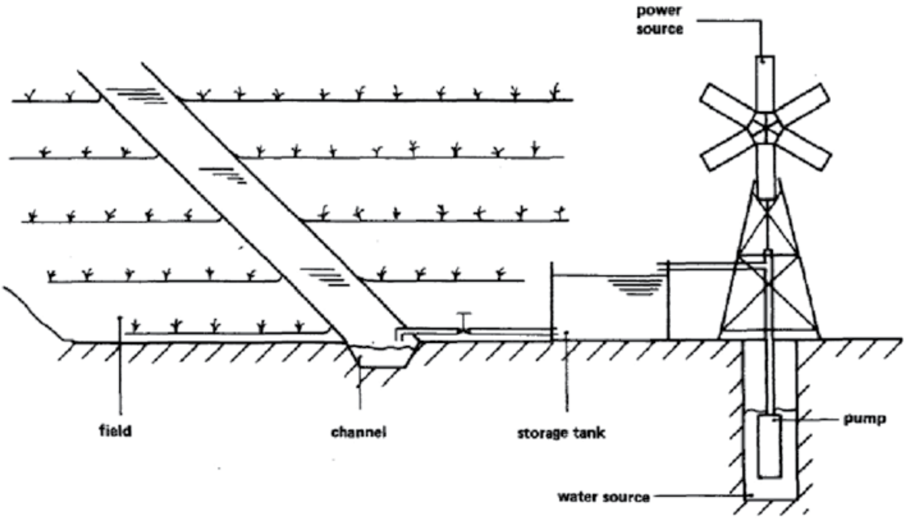
In order to select the best possible pump with the supporting PV or other renewable energy power supply the following questions need to be answered:

Well	Others
Total vertical height	Tank height
Depth of well	Tank volume
Recovery rate	Volume of required water/day
Length of pipe	Seasonal variations (rain season/dry season)
Kind of water to be pumped	Delivery distance
Storage	Total length of pipe and pipe diameter
Static water level	Power supply (PV direct or indirect via battery)
Dynamic well characteristics (m at m^3/hr)	
Well diameter	
Water quality	

6.1.2.4 Wind Pump

Wind primarily occurs because of temperature differences in the air caused by sun radiation. When air is heated it becomes less dense and therefore rises. The pressure at ground level decreases, and because air always flows from high pressure to low pressure, thermal circulation is then developed. The wind speed increases with altitude and can be estimated using the Beaufort scale, which is based on observations of the surroundings. The wind speed increases with altitude and can be estimated using the Beaufort scale, which is based on observations of the surroundings. One disadvantage with wind power is that it is unreliable, as the wind cannot be controlled. Hills and trees can reduce wind speed and cause the wind to change direction. With a suitable location and with good wind conditions, wind power is a good energy source.

The kinetic energy in the wind can be converted into different useful energy forms, such as mechanical energy or electricity. This is called wind power. It is a renewable energy resource that is under steady development worldwide. It is also said to be an absolutely clean source of energy, since there are no emissions or direct influences on the environment.



Source: Van Meel, J & P. Mulders

Figure 91: Wind Energy Driven Pump Irrigation Layout

Figure 92: Windmill for Water Abstraction Prototype

Table 15: Average Daily Hydraulic Power Demand in Critical Month

Average Wind Speed V in Critical Month in m/s	AVERAGE DAILY HYDRAULIC POWER DEMAND IN CRITICAL MONTH					
	20 – 500 m⁴/day		500 – 2000m⁴/day		2000 – 100000m⁴/day	
	Rural Water Supply	Irrigation	Rural Water Supply	Irrigation	Rural Water Supply	Irrigation
>5	Wind best option	Wind best option	Wind best option	Wind best option	Wind best option	Wind best option
3.5 – 5	Wind best option	Wind probably best option but check with kerosene and diesel	Wind best option	Wind probably best option but check with kerosene and diesel	Wind very good option but check with diesel	wind very good option but check with diesel
2.5 – 3.5	Consider all options wind, Solar, Kerosene, diesel	Consider all options wind, Solar, Kerosene, diesel	Consider wind, diesel, kerosene	Consider wind, diesel, kerosene	Consider wind and diesel	Consider wind and diesel
2.0 – 2.5	Consider solar, diesel, kerosene, check wind	Consider solar, diesel, kerosene, wind doubtful	Consider diesel, kerosene, check wind	Consider diesel, kerosene, wind doubtful	Diesel best option, wind doubtful	Diesel best option, wind doubtful
<2.0	Consider solar, kerosene, diesel	Consider solar, kerosene, diesel	Consider kerosene, diesel	Consider kerosene, diesel	Diesel best option	Diesel best option

In Ethiopia Wind farming is used in large scale for at Adama and Ashogoda and also as water abstraction energy for small water supply in rift valley.

6.1.2.5 Horizontal Centrifugal Pumps

Among the kinetic pumps, centrifugal pumps are widely used by farmers. Centrifugal pumps usually give efficient operation over a relatively wide range of operating conditions; because of its relative simplicity, range of head and flows and relative low cost. A centrifugal pump consists of a motor, pump casing, and impeller (Figure 93).

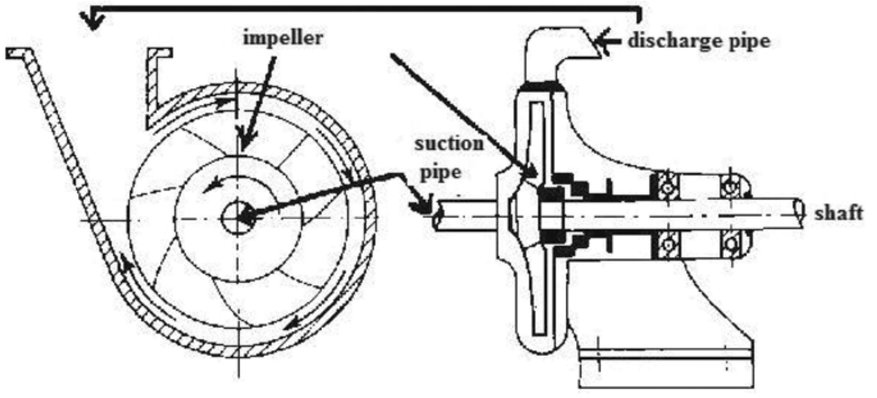


Figure 93: Horizontal Centrifugal Pump with Motor Assembly

Centrifugal pumps are suction pumps operating on the principle of centrifugal action. In a centrifugal pump, a motor or other driver rotates an impeller fitted with vanes immersed in water and enclosed in a casing. Water enters the case at the center and is immediately engaged by the impeller, which is in rapid rotation; this rotation causes a flow from the center of the impeller to its rim or the outside of the case where pressure head is rapidly built up. To relieve this pressure, the water escapes through the discharge pipe. The centrifugal pump will not operate until the case is entirely full of water or primed. The need of priming is one of the disadvantages of the horizontal centrifugal pump.

Suction lifts head of centrifugal pumps is theoretically 10 m but practically it is not greater than 6 – 7 m which depend on altitude, temperature, friction in the suction hose. Therefore as already discussed in chapter 5, the recommended suction lift of centrifugal pumps for tube wells is 2.5 m; therefore proper pump house excavation has to be done for tube wells whose static water level is deeper than 2.5 m. In other words the net positive suction head required must not be greater than net positive suction head available. Problems that may occur, although the pumps performed well during testing, include the following items, each followed by the problem's possible causes (Table 16).

Table 16: 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

Problem	Causes
Power Demand Increase	Drop in pump efficiency. As the efficiency drops, horsepower requirements increase. This may be as result of: • Pump misalignment • Damaged bearings
Cavitations	• 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

6.1.2.6 Submersible Pump

Submersible pump is simply a turbine pump close-coupled to a submersible electric motor attached to the lower side of the turbine. Both pump and motor are suspended in the water. Submersible pumps are adapted to cased wells of 4 inches in diameter or larger and generally greater than 15 m deep wells (Figure 94).

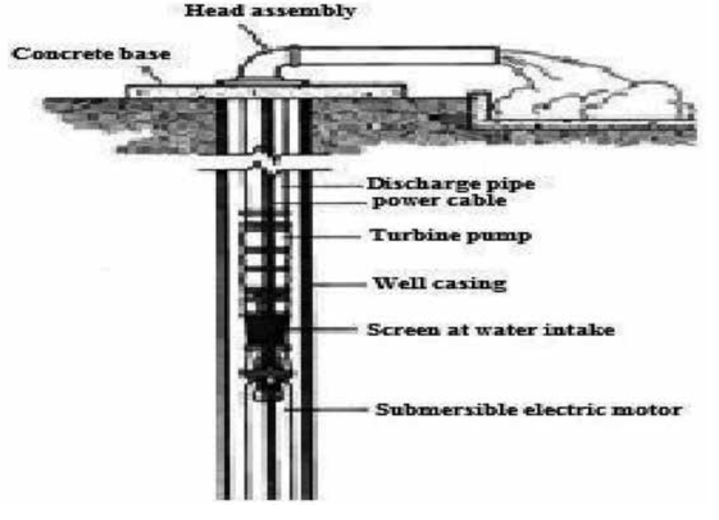


Figure 94: Submersible Pump

The submersible pump consists of a pump and motor assembly, a head assembly, discharge column, and a submarine cable to furnish power to the motor (Figure 94). The pump, being a centrifugal-type turbine, is equipped with either closed impellers or open impellers or some modification of these two types arranged in series. The closed-impeller type is generally used where it is necessary for the pump to develop high pressures. Water enters the pump through a screen located between the motor and pump.

6.2 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.

The total head of a pump is composed of several types of head that help define the pump's operating characteristics.

6.2.1 Total Dynamic Head

The total dynamic head of a pump is the sum of the total static head, the pressure head, the friction head, and the velocity head. An explanation of these terms is given below and graphically shown in Figure 95.

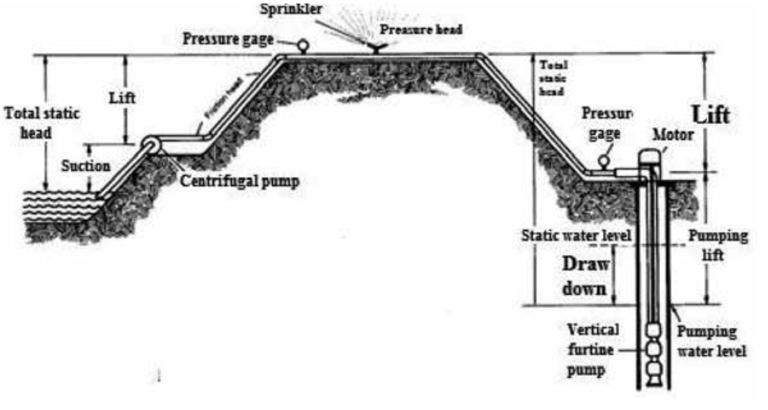


Figure 95: Basic Pump-Operating Characteristics

6.2.2 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.

6.2.3 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 pounds per square inch (PSI) to feet of head by multiplying by 2.31. For example, 20 PSI is equal to 20 times 2.31 or 46.2 feet of head. Most city water systems operate at 50 to 60 PSI.

6.2.4 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.

6.2.5 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.

6.2.6 Suction Head

$TDH = Hs + Hd + hf$ ------------- (5) 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. The total lifting head of the pump can be summarized as Equation 5:

Where:

TDH Total dynamic head

Hs Suction head – the distance between the static water level and the centerline of pump

Hd Delivery head – the distance between the centerline of pump and the point of delivery

Hf Head loss – the total loss of due to friction when the water flows through the pipe

The head loss by friction (hf) can be calculated using Equation 6 (Michael, 1978)

$$hf = \frac{fl Q^2}{3 d^5} \text{ --------------- } (6)$$

Where:

F coefficient of friction

L total length of pipe (suction plus delivery), m

D diameter of pipe, m

Q m3/s

6.2.7 Pump Power Requirements

The pump power requirement of a pump is determined by the work done by the pump in raising a particular quantity of water to some height. Work is defined as force times distance and Power is defined as work per unit of time or the rate of doing work. Work is required to lift water out of a well and the amount of water delivered in a unit of time can be related to power and is referred to units of horsepower.

The power added to water as it moves through a pump is therefore can be calculated with Equation7:

$$WHp = \frac{Q * TDH}{273} \text{ ---------------- } (7)$$

Where:

WHp	Water Horse Power
Q	Flow rate in m cubic per hour (m^3/hr)
TDH	Total dynamic head

Or

$$WHp = \frac{Q * TDH}{76}$$

Where:

Hp	horsepower
WHp	Water Horse Power
Q	Flow rate in l/s
TDH	Total dynamic head

However, the actual power required to run a pump will be higher than this because pumps and drives are not 100 percent efficient. The horsepower required at the pump shaft to pump a specified flow rate against a specified TDH is the Brake Horsepower (BHP) which is calculated as given in Equation 8:

$$BHP = \frac{WHP}{Pump\ Eff} \text{-------------} (8)$$

Where:

BHP Brake Horsepower (continuous horsepower rating of the pump unit)

Pump Eff Efficiency of the pump usually read from a pump curve and having a value between 0 and 1

Motor (drive) horsepower

The motor (drive) horsepower (MHP) can be calculated using Equation 9:

$$MHP = \frac{BHP}{Motor\ (drive)\ Eff} \text{-------------} (9)$$

Motor (drive) Eff Efficiency of the drive unit between the power source and the pump. For direct connection this value is 1, for right angle drives the value is 0.95 and for belt drives it can vary from 0.7 to 0.85.

Example 5

A centrifugal pump is required to lift water at a rate of 150 l/s. Calculate the BHP of the engine from the following data:

- Suction head = 6 m
- Coefficient of friction = 0.01
- Efficiency of pump = 75%

Example 5

- Water is supplied to the field channel
- Diameter of pipe 15 cm

Solution

Calculate for h;

TDH = hs+hd+h = 6m +0+hf, hd= 0 since water is supplied to the irrigation field directly, while hf to be calculated

Example 5

$$hf = \frac{flQ^2}{3d^5} = \frac{0.01*6*0.15^2}{3*0.15^5} = \frac{0.00135}{0.000228} = 5.92m$$

Hence, TDH will be:

TDH = hs+hd+hf= 6+0+5.92 = 11.92 m

Then, BHP will be:

$$BHP = \frac{Q*TDH}{Pump\ Eff*76} = \frac{150l/s*11.92m}{0.75*76} = \frac{1788}{57} = 31hp$$

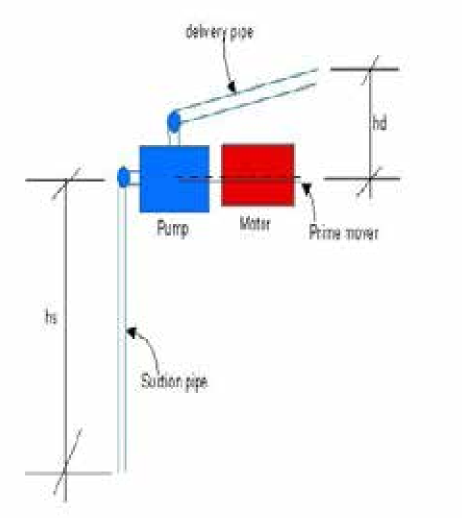
Note, when buying a pump, the following points shall be checked:

- Discharge
- BHP
- Head (total head)

Example 6

An irrigator desires to lift an irrigation water of 30 l/s a vertical height of 12 m. If the loss of head in the casing and pump results in a 62% overall pump efficiency and the electric motor has an efficiency of 91%, how many horsepower will his motor need? How many kw will it use while pumping? Assume 1hp=0.746 KW
Solution:
Given data:
Q= 30 l/s
h= 12 m
Pump Eff (Ep) =62%
Motor Eff=91%
Asked: Motor hp?, Kw to be used?
BHP= WHP/(Ep*76)= (Q*h)/(0.62*76)=(30*12)/(0.62*76)= 7.64 hp
Then, MHP (motor horsepower)= BHP/Efficiency of motor (Em)=7.64/0.91= 8.39 hp
And
KW to be used= MHP*0.746 KW= 8.39*0.746= 6.26 KW

Example 7
From data given below, how many KW would a motor require in order to deliver a stream that would supply enough water in 30 hrs to cover a 4 ha land to a depth of 150 mm? Assume 1hp = 0.746 KW. Data given:

Example 7
H= 12 m Ep= 62% Em= 91% 
Depth of irrigation (d)= 150 mm=0.15 m
Area of irrigable land (A) = 4 ha=4*10000 m^2
Step 1: calculate the total volume of irrigation water (V) for 4 ha at a depth of 150 mm
V= A*d=4*10000*0.15=6000 m^3
If this amount is applied in 30 hrs (T), then discharge (Q) per hour will be:
Q= V/T= 6000 m^3/30hr= 200 m^3/hr
Step 2: calculate BHP;
BHP= WHP/(Ep*273)= (Q*h) / (0.62*273)= (200*12) / (0.62*273)= 14.18 hp
Step 3: Calculate for motor horsepower, MHP;
MHP= BHP/ME= 14.18/0.91= 15.58~16 hp
Step 4: Calculate for motor power required in KW,
Mp= MHP*0.746= 11.62 KW

Example 7
Step 5: Calculate the electric requirement:
Electric KWH (kilowatt hour)= 11.62 KW*30 hrs= 349 KWH

Basic information required for pump determination is given in table 17 below:

Table 17: Basic Information Required for Pump Determination

Descriptions	Data	Remark
Name of the site ____		
Region	Zone : ______________________	NPSH
	District : ____________________	
	Kebele : _____________________	
	Altitude __________________ (m)	
	Special Area : _________________	
Source of Water :	Tube Well	Selection of Type of pump
	Hand dugout	
	Cistern	
	Pond	
	Other/stream	
Conveyance/Distribution/Application	Furrow	Head loss consideration
	Drip	
	Sprinkler	
	hand bucket/ hose	
	Other______________________	
Discharge/yield of source	________________________(L/min)	For design
Well Depth	__________________________ (m)	Suction head
Pumping Water Leve – delivery	____________ (m)	
Well Diameter	____________ (m)	
Well physical characteristics	Length__ Width/ diameter___ Depth _____________m.	
Distance between pump and well	_____________m	Suction length

Descriptions	Data	Remark
Distance between pump location and final outlet point	______________m	Delivery length
Height difference between well or dugout and outlets	______________m	Total head w/o loss

6.3 Manual Lifting Devices their Possible Irrigation Capacity

Studies done in Ethiopia and in the rest of the world indicates, manual lifting devices can irrigate limited areas due to their discharge, lift and suction capacity.

Table 18: Recommended Irrigation Areas of Different Manual Lifting Devices

Type of Lift	Yield (li/sec)	Depth/Suction(m)	Delivery (m)	Possible Area (ha)
Rope and Washer	0.6	10	NA	0.1 ha/4hour per day
	0.15	35	NA	
Treadle pump (suction/Pressure)	3.6	7.5 – 10	-	0.25ha/4hour per day
Solar pump	Refer the solar pump section			
Engine	16	6	30	3–5

6.4 Conveyance and Distribution System

The conveyance and distribution systems consist of pipes and canals transporting the water through the whole irrigation system. The water through the distribution system is conveyed from the source of supply to the fields and this process may comprise pipes, flexible hose, open channels or a combination of both. Accordingly, in this guideline water pumped from tube well can be supplied directly to farm fields using pipes, hoses, open channels or a combination of these.

6.4.1 Pipelines

Since the tube well is constructed nearby or inside the irrigable land, longer distance conveyance of water through pipes is not expected. Complicated pipe line design may not be necessary; a simple PVC pipe or low pressure hoses can be used. If the pump used for lifting is 3" pump, the size of PVC pipe can be of the same size or more. If the farmers are using gravity surface irrigation systems, simply measure the discharge at the delivery pump out let and by considering the water demand or command area match pumping hours. In this case, at the end of the delivery pipe a small delivery pool of 50 cm wide, 40 cm deep and 60 cm long (Figure96) would be required to deliver water directly to open channels. The delivery pool will also help in dissipating the energy of the water from scouring the soil and let the water to flow through its outlet to field canals. The delivery pool may be constructed from different locally available materials like barrel, dry masonry, plastic sheets, corrugated sheets, cut part of oil drum, etc.

Figure 96: Delivery Pool with Masonry Structure

Some important advantages of low-pressure irrigation pipes are:

- Low water loses in the distribution system: can be less than lined canals. It is much easier to close off the flow in a pipe than in an open channel and minimize or avoid wastage of irrigation water. In this case more land can be irrigated.
- Buried pipes again increasing the cropped area within the scheme, where earthen or lined canals can take up 0.5 to 2% of the command area, take up less land area.
- Pipes can often be installed at lower cost than lined canals.

6.4.2 Open Canal or Channel

An open canal, channel, or ditch, is a structure whose purpose is to carry water from one place to another. Channels and canals refer to main structure supplying water to one or more farms. Field ditches have smaller dimensions and convey water from the farm entrance to the irrigated fields.

According to the shape of their cross-section, canals can be rectangular (a), triangular (b), trapezoidal (c), circular (d), parabolic (e), irregular or natural (f) (Figure 97).

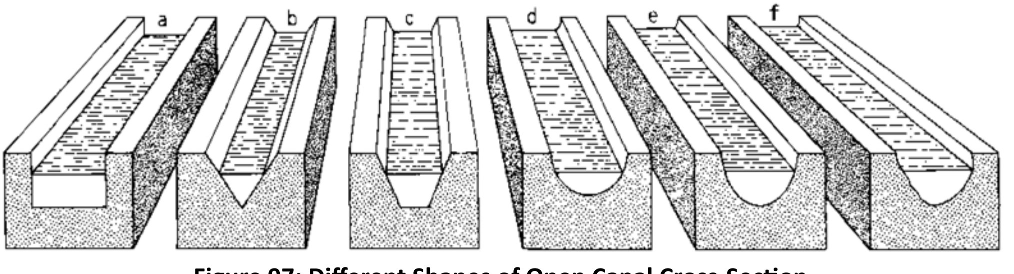


Figure 97: Different Shapes of Open Canal Cross-Section

The most commonly used canal cross-section in irrigation and drainage is the rectangular and trapezoidal cross-section. The typical cross-section of an earthen rectangular canal is shown in figure 98.

Figure 98:Open Canal (Farmers Practice in Ziway)

The disadvantages of earthen canals are the risk of the side slopes collapsing and the water loss due to seepage. They also require continuous maintenance in order to control weed growth and to repair damage done by livestock and rodents.

6.4.3 Irrigation Canal Design

Open channel system is widely used in irrigation water distribution system in many irrigation schemes of Ethiopia. Open channels can be lined or unlined; however, in lift irrigation unlined canals would be expensive and may not be recommended in this guideline. The household irrigation practice in Ethiopia using lift irrigation is dominantly with low discharge rate (2.5– 6 l/s) and water sources (wells) are located near by the land to be irrigated. In this case, the water distribution system can be managed by farmers themselves as shown in figure 99.

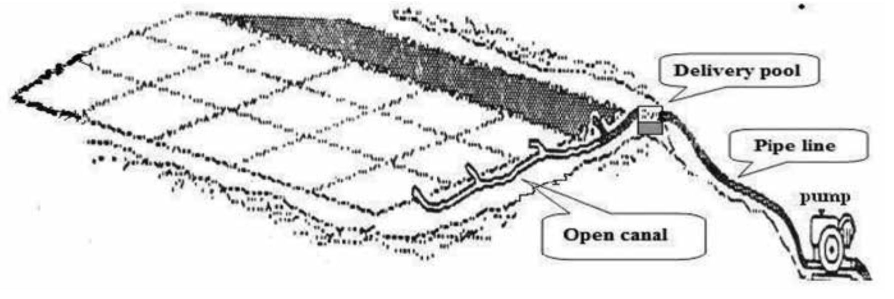


Figure 99: Pipeline with Canal Conveyance System

Basic data required for canal design are:

- maximum/peak discharge of the tube well pump
- Peak water requirement or duty of the area in (l/s/ha)
- The maximum command area A in ha
- Manning's roughness coefficient
- Canal gradient or slope for the given soil
- The type of canal section to be used

In canal design, key elements that need to be determined include, top bank width (T), bottom width (b), side slopes (z), water depth (d), freeboard (f), total depth (D = d + freeboard), wetted area (A), wetted perimeter (P).' and hydraulic Radius R, (R = A/P) (Figure 100).

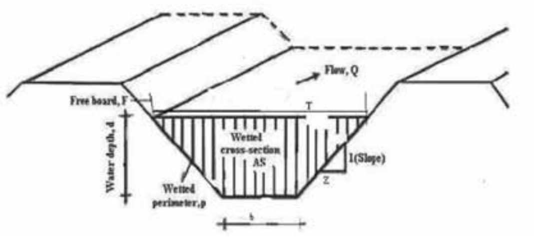


Figure 100: Typical Trapezoidal Canal Section

Commonly, the Manning's Equation: Equation 10 is used to determine canal sections:

$$Q = \frac{AR^{\frac{2}{3}}S^{\frac{1}{2}}}{n} \text{ ------------------ } (10)$$

Where:

Q	Discharge (m^3/sec) = V* A
V	velocity (*m/s*)
N	Manning roughness coefficient (dimensionless)
A	Wetted cross – sectional area (m^2) = d (b + dZ)
P	Wetted perimeter (*m*)
R	Hydraulic radius (*m*) (R=A/P)
S	Canal gradient or longitudinal slope of the canal (dimensionless)
Z	side slope gradient (dimensionless)

Select the known and unknown parameters

Canals carrying water with excessively high velocities may cause erosion of the bed and the sides of the channel leading to the collapse of the canal. If the velocity is low, the sediment will deposit in the canal requiring frequent cleaning. Low velocities also encourage weed and plant growth in the channel. The velocity chosen should be higher than the "Minimum permissible velocity" to prevent growth of vegetation and lower than the "Maximum permissible velocity" which will prevent both sedimentation and vegetative growth. Maximum permissible velocities depend on the soil material, but generally, for small-scale irrigation projects a design velocity of about 0.75 to 1 m/s is recommended. The maximum velocity should vary with the soil type as recommended below in table 19.

Table 19: Maximum Permissible Velocities in Canals based on Soil Type

Type of soil	Maximum Permissible Velocity m/s
Sand	0.3 – 0.7
Clay loam	0.6 –0.9
Clay	0.9– 1.5
Gravel	0.9–1.5
Rock	>1.5

Source: FAO 1996

Based on the dominant soil type of the farm field referred to in table 19, the velocity can be known. Canal side slope, Manning's coefficient and canal width to depth (b/d) ratio can be estimated from table 20 and 21.

Table 20: Recommended Values for Canal Parameters

Canal	Water Depth(m)	b/d Ratio	Minimum Canal Width(b)(m)	Side Slopes (z)	Minimum Free Board(m)	Man-ning's(n)
Head Ditch	< 0.3	1	0.3	1	0.1	0.04
Small	< 0.75	1(clay) – 2(sand)	0.5	1	0.2	0.035
Medium	0.75 – 1.5	2(clay) – 3(sand)	0.5 – 1	1–2	0.3	0.03 – 0.035
Large	> 1.5	> 3	> 1	> 2	0.4	0.03

Source: FAO 1996

Table 21: Maximum Flow Velocities, Coefficient of Roughness and Side Slope for Lined and Unlined Canals

Type of Surface	Maximum Flow Velocities (m/s)	Coefficients of Roughness (*n*)	Side Slope (H:V)
Unlined Canals/Ditches			
Sand	0.3 –0.7	0.030 – 0.040	3:01
Sandy loam	0.5 – 0.7	0.030 – 0.035	2:1 to 2.5:1
Clay loam	0.6 – 0.9	0.03	1.5:l to 2:1
Clays	0.9 – 1.5	0.025 – 0.030	1:1 to 1.5:1
Gravel	0.9 –1.5	0.030 – 0.035	1:1 to 11:1
Rock	1.2 – 1.8	0.030 – 0.040	1/4:1 to 1:1
Lined Canals/Ditches			
Concrete			
Cast-in-place	1.5 – 2.5	0.014	1:1 to 1.5:1

Precast	1.5 – 2.0	0.018 – 0.022	1.5:1
Bricks	1.2 –.8	0.018 – 0.022	1.5:1
Asphalt			
Concrete	1.2 – 1.8	0.015	1:1 to 1.5:1
Exposed membrane	0.9 – 1.5	0.015	1.5:1 to 1:1
Buried membrane	0.7 – 1.0	0.025 – 0.030	2:01
Buried membrane	0.6 – 0.9	0.025 – 0.030	2.5:1

Source: FAO 1996

The longitudinal slope of canals can be estimated referring to Table 22.

Table 22: Longitudinal Slope of Canals

Type of Canals	Range of Slope (%)
Main canals	1/700 – 1/1500
Secondary canals	1/700 – 1/1000
Tertiary canals	1/500 – 1/700
Field ditches	1/300 – 1/500

6.4.4 Seepage Control

Groundwater is very scarce resource and relatively expensive (limitations on recharging, investment cost for drilling and lifting). These forces us to adapt water saving irrigation technology that can maximize the profit of the resource.

Minimizing loss at different stage at abstraction, storage, distribution and application is important. Lining the canals with geo-membrane/plastic lining or clay lining or masonry lining or conveying with pipe system is advisable. The water application also has to consider water saving, like drip, bucket irrigation, or other system. It is advised to cover the storage or use cover tanker.

CHAPTER 7

IRRIGATION AGRONOMY

7.1 Definition and Necessity of Irrigation

The process of artificial application of water to the soil for the growth of agricultural crops is termed as irrigation. It is practically a science of planning and designing a water supply system for the agricultural land to protect the crops from bad effect of drought or low rainfall. It includes also the construction of weirs', dams, barrages and canal systems for the regular supply of water to cultivable lands.

Throughout the crop period adequate quantities of water is required near the root zone of the plants for their growth. At times during the crop period the rainfall may not be adequate to fulfill the water requirement. The intensity of rainfall is practically uncertain and beyond the control of human power and it may not be well distributed throughout the crop season or the cultivable area. So, irrigation becomes absolutely necessary to fulfill the water requirement of crops. The following are the factors, which govern the necessity of irrigation.

(a) Insufficient Rainfall: when the seasonal rainfall is less than the minimum requirement for the satisfactory growth of crops, the irrigation system is essential.

(b) Uneven Distribution of Rainfall: When the rainfall is not evenly distributed during the crop period or throughout the cultivable area, the irrigation is extremely necessary.

(c) Improvement of Perennial Crops: Some perennial crops like sugarcane, cotton, etc. require water throughout the major part of the year. But the rainfall may fulfill the water requirement in rainy season only. So, for the remaining part of the year, irrigation becomes necessary.

(d) Development of Agriculture in semiarid and arid areas: In semi-arid and arid areas where the rainfall is very scanty, irrigation is required for the development of agriculture.

7.2 Soil-Water-Plant Relationship

7.2.1 General

The knowledge and concept of soil-water-plant relationship helps us to understand the basic relationship of soil-water-crop, their composition, physical properties, and their applicability for irrigated agriculture and to determine the methods of irrigation and water management practices.

7.2.2 Soil Composition

Soil is self-sustained and firm mass in the biosphere composed of mineral particles, air water, organic matter, macro, micro-organisms and insect (Figure 101). It is the medium, which supports the growth of plants. It provides mechanical support, water, oxygen and nutrients to plant roots. Soil fertility is the capacity of soil to supply basic inputs for optimum plant growth.

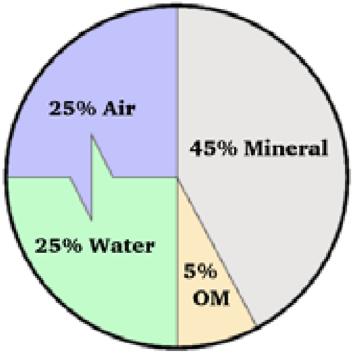


Figure 101: Soil Composition by Volume

When the soil is "dry", the pores are mainly filled with air. After irrigation or rainfall, the pores are mainly filled with water. Living materials such as live roots and worms (beetles, larvae, etc.) are found in the soil. They help to aerate the soil and thus create favourable growing condition for the plant roots.

7.2.3 Soil Texture

Soil texture is a qualitative classification tool used in both the field and laboratory to determine classes for agricultural soils based on their physical texture. The classes are distinguished in the field by the 'textural feel' which can be further clarified by separating the relative proportions of sand, silt and clay using grading sieves Figure102

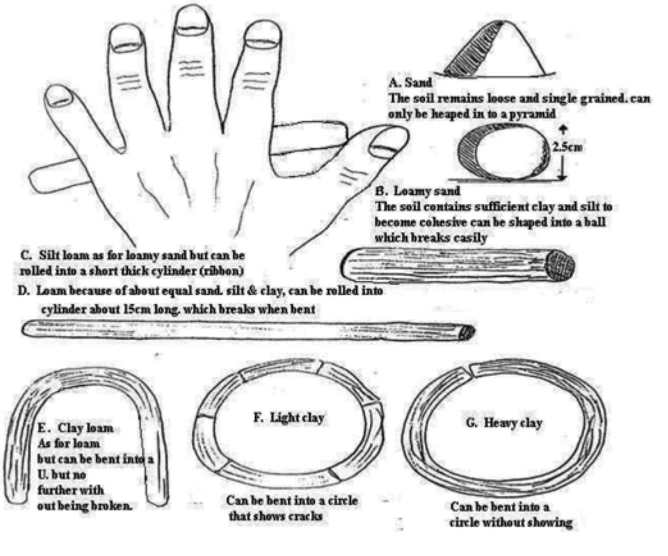


Figure 102: Practical Field Method of Assessing Soil Texture

7.2.4 Soil Separates

Soil separates are specific ranges of particle sizes. In the United States, the smallest particles are clay particles and are classified by the United State Department of Agriculture (USDA) as having diameters of less than 0.002mm. The next smallest particles are silt particles and have diameters between 0.002mm and 0.05mm. The largest particles are sand particles and are larger than 0.05mm in diameter. Furthermore, large sand particles can be described as coarse, intermediate as medium, and the smaller as fine. Other countries have their own particle size classifications (Table 23).

Table 23: Soil Separate (USDA Classification)

Name of Soil Separate	Diameter Limits (mm) (USDA classification)
Clay	less than 0.002
Silt	0.002–0.05
Very fine sand	0.05–0.10
Fine sand	0.10–0.25
Medium sand	0.25–0.50
Coarse sand	0.50–1.00
Very coarse sand	1.0 2.00

Determination of soil texture in the field is made mainly by feeling the soil with fingers. For high accuracy, the texture determined in field by surface feel should be checked against laboratory analysis. Thus, by means of different feels among the sand, silt and clay, the soil textural class is estimated. However, errors are expected due to presence of organic matter gypsum, calcium carbonate, coarse fragments, soluble salts, etc.

7.2.5 Soil Structure

Structure of the soil is described as the arrangement of individual particles of soil with aggregates less than 0.25 mm (microstructure) and aggregates larger than 0.25 mm (macrostructure). It is one of the most important soil factors, which determine the infiltration rate, application of irrigation, soil tillage practices.

The basic types of aggregate arrangements are shown in Figure 103, granular, blocky, prismatic, and massive. Ideally granular is considered the best for irrigation agriculture practices because of their good nature water permeability.

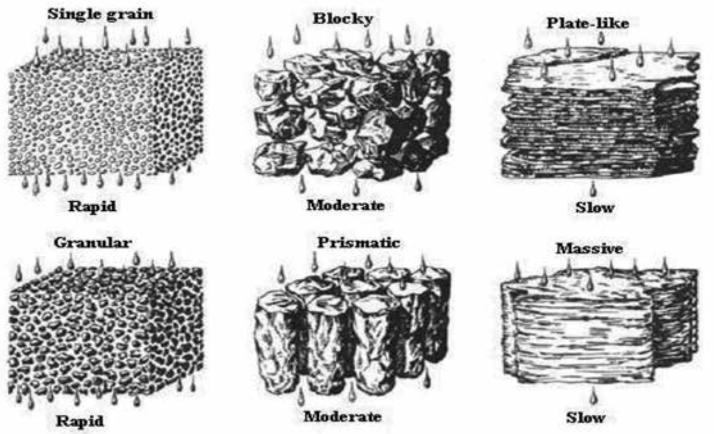


Figure 103: Soil Structure Types and their Effect on Downward Movement of Water

7.2.6 Infiltration of water

When rain or irrigation water is supplied to a field, it enters the soil. It is the most important process in surface irrigation. The rate of infiltration is determined as the amount of water per surface area and unit of time that penetrates the soil. This is usually expressed in terms of mm/hr. The initial penetration of water in to the soil is fast, reducing gradually over time until the constant rate is reached, the basic infiltration rate.

Soil with low (0 – 10 mm/hr) or medium (10 – 30 mm/hr) infiltration rate are suitable for surface irrigation (Table 24). Those with high infiltration rate (greater than 30 mm/hr) may only be suitable for sprinkler or drip irrigation.

Table 24: Typical Infiltration Rate for Different Soils

Type of soil	Basic Infiltration Rates (mm/hr)	Remark
Sand	>40	High
Sandy loam	25−40	Medium/moderate
Silty loam	15−25	Medium/moderate
Clay loam	7−15	Low
Clay	<7	Low

7.2.7 Soil Moisture Conditions

The soil moisture content indicates the amount of water present in the soil. It is commonly expressed as the amount of water (in mm of water depth) present in a depth of one m of soil.

For example: when an amount of water (in mm of water depth) of 150 mm is present in a depth of one m of soil, the soil moisture content is 150 mm/m (Figure 104).

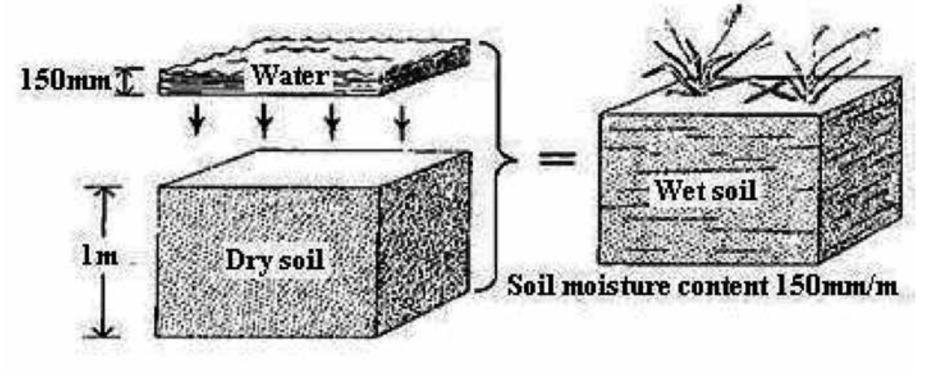


Figure 104: Example for Soil Moisture Content

The soil moisture content can also be expressed in percent of volume. In the example above, 1 m3 of soil (e.g. with a depth of 1 m, and a surface area of 1 m2) contains 0.150 m3 of water (e.g. with a depth of 150 mm = 0.150 m and a surface area of 1 m^2). This results in soil moisture content in volume percent is shown in Equation 11:

$$\frac{0.150m^3}{1m^3} \times 100\% = 15\% \text{ -------------------- } (11)$$

Thus, a moisture content of 100 mm/m corresponds to a moisture content of 10 volume percent.

7.3 Soil Water Classification

Based on its water holding capacity, soil can be classified as follows.

7.3.1 Saturation

During a rain shower or irrigation application, the soil pores are filled with water. If all soil pores are filled with water the soil is said to be saturated. The water is free to move out of soil under gravity and is known as gravity water. There is no air left in the soil and the plant will suffer. It is easy to determine in the field if a soil is saturated. If a handful of saturated soil is squeezed, some (muddy) water will run between the fingers.

The period of saturation of the topsoil usually does not last long. After the rain or the irrigation has stopped, part of the water present in the larger pores will move downward. This process is called drainage or percolation. The water drained from the pores is replaced by air. In coarse textured (sandy) soils, drainage is completed within a period of a few hours. In fine textured (clay) soils, drainage may take some 2 – 3 days.

7.3.2 Field Capacity (FC)

After the drainage has stopped, the large soil pores are filled with both air and water while the smaller pores are still full of water. At this stage, the soil is said to be at field capacity. At field capacity, the water and air contents of the soil are considered to be ideal for crop growth.

7.3.3 Permanent Wilting Point (PWP)

Little by little, the water stored in the soil is taken up by the plant roots or evaporated from the topsoil into the atmosphere. If no additional water is supplied to the soil, it gradually dries out. The dryer the soil becomes, the more tightly the remaining water is retained and the more difficult it is for the plant roots to extract it. At a certain stage, the uptake of water is not sufficient to meet the plant's needs. The plant loses freshness and wilts; the leaves change colour from green to yellow and finally the plant dies. The soil water content at the stage where the plant dies is called permanent wilting point. The soil still contains some water, but it is too difficult for the roots to suck it from the soil. The soil water content between the field capacity and permanent wilting point is known as available water while the soil water content below the permanent wilting point is known as hygroscopic water (Figure 105).

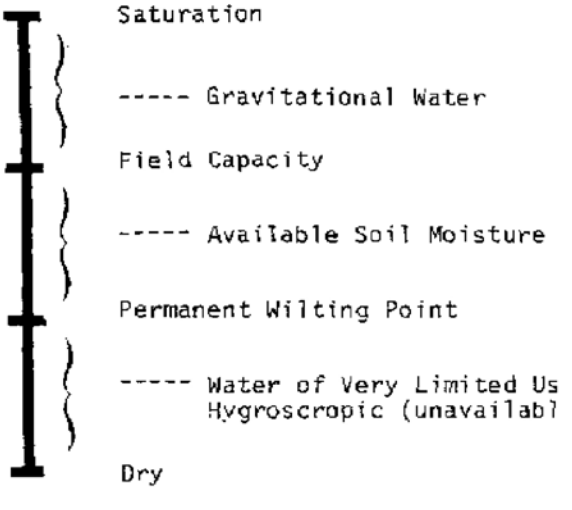


Figure 105: Soil Water Classification

Available Moisture (Water) Content

The soil can be compared to a water reservoir for the plants. When the soil is saturated, the reservoir is full. However, some water drains rapidly below the root zone before the plant can use it. When this water has drained away, the soil is at field capacity. The plant roots draw water from what remains in the reservoir. The amount of water actually available to the plant is the amount of water stored in the soil at field capacity minus the water that will remain in the soil at permanent wilting point. Typical available soil moisture values are shown in table 25.

Table 25: Typical Available Soil Moisture

Soil Type	Available Soil Moisture (mm/m)
Sand	55
Fine sand	80
Sandy loam	120
Clay loam	150
Clay	135

Source: Withers and Vipond, 1974

Available soil moisture can be identified practically by hand feeling methods.

Clay Soil		
		
25 – 50% soil moisture available	50 – 75 % soil moisture available	75 – 100% soil moisture available
Sandy Soil		
		
25 – 50% soil moisture available	50 – 75 % soil moisture available	75 – 100% soil moisture available
Medium Soil		

Figure 106: Hand Feeling Available Soil Moisture

7.4 Plan for Irrigation Agronomy

The agricultural practitioners together with the farming community have to prepare an irrigation plan to ensure success in irrigated agriculture. Important factors that should be considered in planning for irrigation are presented in this section.

7.4.1 Selection of Crops

Agro-climate factors are one of the key determinant factors for selection crops to be grown in irrigated land. These include topography, rainfall pattern, temperature and other factors. Besides water availability, other important factors to consider in crop selection are prevailing soil conditions, length of growing period, both female and male farmers preference, access to market, availability of labor forces, etc.

7.4.2 Cropping Patterns

It is the allocation of a certain proportion of land for different crops during the growing season. The cropping pattern depends not only on agronomic factors /length of growth period, crop calendar, and cropping intensity but also on issues such as relative importance of irrigated and rain fed production to family food security and generates additional income.

7.4.3 Crop Water Requirement (ETcrop)

The design and operation of efficient irrigation systems require a proper understanding of soil-water-plant relationships in order to obtain reliable information on the irrigation water requirement of particular crop which forms the basis for appropriate and sustainable water resource management.

ETcrop is defined as the depth (or amount) of water needed to meet the water loss through evapotranspiration. In other words, it is the amount of water needed by the various crops to grow optimally.

The crop water need always refers to a crop grown under optimal conditions, i.e. a uniform crop, actively growing, completely shading the ground, free of diseases, and favourable soil conditions (including fertility and water). The crop thus reaches its full production potential under the given environment.

The crop water need depends on:

- The climate: in a sunny and hot climate crops need more water per day than in a cloudy and cool climate.
- The crop type: crops like maize or sugarcane need more water than crops like millet or sorghum.

- The growth stage of the crop; fully grown crops need more water than crops that have just been planted.
- The major climatic factors (Table 26) which influence the crop water needs are:
  - sunshine
  - temperature
  - humidity
  - wind speed

Table 26: Effect of Climate on Crop Water Need

Climatic Factor	Crop Water Need	
	High	Low
Temperature	Hot	cool
Humidity	low (dry)	high (humid)
Wind speed	Windy	little wind
Sunshine	sunny (no clouds)	cloudy (no sun)

The highest crop water needs are thus found in areas, which are hot, dry, windy and sunny. The lowest values are found when it is cool, humid and cloudy with little or no wind. The influence of the climate on crop water needs is given by the reference crop evapotranspiration(ETo). The ETo is usually expressed in millimetres per unit of time, e.g. mm/day, mm/month, or mm/season. Grass has been taken as the reference crop.

ETo is the rate of evapotranspiration from a large area, covered by green grass, 8 to 15 cm tall, which grows actively, completely shades the ground and which is not short of water (Figure 107).

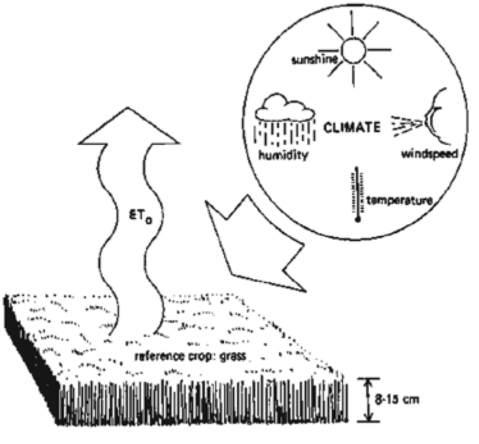


Figure 107: Process of Reference Evapotranspiration

Reference crop evapotranspiration or reference evapotranspiration denoted as ETo is a climatic parameter expressing the evaporation power of the atmosphere independently of crop type, crop development and management practices (Allen et al., 1998). Most commonly used methods in estimating potential ETo are Blaney-Criddle method, Thornthwaite method, Penman method, modified Penman method, FAO Penman-Monteith method, Christiansen method, Hargreaves method, Jensen-Haise method, and Pan evaporation methods (Hansen, 1979, Michael 1978, Doorenbos and Pruitt, 1977).

CHAPTER 7

ETo can also be estimated from pan evaporation data (Figure 108). Pans have proved their practical value and have been used successfully to estimate ETo by observing the water loss from the pan and using empirical coefficients to relate pan evaporation to ETo, however, special precautions and management must be applied (Allen et al., 1998).

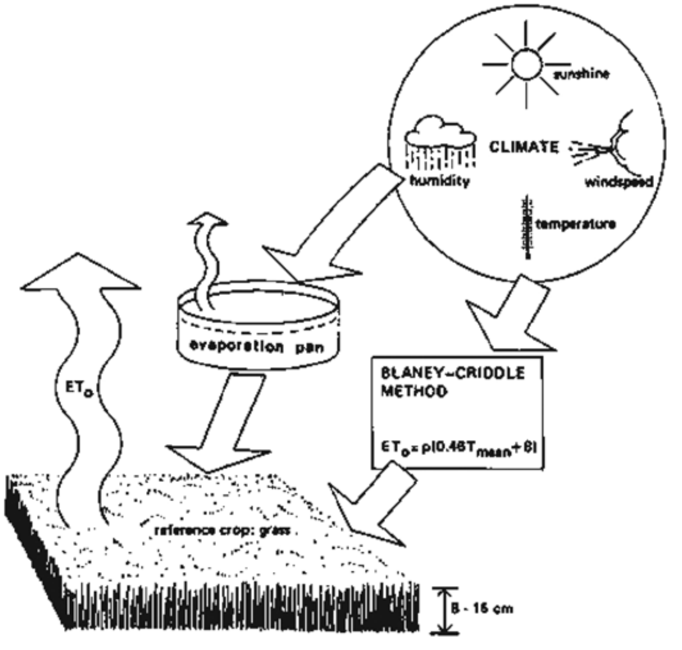


Figure 108: Evaporation Plan for Estimating ETo

The pan method makes use of the evaporation data (Epan) which is measured with evaporation pan. In order to compute ETo, from the Epan data, a pan factor (kp) is used. kp varies between 0.35 and 0.85. If the precise pan factor is not known, the average value, 0.7, can be used for Class A pan. The formula for estimating ETo is-Equation 12:

$$ETo = Kp * Epan ---------------- (12)$$

For converting ETo values in to ETcrop, suitable crop coefficient (Kc) should be involved for different crops, soils and climatic conditions and for different stage of growth for the same crop (Doorenbos and Pruitt, 1977).

The relationship between the reference grass crop and the crop actually grown is given by the crop factor, Kc, as shown in Equation 13:

$$ETo * Kc = ETcrop ----------------------$$

Where:

ETcrop	crop evapotranspiration or crop water needs (mm/day)
Kc	crop coefficient
ETo	reference evapotranspiration (mm/day)

Both ETcrop and ETo are expressed in the same unit: usually in mm/day (as an average for a period of one month) or in mm/month. For converting ETo values in to ETcrop, suitable Kc should be involved for different crops, soils and climatic conditions and also for different stage of growth (for the same crop (Doorenbos and Pruitt, 1977). The Kc is crop specific and expresses potential evaporative demand of a particular crop in relation to ETo. The value of Kc largely depends on the level of ground cover and the frequency with which the soil is wetted by rain and/or irrigation (Sijali, 2001). Values of Kc and ETcrop for some selected crops are given in Annex D and E, respectively.

7.4.4 Determination of the Total Growing Period

The total growing period (in days) is the period from sowing or transplanting to the last day of the harvest. It is mainly dependent on:

- type of crop and variety
- climate
- planting date

As the growing period heavily depends on local circumstances (e.g. local crop varieties), it is always best to obtain these data locally. If local data is limited, the value given in Annex F can be used.

7.4.5 Determination of the Growth Stages

Once the total growing period is known, the duration (in days) of the various growth stages has to be determined. The total growing period is divided into 4 growth stages (Table 27).

Table 27: Description for Crop Growth Stage

Crop Development Stages	Distinguishable Characteristics
Initial stage	This is a period from sowing or transplanting through germination and plant emergence until about 10 % ground cover is achieved. Water loss is practically all evaporation at this time
Crop development	This period starts from the end of initial stage to attainment of effective full ground cover (ground cover ≅ 80 %)
Mid-season stage	This period starts at the end of crop development stage to the time of start of maturing /ripening/ of a crop as indicated by discolouring of leaves or leaves falling off. The crop is physiologically capable of the highest water use during this time. The crop coefficient is highest.
Late-season stage	This period starts at the end of mid- season stage until full maturity or harvest of a crop.

7.5 Irrigation Water Requirements (IWR)

Based on regular soil moisture record, irrigation water will be applied in equal amount to the water depleted from crop root zone. Amount of water to be applied to refill the depleted moisture will be equal to the value calculated for ETcrop in depth of water. The values of ETcrop will be calculated in two days interval and net and gross irrigation requirement in two days basis for the whole season will be calculated. The net irrigation water requirement can be calculated using Equation 14 below (FAO, 1998):

$$Net \quad irrigation = ET_a + L_R - Pe - - - - - - - -$$

Where:

Net irrigation	(mm/day)
LR	Leaching requirement, mm (=considered zero in this study)
Pe	Effective rainfall, mm (if exist)
ET_a	Actual evapotranspiration of crop, mm

Effective rainfall (the fraction of the total rainfall) will be calculated as in equation 14a and 14b (FAO, 1998):

$$Pe = 0.8P - 25 \quad if \quad P > 75 mm/month - - - - - - - - - - (14a).$$

$$Pe = 0.6P - 25 \quad if \quad P < 75 mm/month - - - - - - - - - - - - (14b)$$

Where:

P	precipitation (mm/month)
Pe	effective rainfall (mm/month)

The gross irrigation requirement can be calculated as: (FAO, 1998)– Equation 15:

$$Gross \quad irrigation = \frac{(ETa - Pe)}{Ea} - - - - - - - - - - - (15)$$

Where:

Gross irrigation	(mm/day)
Pe	Effective rainfall, mm (if exist)
Ea	Irrigation application efficiency (%)
ET_a	Actual evapotranspiration of crop, mm

Gross irrigation requirement in terms of volume of water per treatment to be applied will be calculated by multiplying the daily gross irrigation requirement with the average wetted area.

7.6 Irrigation Scheduling

Irrigation scheduling is concerned with the farmer's decision process concerning "when" to irrigate and "how much" water to apply in order to maximize profit. How much and how often water has to be given depends on the irrigation water need of the crop. Irrigation water need usually expressed in mm/day or mm/month. When, for example, the irrigation water need of a certain crop, grown in a hot, dry climate is 6 mm/day, this means that each day the crop needs a water layer of 6 mm over the whole area on which the crop is grown. This water has to be supplied by means of irrigation.

An irrigation water need of 6 mm/day, however, does not mean that this 6 mm has to be supplied by irrigation every day. In theory, water could be given daily. But, as this would be very time and labor consuming, it is preferable to have a longer irrigation interval. It is, for example, possible to supply 18 mm every 3 days or 30 mm every 5 days. The irrigation water will then be stored in the root zone and gradually be used by the plants: every day 6 mm. The irrigation interval has to be chosen in such a way that the crop will not suffer from water shortage. Agronomic practices for selected irrigated crops given in Annex G.

7.7 Irrigation Methods

The choice of irrigation method is site specific and depends on topography, the amount of water available, the quality of the water and soils, as well as economic and social considerations. Irrigation water must be moved from where it is collected or stored to the field where it is used. Irrigation water is therefore, applied to land by the following three general methods:

- Surface irrigation
- Sprinkler irrigation
- Drip irrigation systems

7.7.1 Surface Irrigation

Surface irrigation is the application of water to the fields at ground level. Either the entire field is flooded or the water is directed in to furrows or borders. Surface irrigation method involves applying water over the soil surface. The water is conveyed over the soil surface and infiltrates into the soil at a rate determined by the infiltration capacity of the soil. Surface irrigation methods include:

- Basin irrigation
- Border irrigation
- Furrow irrigation

However, in this guideline only furrow irrigation method is considered and described in detailed.

Furrow Irrigation

Furrows are small, parallel channels, made to carry water in order to irrigate the crop. The crop is usually grown on the ridges between the furrows. Furrow irrigation is one in which the entire plot is not flooded. This reduces evaporation losses, improves aeration of the root zone, less puddling of the soil surface and permitted earlier cultivation after irrigation. Besides, furrow prevents an accumulation of salt near the plant bases in areas where salt is a problem.

Figure 109: Shorter Furrow Irrigation (Farmers' Practice in Ziway)

Furrow irrigation is suitable for a wide range of soil types, crops and land slopes, as indicated below.

A) **Suitable crops**

Furrow irrigation is suitable for:

- Crops – especially row crops such as onion, cabbage, garlic etc.
- Crops that would be damaged if water covered their stem
- Crops that would be damaged by inundation, such as tomatoes, vegetables, potatoes, beans etc.
- Different fruit trees such as citrus, grape

Suitable Slopes

Uniform flat or gentle slopes are preferred for furrow irrigation. These should not exceed 0.5%. Usually a gentle furrow slope is provided up to 0.05% to assist drainage following irrigation or excessive rainfall with high intensity.

Suitable Soils

Furrows can be used on most soil types. However, as with all surface irrigation methods, very coarse sands are not recommended as percolation losses can be high. Soils that crust easily are especially suited to furrow irrigation because the water does not flow over the ridge, and so the soil in which the plants grow remains friable.

B) **Furrow Design and Layout**

Furrow length

Furrows length is determined by slope, the soil type, the stream size, the irrigation depth, the cultivation practice and the field length. The impact of these factors on the furrow length is discussed below.

Slope

Although furrows can be longer when the land slope is steeper, the maximum recommended furrow slope is 0.5% to avoid soil erosion. Furrows can also be level and are thus very similar to long narrow basins. However, a minimum grade of 0.05% is recommended so that effective drainage can occur following irrigation or excessive rainfall. If the land slope is steeper than 0.5%, then furrows can be set at an angle to the main slope or even along the contour to keep furrow slopes within the recommended limits. Furrows can be set in this way when the main land slope does not exceed 3%. Beyond this there is a major risk of soil erosion following a breach in the furrow system. On steep land, terraces can also be constructed.

Figure 110: Practical Furrow Slop Layout

Soil Type

In sandy soils water infiltrates rapidly. Furrows should be short, so that water will reach the downstream end without excessive percolation losses. In clay soils, the infiltration rate is much lower than in sandy soils. Furrows can be much longer on clayey than on sandy soils.

Stream Size

Normally stream sizes up to 0.5 l/s will provide an adequate irrigation provided the furrows are not too long. When larger stream sizes are available, water will move rapidly down the furrows and so generally furrows can be longer. The maximum stream size that will not cause erosion will obviously depend on the furrow slope; in any case, it is advised not to use stream sizes larger than 3.0 l/s.

Irrigation Depth

Applying larger irrigation depths usually means that furrows can be longer as there is more time available for water to flow down the furrows and infiltrate.

C) **Cultivation Practice**

Short furrows require a lot of attention as the flow must be changed frequently from one furrow to the next. However, short furrows can usually be irrigated more efficiently than long ones as it is much easier to keep the percolation losses low. Generally furrow length of 10–20 m is recommended for this technology.

Field Length

It may be more practical to make the furrow length equal to the length of the field, instead of the ideal length, when this would result in a small piece of land left over.

Furrow Shape

The shape of furrows is influenced by the soil type and the stream size.

Soil Type

In sandy soils, water moves faster vertically than sideways (= lateral). Narrow, deep V-shaped furrows are desirable to reduce the soil area through which water percolates. However, sandy soils are less stable, and tend to collapse, which may reduce the irrigation efficiency. In clay soils, there is much more lateral movement of water and the infiltration rate is much less than for sandy soils. Thus a wide, shallow furrow is desirable to obtain a large wetted area to encourage infiltration.

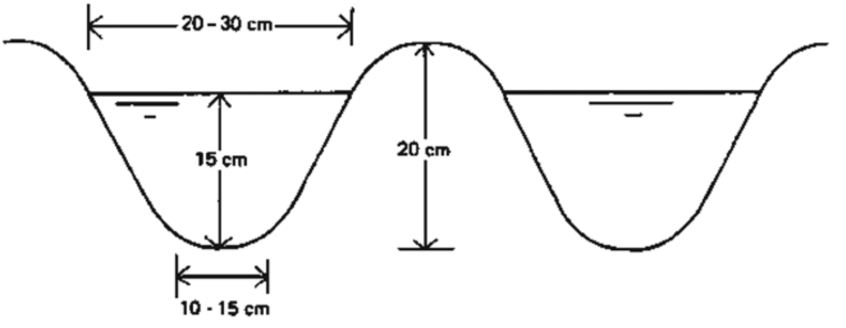


Figure 111: A Deep, Narrow Furrow on a Sandy Soil

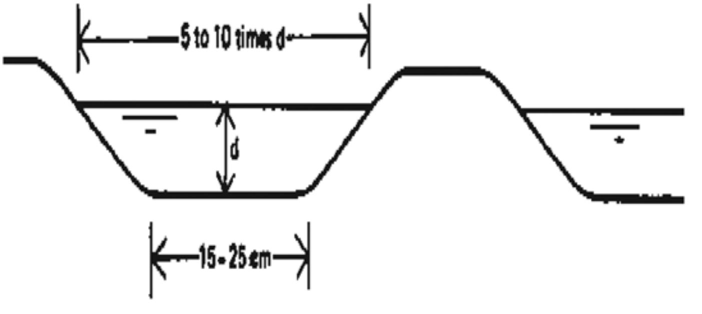


Figure 112: A Wide Shallow Furrow on a Clay Soil

Stream size

In general, the larger the stream size the larger the furrow must be to contain the flow.

D) **Furrow Spacing**

The spacing of furrows is influenced by the soil type and the cultivation practice.

Soil Type

As a rule, for sandy soils the spacing should be between 30 and 60 cm, i.e. 30 cm for coarse sand and 60 cm for fine sand. On clay soils, the spacing between two adjacent furrows should be 75 – 150 cm. On clay soils, double-ridged furrows (sometimes called beds) can also be used. Their advantage is that more plant rows are possible on each ridge, facilitating manual weeding. The ridge can be slightly rounded at the top to drain off water that would otherwise tend to pond on the ridge surface during heavy rainfall.

Figure 113: A Double-Ridged Furrow

E) **Furrow Construction**

The most common way to construct furrows is with a ridger. The following shows animal and hand-drawn ridgers.

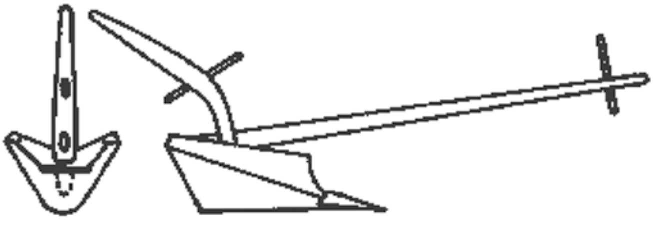


Figure 114: Ridger Plough: (a) Wooden Body, Animal-Drawn

Figure 115: Ridger Plough: (b) Iron Type, Animal-Drawn

Figure 116: Ridger Plough: (c) Hand-Drawn Version

Construction of Furrow on Flat or Mildly Sloping Land

The following steps are taken to construct furrows: setting out, forming one (or more) ridge(s); forming one (or more) parallel ridge(s).

Step 1

After deciding the furrow slop, length, width and depth a straight line is set out in the field along the proposed line of furrows. This can be done by setting up ranging poles or marking a line on the ground with chalk powder or small mounds of earth. An experienced ploughman should be able to plough along the line by aligning the poles or earth mounds by eye.

Step 2

The ridger is moved along the line. The resulting furrow should be straight. If not, the area should be ploughed again and the procedure repeated.

Step 3

About every 5m, a new straight line should be set out.

7.7.2 Sprinkler Irrigation

In the sprinkler method of irrigation, water is sprayed into the air and allowed to fall on the ground surface somewhat resembling rainfall. The spray is developed by the flow of water under pressure through small orifices or nozzles. The pressure is usually obtained by pumping. With careful selection of nozzle sizes, operating pressure and sprinkler spacing, the amount of irrigation water required to refill the crop root zone can be applied nearly uniform at the rate to suit the infiltration rate of soil (Figure 117).

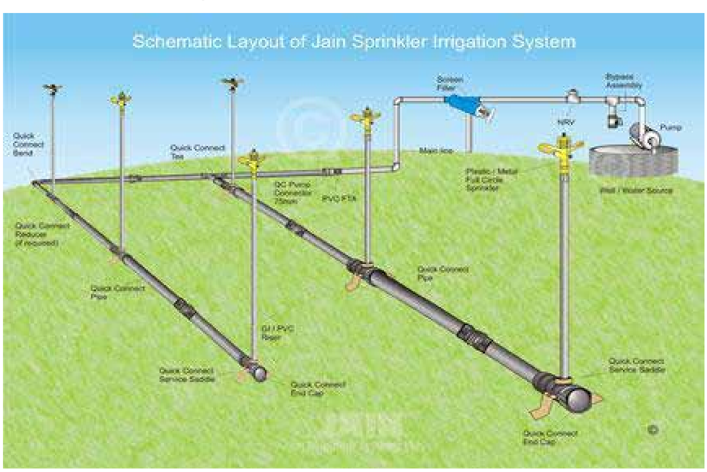


Figure 117: Sprinkler Irrigation using Several Rotating Sprinkler Heads or Spray Nozzles

Advantages of Sprinkler Irrigation

- Elimination of the channels for conveyance, therefore no conveyance loss
- Suitable to all types of soil except heavy clay
- Suitable for irrigating crops where the plant population per unit area is very high. It is most suitable for oil seeds and other cereal and vegetable crops
- Water saving (20 – 30%)
- May also be used for undulating area
- Saves land as no bunds etc. are required
- Areas located at a higher elevation than the source can be irrigated
- Possibility of using soluble fertilizers and chemicals
- Less problem of clogging of sprinkler nozzles due to sediment laden water

7.7.3 Drip Irrigation

Drip irrigation involves dripping water onto the soil at very low flow rates from a system of small-diameter plastic pipes fitted with outlets (drip emitters). The basic concept underlying the drip irrigation method is to supply the amount of water needed by the plant within a limited volume of soil and as often as needed. Water is applied close to the plant so that only that part of the soil immediately surrounding the plant is wetted. The volume of soil irrigated by each drip emitter and the water flow along the soil profile are a function of the characteristics of the soil (texture and hydraulic conductivity) and the discharge rate of the drip emitter. Applications are usually frequent (every 1 – 3 days) to provide a favourable moisture level for the plants to flourish. Compared to the sprinkler and furrow-irrigation methods (with efficiencies of 60 – 70% in high-management systems), drip irrigation can achieve 90 – 95% efficiency. Table 28 below shows comparative irrigation requirements for meeting crop demand with the different irrigation methods.

Table 28: Comparison of Irrigation Methods with Drip Method

Crop Water Demand	Drip Irrigation Requirement	Sprinkler Irrigation Requirement	Furrow Irrigation Requirement
3.0	3.3	4.3	5.0
3.5	3.9	5.0	5.8
4.0	4.4	5.7	6.7
4.5	5.0	6.4	7.5
5.0	5.6	7.1	8.3
5.5	6.1	7.9	9.2
6.0	6.7	8.6	10.0

Source: (Sijali, 2001)

Advantages of Drip Irrigation

More uniform and higher crop yields: With a drip irrigation system, irrigation takes place on a frequent basis, enabling the water manager to maintain the soil moisture at an optimum level. A well-designed, well-maintained drip irrigation system can also apply water more evenly than other irrigation methods. These features lead to uniform and higher crop yields per unit area of land.

More efficient use of available water: Precise water application with drip irrigation is possible making irrigation much more efficient. Direct water losses by evaporation from the soil surface and water uptake by weeds are reduced. Drip irrigation can reduce or eliminate runoff and deep percolation, making it possible to manage difficult soils ranging from crusting soils to porous sandy ones.

Reduced cost for fertilizer and other chemicals: Precise application of nutrients is possible using drip irrigation. Fertilizer costs and nitrate losses can be reduced considerably when the fertilizer is applied through the irrigation water. Besides fertilizers, other water additives such as herbicides, insecticides and fungicides can be supplied to improve crop production.

Reduced labor costs: Cultural practices such as weeding can be performed when the plants are being irrigated. Labor and operational costs can be reduced by simultaneous application of water, fertilizer, herbicide, insecticide or other additives through the drip system.

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.

Reduced salinity hazard: When the drip lines are placed close to a row of plants, the root zone tends to be relatively free of salt accumulations as the salts always accumulate towards the edge of the wetted area. Since the drip irrigation system can supply water frequently, the irrigation regime leaves a zone of wetted soil with a lowered salt content, which is beneficial for root activity. Furthermore, applying water directly on the soil surface eliminates the opportunity for salts to be absorbed through the leaves, as may occur in sprinkler irrigation.

Disadvantages of Drip Irrigation

Cost: Initial investment cost of drip irrigation systems is relatively high for smallholder farmers. However, recent advances have introduced some adaptations in the systems that are making them accessible to small-scale farmers. Accordingly, in Ethiopia there are simple drip irrigation systems which would cost a farmer about US$15 to cover 15m^2, and US$175 – 200 for a bigger system that can covering an area of 500 m^2.

Technical limitations: A higher level of management and maintenance is required with drip irrigation than other methods. Good water management under drip irrigation is essential as irrigating with more water than the plants require will result in the loss of most of the benefits of drip irrigation. Over-irrigation will also make the soil excessively wet and therefore promote disease, weed growth and nutrient leaching.

Clogging of emitters: This is the most serious problem associated with drip irrigation. Clogging causes poor water distribution along the drip laterals and this affects plant growth. To prevent blockage, care should be taken to filter the water properly before use, depending on the particular particle size and type of suspended material contained in the irrigation water.

Restricted root zone: Particularly in regions of low rainfall, plant root activity is limited to the soil zone wetted by the drip emitters. Thus, if a drip irrigation installation fails, the crops will suffer even more from drought than crops watered by sprinkler or surface irrigation. This is because under drip irrigation the confinement of roots to a relatively shallow profile means less available soil water storage for the plants.

Components of a Drip Irrigation System

There are different kinds of drip irrigation systems with varying components. However, the basic components of any drip irrigation system are the following (see also Figure 118).

- Water source–to provide the amount of water required at the necessary pressure to distribute and push water out of the drip emitters.
- Control valve–to open and shut off the water.
- Injection equipment–to apply fertilizers and other additives through the system (optional).
- Flow meter– to measure the amount of water moving through the system (optional).
- Filter– to remove particles from the irrigation water that may clog the drip emitters.
- Pressure regulator–to regulate water pressure (optional).
- Main and sub main lines–to carry and distribute water to the drip laterals.
- Drip laterals–to carry the water and distribute it to the drip emitters.
- Emitters–to control the flow of water from the laterals into the soil.

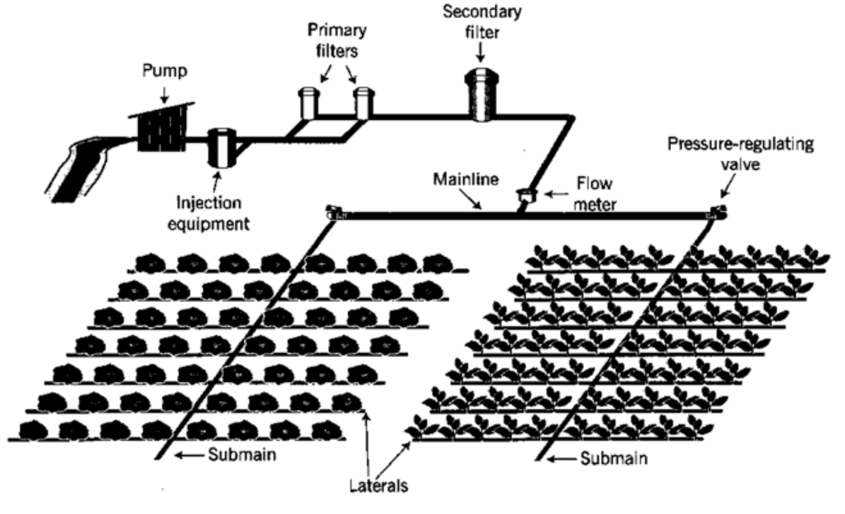


Figure 118: An Example for Drip Irrigation System Installation

Types of Smallholder Drip Irrigation Systems

For smallholder farmers, drip irrigation provides a means of maximizing returns on their cropland by increasing the economic biomass production per unit of water and increasing cropping intensity by also growing a crop during the dry season. Drip irrigation systems are normally used for row crops (vegetables, fruits and food crops). Characteristics of different categories of Smallholder drip irrigation are given in table 29.

Table 29: Characteristics of Different Categories of Drip Irrigation System (Family Drip)

System	Pressure requirement (m)	Area covered by individual system (m^2)
Bucket kits	0.5 – 1	<20
Drum kits	0.5 – 5	20 – 1000

Bucket Kits Systems

With bucket kit drip irrigation system, water flows into the drip lines from a bucket reservoir placed 0.5 – 1 m above the ground to provide the required water pressure. The efficient use of water that is possible with drip irrigation enables a farmer to grow vegetables using 30 – 60 litres of water daily during the crop-growing season.

The standard bucket kit system consists of two drip lines placed 0.5 m apart on a bed with a width of 1 m. A bucket is placed on a stand at one end of the bed and connected to the drip lines. These bucket kit systems with two drip lines can irrigate 30m2, depending on the length of the drip tube and plant spacing. The bucket should be filled once in the morning and once in the afternoon to supply 30 – 60 litres of water to the crop per day. The actual amount of water depends on crop water requirements and rainfall. In very dry areas and during the dry season 60 litres of water will be required per day. Layout for some most popular type of bucket kit drip irrigation system adopted in many countries is given in figure119.

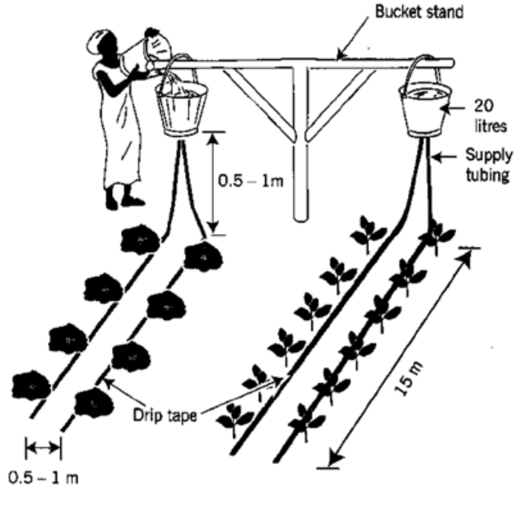


Figure 119: Bucket Kit Drip System

Drum Systems

Drum systems operate under a low-pressure head of water (0.5 – 5 m). Mounting the drums on block supports raised at least one m above the planting surface is recommended. The higher the drum is placed the greater the area that can be irrigated. An area of up to 1,000 m2 can be covered by a drum system.

The main advantage of drum systems is the bigger area that can be covered compared to the bucket system. This presents an economic advantage because of the number of plants per drum system. A drum system covering 5 beds each 1 m wide and 15 m long can be used to grow 250 plants (tomato, eggplant and similar plants requiring a spacing of 60 cm along the plant rows); 500 plants (spinach, cabbage, kale, peppers and similar plants requiring a spacing of 30 cm along the plant rows); or 1,500 plants (onion, carrot and similar plants requiring a spacing of 10 cm).

The standard drum kit system comprises a drum, control valve, a manifold and drip lines. The drum should be filled with the valve in the closed position. To irrigate it is important to open the valve fully. This allows the water to be distributed quickly through the drip lines and allows for good water distribution. Layout for some most popular type of drum kit drip irrigation system adopted in many countries is given in figure120.

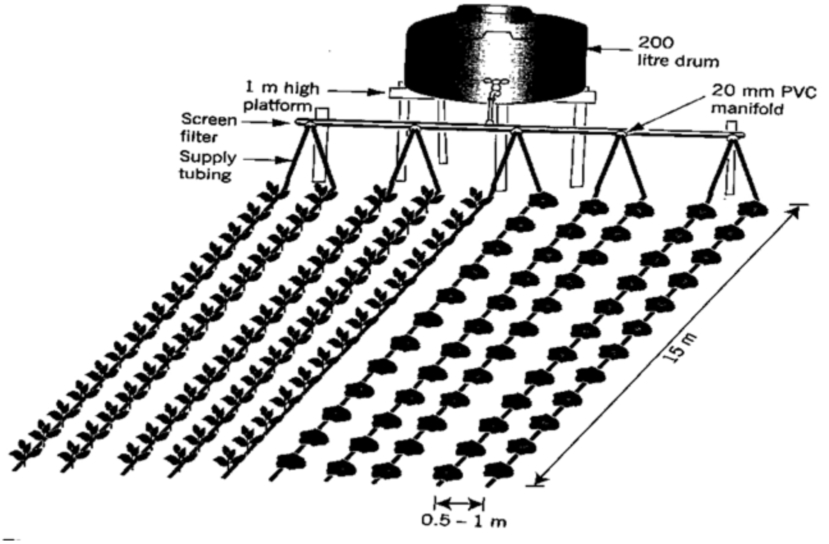


Figure 120: Drum Kit Drip System

CHAPTER 8

ARTIFICIAL RECHARGE TO GROUNDWATER

8.1 Introduction

Rain forms the most important natural source of water. Rain that falls on the earth's surface can do one of the three things:

- it may evaporate quickly
- it may seep into the soil
- it may run off the surface

If the water evaporates, it is lost into the atmosphere (though it may fall again somewhere else as rain). If the water seeps in, it may stay in the soil where plant roots can reach it. Or it may filter further down in to the ground to recharge groundwater. This water may be reached by deep-rooted plants, or it may reappear at a lower surface lower down as a spring or people can tap it by digging wells. Runoff either evaporates, or penetrates the surface to become groundwater.

Groundwater is one of the important sources of water for irrigation. With increasing irrigation schemes and urbanization depletion of groundwater resources is inevitable. It is very evident to see from the number of failing bore wells/HDW that their water table is lowering and pumps are stop pumping. To reverse the trend or to reduce the effect of over exploitation, techniques which can enhance groundwater recharge need to be promoted along with groundwater development. The basic purpose of artificial recharge of groundwater is to restore supplies from aquifers depleted due to excessive groundwater development. There are many methods of groundwater recharge. This chapter is therefore presents some important artificial methods for recharging groundwater.

Artificial recharge techniques normally address to following issues:

- To enhance the sustainable yield in areas where over-development has depleted the aquifer.
- Conservation and storage of excess surface water for future requirements, since these requirements often changes within a season or a period.
- To improve the quality of existing groundwater through dilution.
- To remove bacteriological and other impurities from sewage and waste water so that water is suitable for re-use.

8.2 Concept of Recharging Groundwater Reservoir

The sub-surface reservoirs are very attractive and technically feasible alternatives for storing surplus runoff. The sub-surface reservoirs can store substantial quantity of water. The sub-surface geological formations may be considered as “warehouse” for storing water that come from sources located on the land surface. Besides suitable lithological condition, other considerations for creating sub-surface storages are favourable geological structures and physiographic units, whose dimensions and shape will allow retention of substantial volume of water in porous and permeable formations.

The sub-surface storages have advantages of being free from the adverse effects like inundation of large surface area, loss of cultivable land, displacement of local population, substantial evaporation losses and sensitivity to earthquakes. No gigantic structures are needed to store water. The underground storage of water would also have beneficial influence on the existing groundwater regime. The deeper water levels in many parts of the country, either of natural occurrence or due to excessive groundwater development, may be substantially raised, resulting in reduction in lifting costs and energy saving. The effluence resulting from such sub-surface storage at various surface intersection points in the form of spring line, or stream emergence, would enhance the river flows and improve the presently degraded ecosystem at large.

8.3 Basic Requirement for Artificial Recharge

8.3.1 Source and Water Availability

The availability of surplus surface runoff water is one of the prime requisites for groundwater recharge. This component can be assessed by analyzing the rainfall pattern, its frequency, number of rainy days, and maximum rainfall in a day and its variation in space and time. The variations in rainfall pattern in space and time, and its relevance in relation to the scope for artificial recharge to sub-surface reservoirs can be considered for assessing the surplus surface water availability.

8.3.2 Hydro Geological Aspects

Detailed knowledge of geological and hydrological features of the area is necessary for adequately selecting the site and the type of recharge structure. In particular, the features, parameters and data to be considered are: geological boundaries; hydraulic boundaries; inflow and outflow of waters; storage capacity; porosity; hydraulic conductivity; transmissivity; natural discharge of springs; water resources available for recharge; natural recharge; water balance; lithology; depth of the aquifer; and tectonic boundaries. The aquifers best suited for artificial recharge are those aquifers which absorb large quantities of water and do not release them too quickly. Theoretically this will imply that the vertical hydraulic conductivity is high, while the horizontal hydraulic conductivity is moderate. These two conditions are not often encountered in nature.

The hydro geological situation in each area needs to be appraised with a view to assess the recharge capabilities of the underlying hydro geological formations. The unsaturated thickness of rock formations, occurring beyond 3 m below ground level should be considered to assess the requirement of water to build up the sub-surface storage by saturating the entire thickness up to 3 m. below ground level. The upper 3 m of the unsaturated zone is not considered for recharging, since it may cause adverse environmental impact e.g. water logging, soil salinity, etc.

8.4 Artificial Recharge Techniques and Designs

Wide spectrums of techniques are in use to recharge groundwater reservoir. Similar to the variations in hydro geological framework, the artificial recharge techniques too vary widely. Artificial recharge techniques commonly used in various countries are presented in this section.

8.4.1 Ditch and Furrow Method

In areas with irregular topography, shallow, flat-bottomed and closely spaced ditches or furrows provide maximum water contact area for recharge water from source stream or canal. This technique requires less soil preparation than the recharge basins and is less sensitive to silting. Figure 121 shows a typical plan or series of ditches originating from a supply ditch and trending down the topographic slope towards the stream. Generally, the following three patterns of ditch and furrow system are adopted (Figure 121).

- Lateral Ditch Pattern
- Dendritic Pattern
- Contour Pattern

Site characteristics and design guidelines

- Ditches should have slope to maintain flow velocity and minimum deposition of sediments.
- Ditches should be shallow, flat-bottomed, and closely spaced to obtain. Maximum water contact area. Width of 0.3 to 1.8 m. are typical.
- A collecting ditch to convey the excess water back to the main stream channel should be provided.

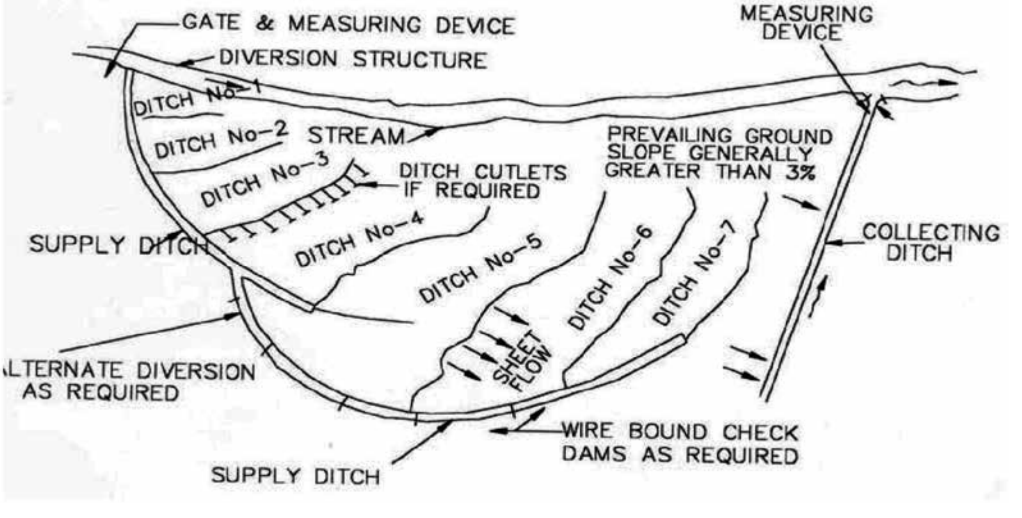


Figure 121: Ditch and Furrow Recharge Method

8.4.2 Percolation tanks (PT) / Spreading Basin

These are the most prevalent structures in many countries as a measure to recharge the groundwater reservoir both in alluvial as well as hard rock formations. The efficiency and feasibility of these structures is more in hard rock formation where the rocks are highly fractured and weathered. Percolation tanks are also constructed to recharge deeper aquifers where shallow or superficial formations are highly impermeable or clayey with certain modification (Figure 122).

Figure 122: Percolation Tank (Spreading Basin)

For area with small catchment like individual houses, a hand dug percolation pit with the help of an augur and filled up with pebbles and river sand on top can be made. The depth of these pits will be anywhere between 4 and 8 m depending on the nature of the soil. If the soil is clayey, the pit has to be dug to a depth till a reasonably sandy stratum is reached. The diameter of these pits will be 25 cm (10 inches) (Figure 123).

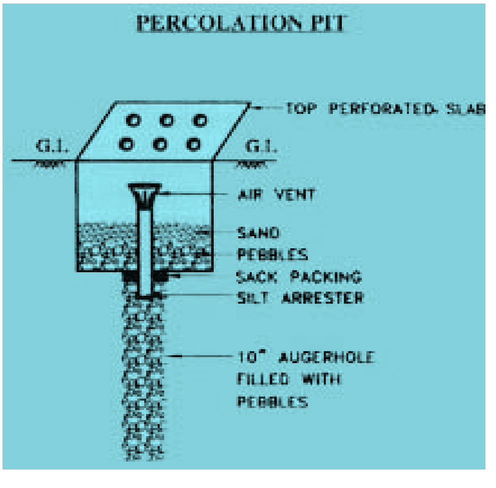


Figure 123: Percolation Pit

8.4.3 Modification of Farm Ponds

The existing earthen farm ponds, which are often silted up or damaged, can be modified to serve as recharge structure. Village level structures can be converted into a recharge structure by modifying to enable use for recharge purpose. Several such structures are available which can be modified for enhancing groundwater recharge (Figure 124).

Figure 124: Modified Farm Ponds

8.4.4 Recharge of Dug Wells

In alluvial as well as hard rock areas, there are thousands of dug wells, which have either gone dry, or the water levels have declined considerably. These dug wells can be used as structures to recharge the groundwater reservoir.

Storm water, tank water, canal water etc. can be diverted into these structures to directly recharge the dried aquifer. By doing so the soil moisture losses during the normal process of artificial recharge, are reduced. The recharge water is guided through a pipe to the bottom of well, below the water level to avoid scouring of bottom and entrapment of air bubbles in the aquifer. The quality of source water including the silt content should be such that the quality of groundwater reservoir is not deteriorated. Schematic diagrams of dug well recharge are given in figure 125.

In urban and rural areas, the roof top rainwater can be conserved and used for recharge of groundwater. This approach requires connecting the outlet pipe from rooftop to divert the water to existing wells/ tube wells/ bore wells or specially designed wells. The urban housing complexes or institutional buildings having large roof areas can be utilized for harvesting roof top rainwater for recharge purposes.

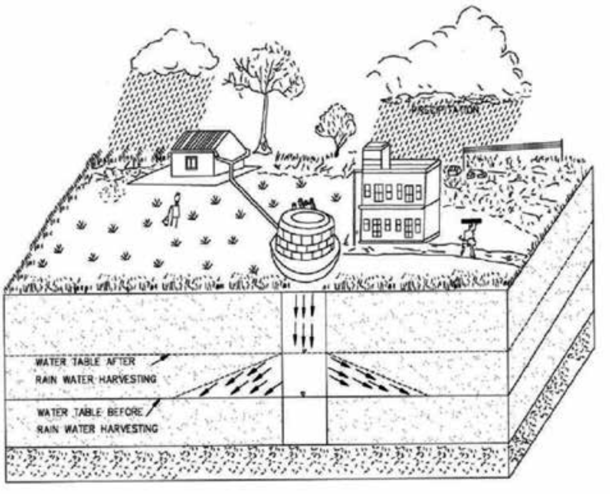


Figure 125: Recharge Dug Wells

Recharge Shaft

These are the most efficient and cost effective structures to recharge the aquifer directly. These can be constructed in areas where source of water is available either for some time or perennially. The recharge shafts can be constructed in two different ways vertical and lateral. The details of each are given in the following paragraphs.

Vertical Recharge Shaft

The vertical recharge shaft can be provided with or without injection well at the bottom of the shaft (Figure 126).

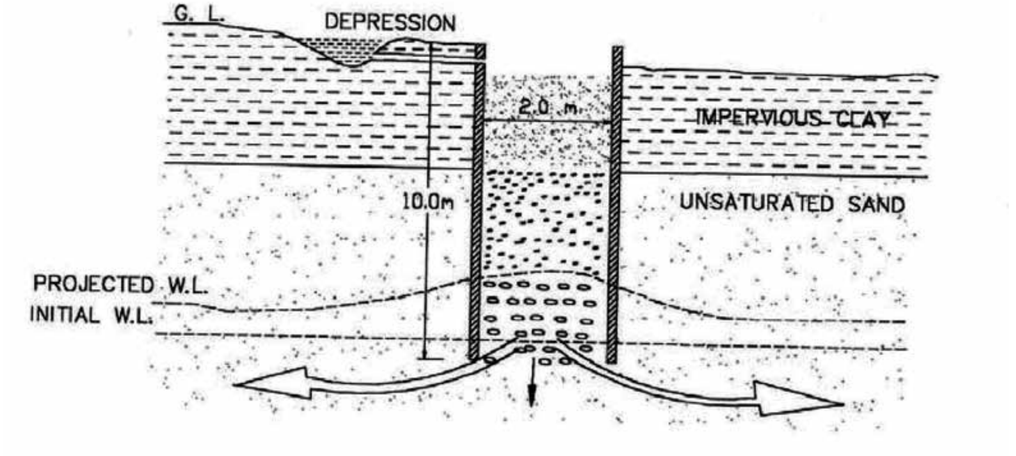


Figure 126: Vertical Recharge Shaft without Injection Well

With Injection Well

In this technique, an injection well of 100 – 150 mm diameter is constructed at the bottom of the shaft piercing through the layers of impermeable horizon to the potential aquifers to be reached about 3 to 15 m below the water level (Figure127).

- Ideally suitable for very deep water level (more than 15 m).
- Aquifer is overlain by impervious thick clay beds.
- Injection well can be with or without assembly.
- The injection well with assembly should have screen in the potential aquifer at least 3 – 5 m below the water level.
- The injection well without assembly is filled with gravel to provide hydraulic continuity so that water is directly recharged into the aquifer.
- The injection well without assembly is very cost effective.
- Depending upon volume of water to be injected, number of injection wells, can be increased to enhance the recharge rate.
- The efficiency is very high and rate of recharge goes even up to 15 lps at certain places.

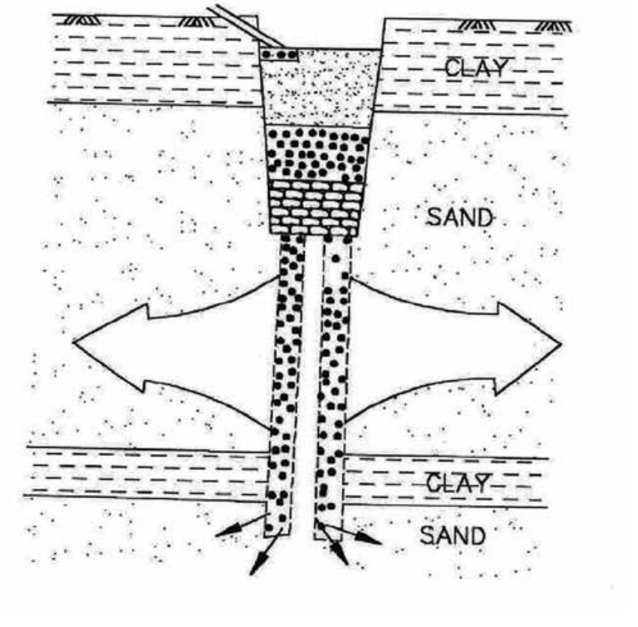


Figure 127: Vertical Recharge Shaft with Injection Well

Lateral Recharge Shaft

- Ideally suited for areas where permeable sandy horizon is within 3 m below ground level and continues up to the water level – under unconfined conditions (Figure 128).
- Abundant water available can be easily recharged due to large storage and recharge potential.
- Silt water can be easily recharged.

- 2 to 3 m wide and 2 to 3 m deep trench is excavated, length of which depends on the volume of water to be handled.
- With and without injection well.

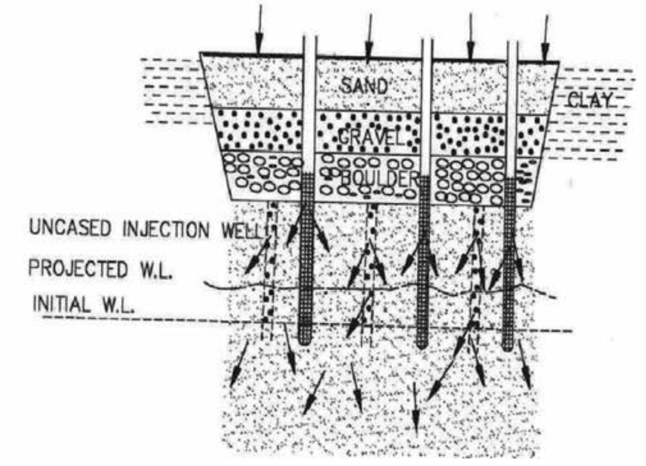


Figure 128: Lateral Recharge Shaft

CHAPTER 9

IRRIGATION EXTENSION SERVICE FOR SMALL-SCALE HOUSEHOLDS

9.1 Introduction

Ethiopia is one of the fastest growing economies in the world with double digit growth of close to 11% for a decade. The overarching objective of Ethiopia's national development strategy, the Second Growth and Transformation Plan (GTP II) is the realization of Ethiopia's vision of becoming a lower middle income country by 2025. Thus, GTP II aims to achieve an annual average real Gross Domestic Product (GDP) growth rate of 11 percent within a stable macroeconomic environment while at the same time pursuing aggressive measures towards rapid industrialization and structural transformation. Despite the marked reduction in the country's poverty levels, an estimated 23 million of the population continue to live below the poverty line for various reasons. Key among these are low agricultural sector production and productivity, low domestic resource mobilization, high levels of unemployment, especially among the youth, poor quality and inequitable distribution of basic social services, low access to finance, and a poor private business climate. Notwithstanding these challenges, Ethiopia has favourable economic opportunities and prospects. The country has abundant natural resources, a low cost and trainable labor force, an emerging middle class, and a developmental state with an ambitious vision, commitment, and strong sense of policy ownership.

Measures of human development have improved but remain unacceptably low. Poverty and food insecurity are concentrated in rural areas. The agricultural sector, critically important to both overall economic performance and poverty alleviation, has performed strongly over most of the last decades, but there is still substantial scope to sustainably improve productivity, production and market linkages. Building on GTP I, GTP II aims to transform Ethiopia into an industrialized middle-income country by 2025. This transformation will be promoted by pursuing; maintaining an annual average real GDP growth rate of at least 11%, pursuing aggressive measures towards rapid industrialization and structural transformation; and ensuring the sustainability of growth by fostering a stable macro-economic framework and climate resilient green economy. Ethiopia plans to become a middle-income country by 2025. Among other things, this will entail significant investment in agricultural transformation, and improved access to quality basic services. Agro-based industrialization will be accelerated and the role of the private sector expanded across all economic sectors. Attaining food security will be emphasized through GTP II.

The agricultural extension system is a major element of the agricultural and rural development strategy. Appropriate technologies need to be disseminated through a strong agricultural research and extension system. The lead technologies in this regard are improved seed, fertilizer, irrigation, marketing etc. The extension system has federal and regional dimensions. Core institutions are the Agricultural Technical, Vocational and Education Training College (A-TVET) centers and the Farmer Training Centers (FTCs). These institutions are currently functioning to produce, as well as use, the human capital that is embodied in DAs. A-TVETs train DAs and the DAs in turn use FTCs train farmers. At present, the agriculture office at the kebele level is staffed with three DAs. These DAs are responsible to provide extension service in their area of assignment, plant science, animal science and natural resources.

9.2 Need Assessment

Need is simply defined as a gap between the present situation and a desired future expectation. It is simply what is and what should be in the future. Need assessment is very crucial to understand the livelihood situations, problems and potentials of the local community to build on their existing activities in fighting against their low level of livelihoods. Like any other development activities, manual drilling includes several activities such as investigating groundwater, drilling/ digging, developing, pumping and irrigating, etc.

The irrigation extension service is therefore, required to work closely with irrigators so that they can confidently own the development, wisely use their labor, upgrade indigenous knowledge, efficiently use water resources and ultimately improve their income and livelihood. Moreover, carrying out participatory need assessment can have several advantages such as:

- helps to ensure the implementation of bottom-up extension services
- helps to gain farmers participation
- ensures proper targeting
- develops farmers and professionals' accountability

9.3 Awareness Creation

It is obvious that the central focus of this guideline is to help farmers to carry out their own manual drilling, which is cost effective and could be implemented with the existing labor within the community. The construction of well, using manual drilling techniques is new to our country and it requires wide range of awareness creation program for its wide adoption. Thus, communities need to get appropriate information at the right time to reach at his own decision. It is necessary to carry out repeated meeting programs and various workshops within the Kebeles at various villages where the potential for groundwater development using simple sludge tube well drilling techniques is expected high.

The agricultural DAs in consultation with Kebele sub-zonal leaders and/or Kebele leaders has to facilitate the arrangement for workshop and/or necessary meeting program. Based on the agreement made to carry out the program arrangement the DA should make full preparation on the subject matter. She/he needs to give clear and precise information about manual drilling, its purpose, the key steps in implementing the manual drilling and expected outputs. He can support his idea by locally prepared aids such drawing.

During the initial stage of manual drilling training program, it is advisable to have participants from different social classes such elders, religious leaders, Kebele administrators etc. to create common understanding among all community members. This will give you an opportunity to collect views and opinions from different angles in line with the issues and challenges that might face in the future.

Thus, the main objective of the workshop would be:

- to deliver necessary information to different community members
- to identify interested groups and to access their opinion to implement manual drilling
- to identify problems & needs of target groups and encourage their active participation in the implementation of the manual drilling
- to discuss and decide appropriate way of group formation to facilitate the drilling process

Farmers can hear about innovation through various means such as from their neighbors, relatives and/or can see and learn from roadside demonstration and then develop an interest to get detail information about the technology. Only awareness creation may not be adequate to give all necessary at various stages to initiate their involvement in technology adoption. It is critically important to give farmers with relevant knowledge, skill, assistance and support on continuous base to enable them reach at final decision whether to accept or reject the new technologies. You have to go through all the stages of adoption process and work hard to fulfill farmers' various requirements at different levels to put them in the right truck of adoption decision.

9.4 Base Line Survey

Baseline survey is critically important to obtain detail information about the specific area that can be used as primary input while conducting impact assessment study. In addition, it will help to identify the social and economic conditions of the interested groups as well as the whole community and their farming practices. Therefore, following the awareness meeting, you need to carry out baseline study within the expected area to identify the existing opportunities that can facilitate or encounter the implementation manual tube well irrigation project. At this stage, information related to the existing resources, strengths, weakness, opportunities and threats will be collected. The following are some important checklists:

- Natural resource conditions in the area (vegetation, soil types, farm land, surface water resource (river, spring, lake, etc.), groundwater condition, etc.
- Available resources/assets all those local resources such equipment, implements as well as indigenous knowledge that can help you to begin the manual drilling. By identifying these resources, it is possible to plan for additional equipment, tools and materials, etc., needed from other places.
- Labor availability: Tube well drilling is labor intensive and hence it is important to identify the availability and/or shortage of labor that can help to decide the number of wells to be drilled in a given area or time. Identifying the availability of local artisans who had experience on hand dug well development would be important for up scaling of the technology.
- Social consideration in relation to religion places, market places, school and/or any other social issues.

9.5 Gender Analysis

The gender approach focuses on men and women and the relationships between them. In case of introducing and promoting irrigation technologies, it is based on the premise that women and men are involving in various steps through specific from of family gender relation. The focus on gender analysis is for women and men effectiveness and efficiency of irrigated intervention. Understanding meaning of gender relation how family members particularly men and women operates, decide on allocation resource and gains benefit is vital to make use of available technologies and sustained adoption. Acknowledging the gender based organization of productive and reproductive activities entitled to women and men is usefully to identify their differential needs and interests as well as opportunities for improvement.

The agricultural DAs in collaboration with woreda gender expert or Women and Childers affaires office conduct quick gender analysis. It is to done with selected Male and Female households where the tub well is proposed to be introduced and promoted. Group composition should include married and FHH and advisable to work with male and female separate groups

Major Areas of Analysis

Activity Analysis: This includes productive activities related to irrigation by using tube wells as a source of water and major domestic activities (family care, water fetching, cooking etc.). Activity analysis showsperiods of labour accessibility/shortage and identifies all computing tasks.

Key questions to be asked: Who does what, when, where for how long?

Table 30: Template for Activity Analysis

List of Activities	Participating Family Member				When	Where	For How Long
	Adult (female)	Adult (male)	Boy	Girls			

Resource Analysis: Who has access to or control over resource for production. Resource includes all the production resources including land, capital labor other inputs (seed fertilized, extension services, credit and market information). Control means who decides whether and how a resource is used, and allocated. Access refers to the freedom permission to use resource.

Table 31: Template for Resource Analysis

List of Resources	Access to Resource		Control over Resource		Reason for Lacking Access	Reason for Lacking Control over Re-sources
	Male	Female	Male	Female		

Benefit Analysis: who benefits from the intervention. This includes all the end users of the product as home consumption, sale, income from sale, change in the farm labor process such as reduced labor demand and reduced risk.

This can be used to monitor and measure the promotion of low-cost technology (tube well), through proper targeting, equitable service delivery and employment of convenient approach

Table 32: Template for Benefit Analysis

List of Items	Change in Practice		Progress on Control over Resource		Reason for Lacking Access	Reason for Lacking Control over Resources
	Male	Female	Male	Female		
e.g. contribution of tube well to minimalize timing of irrigating crop						

Once the analyses are completed, the development agent will have expected to prioritize key gender issues. Then based on the priority possible to easily identify the appropriate timing for male and female participation, kind of capacity building support needed for male and female and design convenient approached based on the output form the activity and resource analysis. The analysis finding can also be used for targeting purpose and identifying activities to increase efficiency of sustained adoption the technology under promotion.

9.6 Selection of Target Beneficiaries

The problem of water shortage for agriculture and water supply for human and livestock is critical issue for all households living in moisture deficit areas. Because of limited resources, it may not be possible to work with all these households at the same time. Therefore, you need to select your target groups to manage and coordinate the program for better achievements. Based on the following criteria, you can carry out appropriate beneficiaries' selection to work effectively and efficiently to achieve your goal. Manual drilling is implemented based on households' approaches. Thus, household will be used as an entry point and contact farmers for the introduction and promotion of manual drilling. However, other surrounding farmers who are interested to accept the technology can be organized into groups to carry out their own drilling by themselves. The contact farmers should give necessary assistance to the contact farmers while they are exercising their own manual drilling and using the water for irrigation development.

In general, you can use the following proposed criteria (plus your own) to identify your target groups.

- Volunteer participants in involving irrigated farming and whose irrigable land is located in an area where the groundwater is shallow (static water level not deeper than 20 m) and the potential well site is not stony.
- Potentially strong, hard worker and readiness to accept technical advice from front line workers.
- He has to accept failure as learning process, rather than pointing his/her finger at someone else.
- He has to have adequate and adjacent farm land to the irrigation point, to avoid extra cost to take the water long distances.

- Adequate family labor fully to cover the labor requirement and/or resources/capital to cover the expensive for labor and materials for manual well drilling and pump facility.
- He has to be socially accepted person to create fertile condition for the dissemination of the technology among different community members.
- Willingness to share his/her knowledge and skill to his/her colleagues.
- Willingness to assist technically others farmers in irrigating as well as handling their motor pump appropriately.

9.7 Beneficiaries Socio-Economic Data

Pre and post program beneficiaries' data are important to identify the impacts obtained as the results of implementing the program. It shows the difference between your initial and final destination. This clearly indicates the real socio-economic change you gained to improve the livelihoods of the target groups, which could be either positive or negative. In line with this, you have to carefully collect socio-economic data of each beneficiary which includes data related to beneficiary name, his/her Kebele, family size, land size (rain fed and/or irrigable), livestock holdings, yield obtained and income attained. For details see Annex H.

9.8 Survey for Manual Drilling Tools and Equipment

Appropriate arrangement need to be made for target households/groups to get the necessary equipment at their locality without wasting too much time in searching of tools, equipment and implements. In line with this, the DAs should carry out survey on the availability of working tools and equipment in the area and if there is a limitation, he/she has to work on establishing new supplier and/or strengthening the existing ones.

9.9 Manual Tube Well Drilling Extension System and Approach

There is dichotomy between extension driven adoption of modern inputs, on the one hand, and community driven local public goods, on the other hand. Despite the obvious trade-offs between these two approaches, the target populations often have a possibility to express their preference between the two. The widely used extension approach in Ethiopia, referred to as Participatory Demonstration and Extension Training System (PADETS),flashes both at extension driven adoption of modern inputs and community driven local public goods. PADETS emphasizes farmers' demonstration plots, and is based on the provision of input credit in collateral arrangements, institutional linkages with rural development committees and systematic inclusion of women and the young. It focuses on food crops that are included in the extension packages; high value/commercial crops include coffee, onions, tomatoes, cabbages, carrots, sweet potatoes and fruit crops. Packages also include artificial fertilizer and improved seeds as well as irrigation agriculture. There are also packages in post-harvest activities and natural resource utilization and conservation.

Extension comes in many sizes and shapes. Although the following classification, made primarily for tube well irrigation agriculture is not complete and the distinctions between the types are not absolute, it gives an idea of the possibilities and opportunities that exist for the tube well irrigation extension planner and decision-maker.

- **Participatory Tube Well Irrigation:** this approach is often applied in a place where farmers seek alternative technologies to access and save water for different household consumption.

Farmers' need and feasibility assessment reveals which irrigation technology can be best fitting. Participatory tube Well Irrigation Extension goal here is to increased production and improve household quality of life. Based on the water yield, tube well technologies can use for irrigation purpose. However, location of a well is mainly determined by the well's purpose. For drinking and irrigation water production wells, groundwater quality and long term groundwater supply are the most important considerations. Hydrogeological assessment is helpful to determine whether and where to locate a well should always be done by a knowledgeable driller or professional consultant to avoid unnecessary costs and risk of drilling. Another important issue under this approach is the water quality criteria to use for drinking or not this should of course fulfil minimum drinking water requirements by the authority. For irrigation wells, the primary chemical parameters are of the concerns.

- **Tube well extension in Agricultural Commercialization Cluster/ACC:** national framework for Agricultural Commercialization Clusters (ACCs) has been developed. ACCs utilize practices that improve land productivity and reduce degradation, while focusing on specific commodities, geographies, markets and value-adding activities. In this way manual tube well drilling private sector and youth employment will be enhanced and increased incomes for rural populations realized. ACCs take a cluster-based approach to enhance existing initiatives focused on increasing crop and horticultural crop production and productivity, aggregation and market linkages. The key characteristic of this approach is that groups function for increased production extension, research, input supply, marketing and prices under one direction.

- **Tube well drilling cost Sharing:** This approach assumes that cost sharing with local people who do not have the means to pay the full cost for manual tube well drilling. Success is often measured by the willingness to pay. It develops tube well ownership when worked in group and ease tube well management and reduce conflict over resource.

- **Tube well drilling project approach:** this approach concentrates efforts on a particular location, for a specific time period. Part of its purpose is often to demonstrate techniques and methods that could be extended and sustained after the project period. Manual tube well drilling can be location specific based on groundwater availability, community demand, types of crops to be irrigated and market access.

- **Formation of working groups**

  Our country is rich to have a number of traditional social organizations such as Iquob for savings, Ider for burial organizations and Debbo (Jiggi/Guzza) for collective actions. These organizations play an important role in bringing together members of the same rural community in building up their social capital and to facilitate collective action to respond to specific development program. Basically manual drilling requires labor which could be covered from different sources such as family members, assistance to be made from relatives, labor share to be made from group members and/or daily laborers.

Manual drilling working group (people in a group) may be formed from two or more interested volunteer group members. Their number can vary from 5 to 7. Target groups who may develop interest to take part in the manual drilling may have similar or different preferences. Depending on their preferences, they can come together to form their own working group, which is critically important to share experiences, knowledge they gained from training during their practical work, share resources and to contribute for labor which is vital during well construction. In addition, it will assist the DAs to work effectively and efficiently in supervising and monitoring the manual drilling in accordance with its action plan. Depending on their specific choices and willingness to work with each other; target groups can form their own group to assist each other.

How to Organize Drilling

Organize unemployed male and female Youth micro enterprises and train tube well drilling techniques: Tube well drilling is new business opportunity for unemployed male and female youths in rural areas. Unemployed male and female youth have a lot of opportunities in manual tube well drilling technology. Such as; they can engage in tube well drilling micro enterprise, work on horticultural crop producer micro enterprise and they can also engage in tube well maintenance and operation service providers. Careful skill training is an important determinant of successful tube well drilling micro enterprise to provide quality services and make its way to a marketable business idea. Regional and zone irrigation bureaus and irrigation development partners should provide tube well drilling basic theory and practical skill training for reasonable number of days to organized tube well drilling micro enterprises. Successive supervisions and technical support is necessary to tube well drilling micro enterprises to avoid undesirable risks and conflicts. The supervision and technical back up is helpful to reduce erroneous well drilling and well spacing, assist efficient use of resources and build social accountability of well driller micro enterprises.

Grouping farmers' as well drillers: Interested and skilled development groups of one to five people or any similar group with of a manageable size can provide well drilling services for themselves and the local community. The group should however be given sufficient skill training and drilling tools and equipment. There are various types of farmer groups, including formal cooperatives, irrigation water user associations, farmers field schools, informal farmer associations or groups, multipurpose groups etc. The benefits of farmer groups among others include; making tube well drilling irrigation agriculture extension services more demand driven and efficient, focused production on high vale and commercial horticultural crops, effective use of irrigation inputs and output, economies of scale, facilitating savings and access to credit; and reducing public-sector extension costs.

Well Drilling Information and Planning: maintaining updated resource and user status assessments as basis for planning of well drilling and further intervention.

Well Drilling Survey and Development: undertaking basic field work and ensuring groundwater supply plans; recharge enhancement measures and demand management interventions.

Well Drilling and Groundwater Management Regulatory: working on resource monitoring, evaluation and regulation in groundwater use, well drilling spacing etc.

The following table summarizes consideration during groundwater use and well drilling.

Table 33: Groundwater Use and Well Drilling

OBJECTIVE OF INTERVENTION	MANAGEMENT PROCESSES & measures
Develop a Shared Vision of Well drilling and Groundwater Resource Availability & Use Priorities	• boundaries of groundwater body and any external influences • average order of annual groundwater replenishment • concept of available storage at onset of dry season • potential for artificial recharge enhancement • protection of quantity and quality of village water supply • implications for crop irrigation availability
Ensure Sustainable Community Participation	• establish community groundwater management committee with village level representatives, respecting local traditions/leaders • facilitate women's participation • involve community in data gathering • ensure two-way communication based on agreed information
Set-up Flexible Management Plan with Achievable Goals	• define an agreed participatory groundwater management plan, incorporating consideration for improving groundwater productivity and making real groundwater resource saving • promote grants/subsidies for approved real water-saving measures • remove subsidies for the growing of high water-use crops in dry season • (e.g. sugar cane, rice, bananas, maize) • periodically monitor groundwater resource status (quantity/quality)
Establish Enforceable Rules/Regulations*	• define realistic water-user entities (individual or aggregate depending on user profiles) • establish a comprehensive groundwater users inventory with active collaboration of community • identify acceptable proxy controls on groundwater use in situation when water abstraction metering is not feasible • introduce (and enforce with community support) indirect controls on • groundwater abstraction in heavily-committed aquifers (through ban on new • well drilling, restrictions on well spacing and constraints on electricity connections)

9.10 Conducting Training on Well Drilling and Irrigation Water and Crop Management

The training to be delivered for the target groups can be arranged in two different phases. These are the training to help them to engage themselves in manual drilling and the training related to high value crop production. The time for the training should be arranged differently in accordance with their plan of implementation.

9.10.1 Training on Manual Tube Drilling

Even though, the practice of machine drilling in Ethiopia is common in many parts of the country, the tube well drilling technique discussed in this guideline is new to Ethiopia. However, some countries in Asia as well as some countries in Africa, for example Sudan has been using this technology since very long time. As lesson learnt from these countries, to implement effectively the technology, appropriate and timely training on site selection, identifying working tools and equipment, well drilling, pump installation and maintenance and irrigation water management is required. Therefore, the training program should be managed as follows:

- Incorporating both the theoretical and practical training session on well drilling.
- The theoretical training session can be delivered at the FTCs training and/or any convenient place for the working group.
- The practical training can take place at one of the group members, well site. The site should be averagely at middle distance for all to avoid time wastage in travelling long distances by some of the other group members.
- All necessary materials to begin the practical work should be prepared before you engage yourself with the job.
- Punctuality should be strict among all participants to avoid waiting time for the others.
- Providing all practical training at once may be difficult for farmers to remember important points. To avoid such occurrence, it is necessary to give the practical training step by step rather giving the training at once.
- Reinforce your participants with what they have done in the previous phase and clearly tell/show them how and what they are going to do in the next phase.
- Ask one of the group members to repeat what you taught them before you directly begin the practical work.
- The success of the training delivered should also be evaluated and commented.

9.10.2 Training on Irrigation Water Management and High Value Crop Production

Initially, package including irrigation water management (how much, when, how and what to irrigate) and irrigation agronomic practices for selected high value crop should be prepared for sustainable adoption of the technology. Based on this package, training material should be produced to facilitate the training. This training is preferred to improve the competence (level of knowledge, skill and experience) of the target groups to produce the required quality of high value crops. The training should accommodate both the formal and non-formal to be delivered during on-job and in-house training. The success of the training at different levels should be also evaluated.

9.11 Problems Identification and Prioritization

We are now at the stage, to give necessary advice to farmers on how they are going to utilize the water for their final goal i.e. improving agricultural production and productivity. At this stage, two major activities are expected to be carried out. One is: need assessment and find out coherent problems. The second is to find out any possible alternative solutions (internal or external) to solve these problems. In order to carry out farmers' need assessments, DAs can make use of either of the following techniques:

- by participating on meeting and farm visit (gathering information about needs raised by farmers during extension events, meetings and farm visits)
- by conducting participatory rural appraisal techniques
- by carrying out problem and formal farmer information need survey

DAs can take a problem survey as an alternative means to assist farmers to analyze, plan and develop their agriculture activities through a focus group discussion where farmers identify their problems and suggest for possible solution through facilitation. For the consideration of the important points see Box below.

- Do not consider community as homogenous group, if you call different social classes with different needs and problems, you may not end. Thus, you need to organize the plenary group from the similar socio-economic background.
- Don't stick yourself to the formal way of doing things.During the Problem Survey process you should use informal approach to encourage farmers participation.
- To come up with clear and concrete need identification and prioritization stick your discussion to specific and clear topic, rather than using general topic.
- Appropriate environment needs to be created for farmers to encourage their participation in the discussion.
- You need to give feedback on the priority needs identified for plenary groups to get their final opinion.

The process for problem survey or census implementation needs to be passed through several steps, as given in table 34 you should go through them carefully to encourage community participation in their own problem identification.

Table 34: Steps for Problem Census Implementation

Steps	Specific Activities	Overall Activities
1	Organize a meeting	Arrange a meeting that can accommodate 20 – 30 farmers with similar farming background, preferably target group. Make the date, time and location appropriate for farmers.
2	Defining topic	Exhaustively work with the farmers to define a topic. It should be as specific as possible, rather than general one.
3	Form Sub-Groups, List Problems	Divide the plenary group into several sub-groups (most probably about 5 farmers per sub-groups). Provide each group with paper and pens. Ask them to list down the main problems they face in relation to the specific topic they identified under step 2.
4	Discuss Problems, Conclude	Bring the groups together to present their lists. Add the number of times each problem is mentioned by the sub-groups. With the group identify the top 5 important problems. Discuss 5 alternative solutions. Record the 5 problems in handbook. Explain that an activity will be planned for this group.

9.12 Organizing High Value Produces into Water Using Groups

In case, if the well yields sufficient discharge which is beyond the capacity of an individual household, depending on their willingness to work with each other, neighboring farmers can come together to form their own water use group. In addition, target groups with different water holes to form groups for various purposes. They may need to work in group for effective and efficient delivery of inputs and to strengthen their power to negotiate for appropriate markets. In this case, the DAs should assist these groups in legalizing the water users group.

9.13 Conducting Market Value Chain Analysis

Conducting market value chain analysis is necessary to give assistance for target groups in relation with high value crops and their products to market and to increase their income.

The potential for high value crop production in our country is only limited to irrigation practices which is very insignificant when it is compared with its overall domestic demand. In general, the production and marketing of various types of vegetables and fruits in our country indicates the existence of similar value chain with four different phases. It is important to know these phases in order to give appropriate technical assistance particularly in relation to market so that our target groups engage themselves with market oriented production system. High value crops value chains are given below:

9.13.1 Input

Unlike other crops, high value crops lack systematic arrangements for the provision of its necessary inputs at adjacent sites to farmers/producers. In addition to this, at some large cities, few agro-input supplying companies involve in the provision some seeds, pesticides and spraying equipment, irrigation equipment such as water pumps and other handle tools and implements. Inputs used for high value crops are mainly supplied through small agro-input stores that exist mostly at Addis and rarely at district levels. Cooperatives are rarely engaged in input provision of high value crops seeds. The seeds are both limited in amount and with less choice for varieties. The provision of fertilizer, which is mostly done through the cooperatives, does not fit with producer's demand. Fuel and equipment repair shops are critically lacking for diesel pump users. So in order to get all services /inputs/ farmers are forced to travel long distances by wasting their working time as well as their limited resources. In order to avoid such problems, it is critically important to encourage/strengthen the existing primary cooperative in the provision of necessary inputs for high value crops. DAs can play great role in facilitate the linkage between producers and cooperative by conducting his/her farmers timely needs assessment and reporting these needs to cooperative. In addition, cooperatives can also play crucial role to introduce and link the products to beneficiaries.

9.13.2 Production

Smallholder who owns very limited irrigable land between 0.25 – 0.5 ha mostly does the production of high value crops. Major activities to be carried out on this piece of land are uniform across different farmers at different parts of the country.

The knowledge about the agricultural production activities is critically important to DAs in several ways.

- It will help them to have their seasonal work plan and to assist farmers' preparation about their plan.
- Enables them to identify critical implementation problems.
- It enables them give necessary alternative solutions.

9.13.3 Wholesalers

Wholesaler is one of the important chains involved in high value crop chain analysis. Wholesalers mostly get their production from the producers and then distribute it to different social classes through home and/or street stalls. Identifying to strengthen and/or establish wholesalers within the production of high value crops is critically important to create fertile market situation for producers.

9.14 Marketing Linkage

Limited access to market is one of the key challenges facing the producers. This is common to all parts of the country. High value crops can be found in all markets of the country at different amount/level. However, the market situation does not favour the produces. High value crops (fruits and vegetables) are perishable. This character, limits producer capacity to negotiate for better price.

Market chain critically affects the moral of the producers and their effort to invest on manual drilling to produce high value crops. Most of the time, producers tried to manage this problem by adjusting their cropping pattern. However, this may not be enough solution for the existing market problems. In addition to this, DAs need to carry out several activities to improve the market problems. Look at the following Box to see detail activities for market improvement.

How Marketing can be improved?

- Organizing and strengthening producers into commercial marketing groups.
- Encouraging local processing and marketing skills to sell value added and diversified products (e.g. dried and powder tomato, packed potatoes cheeps).
- Identify and link farmers to new market outlets (local and regional).
- Critically investigate the economic relationship between producers and brokers to find an alternative solution:
    - if the economic relation is for mutual benefit it should be encouraged
    - unless it is unhealthy it should stopped
- Alternative solution must be provided to avoid the impact of unhealthy brokers relationship:
    - organizing youths and women into market group
    - encourage them to involve themselves in high value crops
    - facilitating credit service provision for these groups
    - encourage them to have their own saving and credit association

9.15 Facilitating the Provision of Necessary Inputs and Credit

Improving access to agricultural inputs and services is one of the key priorities for high value crop production. Adequate supply of necessary inputs such as seeds, pesticides and spraying equipment, irrigation equipment, water pumps, handle tools, implements, fuel and equipment repair shops are important to improve the production and productivity of high value crops. These inputs are/were ether inadequate in amount or limited in choice of varieties for farmers. In order to get these inputs, usually producers are forced to travel long distance, which affects their working time and as a result they will exposed to unnecessary extra-cost, which critically affects their final income. In order to improve such problems, strengthening of the existing farmer's cooperative and/or establishing new cooperatives would be advisable. In addition, DAs can play important role to carry out necessary survey to:

- identify appropriate cooperative in his/her surrounding that can fulfill the provision and distribution of inputs for high value crops
- facilitate the linkage between producers and cooperative by conducting his/her farmers timely needs assessment and reporting these demand to cooperative
- Following up the response given by the cooperative and delivering the feedback to the farmers/
- strengthening selected farmer cooperatives and establishing credit linkages with rural micro finance institutions
- linking the cooperative with other external services to strengthen their capacity

In addition, cooperatives can also have crucial role to act as market agent to promote and introduce farmers' products to consumers.

9.16 Monitoring and Evaluation Aspects

Effective and timely monitoring and evaluation of activities are important measures to provide necessary information to take timely decisions and actions. Monitoring is an inbuilt system within each activity. It is mostly carried out during the implementation of different activities, and usually it comes before evaluation to enable collect valuable information for the evaluation to take place. The purpose of monitoring may be:

- To give information and ideas on how to improve the management of the ongoing activities of manual drilling.
- Propose remedial actions when problems are detected in either in the implementation of the activities.
- Identify the follow up of activities needed to achieve the goal of the program.
- Plays crucial role to improve the planning of the future manual drilling activities.

Thus, monitoring will contribute for evaluation, if and only if the information will be reviewed to learn lessons. The information generated from both monitoring and evaluation will highly help to re-plan the manual drilling activity. Evaluation is a systematic assessment of the implemented activities of the manual drilling physical plan. As discussed earlier, need assessment targets in identifying key problems and alternative solutions to address the problems. Thus, evaluation should be carried out whether if these problems have been addressed or not and to what extent the problems have been solved. Thus, evaluation will be initiated to determine:

- Whether if manual drilling is relevant: performance evaluation, in relation totechnical, social, economic, environmental, etc.
- The overall plan and implementation of the activity is logical and still appropriate in the present situation.
- The planned activity is achieving its immediate objective and output, and if not, to identify the reasons.
- The planned activity is efficient enough in using an appropriate level of technology.

9.17 Reporting

Reporting is one of the important tools that ensure the implementation of monitoring process. Necessary format should be developed to initiate reporting process. Relevant data for regular reporting of the status of each activity should be included in the report. In line with this, each DA is responsible to carry out bi-weekly physical plan achievement report to his/her FTC. DAs are fully responsible to monitor his/her manual drilling site technically to assist his/her target groups.

Based on the data received from report system, evaluation program will arranged to take place bi-annually to see if the bi-annual physical plan are performed and achieved in accordance with its plan or not and if any further consideration will be required. The evaluation process may involve different staff from relevant Ministry of Agriculture (MoA) Directorates, Regional and District Experts.

Key stages for adoption of new technology and the role of DAs to move farmers towards appropriate decision is given in table 35.

Table 35: Adoption Stages and the Role of DAs

No	Stage	Beneficiaries Need	DAs Role
1	Awareness creation	They want to hear and get detail information about the new innovation	• Arrange for information meeting • Prepare clear and precise message to deliver necessary knowledge to your beneficiaries • Used local language , culture and social norms to communicate with your clients
2	Interest stage	They want to get additional information from DAs and/or other farmers like them	• Arrange for group meeting and group discussion • Provide your beneficiaries with necessary to building their desired attitude

3	Evaluation stage	They want practically to check whether if the new innovation will work within their environment or not	• Conduct demonstration which could be either result or method demonstration
4	Trial stage	They need to know how they can manage the new innovation to change their farm	• You need to deliver appropriate technical and management skill to farmers • Arrangement for learning by doing
5	Adoption stage	They need to get continuous assistance and support to incorporating with farming system	• DAs need to provide his/her beneficiaries with continuous assistance or support so that they will make use of the new technologies without any obstacles.

CHAPTER 10

ECONOMIC COST BENEFIT ANALYSIS OF IRRIGATION WATER SELF-SUPPLY FROM SHALLOW GROUNDWATER WITH MANUAL TUBE TECHNOLOGY

10.1 Introduction

Manual tube technology that enables the exploitation of shallow groundwater is one of the best technologies that aid to increase the coverage of irrigation-development per household. It enhances irrigation development by creating water source opportunity for irrigation as it goes with small holder's affordability and capacity of operation. Experience of east and west Hararge zones has shown that, manual well tube is one of the best technologies to enhance self-supply of water for irrigation.

Currently, irrigation opportunity is not access to all household farmers due to lack of alternative sources of irrigation water and means of lifting device water from nearby ground sources. In many parts of our country where shallow groundwater potential is available manual tube technology demand is growing due to a number of factors. Among these are; initial investment is so easy and the payback period is so short. Since the source of water is privately owned, there is no probability of conflict raised among the irrigation water users. It enables to speed up structural transformation as farmers engaged in irrigation development are doing their activities with the objective of maximizing profit margin from the economic activities they are engaged in. Economic advantage gained due to best alternative utilization of resources enables to speed up social Development such as increasing employment opportunities, education and health improvement.

One of the driving factors for speedy adoption of this technology is its attractive economic feasibility that speeds up economic structural transformation of rural society.

Details of cost benefit analysis of this technology have been portrayed as follows:

		
Groundwater exploration	*Groundwater exploitation*	*Groundwater supply for irrigation*

Figure 129: Shallow Groundwater Exploration and Exploitation

Shallow well groundwater resource exploration can be done by farmers who have been acquainted with endogenous knowledge assisted with development agents or small scale irrigation development assistant engineer.

*Once Ummer who lives in East hararge zone Babile district andErerIbada PA, was poor. He had lost all his summer rain fed agricultural crop due to **El-Niño**. There he had learned how to explore and develop shallow well water for irrigation. Now he is owner of farm irrigated by shallow well underground water.*

Cost Benefit analysis of investing on shallow groundwater irrigation

1. Fixed cost (initial investment cost)

Initial investment cost is a cost incurred to acquire fixed asset that enables lift water from shallow ground sources.

No	Material and Labor	Unit	Amount	Cost /Unit(ETB)	Total Cost(ETB)
1	PVC	4 inch	2	230	460
2	Pump	2 inch	1	24,000	23,000
3	suction hose	M	15	150	2,250

No	Material and Labor	Unit	Amount	Cost /Unit(ETB)	Total Cost(ETB)
4	Delivery hose	M	50	60	3,000
5	Labor	No	18	100	1,800
6	Professional advice	No	1	5000	6,000
	Total Cost	**ETB**	$\sum_{6}^{1} \quad 1+2+3+4+5+6 = 36{,}510$		

As it has been depicted on the above table, the total fixed cost required to invest on fixed asset of shallow groundwater lifting device for irrigation is found to be about ETB 36,510. After investing on this alternative source of water for irrigation farmers required to incur variable cost for irrigation Agricultural development.

2. Variable Cost (cost of irrigation agricultural development

Variable cost is a cost incurred through the process of operation of irrigation agricultural development. This cost varies through season of production based on type, intensity and farmer`s level of input utilization. Even though, irrigating capacity of a given shallow groundwater goes up to 5 ha of land, as the land holding capacity of household is only 0.5 ha, cost benefit analysis of this technology is executed based on 0.5ha of land.

Commonly irrigated horticultural crops by household irrigation are tomatoes, potatoes, peppers and onions. The following cost benefit analysis has been done on a half-hectare (0.5ha) of land on which tomato produced on first round and followed by pepper production in the rest rounds with in a given year (2008).

Table 36: Variable Cost of Tomato Production (per 0.5ha)

No	Activities	Unit	Amount	Cost/Unit	Total Cost
1	Land preparation	Round	6	500	3000
2	Improved seed	kg	2000		2,000
3	Seedling preparation	Labor	3	100	300
4	Cost of bed preparation	Labor	28	100	2,800
5	Planting	Labor	12	100	1,200
6	Fertilizer	Qu	2	1700	3,400
				102	
7	Fuel	lit		17	
				1,734	
8	Pesticide	lit/kg	1	600	600
9	Weeding/cultivation	labor	12	100	12,000
10	Harvesting	labor	20	100	1,600
	Total Variable Cost				**28,934**

Table 37: Variable Cost of First Round Production of Pepper (0.5 ha)

No	Activities	Unit	Amount	Cost/Unit	Total Cost
1	land preparation	Round	3	500	1500
2	land leveling	man, power	4	100	400
3	Ridge making	"	6	100	600
4	Fertilizer	Qu	1	1700	1,700
5	cost of seedling	Bed	3	180	540
6	Planting	man, power	7	100	700
7	Weeding	"	20	100	2000
8	Pesticide	Litre	0 .5	600	300
9	Fuel	"	60	17	1,020
10	Harvesting	man, power	30	100	3000
Total Variable Cost:					

Table 38: Variable Cost of Second and Third Round Harvest of Peppers (0.5 ha)

No	Activities	Unit	Amount	Cost/Unit	Total Cost
1	Fertilizer	Qu	1	1275	1,275
2	Weeding	"	20	70	1,400
3	Pesticide	Litre			1,390
4	Fuel	"	30	17	510
5	Harvesting	man, power	35	70	2,450
	Total Cost of 2nd and 3rd Round Harvest				**7,025**

In a ½ ha of land developed in shallow well irrigation water self-supply where tomatoes and peppers are produced in rotation pattern the total physical produced and revenue generated, cost incurred and annual marginal profit as of year 2008 production year has been analyzed as follows.

Table 39: Physical Product and Revenue Generation

No	Round	Type of Product	Total Product (0.5 ha/round)	Unit	Price/Unit (ETB)	Total Revenue (ETB)
1	First round	Tomatoes	175	qu	800	140,000
2	2nd round 1st-harvest	Peppers	22.5	"	3,500	78,750
3	2nd harvest	""	28 = 70.5	"	3,500	98,000
4	3rd harvest		20	"	3,500	70,000
	Total	Tomatoes and peppers	245.5			386,750

Table 40: Fixed and Variable Cost, Revenue Generated, Annual Marginal Product of Two Round and Four Harvest Irrigation Development by Manual Tube Well

No	Round	Fixed Cost (ETB)	Variable Cost (ETB)	Total Cost (ETB)	Revenue (ETB)	Profit/Round or per Harvest (ETB)
1	One harvest	36,510	28,934	65,444	140,000	74,556
2	Two harvest one	3,651	11,760	15,411	78,750	63,339
3	2nd harvest	3,285	7,025	10,310	98,000	88,770
4	3rd harvest		7,025	7,025	70,000	62,975
	Total	**43,447**	**47,749**	**98,190**	**386,750**	**289,640**

Table 41: Variable Cost of Production of Onion (Adama red and bombe red) (on ½ ha **of land)**

No	Costs	Unit	Amount	Unit Cost (ETB)	Total Cost (ETB)
1	***Seed***	***Kg***	***6***	***350***	***2,100***
2	***Fertilizer***		***4***		
	Diammonium phosphate (DAP)	qu	2	1554	***3,108***
	UREA	“	2	1298	***2,596***
3	***Chemicals***				
	Solectron	Litre	1	1350	***1,350***
	Hilarity	Litre	0.5	220	***110***
	Matko	Kg	1	300	***300***
	Rodmil MZ gold	Kg	1	140	***140***
	Fuels	Litre	525	19.2	***10,080***
	Oils	Kg	6	95	***570***
	Weeding and watering	No	168	70	***11,760***
	Harvesting	No	32	70	***2,240***
	Land plowing	hour	380	7	***2,660***
	Ridge making	hour	140	6	***840***
Total Cost					***37,854***

Table 42: Physical Product, Variable Cost Revenue and Marginal Product of Onion, Cabbage and Potatoes (Produced on a ½ ha of land by manual tube-well irrigation water supply)

No	Physical Output	Unit	Total Output	Total Cost of Production (ETB)	Unit Price (ETB)	Total Revenue (ETB)	Total Profit (ETB)
1	Onion	Qu	245	37,854	450	110,250	72,396
2	Cabbage	"	600	32,484	300	180,000	147,516
3	Potatoes	"	302	36,140	700	211,400	175,260
	Total	"	1,147	106,478		501,650	395,172

As it has been depicted on the above table investment on manual well tube which enables to exploit irrigation water from shallow ground is highly profitable if the land under irrigation development is used for its first best alternative production system. In the above analyzed shallow well investment by small holder who allocate his land for first best alternative production system can realize book value of fixed asset estimated to be 17,869 plus annual profit 301,230 which accounts to be ETB 319,099 on tomatoes and peppers annually and secondly, farmers who allocate their land for production of onion first round for cabbage at second round and for potatoes in the third-round end up with annual marginal profit estimated to be about:

		ETB
1	Total marginal profit	395,172
2	Annual depreciation or maintenance	6,641
3	Book value of investment asset	17,869
4	Annual profit = marginal profit – depreciation + book value of asset	406,869

Chapter 11
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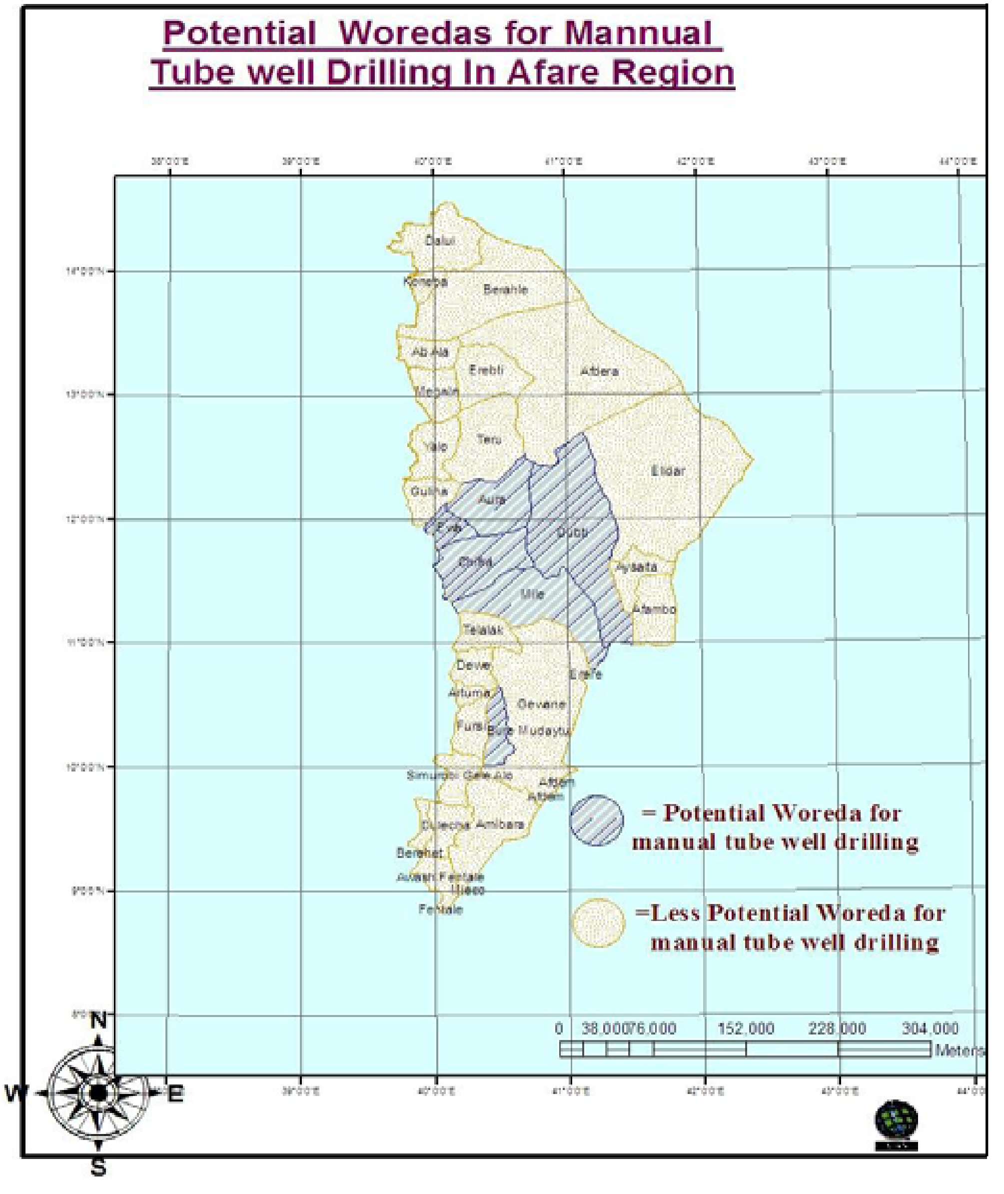
Annex A

POTENTIAL SITES FOR MANUAL TUBE WELL DRILLING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Aura
Ewa
Dubti
Chifra
Aysaita
Mile
Afambo
Telalak
Dewe
Erefe
Artuma
Gewane
Fursi
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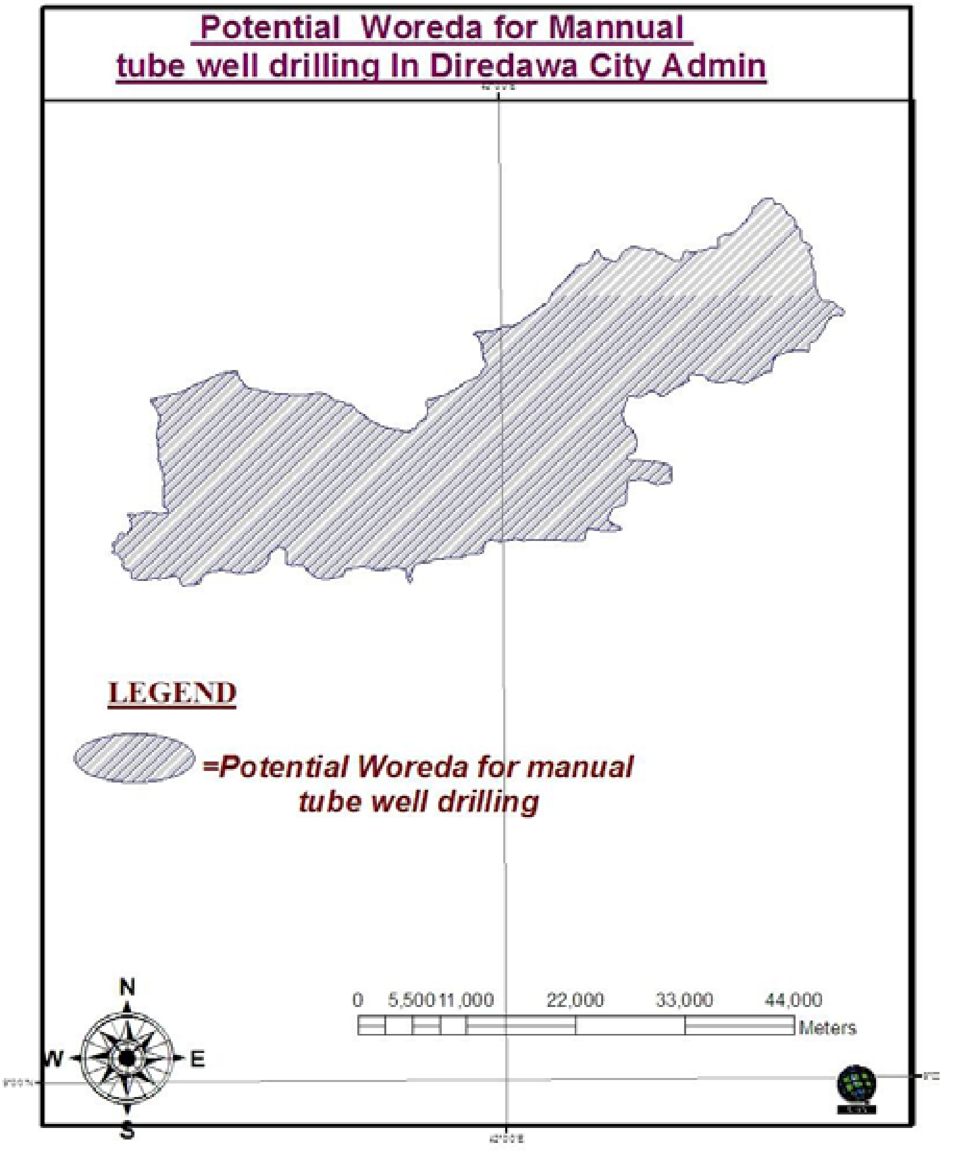
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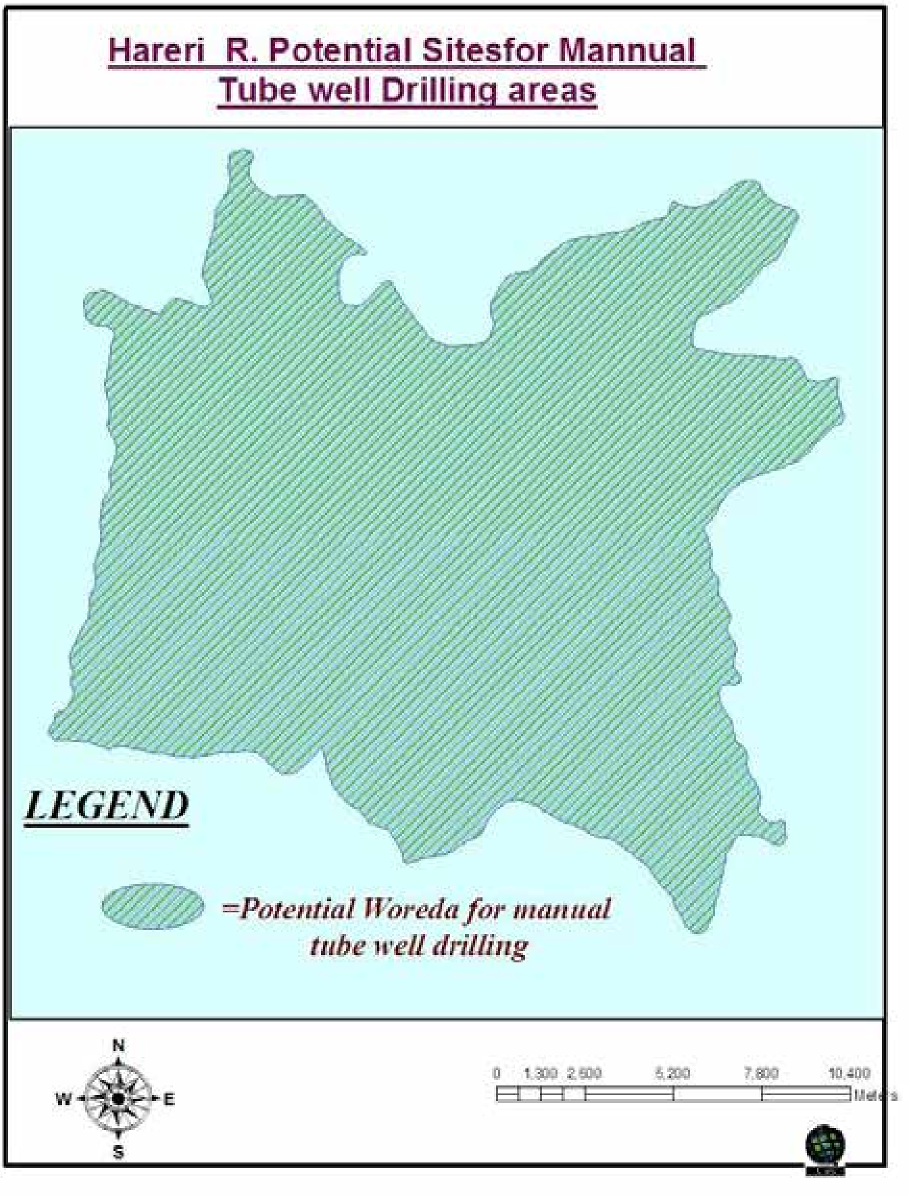
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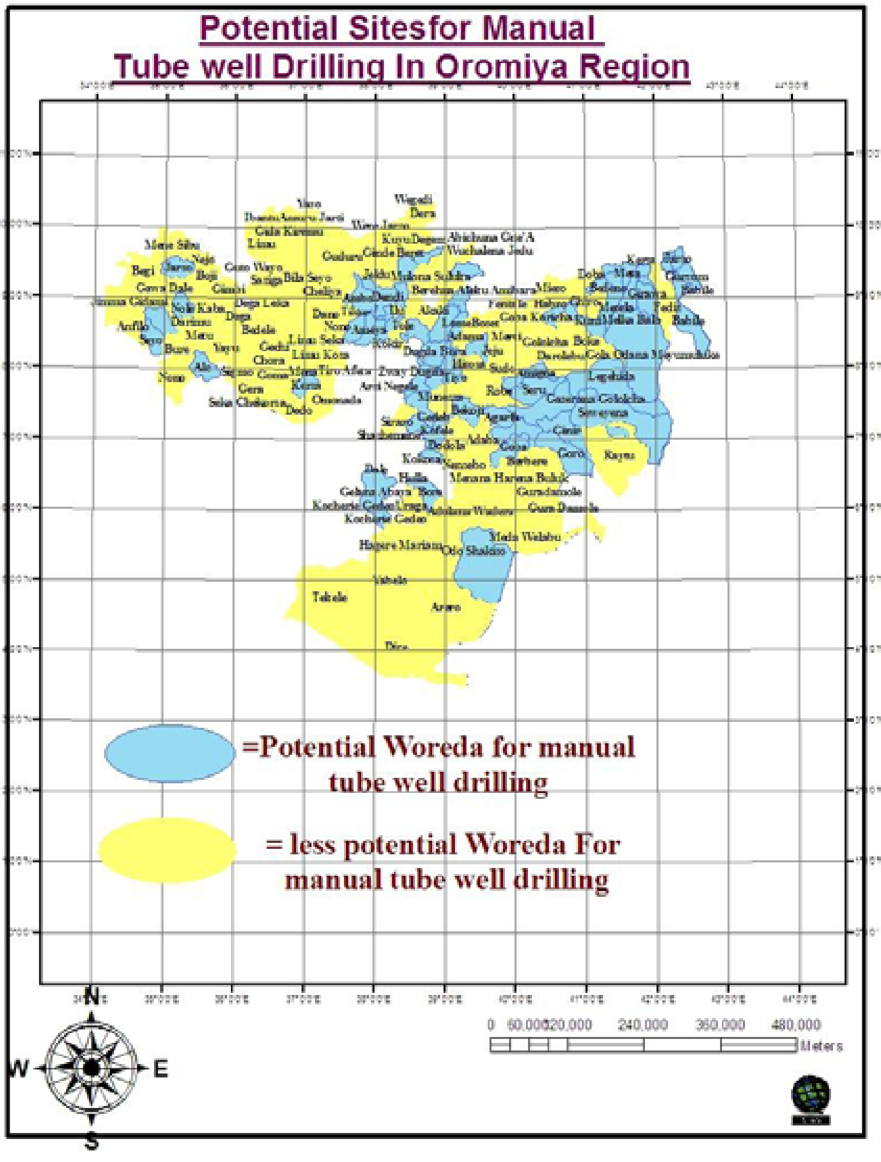

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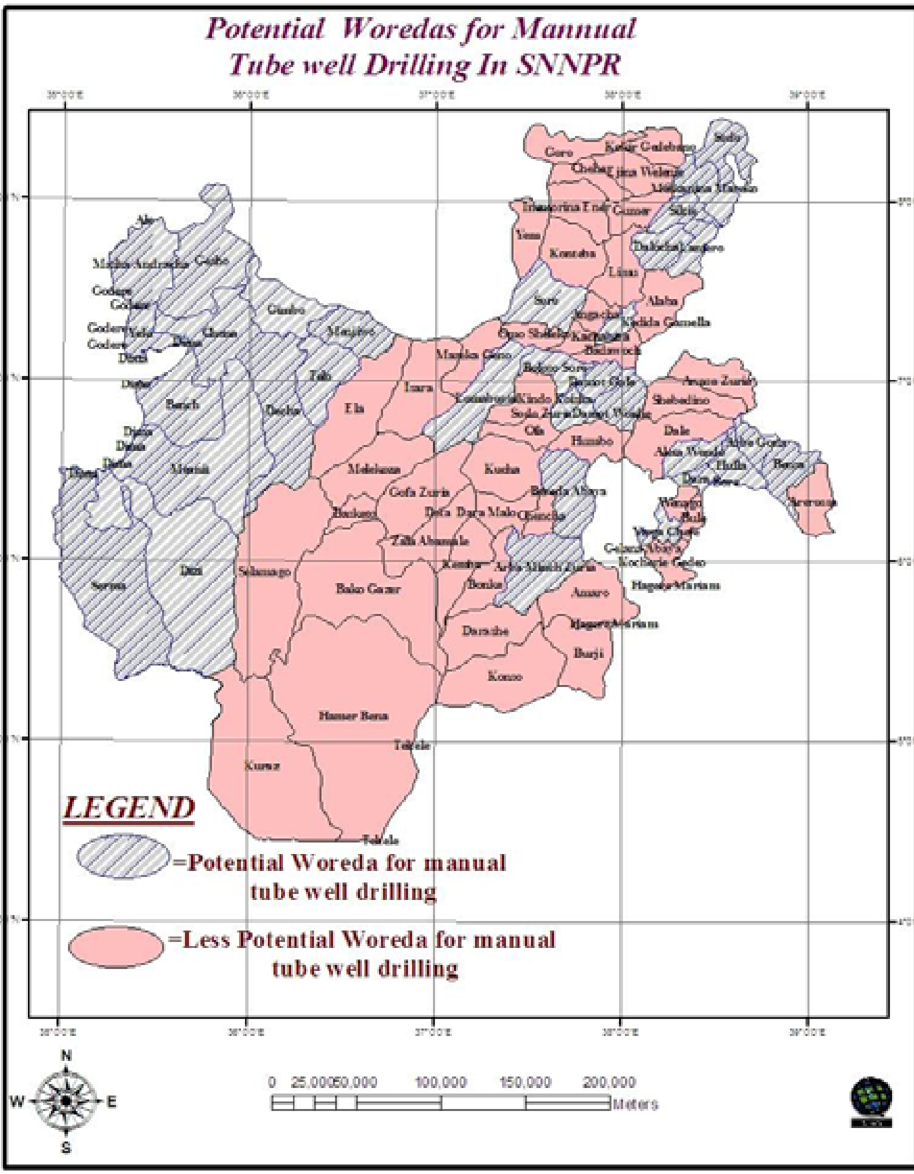
Potential Woredas for Mannual
Tube well Drilling In SNNPR
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Melekoza
Bench
Meinit
Surma
Dizi
Selamago
Bako Gazer
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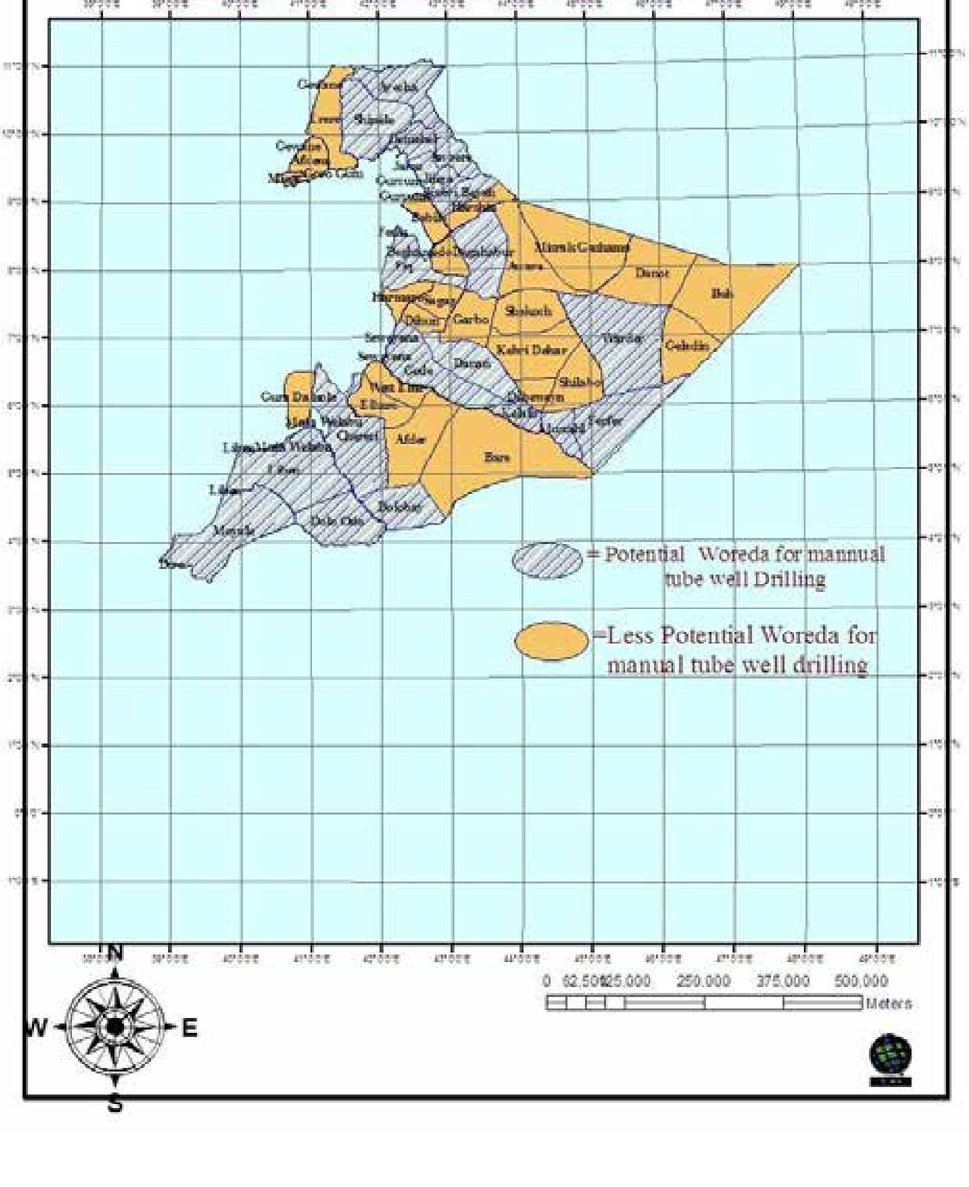
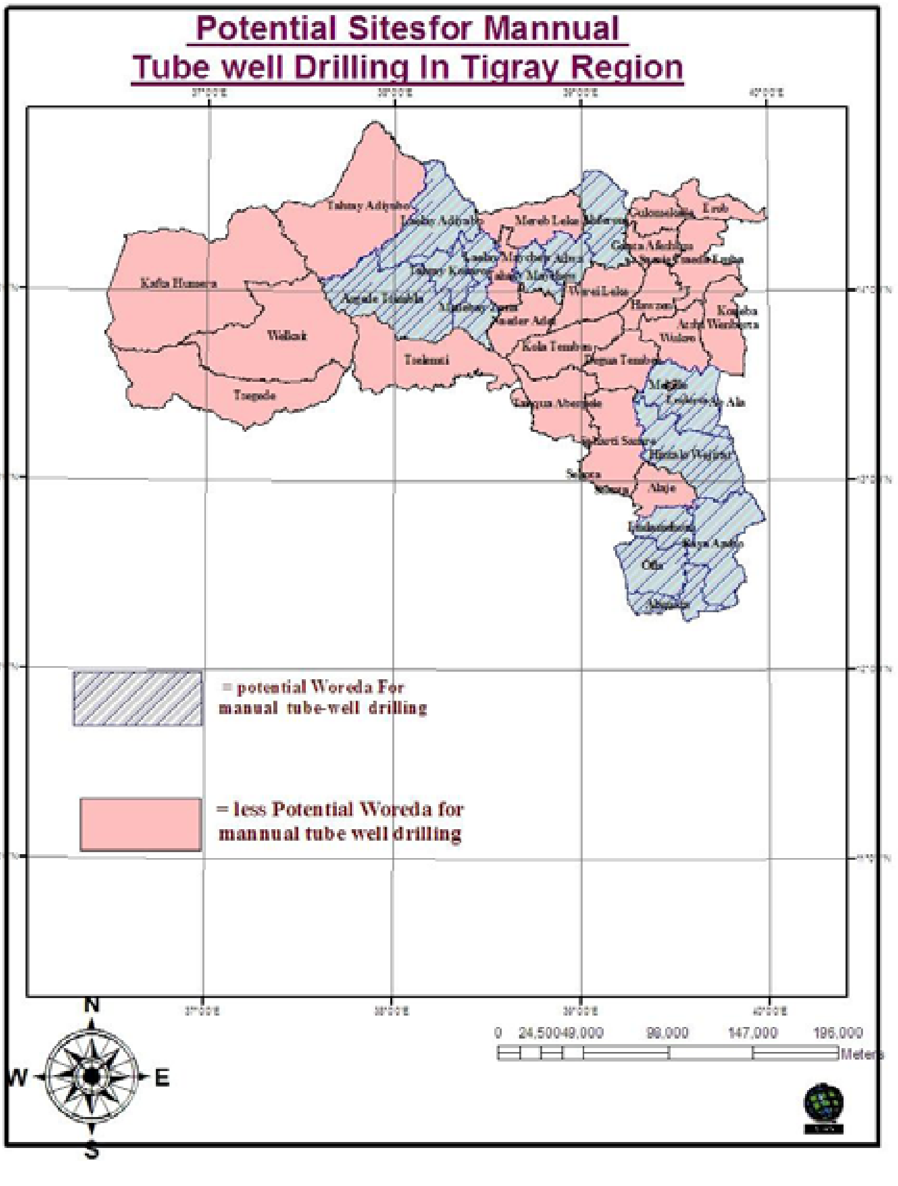
Potential Woredas for Mannual Tube well Drilling In Somali Region

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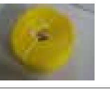
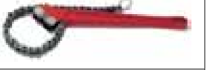
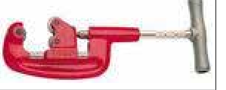
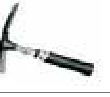
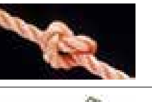
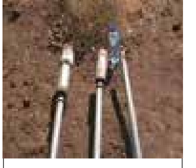
Annex B

TOOLS, EQUIPMENT/MATERIALS REQUIRED FOR SIMPLE SLUDGE WELL DRILLING

S/N	Items with Specification	Unit	Qty	Responsibility for Provision of Tools and Equipment	Image
1	**Pump House Excavation**				
1.1	Measuring tape(30 m)	Pcs	1	Beneficiaries	
1.2	Measuring tape (5 m)	Pcs	1	Beneficiaries	
1.3	Nylon rope (thin-lay-out)-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	

S/N	Items with Specification	Unit	Qty	Responsibility for Provision of Tools and Equipment	Image
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)-12mm	m	20	Driller	
2.15	shovel	Pcs	1	Driller	

S/N	Items with Specification	Unit	Qty	Responsibility for Provision of Tools and Equipment	Image
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	
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	

S/N	Items with Specification	Unit	Qty	Responsibility for Provision of Tools and Equipment	Image
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	

S/N	Items with Specification	Unit	Qty	Responsibility for Provision of Tools and Equipment	Image
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	

Beneficiaries = household farmer/pastoralists, group of households or community.

Annex C

MANUAL TUBE WELL CONSTRUCTION RECORD FORMAT/CHECKLIST

1.0	Well Location
•	Country
•	Region
•	Zone
•	Woreda
•	PA
•	Village
•	Site description
•	Map (sketch)
2.0	Client (owners) Information
•	Name
•	Age
•	Family member
•	Total area to be irrigated (ha)
•	Main crops to be irrigated
3.0	Driller's Information (name, age, requested drilling cost)
•	Number
•	Name
•	Age
•	Agreed cost for drilling (ETB/m)
4.0	Pump House Excavation
•	Shape
•	Total depth
•	Top width
•	Bottom width
•	Side slope (V:H)
•	Soil type
•	Access provided
•	Width of access provided
•	(Horizontal width
•	Vertical height
•	Cost of pump house excavation (ETB)

5.0	Drilling Description
•	Drilling method
•	Depth of water added in 3 m by 3 m pump house (m)
•	Dimension of mud pit inside the pump house (if exist) (depth, width, length or diameter and depth)
•	Volume of mud pit (m3)
•	Frequency of adding water to pump house or mud pit (number)
•	Volume of drilling water applied at one time
•	Total volume applied per day
•	Static water level: from the pump house (m), from the ground surface (m)
•	Material of drilling pipe
•	Thickness of drilling pipe
•	Diameter of drilling pipe
•	Depth of borehole (m)
•	Borehole yield (lpm)
•	Duration of test (9hour)
•	Specific capacity (lpm/m)
•	Drilling log
6.0	Reaming
•	Materials used for reaming
•	Thickness of material
•	Diameter of reaming
•	Length of reaming
7.0	Well Casing and Screen
•	Casing
•	Material
•	Overall length (m)
•	Blind length (m)
•	Perforated length (m)
•	Diameter (inch)
•	Thickness (mm)
•	Screen/slots
•	Shape
•	Diameter
•	Vertical spacing
•	Horizontal spacing (mm)
•	Total length of perforated portion on the casing (m)

•	Price of casing per 6 m
•	Price of perforation per hole
•	Total number of holes in the perforation portion
•	Total cost for perforation or total drilling cost (ETB)
8.0	Screen Mesh Wire
•	Material
•	Mesh wire thickness
•	Hole shape
•	Mesh wire opening/hole size (diameter or length and width)
•	Gravel filter pack
•	Gravel pack material diameter (mm)
•	Gravel pack volume (m^3/litre)
•	Total depth of gravel pack (m)
9.0	Pump and Pumping
•	Materials used for connection (pump to casing)
•	Pump type (diesel, petrol, hand pump, submersible, etc)
•	Model
•	Hp
•	RPM
•	Suction pipe diameter (inch)
•	Total dynamic head
•	Maximum suction head
•	Delivery head
•	Friction head
•	Fuel consumption (l/hour)
•	Sustainable pump rate (lpm)
•	Type of material for delivery pipe
•	Length of delivery pipe
•	Thickness of delivery pipe
•	Diameter of delivery pipe
•	Total price of pump
•	Price of delivery pipe (ETB/m)
•	Costs related to connecting pump to well casing

10.0	Well Development
•	Well development techniques used
•	Developed time (hour)
•	Well development process

•	Well yield (lpm)
11.0	Estimating Well Recovery (hour)
12.0	Potential Well Yield Estimation
•	Well yield from well log (lpm)
•	Draw down from well log (m)
•	Specific capacity (lpm/m)
•	Static water level from the well log (m)
•	Total well depth from well log (m)
•	Calculated available draw down
•	Estimated potential yield (lpm)
13.0	Water Quality
•	Colour
•	Odor
•	Turbidity
•	Bacterial test type and results
•	PH
•	Total dissolved salts
•	Nitrate
•	Florid
•	Sodium
•	etc.
14.0	Drilling Performance and Cost
•	Date of drilling started
•	Date drilling completed
•	Average depth drilled per day (m/day)
•	Total days taken drilling (days)
•	Number of drillers
•	Number of assistances
•	Tools and equipment
•	Professional
•	Total cost incurred by the client
•	Total cost (ETB)
•	Cost per m depth (ETB)

Drilling Log

Depth (m)		Thickness (m)	Drilling Speed (hour)	Soil Type	Formation Type (soft, medium, hard)	Drilling Depth (m)
From	**To**					

Annex D

CROP COEFFICIENTS (Kc) FOR SELECTED CROPS

Crop	Crop Development Stages					Total Growing Period
	Initial	Crop Development	Mid-Season	Late-Season	At Harvest	
Banana	0.4 – 0.65	0.7 – 0.9	1.0 – 1.1	0.9 – 1.0	0.75 –0.85	0.7 – 0.95
Bean	0.3 – 0.4	0.65 – 0.8	1.0 – 1.2	1.0 – 1.15	1.0 – 1.15	0.7 – 0.9
Cabbage	0.4 – 0.5	0.7 – 0.8	0.95– 1.05	0.9 – 1.0	0.85 – 0.95	0.7 – 0.8
Cotton	0.4 – 0.5	0.7 – 0.8	0.95–1.1	0.8 – 0.9	0.25 – 0.30	0.65– 0.70
Grape	0.35 – 0.55	0.6 – 0.8	0.7 – 0.9	0.6 – 0.8	0.55 – 0.7	0.55– 0.75
Ground nut	0.4 – 0.5	0.7 – 0.8	0.95–1.1	0.75 –0.85	0.55 – 0.6	0.75 – 0.8
Maize	0.3 – 0.5	0.7 – 0.85	1.05 –1.2	0.8 – 1.15	0.55 – 1.1	0.75 – 0.9
Onion	0.4 – 0.6	0.7 – 0.9	0.95–1.1	0.85 – 1.05	0.75 –1.05	0.65 – 0.90
Pea	0.4 – 0.5	0.7 – 0.85	1.05 –1.2	1.0 – 1.15	0.95–1.1	0.80 – 0.95
Peppers	0.3 – 0.4	0.6 – 0.75	0.95–1.1	0.85 – 1.0	0.80 – 0.9	0.7 – 0.8
Potato	0.4 – 0.5	0.7 – 0.8	1.05 –1.2	0.85 – 0.95	0.7 – 0.75	0.75 – 0.9
Rice	1.1 – 1.15	1.1 – 1.15	1.1 –1.3	0.95 – 1.05	0.95 – 1.05	1.05 –1.2
Sorghum	0.3 – 0.4	0.7 – 0.75	1.0 – 1.15	0.75 –0.80	0.50 –0.55	0.75 –0.85
Soybean	0.3 – 0.4	0.7 – 0.8	1.0 – 1.15	0.7 – 0.8	0.4 – 0.5	0.75 – 0.9
Sugar cane	0.4 – 0.5	0.7 – 1.0	1.0 –1.3	0.75 –0.80	0.50– 0.60	0.85 – 1.05
Sunflower	0.3 – 0.4	0.7 – 0.8	1.05 –1.2	0.7 – 0.8	0.35– 0.45	0.75 –0.85
Tomato	0.4 – 0.5	0.7 – 0.8	1.05 –1.25	0.80 – 0.95	0.6 – 0.65	0.75 – 0.9
Water melon	0.3 – 0.4	0.7 – 0.8	0.95–1.05	0.80 – 0.90	0.65– 0.75	0.75 –0.85
Wheat	0.3 – 0.4	0.7 – 0.8	1.05 –1.2	0.65 – 0.75	0.2 – 0.25	0.8 – 0.9
Alfalfa	0.3 – 0.4				1.05 –1.2	0.85 – 1.05

ANNEX E

APPROXIMATE ET_{crop} FOR SELECTED CROPS

Crop	Total Growing Period	Initial	Crop Development Stage/kc	Mid-Season Stage/kc	Late-Season Stage/ kc	Total Water Requirement (ETcrop)mm
Maize / grain	125 – 180	20 –30/ 0.5	35 –50/ 0.85	40 –60/ 1.2	30 –40 /0.95	500 –800
Rice	120 –180	1.1	1.15	1.3	/1.2	700
Onion / dry	150 –210	15 –20 /0.4	25 –35 / 0.7	70 –110/ 1.1	40 –45 /0.75	350 –550
Peppers	120 –210	25 –300.4	35 –40 / 0.75	40 –110 / 1.1	20 –30 /0.85	600 –900
Tomato	135 –180	30 –35 /o.4	40 –45 /0.0.7	40 –70/ 1.05	25 –30 / 0.8	400 –600
Banana	0.5	1.1				1200 –2200
Papaya	0.5	0.8				
Mango	0.5	0.8				1000
Avocado	0.4	0.7				650 –1000
Citrus	0.3	0.65				900 –1200

NB: The sum of the four growth stages should always equal to the total growing period of each crop (Doorenbos and Pruitt, 1997).

Annex F

APPROXIMATE CROP GROWTH STAGES FOR SELECTED CROPS

Crop Type	Total	Initial Stage	Crop Development Stage	Mid-Season Stage	Late-Season Stage
Barley/Oats/ Wheat	120	15	25	50	30
	150	15	30	65	40
Bean/green	75	15	25	25	10
	90	20	30	30	10
Bean/dry	95	15	25	35	20
	110	20	30	40	20
Cabbage	120	20	25	60	15
	140	25	30	65	20
Carrot	100	20	30	30	20
	150	25	35	70	20
Cotton/Flax	180	30	50	55	45
	195	30	50	65	50
Cucumber	105	20	30	40	15
	130	25	35	50	20
Eggplant	130	30	40	40	20
	140	30	40	45	25
Grain/small	150	20	30	60	40
	165	25	35	65	40
Lentil	150	20	30	60	40
	170	25	35	70	40
Lettuce	75	20	30	15	10
	140	35	50	45	10
Maize, sweet	80	20	25	25	10
	110	20	30	50	10
Maize, grain	125	20	35	40	30
	180	30	50	60	40
Melon	120	25	35	40	20
	160	30	45	65	20

Crop Type	Total	Initial Stage	Crop Development Stage	Mid-Season Stage	Late-Season Stage
Millet	105	15	25	40	25
	140	20	30	55	35
Onion/green	70	25	30	10	5
	95	25	40	20	10
Onion/dry	150	15	25	70	40
	210	20	35	110	45
Peanut/Ground-nut	130	25	35	45	25
	140	30	40	45	25
Pea	90	15	25	35	15
	100	20	30	35	15
Peppers	120	25	35	40	20
	210	30	40	110	30
Potato	105	25	30	30	20
	145	30	35	50	30
Radish	35	5	10	15	5
	40	10	10	15	5
Sorghum	120	20	30	40	30
	130	20	35	45	30
Soybean	135	20	30	60	25
	150	20	30	70	30
Spinach	60	20	20	15	5
	100	20	30	40	10
Squash	95	20	30	30	15
	120	25	35	35	25
Sugarbeet	160	25	35	60	40
	230	45	65	80	40
Sunflower	125	20	35	45	25
	130	25	35	45	25
Tomato	135	30	40	40	25
	180	35	45	70	30

Annex G

PRODUCTION TECHNOLOGY PACKAGES FOR SELECTED IRRIGATED CROPS

1. Onion (Allium Spp)

General

Onion is among the bulb crops, which are economically important in human diet. Onion has considerable importance in the daily Ethiopian diet and has the potential for domestic and export market in case of Onion seed production. Practically, all plant parts are edible, but the bulbs and the lower stem sections are the most popular as seasonings or as vegetables.

Onion is probably native to the Middle East region. The edible onion bulb on the averages contains 85 to 87 % water, 1.4 % protein, 10 % carbohydrates, 0.2 % fat and about 0.6 % ash. It is rich in calcium and iron. Onion is well known for its flavoring. All parts of the plant contain the pungent substance that makes Onions desirable as seasoning herbs. The pungent substance is due to volatile sulfur compounds. In most cases, it is being produced for marketing and to earn cash. Onion production by smallholder farmers in Ethiopia is mainly for the market purpose.

Growth Requirements

Altitude: The optimum altitude ranges for onion production is between 700 and 2,200 m above sea levels.

Seasonal water need: For optimum yield, onions require 350 – 550 mm depth of water during the growing period. Onion can be grown during the rainy season, but the latter part of growing period should be dry.

When grown under irrigated condition Onion should be irrigated at 3 – 5 days interval However, a longer interval may be necessary when it is grown on heavy soils. Irrigation should be stopped before full size development stage of the bulbs.

Temperature: The optimum growing temperature for Onion lies between 150 C and 230 C.

Soil Condition: Onion needs well-drained sandy loam soils with a high content of organic matter and PH of 6.0 –7.0.

Improved Onion Varieties

Onion is strongly influenced by day length to produce bulbs and only short- day varieties (approximately 12 hours) are well adapted to Ethiopian conditions. Varieties that are either long or intermediate are not adapted to Ethiopian condition, since they do not produce bulb when grown in region having less than 12 hours day length. Varieties adapted to specific areas must be resistant to diseases, and have good size and yielding capacity, long storage properties and the pungency or flavor desired of the onions. The recommended varieties under irrigation are, therefore, Adama Red, Red Creole, Bombay Red and Melkam Red. However, Red Creole is not widely adapted and usually imported seeds of this variety have low quality standards.

Improved Onion Varieties

Character.	Adama Red	Melkam	Red Creole	Bombay Red	Nasik Red	Nafis
Leaf colour	Medium green	Dark green	Light green	Dark green	Deep green	Deep green
Leaf arrangement	Erect	Erect	Medium	Medium	Erect	Erect
Bulb size(g)	60 – 80	70 – 90	80 – 100	85 – 100	85 – 100	100 – 130
Bulb shape	Flat globe	High globe	Thick flat	Flat globe	Globe	Globe
Bulb skin colour	Dark red	Medium Red	Medium red	Light red	Medium red	Medium red
Bulb flesh colour	Reddish white	Reddish white	Reddish white	Reddish white	Reddish white	Reddish white
Maturity (days)	110 – 130	110 – 130	130 – 145	<120	90 – 110	90 – 100
TSS%	10– 13	10 – 12	11 – 14	9 – 11	10 – 18	10 – 18
Dry bulb q/ha	350	400	300	300	300	400
Character.	Adama Red	Melkam	Red Creole	Bombay Red	Nasik Red	Nafis
Seed set	High	High	Resistant	High	High	High

Source:Ethiopian Institute for Agricultural Research (EIAR) (2006).

Cultural Practices

Land Preparation: The land to be used for Onion production should be ploughed 3 – 4 times in order to have fine seed bed to properly grow seeds and transplanting seedlings.

Nursery Managements: For transplanted onions, seeds are generally sown on raised nursery beds of 15 – 22 cm in height. To cover one ha, onion production of 560 m^2 nursery beds is needed. Seeding rate for direct sowing 6 – 7 kg/ha).

Planting methods: When Onion is transplanted in the field, the height of the seedlings should be 12 – 15 cm in the time of (40 – 50 days). Seedlings of Onion are usually transplanted in flat bed or flat top ridges with furrows between ridges and making double rows on the flat ridges 20 cm apart. The spacing between double rows is 40 cm and between plants is 10 cm. (40 cm× 20 cm × 10 cm).Seed Rate: – 4 kg of onion seed per ha is the optimum seeding rate for transplanted onion.

Fertilizer Application

For successful onion production, 200 Kg. DAP or 242kg NPS and 100 Kg Urea is optimum rate. The whole dosage of DAP and half Urea should be added to the soil before transplanting. The remaining half Nitrogen should be applied as top dressing at 30 – 45 days after transplanting. Proper and timely weeding and cultivations are needed to destroy weeds at an early stage of crop development.

Irrigation

Onion, as most vegetable crops, is sensitive to water stress. Onion is shallow rooted crop not more than 30cm deep and it needs frequent but light irrigations. For optimum yields the soil water depletion should not exceed 25% of the available soil water. When the soil is kept relatively wet, root growth is reduced and this favours bulb enlargement. Irrigation should be discontinued as the crop approaches maturity to allow the tops to dry out and also to prevent a second flush of root growth and avoid problems of curing.

The crop is very sensitive to water deficit during the yield formation period, particularly during the period of rapid bulb growth, which occurs about 60 days after transplanting. In order to achieve large bulb size and high bulb weight, water deficit during the yield formation period / bulb enlargement/ should be avoided. Since the crop is shallow root it requires frequent but light irrigations, which should be planned to irrigate when the 25% available soil water in the first 0.3 m soil layer has been depleted by the crop.

Irrigation should be scheduled by observing soil moisture level and not by observation of the crop. In the initial growth stages up to four weeks period of time after transplanting it will be necessary to apply irrigation water at every 4 – 5 days interval and every 5 to 7 days is commonly practiced then after. Over irrigation sometimes causes spreading of disease such as downy mildew and white root rot. Irrigation should be discontinued 15 to 25 days before harvest. The most common irrigation methods applied under onion crop is furrow.

Insect, Pest and Disease Control

Thrips (Thrips tabaci), a small, yellowish sucking insect which attacks the leaves of onion are the most injurious insects usually during dry weather conditions.

To control thrips: Spray Sypermethrin 10% at the rate of 500 ml per ha mixed with 200 – 300 litres of water.

Diseases control: Among major diseases attacking Onion plant, Purple Blotch (Alternarea porri) is the major one. Purple Blotch attacks leaves, seed, stem and bulbs. In the end, darkened mass of spots develop in the centers of the lesions. The infected leaves turn yellow and within three to four weeks. Then, the fungus grows down ward into the bulbs if control measures are not taken in time.

Downy mildew (Perenospora destructor) is also another distractive fungal disease that attacks onion plant. To control these diseases:

- Use long rotation cropping system.
- For both fungal diseases apply 3.5 kg Ridomil per ha mixed with 600 litres of water and spray it at one week interval.
- Mankozeb 2.5 kg with 600 litres of water in every 10 days interval.

Harvesting

Onion should be harvested when 50 to 80% of the top leaves have fallen over. Every harvest results in sprouting of the bulbs and late harvest gives also rise to formation of roots during storage. After harvest, spread the onions in the row in the field and let them dry in the field for about 5 days. The top part should not be removed until the necks are dry. After the onion is properly dry or cured, the top part of the bulb should be trimmed to a length of about 2.5 cm.

2. Tomatoes (Lycopersicum esculentum)

General

Tomato is one of the most important high vale vegetable crops grown in Ethiopia. It is grown as annual crop and is produced for its fruits. Tomato in Ethiopia is produced for fresh consumption as well as for processing in the form of tomato juice or tomatoes paste used sauce in the preparation of different meals.

There are different varieties of Tomatoes that can be used for fresh consumption and for processing purpose. The different Tomato types include the tall set indeterminate, erect and bushy types with thin stems and the short set determinate types with strong stem. The determinate types produce more flowers within a given length of vine in relatively shorter period of time than the indeterminate ones which produce higher yield for a long time.

<u>Growth Requirements</u>

Altitude: Tomatoes are well grown best in a warm and dry climate and not withstand cold weather. Damp air and rain encourage disease specially Blight. Therefore, in regions where the air is very damp, it is recommended to grow Tomatoes in the dry under irrigation. Even though the crop can be grown in areas having altitudes below 2500 m above sea level (m.a.s.l), altitude ranges from 1100 to 1800 m.a.s.l are considered the best areas for successful tomatoes production.

Seasonal water requirement: Tomatoes can be grown successfully with an average annual rainfall of 400 – 500 mm depth of water depending on the climatic conditions of the location.

Temperature: The optimum mean daily temperature for proper growth is 18 to 25°C with night temperature between 10 and 20°C. The crop is very sensitive to frost and therefore it should be grown in frost free period. Temperatures above 25°C when accompanied with high humidity and strong wind resulted in weak growth and reduced yield. High humidity leads to high incidence of pests and diseases and fruit rotting and therefore, dry period is preferred for Tomatoes production. Temperatures above 35°C during fruit development inhibit the formation of red colour.

Soil condition: Tomatoes can be grown on a wide range of soils but well drained light loamy sand to silty loam soils with pH of 5 to 7 are more preferred. The requirement on the organic matter content of the soil is not so high but soils with medium organic matter content have better yields than soils with low organic matter content. Good soil drainage is also important. Tomatoes need deep soil because it has deep root system. Water logging can increase incidence of diseases such as Bacterial Wilt and Root Rot. The crop is moderately sensitive to salinity.

Improved Tomato Varieties

	Variety	Maturity Days	Average Fruit Weight(g)	Average Yield (q/ha)	Purpose
1	Melkashola	100 – 120	80 – 70	430	Processing and fresh market
2	Melkasalsa	100 – 110	40 – 50	450	"
3	Oval Red	85 – 100	80 – 92	495	"
4	Chali	85 – 100	80 – 90	430	"
5	Cochoro	85 – 90	70 – 80	463	Fresh market
6	Eshet	75 – 80	130 – 140	394	Fresh market
7	Metadel	75 – 90	90 – 140	345	Fresh market
8	Fetan	75 – 80	110 – 120	454	Fresh market
9	Bishola	85 – 90	140 – 150	340	Fresh market
10	Miya	90 – 100	75 – 80	471	Fresh market
11	Woyeno	85 – 90	40 – 50	249	Fresh market
12	Sirenka-1	95 – 100	60 – 70	382	Fresh market
13	Mersa	100 – 120	42 – 50	276	Fresh market
14	Lekku	75 – 80	55 – 60	337	Fresh market
15	ARP Tomato d_2	75 – 80		395	Fresh market

Registered Hybrid Tomato Varieties

No	Variety	Yield (q/ha)	Imported Through
1	Shanty	650	Axum Green Line Plc
2	Irma	815	
3	**Galilea**	**659**	
4	Briget 40	543	
5	Anna	501	Makubou PLC
6	Eden	599	
7	Barnum	345	Markos PLC
8	Topspin	701	CropGrow
9	Rainbow	436	ERA Agri-link
10	STH 808	456	ViBHA seed
11	STH 805	308	ViBHA seed

Cultural Practices

Nursery bed preparation and management: Tomatoes seeds (Use 250 – 300 gram seed) are generally grown in nursery plots and emergence takes place in about 10 days. Seedlings are transplanted to the permanent field after 35 to 45 days. As far as nursery bed management is concerned it is recommended to apply 200 grams of DAP or 242gm NPS and 100 grams of Urea during Nursery bed preparation. Sow the tomatoes seeds in one cm depth in rows leaving approximately 10 – 15 cm. between rows and 5 cm between plants. Mulching of the nursery bed immediately after sowing with thin layer of grass or straw is essential

Land preparation: Tomatoes seed goes deep in to the soil and land must be tilled fairly deep. The permanent field where Tomatoes seedlings are going to be transplanted should be ploughed 20 – 30 cm depth and ploughed repeatedly until the seed bed is fine and the field must be prepared several weeks before transplanting the seedlings.

Transplanting: Tomatoes seedlings can be ready for transplanting within 4 – 6 weeks after germination or when the seedlings reaches 12 – 15 cm in height. During transplanting, the seedlings must not be dry and it should not be exposed to strong heat from the sun. While transplanting, keep 30 – 50 cm between plant to plant and 90 – 100cm between rows. Irrigate the newly planted seedlings immediately and water them regularly until they are well established. After the plants are well-established application of irrigation, water could be extended depending on the climatic and soil conditions of the area.

Fertilizer Application

Tomatoes are responsive for both nitrogen and Phosphorus application. The Nitrogen requirement of the plant is generally moderate until fruit set. Excess application of nitrogen causes luxuriant vegetative growth, retards production and decreases fruit quality. Phosphorus is also important throughout the growing period of the crop and Phosphorus deficiency results in violet coloration of the leaves. The recommendation regarding fertilizer application is to apply 100 Kg/ha of DAP or 121kg NPS during planting time and 100 Kg/ha of Urea in a split application that is half at the time of planting and the other half 45 days after transplanting.

Staking: Tomatoes is among the crops that need staking. Staking improves production and quality by keeping the fruit off the ground and thus minimizing disease infection and rotting. In addition, photosynthesis is enhanced through improved light penetration into the canopy of the crop. Varieties which require staking include indeterminate and tall varieties such as Money Maker and Marglobe. Stakes could be put in the field before transplanting or it could be placed later. Whatever method is used, it is essential that the stakes should be strong enough to support the mature fruit laden crop. The stakes should be fairly strong and about 1.5 m high. When the plant is growing about 40 cm it is the right time to tie it to the stakes.

Cultivation and earthen up: Cultivation is performed for the purpose of improving aeration and the structure of the soil, facilitating water penetration and removing weeds which will compete with the crop for water, light and nutrients. Earthen up in the case of tomatoes can be used to support the crop or to stimulate the development of adventitious roots. Therefore, the first round should be done during fertilizer application approximately 45 days after transplanting and the second round should be done before flowering.

Pruning: Tomatoes plants grow very quickly and develop many branches. Pruning is important in order to control the apical dominance of the plant and initiates the formation of limited numbers of stems needed for better fruiting. Pruning is also important to facilitate staking and tying up by reducing the number of stems per plant. Usually leaving 2 – 3 stems during pruning is ideal for better fruiting capacity and also gives better leaf coverage to protect the fruits from sun scorching. A common and effective pruning method is to let one or two suckers growing out from near the plant base to form a 2 – 3 stem plant. Consider the following procedures during pruning.

- Remove the shoot.
- Remove the buds which show between the leaf and stem.
- With quick growing varieties keep only one stem but with slow growing varieties keep two main stems with their leaves and flowers.
- Pruning should be carried out once or twice in a month.
- Do not prune before the Tomatoes plant has two flowers and one leaf above the second flower.
- Cut the top of the stem above the leaf and two shoots will form and then leave one or both depending on the growth habit if the variety.
- The buds develops into a new stem and wait until two flowers develop on the stem and then cut back in the same way as it was done with the first stem.

Mulching: Mulching is an important practice in tomato production. In this regard, cover the soil between the plants with cut leaves or grasses in order to keep the soil moist and suppress weed growth. Mulching prevents the leaves and fruits from being spoiled by dirt during irrigation water application. The mulch must not be too thick and affect proper air circulation in the soil.

Irrigation: Furrow length of 10 – 15m is preferable irrigation method. Irrigation interval depends on soil type and variety. But irrigation interval can be every three to four days for the first three weeks and weekly then after.

<u>Weed, Pest, Insect and Disease Control</u>

Weed control: Tomatoes is very sensitive to weed completion at the early stage of growth. Transplanted Tomatoes seedlings are more sensitive to weed competition than the direct sown once and yield loses as high as 705 could be encountered in sever conditions. Therefore, weed control in Tomatoes field is very important starting from the early stage of crop growth and should be performed at different stages depending on weed infestation. In this regard, the crop must be cultivated and weeded at least 2 – 3 times throughout the growing period. The first cultivation and weeding must be done after 20 – 30 days after transplanting and the second after 45 – 50 days after transplanting. When the crop is well established, it can withstand weed completion reasonably well. The following are the recommended weed control methods in tomatoes field.

The parasitic weed, orobanche can cause severe problem in tomatoes field. This parasitic weed is spread by wind, irrigation water, humans and animals and this parasitic weed should be destroyed before it sets seed. Frequent weeding and cultivation should be performed before irrigation water is applied.

Insect control: Tomatoes Fruit worm, Leafhopper, white fly, cut worms and Bugs are the major insect pests attacking the plant. Of this, Fruit worm is the most important one economically and when the fruits are attacked in the very young stage they generally fall down.

To control fruit worm:

- Employ deep plough in order to expose the eggs and pupa to their natural enemies and sun's heat.
- Destroy alternative plants around the field, which could serve as food and hibernating source to the pest.
- Spray the field with Endosulphasn.
- All sprayings should be performed before flowering and ripening of fruits.

Nematodes: Tomatoes are especially susceptible to root Knot nematode. The nematodes induce the development of irregular swellings or knots on the roots. The water and nutrient uptake from the soil is disturbed and the plants growth and development becomes very poor.

To control Nematodes:

Use resistant varieties

- Rouge out infected plants and destroy them.
- Include crop rotation in the production program.
- Apply field sanitation and destroy crop residue after harvest.

Disease control: Many diseases attack the roots, stems, leaves and fruits of tomatoes plant. The major diseases on Tomatoes are Early Blight (Altenaria solani), and Late Blight (Phthraptera spp), Septoria Leaf Spot (Septoria lycopersici), Powdery Mildew (Leveilula taurical) and Bacterial and Fusarium wilt.

Early blight: This is a seed born fungal disease and symptoms of this disease include formation of elongated spots on the lower stem, brown zoned spots up to 8 mm in diameter surrounded by a yellow hallo on the leaves and large spots up to 2 cm in diameter on the fruit. Affected plants may partially defoliate and reduce in yield and quality.

Septoria leaf spot: Small black spots on the leaves increasing in size and becoming gray with black margin are observed. If the spots are very numerous, the leaves will wither and drops off. Usually infection first appears on the older leaves near the ground level and under favourable condition progresses rapidly until very few leaves are left at the tip of the stem. In general, temperatures of above 250°C associated with very high humidity favours the development of this fungal disease.

Powdery mildew: The most common symptoms of powdery mildew on Tomatoes are light green to bright yellow lesions on the upper leaf surface. Under favourable condition for the disease abundant powder develops on the upper and lower leaf surface.

Late blight: Late Blight is a very destructive disease on Tomatoes. The disease becomes serious particularly when the weather is constantly cool and rainy. Late blight is caused by fungus called Phytoptera infestans. The pathogen survives from one season to another cropping season on volunteer and alternative host plants in close by areas. This fungal disease can attack all above ground parts. Water soaked spots or lesions which may enlarge rapidly in to pale green to brown on the leaves. Infected leaves become

brownish and soon fall off.

The followings are the recommended practices for the control of different Tomatoes diseases.

Seed treatment with appropriate fungicides

- Use resistant varieties.
- Use clean and disease free seeds for raising seedlings.
- Rouge out infected plants and get rid of them by burning or other appropriate means.
- Use optimum spacing to produce the Tomatoes plant.
- Follow a four year crop rotation cycle with cereals and pulses and do not grow tomatoes next to cucumber, potatoes, and tobacco which may have the same disease.
- For blight disease, spray Ridomoil by mixing with 500 litres of water immediately after the disease is observed. Repeat spraying in a week interval in case of sever infestation.

Harvesting

Tomatoes will physiologically mature and ready to be harvested in about 80 – 100 days after transplanting depending on the cultivar and climatic conditions of the area. For immediate use such as for fresh home consumption, it is possible to pick ripen fruits whereas for fresh marketing the fruits should be harvested when they are green ripe that is before they are fully ripe. For processing purpose that is for canning and paste it is important to pick the fruits when they are fully mature and red all over.

3. Peppers-(Capsicum spp.)

General

Red peppers or chilies is an important vegetable crop for fresh consumption, processing as a spice (for making stew) and has much importance in the spices extraction factories for its oleoresin.

Red pepper has high content of capsaicin; Sweet pepper and paprika have low capsaicin. Birds eye chilies, is the most pungent among chilies, and has smallest fruit size.

Growth Requirement

Altitude: Peppers grows well in areas found within altitude ranges of 1,000– 1,800 m above sea level.

Seasonal water requirement: High yields can be obtained with a water depth of 600 –1,250 mm during the growing period. Peppers do not require heavy irrigation. Heavy rain fall and high humidity results in rotting of fruits.

Temperature: The plant can grow in hot and frost free areas. The optimum growing temperature for peppers is between 210C°– 240C°.

Soils Conditions: Light texture soils with adequate water holding capacity and good drainage are preferred for proper growth and development.

Improved Pepper Varieties

Different types of peppers are produced in Ethiopia. The varieties vary in mode of growth, fruit size, colour, shape and pungency. At the moment two improved hot pepper varieties are widely produced in the country. These are: Mareko Fana and Bako Local.

Mareko Fana is a dark red, thick fleshed, very pungent and most accepted in local markets. Bako Local is light coulored, thin skinned, smaller in size and less pungent than Mareko Fana.

Improved Pepper Varieties

No.	Variety	Maturity (Days)	Yield on Research Plot (q/ha)	Unique Characters/Important Features	Source of Seed
1	Mareko Fana	110 – 130	15 – 20	High acceptance for local use for its brown pod colour	MAR
2	Melka Awaze	100 – 110	25 – 28	Tolerant to soil-borne diseases, early maturing	
3	Melka Shote	110 – 120	20 – 30	Tolerant to soil-borne diseases	
4	Melka Zala	130 – 150	15 – 25	Tolerant to soil borne diseases	
5	Melka Dima	120 – 140	13 – 20	Processing type, high oleo resin content	
6	Melka Eshet	100 – 120	15 – 20	Processing type, high oleo resin content	
7	Oda Haro	139	11 – 12.5	Resistance to bacterial leaf spot, fungal leaf disease, Phy-tophtora (root dis), virus	BARC/ ORARI

Registered Commercial Hybrid Hot Pepper Varieties

No.	Cultivars	Yield – ton per ha(t/ha)	Company/Source of Seed
1	Serenade	15 – 20	Axum Green line PLC.
2	Saidah	52.9	Syngenta trading PLC
3	Capsi	6 – 6.5	ViBHA seed
4	Spicy	5 – 5.5	ViBHA seed
5	SCH 925	6 – 6.5	ViBHA seed
6	SCH 942	6 – 6.5	ViBHA seed
7	Seranno	19.63	MEKAMBA PLC
8	Harbad	19.22	MARKOS PLC

Cultural Practices

Land preparation: Peppers require a properly prepared fine seed bed for optimum production. Therefore, the land must be ploughed 2 – 3 times with oxen drawn traditional plough or with tractors in case of mechanized farming.

Planting date: The first week of June is the optimum time to plant red pepper under rain fed condition. Under irrigated condition, planting time could be adjusted as required.

Planting Methods: Seeds of red pepper may be sown directly in the field or seedlings could be raised in the nursery beds. The required seed bed area to cover one ha for transplanting red pepper field is about 300 m2.

The seedlings can be transplanted to the field when they have reached a height of 10 – 12 cm. or during 45 – 50 days after sowing. Red pepper seedlings under irrigation would be planted in double rows on flat-topped ridges. The double spacing is 40 cm apart and the spacing between double rows is 80 cm and between plants is also 30 cm. In this case, the plant population per/ha is 42000 plants.

In addition, hot pepper under rain fed condition is planted in double rows 40 cm apart. The distance between the double rows is 60 cm and spacing within the plants is 40 cm apart. In this case, the plant population will be 50000 plants/ha.

Seed rate: The optimum seeding rate for transplanted nurseries is 0.6 kg/ha.

Fertilizer Application

200 kg of DAP or 242kg NPS fertilizer before planting and 100 kg /ha UREA by splitting into two parts, half of the doze of nitrogen fertilizer during transplanting and the rest after 45 days is recommended for peppers.

Irrigation

The total water requirements are 600 to 900 mm and even sometimes up to 1250 mm for long growing varieties and for several pickings. For high yields, an adequate water supply and relatively moist soils are required during the total growing period. Irrigation water supply shortage during the growing period in general has an adverse effect on yield and the greatest reduction when there is a continuous water shortage until the time of first picking. The recommended irrigation method for peppers is furrow method.

Water shortage just prior and during early flowering reduces the number of fruits. The effect of water deficit on yield during this period is greater under conditions of high temperature and low humidity. Irrigation can be done early in the morning or late afternoon. For optimum yield levels the soil water depletion in most climates should not exceed 30 to 40 % of the total available soil water. Due to low depletion level light irrigation applications are required. Irrigation frequencies of 5 to 7 days interval are common, particularly in the early growth stages but at latter growth stages it might extend up to 7 to 10 days interval.

Weed, Pest and Diseases Control

Weed control: Red pepper/chilies plants are initially slow growing crops, incapable of offering any competition to the aggressive weeds. Heavy infestation of weeds will also increase insect population. Therefore, weeds should be removed by hand weeding and /or inter row cultivation using hoe.

In this respect, Red pepper plant should be weeded at least 3 times during the growing period; the first and the second hand weeding can be done 20 and 40 days after emergence on the average and the last before flowering stage

Insect control: Several insects attack pepper plants. However, Boll worm is the most dangerous insect that attacks the leaves and fruits. In addition to this, Aphids are also attacking the plant leaves causing considerable yield losses. To control Aphids and Thrips: use 0.5 litre Cypermethrin 10 % with 600 litres of water mixture for one ha. To control Boll Worm infestation, use fenithrothion /Summation/ 50 % E.C. at the rate of 1.5 litres per ha mixed in 600 litres of water.

Diseases control: Several strains of Viruses, Bacteria and Fungus attack pepper plants. Among these, Tobacco Mosaic Virus (TMV), Cucumber Mosaic Virus (CMV) and Alfalfa Mosaic Virus attack Capsicum species and other plant species of solanacea family.

Among Fungal diseases Powdery mildew (Loveillula taurica) severely attacks the pepper plant leaves. The symptoms are chlorotic blotches on the upper side of the leaves and powdery blotches on the lower side of the leaves.

Bacterial Leaf Spot and Bacterial Blight (Pseudomonas vesicatoris) causes small, dark, greasy spots on leaves and stems of young plants. As the attack progresses the leaf tips and margins will shrivel and die. Control methods are:

- Apply crop rotation system.
- Use clean seeds.
- For powdery mildew, spray Ridomil MZ 63.5 fungicide at the rate of 3 kg/ha mixed with 600 litres of water repeated every 10 days interval.

Harvesting

Peppers or chilies can be harvested for either green fruits (kariya) or red ripe fruits (Berberi) by hand picking. The picking of red ripe fruits will be three to four pickings. After harvesting, drying of red ripe fruits for about 5 – 7 days in bright sun light is necessary before storage. However, over drying can affect the quality by making the product brittle and easily broken. Peppers should be dried on mats or trays constructed at table height, not on ground in order to get quality products.

4. Potato Production

Introduction

Recently potato became a very important non-cereal staple in Ethiopia and increasingly gaining importance as a food security crop owing to its ability to produce more edible energy and protein per unit area and time than most cereal crops. It is an important food and cash crop in the high land of Ethiopia. However, the national average yield of potato is quite low being about 8 t/ha which is far below worlds' average yield of about 13.9 t/ha. It has been reported that the progressive farmers however, regularly harvest over 25 t/ha.

Nutritional Uses

Potato is a moderate source of iron, and its high vitamin C content promotes iron absorption. It is a good source of vitamins B1, B3 and B6 and minerals such as potassium, phosphorus and magnesium, and contains folate, pantothenic acid and riboflavin.

Adaptation/growth requirement

For healthy tuber production, potato should strictly be cultivated in high altitude areas. Potato is susceptible to frost damage and it should be grown at frost free periods. It can grow at altitude of 1500 – 2800m and temperature of 15 – 18°C. It grows well on soil of sandy loam or loamy sand soil with pH of 4.5 – 7.5.

Recommended Agronomic Practice

Site selection

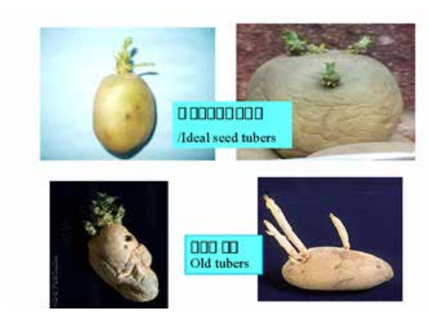
The site we select has not been planted with any Solanaceous crop for the last three seasons. Potatoes must be rotated with other crops to slow the accumulation of diseases and reduce the impact of insects' pests. Select field that distant from other potato fields. The soil for potato has to have good drainage. The selected area should be with low aphid pressure, no soil-borne disease, no host weeds, no nematodes, and that have low air-borne pathogens (LB).

Land preparation

The land should be cleaned from any debris and residual material. And it should be plough properly from 2 – 3 times before onset of rains.

- The recommended seed rate is 18−20qt/ha and the tuber size is 35−45 mm.
- Planting Methods: Plant the seed potatoes with their sprouts facing upwards at a depth of 10−15 cm planted in rows in spacing of 30cm by 75cm.
- Planting Time: Planting can be done any time provided, there is moisture but frost should be avoided at early growth of the crop.

Properly Sprout and Old Tubers



Planting and Covering with Soil

Difference between Young and Old Tubers

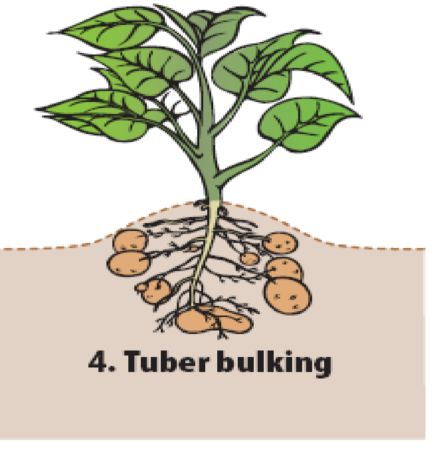
Young Tuber Seed Leads to	Old Tuber Seed Leads to
Late emergence	Early emergence
Late tuberization	Early tuberization
High foliage production	Reduced foliage production
High tuber number	Reduced tuber number
Late maturity	Early maturity
High yield	Reduced yield

Fertilizer application: In Ethiopian condition, it is recommended to apply manure at a rate of 20 t/ha if it is available. The recommended amount of manure has to be applied 2 to 3 months prior to planting and incorporate with the soil thoroughly in order to give time for decomposition and make available the nutrients required by the crop. If chemical fertilizers are used, apply phosphorus containing fertilizers such as DAP 200kg/ha or 242kg/ha NPS at the time of planting, by placing the fertilizers under the seed or on the sides of the seed. The fertilizer should not come in contact with the seed so cover the fertilizer with soil. Cover the seed and manure with soil to a depth of about 10 – 15 cm. Nitrogen containing single fertilizers such as Urea 150kg/ha should be split applied at planting, two weeks after germination and the third flowering or earthling up.

Side Dressing Application of Fertilizer

- Potato field should be free of weeds, then cultivation and weeding is important.
- 2 – 3 times cultivation and earthing-up is important till the canopy is well established.
- Shallow cultivation and earthing-up is also important to perform when the crop is at 15 to 30 cm height, particularly to avoid greening of tubers when exposed to sunshine and to maintain its food value and to kill weeds and to control potato tuber moth.

Cultivation and Earthing-Up



Irrigation

To optimize yields the total available soil water should not be depleted by more than 30 – 50 %.Water deficit during the period of stolonization and tuber initiation and yield formation have the greatest adverse effect on yield, whereas ripening and the early vegetative periods are less sensitive. Irrigation intervals for sandy loam soils may be from 6 to 7 and 9 to 10 days for loam soils. The field may be pre- irrigated before planting with aim of enhancing rapid germination and uniform crop development. Irrigation should be discontinued 2 to 3 weeks before harvesting in order to enforce uniform maturity and to develop stronger skin of tubers that increase the keeping quality of tubers. Irrigation scheduling should be based on avoiding water deficits during the period of stolonization, tuber initiation and yield formation (critical stage for water deficient).

<u>Disease and Pest Management</u>

Diseases

Potato disease control practices are generally preventative in nature as opposed to curative. Seed and the growing plant are treated to prevent or minimize diseases. There are not many curative treatments to apply once to prevent disease. Many potato diseases are fungal diseases, which flourish under certain temperature and humidity conditions. Other diseases such as viruses may be spread by aphids or other insects or be seed borne.

Early Blight

Early blight is primarily a disease of stressed or ageing plants. Symptoms appear first on the oldest foliage. Affected leaves develop circular to angular dark brown lesions 3–4 mm in diameter. Concentric rings often form in lesions to produce a characteristic "target" effect. Severely infected leaves turn yellow and drop. Infected tubers show a brown, corky dry rot.

Management

Early blight can be minimized by maintaining optimum growing conditions, including proper fertilization, irrigation, and management of other pests. To avoid early blight grow later maturing, longer season varieties. Fungicide application is justified only when the disease is initiated early enough to cause economic loss. Watch for disease symptoms during routine monitoring, and keep records of your results. When justified, apply fungicides as soon as symptoms appear; continued protection requires application at 7 to 10 day intervals.

Late Blight

Late blight lesions can occur on all above-ground plant parts. On leaves, lesions typically first appear as small pale to dark green water-soaked spots that are irregular in shape and surrounded by a zone of yellowish tissue. Under conducive conditions, lesions expand rapidly and become brown to purplish black as tissue is killed. Under sufficient humidity white sporulation of the fungus can be observed at the edge of lesions, principally on the underside of leaves. On stems and petioles lesions are brown to black and may also support sporulation of the fungus. Infected tubers develop a firm brown decay that starts on the outside and may later extend to include the outer 3–12 mm of tissue.

Symptoms of Late Blight

Management

Late blight is controlled by eliminating cull piles and volunteer potatoes, using proper harvesting and storage practices and applying fungicides when necessary. Air drainage to facilitate the drying of foliage each day is important. Plant certified seed potatoes to limit this disease. When late blight has developed on foliage and tubers are at risk of infection, make sure that vines are completely dead for 2 to 3 weeks before harvesting. Phytophthora Infestans does not survive very long in dead foliage. In districts that are commonly subjected to outbreaks of late blight, preventive applications of fungicides are advised when environmental conditions are favourable for the disease. Continue fungicide applications at 7 to 10 day intervals as conditions require. Apply fungicides when late blight lesions appear in the field or in nearby plantings. Strains of Phytophthora infestans have developed resistance to mefenoxam (Ridomil Gold).

Harvesting

Potato from planting to full maturity will take about 90 to 120 days on average depending on the specific environmental conditions and the variety. When the potatoes leaves are just turning to yellowish in colour, it is then the typical sign of maturity. During harvesting in order the skin of tubers to become stronger and to harvest easiest is recommended to cut down the shoot or vegetative parts above the ground and leave for about 10 – 15 days before harvest, particularly in hot climates. After the skin of tubers has become stronger it is then possible to dig out tubers using appropriate tools. Then afterwards it will be important to separate the tubers for seed purpose and for marketing or consumption and should be kept safely in appropriate areas not exposed to insect pests attack. But tubers isolated for seed purpose should be kept in diffused light store.

Tuber Harvesting


5. Cabbage

Economic and nutritional importance of cabbage

Cabbage is a cool season crop. It is considered as one of the most popular vegetables grown successfully in high and mid altitude of Ethiopia, in most cases under subsistence farmers.100 g edible portion of cabbage contains 1.8g protein, 0.1g fat, 4.6g carbohydrate, 0.6g mineral, 29 mg calcium, 0.8 g iron and 14.1 mg sodium. Moreover, it is a rich source of vitamin A and C. It may be served in slaw, salads and cooked dishes and can be served with other traditional dishes. All agro-climatic requirements of cabbage are describe in table5.

Recommended Agronomic Practice

Soil preparation: The soil should be prepared thoroughly and deeply before planting. The soil should first be ripped and then ploughed.

Planting period: Depending on the variety and region, cabbages can be grown throughout the year. Cabbages are generally transplanted as seedlings. Healthy one month old seedlings are recommended for transplanting purpose.

Seedling production: Seedling production is discussed under Nursery management.

Transplanting: Seedlings are ready for transplanting at 25 – 30 days. The field to be transplanted should be irrigated one day before transplanting. Open a hole with hoe or peg and plant the seedlings. The seedlings should be carefully lifted late in the afternoon or during cloudy days and kept under shade. Higher plant populations raise the average yield per ha, but the heads are smaller. However it must be noted that the population of a cabbage field per ha for a commercial grower can vary and planting is dependent on what the specific market needs and available resources are. Cabbages are transplanted with row spacing of 50 and plants are 40cm apart. Direct seeding is not successful for tropical areas. For baby cabbage, varieties have a smaller head size and the population can be increased.

The following points should be considered when transplanting cabbage seedlings. Firstly the seedlings must be transplanted and watered as soon as possible after delivery from the nursery. Duration of seedling stay period at the nursery, from seeding to transplanting, might range 25 – 30 days, depends on climate conditions.

Secondly these seedlings should be placed vertically into the ground and not sideways. This is to avoid a condition known as “J rooting”. This condition results in a J shaped root system that ultimately decreases yield and head size.

Thirdly the grower should ensure that seedlings are planted at the correct depth in a little hole that has been formed into the ground prior to planting. If the seedlings are forced into the ground, without a hole being prepared for them to be inserted into, the root system will be compromised and the plant will experience stress resulting in poor yield.

Fertilizer Application: Well decomposed manure can be applied and incorporated into the soil. The blanket recommendation is 200 kg DAP or 242kg NPS and 100 kg urea can be used. DAP is applied at transplanting while urea can be applied in two splits; half at first cultivation and the remaining half one month later.

Irrigation: Young seedlings should be irrigated every three days until they are established. Then irrigation can be done every 5 – 7 days depending on the weather and soil conditions. Irrigation should cease at maturity, especially if coupled with excess nitrogen, leads to splitting of the head.

Cultivation: Cultivation may start two weeks after transplanting and continues every two weeks depending on weed infestation. Deep cultivation may lead to uprooting of seedlings and should be avoided. Once heads are formed, hand weeding is sufficient to reduce the weeds that may interfere with harvesting.

<u>**Diseases and Insect Pests of Cabbage**</u>

Damping off: It is caused by fungus (Rhizoctonia, Fusarium, Pythium spp.). It is a disease of seedlings. The causative agents can exist in soil or in plants for a long period of time. Seeds infected at germination fail to germinate. Cool, cloudy, high RH, moist clay soils and densely sown seedlings favour disease development lead to heavy seedling losses.

Disease symptoms: It appears before or after seedlings emerge from the soil. If it appears before emergence the seedlings rot and die. Wire like lesions appears on the stem and then the seedlings dry & die.

Damping of Symptom

Control

- Sanitation of the field.
- Seed beds should be prepared on well drained soils.
- Treat the seed with Apron star and dipping the seedling in theram solution during transplanting.
- Avoid weed on seed bed.
- Avoid use of excessive water.
- Transplant only healthy seedlings.
- If symptoms are observed in the seedbed, stop irrigation & drain the soil.
- Crop rotation with cereal crops to reduce inoculums load in the soil.
- Spray quadris or Soil Gard bio-fungicide (especially against Rhizoctonia, Pythium spp.) based on manufacturer's recommendations.

Downy mildew (Peronospora parasitica): High humidity, cloud and dew favour the spread of the fungus.

Temperature (8 – 16°C) night and 24°C during the day favours disease development.

Disease symptoms: Greenish-yellow lesions appear on the upper and then on the lower part of leaves. The lesions gradually become yellow.At high RH the white signs of the fungi appear on the lower parts of leaves.

Control: Remove Brassica spp. weeds from the field. Properly manage irrigation to reduce RH

spray with agri-phos fungicide every 7 – 21 days and quadric every 7 – 14 days.

Black rot: Black rot is a bacterial caused by Xanthomonas campestris. It attacks all Brassica spp. in many countries as well as in Ethiopia reducing yield and quality. Long periods of warm and wet conditions favour disease development and high loss. The bacteria can stay on unharvested plants and on Brassica spp. Weeds. It can also be transmitted by agricultural equipment.

Disease symptoms: The disease infects all stages of the crop. Infected leaves appear yellow and V shaped lesions. The yellow lesions develop into brown and then black symptoms. When a stem of an infected plant is dissected vascular bundles appear black. Under high RH the cabbage rots and emits unpleasant odder.

Control

- Exclusion is the main mean of controlling bacterial diseases.
- However, once the disease has entered the field, use the following control measures.
- Use clean seed.
- Treat the seeds in warm water (45°C) for 25 minutes.
- Crop rotation – do not plant in a field that has been planted with Brassica spp. for the last two years.
- Destroy left-over plants.
- Spray with copper fungicide at the rate of 3 kg per ha.

Insect pests of cabbage: Diamondback moth (Plutella xylostella)

Diamond back ⇒ front two wings form diamond shape. It is widely distributed across all cabbage growing areas of Ethiopia especially in irrigated lowlands and where there is heavy spray against the pest. The eggs are yellow or light green, the larvae bores into feeds inside a leaf. The 2nd instar larva is green and feeds on the lower side of a leaf forming holes on the leaf. The 4th instar larva pupates on the lower side of the leaf and develops into an adult after 14 days. The adult lives from 12 – 16 days. Depending on weather conditions one generation takes 17 – 51 days.

Damage: The green larvae with tapering ends or an enclosed pupa appear on leaves. The adults can fly whenever the leaves are agitated. The pest feeds on leaves and makes many irregular shaped holes on the leaf depending on the number of the larvae.

Control

- Crop rotation with Solanacious crops (tomato, potato, eggplant).
- Use sprinkler irrigation to discourage adult moths from laying eggsand to dislodges and kills the larvae from leaves.
- Harvest mature heads, clean the field from weeds, spray with water, destroy left over pants or feed to animals.
- Crash neem seeds, soak them in water over night and spray.
- Use Bio-pesticides (such as Diadegma semiclausum) and Bassilus trungensis.
- Spray with pesticides for two weeks ahead of harvest date.
- Use Remon 10% E.C (Novaliron), Karate, Diazinon, fungicides.
- Use crashed neem seeds to control pests.
- NB. The pest easily develops resistance against pesticides if no optimum arte is used.

Cabbage mealy aphid: Cabbage aphid is the pest of Brassica spp. It reproduces itself not by laying eggs but by bearing off-springs. The female aphid can give birth to 15 – 87 off-springs. Air temperature of 20°C is suitable for reproduction. The off-springs feed around their mother and form colonies as their number increases. The aphids are covered with wax that resembles wood-ash.

Damage: Aphids attack the plant by sucks the sap and by transmitting viruses.

The pest first appears on the upper side of a leaf and the leaf rolls inwards as the pest population increases thus observe rolled leaves observe the aphids. Young plants start wilt and stunted. They exude waxy dews which is suitable for development of black sooty mould.

Control

- Aphids usually attack weak plants ⇒improve the condition of the plant.
- Do not spray with pesticides unless mandatory – natural enemies may be killed.
- Destroy plants left-overs after harvesting the crop.
- Crop rotation with legumes.
- Spray with neem extract at the rate of 15-30 kg ha per ha
- If the above options are not effective, use insecticides such as Dimetiote, cypermetrin, Karate, Diazinon, etc.

Harvesting and postharvest handling: Cabbage heads become ready for harvesting when the heads get firm. Holding the head with both hands and pressing it with thumbs can indicate the level of firmness. Puffy head is an indication of a head that is not fully packed with leaves. Mature heads should be harvested immediately; otherwise the leaves split progressively from the outer into the core. Cut the stem from underneath the leaves and remove the lower old leaves, leaving one circle of leaves to protect the head from dirt and damage.

Collect the heads in plastic crates to avoid damage during transportation. Depending on variety and management about 300 – 400 q/ha yield can be obtained. A single head of cabbage can weigh from 0.5 –3.0kg. Cabbage heads can only keep well for several days under optimal storage and it has to be consumed when it is still fresh. After harvesting, it is recommended to not expose to direct sun light because it wilts quickly.

Store in cold and dry storage areas if it is not consumed immediately. The optimum temperature for storage of cabbage is from 0°C– 2°C with RH of 90 – 98%. Under optimum condition cabbage can be stored for about 5 months.

Matured (left) and Over Matured (split, right) Cabbage Heads

6. Papaya (Carica papaya)

General

Papaya is a popular fruit crop, which can be produced well in areas having warm climate. Papaya is a native of Central America and is widely grown in Latin America and West Indies. Papaya is a herbaceous fast growing plant usually with unbranded stem. The fruit is rich in Vitamin A and also contains other vitamins to some extent. Major producing countries are USA, Brazil, Mexico, South Africa, Ivory Coast, India and Peru.

Growth Requirements

Altitude: Papaya grows well from sea level to 1200 m.a.s.l. It thrives well from the humid tropics to the sub-tropics where frost does not occur. The production of best quality fruits requires relatively high temperature ranging between 22 – 28˚C.

Seasonal water need: Papaya has a high water demand and when grown under irrigation condition it requires 1000 – 1500 mm. of irrigated water. For commercial production, irrigating the field is necessary. Irrigation interval depends on soil type and climatic conditions of the area and the moisture content of the soil should be determined before applying irrigation water as over irrigating the field could be injurious to the plant.

Soil Condition: For maximum production, Papaya prefers well drained medium textured fertile soils rich in organic matter and optimum pH range of 6.0 – 7.0

Cultural Practices

Propagation: Unlike most tropical fruit trees papaya is mostly propagated by seed. The difficulty with common Papaya production is that the sex of the seedlings cannot be identified until they start to produce flowers.

The seed to be used for the purpose of raising Papaya plantation must be selected from a healthy, vigorous and high yielding mother plants. Seeds extracted from ripened fruits should be dried under shade for optimum germination.

Planting: Papaya is usually planted in 2.0 m by 2.5 m spacing in the field. The land should be prepared for planting seedlings by digging a hole 30 cm in diameter and depth. The holes should be refilled with well decomposed organic matter until planting time.

Commonly, Papaya seeds may be sown directly in the field. About 3 – 4 seeds should be dropped in each hole at a depth of 2 – 3 cm and marked with a peg. The soil surface above the seeds should be mulched with dry grass which should be removed as soon as the seeds germinate. When the seedlings are about 20 cm tall the number should be reduced to 2 – 3 plants per hole.

Another method of establishing Papaya is to raise seedlings in nursery beds and transplanting the seedlings in plastic pots. The potted seedlings should be planted in the field when they are 10 – 15 cm tall.

Fertilizer Application

Application of Farm Yard Manure (FYM) at the time of planting as basal application gives good result. Papaya trees planted on deficient soils should receive about 200 gm DAP and 500 gm Urea per tree per annum.

Weed, Pest and Disease Control

Weed control: Cultivation of the soil should be confined to shallow hoeing in order to control weeds. Papaya plant will benefit a lot if the surface of the soil is mulched with dry grass and doing so will also reduce weeding cost.

Disease control:-Papaya fruit must be handled very carefully all the time because they are extremely sensitive to bruising and quick decay due to attack by disease called Colletotrichum gloesporiodes which develop from bruised sites.

Harvesting

For local market, the fruits should harvest when their tips turn yellow. At this stage the fruit is still hard and easy to transport. Fruits which are picked when they are still green do not develop their full aroma. On the other hand, fruits picked when fully ripe are extremely sensitive to bruising and can only be stored for a few days.

Papaya trees come in to production in 9 – 11 months after planting. The tree remains in prime condition for 2 – 3 years and after this harvesting becomes more difficult with increasing height as well as rapid decline in yield. Under good management Papaya tree can produce 25 – 30 tons per ha.

7. Mango (Mangifera indical)

General

Mango is the most important tropical fruit after banana but it plays a minor role in world trade because it needs very careful handling due to the sensitivity of the fruits to bruising. The center of origin of Mango is South-East Asia and mango was brought to Africa in the first millennium. At the moment Mango is grown in most warm tropical countries and far in to the sub-tropics. The cultivars differ in fruit shape, fruit size, texture, taste and climatic requirements in general.

Growth Requirement

Altitude: Mango grows from sea level up to an elevation of about 1220 m.a.s.l. In Ethiopia Mango is grown up to an elevation of 1800 m.a.s.l. Mango trees never bear fruits at higher altitudes. The lower and mid-altitude areas of Southern Ethiopia have tremendous potential for Mango production. Seasonal water need 890 – 1160 mm depth of water is considered sufficient for the successful production of Mango.

Soil condition: Mango trees can grow well on a variety of soils. In general, deep, fertile and well drained soils with a pH range between 5.5 – 7.5 are considered to be ideal for Mango production.

Cultural Practices:

Propagation: Mango cultivars with poly embryonic seeds can be propagated similar to Citrus. However, as with other mono embryonic cultivars it can be propagated by grafting by using different grafting methods like budding on seedling root stalk. Grafted seedlings are to be transplanted after 4-6 months after grafting.

Planting: Mango is planted on selected site after clearing the land of all wild growths and weeds. The seedlings are generally planted during the beginning of the main rainy season (June on wards) Pits of 0.5 by 0.5 by 0.5 m are dug during the dry period and are filled with a mixture of well decomposed FYM and top soil.

Mango trees will grow to a very large size and hence they have to be spaced wide enough to avoid the problem of overcrowding. In a condition where the soil is very fertile wider spacing of 12 m by 14 m can be used whereas, on relatively poor soil types 9 m by 9 m spacing can be used. The optimum spacing recommended in general is 7 m by 7 m and control the size of the tree by regular pruning as necessary.

Fertilizer Application

There is no information available on fertilizer application under Ethiopian condition. However, in other countries application of nitrogenous fertilizers are recommended after production in order to stimulate vegetative growth for the next season. Fertilizer application may be done after proper soil testing.

Weed Control: Weeds compete with mango tree for water, and nutrients and also harbor various diseases and insects and hence the field must be kept clean as much as possible.

Harvesting

Fruit bearing in Mango may start four years after planting in the case of grafted trees. A plantation of full grown Mango trees can produce 10 – 25 tons/ha/year. Mango fruits are usually harvested when the colour of the skin changes from green to yellow. Some varieties first show this change near the stylet end others on the entire fruit. Fruits which are to be transported for a long distance should be harvested a little bit earlier. The ripening temperature ranges from 21 –24˚C

8. Avocado (Persian American)

Growth Requirements

Avocado is native to Tropical America and from there it has extended to East Asia, Cuba etc. Avocado fruit is of high nutritive values containing up to 30 % oil and could make a significant contribution to improving local food supplies.

Altitude: Avocado is a sub-tropical fruit tree and is well adapted in low altitude areas with altitude below 1800 m.a.s.l.

Seasonal water need: Avocado gives better yield with an irrigation depth of 1100 mm.

Temperature: Avocado prefers mild winters of the tropics and sub-tropics. The trees are tender and thus susceptible to frost and similarly they do not stand hot and dry winds.

Soil Conditions: The tree prefers loam, medium textured, well drained with a pH of about 7.5.

Varieties

A number of important and market oriented Avocado varieties have been imported to Ethiopia from California for trial and subsequent multiplication purpose. Some of the standard Mango varieties which were imported to Ethiopia include Ettinger, Hass, Bacon, Pinkerton and Fuerte. Of these Fuerte and Bacon were found to perform well in our country.

Cultural Practices

Propagation: Different grafting methods such as Cleft Grafting Shield Budding etc. can be used in the propagation of Avocado plant. In Ethiopia, tree seedlings have are planted sporadically without adopting a definite propagation method.

Regarding Rootstalk propagation, seeds of Rootstocks are sown immediately after they are removed from the flesh on a seedbed. When the seedlings attain a height of 10 cm they are transplanted in polythene bags and when they attain a pencil thickness about 4 – 6 months after transplanting they are ready to be grafted.

With respect to scion they should be collected from a healthy mother tree which is true to type. Scions should be grafted immediately after collection. 7 – 10 cm long apical parts of branches should be selected for scion collection.

Planting: The recommended spacing for grafted Avocado tree under Ethiopian conditions is 8 m by 8 m which is about 156 trees per ha. This allows enough space for different field operations including harvesting. Seedling trees are more vigorous and should not be planted closer than 9 m by 9 m. Normally, planting is done in 40 cm by 40 cm by 40 cm holes and the seedlings are transplanted when there is low evapo-transpiration for better seedling survival in the field.

Irrigation: For small scale production, irrigation is not essential provided that the precipitation is more than 1000 mm per annum. However, for commercial production, it is essential to use irrigation water and in this case furrow irrigation is recommended. When using irrigation it is important to control water application as over irrigation may destroy the plants due to suffocation.

Fertilizer Application

The amount and type of fertilizers to be applied depends on the fertility and availability of nutrients in the soil. In general, young Avocado trees should supplied with nitrogenous and phosphorus fertilizers in two months intervals. The recommended practices in Upper Awash State Farms is 200 gm of Urea and 50 gm of DAP per plant per year.

Crop Protection

In general, avocado grows well and so far no insect and disease pest of economic importance has been observed. As far as weeds are concerned shallow cultivation is recommended not to injure the roots. If the weed population is intense, application of appropriate herbicide such as Round-Up at the rate of 3.5 litres per ha is advisable.

Harvesting

Good experience is required to harvest Avocado fruits at the correct stage of maturity. If harvested too early, the fruit will shrivel without ripening whilst if the fruits are harvested late, the fruits will become soft and over matures before the product reaches the targeted consumers.

9. Banana (Mussa paradisiaca)

General

Banana is a herbaceous perennial plant with an underground rhizome from which the new fruit bearing shoot sprout. These sprouts or suckers are used for propagation purpose. Banana is one of the oldest fruit types which have probably originated in East Asia. It has the largest production area in the world after Grape Vine and it is widely distributed and grown in different countries throughout the world.

Growth Requirements

Altitude-Banana is a tropical region crop which can be grown up to an elevation of 1540 m.a.s.l. However, as altitude increases the performance of the plant becomes lower on account of low temperature. Banana gives optimum yield in areas with altitudes ranging from sea level up to 770 m.a.s.l.

Seasonal water need: Under irrigated condition 2000 mm is adequate for optimum production. Banana is a water loving plant and under irrigated condition the growth and development of Banana will be luxuriant and high yield could be obtained.

Temperature: The optimum temperature for Banana is 27°C. At very high temperatures leaves are damaged and at lower temperatures the duration to come to production will be extended, bunches are smaller and sucker production is adversely affected.

Soil Condition: As far as soil condition is concerned, Banana performs best when it is grown on deep, fertile and well drained soils rich in organic matter. For best performance, the soil reaction must be neutral in general.

Improved Banana Varieties

Three important and widely produced Banana varieties include: Dwarf Cavendish, Giant Cavendish and Poyo:

- **Dwarf Cavendish:** This variety is short, early maturing type with reasonably good yield. However, it is highly susceptible to Burrowing Nematodes and Cigar End Rot diseases.
- **Giant Cavendish:** This is a very tall variety growing up to a height of 2– 3 m. This variety has good tolerance to Burrowing Nematode infestation.
- **Poyo:** Poyo is the leading Banana variety under commercial production. It is comparatively resistant to Burrowing Nematodes and is little affected by transport damage.

Cultural Practices

Land preparation: For maximum production the land to be used for Banana production should be properly prepared by plowing/harrowing it 2 – 3 times. The field must be free from clods and weeds as well as other crop debris.

Planting method: Planting holes 45 cm by 45 cm are dug and filled with well decomposed organic matter. The spacing for tall varieties is 3 m. by 3 m. while for dwarf varieties 2.5 m by 2.5 m is enough.

Planting Material: Sword suckers that are coming out from bud eyes are used for propagation purpose. Suckers are taken and planted when they attain about 75 cm height. Sword suckers have well developed base, vigorous, and they come to production early.

Wind Breaks: Banana is very susceptible to wind damage and in areas where there is high velocity of wind planting windbreaks is recommended to minimize damage.

Fertilizer Application

Optimum applications of both organic and inorganic fertilizers result in high yield and extend the economic life of the plantation. In this regard, applications of 375gm DAP or 453 NPS, 375gm Urea and 200 gm Potash per hole is recommended.

Weed, Insect and Disease Control

Weed Control: As much as possible Banana field should be free of weeds at an early stage of growth. Shallow cultivation of young plantation is advised to control weeds. At full maturity the dense growth of Banana plant can suppress underground weed growth by shading effect.

Insect Control: Insects such as Nematodes cause substantial damage on banana plant.

To control nematodes: Hot water treatment of the planting for five minutes in 56°C is recommended.

Disease control: Diseases of economic importance on Banana include: Banana Wilt (Panama disease), Leaf Spot, Bacterial blight, and virus disease transmitted by Aphids.

Harvesting

Banana plant will come into production in about 9 – 18 months depending upon the variety and location. It is good to harvest banana when the fruits are green-ripe. Here, the branches are cut off and brought to the shade with as minimum mechanical damage as much as possible. Under good management practices, yield as high as 30 t/ha could be obtained.

Annex H

SOCIO-ECONOMIC BASELINE SURVEY QUESTIONNAIRE

Description		Filling information
1	**General Information**	
1.1	**Introduction**	
	Name; My name is:	
	Date:	
	Fathers Name:	
	Village name:	
	PA:	
	Woreda:	
	Zone:	
	Region:	
1.2	Interview	
	The owner:	
	Child:	
	Close family member:	
	Sex:	
	Male	
	Female	
2	**Household Information**	
2.1	Number of people in household:	
	Number of adult women:	
	Number of Adult Men:	
	Number of children:	
2.2	Do you have any other house or shop other than the one you live in now? (Y/N)	
2.3	Do you access any hired labor? (Y/N)	
	If yes, how many people per growing season?	
2.4	Are there any health problem affecting agricultural activates? (Y/N)	
2.5	Household education level (illiterate, writing skill, certificate, diploma, degree)	
2.6	Are you employed? (Y/N)	
	If yes, which organization? (government, Non-Government Organization (NGO), private company, other(specify)	

Description		Filling information
2.7	Household income(per annum):	
3	**Irrigated Farming**	
3.1	Do you practice any irrigation? (Y/N)	
	If yes, what type of irrigation? (furrow, sprinkler, basin, drip, bucket)	
3.2	Which irrigation equipment do you possess:	
3.3	Irrigation water source:	
3.4	Irrigation scheme type:	
3.5	If groundwater pump irrigation: Depth of static water level(m): During winter During summer(dry period)	
3.6	Type of water lifting and discharge (l/s)	
3.7	If motor pumps are used, pumping hour per day: Total area irrigated per day: Fuel consumption per hour and day: ....(l/hr)...........(l/day)	
3.8	Source of water for irrigation: Is it shared?(Y/N):	
3.9	What is the source of power for the irrigation?	
3.10	Is irrigation water available throughout the year?(Y/N)	
3.11	Is irrigation farming main source of income?(Y/N)	
3.12	Have you ever used drip irrigation kits?(Y/N)	
	If yes, are you still using the drip kits?	
	If no, Why have you abandoned using kits?	
3.13	What is the total area of your farm?	
	If farmer gives area in acres, multiply by 0.4 to get area in ha).	
3.14	What is the area under irrigation __________ha What is the area under rain fed? __________ Which crops are under irrigation? ___________	
3.15	Which crops are under rain fed?	
4	**Agronomic Issues**	
4.1	Do you practice any crop rotation with irrigation?(Y/N)	

	Description	Filling information
	If yes, Specify the number of crops under a rotational system the whole year?	
4.2	Is there any other information you need to learn about irrigated agriculture? (Y/N)	
	If yes what would you like to learn?	
4.3	Do you apply any organic and inorganic fertilizer?(Y/N)	
	If yes, which fertilizer do you use for which crops?	
4.4	When do you apply fertilizer?	
4.5	Are the fertilizers adequately (Y/N)	
	Table A	
	If not, what are the constraints	
4.6	Do you use any certified seeds?(Y/N)	
	If yes, what are the source(s) of seed?	
4.7	Is the seed readily available?(Y/N)	
	If no, What are the alternative sources of seeds?	
5	**History of Production**	
5.1	Please can you give me the details of production of horticultural and field crops on your farm?	
	Table B	
6	**Marketing**	
6.1	Where do you market your farm produce?	
6.2	How far is the market?	
6.3	What mode of transport do you use to carry your produce to the market? (lorry, bus, small car, cart, other)	
6.4	Is there farmer association help with input procurement? (Y/N)	
6.5	Is there farmer association help with marketing? (Y/N)	
6.6	Do you belong to any local farmer group or association? (Y/N)	
6.7	If yes,	
	How many are you in the group?	
	How many have left the group since its formation?	
6.8	What were the reasons for the people leaving the organization? ________	

Description		Filling information
6.9	What would you invest in as a priority if you get money from cultivation? List according to priority	
7	**Farmers Resource Endowment**	
7.1	How many livestock do you have? (Oxen, cows, claves, donkeys, goats, sheep, poultry)	
7.2	Are there any incidences of theft to livestock(crops, farm implements and irrigation equipment)	
	If Yes, What are the security measures that you have put in place?	
7.3	Do you own any of the following	
	Television (Y/N)	
	TV satellite dish (Y/N)	
	Car, minibus, truck (Y/N)	
	Tractor (Y/N)	
	Mould board plough(Y/N)	
	Donkey/horse/oxen cart (Y/N)	
	Bicycle (Y/N)	
	Wheel barrow (Y/N))	
7.4	Can you please tell me your monthly expenditure for each item?	
	Items Monthly (USD) Annually (USD)	
	Food (monthly)	
	Clothing (shoes, dress, shirts etc.) (annually)	
	Transport (monthly)	
	Medical expenses (annually)	
	Hired labor (annually)	
	Seed, fertilizer, pesticide etc. (annually	
	Animal feed, vaccines, etc. (annually)	
	School fees (annually)	

Table A

Fertilizer Type	Before Planting	At Planting	During Plant Growth
Manure			
Basal			
Top Dressing			

Table B

Year	Horticultural Crop	Area (ha)	Inputs (fertilizer, pesticides etc.)	Yield
Year 1	1			
	2			
	3			
	4			
Year 2	1			
	2			
	3			
	4			
	Field crop			
Year 3	1			
	2			
	3			
	4			
Year 4	1			
	2			
	3			
	4			

Annex I

INSTALLATION, OPERATION AND MAINTENANCE OF ROPE AND WASHER PUMP

1. How it Works

The Rope pump consists of a wheel and an endless rope with small pistons, made of polyethylene (or car tire in homemade models) which are attached to the rope at intervals of 1 m. The pistons fit, with a clearance of around 1 mm, in the PVC pipe called 'rising main'. The rope and pistons move freely (no pipe) down into the well. At the bottom, the rope is led by a guide box into the rising main. The rope and pistons are lifted by the wheel. The weight of the water column forces the rope further into the V-shaped wheel, creating more resistance between the wheel and the rope. This prevents the rope from slipping. (It's therefore that U-shaped concrete wheels don't work). The water is brought up by the pistons and discharged at the surface.

1.1 Static Head

The size of the PVC rising main depends on the static head. The static head is the water column which has to be pumped up. This water column is the entire distance between the water level in the well (draw down water level in bore holes) and the point where the water is discharged at the surface.

> ***Remember!***
>
> *The size of the PVC rising main depends on the depth of the water level in the well and NOT on the total depth of the well.*

The water column is brought up by the rope and pistons driven by the wheel, which is powered by the user. If the water level in the well is high, the relative weight of the water column is low. The wheel is easily turned around by the user. If the water level in the well is low, the relative weight of the entire water column is high and therefore very heavy. In this case it would be difficult for the user to turn the wheel. To reduce the weight of the water column at greater depths, smaller PVC rising mains are used.

Example

For example, a 30 mm PVC pipe contains around 700 ml of water per m (0.7kg). If this pipe is used in a well with a water level on 10 m, the total weight of the water column will be: 10 by 0.7 kg = 7 kg. This weight can be lifted easily by the user. If the water level would be at 30 m, the total weight of the column would be: 30 by 0.7 kg = 21 kg. This is too heavy for the average user of the pump (mainly woman and children). Therefore the weight of the water column has to be reduced. To overcome this problem a smaller diameter rising main is used. For example, 18 mm PVC pipe contains 250 ml of water per m (0.25kg). Using this pipe in combination with water level of 30 m the total weight of the water column will be: 30 by 0.25 = 7.5 kg. Again this can easily be lifted by the users.

1.2 Main Parts

Rising Main

Often an inventory of available PVC pipes and pieces show that different 'standards' are used by different PVC factories and imported PVC pipes. PVC pipes of different origin are often slightly different in size. The main problem is that 'the same looking' and coded pipes, reducers and T-pieces produced in one factory, not always fit pipes of other factories.

Static water level (m)	*Rising main pvc size (inch)*
0 – 10	1
10 – 20	3/4
20 – 30	1/2

Combining pipes from different origin (factories) will result in:

- breaking or disconnection of riser pipe, reducer and T-piece

OR

- too much or too little clearance between the (standard size) poly ethylene(PE) pistons and the riser main resulting in flow loss or pistons which get stuck in the riser main

It is advised to determine the most commonly available sizes of, the low pressure type, PVC pipes, at all places where pumps will be produced. As a result of this inventory the most commonly available pipe can be set as a standard for future piston production.

It is recommended to use 'low pressure type' pipes because 'pressure type' (thick wall) pipes are more expensive and the smaller inner diameter result in a lower flow rate.

These 'low pressure' pipes have, on average a wall thickness of 1.5 – 2.5 mm.

Discharge Point

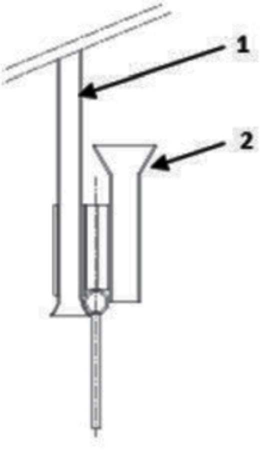
The water is lifted by the rope and pistons which fit, with a clearance of 1 mm, in the riser main (nr 10). The riser main ends in a 'reducer' (nr 18), increasing the inner diameter with one or two 'pipe sizes'. The 'reducer' fits into the bigger T-piece (nr 6), with the outlet (nr 7) and the top pipe (nr 4) attached to it. The water is carried up until the pistons arrive in the bigger top pipe (nr 4), where the water can easily pass between the pistons and the pipe wall. The water is discharged through the outlet (nr 7).

Washers/Pistons

Pistons can be made out of PE or rubber. It is recommended to use and produce the triangular shaped PE piston. As the rope pump will be used for potable water, PE pistons are cleaner and will be easier accepted by government, NGOs and donors (in terms of hygiene) and will give less friction in the pipes during operation of the pump, making it more attractive for users. Pistons should be made out of PE plastic. Other plastics will either break or deform during operation! PE can be obtained as pellets (imported by the factory) or from recycled plastic. Pistons should be produced with a clearance between 0.5 and 1 mm on both sides between piston and pipe.

Different Types of Pistons/Washers

Guide Box



The guide box will guide the rope and pistons into the rising main at the bottom of the well. The rope and pistons move freely (no pipe) down into the well and are collected by a flared 'catcher' pipe (2). The rope and pistons are then guided into the rising main (1). The catcher pipe (2) is easily attached to the guide box by a strip of inner car tube.

Rope

Ropes made of Poly Propylene (PP) give the best results. These ropes don't slip and don't stretch too much. The alternative is a rope made of Nylon, but these ropes tend to slip and stretch! The rope diameter should be 6 mm.

Rope length: twice the depth of the well, + 2 m + 5% (for the knots)

The pistons are thread on the rope and positioned in between two knots, which are roughly 8 cm apart. The distance between two pistons is 1 m (not closer, because more pistons on the rope will create slipping between the pistons and the wheel).

2. Installation

2.1 Materials

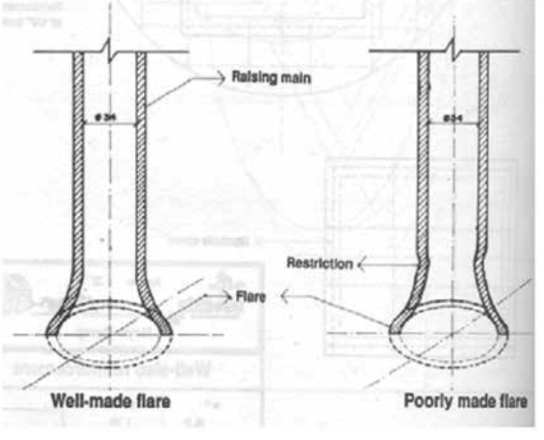
Before going into the field, check all tools and materials needed for the installation. A good indication on the water level in the well is essential to purchase the PVC parts. At least two people, preferably the new owner and/or some of the users are needed for installation. Also there need to be a sufficient amount of people to lift the well cover halves, in situations where the rope pump is placed on a hand dug well. Before installation, measure the water level and the total depth of the well.

2.2 Making Flares

Flares have to be made on those ends of the PVC pipe, where rope and pistons enter:

- On the guide box: rising main and catcher pipe
- On top of the well: place where rope and pistons enter the well through the well cover

Flares



The flare is made by heating the end of the pipe and then opening it up with a flaring tool (for example a V-shaped stick or soft drink bottle).

Don’t heat up the pipe-end too much! This will create restrictions which hamper the entry of the pistons.

2.3 Connecting Pipes

To connect the PVC pipes of the rising main a socket has to be created. To make a centralized socket, a simple tool (1) can be made out of two pipes; one which fits the inside diameter of the rising main and one which is equal to the rising main.

Connecting Pipes

Heat up the end of the rising main. Insert the tool. Cool the end of the rising main with water (turn the tool around to prevent it from getting stuck).

Remove the tool out of the rising pipe.

The socket is created.

Roughen up the inside of the female and the outside of the male part with sandpaper.

Glue the pipes together

When glue the pipes together, only glue the male part. NOT the inside of the female part. If you do so, the male part will push the glue inside the female part forward, creating a rim on the inside, which could block the pistons.

Installation step by step

Step 1

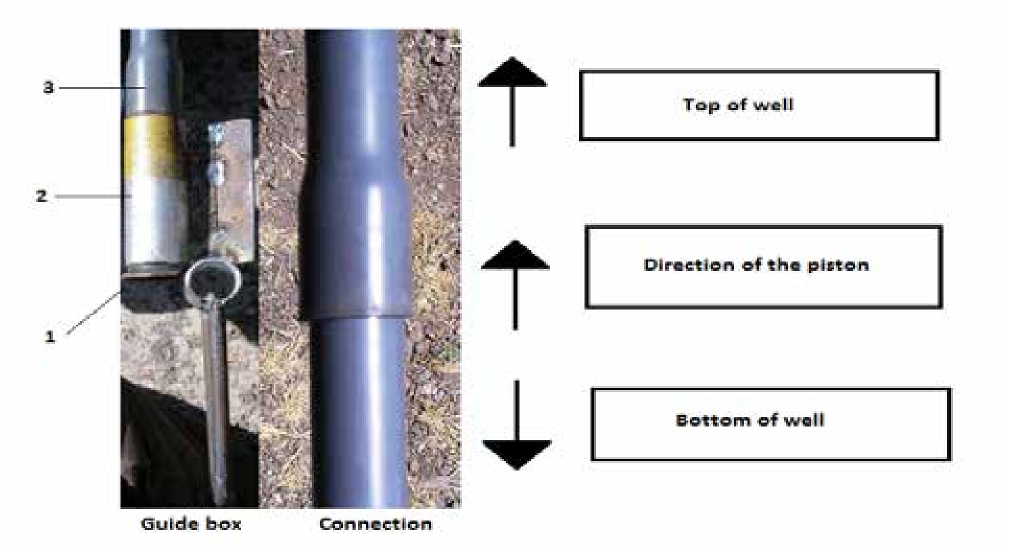
Measure the depth of the well. Glue the riser main together. During installation the length of the riser main will be:

- Total depth of the well (bottom – base of rope pump) + 1 m.

Step 2

Connect Rising Pipe

Connect Rising Pipe



Take a short piece of riser main and make a flare. Insert the flare into the GI pipe. Glue a female part of the riser pipe on top. Make sure during installation all connections are constructed with the male parts towards the bottom side of the well and the female parts towards the top side of the well. In this way the up moving pistons will not get stuck behind the male the end of the male (rim) inside the pipe.

Step 3

Pull the rope with pistons through the pipe and make sure PE pistons will move in the right direction.

Guide Box with Rope and Pistons running through

To pull the rope through the pipe:

Take a thin rope and connect a heavy bolt to it. Drop the bolt and the rope through the pipe. Connect the rope with pistons on the thin rope and pull it through. Connect both ends of the rope temporarily together on the top end of the riser main to prevent the rope from dropping into the well during installation.

Step 4

Mark on the top end of the riser main on which side the catcher pipe of the guide box is situated. This is needed to get the guide box (at the bottom) and the pump (on top) properly aligned after installation. If this is not carefully done, the rope and pistons might wind around the riser main and get stuck.

Step 5

Lower the guide box with rising main and rope into the well.

Installing the Guide Box with Rising Main and Rope

The rising main should be lowered in a bend as large as possible, to prevent cracks or even breaking of the pipe.

Don't turn the rising main around during installation to prevent the rope from winding around the rising main. Keep the rope on one side of the rising main.

Lower the guide box and rising main to the bottom of the well. Keep a clearance between the guide box and the bottom of the well to avoid sediment to be pumped. For HDW this clearance is 10 cm. For tube wells this clearance is recommended to be at least 50 cm.

Step 6

When the guide box and rising main have reached the correct depth, the rising main has to be cut around 5 cm above the well cover. Especially in case of a tube well, make sure a can or bucket (to be filled with water) will fit under the outlet. If not, the rising main should be cut higher.

While cutting the riser main, hold the rope on the opposite site of the cutting line.

Make sure the rope is not cut or damaged.

Step 7

Aligning the pump

Aligning the Pump

When the pump is installed on a tube well, the pump (wheel) should be aligned with the rising main and/or the hole in the well cover for the rising main, before final installation.

Put a plumb (rope and weight) over the wheel. The rope should be in the middle of the rising main. When a concrete slab or concrete well cover with bolt connections for the pump is installed, alignment should take place during construction of the slab (to position the bolts in the concrete).

Step 8

Connecting PVC Parts Together

Roughen up with sandpaper:

- The top outside of the riser main
- The outside of the reducer.
- All three insides of the T-piece.
- One side of the outlet.
- One side of the top pipe.

Glue all parts together.

Make sure all parts fit each other exactly.

Step 9

1. Making a Loop by Threading the Rope Back

Take the rope between thumb and forefinger. Turn your hand. If the turn can be completed between 90 and 180 degrees, the rope tension is ok.

2. Checking the Tension

Make a loop on one of the rope ends by threading the rope three times back, through its own base.

Put the other rope end through the loop and check the rope tension.

There should be little play on the rope. If not, the pistons get stuck in the guide box and the rope might slip on the wheel.

When the rope tension is ok, create a second loop with the other rope end.

3. Create the Second Loop

If nylon rope is used instead of PP, it is recommended to seam the end of the loop to avoid disconnection of the loop (nylon tends to slip)

Make sure the length of the full loop does not exceed 30 cm. As the loop consists of a double threaded rope, this part will not fit the V-shaped wheel very well. A long which is too long might slip on the wheel.

4. Seaming the End of a Nylon Rope Loop

Just after installation the rope tends to stretch a bit, making the rope longer. Check the rope tension again after the pump is tested. Make sure the users will check the tension periodically.

3. Operation and Maintenance

3.1 Operation

Functioning and life time of the pump will be increased when care is taken during operation of the pump.

Guidelines:

- Only rotate the pump clockwise, never turn the pump reverse direction.
- Always use the pumping lock when pumping is stopped.
- Don't let very small children operate the pump. If the handle slips out of their fingers, the pump will turn in backwards direction and the handle could hurt the children.
- Don't operate the pump with more than one person at the time. Avoid children hanging on the handle.

3.2 Regular Maintenance

Regular maintenance is necessary to keep the pump in good shape and guarantee a long running time.

Tasks are:

- Checking the tension of the rope and adjusting when needed.
- Lubricating the bushings every 2 weeks or when the bushings are running dry.
    - If the bushings start to make a shrieking noise oiling is URGENTLY needed. Add a few drops of NEW motor oil. (In case motor oil is not available, cooking oil can be used for emergency. Use a clean stick to apply the oil, NOT with your fingers and remember. Old oil contains iron particles and dirt, and will sand the inside of the bushings, reaching the opposite effect. Don't use too much oil at the time to prevent leaking into the well.

Potential Repairs

- *Replacement of the rope*
  Pistons usually last about twice as long as the rope. When the rope shows a lot of damage, the rope should be changed preferably before it breaks. Tie the new rope (with the pistons) to the old rope (be sure pistons are running in the right direction) and pass it through the tubing. It is not necessary to take out the tubing.
- *Replacement of pistons*
  The pistons should be changed, when the user has noted a reduction output. Before changing the pistons, check the clearance in a piece of riser main to check whether a reduced output is due to worn-out pistons.
- *Painting*
  To avoid corrosion, it is essential to paint parts again that start corroding. Clean the parts with a steel brush and roughen it with sand paper. Then apply anticorrosive

primer paint, and when it's completely dry, finish it with paint. Allow the paint to dry in the shade, NOT in the sun.

- *The bushings*
  If bushings are worn out, dismantle and replace them.(If properly oiled, bushes last for 10 years or more!).
- *PVC tubing*
  If a pump is placed in direct sunlight, the ultra-violet rays will affect the PVC parts, causing cracks. (To prolong life of PVC, paint it!) If the well contains fine sand, the sand will wear out PVC parts as well. In case wear is excessive, replace tubing.

The list of materials and tools for installation of rope and washer pump is given below:

Materials:

- Rising main as long as the depth of the well + 2 m of the right diameter
- T-piece
- Reducer
- Elbow
- PVC tubing for outlet and top pipe
- PVC glue
- Guide box
- Rope with pistons
- Rubber strips made of inner tire tubes: 2 m total length, width 30 mm

Tools:

- 2 Spanners (M10)
- Knife
- Pliers
- Pipe-cutting saw
- Sandpaper
- Hammer
- Measuring tape
- Flaring tools
- Pole to lift the slab
- Thin rope, with a length more as the total depth of the well
- Cigarette lighter to burn the ends of the rope

Annex J

GLOSSARY

Adsorption: The process whereby small particles (e.g. clay) attract and hold ionic constituents

Air rotary drilling: A well-drilling method that uses compressed air as circulating fluid

Alluvium: Soils that are deposited by running water.

Anchor bolts: Screws welded into a frame or plate or are grouted directly into the cement pad.

Annular space ("annulus"): the space between the well casing and the borehole wall.

Apron: A slightly sloped concrete platform built around wells and standpipes to prevent the infiltration of contaminated water into the well and to ensure that the area around the structure remains dry.

Aquiclude: Subsurface rock or soil unit, such as clay, shale, and unfractured igneous and metamorphic rock that do not transmit water readily and cannot be used as a water-supply source.

Aquifer: A saturated geological unit (e.g. sands, gravels, fractured rock) which can yield water to wells at sufficient hydraulic conductivity to supply water for a well or spring or water-bearing layer (stratum) of permeable rock.

Aquitard ("aquiclude"): Geological formations or strata that have the ability to store water but can only transmit water in very small quantities (e.g. silt, siltstone).

Artesian well: A well that reaches water which, from internal pressure, flows up like a fountain.

Backwashing: Well-development method. See also jetting method; gravity-outflow method; pressure-pumping method; pump-surge method; surge-block method

Bail-down placement: A method of simultaneously placing gravel pack and installing screen casing

Basalt: A hard, black fine grained volcanic rock composed largely of plagioclase with pyroxene and olivine. When it is found fractured and weathered, it can be very productive water bearer.

Bearings ("fulcrum"): Pivot points used in all lever action hand pumps to connect handles to the pump head.

Bentonite: Commercially processed clay used for drilling; bentonite forms naturally from decomposition of volcanic ash, consists of aggregates of flat platelets, and contains sodium montmorillonite, which is important in building viscosity.

Bit: The piece which operates at the bottom end of the tool string to loosen the soil or rock to deepen the hole.

Blast: Blow-up or break rocks apart with explosives.

Borehole: A hole drilled, bored or dug into the ground into which a well casing is placed.

Bore well: A machine or hand-drilled well (usually small diameter)

Bottom plug: A concrete slab across the bottom of a well which can act to prevent anything from entering the well or allow only water to enter.

Bottom section: That part of the well that extends beneath the water table.

Bowline: knot forming tight loop. A knot used to form a loop that will not slip at the end of a piece of rope.

Boundary indicators: Characteristics that is indicative of local or regional groundwater flow systems.

Cable-tool method: A very slow drilling method that can be used to penetrate rocky soil or moderately hard sedimentary rock; the drill used in this method does not require large amounts of drilling fluid.

Capture zone: The area of water table/piezometric surface drawdown created by pumping a well.

Casing: Metal pipe or PVC used to reinforce a drilled well.

Cement: A gray powder used as an ingredient in mortar and concrete.

Centralizers: Devices used to ensure that the pump rod moves straight up and down within the rising main. Can also be installed to ensure the well casing is installed within the center of the borehole

Centrifugal pump: A variable displacement pump in which water flows by the centrifugal force transmitted to the pump in designed channels of a rotating impeller.

Clay: Extremely fine particles, smaller than 0.004 mm in size.

Clay layer: Layer of clay deposits (sediment).

Cohesive: The characteristic of particles that makes particles stick together

Compressed-air methods: Rapid, effective well development methods.

Concrete: A hard strong building material made by mixing cement, sand and gravel with sufficient water to cause the cement to set and bind the entire mass.

Cone of depression: Cone of depression (or “influence”) is the draw-down of the water table or potentiometric surface that happens when a well is pumped. The drawdown cones of two wells close together may overlap so that if the wells are pumped simultaneously they will compete with each other for available groundwater (well interference).

Cone of influence: The cone of influence is the depression in the water table or potentiometric surface that is produced when a well is pumped. The cones of influence of two wells close together may overlap so that if the wells are pumped simultaneously they will compete with each other for available groundwater (well interference).

Confined aquifer: A confined aquifer is a fully saturated aquifer where the upper and lower boundaries are impervious geologic units. Water is held under pressure and the water level in wells stands above the top of the aquifer. Completely impervious layers rarely exist in nature and hence truly confined aquifers are relatively rare.

Confining bed: Aquiclude that exists between aquifers, water moves only within the aquifer.

Consolidated deposit: Rock that consists of mineral particles of different sizes and shapes.

Consolidated ground formation: Any of the various kinds of rock; hard rock; examples: granite.

Curb: A part of the well lining that extends out from the dining into the surrounding soil, helps to hold it in place and prevents it from sliding down.

Darcy's Law: Principle that describes the flow of groundwater.

Well development: The act of pumping and surging water in a well to remove mud and dirt from within the filter pack, borehole wall and local aquifer. When done completely, pumped water will be free of suspended material. Wells must be developed after drilling to ensure that the cylinder is not prematurely worn-out by the abrasive action of suspended material moving between the plunger and cylinder walls.

Discharge: Water that moves from one area into another.

Discharge area: The zone in which groundwater leaves the ground either as a spring or into a water body.

Dolomite: A carbonate rock that dissolves when carbon dioxide from the atmosphere and groundwater mix to form carbonic acid.

Drainage basin: an area drained by a stream or river.

Drawdown: Drawdown is a measure of the amount of lowering of the water level in a well when pumping is in progress.

Drilling log: Written record of the formations (soil layers and characteristics) drilled, according to depth.

Drop pipe: That section of pipe in a deep well pump assembly which extends between the pump cylinder and the pump body.

Effective hydraulic diameter: The area in which water from the aquifer can move freely into a well. If a borehole is completed with a well casing plus surrounded by a filter pack material, the effective hydraulic diameter is equal to the diameter of the borehole.

Evaporation: Direct radiation from the sun that causes liquid at the surface of a body of water to change from a liquid to a vapor

Evapotranspiration: A combination of evaporation from open bodies of water, evaporation from soil surfaces, and transpiration from the soil by plants.

Filter pack: A filter pack is coarse sand or fine gravel (2 – 6 mm diameter) that is placed between the borehole wall and screen. Filter packs are used to settle-out fine grained particles that may otherwise enter the well.

Fishing: The act of trying to retrieve a tool or pump part dropped down into a well. It ia also the name for the tool used to extract foot valves from open top cylinders.

Flowing well: A well in which the static water level is above ground level

Foot valve: Part of the cylinder that holds the column of water in the rising main while the plunger is being pushed down after each upstroke.

Geological formation: Formed rock types / sedimentary layers under the surface of the earth.

Geologic structure: Feature, such as a fold, fracture, joint, or fault, that disrupts the continuity of rock units.

Geology: The study of the earth, (formation of rocks and sedimentary layers).

Gneiss: A hard, coarse-grained, foliated (banded), metamorphic rock (altered by great temperature and/or pressure) of quartz, feldspar and mica; often has low water yield.

Gravel: Particles ranging from 2 mm up to 64 mm in diameter. Particles from 4 mm up to 64 mm are also called pebble.

Gravel pack: Coarse sand around the well-screen.

Groundwater: Water that occurs in the subsurface below the water table. Water deep enough in the ground so that it cannot be drawn off by plants or evaporated out through the ground surface; accumulates in quantity in aquifers from which it can be drawn out of the ground through wells.

Groundwater flow system: The total system which describes the movement of water in the subsurface from the point where it enters the ground to where it leaves. Water moves in the direction of decreasing pressure that may be upward in some localities.

Groundwater indicators: Features that suggest the presence of groundwater.

Grout: A sealing material of cement or bentonite (swelling clay) used to create a sanitary seal in the annular space above the filter pack to prevent contaminants from entering the well.

Hand auger: A device that consists of a shaft or pipe with a wooden handle at the top and a bit with curved blades at the bottom; a hand auger can penetrate clay, silt, and those sands in which an open borehole will stand without caving.

Hand-dug well: A well (usually large diameter) constructed by hand.

Hand pump: A water pump powered by the movement of people's arms or legs.

Hitch: To fasten or tie something temporarily to keep it from moving away.

Hydraulic conductivity: A measurement of the relative flow of water through a subsurface material; the results of the measurement are related to the size and spacing of particles or grains in soils or to the number and size of fractures in rocks.

Hydraulic gradient: The change in hydraulic head (pressure) per unit distance in a given direction (dimensionless). It is the driving force of fluid flow in a porous medium which determines the direction of groundwater flow.

Hydrogeology: The subject dealing with the occurrence, characterization and movement of water below the earth's surface.

Hydrological cycle: The continuous circulation of moisture and water on earth. Continuous natural cycle through which water moves from oceans to clouds to ground and ultimately back to oceans.

Igneous rock: Rock that forms when hot molten material (magma) cools or solidifies either inside the earth's crust or on the earth's surface (lava).

Impermeable: Material that does not transmit water through it.

Impermeable barriers: Features (solid rock masses) through which groundwater cannot flow.

Infiltration: Precipitation on land surfaces that seeps into the ground

Intake section: That part of the bottom section through which water enters the well.

Intermittent: Appearing or occurring at irregular intervals.

Jet pump: A combination of a surface centrifugal pump, a down-hole nozzle and a venture arrangement used in small diameter wells requiring a lift of 30 m or less.

Jetted well: A well that is dug using a high velocity stream of water

Jetting method: A backwashing method that involves using a jetting tool to remove caked drilling mud from the borehole wall; this method requires a large water supply.

Knot: A fastening made by looping a piece of string, rope, etc. on itself and tightening it.

Level: A device used to establish a perfectly horizontal line.

Limestone: A carbonate rock that dissolves when carbon dioxide from the atmosphere and groundwater mix to form carbonic acid.

Lining: Masonry wall built to reinforce dug well hole walls.

Lining ring: A hollow circular column usually made of concrete, which is used to reinforce a dug well.

Manual drilling: Drilling boreholes with hand powered drilling tools and drilling rigs.

Mechanized drilling: Drilling boreholes with machines or mechanized drilling rigs.

Milligram per litre (mg/l): A unit of measure expressing the concentration of a substance in a solution is equivalent to parts per million (ppm).

Observation well: A well drilled solely for the purpose of monitoring a potential or an existing source of contamination.

Outlet: The term used to describe the spout assembly of some pumps.

Overburden: Unconsolidated (loose) soil overlying rock.

Permeable: Material that easily allows water to flow through its pores.

Permeability: The ability of an aquifer or water-bearing formation to allow water to pass through it. Permeability is also known as effective porosity because it is a function of interconnected saturated pore spaces; or a measure of the ability of a material to transmit water through it.

Piezometers: A device for measuring pore water pressure (i.e. measuring the location of the water table).

Piezometric surface: The water level surface that can be defined from the mapping of water level elevations in wells tapping into a confined aquifer.

Porosity: The ratio of the volume of voids to the total volume of a rock or unconsolidated material. It is a measure of the amount of empty 'space' in a material. Potable water: Water fit for human consumption.

Pump head: Pump assembly attached to the stand.

Metamorphic rock: Igneous, sedimentary, or preexisting metamorphic rock that undergoes further transformation by changes in pressure, temperature or chemistry.

Mold: Form used in the construction of linings and lining rings.

Monitoring well: Small water wells; used for measuring water level, estimating well yield and taking samples for quality analysis. Monitoring wells are drilled next to permanent wells at specified intervals.

Mud pump: A positive-displacement double acting piston pump with capacities ranging from one to several hundred gallons per minute (gpm) at pressures up to several hundred psi.

Mud rotary drilling: Method of well drilling that uses mud to circulate the drilling fluid during the drilling process.

Perched aquifer: An aquifer that lies above an unconfined aquifer and is separated from the surrounding groundwater table by a confining layer.

Percussion drilling: A method of drilling that involves crushing by impact from the teeth of the drill bit percussion drilling for water wells uses down-hole, pneumatic-percussion hammer drills.

Permeability: The speed which water can move through a certain type of soil or rock. Water will move much faster through sand than it will through clay so the sand is said to be more permeable.

Porosity: Voids in soil and rocks.

Power auger: A device that is rotated, raised, and lowered by a power-driven mechanism; a power auger has a depth limit of about 10 feet and can be used only in areas where the water table is close to the surface.

Precipitation: Moisture released from clouds to the earth in the form of rain, sleet, hail, or snow.

Pump-surge method: A backwashing method that involves alternately pumping water to the surface and letting water run back into the well through the pump-column pipe.

Raw water: Surface or groundwater that is available as a source of drinking water but has not received any treatment.

Recharge: Water that infiltrates the soil.

Recharge area: The part of a flow system where precipitation percolates downward. Area where the groundwater reservoir' is replenished.

Reservoir indicators: Characteristics in soils, rocks, and landforms that defines the ability of an area to store and transmit groundwater but which do not directly indicate the presence of groundwater.

Rotary pump: A pump that uses a system of rotating gears to create suction at the inlet and force a water stream out of the discharge.

Rotary table: Rotating platform on a rotary rig that transmits torque to the drill rod through the Kelly.

Runoff: Precipitation on land surfaces that flows along the surface.

Sandstone: Consolidated or cemented sand.

Sanitary seal: Seal made of bentonite or cement which is placed in the annular space between the casing and the formation (borehole wall) to stop poor quality water from contaminating the well.

Saturated thickness: Distance between the top of the groundwater and the bottom of the aquifer.

Saturated zone: The zone below and including the water table in which all pore spaces or fissures are totally filled with water.

Sedimentary layers: Layers formed by the weathering, transport (by wind or rivers) and deposition (sediment) of particles.

Sedimentary rock: Rocks that are composed of sediments that are converted to rock through compaction, cementation or crystallization.

Self-jetting method: Digging a jetted well by sinking a continuous-slot, brass-jacket, or jet-head-tapering-type well point.

Semi-confined aquifer: A semi-confined (leaky) aquifer is a completely saturated aquifer overlain by a semi-impervious layer and underlain by impervious layer. Lowering of the potentiometric head in a leaky aquifer by pumping will generate a vertical flow of water from the semi-pervious layer into the pumped aquifer.

Semi permeable barriers: Features (faults or fractured rock masses) that restrict flow but do not act as a complete barrier.

Shale: Fine-grained sedimentary rock that does not store much groundwater and does not transmit large quantities of groundwater.

Silt: Fine particles with a size between 0.004 mm and 0.063 mm. Silt is larger than clay and smaller than sand.

Sinking method: Any technique used to dig or drill a well.

Slurry: "Thin mud"; a semi liquid mixture, especially of fine particles of manure, cement, or cool and water.

Soil moisture: Surface indicators that can provide some indication of recharge and discharge areas; soil moisture content is related to local rainfall and to grain size.

Specific capacity: A measure of pumping rate per unit drawdown. If you know a wells specific capacity, you can estimate drawdown at different pumping rates. For example, the specific capacity of a well that delivers 20 gpm with 40 ft of drawdown would be 0.5 gpm/ft. At 30 gpm the drawdown would be 30/.5 = 60 ft.

Specific yield: Water that can be pumped from a well.

Spring: Effluence of groundwater occurring where the water table intercepts the ground surface. A spring is a good surface indicator of the presence of shallow groundwater occurrences.

Static water level:Static water level is the level at which water stands in a well when the water level is at equilibrium with atmospheric pressures. It is a measure of the depth from the ground surface or from a known measuring point to the water level.

Storativity: The volume of water released from storage per unit surface area of aquifer per unit decline in hydraulic head (dimensionless).

Strata: Layers of deposited rock, soil etc. which are distinguishable from each other.

Streams and rivers: Surface indicators that are usually recharge areas in arid regions and may be recharge or discharge areas in temperate climates; areas adjacent to streams are considered good locations for wells but are not always the best available areas for water wells because of soil content.

Submersible pump: A centrifugal pump closely coupled with an electric motor that can be operated underwater.

Suction: Pumps without down-hole cylinders rely on suction generated by above-ground cylinders to lift water up the rising main.

Suction pipe: That part of the pump assembly which extends beneath the cylinder into water.

Sump:1– 2 m of plain casing pipe closed at the bottom end, attached to the bottom end of the well-screen.

Surface indicator: Feature that suggests the presence of groundwater.

Surface water: Water that is found on the ground surface in water bodies (lakes, wetlands, puddles, ponds -including dugouts), water courses (rivers, streams, drainage ditches), infiltration trenches and areas of temporary precipitation ponding.

Surface water divide: Boundary between groundwater flow systems.

Surface recharge: The amount of water that soaks down through the ground to reach an aquifer in a certain length of time.

Surge plunger: A device that can be inserted into the casing pipe and is moved up and down to develop the well.

Swelling soil (squeezing):In-hole effects of shale or clay that absorb water from the drilling fluid

Top section: That part of the well above the ground surface.

Transmissivity: The rate at which groundwater can flow through an aquifer section of unit width under a unit hydraulic gradient. It is the average permeability of a section of the entire aquifer at a given location multiplied by the thickness of the formation. ie. the product of hydraulic conductivity and the saturated thickness expressed in gallons per day per foot of aquifer width.

Transpiration: The passage of water vapor from plants into the atmosphere.

Unconfined Aquifer: An aquifer whose upper boundary is defined by the water table (water is at atmospheric pressure). Water usually saturates only part of the geologic unit and there is no upper confining layer. Also called, "water table aquifer".

Unconsolidated ground formation: Any type of soil other than hard rock; examples: sand, gravel, clay.

Unconsolidated layer: Layer consisting of loose particles such as clay, silt, sand and gravel. Viscosity Measure of the "thickness" of a fluid.

Unsaturated zone: The zone above the water table in which soil pores or fissures are less than totally saturated. It is also called the zone of aeration.

Unscreened well: A well in competent rock that does not require a screen; the aquifer is tapped through numerous, irregularly spaced fractures.

Valve: A device that allows water to move in only one direction. A valve at the bottom of each cylinder holds the column of water in the rising main while the plunger is being pushed down after each upstroke. A one-way valve in the plunger allows water to flow through the plunger while it is being pushed down.

Vegetation type: Surface indicators that can help define the location of recharge and discharge areas end groundwater.

Viscosity: The state of being viscous. Relates to true (Newtonian) fluids such as water; viscosity is a proportional constant between sheer stress and rate in laminar flow.

Water: A compound of oxygen and hydrogen. Water is commonly found in liquid form, but below freezing (0°C) it forms a solid and above 100^{0}C it forms a vapor (steam). In pure form it is colourless, odorless and tasteless, but usually contains dissolved compounds that give drinking water sources their unique taste, appearance and odor.

Water Quality: Term that tells whether water is safe or not (polluted or not polluted) for drinking or irrigation.

Water table: The top of the zone in which all pore spaces or fissures are totally filled with water. The upper surface of the groundwater (groundwater table).

Water-table wells: Wells drilled into an unconfined aquifer.

Weathering: Breakdown of rocks through contact with atmospheric conditions such as heat, water, ice and pressure.

Well: A hole drilled or dug into the ground to extract liquid. Drinking water wells must be deep enough to reach far below the water table or they may have no water during the dry season when the large of recharge causes the water table to fall.

Well casing: Blind pipe of PVC or steel.

Well construction: The construction (drilling, installation and backfilling) of a well.

Well development: The process of rearranging the soil particles around the intake section of a well to permit easier and better water flow into the well. Removing fines and drilling fluid additives from the well and the surrounding aquifer, and settlement of the gravel pack.

Wellhead protection: The pro-active management of land to assess and mitigate potential risks posed to well water quality.

Well screen: Slotted PVC or steel pipe through which water from the aquifer flows into the well.

Well yield: The volume of water produced by the well (generally measured in m^3/day or l/s).

Wetlands: Marshes, bogs, and swamps that arc indicative of very shallow groundwater.

Working water: Water with or without drilling fluid used during the drilling process.

Yield: The amount of water that is produced when a pump is operated for a fixed number of full strokes. Well yield is a volume of water per unit of time produced by water well

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