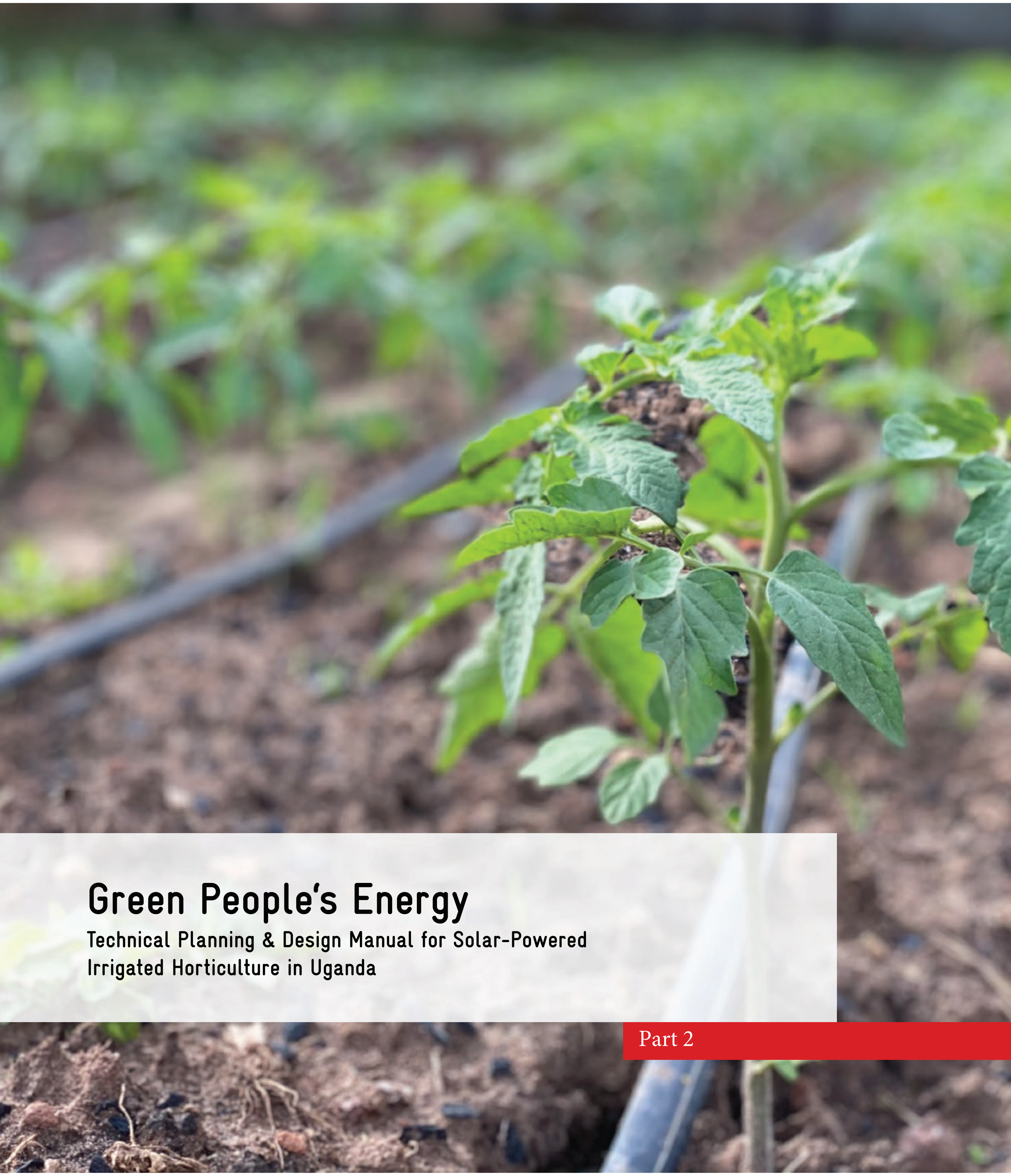

Green People's Energy

Technical Planning & Design Manual for Solar-Powered Irrigated Horticulture in Uganda

Part 2

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2.3. Irrigation Methods

There are three main methods of irrigation practiced throughout Uganda. Some other minor methods are also practiced based on specific favourable conditions, but for our purposes here, we will focus on the top three below.

2.3.1. Surface Irrigation

Surface irrigation is where water is applied and distributed over the soil surface under gravity from one side of the irrigated plot to the other. There are a number of surface irrigation methods namely flood, furrow, border, basin irrigation. It is a common type of irrigation throughout the world because it is simple and inexpensive. However, it is highly discouraged for horticultural production because of the following reasons;

- High water loss in-form of tail water(runoff), infiltration and evaporation
- The method requires a drainage system which may be expensive
- Erosion of top soil and fertilizer hence reducing soil fertility.
- Levelling and grading are labour intensive and expensive
- Limited water application uniformity over the wirrigated land.
- It is difficult to apply small amounts for example especially during supplemental irrigation

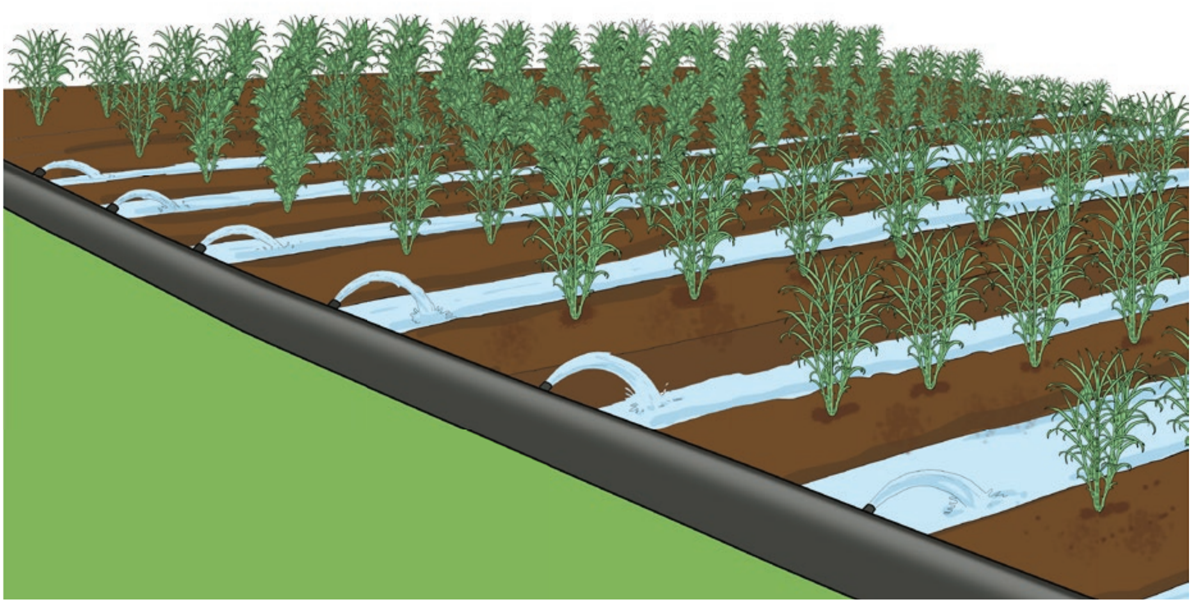


Figure 5: Surface Irrigation

2.3.2. Drag-Hose Irrigation

This is a low-cost irrigation method where a hose pipe is connected either directly to a main line from a pump or to a raised storage tank and dragged around the field by the farmer, often from crop to crop along rows. It is a laborious and time-consuming method, but it can be a good starting point for farmers who are newly adopting irrigation. The method uses much more water than drip or sprinkler since the application rate is not measured and provides less uniformity. However, it is simple and inexpensive since even a small pump can manage it.

2.3.3. Sprinkler Irrigation

The sprinkler irrigation method basically mimics rainfall. Depending on the specific type of sprinkler, water sprays out horizontally, or sometimes vertically and can be adjusted to fall in a specific way on the plants, just as a steady rain might fall.

Sprinkler irrigation systems have various units or components that include the sprinklers themselves, main lines, sub-mains, laterals, pumping plants, boosters, and operational and control equipment. These are all required for a comprehensive sprinkler system set up.

Sprinkler irrigation is suited for most row, field, and tree crops, and water can be sprayed over or under the crop canopy. Larger sprinkler models, however, are not recommended for irrigation of delicate crops such as lettuce, because the large water drops, they produce can damage the crop.

Sprinkler irrigation is adaptable to any farmable slope, whether uniform or undulating. The lateral pipes supplying water to the sprinklers should be laid out along the land contour whenever possible. This will minimize the pressure changes at the sprinkler heads and provide a uniform irrigation.

Sprinklers are best suited to sandy soils with high infiltration rates, although they are adaptable to most soils. The average application rate from the sprinklers (in mm/hour) is always chosen to be less than the basic infiltration rate of the soil so that surface ponding and runoff can be avoided.

Sprinklers are not suitable for soils that easily form a crust. If sprinkler irrigation is the only method available for these soil types, then light fine sprays should be used. Larger sprinklers producing larger water droplets are to be avoided. A good clean supply of water, free of suspended sediments, is required to avoid sprinkler nozzle blockage, and/or spoiling of the crop from coating it with sediment.

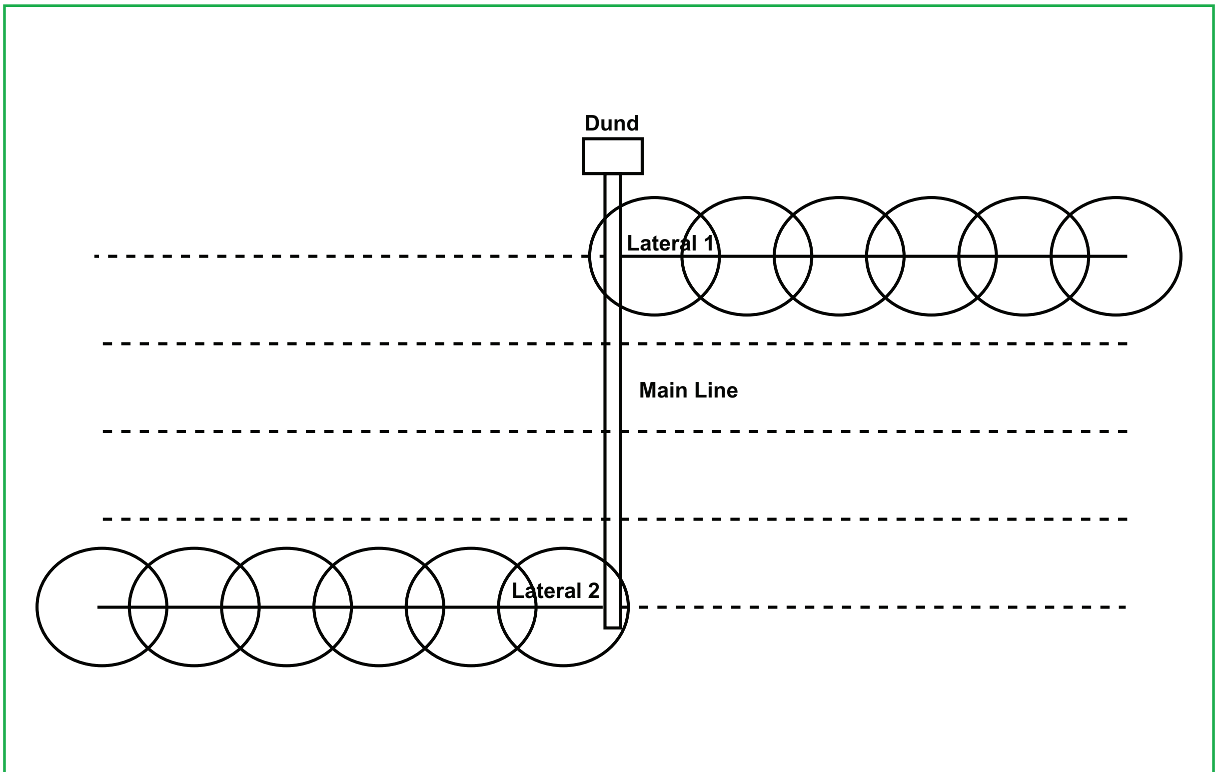


Figure 6: An example of a sprinkler irrigation system layout[10]

10 Source: FAO, Irrigation system design Chapter 5, Sprinkler irrigation, http://www.fao.org/3/s8684e/s8684e06.htm

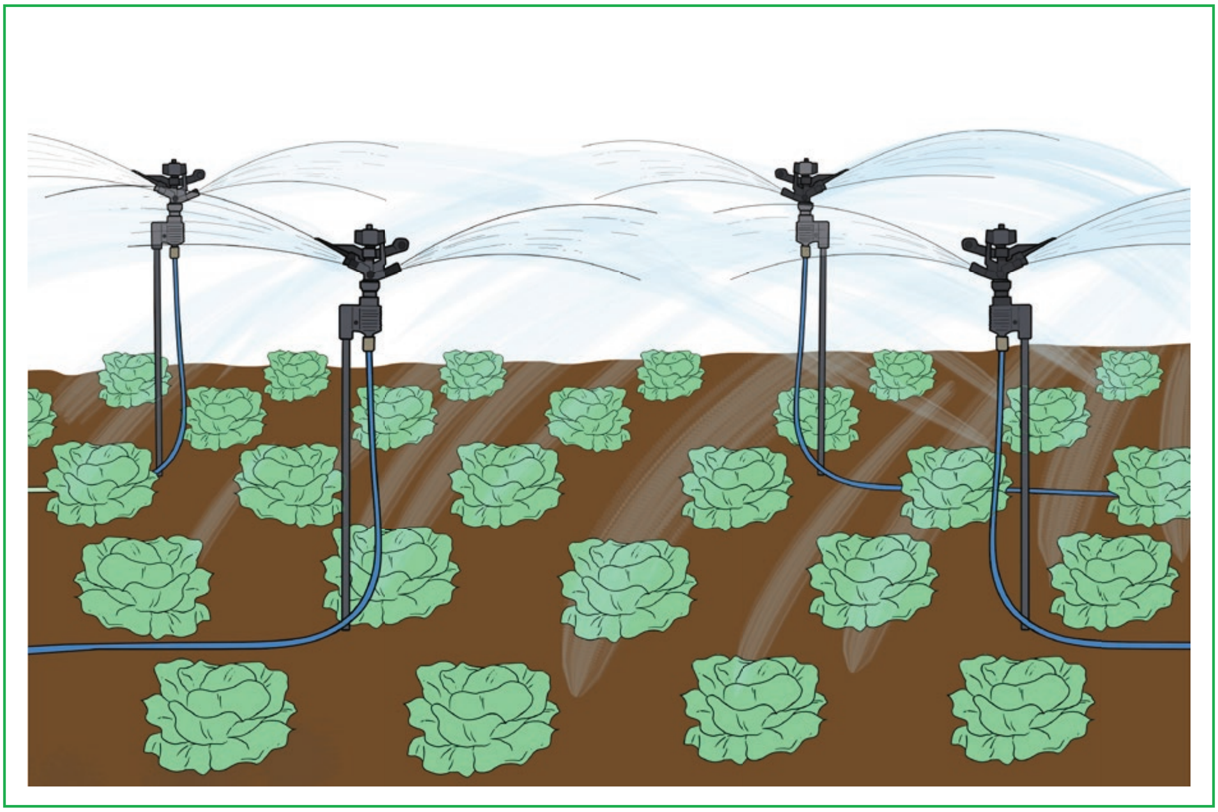


Figure 7: Fixed sprinkler Irrigation system

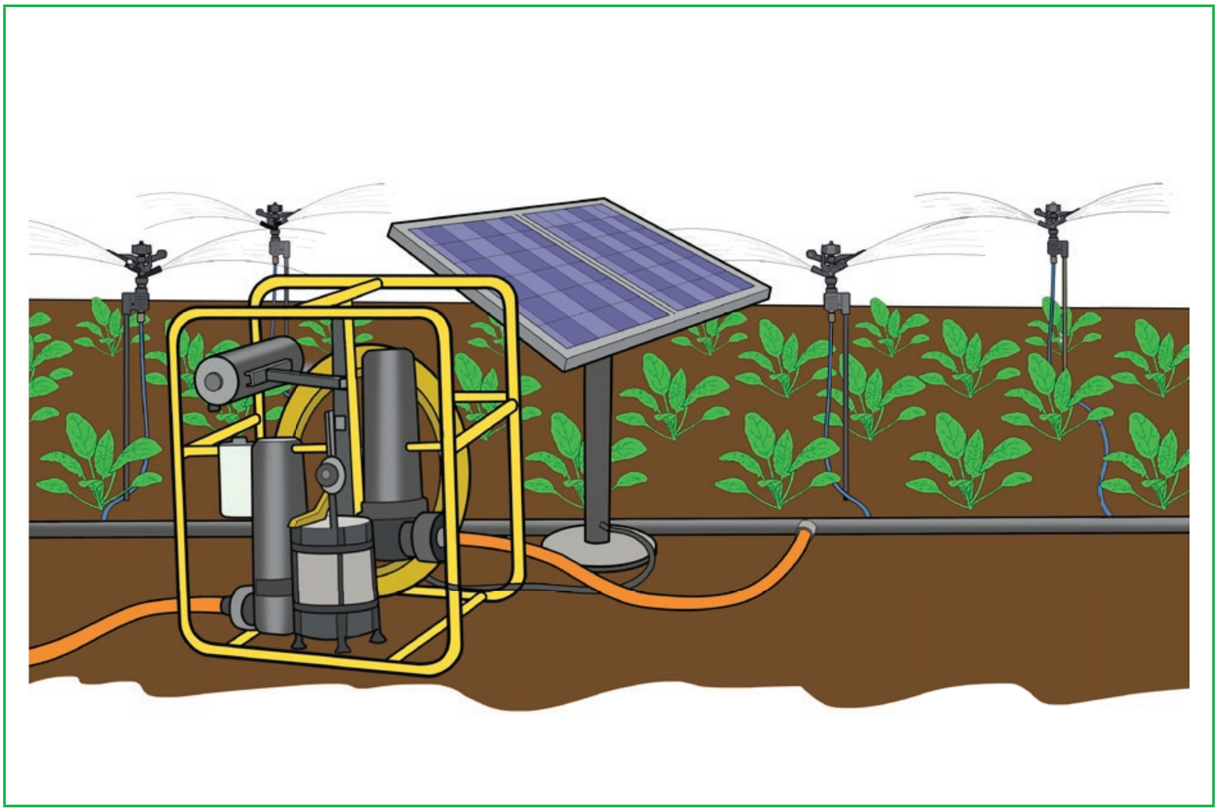


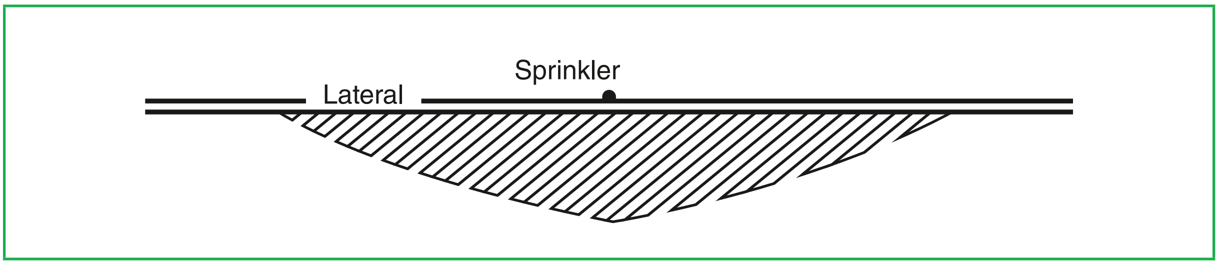
Figure 8: Portable sprinkler system

The most common type of sprinkler system layout is shown in the diagram above. It consists of a network of lightweight aluminium or plastic pipes which can be moved by hand. Rotary sprinklers are usually spaced 9-24 m apart along the lateral which is a pipe normally 5-12.5 cm in diameter, so that it can be carried easily. The lateral pipe remains in the field until the irrigation is complete. The pump is then switched off, and the lateral can be disconnected from the mainline and moved to the next location. The lateral is then re-assembled and connected to the next mainline and irrigation begins again. The lateral can be moved one to four times a day, gradually moving around the field until the whole field is irrigated. A single lateral system is the simplest of all sprinkler systems. Some farmers use more than one lateral to irrigate larger areas.

The main objective of a sprinkler system is to apply water as uniformly as possible to fill the crop's root zones with water, but sprinklers also have the ability to deliver dissolved fertilizer as a top dressing, and even to help wash dust off crop leaves.

Wetting patterns

The wetting pattern from a single rotary sprinkler is not very uniform. Normally the area wetted is circular and the heaviest wetting is closest to the sprinkler itself. As a result, to obtain uniform wetting, several sprinklers must be placed so that their patterns overlap. For good uniformity the overlap should be at least 65% of the wetted diameter. This determines the maximum spacing between sprinklers.



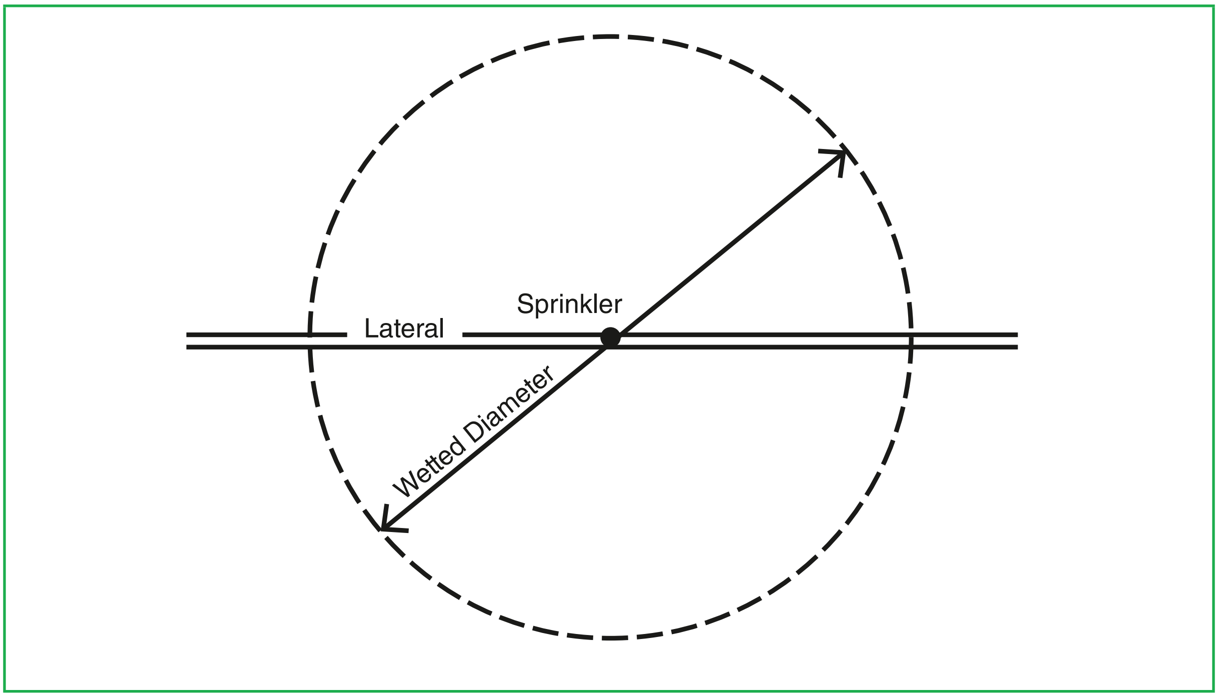


Figure 9: A typical view of the wetted area by a sprinkler.[11]

11 Source: FAO, Irrigation system design Chapter 5, Sprinkler irrigation, http://www.fao.org/3/s8684e/s8684e06.htm

The uniformity of sprinkler application can also be affected by wind and water pressure. Spray from sprinklers is easily blown about by even a gentle breeze, and this can seriously reduce uniformity. To reduce these effects, sprinklers can be positioned more closely together.

Sprinklers will only work well at the proper operating pressure recommended by the manufacturer. If water pressure is above or below the recommended range, water distribution will be affected. The most common cause of low pressure is when pumps and pipes wear. Friction increases and so pressure at the sprinkler is reduced, resulting in the water jet not properly dispersing, and the water falling in only one area towards the outside of the wetted circle. Conversely, if the pressure is too high, a fine spray develops which more easily evaporates or falls only close to the sprinkler.

Application Rate

This is the average rate at which water is sprayed onto the crops and is measured in mm/hour. The application rate depends on the size of sprinkler nozzle, the system operating pressure, and the distance between sprinklers. When selecting a sprinkler system, it is important to make sure that the average application rate is less than the basic infiltration rate of the soil. In this way all the water applied will be readily absorbed by the soil and there should be no runoff.

Sprinkler Drop Sizes

As water sprays from a sprinkler, it breaks up into small drops between 0.5 and 4.0 mm in size. The smaller drops fall closer to the sprinkler whereas the larger ones fall closer to the edge of the wetted circle. Large drops can damage delicate crops and soils and so in such conditions it is best to use smaller sprinkler models.

Drop size can also be controlled by pressure and nozzle size. When water pressure is low, drops tend to be much larger, as the water jet does not break up easily. So, to avoid crop and soil damage, it is recommended to use smaller diameter nozzles operating at, or above, the normal recommended operating pressure.

Advantages of sprinkler systems

- Affordable and easy to set up. Sprinkler systems are not sophisticated in their layout as compared to drip systems.
- Water measurement is easier than with a surface irrigation system, as water spreads out almost naturally like rain.
- Less interference with cultivation and less erosion. Favourable with any soil type as long as water is reliably supplied.
- High volume and frequent application can be effectively accomplished as per the wide coverage of the water spread over the land area.
- The system can easily be used for other purposes such as cooling of the plants during very high temperatures.
- The ability to deliver dissolved fertilizer as a top dressing and to help wash dust off crop leaves.
- Easy mechanization and automation

Disadvantages of sprinkler systems

- Relatively high operating cost
- Water will drift when there is a lot of wind or high humidity conditions. Unwanted drift brings about evaporation of the water that should be reaching the plants instead.
- A stable water supply is needed to regulate proper pressure and avoid sediment getting into the system.

- Saline water may cause problems.
- Water must be free from sand, debris, and large amounts of salt. Otherwise, sprinkler nozzles can easily be clogged.
- Compared to drip irrigation, more weed growth and labour intensive

2.3.4. Drip irrigation

This is a localized method of irrigation wherein water is applied slowly at intervals directly to the soil near each plant stem through a series of mechanisms called emitters. The movement of water into the soil is mostly by unsaturated flow. Drip irrigation is the most efficient method of irrigation, with water savings ranging between 90% and 95%[10].

Depending on size, a complete drip irrigation system can contain the pumping unit from the source, a control head, metered main and sub lines, lateral lines, and the emitters/drippers themselves. Fertilizers can be efficiently applied through the system by dissolving them into a small reservoir of water, as per required ratio, and piping the solution from a branch into the main line through simple suction. This method of applying fertilizer is called fertigation.

Drip irrigation is most feasible for farmable land on sloping grounds. A slope away from the source favours the flow of water, either from the source directly or from a gravity-fed storage tank, thus minimizing additional pumping costs. Some farmers may opt to irrigate their land directly from the source if feasible, while others may opt, or need, to pump and store their irrigation water in a storage tank that can later be used for irrigation at various scheduled times.

The mechanism of water flow can be highly dependent on the nature and structure of particular soils. For example, clay soils absorb water very slowly, so there is a need to apply any irrigation water slowly also, in order to avoid ponding and runoff in the irrigated area. Whereas, sandy soil absorbs water at a much faster rate, so water needs to be applied more often and at a faster rate.

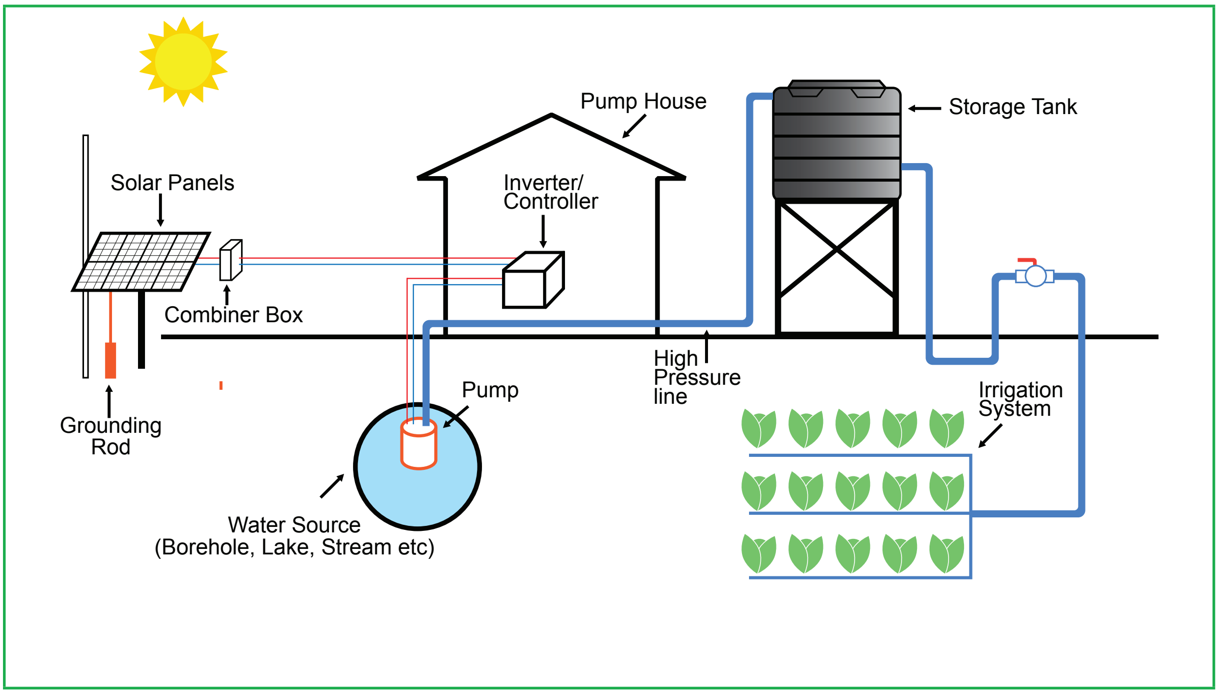


Figure 10: Example diagram of a solar powered drip irrigation layout[12]

12 www.fao.org

Advantages of Drip Irrigation

- The rate of evaporation is greatly reduced as water is directed to a smaller surface area near the plant's root zone, thus limiting losses before absorption into the soil.
- Reduced weed growth, as water is directed only to the crop root zone, rather than to surrounding ground where weeds can utilize it.
- Slow application of water by drip improves the penetration of water into problematic soils thus improving plant growth on these kinds of soils.
- Drip has a higher degree of inbuilt crop management, which means that once it is in place there is less work for the farmer to do, and which brings about higher irrigation efficiencies.
- Drip irrigation is noted as a water-saving technology as compared to other types of irrigation, making it more environmentally friendly.
- Moisture availability in soils at low soil tension results in faster growth, higher yields, and overall better quality of plants.
- Fertilizer losses are subsequently reduced, especially with fertigation.
- Less attack from pests and diseases due to limited humidity around the crops
- Drip irrigation performs with low pressure and low water requirement hence less energy requirement.

Disadvantages of Drip Irrigation

- Emitters can clog easily due to their small diameter. Sediments collect and can eventually bring about blockages in the emitters, which can take time to be noticed, thereby depriving the affected plant of water.
- Movement of salts to the fringes of the wetted area may bring about increased salinity through that salt leaching by rain into the main root volume. This can result in dehydration of the plant and thus productive loss.
- Rodents, dogs, and other animals in search of water can easily damage the lines. Drip pipelines can also be more easily vandalized by human beings.

For very large plots and plantations, drip irrigation is uneconomical as large numbers of laterals and emitters would be required.

Comparing all methods, surface irrigation is the least efficient method of irrigation. According to FAO, below are the indicative values of field application efficiencies of different irrigation methods[13]

Table 13: Water use efficiency of irrigation methods

Irrigation methods	Field application efficiency
Surface irrigation (border, furrow, basin)	60%
Sprinkler irrigation	75%
Drip irrigation	90%

Note: For purposes of determining the irrigation water supply from the crop water requirement, we recommend use of scheme irrigation efficiencies of 35% for surface irrigation, 60% for sprinkler, and 85% for drip irrigation. Scheme Irrigation efficiencies is the combination of the conveyance efficiency and field application efficiency. Field Application efficiency is the percentage of the applied water that is actually used by the crops. Field application efficiency depends on the method of irrigation and the farmer's discipline.

13 (http://www.fao.org/3/t7202e/t7202e08.htm#TopOfPage).

Summary of Irrigation Types and Applications

Table 14: Comparison of irrigation methods

Irrigation Type	Water supply	Climate	Slope	Soil type
Drip	Suitable for areas with limited water.	Preferred for very windy and semi-arid or arid climatic conditions	Suitable for all slopes. Most Suitable for undulating slopes	Suitable for all types. Most suitable for Sandy soil with low water holding capacity and high frequency of application
Sprinkler	Suitable for reliable and adequate water sources	Preferred for humid climates conditions as the windy and dry climatic areas can cause drifting	Suitable for low slopes	Suitable for all types except deep clay with low infiltration rate

2.4. Irrigation Scheduling

The crop water requirement can be met by rainfall, irrigation, or by a combination of both rainfall and irrigation. Usually in Uganda irrigation water supplements natural rainfall in the dry season when irrigation is the only reliable source of water and/or when rainfall is insufficient to meet the crop water requirement.

This section will review how much water is required given the selected crop's water needs, the soil type, and the climate in the area. This will result in a calculation indicating whether the available water is sufficient for the crop type and will assist in many of the following feasibility and technical decisions.

Irrigation Selection

You should be able to fill in the below table after this section.

Table 15: Irrigation method selection

IRRIGATION	RESULT	NOTES
Irrigation Type selected		

Although a calculation may show that an irrigation schedule should require watering of crops only every two days, it is best to identify the highest water demand to allow for losses, cloudy days, and other unforeseen problems.

2.5. Water Demand

The example below provides a methodology for determining water demand for the peak day in the driest conditions for an area. The methodology for calculating the peak day demand considers:

- Crop water requirement in L/plant or m^2
- Expected of Number of plants or planting area in m^2
- Soil type
- Climatic conditions

    - ❖ Crop Water Requirement

The crop water requirement is measured in L/plant/day or in L/m^2 of planted area. It is often difficult to obtain such detailed information, so we will use the below rule of thumb.

<u>Rule of the thumb:</u>

In absence of data during design of small irrigation systems for the Ugandan environment during the dry season, the following can be considered:

✓ For vegetables, an average of one (1) litre per plant per day, or approximately 4 litres of water per square meter per day.

✓ For young fruit tree plants, approximately 6 litres per plant per week

✓ For mature fruit tree plants, approximately 12 litres per plant per week.

These estimates can be used to inform the design process, but a proper irrigation schedule must be practiced during the actual system operation.

❖ Crop growth stage

Crop stages have different evapotranspiration rates implying different crop water requirements. There are basically four crop growth stages

1. The initial stage- from sowing to 10% ground cover
2. The crop development stage- from 10% to 70% ground cover
3. The mid-season stage- includes flowering and yield formation
4. The late season stage-including ripening and harvest

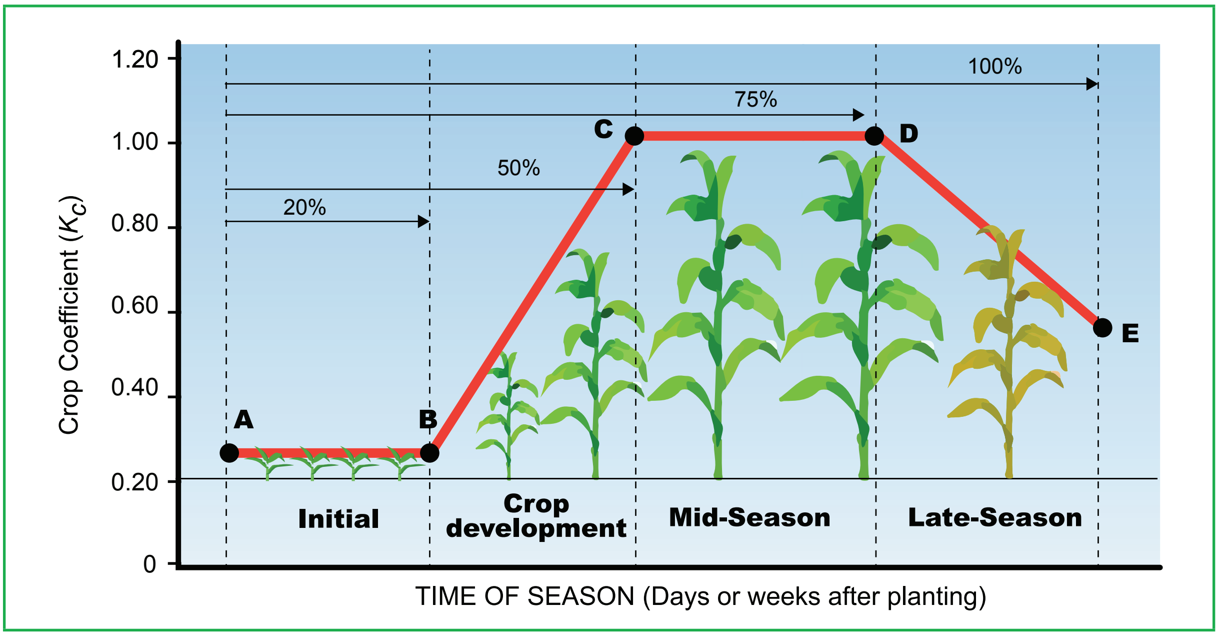


Figure 11: Crop growth stages[14]

In general, it can be stated that of the four stages, the mid-season stage is the most sensitive to water shortages. This mainly because it is the period of highest crop water needs. If the water shortages occur during this season, the negative effect on the yield will be pronounced. The least sensitive to water shortages is the late season stage. This stage includes ripening and harvest. Water shortages in this stage have only a slight effect on the yield especially if harvested dry. Care should however be taken even during this stage with crops which are harvested fresh such as lettuce. Fresh harvested crops are sensitive to water shortages during the late season stage. The initial and crop development stages are between the mid-season and late season with respect to sensitivity to water shortages. Some crops react favourably to water shortages during the crop development stage, they react by developing a deeper root system which is helpful during the later stages. In general, crops grown for their fresh leaves or fruits are more sensitive to water shortages than those grown for their dry seeds and fruits.

Note: Always consult an agronomist or irrigation expert about the crop water requirements at a specific growth stage.

❖ Soil Type

As mentioned earlier, there are water-retaining and porous soils. Depending upon which end of the scale the soil type falls, the water requirement may increase or decrease.

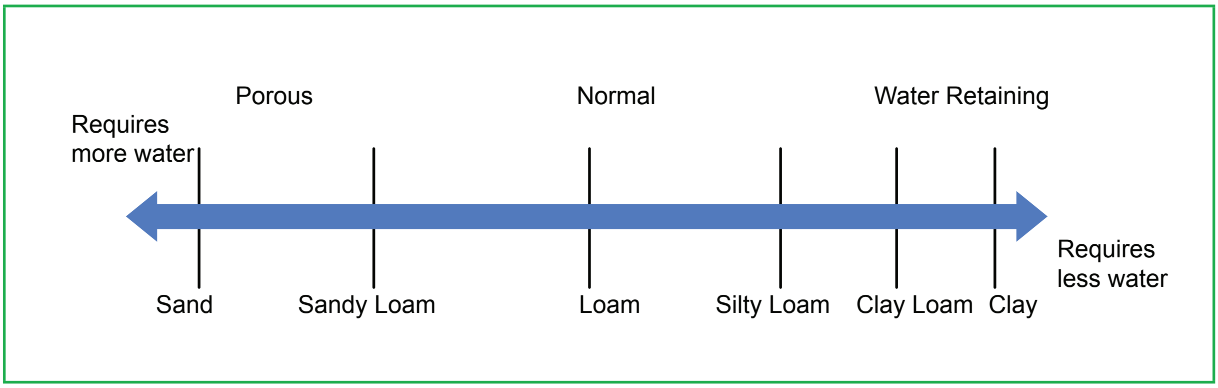


Figure 12: Impact of Soil type on water requirement

14 Source: University of Nebraska-Lincoln, 2008, https://cropwatch.unl.edu/estimating-crop-evapotranspiration

Because obtaining a precise calculation for the variance in water requirement due to soil type is laborious and requires soil testing in a lab, amongst other factors, we will give a rough estimate of the percentages for each soil type here.

Table 16: Soil / Water balance

Soil Type	Increase /decrease in water required
Sand	+10%
Sandy Loam	+5%
Loam	0
Silty Loam	-5%
Clay Loam	-10%
Clay	-15%

❖ **Climatic Conditions**

Just as with soil, the climatic conditions of an area may adjust the water demand. And, just as with soil adjustments, the adjustments for climate are not precise. Below is table of estimates that can be used to overcome the ambiguity of these adjustments. Note that the table provides estimates only.

Table 17: Climatic Adjustments to crop water requirements

Climate parameter	State		Action
Temperature	Hot	Cool	Increase or decrease water requirement by 1% for each degree away from average of 25C
Wind speed	Windy	Low wind	Increase water requirement for windy locations by up to 10%
Humidity	Dry (low)	Humid (high)	Increase water requirement for very dry locations up to 10%
Sunshine	Sunny (no clouds)	No sun (cloudy)	Increase water requirement for very sunny locations up to 10%

2.5.1. Calculation of Water Demand

Water demand is calculated for the worst-case scenario called the peak day demand in Litres per square metre per day(L/M^2/day) or litres per plant per day. The peak demand is taken from the driest month of the growing season. Interestingly, the driest and sunny month(worst-case) has the highest solar radiation good for SPIS. The amount of water to be supplied by an irrigation system is slightly higher than the crop water requirement due to the soil type, climate (temperature, wind, humidity and sunshine) and the irrigation method efficiency. Therefore, the irrigation water demand is the sum of the crop water requirement and its adjustments due to climate, soil type and irrigation efficiency.

When the source is unable to supply the amount of water required for irrigation on a peak demand day, it is important to consider irrigating a smaller area or selecting a crop with a lower crop water requirement.

In order for drip, sprinkler, or flood irrigation to operate successfully in the widest range of conditions, water is usually pumped from its source to a raised storage tank from which the water can then flow by gravity through the system pipes, and into the field as appropriate crop irrigation.

It is important to note here that many sprinkler irrigation solutions may require additional pressure beyond gravity to operate properly.

Energy sources for pumping of a water supply can be grid, diesel generator, solar, and others. The section below outlines the specific option of a solar-powered water supply and provides a step-by-step rapid feasibility assessment of this option that will assist in calculating preliminary investment costs for the overall project.

Tools/Resources for Crop Water Requirement:

- FAO CropWAT
- FAO AquaCrop
- ETo Calculator
- CRIWAR
- ECOCrop
- SPIS Toolbox
- Crop Water and Soils (app)

And many others

2.6. Financial Feasibility

To measure the profitability of the intended horticultural farm, calculate the income and expenses, and estimate how long it will take to pay back the capital investment.

2.6.1. Gross Margin Analysis

Gross margin is the difference between the gross income and the total variable costs. It is basically the income generated from a horticultural enterprise.

A positive gross margin does not necessarily mean the business is a worthwhile proposition. The margin has to be significant enough that it has a higher return on investment. A good benchmark would be an increase of at least 30% on current margins. On the other hand, having a negative margin does not necessarily mean that one should abandon the horticulture business plan. Instead, a farmer may need to either increase the gross income or reduce the cost of production enough to create an appropriate margin. Gross income can be increased by raising the expected crop yield and/or its selling price or considering a more marketable crop type. Cost of production can be reduced by simply eliminating any unnecessary costs.

The process outlined here provides an opportunity to make informed decisions based on financial realities and is not exhaustive.

Calculating Income

Calculating gross margin requires the following information:

- Estimated Market value / kg

- Estimated Yields / plant or m^2
- Size of plantation (# of plants or total m^2)
- # Of expected harvests per year
- Losses* (usually calculated as an average of 30%/ year

*Losses are to be expected. Depending on how estimates were calculated for market value and yield, losses may be higher or lower. Losses are due to perished items (both pre- and post-harvest), unforeseen events, market value crash, etc.

Calculation Method

(Market value x Yield x Size x Harvests) x .7 = Income
Production and Operating Expenses
Production and Operating expenses include the following:

- Seed
- Inputs (Fertilizer, pesticides and herbicides)
- Labour
- Operation and Maintenance

Calculation Method

(Cost of seed / plant or m2 x # of harvests) + (Cost of inputs / plant or m2 x # of harvests) + Labour + Annual operation and Maintenance costs (water supply + general upkeep) = Expenses

Example:

Estimate the Gross Margin for a $200m^2$ plot of tomatoes with 3 harvests per year.

NB: All units in UGX.

Income:

- Estimated Market value / kg = UGX 2,000
- Number of plants/m^2= 4 plants
- Estimated Yields / plant = 2kg/Plant
- Size of plantation (# of plants or total m^2) = $200m^2$
- # Of expected harvests per year = 3
- Losses* (usually calculated as an average of 30%/ year

(2,000 x 2 x 4 x 200 x 3) x .7 = 6,720,000

Expenses:

- Seed = 250,000/harvest
- Inputs = 400,000/harvest
- Labour = 1,000,000/yr.
- Operation and Maintenance = 1,000,000/yr.

(250,000 x 3) + (400,000 x 3) + 1,000,000 + 1,000,000 = 3,950,000

Gross Margin: 6,720,000 – 3,950,000 = 2,770,000

2.6.2. Payback Period

Capital expenses, or investment costs, need to be deducted from the gross margin to calculate the return on investment. From the cost estimate made during rapid assessment, it is important to figure out how long it will take to pay back the investment. It is generally advisable to pay back not more than 50% of the gross margin annually to investment costs. To calculate how many years, it will take to pay back the entire investment cost use the following calculation:

Investment cost / (gross margin x .5) = # of years to pay back investment.

<u>Example: If the investment cost is 5 million shillings, then the payback period</u>

5,000,000[15] / (2,770,000 x .5) = 3.6 years

2.6.3. Return on Investment (ROI)

If the capital expenditure cannot be paid back within 5 years with an annual repayment of not more than 50% of your gross margin, then the return on the investment exceeds advisable parameters and is not recommended.

The above examples are manually done. However, some application such as SPIS toolbox can be used to perform the financial feasibility analysis[16].

From this information, a preliminary cost estimate can be calculated.

Table 18: Rapid Assessment Cost estimate example

Component	Description	Cost Estimate
Water source development	Drill Borehole, construct valley tank, spring box etc.	
Pumping system	Pump type (surface, submersible), pump size, solar array size required.	
Transmission line	Size of pipe, pipe material, length	
Water storage	Tank stand height, storage size	
Distribution and Irrigation	Irrigation type, length of irrigation lines	
Labour		
Contingency		
Total Estimate		

15 Five million is an example amount for the investment cost in order to demonstrate the formula. The actual investment will depend on the site parameters.

16 https://energypedia.info/wiki/Toolbox_on_SPIS

2.7. Conversion from Fuel powered system to solar powered system

When a farmer opts to convert to solar from a fuel powered system, the irrigation system and the pump will remain the same, only the source of power will change. In order to power a DC pump that is commonly used with fuel-powered system, the power requirement of the pump will be needed to size the solar array and inverter necessary. These will be the only components required as far as capital investment is concerned.

However, for small portable systems, many things including the pump may change. Therefore, a well experienced technician is recommended to identify how many system components need to change and estimate the overall cost. The conversion of a portable system may be costed in the same way a new system is costed for purposes of estimation and feasibility.

The advantage of converting from a fuel powered system to a solar system is recognized over time. The graph below shows the economic advantage of solar powered systems, showing the capital cost and operation and maintenance costs comparison between diesel and solar powered systems over their economic life.

Year	Generator	Solar
Capital Costs	929,500	2,401,245
1	2,084,610	2,566,245
2	3,116,123	2,713,590
3	4,036,746	2,845,095
4	4,964,916	2,962,575
5	5,699,566	3,067,515
6	6,354,514	3,161,070
7	6,940,154	3,345,111
8	7,529,386	3,419,691
9	7,996,050	3,486,351
10	8,413,045	3,545,916
11	8,784,991	3,599,046
12	9,159,127	3,646,401
13	9,455,990	3,688,806
14	9,833,865	3,771,933
15	10,070,663	3,805,758
16	10,282,048	3,835,953
17	10,470,331	3,862,848
18	10,660,658	3,886,938
19	10,810,822	3,908,388
20	10,944,815	3,927,528
21	11,064,946	3,944,688
22	11,186,182	3,978,447
23	11,282,056	3,992,142
24	11,367,534	4,004,352
25	11,443,772	4,015,242

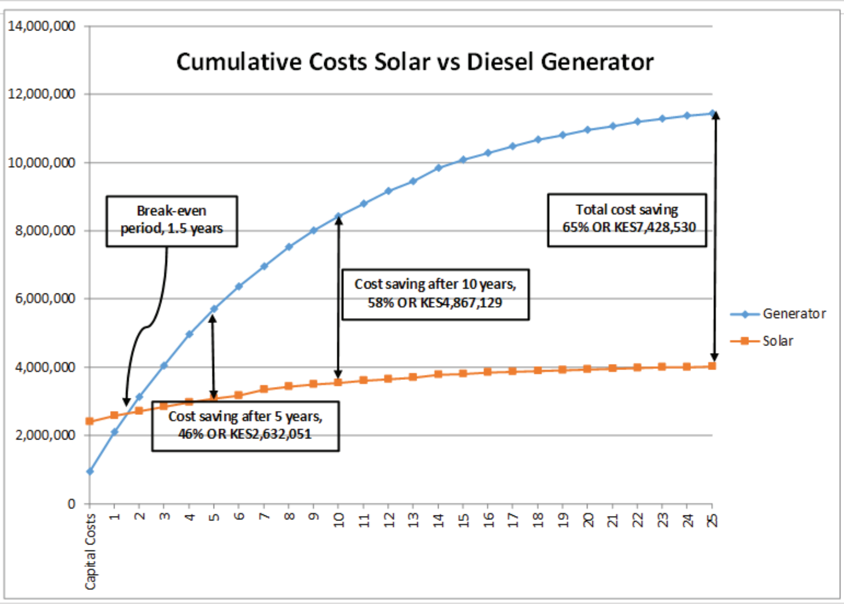


Figure 13: Comparison over time of costs for solar vs generator[17]

Tools/Resources for Financial Feasibility Analysis

- SPIS Toolbox
- Excel spreadsheets
- Feasibility study (app)

And many others

17 Source: Asian Development Bank, Microsoft Excel-based Tool Kit for Planning Hybrid Energy Systems.

2.8. Rapid assessment for solar powered water supply

The reason we do a rapid assessment of the required water supply in conjunction with its intended farmland is to assess the estimated cost of an appropriate mechanized system and determine if the return on investment justifies the investment itself. The below activities are recommended during a site visit.

2.8.1. 2.8.1 Feasibility Checklist

Interview the farmer and confirm that the following are positive. More information may be obtained from local government officials and neighbors.

- ✓ Secure access to land for at least 12 months
- ✓ The land is not in a protected area such as wetland, forest, park
- ✓ The land is at least 200 m away from lake, 100 m from river or swamp
- ✓ If land is in an urban area, it should be checked with the development plan
- ✓ Potential of water source such as river, stream, lake, pond, or well and not more than 700m away from the irrigated farm (Water source must be evaluated for feasibility).
- ✓ The water source is permanent not seasonal
- ✓ The crop to be grown is a horticultural crop
- ✓ Willingness of the farmer to finance and operate the system

2.8.2. Site Assessment tool

Table 19: Technical site assessment tool

1	Site Details	
Individual or Group site		
Farmers' Name/Group Name		
Village		
Parish		
Sub-county		
District		
GPS Coordinates		
Site access		
2.	Existing Water sources	
	Type	Details
	Swamp	Perennial Seasonal
	Surface water (river, lake)	Perennial Seasonal
	Ground water	Deep well Shallow well
	Dam/Valley Tank	

Distance between the source and proposed site (m)	
Water Quantity	
Water quality assessment	
GPS Coordinates of source	
GPS Coordinate site (Highest point)	
Comment	

3	Land Suitability and Availability
Land Size (acres)	
Land Ownership	Communal Individual Hired/leased Public
If hired, for how long? (years)	
Soil texture	Loam Clay Sand/silty Sandy clay Sandy loam Clay loam comment
Top soil Depth (cm)	
Vegetation Cover	
Site Slope	Flat Mild Gentle Gradual Steep
Comments	

4.	Crop Enterprise
Crop type if possible, and variety	
Agronomic properties	
Agroclimatic zone	
Farm records	Production Sales Expenses Schedules Others
Planting season	
Pests and Diseases	

Available market	
Comments	

5	Operation, Maintenance and Management
Willingness to operate and maintain	
Labor availability	Skilled Semi-skilled Unskilled
Existing services	
Level of mechanization	Water pump Generator Tractor Rotavator Harvesters Seeders irrigation system Processing units Stores

6. Contact Person		
Name	Title	Contact
General Comment:		

After the site assessment, discus the irrigation method with the farmer and guide on the proposed location of the storage tank. Provide a preliminary estimate of cost of the SPIS.

2.8.3. Summary of the Rapid Assessment Data:

Table 20: Summary example for Rapid Assessment Data

Parameter	Observation/Result
Estimated Water supply (L/min or m3/hr)	
Water Demand (extracted from earlier estimations)	
Distance from water source to tank stand	
Elevation changes between water source and tank stand	
Plot size	
Irrigation Type Selected	

2.9. Decision Matrix

Question	If NO
Is there sufficient water available?	Stop Here. Without water the site is not suitable for irrigated agriculture.
YES ↓	
Is the Gross Margin greater by at least 30% of your current income?	Stop Here. This solution may not be the right fit for the you. But first, consider alternatives that may make more sense for investment. For example, would you have a greater return on investment if you were to grow tomatoes instead of Okra?
YES ↓	
Can you pay back your investment within 5 years?	Stop Here. This solution may not be the right fit for the you. However, there may be other factors that lead you to another conclusion. For example, should the time saved through automated watering allows you to earn supplementary income, this may lead towards a positive response to this section of the decision matrix.
YES ↓	
Are funds available for the capital investment? Either through loans or Pay As You Go. (PAYG)	Stop Here. Seek funding options that work for you and come back to this question.
YES ↓	

YOU ARE READY TO DESIGN YOUR IRRIGATION SYSTEM!

3. SOLAR POWERED IRRIGATION SYSTEMS DESIGN

This section covers the design principles and process for a small-scale solar-powered gravity-fed irrigation system which is defined as a system in which water from a source is tapped and energized using solar energy into an overhead storage tank and then distributed under gravity to an irrigation solution of choice within 1km radius or whose demand is within 25m3/day.

While this system design does allow for conversion of solar to solar-hybrid (grid or generator power), this document concentrates on the design of stand-alone solar ONLY.

3.1. Design Assumptions

A number of design assumptions have been made in the development of this design process:

i. There is a potential water source – borehole, valley tank, or spring box.

ii. The proposed system will be powered by solar irradiation ONLY. The average sun day consists of 6 hours of irradiation, according to MWE guidelines

iii. This system will be comprised of:

    a. An existing water source, a solar powered motor driven pump and a supply line to an elevated tank.

    b. A gravity-fed irrigation system containing a mainline, sub-mains and valves (that supplies water to different plots)

    c. laterals and emitters that apply water to the irrigation fields.

iv. The personnel performing the evaluation, design, and installation have sufficient technical knowledge of water/energy systems including their operation and maintenance along with general electrical and plumbing knowledge.

v. Installation work will be done and/or overseen by trained technicians. This manual is not intended for use by people with no experience in water system or electrical installation.

❖ Selection of Pumping System

Before entering the design process, you will need to assess the appropriate system to design based on the parameters identified during the feasibility section. The below table has been developed to guide this process.

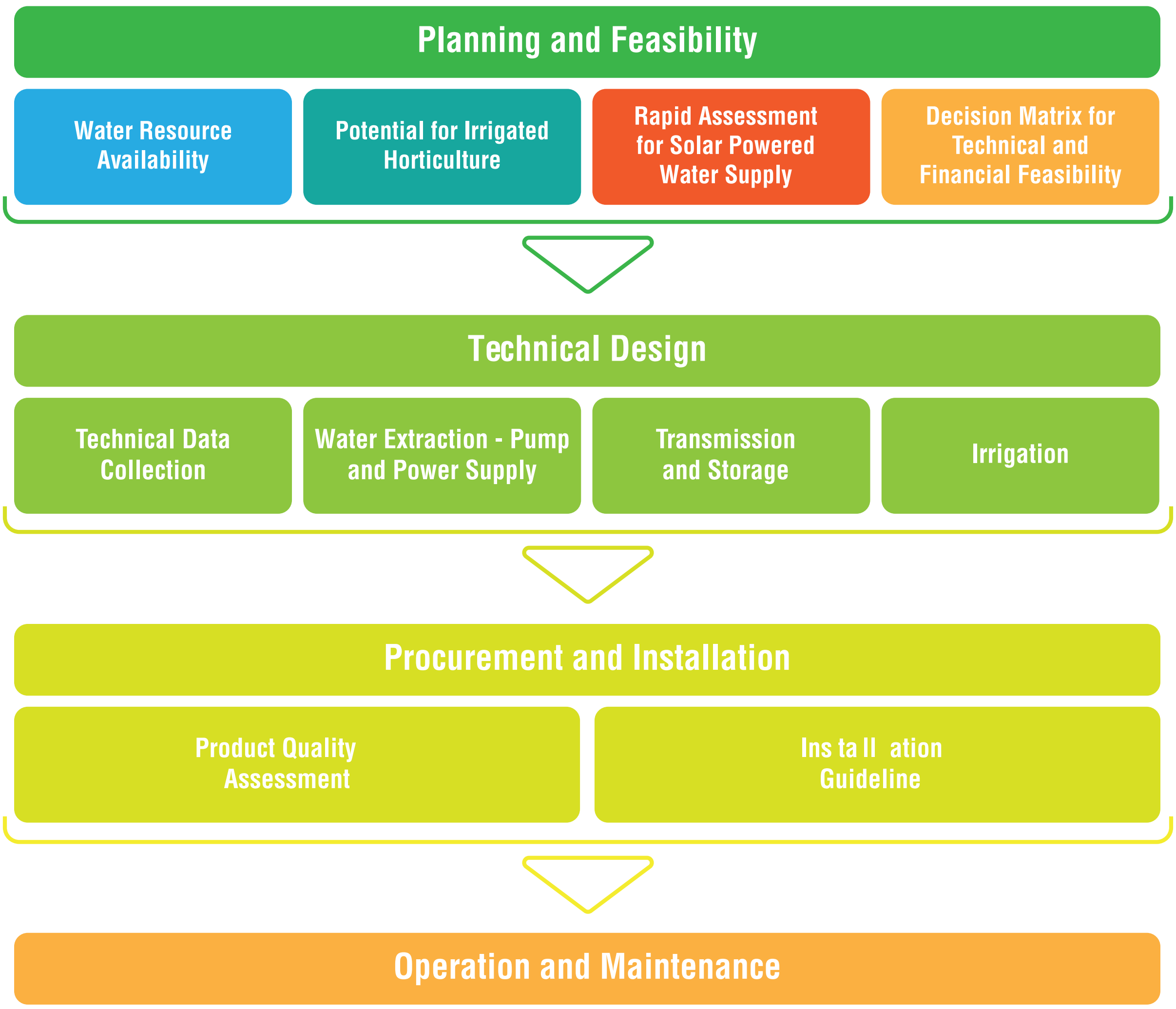
Table 21: Pumping system selection

System	Surface Water Source	Ground Water Source	Source Depth		Irrigated Area	
			<7m	>7m	<2 acres	>2 acres
Portable surface systems	••••	•	••••		••••	
Portable submersible	••	••••	••	••••	••••	
Fixed Submersible pumps	••	••••		••••	•••	••••
Fixed Surface pumps	••••		••••		•••	••••

▪ is an equivalent of 25%

3.2. Design Process

The process of design of the system follows the following sequential steps.



3.2.1. Technical Data Collection

The collection of technical data is obviously critical to an accurate design. This section will discuss the collection of the following components:

1. Water resource capacity
2. Demand and Irrigation Area - including a topographical survey
3. Other considerations – water supply for multiple use

3.2.1.1. Water Resource Capacity

It is critical to know how much water is available. This is evaluated in a number of ways depending on the water source. For a borehole (well), this is done through a pumping, or well drawdown/step test. For a Valley Dam, this may be calculated by the volume of the valley dam. For a spring box, this can be done by capturing the water and counting volume with jerry cans. Below each of these processes are described.

❖ Well Drawdown (Step) Test

The well capacity is established through a well drawdown test, also known as a step test and a pumping test. There are numerous guidance documents available describing a detailed well drawdown test. The technician should become familiarized with these procedures if choosing to conduct the pumping test independently. Alternatively, a competent party can be contracted to conduct and/or supervise the well drawdown procedure.

In general, there are several critical components of a successful well test:

i. The party conducting the test should be given all known information about the well, location and any available drilling logs or records. They also require approximate depth and diameter of the well casing to provide cost estimates for the work.

ii. The tester shall be provided with an estimate of the pumping rate for the test. This can be provided through the drilling logs.

iii. The testing will take up to 72 hours, depending on the volume of the well and the demand – longer for higher volumes and higher demands, less time, down to 24 hours, for lower yields and demands.

iv. Written logs shall be completed during the testing to document results.

v. The test must begin by measuring the static water level. Then, the pump must be run at a low, sustained rate for an hour. The water level should be recorded at regular intervals **WHILE** the pump is still running. This is typically repeated for 4 cycles with the pumping rate increased after each cycle. This type of testing is called a step test. All relevant procedures and standards shall be followed.

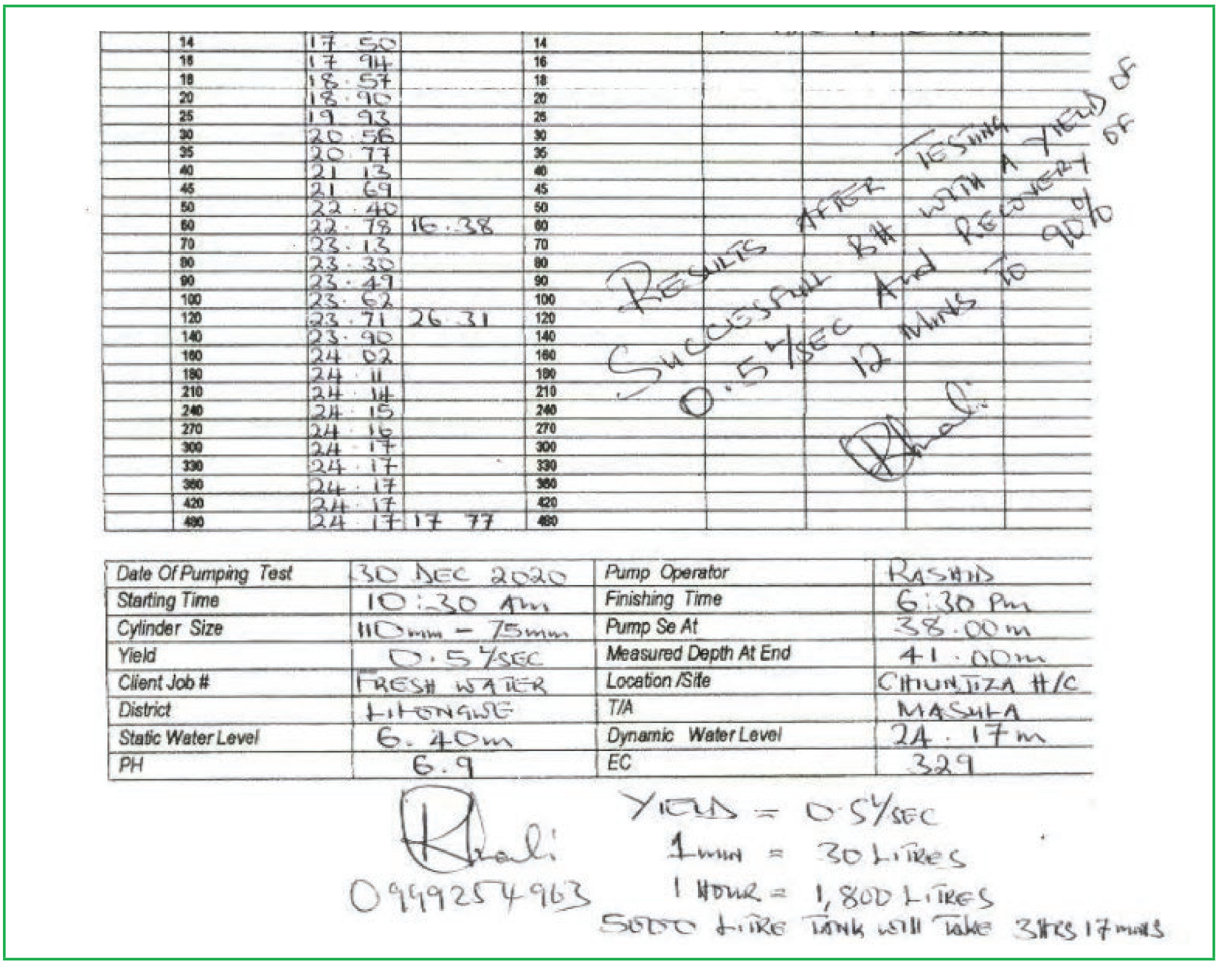
vi. Based on the data gathered, the contracted firm will pump the highest flowrate they believe the borehole can sustain. They will pump at this rate for typically 24 hours.

vii. Once pumping has stopped and the water level is measured, the well must be allowed to refill with water from the aquifer. Water levels are usually taken several times during the first hour and are then measured on an hourly basis for 24 hours or until the water has returned to prior measured static level. Typically, groundwater will return to its static elevation within an hour. Water levels should be measured several times at regular intervals during this first hour.

Data from the drawdown test is used to calculate the maximum sustainable yield of the borehole on an hourly and daily basis and then calculate the maximum allowable draw (allowable rate of abstraction) according to

Ministry guidelines. The following data will be provided by the contractors upon completion of the well draw-down test.

Interpreting pump test results for during data collection in the field:
Example results from a pump test:



14	17.50		14				
16	17.94		16				
18	18.57		18				
20	18.90		20				
25	19.93		25				
30	20.56		30				
35	20.77		35				
40	21.13		40				
45	21.69		45				
50	22.40		50				
60	22.78	16.38	60				
70	23.13		70				
80	23.30		80				
90	23.49		90				
100	23.62		100				
120	23.71	26.31	120				
140	23.90		140				
160	24.02		160				
180	24.11		180				
210	24.14		210				
240	24.15		240				
270	24.16		270				
300	24.17		300				
330	24.17		330				
360	24.17		360				
420	24.17		420				
480	24.17	17 77	480				

Results After Testing Successful BH With A Yield of 0.5 l/sec And Recovery of 90% To 12 Mins

Date Of Pumping Test	30 DEC 2020	Pump Operator	RASHID
Starting Time	10:30 Am	Finishing Time	6:30 Pm
Cylinder Size	110mm – 75mm	Pump Se At	38.00 m
Yield	0.5 l/SEC	Measured Depth At End	41.00m
Client Job #	FRESH WATER	Location /Site	CHUNJIZA H/C
District	LILONGWE	T/A	MASULA
Static Water Level	6.40m	Dynamic Water Level	24.17m
PH	6.9	EC	329

0999254963

YIELD = 0.5 l/SEC
1 min = 30 LITRES
1 HOUR = 1,800 LITRES
5000 LITRE TANK WILL TAKE 3Hrs 17mins

Figure 14: Example results for Pump test

Table 22: Well drawdown test definitions

Well Depth	Full depth of well as drilled
Static water level	Depth of water before pumping starts. Static conditions.
Well tested yield (m^3/hr)	Maximum amount of flow the borehole is able to continuously produce as determined by testing.
Dynamic water level	Dynamic (or Pumping) water level is the water level (from grade) while the pump is operating at a given flow.
Recovery Rate	The length of time the well requires to refill to static water level after sustained pumping.

It is important to note that the safe (hourly) yield for stand- alone solar water systems is 100% of total hourly yield* (MWE Design Guidelines, 2019), as opposed to the 80% safe yield for full production with a constant power source. This is due to the variable speed of the pump and the recovery time stand-alone solar offers the well each day without pumping.

❖ Valley Dam Capacity Assessment

It is important to record the volume of the water in the dam at the beginning of the dry season so that you budget for the critical periods. Due to the accumulation of silts and organic materials in the dam during flooding over time, the dam may not be as deep as you think. Therefore, the volume is only an estimate as the exact dimensions of the dam are difficult to measure while in use. A rough estimate of the water in the dam can be done from the equation below;

Volume (m^3) = Surface area x maximum depth x 0.4. The 0.4 factor accounts for standard slope (3:1) of the internal wall of the dam. This method most times underestimates the volume but provides for some reserve. Surface area can be estimated by use of a tape measure or pacing along the length and width of water surface for rectangular dams. For round dams, pace the circumference(C) of the water level. The surface area,

The depth of the dam can be measured by two people holding a string across the middle of the dam with a string having a weight at the midpoint. The weighted string should be longer than the full depth of water, and have coloured markers tied to it at set distances so the depth can be seen from the side of the dam. Allow the weight at the end of the string to rest on the dam floor.

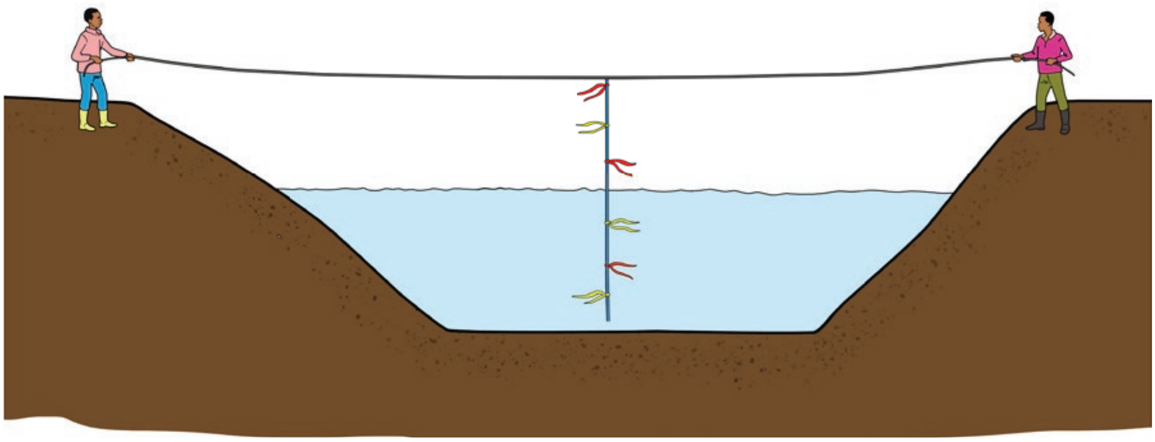


Figure 15: Measuring the Length of the dam

For budgeting, it is always good to consider 10% less than the estimated capacity and allow for evaporation and difficulty of pumping or using the last 0.5 metre (m) of water in the dam. For more accurate results of dam volume, there are dam volume tables available.[18]

❖ Spring Box Capacity Assessment

For springs where flow can be captured into a container of known volume (V), one of the most straightforward methodologies for determining discharge is to time the filling of the container. This method is commonly employed at discharge pipes or other places where flow can be captured into a container. It is simple and accurate at lower discharge rates. It can be accurate at higher discharge rates as well depending on the geometry of the discharge pipe, though it may not be possible to capture flow adequately at higher discharges. It also will not work where outflow pipes are submerged.

18 https://www.agric.wa.gov.au/water-management/calculating-farm-dam-excavated-earth-tanks-water-volume

3.2.1.2. Water Quality Testing

Water Quality Testing must be approached with care. It is ok to capture samples with a clean water bottle, ensuring that the water is not contaminated by the collector's hands during collection.

- Once samples are captured, they should be iced or kept cool as required by national water testing protocols.

- Samples should be sent to the lab as quickly as possible. Lab tests shall have time and date recorded. Time of lab testing and sample collection should be compared to ensure relevant standards and protocols were followed. Excessive time between sample collection and testing may lead to incorrect results of bacteriological results.

❖ Water Quality Standards

Water quality assessment for human consumption and for irrigation purposes are quite different. Should the water be used for multiple purposes including human consumption, Ministry of Water and Environment guidelines must be followed.

Important Note: Water Treatment plans, when intended for human consumption, should be provided by a trained consultant based on the results of the water quality test taken during technical assessment and according to the National Water Quality Standards.

❖ Water Quality and Treatment Solutions for Irrigation

For irrigation purposes we are looking for the following Parameters:

Table 23: Water Quality Parameters

Parameter	What it is	What it does	Solution
Turbidity	In this case, it represents the suspended particles in the water such as silts and debris	This affects the level of filtration and the method of irrigation. Drip irrigation requires water with very limited suspended particles to avoid clogging of the emitters	Water with high of suspended solids can be corrected through filtration either at one stage or a series of filter stages.
Bacteria content	Normal testing is for both total coliform bacteria and faecal coliform. Faecal coliform count indicates E. Coli and related pathogenic species. These typically indicate human or animal faecal contamination and will require ongoing water treatment before irrigation use is acceptable.	This is most times ignored in irrigation water quality analysis. However, for vegetables consumed in raw form it is a significant factor as it may lead to water related diseases. More so for the people handling irrigation water.	The water will need to be chlorinated to remove the bacteria

Parameter	What it is	What it does	Solution
pH	This describes the acidic or basic chemical nature of the water and is critical for selecting pump and piping materials. A pH value 7 is neutral and lower numbers are increasingly acidic, while larger numbers are waters with higher alkalinity. The normal range for irrigation water is 6.5 to 8.4	Alkaline water could intensify the impact of high SAR water on sodic soil conditions. Excessive bicarbonate concentrates can also be problematic for drip or micro-spray irrigation systems when scales build up causing reduced flow rates through emitters.	Correction by injecting sulfuric or other acidic materials into the system may in reduce alkalinity. Also, a common method to adjust both water and soil PH is use of ash in the field
Chemical contents			
Salinity	Measured by the electrical conductivity of the water. EC measures salinity from all the ions dissolved in a sample. This includes negatively charged ions (e.g., Cl^-, NO^-3) and positively charged ions (e.g., Ca++, Na+)	This affects the plants' ability to uptake water. The higher the EC, the less water is available to plants, even though the soil may appear wet.	Salinity issues may be overcome by growing crops tolerant to available salts or increasing the irrigation frequency.
Sodium Adsorption ratio (SAR)	SAR is the relative concentration of sodium (Na) compared to the sum of calcium (Ca) and magnesium (Mg) ions in a sample	SAR significantly affects the infiltration of the water into the soil. However, the overall effect is accurately assessed with a combination of SAR and EC	

3.2.2. Water Demand Assessment

For each system the total DAILY quantities of water that are required need to be assessed.

Check if other water usages are required to be supported by the system, such as human consumption, animal watering, brickmaking etc. If so, additional allowances for those activities must be made. In these cases, water usage varies with season of the year, and the worst-case must be selected for daily water demand. It is highly recommended for multi-use water supply to design for the maximum water supply or full capacity of the water source.

❖ Estimating Water Demand for Irrigation:

The process below has been extracted from Section One – Planning and Feasibility. If further investigation is needed to properly define the demand estimate, this is the appropriate time to do so. These investigations might include crop type water needs that are not provided for in the rule of thumb.

❖ Water Demand

The below example provides a methodology for determining water demand for the peak day in the driest conditions for an area. The methodology for calculating the peak day demand considers:

- Crop water requirement in L/plant or m^2
- Number of plants or planting area in m^2
- Soil type
- Climatic conditions

We will use the data collected during the assessment to inform the water demand calculation process.

The influence of climate on crop water requirement is defined as Reference evapotranspiration (ET_0) expressed as millimeters per unit of time such as mm/day, mm/month, mm/year. ET0 can be calculated experimentally using an evaporation pan, or theoretically using measured climatic data leveraging on well-developed tools such as ETO calculator, CROPWAT, Aqua Crop, CropSyst and many others.

a) The crop selected: Crops like tomatoes like more water than cabbages

b) The growth stage of the crop: Most crops like more water at flowering stage than at harvest stage. In general, young plants like less water than fully grown plants

The crop water requirement (ET_{crop}) is defined as the depth of water needed to meet the water loss through evapotranspiration. The relationship between crop water requirement (ET_{crop}) is a crop factor (Kc). Therefore, $ET_{crop} = K_c \times ET_0$. It is most times difficult to have data on the crop stages coefficients. However, FAO provides tables of crop growth stage Kc Values of most crops.

In general, the rule of the thumb stated in section one is used for the calculation with adjustments.

❖ Calculation of Water Demand

<u>Adjustments of crop water requirement:</u>

NB –when calculating the water demand, always use the crop water requirement during the highest consumption phase as outlined in the feasibility section.

Example:

Determine the water requirement for a plantation of tomatoes, 2000m², in Lira, Uganda with silty loam soil, planting in January (avg. 25°C).
Using the rule of the thumb, Crop water requirement = 4L/m²
Adjustment for soil type: 4 x – 0.05 = -0.2
Adjustment for temperature: 4 x 0 = 0
Adjustment for humidity*: 4 x + 0.05 = +0.2
Adjustment for wind: 4 x 0 = 0
Adjustment for sunshine**: 4 x + 0.05 = +0.2
Adjusted crop water requirement: 4 – 0.02 + 0.2 + 0.2 = 4.2L/m²
Peak day water demand: 4.2 x 2000 = 8400L
<u>This day demand is further adjusted according to the efficiency of Irrigation method to be used.</u>
If we assume using drip Irrigation system in our example above, the scheme efficiency is 85%.
The peak day demand = 8400/0.85 = 9883L which is approximately 10,000 L.

Once a solid estimate of daily water demand is made, an evaluation of the sustainable capacity of the water source should be reviewed.

This can be done by taking the hourly capacity of the water source previously evaluated and multiplying that hourly capacity by the operating capacity of stand-alone solar pumping, or an average of 6 hours/day.

Hourly yield x solar pumping hours = total daily supply

Total daily demand should be less than total daily supply

Note: When the source is unable to supply the amount of water required for irrigation on a peak demand day, it is important to consider irrigating a smaller area or selecting a crop with a lower crop water requirement. Furthermore, another practical decision to make when the water supply does not meet the demand is to shift the planting date so that the growing season does not coincide with the peak demand months.

Crop water requirement for an area can be quickly estimated using FAO CROPWAT software. This is an open-source software with a database whose non-conservative parameters can be easily calibrated to the site conditions. CROPWAT can be downloaded from http://www.fao.org/fileadmin/user_upload/faowater/Applications/CRW8.ZIP

For the purpose of this manual, we will provide a process for designing for the maximum water supply or full capacity of the water source.

3.2.3. Topographic Survey and Hand Sketch of Well and Proposed Installation

A dimensioned sketch of the site should be prepared showing:

- Supply location (water source/pump location and location of solar array)
- Transmission/delivery line to the reservoir
- Reservoir (storage tank),
- Irrigation system (including important attributes such as submains, valves, laterals and emitters)

Once the sketch has been prepared, go back over the site with the community members/users and other stakeholders, and walk them through the proposed installation work to reach a consensus on what will be built and the needed inputs from each of the stakeholders.

An example of a completed hand sketch is shown below along with a brief description of the process and the information the sketch intends to capture.

❖ Hand Sketch Development

The following steps are provided as a practical guide on preparing a hand sketch with a measuring tape, surveyor compass and a site/hand level or with just a standard compass

Brief Hand Sketch Outline

- On a ruled sketchpad, layout the features around the boundary of the site, including the water source, even if it is not located within the boundaries of the irrigated land. Note: Using a google map view of the site, if available, can be a good starting point.
- Identify the location (including the GPS location) of the water source.
- Set the elevation of the water source as 0 meters (datum).

- Measure and sketch the estimated transmission line from the water source to the location of the reservoir (water tank)
- Capture the elevation of the reservoir tank in relation to the water source (at 0m)
- Sketch in the boundaries of the irrigated land, including GPS points for each corner.
- Roughly sketch the irrigation plan.
- At the end of this process, the original sketch may be crowded or difficult to read - redo the sketch to improve clarity as necessary.

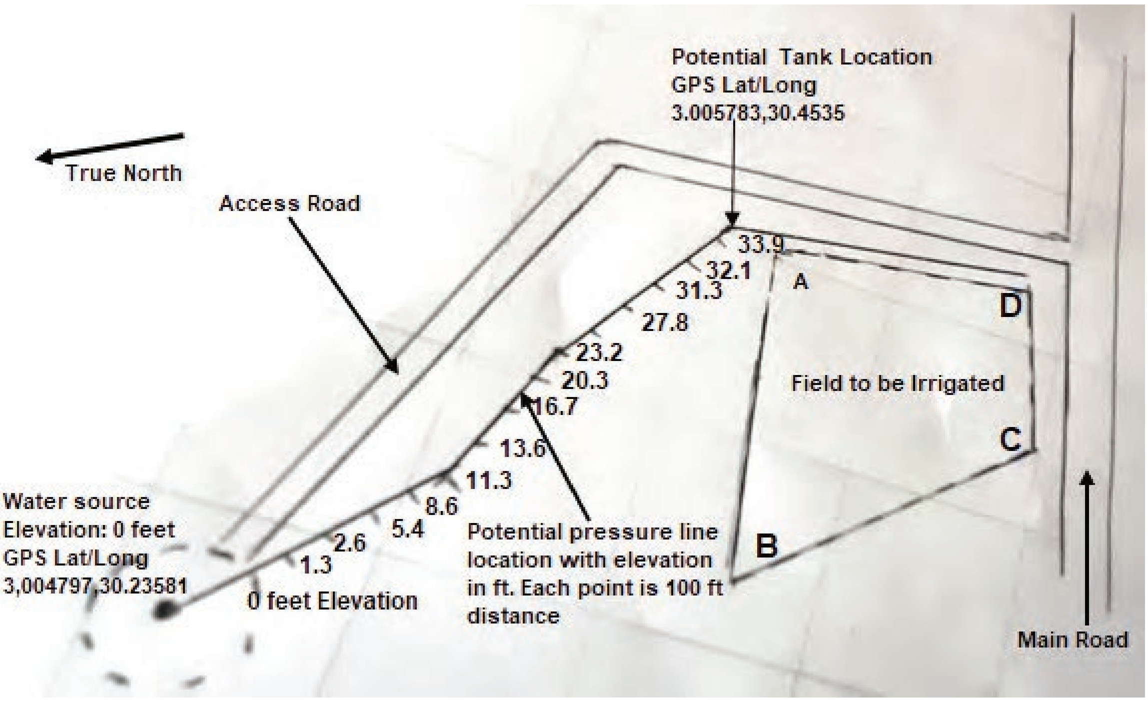


Figure 16: Hand Sketch Example

<u>Some important considerations when laying the transmission line from the water source to the reservoir:</u>

- Avoid passing through private property.
- Avoid vehicular traffic areas wherever possible so the line is not damaged by the weight of larger vehicles.
- Avoid tree roots or dense bush.
- Avoid building foundations or other load bearing structures which may add weight on to the pipe causing damage or which may be impacted by excavation.
- Avoid laying pipes next to existing or planned buried utilities where utility strikes may occur.
- Avoid routing piping through low-lying areas or areas that are known to be contaminated. Consider possible points of contamination if any portion of piping breaks.
- Avoid high or low points in the pipelines as well as sharp horizontal or vertical turns that will increase friction and accumulate air or solids.
- Avoid areas of solid rock that will not allow the pipes to be buried, if possible.