Food and Agriculture Organization of the United Nations · USAID FROM THE AMERICAN PEOPLE · SWEDEN · german cooperation DEUTSCHE ZUSAMMENARBEIT · DUKE ENERGY · OPIC

ADVISING WITH THE TOOLBOX ON SOLAR POWERED IRRIGATION SYSTEMS

1 PRECONDITIONS

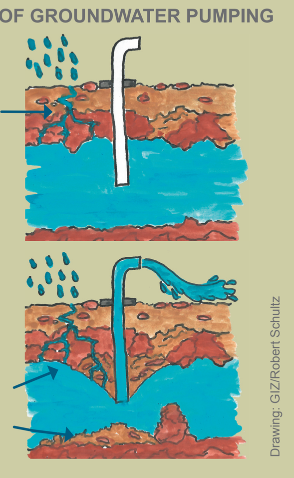
What are the first things I need to know?

WATER EXTRACTION AND EFFECT OF GROUNDWATER PUMPING

Water is a finite resource and its use is often regulated. Key values related to the water abstraction (m^3/hour) include:

- **Water source flow rate**: the quantities of water that can sustainably be abstracted from a water source (m^3 per hour).
- **Water license quota**: maximum quantity of water a permit holder is legally entitled to in a given period of time (m^3 per day, month or year).
- **Water pump flow rate curve**: the quantities of water that can technically be abstracted from a water source with the installed abstraction/pumping device (m^3 per hour).
- **Expected water demand**: the maximum quantity of water expected to be needed (m^3 per day).

EFFECTS OF GROUNDWATER PUMPING



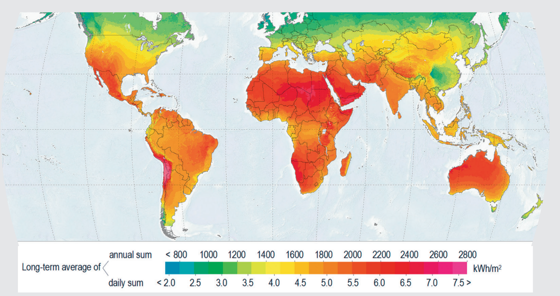
SAFEGUARD WATER – Module
www.aqtesolv.com/pumping-tests/pump-tests
IRRIGATE – Module

SOLAR IRRADIATION

is the power (W) per area (m^2) received from the sun measured in W per m² or Wh per m². It varies according to the exact location and is thus subject to longitude, latitude, altitude and climate. Through definition, the amount of sun hours [h per day] equals the average daily irradiation [kWh per m² day].

The higher the solar irradiance and the lower the ambient temperature the higher the efficiency of the solar generator

DIRECT NORMAL IRRADIATION



www.solargis.info | www.meteonorm.com

WATER QUALITY

influences the system design and maintenance requirements:

- High **sediment load** increases wear and tear in pumps and clogging in the irrigation system
- High water **salinity** increases corrosion of pump components
- High **lime content** (water hardness) clogs irrigation piping when exposed to sunshine, as dissolved lime solidifies under the influence of heat
- High **quantities of algae** in uncovered water reservoirs can jam internal moving parts of pumps and clog piping

Avoiding the effects of poor water quality …

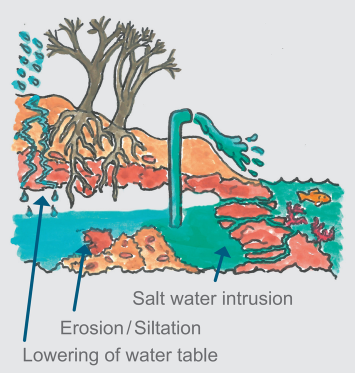
- can be time intensive (regular cleaning),
- requires installation precautions (burying pipes),
- requires additional equipment (e.g. specialized pumps and irrigation components, self-cleaning sprayers, and water softening).

WATER RESOURCE

To manage the water resource sustainably the following issues must be assessed:

- How much water is **available**? What is the **safe yield** for the water resource? Are there **seasonal variations**/restrictions in water availability?
- Do I have a water withdrawal **license**? Does the license provide for a sufficient amount of water?
- **Who else** uses the water resource? Are there **user agreements** or a water user association in place?
- What conditions and restrictions are in place to receive **loans** or **subsidies**? Are certain crops or technologies favored or disqualified?

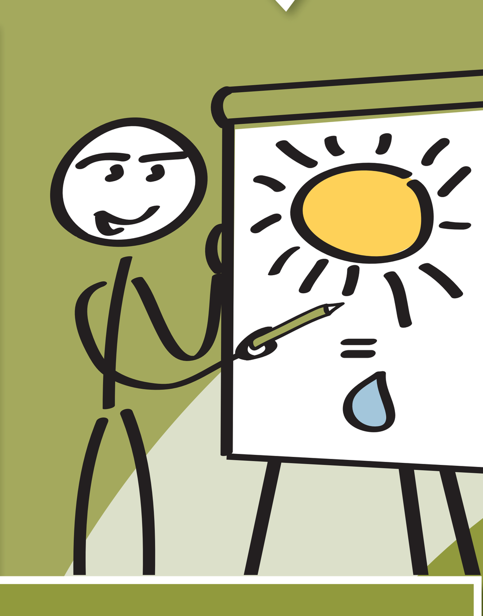
ENVIRONMENTAL IMPACTS DUE TO OVERABSTRACTION OF WATER



SAFEGUARD WATER – Water Resource Management Tool
SAFEGUARD WATER – Module
IRRIGATE – Module

2 PLANNING

How to start planning a Solar Powered Irrigation System?



PRESSURE LOSS

Energy is lost within the distribution pipe network due to the friction of water passing through it. Pressure loss through friction increases the total dynamic head (m).

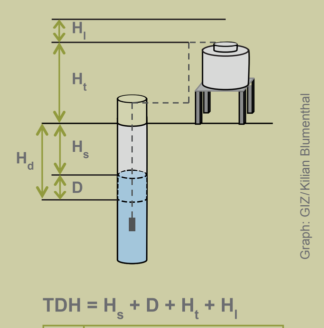
Friction losses depend on:

- Inner diameter of the pipe
- Pipe length
- Wall roughness
- Volume flow rate
- Fittings
- Filters/water meter
- Irrigation system

DESIGN – Pump Sizing Tool
DESIGN – Pressure Loss Tool

TOTAL DYNAMIC HEAD (TDH)

is the total equivalent height that a fluid is to be pumped, taking into account friction losses in the pipe. TDH is calculated as follows:



$$TDH = H_s + D + H_t + H_l$$

H_s	Static water level
D	Drawdown
H_d	Dynamic water level
H_t	Height of tank inlet
H_l	Head losses in pipeline

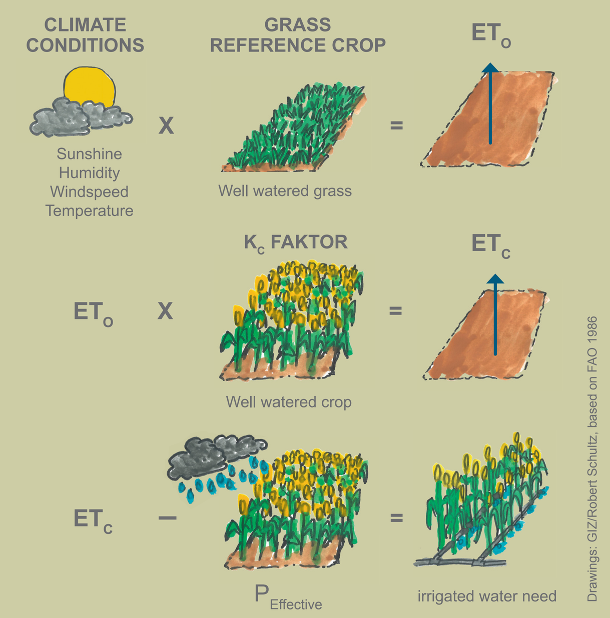
As a result of different climate conditions H_s may vary over the year.

DESIGN – Pump Sizing Tool

WATER REQUIREMENTS

are calculated based on the **maximum daily demand** (m^3 per day) to be irrigated (in ha) or supplied (heads) **from a single water source.**

Water requirements for a given crop depend on the prevailing local reference evapotranspiration (ET_o) representing the environmental demand in a given location. The ET_o and livestock daily water needs depend on seasonal variations. Based on the ET_o and a unique crop water requirement factor (K_c) the actual daily crop water requirement (ET_c) is calculated.



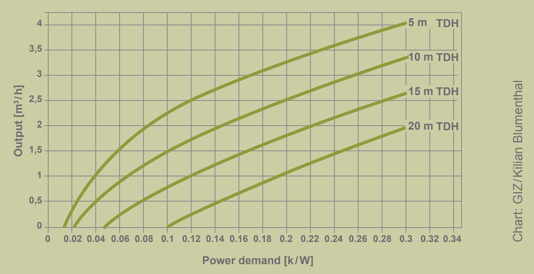
Typically an irrigation pump will be designed to satisfy the maximum daily water need (even if this only applies for a limited time in the year).

SAFEGUARD WATER – Water Requirement Tool
FAO 1986: Irrigation Water Management. Training Manual No. 3. Irrigation Water Needs. http://www.fao.org/docrep/s2022es2022e07.htm

PUMP POWER DEMAND

Data sheets from pump manufacturers include charts containing volume flow, total dynamic head and power requirements.

SAMPLE PUMP PERFORMANCE CHART 1



As power losses occur with high cell temperatures, in wires and through dust on the panels, the generator should be slightly oversized. A factor of 1,25 is the rule of thumb.

SYSTEM SIZING

depends of three main parameters:

1. **water demand** (m^3 per day)
2. **solar irradiation** (kWh per m^2)
3. **total dynamic head** (m)

DESIGN – Site Data Collection Tool
DESIGN – SPIS Suitability Checklist
DESIGN – Pump Sizing Tool
SAFEGUARD WATER – Water Requirement Tool
DESIGN – Module

SOLAR GENERATOR CAPACITY

Solar generator peak power (kWp) is calculated as follows:

$$P_{peak} = 8.0 \times \frac{TDH \times V_{day}}{G_{total,day}}$$

V_{day}	Daily crop water requirement (m^3 per day)
TDH	Total dynamic head (m)
$G_{total,day}$	Mean daily global solar radiation for the design month (kWh per m^2 per day)
P_{peak}	Solar panel power (Wp)

Choosing the solar generator, the specific pump performance characteristics (requirements of voltage and current) have to be fulfilled. They determine the quantity and wiring of the panels.

If wired in parallel, the Voltage (V) of the solar panels sums up, if wired in series, the Current (Amp) sums up.

The **water output** is calculated by dividing the water need by the amount of peak sun hours

$$Output = \frac{V_{day}}{Sun\ hours}\ [m^3/h]$$

DESIGN – Pump Sizing Tool

3 ECONOMICS

What does it cost? Is it affordable?

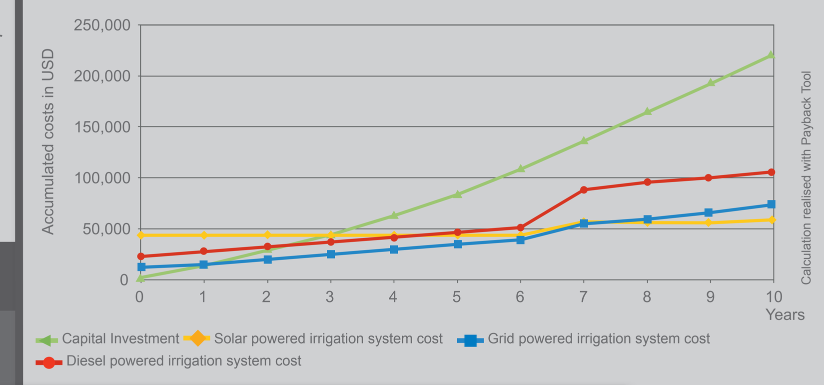
COST COMPARISON OF PUMPING OPTIONS (SOLAR, DIESEL, AND GRID)

A cost comparison over time is essential to determine **which pumping option to invest in**. A comparative calculation, including projected farm income considers:

- **Amortization (years)**: the pay-back time (years) for the irrigation options against projected income and against each other. Amortization determines when the investment costs have been recovered.
- **Internal Rate of Return (%)**: profit rate generated by a certain investment over its life-span. This answers the question whether the money is well spent or if less risky investment alternatives might be more profitable in the long run, e.g. putting the money in a bank account to earn interest.
- **Net Present Value (money currency)**: the present worth of an investment by discounting the cash inflows and cash outflows generated by this investment over its life span. For the determination of the NPV you need to define the expected life span of the investment and a discount factor, which might be near to the interest rate on bank deposits. You could also use the NPV for comparison of alternative investment options.

INVEST – Payback Tool

COST COMPARISION OF DIFFERENT PUMPING OPTIONS IN USD (EXAMPLE)



Pump Type	Solar pump	Grid pump	Diesel pump
Initial investment	42,000 USD	10,000 USD	20,000 USD
Payback on investment	3 years	1 year	2 years
Internal Rate of Return	41 %	114 %	57 %
Net Present Value	2,196,509 USD	2,025,426 USD	1,544,248 USD
Comparative payback with diesel	2.5 years	5 years	–

FARM INCOME STATEMENTS AND VARIABLE COSTS

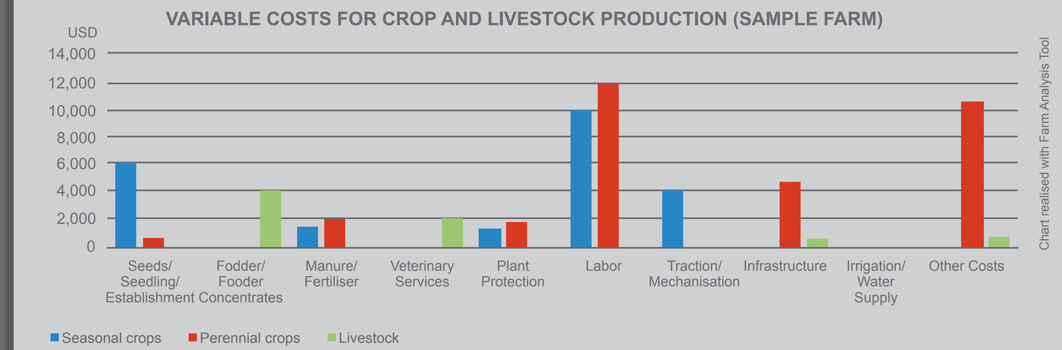
An irrigation system can be a substantial investment. The costs thereof should be recovered through the income from agricultural production. Pumping needs also differ between crops (where seasonal irrigation is required) and livestock (where water needs are fairly constant throughout the year). A thorough assessment of expenses and incomes on a farm level is essential in order to formulate a farm income statement.

FARM INCOME STATEMENT (SAMPLE FARM)

+ Gross value of seasonal crop production	50,400	USD	+ 35 %
+ Gross value of seasonal crop by-product production	5,000	USD	+ 3 %
+ Gross value of perennial crop production	80,000	USD	+ 56 %
+ Gross value of perennial crop by-product production	0	USD	+ 0 %
+ Gross value of livestock production	5,460	USD	+ 4 %
+ Gross value of livestock by-product production	2,800	USD	+ 2 %
+ Gross value of other income	0	USD	+ 0 %
– Anticipated losses of total sales	10 %	%	
= GROSS FARM INCOME	**129,294**	**USD**	**= 100 %**
– Total fixed costs	2,760	USD	+ 3 %
– Total variable costs (others)	14,736	USD	+ 19 %
– Total variable costs for crop and livestock production	61,800	USD	+ 78 %
= TOTAL EXPENSES	**79,296**	**USD**	**= 100 %**
= GROSS FARM PROFIT	**For period 2019 to 2020**	**49,998**	**USD**
	Farm Profit Margin	39 %	

Calculation realised with Farm Analysis Tool, in USD

VARIABLE COSTS FOR CROP AND LIVESTOCK PRODUCTION (SAMPLE FARM)



INVEST – Farm Analysis Tool

4 COMPONENTS

So many components! What are they for?

SOLAR TRACKING

has two advantages:

- The amount of solar **radiation received** by the solar panels increases between 25 and 35 %.
- The generated electricity and thus the pump's **water flow** is more **constant** over the day. This is important in an SPIS configuration where the water is pumped directly to the field without passing through a reservoir.

However, tracking is more expensive, may need complicated electronics and has wear and tear components.

Tracking purchase and maintenance costs should not exceed 30 % of the cost of the solar generators mounted on the array.

GET INFORMED – Module
IRRIGATE – Soil Tool

IRRIGATION HEAD

is the part of the irrigation system where water quantity, quality and pressure are managed.

The irrigation head typically contains:

- **Valves** to control the quantity of water flowing to the different sections of an irrigation system
- **Filters** to remove particles that could block drip emitters or sprinkler nozzles
- **A fertigation system** to mix soluble fertilizer in the irrigation water
- **Pressure regulators**
- **Water meter** and other monitoring equipment

GET INFORMED – Module

WATER STORAGE TANK

contains water pumped by the system and serves as a form of energy storage for a longer autonomy of the SPIS. Thus an SPIS does not require electric batteries.

- The **sizing** depends on the days of autonomy.
- Volume of three times the daily need is recommended.
- **Closed** or **covered** tanks decrease evaporation and contamination of the stored water.
- Sun **resisting materials** or a **UV protection** increase the tank's lifespan.
- Putting the tank on a **platform** leads to a higher pressure when distributing the water, but also a higher total dynamic head.
- The tank serves as **energy storage** and water can thus be distributed on cloudy days or during early mornings.
- Tanks can be used to mix in soluble **fertilizers.**

GET INFORMED – Module

ORIENTATION

In the **northern hemisphere**, the solar generator (PV panels) should face south to maximize the energy yield, whereas in the **southern hemisphere**, panels should be facing north.

Deviations from true north/south are possible but will result in a reduced overall energy yield.

TILT ANGLE

Most solar panels are installed with a fixed tilt angle (α) to increase the energy yield. Tilt angle is site-specific. A horizontal surface would collect less sunshine over the year, than an inclined, tilted surface.

To allow rain water and accumulated dust to run off the panel surface, the tilt angle should be at least 15°, even if the system is installed close to the equator. To focus the applications in winter months, the tilt angle might be increased up to +10°, for summer months, the tilt angle might be reduced up to –10°.

www.meteonorm.com

SOLAR GENERATOR

provides the necessary energy to operate the motor pump unit. It comprises several solar panels (**photovoltaic or PV modules**) connected together on a fixed or tracking mounting structure (**array**).

Solar panels are rated in **Watts peak** (Wp) according to their output under internationally defined Standard Test Conditions (STC).

GET INFORMED – Module

PUMP CONTROLLER

is the link **between the solar generator and the motor pump**. It regulates the automatic starting and stopping of the pump, based on available solar irradiation, and may incorporate other features like:

- Connected sensors measure the water level in well and tank and **prevent dry operation** of the pump
- **Maximum Power Point Tracking (MPPT)** maximizes the poweruse from solar generator
- **Torque-adaption** increases the lifespan of pumps

GET INFORMED – Module

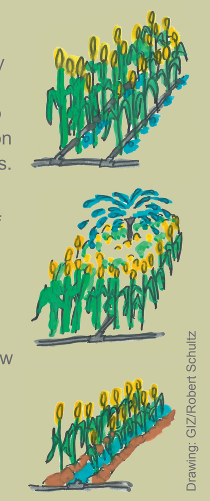
COMPARISON OF IRRIGATION TYPES

Irrigation type	Initial cost	Land leveling	Efficiency	Adding of fertilizers	Labor requirements
Drip	High	Not required	High	Highly efficient	Low
Sprinkler	High	Not required	Middle	Economical	Low
Surface	Low	Required	Low	No	Intensive

IRRIGATION SYSTEM

There are various methods used for irrigation, each with different requirements and considerations:

- **Drip irrigation** involves dripping water onto the soil at very low rates. Water is applied close to plants so that only part of the soil in which the roots grow is irrigated. A typical drip irrigation system consists of: pump unit, mainlines, irrigation head and submainlines, lateral lines and emitters or drippers.
- **Sprinkler Irrigation** is a method of providing rainfall-like irrigation to crops. Water is distributed through a system of pipes usually by pumping. Spray heads at the outlets distribute the water over the entire soil surface. A typical sprinkler irrigation system consists of: pump unit, mainline, irrigation head, lateral lines and sprinklers.
- **Surface Irrigation** is the application of water by gravity flow to the surface of the field. Either the entire field is flooded (basin irrigation) or the water is fed into small channels (furrows) or strips of land (borders). Surface irrigation can be operated without any high-tech applications but is often more labor intensive than other irrigation methods.



GET INFORMED – Module
Irrigation Efficiency according to SABI, 2014
IRRIGATE – Module

IRRIGATION EFFICIENCY PER IRRIGATION TYPE

Application system	Irrigation efficiency
Drip systems	90 %
Micro sprinkler systems	80 %
Permanent sprinkler systems	75 %
Moving sprinkler systems	80 %
Movable quick coupling sprinkler systems	70 %
Travelling sprinkler systems	65 %
Surface irrigation systems (piped supply)	80 %
Surface irrigation systems (earth channel supply)	60 %

Source: SABI, 2014 (http://www.sabi.co.za/0-pdf/SABI%20Norms%2012%20March%202014.pdf)

PUMP

moves water through mechanical action, which is **powered by electricity**. It can be installed in almost any water source (borehole, well, canal, and reservoir) and can pump water into a tank or directly into a pipeline and irrigation system.

Pumps are either **submersible** (installed below water level) or **surface** (installed at water level) and of a **positive displacement** or **centrifugal** type.

COMPARISON OF PUMP TYPES

Pump type	Pumping head	Volume flow
Positive displacement	High	Low
Centrifugal	Low	High

GET INFORMED – Module

FILTERS

are used to avoid problems of clogging in the irrigation system by trapping sand, clay, algae and bacteria.

- **Screen Filter**: a rigid or flexible screen is used to separate sand and other fine particles out of the irrigation water.
- **Disc Filter**: the filter cartridge is made of a number of discs stacked on top of each other. Debris from the flowing water is trapped by the interlocking grooves.
- **Sand Filter**: water is routed through a sand filled tank where the sand traps particles.

The use of filters always comes with a pressure loss, which increases when the filter fills up with particles. Depending on the filter type, back-flushing or manual cleaning of the filters is necessary to keep pressure losses on a low level.

GET INFORMED – Module

5 MANAGEMENT

How to take care of it?

MAINTENANCE

Defining and implementing a **routine maintenance** plan can greatly improve system life time and efficiency.

This plan, as a rule of thumb, should include:

Regularly clean …

- solar panels to remove accumulated dust (depending on location and tilt angle),
- water storage to improve water quality (1–4 times per year),
- filters (daily) and replace filter mesh (every 6 month),
- or pump out the well to remove particles and mud.

Regularly check …

- controller to remove insect nests,
- and system visually (pipes, cables, panels, controller, pipelines), for any leaks or kinks in pipes.

MAINTAIN – Maintenance Checklist
MAINTAIN – Water Application Uniformity Guide
SAFEGUARD WATER – Module

INSTALLATION QUALITY

Correctly installed SPIS = avoidance of future frustration!

It is important to inspect the entire system as a whole. Even excellent individual components cannot compensate for overall poor and faulty installation workmanship. Basic **performance tests and checklists assist** in a systematic inspection.

SET UP – PVP Acceptance Test
SET UP – Workmanship Quality Checklist
SET UP – Module

THEFT PREVENTION

Effective techniques to mitigate the likelihood of theft:

- Anti-theft **mounting** structures
- **Special screws**
- **Fencing**
- Components inside **locked cabins**
- Prominently **marking** (with farm address) the underside of the solar panels with non-removable paint
- Note the **serial numbers** of key components and all solar panels, in order to demonstrate ownership when components are recovered.

LEGEND TOOLBOX: MODULE · TOOL · WEBLINK · RULE OF THUMB

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POWERING AGRICULTURE: AN ENERGY GRAND CHALLENGE FOR DEVELOPMENT

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