TOOLBOX ON SOLAR POWERED IRRIGATION SYSTEMS (SPIS)

POWERING AGRICULTURE:
AN ENERGY GRAND CHALLENGE FOR DEVELOPMENT

Module 3: Safeguard Water

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ABBREVIATIONS

Ah	Ampere hour
CWR	Crop Water Requirement
DC/AC	Direct Current / Alternating Current
ET	Evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
Gd	Daily Global Irradiation
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)
GIWR	Gross Irrigation Water Requirement
GPFI	Global Partnership for Financial Inclusion
HERA	GIZ Program Poverty-oriented Basic Energy Services
H_T	Total Head
IEC	International Electrotechnical Commission
IFC	International Finance Corporation
IRR	Internal Rate of Return
IWR	Irrigation Water Requirement
MPPT	Maximum Power Point Tracking
NGO	Non-Governmental Organization
NIWR	Net Irrigation Water Requirement
NPV	Net Present Value
m^2	Square meter
PV	Photovoltaic
PVP	Photovoltaic Pump
SAT	Side Acceptance Test
SPIS	Solar Powered Irrigation System
STC	Standard Test Conditions
TC	Temperature Coefficient
UV	Ultraviolet
Vd	Daily crop water requirement
W	Watt
Wp	Watt peak

SAFEGUARD WATER

1. Understanding groundwater
2. Analyze water management and regulation
3. Analyze water extraction
4. Explore cooperative water governance
5. Review potential risks and impacts
6. Adjust planning and operation

MODULE AIM & ORIENTATION

The **SAFEGUARD WATER** module aims to give an introduction to groundwater management and the principles of sustainable water management. It furthermore reviews the risks and impacts related to an overdraft of groundwater resources. This should sensitize the planner and the future user of a SPIS for a responsible and sustainable utilization of water sources in most cases to be shared with neighboring farmers or other users. Finally, this module provides a practical guideline for the integration of water management into the planning and operation of SPIS.

In the **GET INFORMED** module the individual components of an SPIS, as well as common system configurations are described. Each component has specific maintenance requirements. The service provider maintaining the SPIS also finds useful information on its promotion in the **PROMOTE & INITIATE** module. Further water-related aspects are described in the module **IRRIGATION**.

The **FINANCE** module gives an insight into financing SPIS components and configurations in different ways. The costs and efforts for maintaining the SPIS are also considered in the previous modules **DESIGN** and **SET UP**.

Population growth and higher living standards, the expansion of agricultural production into dry lands or marginal lands, and the impacts of climate change increase additional need for food, energy and water. The sound financial viability of Solar Powered Irrigation Systems (SPIS) may substitute conventional water extraction and pumping options to save energy and increase agricultural production. Governments and international development agencies support the implementation of SPIS because of several advantages:

- The use of renewable green energy is CO2-neutral and does not contribute to the emission of greenhouse gases and hence climate change;
- CO2-Certificates can be sold to fossil energy users;
- Decentral solar powered energy does not rely on energy networks infrastructure and regular fuel supplies which is interesting especially in less developed rural areas;
- Solar powered irrigation can enable agriculture in areas regarded not suitable or profitable and thus increase food production and food security.

However the previous significant financial hurdle for solar irrigated agriculture from low energy costs for diesel or electricity is diminishing. SPIS saves variable costs for energy production and therefore the incentive for water-efficient technologies and crop patterns is undermined. SPIS technology is on the rise while the abstraction of surface and groundwater for agricultural use around the globe increases and often exceeds the availability of renewable groundwater resources. In India, for example, about 30 per cent of aquifers are considered at critical status[1]. Globally, nonrenewable groundwater abstraction contributes nearly 20% to gross irrigation water demand[2]. In some cases, irrigated agriculture is even practiced through exploitation of fossil groundwater that is not renewable at all.

Hence, SPIS might cause or aggravate over-extraction of limited water resources with several side-effects for the environment, economy and society, such as:

[1] Source: Central Ground Water Board of India 2014. Dynamic ground water resources of India as of 2011. Faridabad.

[2] Values for 2000, according to Wada et al. 2012. Nonsustainable groundwater sustaining irrigation: A global assessment. In: Water Resources Research 48, W00L06.

- Unsecure water availability through drying wells and springs increase the risk of crop failure;
- Aquifer salinization and seawater intrusion with long-term implications for agricultural productivity;
- Increased risk of conflicts between different users (e.g. farmers, domestic water supplier, industrial users);
- Environmental impacts on groundwater-dependent ecosystems, such as drying up of wetlands and river base flows.

Irrigation requires the integration of principles of sustainable water management. Especially if groundwater regulation and protection in target countries is weak or even absent. Therefore, this module aims to sensitize SPIS developers about fundamental processes of groundwater use and regulation. Practicing sustainable groundwater use is in the self-interest of farmers and stakeholders of the solar powered agricultural development. That includes strict compliance to the mechanisms of water regulation and monitoring, as further detailed in the following chapters.

Water is one of the most vital natural resources for agriculture. Conservation, protection and sustainable use and management of water represents a global challenge of the 21st century.

Clean water is a vital resource

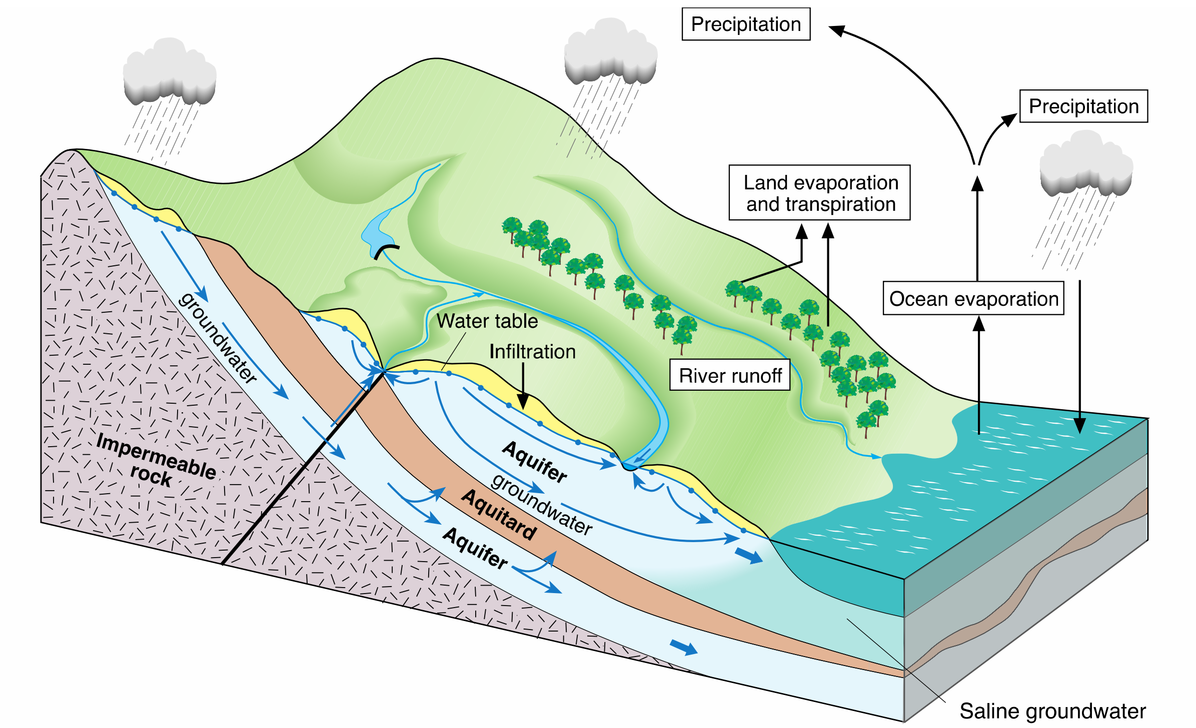
(Source: Federal Institute for Geosciences and Natural Resources (BGR))

1. UNDERSTANDING GROUNDWATER

Groundwater within the hydrogeological cycle

SPIS is based on the abstraction of groundwater from open wells or tube wells. Therefore, it is necessary to understand groundwater systems to manage groundwater in a sustainable manner. Groundwater is the water found underground in the cracks and pores in soil, sand and rock, called aquifer. Aquifers store high amounts of groundwater and are therefore an important reservoir and buffer within the hydrologic cycle (see figure below).

Groundwater is naturally recharged by precipitation or by infiltration from rivers and lakes. The underground water movement from areas of recharge to areas of aquifer discharge through springs and seepage to rivers, lakes, wetlands and coastal zones is called groundwater flow. The natural flow of groundwater occurs, generally at low velocities, through pore spaces and fractures in rock materials. Depending on the aquifer geological composition, water flow velocity varies from 1 meter per day to 1 meter per year or per decade. In contrast, velocities of river flow are much faster and expressed in meter per second. Groundwater levels may vary seasonally and annually. They are then high after the wet season and low at the end of the dry season.



The Hydrologic Cycle

(Source: BGR)

Groundwater balance

Under natural conditions, groundwater storage within the aquifer is in balance. It recharges in wet seasons and provides water for the base flow of rivers, lakes and wetland throughout the year. This balance can be disturbed by human interventions that may affect both the amounts of recharge and discharge.

Important agricultural activities with effects on the groundwater balance

Agricultural activity	Process	Examples for regulative measures
Recharge		
Land use	Soil sealing accelerates surface runoff on the cost of infiltration of rain- and surface water, whereas increased vegetation cover retards runoff and favors infiltration	Land use planning that procures local rainwater infiltration
Crop choice	As crops have different effects on soil moisture and surface runoff, crop choice influences the amount of rainwater infiltration and thereby the recharge, especially of shallow groundwater	Prescribed cropping arrangements and planting patterns
Soil compaction	Due to natural conditions of drying and wetting, heavy machineries and inappropriate tillage top- and subsoil is compacted and groundwater recharge decreases	Regulations for tillage practices and machinery use
Excess irrigation	Irrigation itself can be an important factor, as surplus irrigation water may infiltrate and recharge groundwater.	Sound irrigation scheduling and appropriate techniques
Discharge		
Groundwater abstraction	Groundwater pumping from wells lowers the water table	Groundwater abstraction quotas, licensing of drilled wells

In order to maintain balanced and plannable groundwater conditions, sustainable groundwater management should be based on the basin's recharge capacity. This capacity is called sustainable yield (or safe yield) of a groundwater system and means the amount that can be extracted without harming ecosystems and communities that depend on it. To determine the sustainable yield it is important to quantify the groundwater recharge.

As recharge processes are complex and dependent of numerous hydrogeological processes, the responsible water authorities and managers need to have as-accurate-as-possible data on the following aspects:

- Total extraction of groundwater by human activities (groundwater pumping) and natural springs
- Whenever possible, the estimation of discharge should rely on metered pumping records and measured spring discharge
- To estimate the recharge, high-resolution data on precipitation, evapotranspiration and runoff are needed. In addition, hydrogeological data on the groundwater flow and underground storage characteristics (e.g. derived from pumping tests) have to be taken into account.
- Land-use and vegetation/crop mapping of the groundwater basin helps to quantify more exactly the evapotranspiration and runoff variables.
- Depending on the available data and resources, the recharge can be estimated via standard formulas and expert knowledge, but also by more sophisticated hydrological (computer) models

In some instances, groundwater may also be subject to artificial recharge, which means the planned technical infiltration of water to groundwater bodies. Some progressive communities are presently practicing the artificial recharge of their aquifers in order to conserve the groundwater resource. For example, in the Terai region of North Bengal (India), gully plugs and bunds have been constructed by local farmer committees to retain rainwater and increase groundwater recharge. This stabilized the water tables and reduced the impact of drought periods on rain-fed paddy cultivation. As a result, the cropping intensity could be doubled and yields as well as farmers' income improved[3].

Groundwater overexploitation

If the extraction of groundwater is higher than the long-term recharge, groundwater decline regionally. This process is called groundwater over-exploitation. In practice however, over-exploitation is invariably much more concerned with the consequences of intensive groundwater abstraction than about its absolute level. Thus the most appropriate definition for over-exploitation is probably that it is reached when the overall costs of the negative impacts of groundwater exploitation exceed the net benefits of groundwater use, although these impacts are not always easy to predict and/or to quantify in monetary terms. It is also important to stress that some of these negative impacts can arise well before the groundwater abstraction rate exceeds long-term average recharge.

Important: Excessive pumping can lead to groundwater depletion. This means that groundwater is extracted at a rate faster than it can be replenished. Aquifer depletion can lead to loss of ecosystems and wetlands, increased greenhouse gas emissions, land subsidence and social conflicts with other water users.

[3] Tuinhof et al. 2012.Profit from storage. The cost and benefits of water buffering. Wageningen: 3R Water Secretariat.

Pumping groundwater causes a drop of the water table. The water table is the surface of the area saturated with groundwater. When groundwater is pumped, the water table drops in the surroundings of the well developing. Cones of depression appear in *unconfined aquifers* as a lowering of water levels (see figure below). In *confined aquifers*, that means that aquifers overlain by a geological layer of low permeability (aquitard or aquiclude), the pressure in the surroundings of the pumped well reduces when water is abstracted.

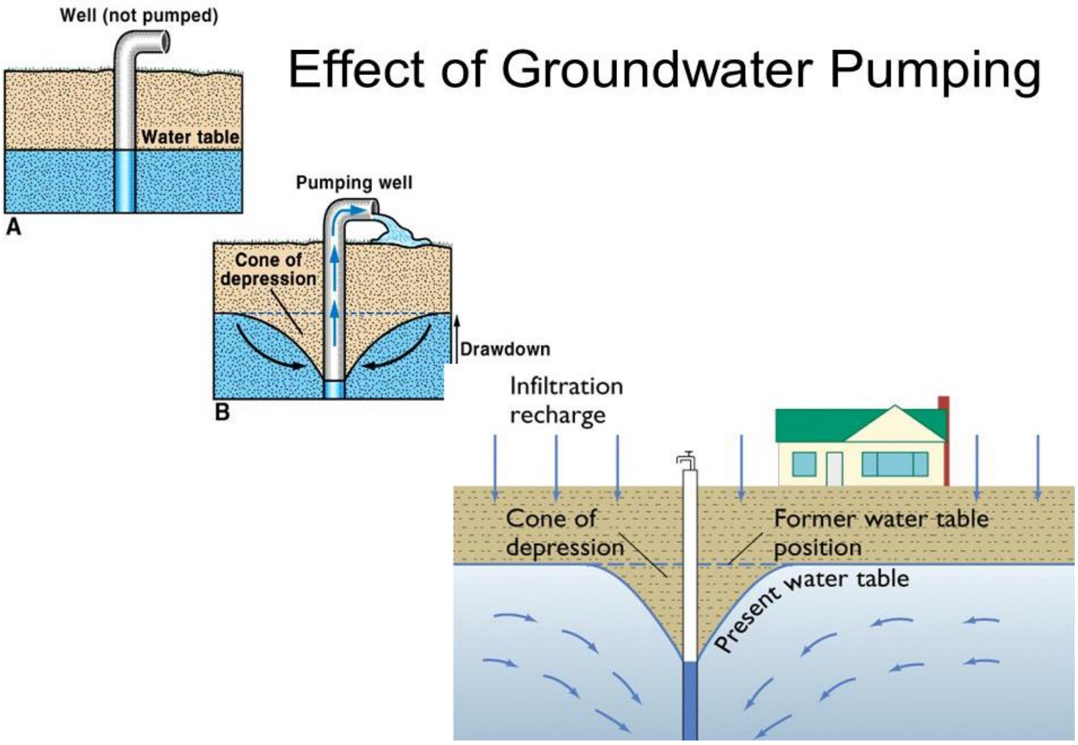


Figure: Effect of Groundwater Pumping

(Source: Thomas V. Cech)

Well interference

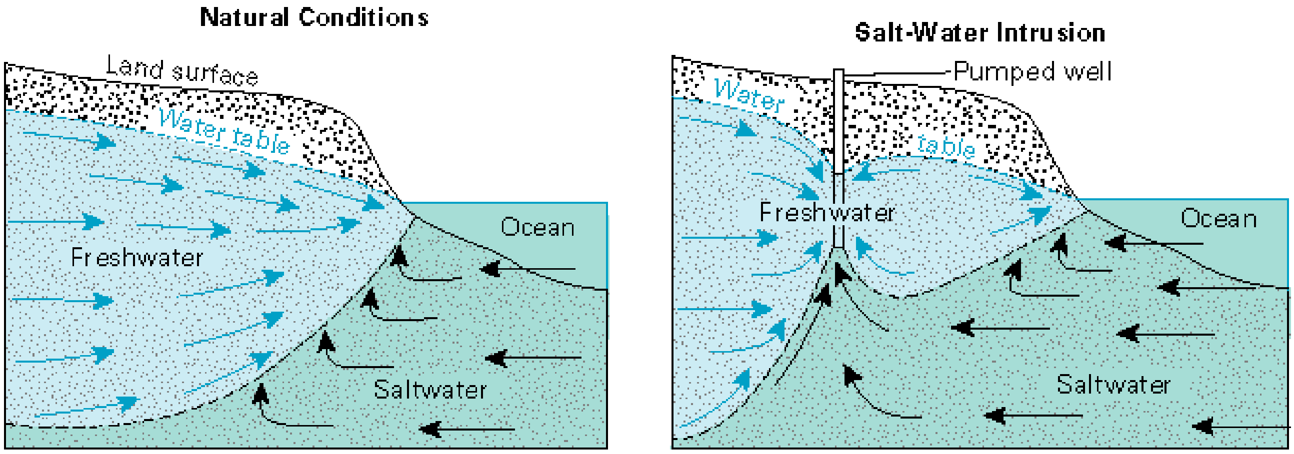
If two cones of depression overlap, there is interference between the wells and the flow of water available to each well reduces. Well interference can be a problem when wells are too close to each other and compete for water from the same aquifer, particularly if they are at the same depth.

Disconnecting groundwater from surface water flow

Ground- and surface water systems often interact closely. Groundwater provides river base flow even in dry periods and supplies freshwater ecosystems. When groundwater is pumped excessively, discharges as springs, base flows and seepages tend to dry out, sometimes permanently. Also groundwater dependent ecosystems are damaged and groundwater availability to user communities is reduced.

Groundwater salinization

A serious thread accompanied with excessive pumping is groundwater salinization. This occurs by up-coning of saline water and mixing with fresh water, giving rise to an irreversible aquifer salinization. Saline water may be mobilized of paleo-saline or connate waters at depth. Special attention has to be paid in coastal areas, as saline seawater may intrude into the freshwater zones of aquifers. The figure below shows a simplified view of the process of seawater intrusion, which can impede groundwater use for agriculture for decades.



Groundwater salinization

(Source: USGS – https://pubs.usgs.gov/gip/gw/images/Intrusion.gif)

Relevance of sustainable management

Despite the risks mentioned, sustainably managed groundwater is *the* crucial resource for agriculture, food security and rural livelihoods. In many regions, it is relatively easy to access and extract, even more if decentralized solar power supply is available. Groundwater has the potential to buffer droughts and increase agricultural production in water-scarce regions, as it is less sensitive to climate variability and change than surface water.

However, groundwater users - and hence the farmer operating a SPIS – share the responsibility for a sustainable management of the resources. Beyond that, in order to take long-term advantage from groundwater, it is rather *self-interest* of the SPIS farmer to avoid aquifer overexploitation and consequent socio-economic and legal conflicts. For the farmer this entails some crucial responsibilities and duties:

- Compliance to the legal and regulatory framework in obtaining user rights and permits and the conditions and quantities they define;
- If no water regulation is in place, farmers should lobby for setting up a regulatory framework in order to get planning and production security (see step 4);
- Monitoring and documentation of water use water based on rights and permits.

Important: Any SPIS development must therefore be integrated into the prevailing legal and regulatory frameworks and into the local water/groundwater management planning and monitoring.

2. ANALYZE WATER MANAGEMENT AND REGULATION

Sustainable groundwater management and governance is based on the concept of an integrated water resources management (IWRM). The three key pillars of IWRM and sustainability in general are:

- **Environmental sustainability** – negative impacts such as water deterioration of aquifers and on groundwater dependent ecosystems have to be avoided;
- **Economic efficiency** - water is an essential good that is required for human consumption and for agricultural and industrial production;
- **Social equity** – access to safe water resources is essential to all human beings and a human right. Transparent and equal water right systems allow for equal access.

A sustainable long-term usage of water resources is in the interest of all users, also with regard to the availability of the resources for long lasting investments in the agricultural sector. Hence, all users should have an interest to set up a functioning institutional environment that safeguards water resources and guarantees water security for agricultural irrigation purpose. Essential parts of public administration of water resources are water management planning and water regulation.

Water management planning is generally undertaken at a basin level by water ministries or basin organizations. At best, a water management plan integrates the needs from all relevant sectors (drinking water, sanitation, irrigated agriculture, industry, environment), matching the available resources with actual and future demands. Apart from water planning, agricultural authorities (e.g. ministries) may also formulate irrigation development plans that may define priority areas and goals for irrigation development.

Water resource management is the activity of planning, developing, distributing and managing the use of water resources. Sustainable water resource management has regard to all the competing demands for water and seeks to allocate water on an equitable basis to satisfy all uses and demands. Observing the principal of a sustainable yield of aquifers is the foundation for the long-term sustainability of water resources development and use.

Water resource regulation is generally based on national law and a set of sound rules and institutions that govern the monitoring of its quantitative and qualitative state, use of the resource, preventing overuse and pollution of the resource as well as guaranteeing its fair distribution among different users and interests. In many places, public water authorities on different governmental levels are in charge of the supervision of water resources. Based on water and environmental laws, these authorities regulate water use, e.g. issuing water rights and licenses for wells and water infrastructure. In many countries, also non-state institutions (self-)regulate water use, such as water user associations. These may be based on local customs and traditions about the use and distribution between the owner of the source and its users.

The information compiled in this process step will be the basis for the technical and agronomic design and planning in following modules. If correctly applied, this process step will also reveal opportunities and limits for the envisaged irrigation development at the earliest point in the SPIS development stage.

The process step "Analyze Water Management and Regulation" is interlinked with the following process steps "Analyze Water Extraction" and "Explore Cooperative Water Governance" - all three process steps define the framework in which the SPIS can be developed from the point of view of a sustainable water resource management.

"Analyze Water Management and Regulation" is based on the collection of information, data and salient features of the source, the water tenure and the legal situation with regard to water permits and licenses. The objective of this exercise is to obtain a clear and legally secure picture with regards to which water source could be exploited, to water tenure rights to be obtained, and to the limits with regard to water abstraction.

The **SAFEGUARD WATER – Water Resource Management Checklist** of this toolbox provides for an orientation for the information and data to be collected and reviewed in section 1. This section of the tool requires compilation of information from public authorities, water management bodies and user groups.

To define the scale of SPIS-infrastructure the farmer or advisor has to consider several **limits and restrictions:**

- **Type of the water source**: the type of source (open or tube well, pond/reservoir, lake or river) and its dimensions (size, depth, water level below surface) are determinants for the technical requirements for an eventual water abstractions – this information is also taken into account in the DESIGN module;
- **Water management and irrigation planning:** the respective plans should guide the decision of the water regulators on water permits and rights. Therefore, it is important for the farmer/advisor to align the envisaged project to these plans;
- **Water rights and obligations**: the ownership of the water source (private, public or common, ownership use-based or property-based) is a determinant for the access of the farmer to a water source;
- **Water permit details and licensing aspects**: the right to withdraw water from the specific source must be based on a legally recognized water permit or water license. The existence of such a legal provision for water withdrawal is the principal determinant for any irrigation development. It also determines quantities (annual quantities, or monthly quotas), conditions and restrictions issued by the water authorities.

The information can be obtained within the authorities/organizations that are managing water licenses and permits.

Important: The information and data required for this process step should be obtained from legally recognized and verified sources. Do not base decision-making on information obtained from secondary sources without proof.

Also informal agreements should incorporate all important information as prescribed by the public authorities, most importantly access rights, abstraction quotas and restrictions/conditions.

A water withdrawal license is mandatory! No SPIS design and planning must take place before a withdrawal license has been obtained! Any SPIS design and planning must be based on the quantities allowed and conditions prescribed by a legally recognized water withdrawal license!

OUTCOME / PRODUCT

- Compilation of data and information on water source, water tenure and water withdrawal license;
- Assessment of principal possibility to develop SPIS based on a specific water source.

DATA REQUIREMENTS

- Information on water source salient features;
- Information on water entitlements and type of water rights;
- Information on type and details of water withdrawal license.

IMPORTANT ISSUES

- Irrigation system development can only be based on a legally recognized water withdrawal license;
- Abstraction quantities/quotas and restrictions as prescribed by the withdrawal license are binding;
- Informal agreements should be legally registered and recognized.

PEOPLE / STAKEHOLDER

- Farmer and Agricultural Advisor
- Water Resource Management and Licensing Authorities
- Farmer Organization / Water User Group

Groundwater pumping and short-term storage

(Source: BGR)

3. ANALYZE WATER EXTRACTION

Water extraction must be based on a corresponding water withdrawal license that also provides for information on the allowed annual or monthly quantities/quotas and on specific conditions or restrictions such as seasonal limits. This step deals with the collection of information on the existing or planned water extraction approach (gravity, manual-lifting or motor-pump) and the water pump. Furthermore, the actual water availability must be evaluated. Both aspects are essential in determining whether an existing or planned irrigation system can be operated in a sustainable way.

The **SAFEGUARD WATER – Water Resource Management Checklist** of this toolbox provides for an orientation for the information and data to be collected and reviewed in Section 2. The analysis of water extraction potential from a well requires technical information that generally is provided by technical service providers (drilling contractor, pump manufacturers, irrigation system contractors and pump installers).

The main aspect in this process is to evaluate the water availability in the selected water source. For surface water sources (pond/reservoir, lake and perennial river) a general assessment is undertaken as to whether the required water quantities can be provided in each month of the year. For wells and boreholes exploiting groundwater resources a test to estimate the hydraulic properties of the aquifer system is required in order to arrive at a sustainable abstraction rate. This is done by means of a pumping test (also called: aquifer test), which should be carried out after the installation of a pump. A pumping test is a 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; response data from pumping tests are used to estimate the hydraulic properties of aquifers, evaluate well performance and identify aquifer boundaries. Typically, aquifer properties are estimated from a constant-rate pumping test by fitting mathematical models (type curves) to drawdown data through a procedure known as curve matching and taking into consideration the geological set-up of the aquifer.

Based on the data obtained, key values related to the water abstraction (indicated as flow rates in m^3/hour or m^3/day) can be compared:

- **Water withdrawal capacity**: The quantities of water that can technically be abstracted from a water source with the installed abstraction/pumping device;
- **Water withdrawal license**: Maximum quantity of water a permit holder is legally entitled to in a given period of time (per year, month or day);
- **Expected water withdrawal**: The quantity of water expected to be needed according to the pre-planning of the irrigation system.

The objective of this exercise is to make sure that the pumping capacity:

- does not exceed capacity indicated in the water permit/license;
- meets the crop water demand plus technical storage requirements.

Recommendation: Require your well contractor and pump installer to perform the analysis and provide the corresponding data before any further planning for the SPIS is undertaken.

Important: If one or more of the above principles with regard to the different flow rates are not applicable in the data comparison, the system cannot be operated on a sustainable basis and its operation may result in severe negative ecological (dried out well, negative water balance in the aquifer, dropping water table) and financial impacts (over-dimensioning of system, insufficient water availability for agricultural production). A need to introduce adaptations to the system design or even abandon the project is thus apparent.

OUTCOME / PRODUCT

- Compilation of data and information on flow rates for water source, pump and system;
- Comparison of flow rates for safe yield of water source, water withdrawal license, pump and irrigation system.

DATA REQUIREMENTS

- Water source flow rate;
- and Licensing Authorities;
- Farmer Organization / Water User Group;
- Technical Service Providers.
- Water license quota;
- Water pump flow rate curve;
- Expected water demand of the irrigation system.

IMPORTANT ISSUES

- Safe yield (sustainable withdrawal) of the water source is the determining factor for a sustainable operation;
- Pumping or aquifer test must be performed and requires special expertise;
- Information on existing water sources and pumping installation is available with technical service providers.

PEOPLE / STAKEHOLDER

- Farmer and Agricultural Advisor;
- Water Resource Management

4. EXPLORE COOPERATIVE WATER GOVERNANCE

Every irrigation system exists in a hydrological, socio-economic and cultural environment. Developing solar powered irrigation may affect the interest of other water users. However, good relations to neighboring water users of a common water resource will not only prevent conflicts and competition but also bring opportunities for cooperation and mutual benefits. Regardless of the institutional setting in charge of regulating the access to water, a sustainable operation of irrigation systems requires a high degree of responsibility and compliance with rules and regulations by the farmer. In this context, self-monitoring and self-regulation on the farm and between the water users of a shared water resource may help to effectively implement resource use regulations of the responsible public authorities. Therefore, collective action of water users should be considered in the system design to enable a sustainable operation. The farmer's knowledge and awareness of the local governance system and the limits and restrictions it sets to his irrigation project is key for its sustainability.

The process step "Explore cooperative water governance" suggests the consideration of three levels of irrigation water governance relevant for project planning:

- **Individual farm level**: Water abstraction from water sources and its utilization needs to be based on the framework given by the water withdrawal license and the safe yield principles (see above). This requires thorough water metering at pump outlet and at system intake and a self-monitoring discipline.
- **Neighborhood level**: As groundwater pumping creates a cone of depression in the local water table (see above), users in the "**area of influence**" of a well may be affected by the water abstraction for the envisaged irrigation system. Likewise, the water abstraction of these users influences the water availability for the envisaged project. In order to maintain a sustainable water withdrawal from the specific water source a user agreement and a self-monitoring of the water abstraction must be in place.

Water metering of source water with a low-cost proportional water meter

(Source: M. Eichholz/ BGR)

- **Water user or farm organization level**: Irrigation water users are often organized in user groups or organizations that are responsible to establish and maintain the rules and regulations for water abstraction and the operation of collective irrigation infrastructure. This organization brings obligations and monitoring requirements to be followed, but also opportunities of sharing risks in case of water scarcity.
- The user that may be affected by (or affect) the projected groundwater abstraction can be derived from the analysis of the pumping test undertaken in the preceding step.

- Based on this spatial delineation an assessment of the following aspects should be undertaken:

1. Are there coordination mechanisms or further institutionalized agreements between users?
2. Does the agreement reflect basic principles of sustainable water resource management? May these principles be included?
3. Do all neighboring farms/users practice self-monitoring and metering of their water abstraction and utilization? Do groundwater users in the radius of influence dispose of technical means for that? Are monitoring data handled in a transparent way, through which way? (e. g. the association or authority or to the general public)
4. Do user agreements incorporate a provision for a uniform and transparent adaptation of water abstraction in periods of constraint water availability or other situations (e.g. restrictions due to pollution accidents, establishment of additional points of extraction, etc.) or could this be agreed upon? Are there mechanisms of cooperation in case of droughts?

Recommendation: Collective action between water users is a very successful approach to help farmers/producers of a shared resource to reach a joint protection of the water source and the adherence to the principles of a sustainable water resource management. Agreements and actions could incorporate important aspects such as the water withdrawal quotas for each farmer, the list of seasonal crops, the utilization of water saving irrigation technologies, the approach and routine for water abstraction and utilization monitoring and the joint information in case of crisis/emergencies.

Important: Solar powered irrigation may only contribute to good water governance if the irrigation system is sustainably designed and prudently operated. This includes: system design and outlay based on the water quantities allowed and integration of water metering along the production process. Furthermore, collective user action should be informed by scientific advisory that sensitizes the users for aspects of a sustainable water resource management and provides them with information on water saving crops, irrigation technologies and cultivation methods.

OUTCOME / PRODUCT

- Assessment of additional farmers/users in the area of influence;
- Assessment of groundwater related rules and institutions in place, such as user agreements and self-monitoring systems;
- Assessment of mechanisms of coordination and cooperation between neighboring groundwater users;
- Sensitized farmers/users.

DATA REQUIREMENTS

- Radius of influence (refer to “Analyze Water Extraction”);
- Details of user agreements.

IMPORTANT ISSUES

- Technical provisions for monitoring of water abstraction and utilization need to be incorporated into system design;
- User agreements should be proactively advertised for by advisory services.

PEOPLE / STAKEHOLDER

- Farmer and Agricultural Advisor;
- Water Resource Management and Licensing Authorities;

- Farmer Organization/Water User Group.

5. REVIEW POTENTIAL RISKS AND IMPACTS

Through a thorough review of the risks and impacts related to the abstraction of water from available water sources, the agricultural advisor or development practitioner (the **promoter**) will be able to identify the limits and restrictions of the irrigation development that is envisaged.

The preceding steps aim to gather information on the available water quantities and usage rights. In many countries, information is held by different authorities and often fragmented or incomplete. Thus, it is important that the promoter triangulates information from different relevant sources. This may be public authorities, water user associations, water professionals as well as scientific institutions dealing with local water management.

- Especially when it comes to hydrological data and estimates of available quantities, it is important to note that stable conditions within the water cycle are rarely found. Climate variability and change as well as upstream water developments may change the predicted water quantities used in the design of an irrigation system. This may relate as to the overall quantities as to seasonal fluctuations.
- Changes in water availability may pose a risk to the farm productivity and thereby to the financial viability of a project.
- Water rights and abstraction permit are mandatory for the setup of an irrigation project. Non-compliance with the water regulations may result in penalties, legal prosecution and lead to the suspension of the project.
- It is important to check, if and how water withdrawal is regulated in detail within these permits. Furthermore, farmer organizations or water user groups can provide information on available water quantities and perhaps schedules and utilization restrictions.
- Subsidizing or financing bodies may have particular obligations/restrictions with regard to the irrigation development if financial support is provided – this may relate to the type of irrigation, the system size, the productive use and also to the adherence of sustainability principles in water abstraction and use.

Recommendation: The review of potential risks and impacts of an irrigation development should rest upon official and reliable information gathered in the preceding steps. The process of planning and designing an irrigation system should only be continued with a valid licenses or permits to abstract water.

Summing up the water-related issues raised in this module, it is crucial that - apart from public regulation - also each irrigation farmer is aware about their role and risks with regard to the shared water resources. During the planning of solar powered irrigation, these **critical issues** concerning potential risks and their impact on the project should be addressed:

Key Question Area	Critical issues	Possible Consequence
Water availability and licensing	No availability of license/permit	No basis for system development Need to identify alternative site
	Insufficient water availability in quantity or quality	Need to adapt system size and design Seasonal operation limitations **Risk of overutilization of water sources, leading to negative environmental and economic impacts**
	Restrictions/limitations on use	Need to adapt production Potential danger of lacking financial viability
	High costs of water (subscription and quantity-based consumption)	Need to adapt production Potential danger of lacking financial viability
Water management and governance	Other users affected by water abstraction	Adaptation of water abstraction to harmonized schedule Need to adapt operation and production
	Restrictions/limitations prescribed by legislation/by-laws	Adaptation of water abstraction to harmonized schedule Need to adapt operation and production
	Prescription of operation principles and technical design specifications	Need to adapt system design Need to adapt operation and production Potential danger of lacking financial viability
	Need to invest into supplementary monitoring and into joint installations	Need to adapt system design Potential danger of lacking financial viability
Water source planning	Limited sustainable yield of water source	Need to rehabilitate/expand source installation Need to adapt system design Seasonal operation limitations **Risk of overutilization of water sources, leading to negative environmental and economic impacts**
	Need to share with other users	Need to rehabilitate/expand source installation Need for agreements and co-management Seasonal operation limitations **Risk of overutilization of water sources, leading to negative environmental and economic impacts**
	Water source planning independently from irrigation system design/planning	Potential danger of over- or under-dimensioning of source installation **Risk of overutilization of water sources, leading to negative environmental and economic impacts** Potential danger of lacking financial viability
	Water source planning without hydrological investigation	Potential danger of over- or under-dimensioning of source installation **Risk of overutilization of water sources, leading to negative environmental and economic impacts** Potential danger of lacking financial viability
Technical design and planning	Irrigation system design and planning independently from water source planning	Insufficient adaption of system design to water availability Potential danger of over- or under-dimensioning of irrigation system **Risk of overutilization of water sources, leading to negative environmental and economic impacts** Need to adapt production

Key Question Area	Critical issues	Possible Consequence
		Potential danger of lacking financial viability
	Irrigation system design and planning without agronomic planning	Potential danger of over- or under-dimensioning of irrigation system Need to adapt production Potential danger of lacking financial viability
	Irrigation system design and planning based on blue print model	Insufficient adaption of system design to water availability Potential danger of over- or under-dimensioning of irrigation system **Risk of overutilization of water sources, leading to negative environmental and economic impacts** Need to adapt production Potential danger of lacking financial viability
	Irrigation system design and planning limited due to prescriptions from subsidizing/financing authority	Insufficient adaption of system design to water availability Potential danger of over- or under-dimensioning of source installation **Risk of overutilization of water sources, leading to negative environmental and economic impacts** Need to adapt production Potential danger of lacking financial viability

A key aspect in the assessment is that none of the question areas can be reviewed independently, because they are strongly interlinked.

At various points, the assessment may identify **risks of overutilization of water sources, leading to negative environmental and economic impacts.** As outlined in the preceding process steps this risk relates to a wide range of negative impacts:

Ecological impacts of over-exploitation of water resources

- Dewatering/drying of biotopes and dying of vegetation;
- Soil degradation;
- Reduction of water levels/flow in surface waters;
- Pollution and salinization of water resources.

Economic impacts of overutilization of water resources

- Increased cost of pumping due to deeper exploitation (higher energy input, larger pumps);
- Increased cost due to treatment requirement of polluted/saline water;
- Limitations in irrigation due to periodic drying/flow reduction of water sources;

Social impacts of overutilization of water resources

- User conflicts due to decreased availability of water;
- Discrimination/marginalization of users with limited financial resources due to drying of open/shallow wells (and inability to invest in even more exploitation);
- Endangered drinking water supply due to competition between irrigation and human water supply.

OUTCOME / PRODUCT

- General analysis of risks and impacts of SPIS project;
- Identification of potential risks endangering viability of SPIS project;
- Check if interdependent factors have been considered.

DATA REQUIREMENTS

- Information on water availability and abstraction regulations and legislation;
- Information on water management and governance framework/organizations;
- Information of system design prescriptions/obligations from subsidizing / financing bodies;
- Data on water source features and capacities;
- Data on water requirements of irrigation system components.

IMPORTANT ISSUES

- No irrigation system development can take place without a legal water abstraction license / water rights;
- Water abstraction quotas are binding and constitute the maximum water availability for peak demand;
- Coordination between stakeholder of the design and planning is not a given, but has to be promoted actively;
- Triangulation (using different information sources) is required to obtain a realistic and comprehensive overview;
- Irrigation systems must be embedded in the hydrological, social and economic context of the region. Blue print systems should be avoided.

PEOPLE / STAKEHOLDER

- Farmer and Agricultural Advisor;
- Water Resource Management and Licensing Authorities;
- Hydrological Services;
- Farmer Organization / Water User Group;
- Well Contractor;
- Manufacturer and Technology Provider;
- Subsidizing/Financing Body.

6. ADJUST PLANNING AND OPERATION

The final process step of this module is based on the results of the preceding steps 2 – 5 in which important factors related to a sustainable utilization of the water resources designated for the irrigation system have been evaluated. None of these process steps should be skipped and it is very important that the underlying analysis along the logic of these process steps is carried out before the envisaged SPIS is finally designed and planned.

The results of the process steps 2 – 5 almost certainly result in limitations and restrictions with regard to the design and outlay of all system components and also the options for the agricultural production. As water resources are limited and increasingly constrained, sustainability criteria with regard to the exploitation of water resources must always prevail. The determining factor for the irrigation system development is therefore the sustainable water availability – **system and production are designed and planned according to the safe yield of the targeted water source**!

Substantial need for adaptation and adjustment in predesigned or blue print model systems based on the above principle may arise from the following:

- **No or insufficient water withdrawal license**: In the worst case, an irrigation development would not be possible due to the non-availability of water abstraction rights or abstraction quotas that are too small to allow for a feasible production. Very often, limits and conditions laid out in withdrawal licenses require a down-sizing of a system design (due to limited water availability) and/or the adaption of crop rotation (due to limited water availability, restriction of crops that can be cultivated seasonally, restriction of use of agricultural inputs due to soil and water protection). This may also impact the management and operation of the system.
- **Low water availability and seasonal variations**: The evaluation of the safe yield of a water source may further limit the options for irrigation and production – often, there are seasonal restrictions (e.g. during dry seasons). It is important to keep in mind that the safe (sustainable) yield of a water sources may be inferior to the quota indicated in a withdrawal license.
- **Overlapping demands on a shared water resource**: Further limitations and thus the need for adaptations/adjustments to system design/outlay, production and operation may result from an analysis of neighborhood effects in the area of influence of the irrigation project. The interest and rights of all affected farmers/users need to be taken into account and need to be harmonized. This can be done by bilateral user agreements between neighboring farmers or under the umbrella of water user associations and result in restrictions of seasonal cultivable crops, rotating water distribution, reduced flow rates).
- **Design requirements from a financing entity:** A particular issue are conditions and restrictions of financing/subsidizing organizations. These conditionalities are often linked to the utilization of a particular technology (e.g. water saving micro irrigation) or the cultivation of particular crops (e.g. x % of crop rotation must be oilseeds or other crops) and may also limit the options for system design and a viable production.

Recommendation: Any irrigation system should be designed and laid out based on a thorough planning from the scratch based on a careful analysis of the framework conditions and the design parameters as further explained in the DESIGN module.

Changes in water availability may also occur when the irrigation has been installed according to the given licenses. Given the global increase in climate variability, it is recommended to design a flexible irrigation system that is resilient towards water scarcity. Steps towards drought resilient irrigation may include e.g. selection of crops with low water demand, high water use efficiency and coping mechanisms such as water buffering or insurances. In this context, the role of collective action and risk sharing among water user should be taken into account.

Important: Ignoring the various limiting framework conditions and restrictions may lead to an over- or under-dimensioned system capacity and an unsustainable operation. As far as an over-dimensioned system is concerned, water abstraction above the safe yield will negatively impact the environment and may result in a violation of the allotted water license/permit. A too small water abstraction may result in a low system utilization rate, or under-irrigation, thus having an impact on financial viability. Sustainability in environmental and financial terms can only be achieved if water availability, system design/outlay, crop production and irrigation management and operation are harmonized from the design stage.

In the sense of an adaptive management, it is important to reevaluate the framework conditions in regular intervals as some factors can change, such as the seasonal restriction of particular (water intensive) crops or changed water allocation patterns/quantities. These changes may require adjustments in system operation and production planning after the irrigation system has been constructed.

OUTCOME / PRODUCT

- Adjusted/adapted system design/outlay oriented in adaptive management;
- Adjusted/adapted system operation with focus on efficiency;
- Adjusted/adapted production.

DATA REQUIREMENTS

- Results of process steps 2 – 5.

IMPORTANT ISSUES

- Lack of adjustment/adaptation of system design, operation or production results in adverse ecological and financial impacts;
- Adjustment/adaptation does not stop after the construction of the SPIS but is an iterative process.

PEOPLE / STAKEHOLDER

- Farmer and Agricultural Advisor;
- Water Resource Management and Licensing Authorities;
- Farmer Organization/Water User Group;
- Technology and Service Providers.

FURTHER READING, LINKS AND TOOLS

Further Reading

Cech, T. V. (2010): Principles of Water Resources: History, Development, Management, and Policy. USA: John Wily & Sons.

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Duffield, G. M.: Aquifer Testing 101. Pumping Test. AQTESOLV. Retrieved fromhttp://www.aqtesolv.com/pumping-tests/pump-tests.htm

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SPIS Tools

- **SAFEGUARD WATER – Water Requirement Tool**: calculator to determine monthly water of different crops and livestock
- **SAFEGUARD WATER – SPIS Water Resource Management Checklist**: includes guidelines for regular inspection for the sustainable and legitimate abstraction of water

Technical glossary

Aquifer	Underground geological formation(s), containing usable amounts of groundwater that can supply wells or springs for domestic, industrial, and irrigation uses.
Chemigation	The process of applying chemicals (fertilizers, insecticides, herbicides, etc...) to crops or soil through an irrigation system with the water.
Conveyance loss	Loss of water from a channel or pipe during transport, including losses due to seepage, leakage, evaporation, and other losses.
Crop coefficient	Ratio of the actual crop evapotranspiration to its potential (or reference) evapotranspiration. It is different for each crop and changes over time with the crop's growth stage.
Crop Water Requirement (CWR)	The amount of water needed by a plant. It depends on the climate, the crop as well as management and environmental conditions. It is the same as crop evapotranspiration.
Current (I)	Current is the electrical flow when voltage is present across a conductor, or the rate at which charge is flowing, expressed in amperes [A].
Deep percolation	Movement of water downward through the soil profile below the root zone. This water is lost to the plants and eventually ends up in the groundwater. [mm]
Drawdown	Lowering of level of water in a well due to pumping.
Drip irrigation	Water is applied to the soil surface at very low flow rates (drops or small streams) through emitters. Also known as trickle or micro-irrigation.
Emitter	Small micro-irrigation dispensing device designed to dissipate pressure and discharge a small uniform flow or trickle of water at a constant discharge which does not vary significantly because of minor differences in pressure head. Also called a "dripper" or "trickler".
Evaporation	Loss of water as vapor from the surface of the soil or wet leaves. [mm]
Evapotranspiration (ET)	Combined water lost from evaporation and transpiration. The crop ET (ETc) can be estimated by calculating the reference ET for a particular reference crop (ETo for clipped grass) from weather data and multiplying this by a crop coefficient. The ETc, or water lost, equals the CWR, or water needed by plant. [mm]
GIWR	The Gross Irrigation Water Requirement (GIWR) is used to express the quantity of water that is required in the irrigation system. [mm]
Fertigation	Application of fertilizers through the irrigation system. A form of chemigation.
Financial viability	The ability to generate sufficient income to meet operating expenditure, financing needs and, ideally, to allow profit generation. It is usually assessed using the Net Present Value (NPV) and Internal Rate of Return (IRR) approaches together with estimating

	the sensitivity of the cost and revenue elements (See Module FINANCE).
Friction loss	The loss of pressure due to flow of water in pipe. It depends on the pipe size (inside diameter), flow rate, and length of pipe. It is determined by consulting a friction loss chart available in an engineering reference book or from a pipe supplier. [m]
Global solar radiation (G)	The energy carried by radiation on a surface over a certain period of time. The global solar radiation is locations specific as it is influenced by clouds, air humidity, climate, elevation and latitude, etc. The global solar radiation on a horizontal surface is measured by a network of meteorological stations all over the world and is expressed in kilowatt hours per square meter [kWh/m^2].
Gravity flow	The use of gravity to produce pressure and water flow, for example when a storage tank is elevated above the point of use, so that water will flow with no further pumping required.
Head	Value of atmospheric pressure at a specific location and condition. [m]: Head, total (dynamic) Sum of static, pressure, friction and velocity head that a pump works against while pumping at a specific flow rate. [m]; Head loss Energy loss in fluid flow. [m]
Infiltration	The act of water entering the soil profile.
Insolation	The rate at which solar energy reaches a unit area at the earth measures in Watts per square meter [W/m^2]. Also called solar irradiance.
Irradiation	The integration or summation of insolation (equals solar irradiance) over a time period expressed in Joules per square meter (J/m2) or watt-hours per square meter [Wh/m^2].
Irrigation	Irrigation is the controlled application of water to respond to crop needs.
Irrigation efficiency	Proportion of the irrigation water that is beneficially used to the irrigation water that is applied. [%]
Irrigation head	Control unit to regulate water quantity, quality and pressure in an irrigation system using different types of valves, pressure regulators, filters and possibly a chemigation system.
Lateral	Pipe(s) that go from the control valves to the sprinklers or drip emitter tubes.
Latitude	Latitude specifies the north–south position of a point on the Earth's surface. It is an angle which ranges from 0° at the Equator to 90° (North or South) at the poles. Lines of constant latitude, or parallels, run east–west as circles parallel to the equator. Latitude is used together with longitude to specify the precise location of features on the surface of the Earth.
Leaching	Moving soluble materials down through the soil profile with the water.

Maximum Power Point Tracking (MPPT)	An important feature in many control boxes to draw the right amount of current in order to maintain a high voltage and achieve maximum system efficiency.
Net Irrigation Water Requirements (NIWR)	The sum of the individual crop water requirements (CWR) for each plant for a given period of time. The NIWR determines how much water should reach the crop to satisfy its demand for water in the soil. [mm]
Power (P)	Power is the rate at which energy is transferred by an electrical circuit expressed in watts. Power depends on the amount of current and voltage in the system. Power equals current multiplied by voltage (P=I x V). [W]
Photosynthesis	Photosynthesis is a process used by plants and other organisms to convert light energy into chemical energy that can later be released to fuel the organisms' activities (energy transformation).
Pressure	The measurement of force within a system. This is the force that moves water through pipes, sprinklers and emitters. Static pressure is measured when no water is flowing and dynamic pressure is measured when water is flowing. Pressure and flow are affected by each other. [bars, psi, kPa]
Priming	The process of hand-filling the suction pipe and intake of a surface pump. Priming is generally necessary when a pump must be located above the water source.
Pump	Converts mechanical energy into hydraulic energy (pressure and/or flow). Submersible pump: a motor/pump combination designed to be placed entirely below the water surface. Surface pump: pump that is not submersible and placed not higher than about 7 meters above the surface of the water.
Root Zone	The depth or volume of soil from which plants effectively extract water from. [m]
Salinity (Saline)	Salinity refers to the amount of salts dissolved in soil water.
Solar panel efficiency	Solar panel efficiency is the ratio of light shining on the panel, versus the amount of electricity produced. It is expressed as a percentage. Most systems are around 16% efficient, meaning 16% of the light energy is converted into electricity.
Suction lift	Vertical distance from the surface of the water to the pump. This distance is limited by physics to around 7 meters and should be minimized for best results. This applies only to surface pumps.
Surface irrigation	Irrigation method where the soil surface is used to transport the water via gravity flow from the source to the plants. Common surface irrigation methods are: Furrow irrigation – water is applied to row crops in small ditches or channels between the rows made by tillage implements; Basin irrigation – water is applied to a completely level area surrounded by dikes, and

	Flood irrigation – water is applied to the soil surface without flow controls, such as furrows or borders.
Transpiration	Water taken up by the plant's roots and transpired out of the leaves. [mm]
Voltage (U or V)	Voltage is the electric potential between two points, or the difference in charge between two points, expressed in Volts [V].