

## Good agricultural practice in irrigation management





**Water is essential for plant-survival and plant-growth. It plays numerous and important roles, for example in the metabolism of the plants in photosynthesis, in nutrient uptake and transport, for cell pressure and as a cooling agent to prevent over-heating of the plant leaves in the sun.**

**In many regions of this world, water is becoming an increasingly limited resource. Today, agriculture is the largest consumer of available water resources using 70% of all water withdrawals worldwide. In the 20<sup>th</sup> century, water withdrawals increased at twice the rate of population increase, not least because of the proliferation of irrigated agriculture. Climate change and a fast growing world population will further intensify the pressure on available water resources.**

**In view of the above circumstances, agriculture is called out to apply all possible measures to minimise waste of water and maximise water use efficiency. Application of good agricultural practices in irrigation management can contribute to reducing the water footprint of agriculture.**

**This guide will help farmers and agricultural consultants to improve irrigation practices and to achieve sustainable water management.**

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## **Capturing some essentials**

### **Soil organic matter – critical and vulnerable**

- Soil organic matter (SOM) can hold up to 90 % of its own weight in moisture. Regular supply of compost and biochar are of special value to increase SOM and thus the water retention capacity of the soil.
- SOM helps to create a soil structure with many water-holding pores and thus contributes to water retention. A well-structured soil also allows uninhibited root growth and is therefore important for optimum water uptake.
- Intensive soil cultivation with rototillers destroys soil structure and reduces the number of water holding pores. Driving with heavy equipment on a wet soil has a similar negative effect.

### How plants take up water

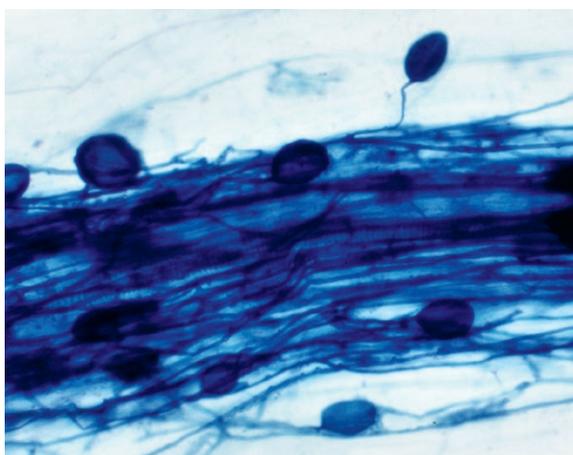
- Plant roots take up water from the soil matrix through osmosis. A higher salt content in the roots than in the surrounding soil water creates a suction force and the roots absorb the water through semi-permeable cell membranes.
- Water loss through transpiration by the leaves creates a negative water potential and «pulls» the water through the plant, from the roots to the leaves. The absorbed water is transported to vascular tissue (xylem) and is then transported to the leaves where it transpires and evaporates.
- Water absorption primarily occurs via young roots, which are furnished with a large number of fine root hairs that increase the root surface and can take up water.



The soil is the main source of water for the plants. A well-structured soil can absorb and store water well. It enables unhindered root growth and eases access to soil water.

### Mycorrhiza – helpers in arid conditions

- Arbuscular mycorrhiza (AM), specialised fungi that live in symbiosis with plant roots, enlarge the plants' «root surface» and rooting zone. They can enter small pores in the soil, mobilise water and nutrients and carry them to the plant.
- Mycorrhiza colonised plants have a higher water stress tolerance and produce higher yields than crops that are not colonised under water scarcity. A microbiologically active soil and/or inoculation of the soil with AM can reduce water stress of a crop in arid conditions.
- Mycorrhizae also play an important role in soil aggregate stability.



Mycorrhiza in a plant root. The symbiotic fungi increase uptake of water and nutrients of crops in arid conditions.

### Crop-specific water uptake capacity and water stress tolerance

Crops differ in their capacity to extract water from the soil and in their ability to withstand water stress due to different reasons, some of which are:

- Generally, plants with large or deep root systems, such as alfalfa, withstand water-stress better than plants with a shallow root system, such as lettuce.
- Plant-species adapted to arid climate conditions, such as olives or mango, withstand water stress better than species from humid climates, such as avocado or cacao.
- Modern hybrids with a shallow root system are more sensitive to water stress than heirloom varieties.

#### Box 1. Good practices: Crop and soil management

- Regularly supply organic matter to maintain the soil humus content.
- Minimise soil cultivation and avoid rotating equipment.
- Cover the soil surface with organic mulch or synthetic mulching sheets.
- Select suitable crops, varieties and rootstocks that perform well under local growing conditions with little water.
- Avoid soil compaction and erosion.

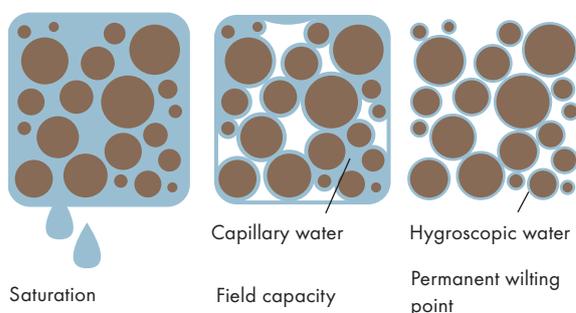
## Indicators for calculating irrigation needs

### Field capacity

The soil can hold significant amounts of water in its pores or hydrostatically bound to the surface of soil particles. Water in pores is more readily available for plants than water bound to particles.

*Field capacity* is the amount of water remaining in a soil after it has been thoroughly saturated and allowed to drain freely, usually for one to two days.

**Figure 1. Conditions of soil water availability**



In saturated soil, all pores are filled with water, and excess water is easily lost. Capillary water in the micropores of the soil is not lost by gravity and is yet available to plants. Strongly bound hydroscopic water, however, is mostly unavailable to plants.

### Permanent wilting point

Permanent wilting point is the moisture content of a soil at which plants wilt and fail to recover when supplied with sufficient moisture.

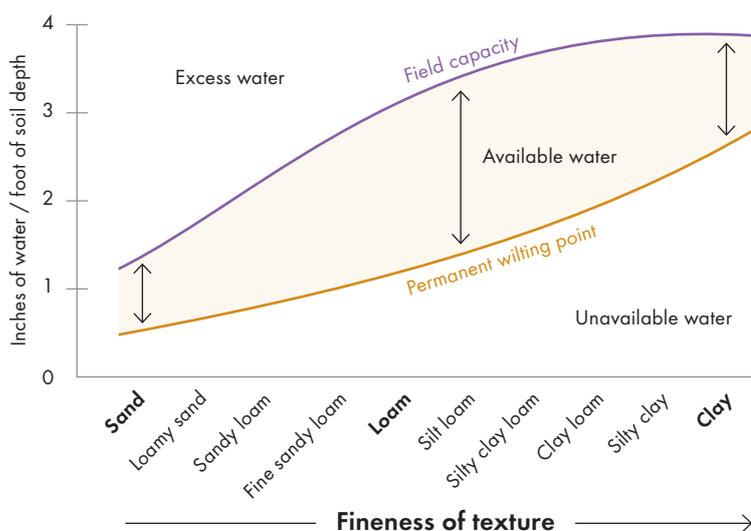
### Available water capacity

The difference between the field capacity and the wilting point of the plant is the *available water capacity (AWC)* (Figure 2). The available water capacity is the maximum amount of plant available water a soil can hold and provide. It is an indicator of a soil's ability to retain water and make it available for plant use. Water capacity is usually expressed as a volume fraction or percentage, or as a depth (in inches or cm).

### Readily available water

The *Readily Available Water (RAW)* is the amount of water in the soil that plants can easily take up before severe water stress occurs (Figure 3).

**Figure 2. Available water capacity in different soil types**



The available water capacity differs significantly in different types of soil. The available water is much lower in sandy soils than in loams or clays. However, in sandy soils almost all of the water capacity is readily available for plants. In clay soils, much of the soil water is strongly bound to the clay particles and cannot be taken up by plant roots.

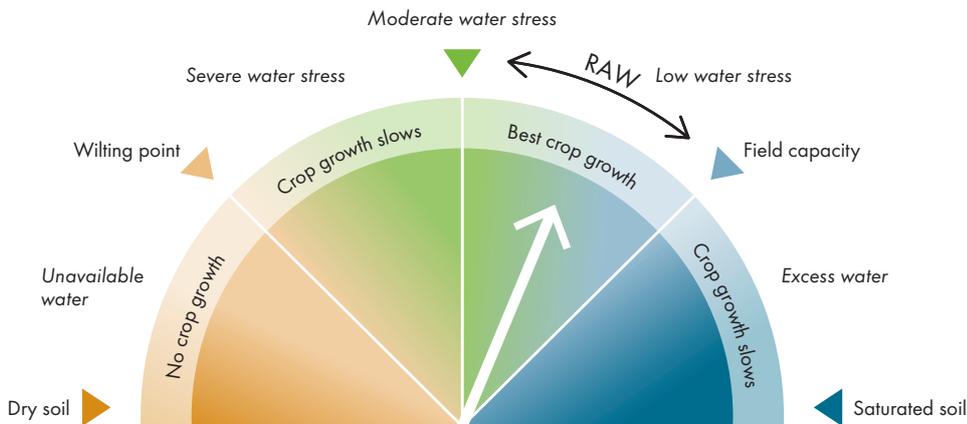
### Soil water tension

Soil water tension describes the adhesion force with which water is bound to the soil particles. Plant roots need to develop a suction force that is higher than the soil water tension in order to be able to absorb water. When the water tension in the soil is higher than in the root, the osmosis process reverses and the plant wilts and dies.

**Table 1. Tolerable soil water tension based water stress of agricultural crops**

Categories	Soil water tension	Examples
Very low water stress	-20 kPa	Leafy vegetables (e.g. lettuces)
Mild water stress	-40 kPa	Hardy vegetables (e.g. eggplant)
Moderate water stress	-60 kPa	Fruit trees, field crops
High water stress	-100 kPa	Hardy crops (e.g. sorghum, alfalfa)

**Fig 3. Soil water availability and crop water stress**



The readily available water (RAW) allows best crop growth.

**Impacts of water over-supply**

- Depletion / reduction of water resources
- Leaching of nutrients out of the root zone and subsequent contamination of the ground water
- Inefficient use of energy and water
- Run-off and soil erosion

Soil water tension is expressed in kPa (kilo Pascal), bar or atmosphere (1 kPa = 0.01 bar = 1 at). At saturation point (= field capacity) the water tension in the soil is practically 0.

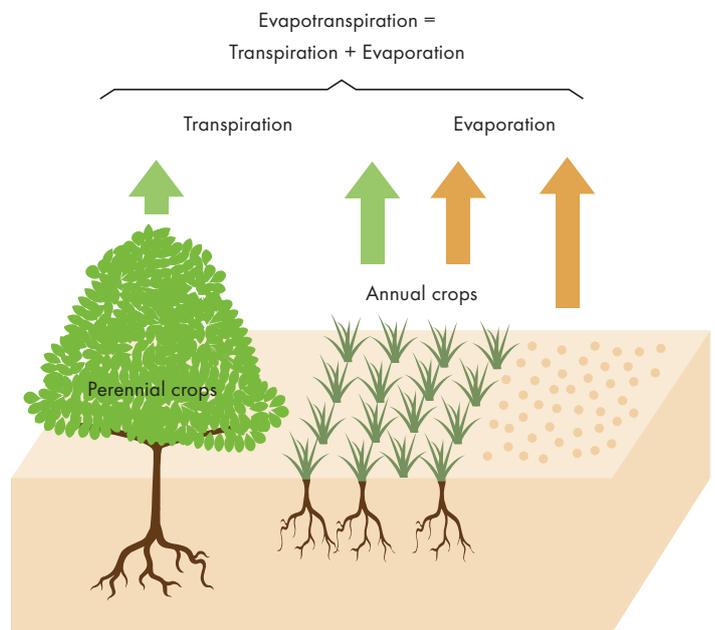
Different plant species / varieties can withstand different degrees of water stress. Water-stress sensitive crops such as leafy vegetables should be irrigated when the water tension in the soil exceeds -20 kPa. For hardy crops that can develop a high suction force, such as sorghum or cotton, the soil water tension can increase to over -100 kPa before irrigation is necessary.

**Evapotranspiration**

The major part of water that plants absorb from the soil through the roots is eventually released to the atmosphere as vapour via the plant's stomata. The release of vapour is called transpiration. Water also evaporates directly from soil into the atmosphere. This process is called evaporation. *Evapotranspiration (ET)* is the sum of transpiration from plants plus evaporation from the land surface.

Evapotranspiration is an indicator for the total daily water demand of a crop and a soil. The goal of irrigation is to compensate for ET, but not to supply water in excess.

**Figure 4. Evapotranspiration**



**Estimating the need for irrigation**

- Evapotranspiration ≥ effective RAW -> irrigation necessary
- Evapotranspiration < effective RAW -> no irrigation required

## How to calculate RAW

To determine the amount of water that needs to be provided to a crop for optimum growth is closely linked to the soil's capacity to retain water and make it available to the plants as well as to the water stress a crop can tolerate (i. e. low, moderate or high water stress tolerance). The amount of readily available water (gross RAW) can be determined in four steps:

1. Determination of the soil type and soil profile
2. Determination of the rooting depth and tolerable water stress
3. Determination of the percentage of gravel and stones in the soil
4. Calculation of the effective RAW based on the data collected in the steps 1 to 3



The longer the ribbon can be rolled before it breaks, the higher the clay content of the soil. The sample on the photo is from a sandy soil with little clay content.

### 1. Determining the soil type

Different soil types can contain differing amounts of water. The smaller the particle size, the more water a soil can hold. However, not all of this water is available to the plants. Sandy soils with a coarse structure and large particles can hold relatively little water, but almost all of it is readily available to the plants. Clay soils, on the contrary, can hold large amounts of water, but only a limited part of the water is readily available to the plants.

The soil type can be determined through particle analysis in a laboratory or by sensory analysis in the field, which is more common. For a **soil analysis in the field**, a handful of humid soil is kneaded into a bolus and its consistency and coherence is evaluated (see table 2). The relative content of clay is determined by rubbing the bolus into a ribbon.

### 2. Determining the rooting depth and the tolerable water stress

Different crops have different rooting depths. However, the effective rooting depth of a crop can vary to some extent depending on soil conditions and availability of water.

The fine plant roots in the top layer of the soil absorb the bulk of water. However, deeper roots also absorb water. Most short cycle vegetables have an effective root depth of about 25 cm. Most tree crops have their effective root mass in the top 60 cm of the soil. The deeper the roots of a crop grow, the higher is its water stress tolerance.

In general, fast growing crops with a shallow root system and a large leaf area are grown under low to moderate water stress. High water stress for

**Table 2. Sensory determination of the clay content of a soil**

Soil type	Behaviour of moist bolus	Ribbon length	Clay content %
Sand	Practically no coherence	Nil	<10% (often <5%)
Loamy sand	Slight coherence	≈5 mm	5-10%
Sandy loam	Bolus just coherent but very sandy to touch	15-25 mm	10-20%
Loam	Bolus coherent and rather spongy	≈25 mm	≈25%
Sand clay loam	Strongly coherent bolus, sandy to touch	25-40 mm	≥25%
Clay loam	Coherent plastic bolus, smooth to manipulate	40-50 mm	20-30%
Light clay	Plastic bolus, smooth to touch	50-75 mm	35-40%

Adapted from McDonald et al. (1998)

such crops reduces yield and quality. Hardy crops with a large root system can be grown under higher water stress. Such crops can develop a high root water tension and take advantage of water that is more strongly bonded to the soil matrix.

### Regular observation of crop growth and water saturation

Visual observation of the plant and regular monitoring of the water saturation level of the soil in various depths can provide information, if the effective root depth has been determined correctly.

Too much soil moisture in the root zone causes asphyxia of the roots; too little soil moisture increases water stress and ultimately results in lower yields. However, choosing a mild to moderate stress irrigation strategy induces the root-mass to grow deeper and wider and thus improve its water uptake capacity.



To determine the effective rooting depth of a crop, a hole must be dug in the root area of the crop.

## 3. Determining the proportion of gravel and stones in the soil

To determine a soil's actual water retainable soil content, the proportion of gravel and stones needs to be subtracted. For this, 1 kg of dry and milled soil is sieved with a 1 mm mesh sieve. Alternatively, very coarse sand, gravel and stones are separated manually.

## 4. Calculating the effective RAW

To calculate the effective RAW based on a soil's gross RAW (see table 3), its actual water retainable soil content and its effective rooting depth, the following equations are used:

$$\frac{\text{gross RAW (l/m}^2\text{)} \times (100 - \text{stones and gravel (\%)})}{100} = \text{net RAW (l/m}^2\text{)}$$

$$\frac{\text{net RAW} \times \text{rooting depth (cm)}}{100 \text{ cm}} = \text{effective RAW (l/m}^2\text{)}$$

### Note

The calculation of RAW by defining soil and crop type is indicative only and should be backed up by regular observations and irrigation intensity must be adapted to the water absorption capacity of the soil.

### Example

If the soil type is a sandy loam with 20 % of stones and gravel and the crop is a vegetable crop with an effective root depth of 30 cm, then the calculation is as follows:

1. RAW for a sandy loam at  $-40$  kPa amounts to  $50 \text{ l/m}^2$  (see table 3, page 8).
2. If the soil content is 80 % (20 % of stones and gravel), the net RAW for this soil is  $50 \times 0.8 = 40 \text{ l/m}^2$ .
3. With a root depth of 30 cm, the effective RAW for this crop and this soil is  $0.3 \times 40 = 12 \text{ l/m}^2$ .

**Conclusion:** When evapotranspiration equals or is higher than  $12 \text{ l/m}^2$  (or the water tension in the soil is higher than  $-40$  kPa), the vegetable crop should be irrigated.

**Table 3. Gross RAW in relation to soil type and crop water stress tolerance**

Tolerable water stress	Very low	Low	Moderate	High
Maximum soil water tension	-20 kPa	-40 kPa	-60 kPa	-100 kPa
Soil type	Gross RAW (mm or l per m <sup>2</sup> )			
Sand	30	35	35	40
Loamy sand	45	50	55	60
Sandy loam	45	60	65	70
Loam	50	70	85	90
Sandy clay loam	40	60	70	80
Clay loam	30	55	65	80
Light clay	25	45	55	70

Adapted from: Calculating RAW, Dep. of Primary Industries and Regional Development, Gov. of W. Australia

## Measuring the water demand of a crop

Water demand of a crop and thus the need for irrigation can also be determined by:

- Measuring soil moisture with sensors
- Measuring the evapotranspiration of the crop
- A combination of both

### Measuring soil moisture

A simple, inexpensive and quite reliable method to measure if the plant is suffering from water stress is the use of water tension or soil moisture measuring instruments. Soil moisture can be defined either by measuring the soil water potential or by measuring the volumetric water content in the soil.

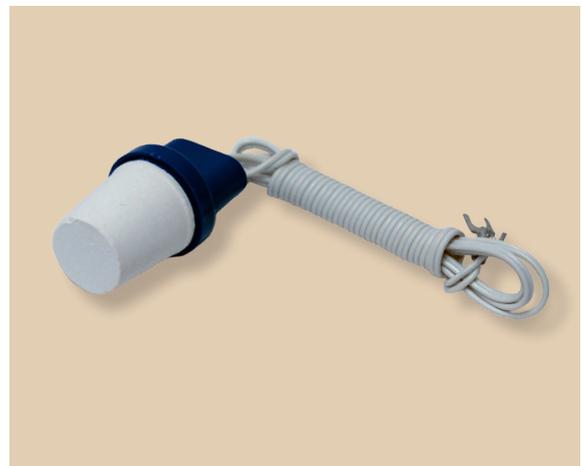
The most common devices are tensiometers, gypsum blocks and Frequency domain reflectometry (FDR) devices.

#### Using tensiometers

A tensiometer is a sealed water-filled tube with a porous ceramic tip. The ceramic tip is placed in the soil and when the water tension of the soil increases (i.e. the soil dries out), water is sucked out through the ceramic tip and a vacuum is created in the tube. The vacuum is measured by means of a gauge, which expresses the water tension of the soil in kPa, bar or at. The measuring range of tensiometers ranges from 0 to -80 kPa.



Tensiometer



Gypsum block

### Using gypsum blocks

Gypsum blocks are the cheapest instrument to measure soil water tension. Two electrodes encased in a gypsum block measure the resistance for an electrical current to pass. However, gypsum blocs do not function well when soil moisture content is high, e. g. in frequently irrigated horticultural crops. An improved version of the gypsum block is the Granular Matrix sensor.

When the sensor is placed into the soil, it absorbs more or less water according to the amount of water present in the soil. The wetter the sensor, the less resistance there is, allowing the related water tension of the soil to be determined. The measuring range of gypsum blocks ranges from -30 to -1000 kPa, that of granular matrix sensors from -10 to -200 kPa.

### Frequency Domain Reflectometry (FDR)

FDR devices consist of 2 electrical plates placed into the soil. When a voltage is applied to the plates, the frequency between the plates can be measured. FDR devices do not measure the water tension in the soil, but the volume of water present in the soil. FDR devices are relatively expensive but precise and among the most common soil moisture sensors used today.

### Applying the measuring instruments in the field

Usually, the measuring instruments are placed at two soil depths, i. e. in and under the active root zone (see figure 5).

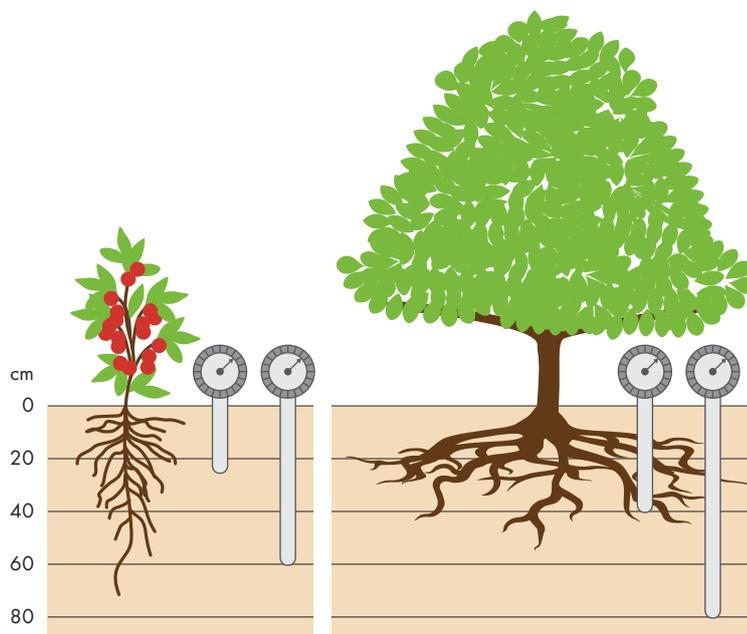
The readings on the probe in the root zone indicate when RAW must be replenished. Continuous logging of the readings from the probes helps to identify whether too much or too little water was irrigated.

If the water tension in the soil below the root zone decreases (i. e. soil water content increases), the plant has not been able to take up all the irrigated water. In this case, more water was supplied than the soil's water retention capacity. As a result, water drains out of the root zone into the subsoil and is lost.



Precision irrigation by soil water tension measurement is a powerful tool to determine optimal irrigation.

### Figure 5. Soil water tension probing depths



Typically, the probes are placed at 25 cm and 60 cm soil depth for annual crops, and at 40 cm and 80 cm for perennial and tree crops.

## Measuring the evapotranspiration of the crop

Another way to schedule irrigation (rather than by measuring soil water tension with probes) is by determining the *evapotranspiration of the crop (ET<sub>c</sub>)*. When ET<sub>c</sub> exceeds RAW, irrigation is necessary. As with other measuring methods, the tolerated water stress degree must be defined.

ET<sub>c</sub> is determined by crop characteristics and environmental factors. Crop characteristics include crop type, canopy area, plant size and growth stage. Environmental factors include air temperature, air humidity, wind speed and solar irradiation. As crop characteristics and climate factors are subject to change, ET<sub>c</sub> varies continuously.

The actual ET<sub>c</sub> is calculated by measuring the ET of a standardised reference crop, referred to as the reference evaporation or ET<sub>o</sub>. The result is multiplied with a crop coefficient (K<sub>c</sub>) specific for the crop grown:

$$ET_c = ET_o \times K_c$$

ET<sub>o</sub> can be measured with the help of an evaporation pan, computed from meteorological data or

a combination thereof. In regions with extensive irrigated crop production, local meteorological stations and / or agricultural authorities monitor and supply information on ET<sub>o</sub>. Large operations often use proper meteorological and crop data to calculate ET<sub>o</sub> and ET<sub>c</sub>.

Crop coefficients (K<sub>c</sub>) can be found in the FAO Guidelines for computing crop water requirements<sup>1</sup>. The standardised FAO crop coefficients are often adjusted by proper crop data and proper crop and soil observations. If, for example, the soil water tension is still very low before the next irrigation is scheduled, then the crop coefficient can be reduced. If the soil water tension, and hence water stress, is very high before irrigation is scheduled, K<sub>c</sub> can be increased.

### Glossary

RAW = Readily available water

ET = Evapotranspiration

ET<sub>c</sub> = Evapotranspiration of the crop

ET<sub>o</sub> = Reference evapotranspiration

K<sub>c</sub> = Crop coefficient

<sup>1</sup> FAO guidelines for computing crop water requirements. Available at <http://www.fao.org/3/X0490E/X0490E00.htm>



Evaporation pan (left) and weather station (right), as used for measuring reference evapotranspiration ET<sub>o</sub>.

## Box 2. Recommended procedure for good irrigation management

- Determine the Readily Available Water (RAW) of the soil.
- Determine the root depth of the crop.
- Define the tolerable degree of water stress for the crop grown.
- Determine the evapotranspiration of the crop (ET<sub>c</sub>).
- Measure the water tension in the soil with appropriate devices.
- Install flow meters to measure the irrigated water volumes.
- Consider deficit irrigation.

## Irrigation systems

### Irrigation system efficiency

Many technologies have been developed to make irrigation systems more efficient. Examples include surge irrigation, low-pressure pivots and micro irrigation.

Irrigation system efficiency is calculated by dividing the volume of evapotranspiration by the volume of irrigation water applied.

$$\text{Irrigation system efficiency} = \frac{\text{evapotranspiration ETc (l/m}^2\text{)}}{\text{irrigation water applied (l/m}^2\text{)}}$$

#### Example:

If, in a given period of time, the total ET of a crop has been 100 l per m<sup>2</sup> and 200 liters of water have been irrigated to compensate for this loss, the irrigation system's efficiency is 50 %.

**Table 4. Efficiency of irrigation systems**

Irrigation system	Efficiency
Flood and furrow irrigation	25–60 %
Surge irrigation	30–80 %
Sprinkler irrigation	60–90 %
Micro sprinkler irrigation	80–90 %
Drip irrigation	80–95 %

Adapted from: BMP Irrigation Management, Colorado State University Cooperative Extension



Micro-sprinkler in a fruit orchard.



Subsoil drip irrigation in a tomato crop.



In sprinkler systems water losses can be considerable in case of wind, high temperatures and/or low relative humidity of the air.

### Irrigation losses

Irrigation losses inevitably occur, e. g. through surface run-off, sub-surface flow, deep percolation and evaporation. Depending on the type of irrigation system, these losses are more or less pronounced:

- **Flood and furrow irrigation:** Irrigation by gravity results in deep percolation of the water into the soil.
- **Sprinkler systems:** In these systems water losses occur through drift, evaporation and irrigation of areas beyond the rooting zone.
- **Drip irrigation:** This is the most efficient type of irrigation. However, its major disadvantage is its limited wetting pattern.

Improving irrigation system efficiency typically requires considerable investments. However, as the costs of water, energy and labour are continuously rising, the return on investment may well be positive. Furthermore, in periods of water scarcity, water must be employed as efficiently as possible.



In flood irrigation systems water losses are high. However, poor smallholders can often not afford high-tech solutions.



The performance of furrow irrigation (here with siphon tubes) can be improved through increasing the flow rate of the water or through surge irrigation reducing the infiltration rate of the water.

### Wetting patterns

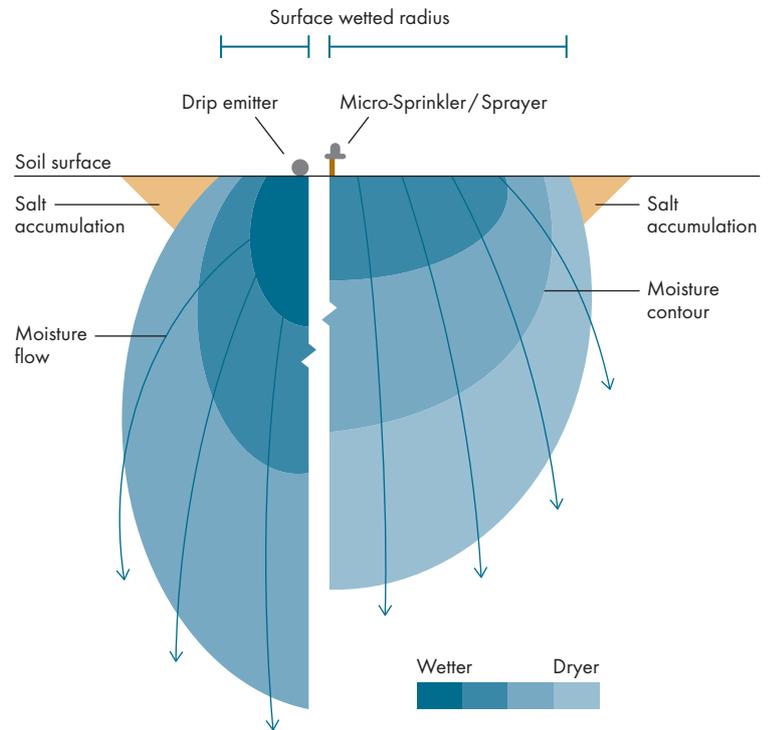
The wetting patterns of drip and micro-sprinkler irrigation differ from each other. In sandy soils, the wetted profile under the emitter is pear shaped and bulb-shaped in loam or clay soils. High discharge volumes widen the shape of the cone.

In light soils, the number of drip emitters needs to be increased, if the wetted zones are to conflate. Micro irrigation systems wet a much larger area and the soil type less influences the shape of the wetted profile (Figures 7 and 8).



Drip irrigation in cucumber.

**Figure 7. Wetting patterns of drip and micro-sprinkler irrigation**



The wetting patterns of drip (left) and micro-sprinkler irrigation (right) differ from each other.

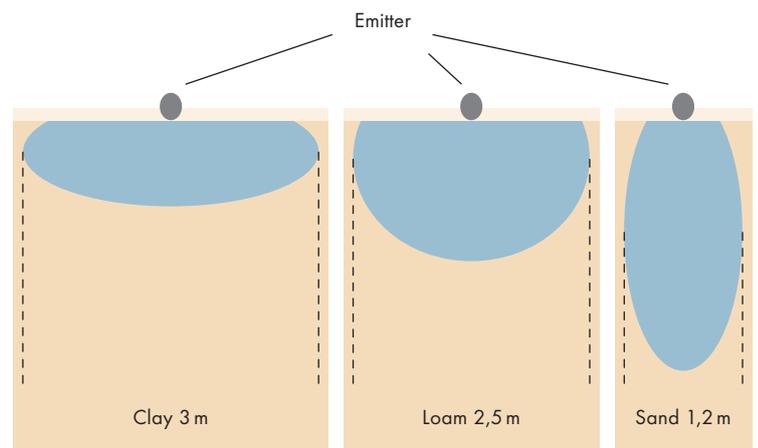
### Box 3. Good practices in choosing irrigation systems

- Choose a system with high irrigation efficiency.
- Choose a system adapted to the crop water needs.
- Design the system for an optimal wetting pattern.

### Good practices in managing irrigation systems

- In surface irrigation systems: avoid water losses through deep percolation and run-off, maintain and improve irrigation canals, install pulse valves.
- In sprinkler systems: avoid overlap between sprinklers; avoid irrigation during sunny hours and under windy conditions.
- Regularly check the irrigation systems for leakage and malfunctioning. Drippers must be controlled for clogging.
- Irrigate in the cool morning hours only.

**Figure 8. Wetting patterns of drip emitters in different soils**



In sandy soils, the wetted profile under the emitter is pear shaped and bulb-shaped in loam or clay soils. High discharge volumes widen the shape of the cone.

## Comparison of irrigation systems

	Surface irrigation	Sprinkler irrigation
		
<b>Types</b>	<ul style="list-style-type: none"> <li>• Flood irrigation</li> <li>• Furrow irrigation</li> <li>• Surge irrigation</li> </ul>	<ul style="list-style-type: none"> <li>• Fixed installed systems</li> <li>• Systems with fixed mains and moveable laterals</li> <li>• Pivot systems</li> <li>• Rain gun sprinklers, etc.</li> </ul>
<b>Characteristics</b>	<ul style="list-style-type: none"> <li>• Irrigation by gravity</li> <li>• Flood irrigation: basin enclosed by earthen dams filled with water (e.g. rice)</li> <li>• Furrow irrigation: water led through furrows along the crop rows (e.g. orchards or vegetable crops)</li> <li>• Surge irrigation: water led through furrows at intervals</li> </ul>	<ul style="list-style-type: none"> <li>• Pressurised system, usually with main and lateral pipes, ending in one or more sprinklers (emitters)</li> <li>• Varying delivery diameters possible</li> <li>• Pressure and emitter dimensions are adjusted to avoid too big or too small droplets.</li> </ul>
<b>Advantages</b>	<ul style="list-style-type: none"> <li>• Low energy requirements</li> <li>• Low investment requirements in traditional systems</li> <li>• No water storage capacity needed</li> <li>• Irrigation of the entire root zone</li> </ul>	<ul style="list-style-type: none"> <li>• Suitable for light soils</li> <li>• Suitable for sloping or uneven fields</li> <li>• Can be used to reduce ET by reducing leaf temperature.</li> <li>• Overhead sprinklers can be used as frost protection in fruit production.</li> </ul>
<b>Disadvantages</b>	<ul style="list-style-type: none"> <li>• Low irrigation efficiency in traditional systems</li> <li>• Risk of oversupply at the upper end and undersupply at the lower end of the field</li> <li>• Risk of deep percolation and leaching of nutrients beyond the root zone</li> <li>• Risk of water losses through runoff (tail water)</li> <li>• Risk of internal and surface erosion of the soil</li> <li>• Risk of waterlogging and consequently asphyxia in poorly drained soils</li> <li>• High labour requirements</li> <li>• High investments necessary for improved systems</li> </ul>	<ul style="list-style-type: none"> <li>• Big droplets can damage the soil structure (especially from rain-guns).</li> <li>• Requires high capacity pumps and pressure-walled piping.</li> <li>• Risk of increased disease pressure in over-canopy irrigation</li> <li>• Uneven water distribution pattern</li> <li>• Water loss through drift, evaporation and irrigation of unproductive areas</li> <li>• Use of clean water only to avoid soiling.</li> <li>• High energy requirement</li> </ul>
<b>Suggested application areas</b>	<ul style="list-style-type: none"> <li>• Regions with ample water resources, but low or infrequent precipitations</li> <li>• Regions with little infrastructure and traditional irrigation channels</li> </ul>	<ul style="list-style-type: none"> <li>• Frequently used in row, fruit and field crops</li> </ul>
<b>Estimation</b>	<ul style="list-style-type: none"> <li>• Mainly used in rice cropping systems</li> <li>• Rapidly declining use in fruit and vegetable crops due to low efficiency and high labour requirements</li> <li>• A system with laser-levelled fields, lined ditches, drainage and tail water re-use, pipelines, flow meters and surge valves can reach a rel. high irrigation efficiency. Yet, the investments in infrastructure and technology are high.</li> <li>• Surge irrigation: more even distribution and reduced deep percolation of the water</li> </ul>	<ul style="list-style-type: none"> <li>• Relatively efficient, when well designed and managed</li> <li>• When the whole field is wetted, the entire soil matrix can be used for water uptake by plants.</li> <li>• In order to improve water efficiency in crops with large row distances, such as fruit trees, overlap between the sprinklers is limited to the rows and not between the rows.</li> </ul>

Micro-sprinkler irrigation	Drip irrigation
	
<ul style="list-style-type: none"> <li>• Micro irrigation system in which irrigation is limited to the actual root zone of the plant.</li> <li>• Has a larger wetting pattern than drip irrigation.</li> <li>• Micro-sprinklers emit higher volumes of water per hour than drip irrigation.</li> </ul>	<ul style="list-style-type: none"> <li>• Subsurface systems</li> <li>• Surface systems</li> </ul>
<ul style="list-style-type: none"> <li>• High irrigation efficiency</li> <li>• The wetted area is wider than for drip systems allowing for maximum root penetration.</li> <li>• Precision irrigation according to the actual need of the plant</li> <li>• Micro-sprinkler emitters are larger than drip emitters and clog up less frequently.</li> </ul>	<ul style="list-style-type: none"> <li>• Micro-irrigation system in which irrigation is limited to the actual root zone of the plant.</li> <li>• Operated at low pressure and low water volumes per hour.</li> </ul>
<ul style="list-style-type: none"> <li>• High investment costs</li> <li>• Requires large water volumes and high capacity pumps.</li> <li>• High energy requirement</li> <li>• High water losses through evaporation when used during hot and sunny or windy conditions</li> <li>• Salt accumulation in the border zone between dry and wet soil</li> <li>• Uneven water distribution because of overlap between sprinklers</li> </ul>	<ul style="list-style-type: none"> <li>• Very high irrigation efficiency</li> <li>• Lower investments required than for mini-sprinklers</li> <li>• Low labour requirement</li> <li>• Minimal water losses through evaporation or percolation</li> <li>• Irrigation possible at any hour during the day</li> <li>• Low fungal disease pressure because of dry canopy</li> <li>• Subsurface drip systems: minimal evaporation from the soil surface and weed growth</li> </ul>
<ul style="list-style-type: none"> <li>• Frequently used in high-value tree crops.</li> <li>• Also suitable for the germination of sown crops</li> </ul>	<ul style="list-style-type: none"> <li>• Clogging of emitters by algae, bacterial slime or sediments possible</li> <li>• Root zone restricted to the wetted area</li> <li>• Sub-optimal wetting pattern in light soils</li> <li>• Needs an efficient filtering system.</li> <li>• Salt accumulation in the border zone between dry and wet soil</li> <li>• Drip lines hinder mechanical weeding.</li> <li>• Subsurface drip systems: maintenance difficult and costly</li> </ul>
<ul style="list-style-type: none"> <li>• Micro irrigation systems wet a much larger area and the shape of the wetted profile is less influenced by the soil type than in drip irrigation (see figures 7 and 8, page 13).</li> </ul>	<ul style="list-style-type: none"> <li>• Particularly suitable for vegetable crops</li> <li>• Not suitable for germination of sown crops</li> <li>• In light soils, the number of drip emitters needs to be increased, if the wetted zones are to conflate.</li> </ul>

## Climate-smart Irrigation

Climate-smart irrigation (CSI) are good irrigation practices that take the mounting impacts of climate change into account. Deficit irrigation and supplemental irrigation are climate-smart irrigation techniques.

### Deficit irrigation

Practicing deficit irrigation means providing less irrigation water than the calculated evapotranspiration of the crop (ETc). It is a way to «maximise crop per drop». The strategy is practiced in regions with scarce water resources or when water costs are very high.

#### Good to know

- In most crops, deficit irrigation causes yield reductions. However, yield reductions are acceptable, if water costs are high or water availability is limited.
- In (table) grapes, the sugar content and the quality of the grapes increase under deficit irrigation, but maximum yield is not realised.
- In olive cultivation, deficit irrigation improves oil extraction, increases the content of unsaturated fatty acids and polyphenols and reduces the peroxide values.
- In other, less drought tolerant crops, deficit irrigation can be applied in periods in which water demand of the crop is low, or lack of water does not seriously affect the quality or yield.



Deficit irrigation aims at increasing the water use efficiency of a crop maximising the yield per quantity of water used.

### Water productivity

Water productivity (WP) can be an important factor in irrigation management in regions with scarce water resources. WP expresses the crop yield per unit of water.

$$\text{Water productivity} = \frac{\text{crop yield (t/ha)}}{\text{water applied (l/m}^2\text{)}}$$

#### Good to know

- In deficit irrigation, WP is higher than under full irrigation. I.e. with the same amount of water, a larger land area can be grown under deficit irrigation than under full irrigation, which ultimately results in a higher total yield.

### Supplemental irrigation

Supplemental Irrigation (SI) is used in essentially rain-fed crops that may suffer from late, irregular or insufficient precipitations. SI aims to supply the crop with limited amounts of water in critical crop development stages in which sufficient water is essential, e.g. during flowering and seed or fruit setting.

#### Good to know

- Yields and water use efficiency can be much improved with supplemental irrigation, especially in semi-arid regions.
- Supplemental irrigation is also used for early sowing, when natural precipitation has not yet started, to prolong the vegetation period and to mitigate drought or hot spells.
- In cold regions, SI can be used to prevent frost damage.
- Supplemental irrigation is an important aspect of Climate-smart Agriculture (CSA).

### Water harvesting

In water harvesting, rainwater is collected and stored. Water harvesting is an important feature in climate-smart agriculture.

### Good to know

- Water harvesting is increasingly important in regions with scarce water resources.
- In some standards on sustainable irrigation management, such as the GLOBALG.A.P. Add-On SPRING (Sustainable Program for Irrigation and Groundwater Use), efforts to harvest water are obligatory.
- Rainwater harvesting can be carried out in many ways. The most common are rainwater collection from rooftops and water collection from field run-off, including the building of dams in water streams to create lakes.
- If the collected water from micro-catchments is not used to irrigate crops directly, it can be stored in e. g. tanks, basins or lagoons.
- Natural storage areas must be made impermeable by lining the sink with concrete, impermeable tarpaulins or compacted clay and are ideally covered to prevent evaporation.

## Water quality

Water quality is of paramount importance for plant growth and product quality. Minerals such as salt are detrimental for plant growth, iron can precipitate and plug pipes and water emitters, sediments can clog up drip emitters and abrade water nozzles and pumps. Microbial contamination e.g. with e-coli or norovirus will render the product unsuitable for consumption.

### Microbial contamination

- Ground water is less likely to contain microbial contaminants than surface water (e. g. ponds, waterways).
- Contamination risk also depends on the irrigated crop: Leafy vegetables that grow close to the ground are more susceptible to contamination than e. g. fruit crops.

#### How prevent microbial contamination?

- Test the water quality of private wells 1 to 2 times per year and surface water 2 to 3 times per year (at planting, during peak use and shortly before harvest).
- Avoid pumping water from areas near livestock facilities and specifically from areas near manure storage areas.



Covering the water storage basin helps to reduce evaporation.

#### Box 4. Good practice in climate-smart irrigation

- Apply deficit or supplemental irrigation.
- Aim for maximum water use efficiency.
- Collect and store rainwater.
- Cover water storage basins.
- Use flow meters or weirs to measure water consumption.

- The use of under-canopy or drip-irrigation systems reduces contact of possibly contaminated water with the harvested crop parts.

## Salinity

Irrigation with saline water can irretrievably ruin soil fertility. The salt in the irrigation water builds up in the soil and eventually reaches levels that make crop production impossible.

#### How to prevent salinity?

- If leaching with good quality water is not possible, crop production should be limited to the rainy season.
- In arid regions, when only saline water is available, only salt- and drought-tolerant crops should be cultivated (e. g. cotton, grains or drought tolerant vegetables such as tomatoes). Crops with high, year-round need for water, such as deciduous evergreen crops (e. g. avocado), should not be planted.
- In arid regions with a season with natural precipitations, crop production should be limited to this period.
- In production areas in proximity to the sea, high quality well water or desalinated water are in-

creasingly mixed with seawater or saline ground water. Such practices do not conform to sustainable agriculture. When irrigating with saline water, the salt tends to build up in the soil. The water is taken up by the plants or evaporates from the soil-surface, but the salts remain in the soil.

- In areas with sufficient water availability, excessive salt can be washed (leached) out to layers beyond the reach of the roots. The amount of water needed to leach salt beyond the root zone, however, is very high (10–15 % of total consumption) and should be practiced only when sufficient water of good quality is available (e. g. in periods when precipitation or water availability is abundant) and nitrogen levels in the soil are low.
- Irrigation water with a high salt content is detrimental not only for soil fertility, but also for plant growth. Ions such as chloride and sodium are toxic for plants and a high salt content in the irrigation water inhibits water uptake. The concentration of salt is usually measured by electrical conductivity (EC) and expressed in deci Siemens per meter (dS/m) or micro Siemens per centimeter (µS/cm). 1 dS/m equals 1000 µS/cm. Another way of measuring salinity is the amount of Total Dissolved Salts (TDS) expressed in ppm. 1 dS/m approximately corresponds to 640 mg/l or ppm.

Most crops can be irrigated with water of up to 1 dS/m without yield reduction. Some vegetable crops such as eggplant, carrots, beans and onions are particularly intolerant to high salinity levels. The EC of the irrigation water for these crops should be less than < 0.8 dS/m. Others, such as tomatoes, beets, zucchini and asparagus are tolerant (EC of the irrigation water up to 3 dS/m). Deciduous fruit crops are generally intolerant to high salinity levels. Pome fruit and avocado should be irrigated with water with an EC of less than 1 dS/m ideally < 0.4 dS/m. Figs, dates and olives, on the contrary, are fairly tolerant to high salinity.

## Iron

High iron content in the irrigation water can create significant problems. Well-water can have a particularly high concentration of iron. Iron precipitates as iron oxide (rust) when it comes in contact with air. This can cause blockage of the drip-emitters or micro-sprinklers.



Salt accumulation in the soil.

**Table 5. Measuring units for salt concentration**

EC (dS/m)	TDS (ppm)	Salinity
0–1	0–640	low
1–2	640–1280	moderate
2–5	1280–3200	high
> 5	> 3200	extremely high

Irrigation water with a concentration of more than 1 mg/l (1 ppm) should be treated before use. The treatment usually consists of pre-storing and aerating the water to precipitate the iron oxide before the water is pumped into the irrigation system.

## Sediments

Both organic and inorganic impurities in the irrigation water can physically block the emitters and thus reduce the efficiency of the irrigation system. Suitable filter systems must be installed to remove any particles that are larger than the emitters can handle. Organic sediments in the water can also cause bacterial or algae-growth that can clog the emitters. A combination of centrifugal and screen filters is usually required, particularly for drip irrigation systems. Visible stains can furthermore reduce the quality of vegetable crops.

## Water temperature

The soil biota and the plant roots react adversely to temperature shocks. In particular, well water can be cold and should be brought to ambient temperature before it is used to irrigate the plants. In case of persistent low temperatures of well water, the water can be intermediately stored in basins before being pumped into the irrigation system.

For the same reason, irrigation should take place in the early morning hours when both the plant and the soil are cooled down by the lower night temperatures. Irrigation in the early morning

also reduces evaporation from a hot soil surface and evaporation in the air before (sprinkler) water reaches the soil.

### Box 5. Good practices to improve water quality

- Regularly analyse well and surface water for heavy metals, microbial contamination and salt content;
- Install filters to eliminate sediments;
- Interim-storage of cold well water to reach ambient temperature.

## Water stewardship

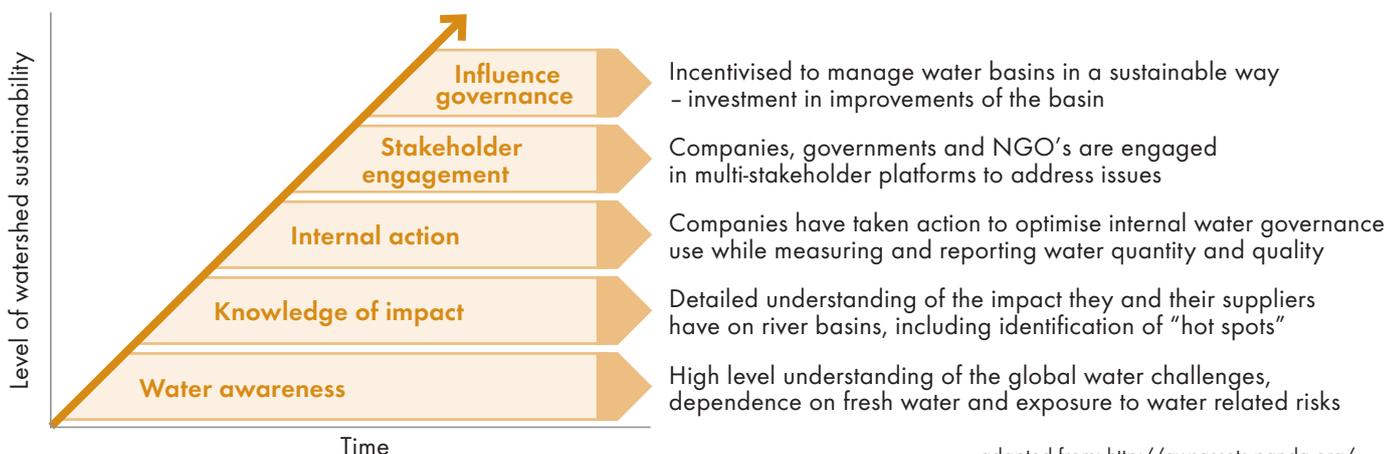
The aim of water stewardship is the responsible planning and management of water resources in the catchment. Water stewardship aims to look beyond the individual farm at the surrounding landscape and society.

Water stewardship is generally limited to a catchment or river basin approach and includes all of the stakeholders therein. Water Stewardship for farmers begins on the farm but includes the needs of other stakeholders in the catchment. Water resources must essentially be equitably and sustainably shared between the stakeholders. The farmer thus needs to be aware of the effects his / her water management has on other water users in terms of water volume, water levels and water quality.

Collaboration and interaction with other stakeholders in the catchment, such as other farms, industries, households, the natural environment, regulatory bodies and government agencies is therefore of vital importance. Whenever possible, participation in stakeholder forums or relevant stakeholder groups shall be pursued. Only when all stakeholders are working together can the common goal of equitable distribution and sustainable use of available water sources be achieved.

The Sustainable Agriculture Platform Stakeholder (SAI,) correctly states “Engagement is a tool to encourage water users to work together to share resources and limit negative consequences of water scarcity. This may include an acceptance that water use must be reduced at critical times”.

**Figure 9. The WWF Water stewardship ladder**



The WWF stewardship ladder helps companies to take internal actions, to address their impact and to contribute to the responsible, sustainable management of water resources.

adapted from: [http://awsassets.panda.org/downloads/ws\\_briefing\\_booklet\\_lr\\_spreads.pdf](http://awsassets.panda.org/downloads/ws_briefing_booklet_lr_spreads.pdf)

The World Wildlife Fund (WWF) developed a concept of water stewardship as presented in figure 9. The steps in the model show the various water-related activities that farms and other stakeholders can and shall engage in.

Organic label organisations such as GLO-ABALG.A.P. with its add-on standard SPRING<sup>1</sup> and the Bio Suisse Standard on Water Resources Management (Part V, Art. 1.7)<sup>2</sup> require engagement in Water Stewardship as a condition for certification.

Guidance documents on how to prepare for inspection and certification against SPRING and Bio Suisse standards can be found on the websites of the respective organisations.

<sup>1</sup> [https://www.globalgap.org/uk\\_en/for-producers/globalg.a.p.-add-on/spring/](https://www.globalgap.org/uk_en/for-producers/globalg.a.p.-add-on/spring/)

<sup>2</sup> [https://www.bio-suisse.ch/media/VundH/Regelwerk/2019/EN/rl\\_2019\\_en\\_excerpt\\_part\\_v\\_\\_6.2.2019.pdf](https://www.bio-suisse.ch/media/VundH/Regelwerk/2019/EN/rl_2019_en_excerpt_part_v__6.2.2019.pdf)

### Box 6. Good Practices in Water Stewardship

- Strive for equitable distribution of water resources in the catchment;
- Understand the water-related challenges in the catchment in which the farm is located;
- Understand and mitigate the effect water use on the farm has on other water users in the catchment;
- Engage in stakeholder forums and relevant stakeholder groups;
- Take all possible measures to limit and economise water use on the farm;
- Carry out an Impact Risk Assessment of water use on the farm;
- Register all water related data of the farm.

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