IRRIGATION

PERENNIAL CROP SUPPORT SERIES

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ALTERNATIVE LIVELIHOODS PROGRAM—EASTERN REGION ALP/E

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Roots of Peace is a humanitarian, not-for-profit organization based in California, USA. Roots of Peace, established in 1997, focuses on post-conflict countries to eradicate remnants of war and to re-establish and promote economic livelihoods and social programs. Roots of Peace is funded by public and private sources.

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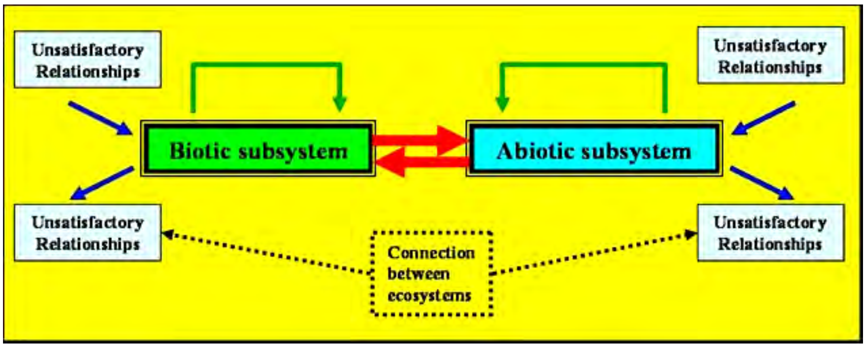
1 Introduction

Agro-ecological technology works with ecosystem principles. These principles include those that govern the soil and water. Different populations sharing a habitat interact each other. The group of interacting populations forms a *community* that interacts with the non-living world around it. Ecosystems are formed by the interaction of particular community with the non-living environment, i.e. *biotic subsystem* + *abiotic subsystem* = *ecosystem*. Water is part of the abiotic subsystem. There is no agricultural production without water, and so water management and the conservation of water resources are two of the most important activities on the farm.

Figure 1 Main components of the ecosystem



Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

The global ecosystem is composed of the geo-sphere, the atmosphere and the hydrosphere, and the links between all of these and human health are critical. An estimated 25,000 people around the world die daily of water-related disease (UNEP 1991 Fresh Water Pollution). Water use is shared between agriculture, industry and the community. The global annual rainfall over land is approximately 110,000 Km^3, and of that only 40,000 Km^3 is a renewable supply of water since the rest evaporates before reaching the sea, or is lost in floods (26 000 Km^3). Of this available water supply only 10% is actually used, i.e. 4 000 Km^3. Agriculture takes 70% of that supply, and industrial and domestic use account for the remaining 30%. However, there is a 10% rise up to almost 30% considering that 26 000 Km^3 of water runs off in floods. Therefore, it is not stable supply.

Around 16% of the total cultivated land on earth is under irrigation and this irrigated land accounts for 40% of global food production. Water distribution in the world is very uneven and large areas suffer from a scarcity of water. Furthermore, where water is available, it is often used inefficiently. If a water management policy is in place, it may be misjudged, thus contributing to low efficiency. Although governments subsidise water use generously, approximately 60% of irrigation water is wasted. Moreover, this wasted irrigation water often erodes the soil.

Irrigation water management influenced by four main factors:

- Precipitation and Evaporation
- Water source
- Irrigation system
- Drainage system

Precipitation and evaporation

The largest part of the world's agriculture production depends on annual rainfall. The rainfall is defined by three characteristics: amount, intensity, distribution in time and effective rainfall.
The amount of water is usually indicated as water depth in millimeters. One millimeter of rainfall in 1m^2 area is equal to 0.001 m^3 of water, which is equal to 1 liter. In other words, each mm of rainfall supplies 1 liter of water for 1 m^2. One hectare is 10 000 m^2, which means 10 000 l of water.

The rainfall intensity refers the amount of water divided by the duration of the rain and is expressed in millimeters per hour.

The rainfall distribution in time refers the date and volume of rain during a specific time period. It is usually measured in two ways:

- During the crop growth divided by month
- Annual rainfall distributed seasonally (dry season, rain season, etc.)

The *effective rainfall* is not the same as the rainfall depth that reaches the surface during rainfall. Only part of the rain-water will be available for planting. During and after rainfall, part of the water will be lost as runoff water, part will evaporate from the stagnating water on the surface afterwards and part will percolate below the root zone and will be lost. Therefore the effective rainfall is equal to:

Effective rainfall = Total rainfall – Runoff – Percolation loss – Evaporation

The amount effective rainfall very much depends from seven factors:

- Climate, which determines the rainfall intensity, amount and distribution

- Soil texture: The water infiltrates quickly into sandy soils reducing evaporation loss, but the percolation loss will be higher, because the soil water holding capacity is low. With clayey soil the effect will be the opposite.

- Soil structure: Granular structured soil has the best balanced water infiltration rate and water holding capacity. Blocky and prismatic structured soil has a moderate infiltration rate, meanwhile massive soil structure is known about its low infiltration rate and high evaporation and runoff loss.

- Depth of the root zone: The available water for deep rooting crops is higher than the shallow rooting crops. Therefore the same soil can have different effective rainfall volume depending from the crop in production.

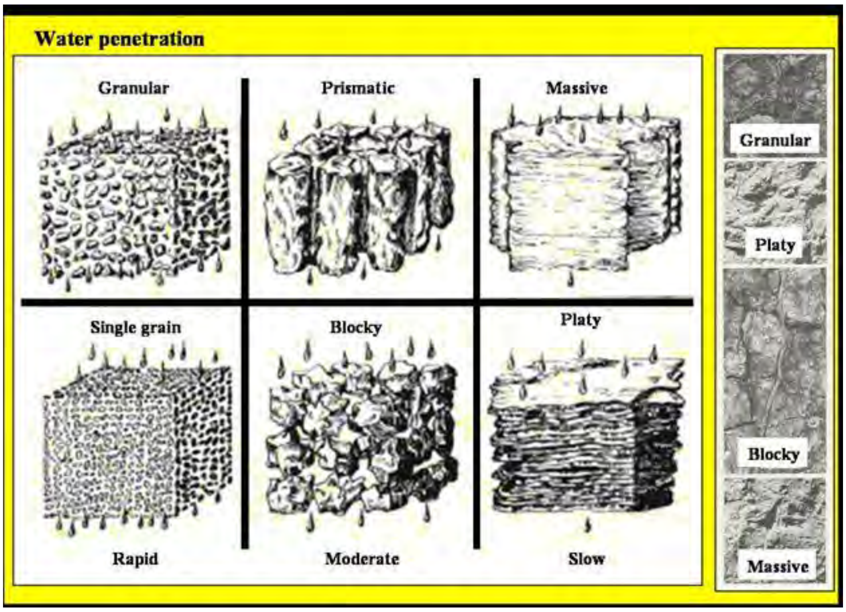
- Topographic conditions: On sloping areas the runoff loss is higher than on flat areas.

- Soil moisture content: Infiltration rate is higher when the soil is dry and decreases gradually when soil becomes wet.

- Irrigation method: The purpose of different irrigation methods is making water use more efficient. In other words, to reduce runoff, evaporation and percolation loss. Therefore, they also influence the rainfall use. Basin and border irrigation by nature does not allow runoff of rainfall. The water will remain inside the bund system. Irrigation practices will keep wet the soil, therefore, the rain water infiltration rate will be slower. Leveling and grading practices do not allow to the water stagnating on the field and so on.

Rainfall, as part of the hydrologic cycle, is a supplier of water to back into soil. Evaporation is also part of the cycle as one of the ways to remove water from the soil. Evaporation rate is influenced by sun heat, temperature, relative humidity of the air and air pressure. The vegetation and the evapo-transpiration of the plants also influence it.

Figure 2 Relationship between water infiltration and different types of soil structures

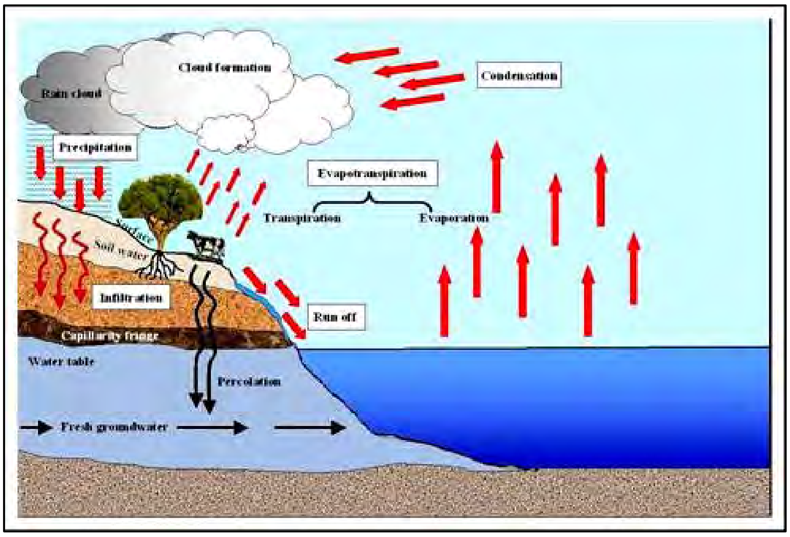


Source: D. Pennock (2005) University of Saskatchewan

2 Water Source

There are many misunderstandings regarding to water. One is the perception that water sources are unlimited. This idea is supported by the fact, that in many countries, farmers do not have to pay for water use. Therefore, over irrigated crops is a common phenomenon. Water brings life, but it is a limited resource. The list of the countries with a scarcity of water is longer every year. The Earth's limited water source is continuously recycling. This cycle is called the hydrologic cycle. Human interventions disturb the balance inside the cycle, which can cause disastrous effects.

Figure 3 Hydrologic cycle



Source: F. Sandor, 2008. RoP-Jalalabad, Afghanistan

The hydrologic cycle is composed of three states: gaseous, condensed and liquid. The dominant processes in the cycle are:

- Condensation: a gas or vapor condenses into water droplets to form clouds or steam
- Precipitation: water is released from clouds as rain, sleet, snow or hail
- Infiltration: water seeps from the soil surface into the ground
- Run-off: water flows on the surface instead of infiltrating the ground
- Evaporation: water evaporates from the soil by evaporation for the soil, water bodies, etc, and through transpiration in the plant
- Respiration: evaporation from gas exchange structures, such as lungs.

The sun gives energy to support this cycle, but is not part of the recycling process itself. Energy does not recycle in the ecosystem! Part of the released water passes through the abiotic subsystem or is trapped in it, and is termed soil hygroscopic water, and part of the water passes through both biotic and abiotic subsystems. Producer organisms use water for sugar synthesis, while both consumer and producer organisms use it for building up most of their body weight, which may be as much as 90%.

Another misconception is that the underground water is like a flowing river, but this is only true where water flows freely in underground caves. Usually water flows through pore spaces between rocks. The pore space net will be saturated with water, which can be exploited as water source.

Photo 1 Waterlogged area

Source: F. Sandor (2003), Kasungu, Malawi

It is also a misconception that under the soil layer we can find a big and unique aquifer, like an underground lake or ocean. The Earth's crust is built up with horizons and soil layers. Each one of them has different hydraulic conductivity, some of them higher and others lower. When the water penetrates into them and finds a layer with very low hydraulic conductivity, the water becomes stuck and an aquifer is created. In the same area we can find numerous aquifers at different depths. Many of them are connected to each other and water flows between them, but others are isolated.

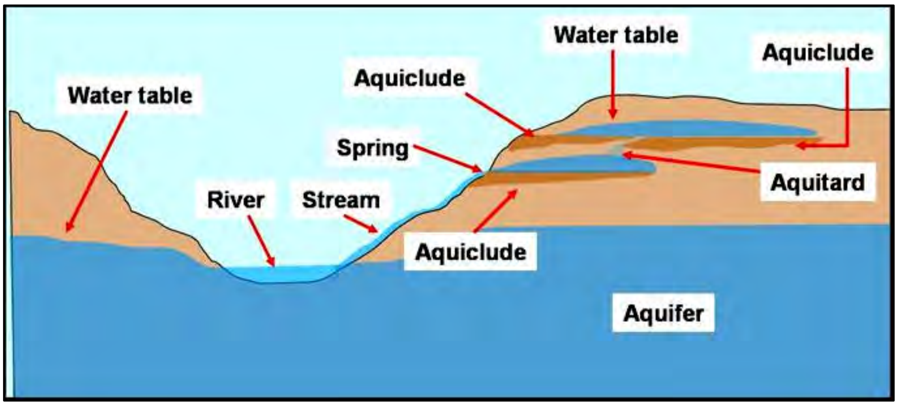


Figure 4 Water Table

Source: F. Sandor, 2008. RoP-Jalalabad, Afghanistan

If we search the land from the point of view of hydrogeology, the Earth's crust reveals the following structure:

1- There are two regions in the crust:

   a. Unsaturated zone, where the pressure head is negative (Gauge pressure <0) and the pore space net is not completely filled up with water.

   b. Saturated zone, where the Pressure head is positive (Gauge pressure >0) and the pore space net completely filled with water. The water table is the surface, where the pressure head is equal to the atmospheric pressure (Gauge pressure =0)

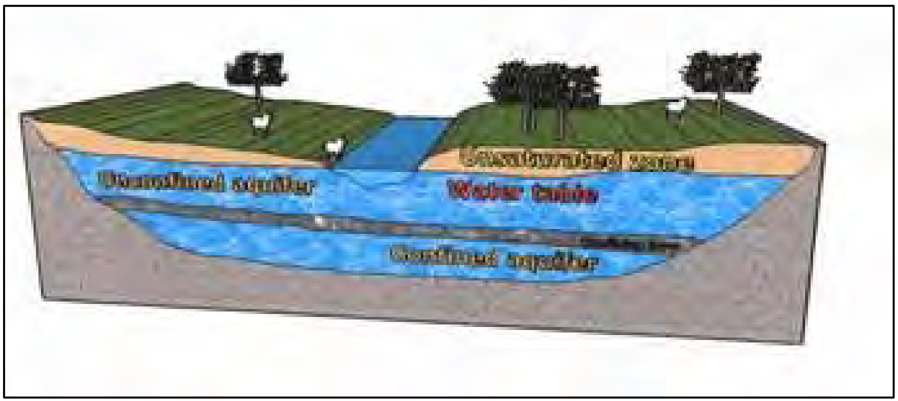
Note: Absolute pressure is zero, when it is referenced against perfect vacuum and it is equal to gauge pressure plus atmospheric pressure. It is never can be negative.
Gauge pressure is zero, when it is referenced against atmospheric pressure and it is equal to the absolute pressure minus atmospheric pressure. It is can be negative.

2- The saturated zone includes three structural elements:

   a. Aquitard zone: The soil layer, which restricts groundwater flow between aquifers

      i. Aquitard zone: Permeable layer, which only restricts water flow
      ii. Aquiclude (Aquifuge): Impermeable layer for water flow

Figure 5 Aquifer



Source: F. Sandor (2008),RoP Jalalabad, Afghanistan

   b. Unconfined aquifer (Phreatic aquifers): Commonly called as water table, because its upper boundry is the surface known as the water table, where the pressure head is equal to the atmospheric pressure. It does not have an aquitard or aquiclude between it and the surface. This is the reason why it is called an unconfined aquifer. Usually, these kinds of aquifers are found above the confined aquifers and they are recharged with water directly from the surface (Shallow aquifers).

   c. Confined aquifer: Its upper boundary is an aquitard or aquiclude. We can find the water table above this boundary. These aquifers are much smaller than the extensive unconfined aquifers.

Table 1 Earth's Crust Division

<table>
<tr><th colspan="5">Earth's crust divisions</th></tr>
<tr><td rowspan="10">Earth's crust</td><td rowspan="5">Groundwater</td><td colspan="3">Unsaturated zone</td></tr>
<tr><td rowspan="4">Saturated zone</td><td rowspan="2">Aquitard</td><td>Aquitard</td></tr>
<tr><td>Aquiclude</td></tr>
<tr><td colspan="2">Unconfined aquifer</td></tr>
<tr><td colspan="2">Confined aquifer</td></tr>
<tr><td rowspan="4">Surface water</td><td colspan="3">Stream</td></tr>
<tr><td colspan="3">River</td></tr>
<tr><td colspan="3">Lake</td></tr>
<tr><td colspan="3">Ocean</td></tr>
<tr><td>Precipitation</td><td colspan="3">Water concentration</td></tr>
</table>

Source: F. Sandor, (2008). RoP-Jalalabad, Afghanistan

3 Irrigation Water Need

3.1 Water Balance

Plant growth requires water. Each and every crop needs a specific amount of water during the growing period. Partly, this water is provided by rainfall and the rest of the water needed is covered by irrigation. Two major factors determine the amount of irrigation water, which needs for the crop:

- The total water need of the various crop
- The amount of rain water which is available for the crop

The soil and the plant are components of the hydrologic cycle. This means that most of the water that is absorbed by the plant roots will not remain in the plant. The soil also looses its water content in different ways. This lost water should be replaced by rainfall and irrigation.

3.2 Evapo-transpiration

Water from the soil and open water surface is released as *vapor* to the atmosphere. This process is called evaporation. The transformation of water from liquid to gas form is caused by the energy movement in the ecosystem. The energy movement can be measured through the climatic conditions, which includes the main contributing factors such as sunshine, temperature, humidity and wind speed.

The plant also looses water through its leaves and stem. The process is called transpiration. Transpiration consists of the vaporization of liquid water contained in plant tissues and the vapor removal to the atmosphere. This process happens mainly in the day-time.

Evapo-transpiration (ET) basically is the loss of water through transpiration and evaporation. It is a significant water loss from the watershed and this is the amount of water which the crop needs. Evapo-transpiration mainly depends on the climate, the crop type and the growth stage.

Evapo-transpiration has a maximum potential capacity in a specific environment. This value is called potential evapo-transpiration (PET). PET is an expression of the environmental demand for evapo-transpiration and it highlights the amount of water that can evaporate and transpire if sufficient water is available. The value of potential evapo-transpiration is equal to the evaporation rate of a short green crop, which has complete shading on the ground and which has a uniform height with optimal water status in the soil profile (Reference crop). Therefore, the evapo-transpiration cannot be greater than potential evapo-transpiration. It is lower or, under perfect conditions, equal to it.

The *hydrological cycle* is moved by energy and evapo-transpiration is an important part of the cycle. Therefore evapo-transpiration may be estimated through an equation of the water balance of the watershed or through the energy balance of the hydrologic cycle. The two equations are expressed on the following ways:

<u>Equation for catchment water balance</u>

$\Delta S = P - ET - Q - D$

where,

P = precipitation

ET = evapo-transpiration

Q = stream flow

D = groundwater recharge

The symbol “S” represents the amount of water stored in the basin. Therefore the symbol of “ΔS” will represent the changes observed in the amount of stored water. These changes are equal to the difference between the precipitation and the sum of evapo-transpiration, stream flow and groundwater recharge. From this equation evapo-transpiration may be estimated as:

$ET = P - \Delta S – Q – D$

Energy balance

$\lambda E = Rn + G – H$
where,
Rn = net radiation
G = soil heat flux
H = sensible heat flux

In this equation the evapo-transpiration is estimated through the energy (λE) to change the phase of water from liquid to gas form.

The potential evapo-transpiration is expressed in depth of water (mm) and can be graphed during the year. The difference between the PET of a specific crop and the precipitation is the amount of irrigation water needed. If the rainfall is sufficient to cover the water need of the crop, irrigation is not necessary. Otherwise the difference may need to be provided through irrigation. Indeed, all the water from rainfall may not be used by the crop. Part of it may be lost as run-off water or deeply percolated into the soil. Therefore the amount of rainfall water is divided into two components:

- Non-effective rainfall: that is the amount of water which is lost through deep percolation and surface run-off.

- Effective rainfall: that is the amount of water, which is stored in the crop root zone and available for plant growth.

3.3 Crop Water Need

The crop water needed is the amount of water needed by a specific crop to grow optimally. This need varies according to the climate, crop type and growing stage. The *crop water need* (ETcrop) is expressed in the depth of water required to compensate the water loss through evapo-transpiration.

3.3.1 Climate effect on crop water need

The effect of the climate on the crop water need is expressed as reference crop evapo-transpiration (ETo). The measurement unit is millimeter per unit of time, which can be a day, month or growing season. Standard grass crop has been used as reference crop. The daily water need of the reference crop depends on the rainfall regime and daily temperature.

Table 2 Average daily water need of standard grass

Daily water need of standard grass			
Rainfall regime	Daily temperature		
	Low (<15C°)	Medium (15-25 C°)	High (>25 C°)
Arid	4 – 6 mm	7 – 8 mm	9 – 10 mm
Semi arid	4 – 5 mm	6 – 7 mm	8 – 9 mm
Sub-humid	3 – 4 mm	5 – 6 mm	7 – 8 mm
Humid	1 – 2 mm	3 – 4 mm	5 – 6 mm

Source: C. Brouwer-A. Goffeau-M. Heibloem, (1985), Irrigation water management, FAO, Rome

3.3.2 Influence of crop type on crop water need

It is possible to calculate the daily water need of different crops from the comparison between one crop and the reference crop's water need.

Table 3 Water need of crops compared to standard grass

Daily water need of crops as compared to standard grass				
-30%	-10%	Same	+10%	+20%
Citrus	Cucumber	Carrot	Barely	Paddy rice
Olive	Radish	Cabbage	Bean	Sugarcane
Grape	Squash	Cauliflower	Maize	Banana
		Broccoli	Flax	Nuts+cover crop
		Lettuce	Grains	Fruit+cover crop
		Melon	Cotton	
		Onion	Tomato	
		Peanut	Eggplant	
		Pepper	Lentil	
		Spinach	Millet	
		Tea	Oat	
		Grass	Pea	
		Cacao	Potato	
		Coffee	Sorghum	
		Nuts	Soya	
		Fruit trees	Sugar beet	
			Sunflower	
			Tobacco	
			Wheat	

Source: C. Brouwer-A. Goffeau-M. Heibloem, (1985), Irrigation water management, FAO, Rome

Equation

$ETcrop = ETo \pm (C_R \times ETo)$ (mm/day)
Where,
ETcrop = Crop daily water need
ETo = Evapo-transpiration (reference crop)
C_R = Crop comparison factor in percentage

Each crop also has a different duration of growing period. Therefore the crop type does not affect only the crop daily water need, but also influences the seasonal water need.

Table 4 Seasonal water need of different crops

Crop	Growing period (days)	Seasonal water need (mm)
Alfafa	100 – 365	800 – 1600
Banana	300 – 365	1200 – 2200
Barley	120 – 150	450 – 650
Green bean	75 – 90	300 – 500
Dry bean	95 – 110	300 – 500
Cabbage	120 – 140	350 – 500
Citrus	240 – 365	900 – 1200
Cotton	180 – 195	700 – 1300
Sweet corn	80 – 110	500 – 800
Maize	125 – 180	500 – 800
Oat	120 – 150	450 – 650
Wheat	120 – 150	450 – 650

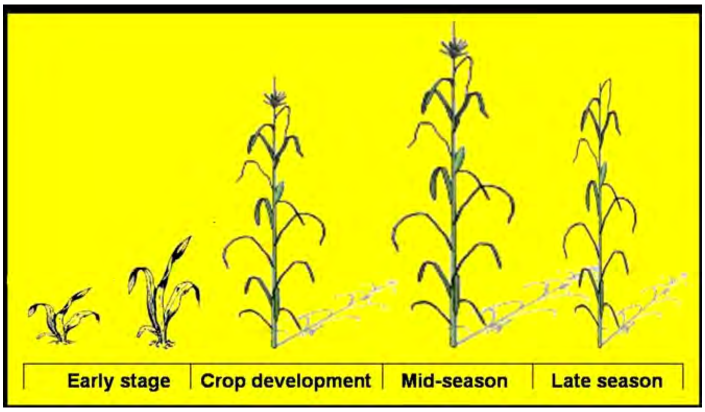
Source: C. Brouwer-A. Goffeau-M. Heibloem, (1985), Irrigation water management, FAO, Rome

3.3.3 Influence of crop growth stage on crop water need

The crop water needs varies according to the development stage of the plant. A fully grown plant requires more water than young, recently planted crops. The shade of a young plant covers less surface area than a fully grown plant, therefore the evaporation rate will also be different. The growing period of the plant contains four stages:

- The initial stage: This stage ends when the plant covers 10% of the ground surface.
- The development stage: It lasts until the ground surface coverage will reach 70-80%
- The mid-season stage: It lasts until maturity
- The late season stage: It lasts until the last day of harvest

Figure 6 Crop growing stages



Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

It is an important factor knowing the duration of each stages of a specific crop.

Table 5 Lengths of crop development stages

Length of crop development stages in days					
Crop	Initial (L_{Ini})	Develop. (L_{Dev})	Mid-season (L_{Mid})	Late-season (L_{Late})	Total
Small vegetables					
Broccoli	35	45	40	15	135
Cabbage	40	60	50	15	165
Carrot	20	30	50/30	20	100
	30	40	60	20	150
	30	50	90	30	200
Cauliflower	35	50	40	15	140
Celery	25	40	95	20	180
	25	40	45	15	125
	30	55	105	20	210
Brussel sprouts	20	30	20	10	80
	25	35	25	10	95
Lettuce	20	30	15	10	75
	30	40	25	10	105
	25	35	30	10	100
	35	50	45	10	140
Onion (dry)	15	25	70	40	150
	20	35	110	45	210
Onion (green)	25	30	10	5	70
	20	45	20	10	95
	30	55	55	40	180
Onion (seed)	20	45	165	45	275
Spinach	20	20	15/25	5	60/70
	20	30	40	10	100
Radish	5	10	15	5	35
	10	10	15	5	40
Solanaceae family					
Eggplant	30	40	40	20	130
	30	45	40	25	140
Sweet pepper	25/30	35	40	20	125
	30	40	110	30	210
Tomato	30	40	40	25	135
	35	40	50	30	155
	25	40	60	30	155
	35	45	70	30	180
	30	40	45	30	145
Cucurbitaceae family					
Cantaloupe	30	45	35	10	120
	10	60	25	25	120
Cucumber	20	30	40	15	105
	25	35	50	20	130
Pumpkin, Winter squash	20	30	30	20	100
	25	35	35	25	120
Squash, Zucchini	25	35	25	15	100
	20	30	25	15	90
Sweet melon	25	35	40	20	120
	30	30	50	30	140

Length of crop development stages in days					
Crop	Initial (L_{Ini})	Develop. (L_{Dev})	Mid-season (L_{Mid})	Late-season (L_{Late})	Total
	15	40	65	15	135
	30	45	65	20	160
Water melon	20	30	30	30	110
	10	20	20	30	80
Roots and tubers					
Beet	15	25	20	10	70
	25	30	25	10	90
Cassava (1 year)	20	40	90	60	210
Cassava (2 years)	150	40	110	60	360
Potato	25	30	30/45	30	115/130
	25	30	45	30	130
	30	35	50	30	145
	45	30	70	20	165
	30	35	50	25	140
Sweet potato	20	30	60	40	150
	15	30	50	30	125
Sugarbeet	30	45	90	15	180
	25	30	90	10	155
	25	65	100	65	255
	50	40	50	40	180
	25	35	50	50	160
	45	75	80	30	230
	35	60	70	40	205
Leguminosae family					
Bean (green)	20	30	30	10	90
	15	25	25	10	75
Bean (dry)	20	30	40	20	110
	15	25	35	20	95
	25	25	30	20	100
Faba and Broad bean	15	25	35	15	90
	20	30	35	15	100
Faba and Broad bean (dry)	90	45	40	60	235
Faba and Broad bean (green)	90	45	40	0	175
Green gram, cowpea	20	30	30	20	110
Peanut	25	35	45	25	130
	35	35	35	35	140
	35	45	35	25	140
Lentil	20	30	60	40	150
	25	35	70	40	170
Pea	15	25	35	15	90
	20	30	35	15	100
	35	25	30	20	110
Soya bean	15	15	40	15	85
	20	30/35	60	25	140
	20	25	75	30	150
Perennial vegetables					
Artichoke	40	40	250	30	360
	20	25	250	30	325

Length of crop development stages in days					
Crop	Initial (L_{Ini})	Develop. (L_{Dev})	Mid-season (L_{Mid})	Late-season (L_{Late})	Total
Asparagus	50	30	100	50	230
	90	30	200	45	365
Fibre crops					
Cotton	30	50	60	55	195
	45	90	45	45	225
	30	50	60	55	195
	30	50	55	45	180
Flax	25	35	50	40	150
	30	40	100	50	220
Oil crops					
Castor bean	25	40	65	50	180
	20	40	50	25	135
Safflower	20	35	45	25	125
	25	35	55	30	145
	35	55	60	40	190
Sesame	20	30	40	20	100
Sunflower	25	35	45	25	130
Cereals					
Barley, Oat, Wheat	15	25	50	30	120
	20	25	60	30	135
	15	30	65	40	150
	40	30	40	20	130
	40	60	60	40	200
	20	50	60	30	160
Winter wheat	20	60	70	30	180
	30	140	40	30	240
	160	75	75	25	335
Small grains	20	30	60	40	150
	25	35	65	40	165
Maize (grain)	30	50	60	40	180
	25	40	45	30	140
	20	35	40	30	125
	20	35	40	30	125
	30	40	50	30	150
	30	40	50	50	170
Maize (sweet)	20	20	30	10	80
	20	25	25	10	80
	20	30	50/30	10	90
	30	30	30	103	110
	20	40	70	10	140
Millet	15	25	40	25	105
	20	30	55	35	140
Sorghum	20	35	40	30	130
	20	35	45	30	140
Rice	30	30	60	30	150
	30	30	80	40	180
Forages					
Alfafa (total)	10	30	Var.	Var.	Var.

Length of crop development stages in days					
Crop	**Initial (L_{Ini})**	**Develop. (L_{Dev})**	**Mid-season (L_{Mid})**	**Late-season (L_{Late})**	**Total**
Alfafa (1st cutting)	10	20	20	10	60
	10	30	25	10	75
Alfafa (other cuttings)	5	10	10	5	30
	5	20	10	10	45
Bermuda (seed)	10	25	35	35	105
Bermuda (hay)	10	15	75	35	135
Grass pasture	10	20	--	--	--
Sudan (1st cutting)	25	25	15	10	75
Sudan (other cuttings)	3	15	12	7	37
Sugar cane					
Sugar cane (virgin)	35	60	190	120	405
	50	70	220	140	480
	75	105	330	210	720
Sugar cane (ratoon)	25	70	135	50	280
	30	50	180	60	320
	35	105	210	70	420
Tropical fruits and trees					
Banana (1st year)	120	90	120	60	390
Banana (2nd year)	120	60	180	5	365
Pineapple	60	120	600	10	790
Grapes and berries					
Grape	20	40	120	60	240
	20	50	75	60	205
	20	50	90	20	180
	30	60	40	80	210
Hop	25	40	80	10	155
Fruit trees					
Citrus	60	90	120	95	365
Deciduous orchard	20	70	90	30	210
	20	70	120	60	270
	30	50	130	30	240
Olive	30	90	60	90	270
Pistachios	20	60	30	40	150
Walnut	20	10	130	30	190

Source: B.C. Allen-L.S. Pereira-D. Raes-M. Smith (1988), Crop evapotranspiration-Guidelines for computing crop water requirement, FAO, Rome

In summary, the calculation of the irrigation water need includes three steps:

- Climate and reference crop evapo-transpiration determines the water need for the reference crop, in this case for standard grass.
  - **Climate** and **Reference crop** → **Reference crop water need**

- The water need for reference crop with the crop type and growth stage determines the crop water need.
  - **Reference crop water need** and **Crop type** + **stage** → **Crop water need**

- The difference between crop water need and precipitation will be the amount of water, which is needed as irrigation water need.

- **Crop water need** – **Precipitation** = **Irrigation water need**

3.4 Calculate Reference Crop Evapo-transpiration

There are different methods to calculate the reference crop evapo-transpiration (ETo). Many scientists tried to establish the most accurate way to measure ETo. This manual describes two of them.

3.4.1 Blaney-Criddle method for the establishment of ETo

It is a theoretical method, which allows one to calculate ETo when measured data on evaporation is not available. Its accuracy is questionable and it can be considered more as a rough estimation than accurate data. The under or overestimated data can fluctuate between a range of 40-60%.

Equation

$T_{max} = (T_{max1}+T_{max2}+…+T_{maxn}) / n$

Where,

T_{max} = Average monthly maximum temperature

T_{max1} = Daily maximum temperature

n = Number of days of the month

$T_{min} = (T_{min1}+T_{min2}+…+T_{minn}) / n$

Where,

T_{min} = Average monthly minimum temperature

T_{min1} = Daily minimum temperature

n = Number of days of the month

$T_{mean} = (T_{max} + T_{min}) / 2$

Where,

T_{mean} = Average monthly temperature

T_{max} = Average monthly maximum temperature

T_{min} = Average monthly minimum temperature

$ETo = p \times ([0.46 \times T_{mean}] + 8)$

Where,

ETo = Reference crop evapotranspiration

p = Daily percentage of annual daytime hours

T_{mean} = Average monthly temperature

Photo 2 Instruments to measure temperature and air relative humidity

Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

Table 6 Daily percentage of annual daytime hours for different latitudes (p)

Latitude North												
Latitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
60º	0.15	0.20	0.26	0.32	0.38	0.41	0.40	0.34	0.28	0.22	0.17	0.13
55º	0.17	0.21	0.26	0.32	0.36	0.39	0.38	0.33	0.28	0.23	0.18	0.16
50º	0.19	0.23	0.27	0.31	0.34	0.36	0.35	0.32	0.28	0.24	0.20	0.18
45º	0.20	0.23	0.27	0.30	0.34	0.35	0.34	0.32	0.28	0.24	0.21	0.20
40º	0.22	0.24	0.27	0.30	0.32	0.34	0.33	0.31	0.28	0.25	0.22	0.21
35º	0.23	0.25	0.27	0.29	0.31	0.32	0.32	0.30	0.28	0.25	0.23	0.22
30º	0.24	0.25	0.27	0.29	0.31	0.32	0.31	0.30	0.28	0.26	0.24	0.23
25º	0.24	0.26	0.27	0.29	0.30	0.31	0.31	0.29	0.28	0.26	0.25	0.24
20º	0.25	0.26	0.27	0.28	0.29	0.30	0.30	0.29	0.28	0.26	0.25	0.25
15º	0.26	0.26	0.27	0.28	0.29	0.29	0.29	0.28	0.28	0.27	0.26	0.25
10º	0.26	0.27	0.27	0.28	0.28	0.29	0.29	0.28	0.28	0.27	0.26	0.26
5º	0.27	0.27	0.27	0.28	0.28	0.28	0.28	0.28	0.28	0.27	0.27	0.27
0º	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27

Latitude South												
Latitude	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
60º	0.15	0.20	0.26	0.32	0.38	0.41	0.40	0.34	0.28	0.22	0.17	0.13
55º	0.17	0.21	0.26	0.32	0.36	0.39	0.38	0.33	0.28	0.23	0.18	0.16
50º	0.19	0.23	0.27	0.31	0.34	0.36	0.35	0.32	0.28	0.24	0.20	0.18
45º	0.20	0.23	0.27	0.30	0.34	0.35	0.34	0.32	0.28	0.24	0.21	0.20
40º	0.22	0.24	0.27	0.30	0.32	0.34	0.33	0.31	0.28	0.25	0.22	0.21
35º	0.23	0.25	0.27	0.29	0.31	0.32	0.32	0.30	0.28	0.25	0.23	0.22
30º	0.24	0.25	0.27	0.29	0.31	0.32	0.31	0.30	0.28	0.26	0.24	0.23
25º	0.24	0.26	0.27	0.29	0.30	0.31	0.31	0.29	0.28	0.26	0.25	0.24
20º	0.25	0.26	0.27	0.28	0.29	0.30	0.30	0.29	0.28	0.26	0.25	0.25
15º	0.26	0.26	0.27	0.28	0.29	0.29	0.29	0.28	0.28	0.27	0.26	0.25
10º	0.26	0.27	0.27	0.28	0.28	0.29	0.29	0.28	0.28	0.27	0.26	0.26
5º	0.27	0.27	0.27	0.28	0.28	0.28	0.28	0.28	0.28	0.27	0.27	0.27
0º	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27

Source: C. Brouwer-A. Goffeau-M. Heibloem, (1985), Irrigation water management, FAO, Rome

3.4.2 Pan evaporation method for the establishment of ETo

Photo 3 Class A Evaporation Pan

Source: F. Sandor (2008), RoP Jalalabad, Afghansitan

Evaporation pans provide much more accurate information about the reference crop evapotranspiration. There are two types of evaporation pans, which are used more commonly. The *Class A evaporation pan* is a circular pan (120.7 cm x 25 cm) and the *Sunken Colorado pan* is a square pan (46 cm x 92 cm x 92 cm). The Class A evaporation pan is placed 5 cm above the surface and the Sunken Colorado pan is placed into the soil at a depth of 41 cm. Evaporation pans provide a measurement of combined effects such as temperature, humidity, wind speed and sunshine. The pan is filled with water. After 24 hours, the remaining quantity of water is measured. The difference between the original quantity and the measured one after 24 hours is the pan evaporation (E_{pan}). This value multiplied with the pan coefficient (K_{pan}) will give the value of the evapo-transpiration (ETo).

Equation

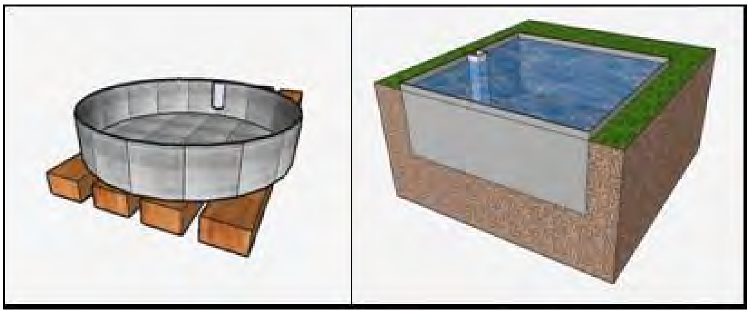
$E_{pan} = V_1 - V_2$
Where,
E_{pan} = Pan evaporation
V_1 = Original depth of water in mm
V_2 = Water depth after 24 hours in mm

$ETo = K_{pan} \times E_{pan}$
Where,
ETo = Evapotranspiration
K_{pan} = Pan coefficient
E_{pan} = Pan evaporation

The *pan coefficient* value equal to:

Class A Evaporation Pan = Between 0.35 and 0.85; Average: 0.70
Colorado Sunken Pan = Between 0.45 and 1.10; Average: 0.80

Figure 7 The class A and Colorado Sunken Evaporation Pan



Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

3.5 Calculate Crop Water Need

Each and every crop has a specific evapo-transpiration rate. This rate can be calculated from the reference crop evapo-transpiration rate (ETo). The relationship between the reference crop and a specific crop is given by the crop factor (K_c) and expressed in mm/day or month.

Equation

$ET_{crop} = K_c \times ETo$
Where,
ET_{crop} = Crop water need
K_c = Crop factor
ETo = Reference crop evapotranspiration

Table 7 Approximate K_c values of different types of groundcover

Vegetation	Low	High	Average
Trees	0.2	0.9	0.50
Shrubs	0.2	0.7	0.50
Ground cover	0.2	0.9	0.50
Mixed	0.2	0.9	0.50
Turf grass	0.3	0.9	0.75

Source: G. Connellan-P. Symus (2006), The development and evaluation of landscape coefficients, Melbourn, Australia

The crop factor varies during the growing period of the plant. According to the length of the crop development stages, three crop factor values are required to describe the value of the crop water need. They are those during the initial, mid-season and late season stages. Tabulated, specific K_c values for different crops and plants are shown in table below.

Table 8 Crop coefficients and maximum heights of crops

Single (Time-averaged) crop coefficients and maximum height of crops				
Crop	**$K_{initial}$**	**K_{mid}**	**K_{late}**	**Height (m)**
Small vegetables	**0.7**	**1.05**	**0.95**	
Broccoli	-	1.05	0.95	0.3
Brussel sprouts	-	1.05	0.95	0.4
Cabbage	-	1.05	0.95	0.4
Carrot	-	1.05	0.95	0.3
Cauliflower	-	1.05	0.95	0.4
Celery	-	1.05	1.00	0.6
Garlic	-	1.00	0.70	0.3
Lettuce	-	1.00	0.95	0.3
Onion (dry)	-	1.05	0.75	0.4
Onion (green)	-	1.00	1.00	0.3
Onion (seed)	-	1.05	0.80	0.5
Spinach	-	1.00	0.95	0.3
Radish	-	0.90	0.85	0.3
Solenaceae family	***0.60***	***1.15***	***0.80***	
Egg plant		1.05	0.90	0.8
Sweet pepper		1.05	0.90	0.7
Tomato		1.15	0.70-0.90	0.6
Cucurbitaceae family	***0.50***	***1.00***	***0.80***	
Cantaloupe	0.50	0.85	0.60	0.3
Cucumber (fresh market)	0.60	1.00	0.75	0.3
Cucumber (machine harvest)	0.5	1.00	0.90	0.3
Pumpkin, Winter squash	-	1.00	0.80	0.4
Squash, Zucchini	-	0.95	0.75	0.3
Sweet melon	-	1.05	0.75	0.4
Watermelon	0.40	1.00	0.75	0.4
Roots and Tubers	***0.50***	***1.10***	***0.95***	
Beets	-	1.05	0.95	0.4
Cassava 1st year	0.30	0.80	0.30	1.0
Cassava 2nd year	0.30	1.10	0.50	1.5
Parsnip	0.50	1.05	0.95	0.4
Potato	-	1.15	0.75	0.6

Single (Time-averaged) crop coefficients and maximum height of crops				
Crop	$K_{initial}$	K_{mid}	K_{late}	Height (m)
Sweet potato	-	1.15	0.65	0.4
Turnip	-	1.10	0.95	0.6
Sugar beet	0.35	1.20	0.70	0.5
Leguminoseae family	***0.40***	***1.15***	***0.55***	
Bran green	0.50	1.15	0.90	0.4
Bean dry	0.40	1.15	0.35	0.4
Chick pea	-	1.00	0.35	0.4
Broad bean fresh	0.50	1.15	1.10	0.8
Broad bean dry	0.50	1.15	0.30	0.8
Garbanzo	0.40	1.15	0.35	0.8
Cowpea, Green gram	-	1.05	0.60-0.35	0.4
Peanut	-	1.15	0.60	0.4
Lentil	-	1.00	0.3	0.5
Pea fresh	0.50	1.15	1.10	0.5
Pea dry	-	1.15	0.30	0.5
Soya bean	-	1.15	0.50	0.5-1.0
Perennial vegetables	***0.50***	***1.00***	***0.80***	
Artichoke	0.50	1.00	0.95	0.7
Asparagus	0.50	0.95	0.30	0.2-0.8
Mint	0.60	1.15	1.10	0.6-0.8
Strawberry	0.40	0.85	0.75	0.2
Fibre crops	***0.35***			
Cotton	-	1.15-1.20	0.70-0.50	1.2-1.5
Flax	-	1.10	0.25	1.2
Sisal	-	0.40-0.70	0.40-0.70	1.5
Oil crops	***0.35***	***1.15***	***0.35***	
Castor bean	-	1.15	0.55	0.3
Rape seed, Canola	-	1.0-1.15	0.35	0.6
Safflower	-	1.0-1.15	0.25	0.8
Sesame	-	1.10	0.25	1.0
Sunflower	-	1.0-1.15	0.35	2.0
Cereals	***0.30***	***1.15***	***0.40***	
Barley	-	1.15	0.25	1.0
Oat	-	1.15	0.25	1.0
Spring wheat	-	1.15	0.40-0.25	1.0
Winter wheat (frozen soil)	0.40	1.15	0.40-0.25	1.0
Winter wheat (non- frozen soil)	0.70	1.15	0.40-0.25	1.0
Maize grain	-	1.20	0.60-0.35	2.0
Maize sweet	-	1.15	1.05	1.5
Millet	-	1.00	0.30	1.56
Sorghum grain	-	1.00-1.10	0.55	1.0-2.0
Sorghum sweet	-	1.20	1.05	2.0-4.0
Rice	1.05	1.20	0.90-0.60	1.0
Forages	***-***	***-***	***-***	
Alfafa hay (average cutting)	0.40	0.95	0.90	0.7
Alfafa hay (individual cutting)	0.40	1.20	1.15	0.7
Alfafa hay (seed)	0.40	0.50	0.50	0.7
Bermuda (average cutting)	0.55	1.00	0.85	0.4
Bermuda (seed)	0.35	0.90	0.65	0.4

Single (Time-averaged) crop coefficients and maximum height of crops				
Crop	$K_{initial}$	K_{mid}	K_{late}	Height (m)
Clover (average cutting)	0.40	0.90	0.85	0.6
Clover (individual cutting)	0.40	1.15	1.10	0.6
Berseem (average cutting)	0.40	0.90	0.85	0.6
Berseem (individual cutting)	0.40	1.15	1.10	0.6
Rye grass	0.95	1.05	1.00	0.3
Sudan (average cutting)	0.50	0.90	0.85	1.2
Sudan (individual cutting)	0.50	1.15	1.10	1.2
Grazing pasture (rotated)	0.40	0.85-1.05	0.85	0.2-0.3
Grazing pasture (extensive)	0.30	0.75	0.75	0.1
Turf (cool season)	0.90	0.95	0.95	0.1
Turf (warm season)	0.80	0.85	0.85	0.1
Sugar Cane	***040***	***1.25***	***0.75***	***3.0***
Sugar cane	040	1.25	0.75	3.0
Tropical fruits and trees				
Banana 1st year	0.50	1.10	1.00	3.0
Banana 2nd year	1.00	1.20	1.10	4.0
Cacao	1.00	1.05	1.05	3.0
Coffee bare ground	0.90	0.95	0.95	2.0-3.0
Coffee weed ground cover	1.05	1.10	1.10	2.0-3.0
Date palm	0.90	0.95	0.95	8.0
Palm trees	0.95	1.00	1.00	8.0
Pineapple bare soil	0.50	0.30	0.30	0.6-1.2
Pineapple grass cover	0.50	0.50	0.50	0.6-1.2
Rubber tree	0.95	1.00	1.00	10.0
Tea non-shaded	0.95	1.00	1.00	1.5
Tea shaded	1.10	1.15	1.15	2.0
Grapes and Berries				
Berries	0.30	1.05	0.50	1.5
Grape table	0.30	0.85	0.45	2.0
Grape wine	0.30	0.70	0.45	1.5-2.0
Hops	0.30	1.05	0.85	5.0
Fruit trees				
Almond, no ground cover	0.40	0.90	0.65	5.0
Apple no cover, frost	0.45	0.95	0.70	4.0
Apple no cover, no frost	0.60	0.95	0.75	4.0
Apple active cover, frost	0.50	1.20	0.95	4.0
Apple active cover, no frost	0.80	1.20	0.85	4.0
Apple no cover, frost	0.45	0.95	0.70	4.0
Apple no cover, no frost	0.60	0.95	0.75	4.0
Apple active cover, frost	0.50	1.20	0.95	4.0
Apple active cover, no frost	0.80	1.20	0.85	4.0
Cherry no cover, frost	0.45	0.95	0.70	4.0
Cherry no cover, no frost	0.60	0.95	0.75	4.0
Cherry active cover, frost	0.50	1.20	0.95	4.0
Cherry active cover, no frost	0.80	1.20	0.85	4.0
Pear no cover, frost	0.45	0.95	0.70	4.0
Pear no cover, no frost	0.60	0.95	0.75	4.0
Pear active cover, frost	0.50	1.20	0.95	4.0
Pear active cover, no frost	0.80	1.20	0.85	4.0
Apricot no cover, frost	0.45	0.90	0.65	3.0

Single (Time-averaged) crop coefficients and maximum height of crops				
Crop	**$K_{initial}$**	**K_{mid}**	**K_{late}**	**Height (m)**
Apricot no cover, no frost	0.55	0.90	0.65	3.0
Apricot active cover, frost	0.50	1.15	0.90	3.0
Apricot active cover, no frost	0.80	1.15	0.85	3.0
Peach no cover, frost	0.45	0.90	0.65	3.0
Peach no cover, no frost	0.55	0.90	0.65	3.0
Peach active cover, frost	0.50	1.15	0.90	3.0
Peach active cover, no frost	0.80	1.15	0.85	3.0
Stone fruit no cover, frost	0.45	0.90	0.65	3.0
Stone fruit no cover, no frost	0.55	0.90	0.65	3.0
Stone fruit active cover, frost	0.50	1.15	0.90	3.0
Stone fr. active cover, no frost	0.80	1.15	0.85	3.0
Avocado. No ground cover	0.60	0.85	0.75	3.0
Citrus, no cover, 70% canopy	0.70	0.65	0.70	4.0
Citrus, no cover, 50% canopy	0.65	0.60	0.65	3.0
Citrus, no cover, 20% canopy	0.50	0.45	0.55	2.0
Citrus, cover, 70% canopy	0.75	0.70	0.75	4.0
Citrus, cover, 50% canopy	0.80	0.80	0.80	3.0
Citrus, cover, 20% canopy	0.85	0.85	0.85	2.0
Conifer trees	1.00	1.00	1.00	10.0
Kiwi	0.40	1.05	1.05	3.0
Olive	0.65	0.70	0.70	3.0-5.0
Pistachios	0.40	1.10	0.45	3.0-5.0
Walnut	0.50	1.10	0.65	4.0-5.0

Source: B.C. Allen-L.S. Pereira-D. Raes-M. Smith (1988), Crop evapotranspiration-Guidelines for computing crop water requirement, FAO, Rome

3.6 Establish Irrigation Water Need

The crop water need can be covered by rainfall, by irrigation or by the combination of both, rainfall and irrigation. If the rainfall is able to cover the crop water need, the *irrigation water need* (IN = 0) will be equal to zero. In most cases, however, the rainfall is not sufficient and irrigation is necessary. Sometimes, there is no rainfall at all and all crop water need may covered by irrigation (IN = ETo).

From rainfall, only the effective rainfall is available for plant growth, which is stored in the crop root zone. Water, which evaporates or stagnates on the surface, runs off and deep percolation losses means this water will be unavailable for plant growth. Therefore, the irrigation water need will be equal to the crop water need minus effective rainfall (effective precipitation).

Equation

Effective rainfall value is always $Pe \geq 0$

$P_e = 0.8 \times P - 25$ if $P > 75$mm/month and maximum land slope ≤ 5%
$P_e = 0.6 \times P - 10$ if $P < 75$mm/month and maximum land slope ≤ 5%
Where,
P_e = Effective rainfall
P = Total rainfall

$IN = ET_{crop} - P_e$
Where,
IN = Irrigation water need in mm/month or mm/day

ET_{crop} = Crop water need
P_e = Effective rainfall

Equation

The calculation of effective rainfall also uses commonly the following equation:

$P_e = P – 5$
Where,
P_e = Effective rainfall
P = Total rainfall

3.7 Landscape Water Requirement

More accurate calculations require the consideration of other climatic and crop factors separate from ETo and K_c. The *landscape water use* (ET_L) equation uses the landscape coefficient (K_L) to calculate a more accurate water need from the reference crop evapo-transpiration value. The landscape coefficient includes not only the crop coefficient (K_c), but also the density factor (K_d) and microclimate factor (K_{mc}).

Equation

$K_L = K_c \times K_d \times K_{mc}$
Where,
K_L = Landscape coefficient
K_c = Crop coefficient
K_d = Density factor
K_{mc} = Microclimate factor
$ET_L = ETo \text{ X } K_L$
Where,
ET_L = Landscape water use
K_L = Landscape coefficient

In this case the Irrigation water need uses the following equation:

$IN = ET_L – P_e$
Where,
IN = Irrigation water need in mm/month or mm/day (same that Irrigation water requirement [IR])
ET_L = Landscape water use
P_e = Effective rainfall

3.8 Turf Water Management

This is applied for turf areas, which involve an additional factor in the calculation. It is not applied to landscape plants. The inclusion of this factor allows saving water for irrigation with a minimum level of stress. A management factor of 70% can be applied for turf grass.

Equation

$ET_{TURF} = ET_L \times K_m$
Where,
ET_{TURF} = Evapo-transpiration turf in mm
ET_L = Landscape water use in mm
K_m = Management factor

4 Irrigation System

An irrigation system consists of 4 main components:

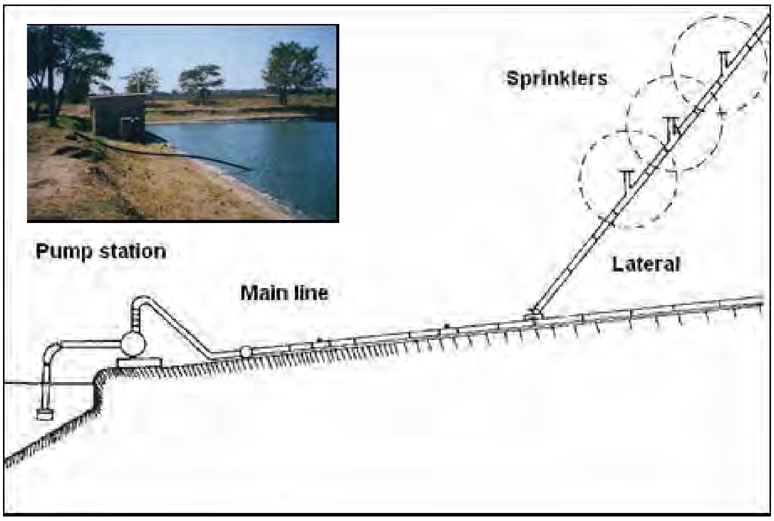
- Intake structure and pumping station: This is the structure which diverts the water from its source to a water reserve or directly to the field if the field application system uses gravity force.

- Conveyance and distribution systems: Conveyance is the structure which transports the water from the main intake structure to the field. The distribution systems are canals, ditches or pipe lines, which transport the water to the irrigated field.

- Field application system: These are the different irrigation methods

- Drainage system: The drainage system removes the excess water from the field.

Figure 8 Irrigation system



Source: D. Brasil Vieira (1989), As Tecnicas de Irrigacao, Sao Paulo, Brasil

4.1 Conveyance and Distribution System

The distribution and drainage system can use canals or pipe lines. When canals are used, the water transport requires extrict controls and measurements of the water flow.

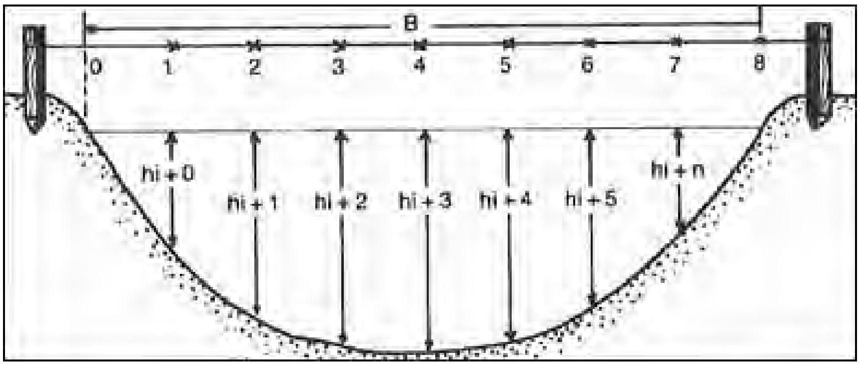
4.1.1 The body of the canal

Usually, open canal systems are used in this practice. A canal has several components. The measurement of these components provides a description about the characteristics of the canal:

- Top of the canal
- Top of the water level
- Height of the canal
- Depth of the water
- Bottom of the canal
- Side slope of the canal

- Free side board
- Bottom slope of the canal

Figure 9 Canal cross section



Source: D. Brasil Vieira (1989), As Tecnicas de Irrigacao, Sao Paulo, Brasil

The bottom slope of the canal can be calculated in two ways:

- Bottom slope (%) = Elevation of the canal / Horizontal distance x 100
- Bottom slope ($^{o}/_{oo}$) = Elevation of the canal / Horizontal distance x 1000

4.1.2 Distribution box

Photo 4 Water canal

Source: F. Sandor (2002), Domasi, Malawi

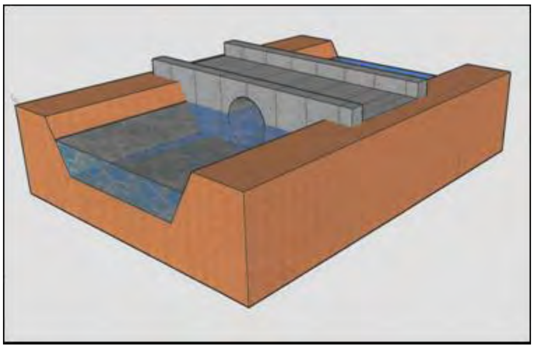
Canals are connected with distribution boxes, which divide the water between canals and redirect water flow. The boxes often use gates to redirect the flow.

4.1.3 Turnout

A Turnout is a structure or pipe, which breaks through the bank and diverts water from one canal to another or from the water reserve to the canal.

4.1.4 Crossing and water flow measuring structures

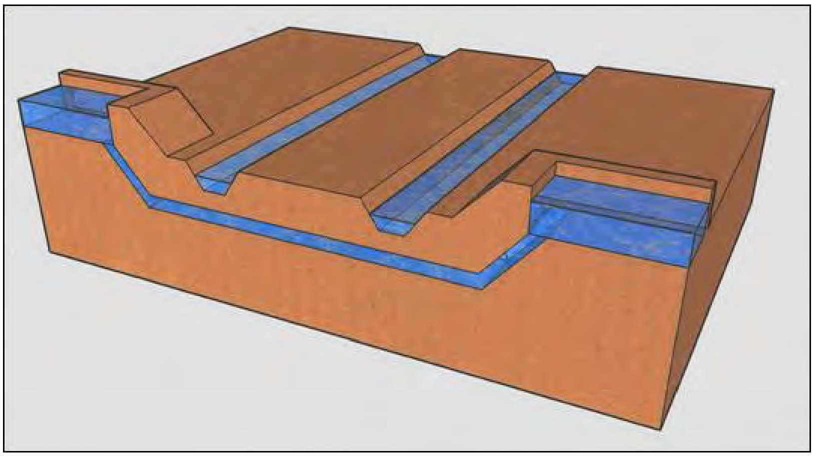
Figure 10 Culvert



Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

There are two types. The culvert consists of headwalls at both sides of the road connected by a pipe line buried under the road. The inverted siphon is a pipe line that connects the inlet and outlet of both sides of the road. This applies to a situation in which the road is at the same level or below the bottom of the canal.

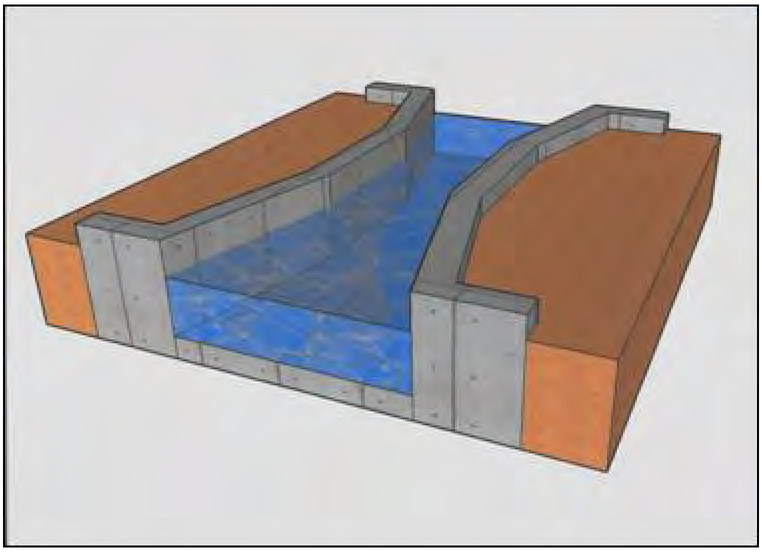
Figure 11 Inverted Siphon cross section



Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

4.1.5 Flume

Figure 12 Flume



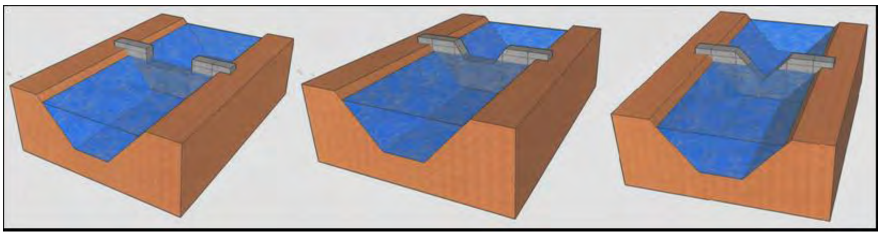
Source: F. Sandor (2008), RoP, Jalalabad, Afghansitan

A Flume is an open artificial water channel that leads water from a diversion dam or weir completely aside a natural flow (often an elevated box structure, typically wood) that follows the natural contours of the land. Often it is used to allow water to cross guillies. It is constructed of wood, bamboo, metal or concrete, which usually needs to be supported by pillars. It is also used to measure water flow (Parshall fume, Cut-throat flume, Rectangular fume, U fume, Trapezoidal flume).

4.1.6 Weir

Weirs are constructed in open channels to determine a certain water flow rate. There are three types: Rectangular, V Notch (Triangular) and Cipoletti (Trapezoidal). It is basically a wall constructed in the canal with fixed dimensions cut in the edge. The opening is the notch. The different types receive their name from the shape of the notch.

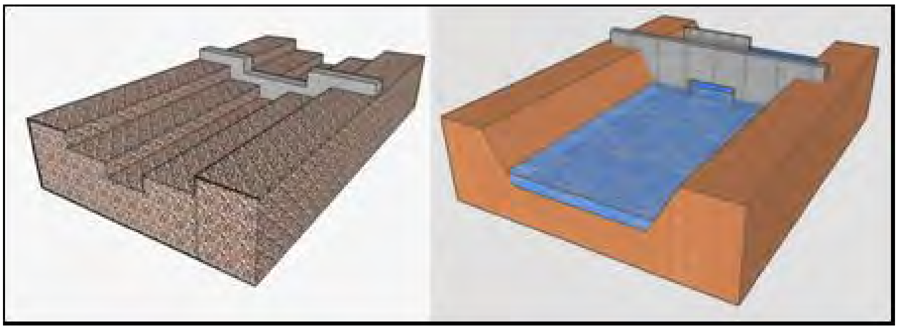
Figure 13 Main types of weir



Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

4.1.7 Check

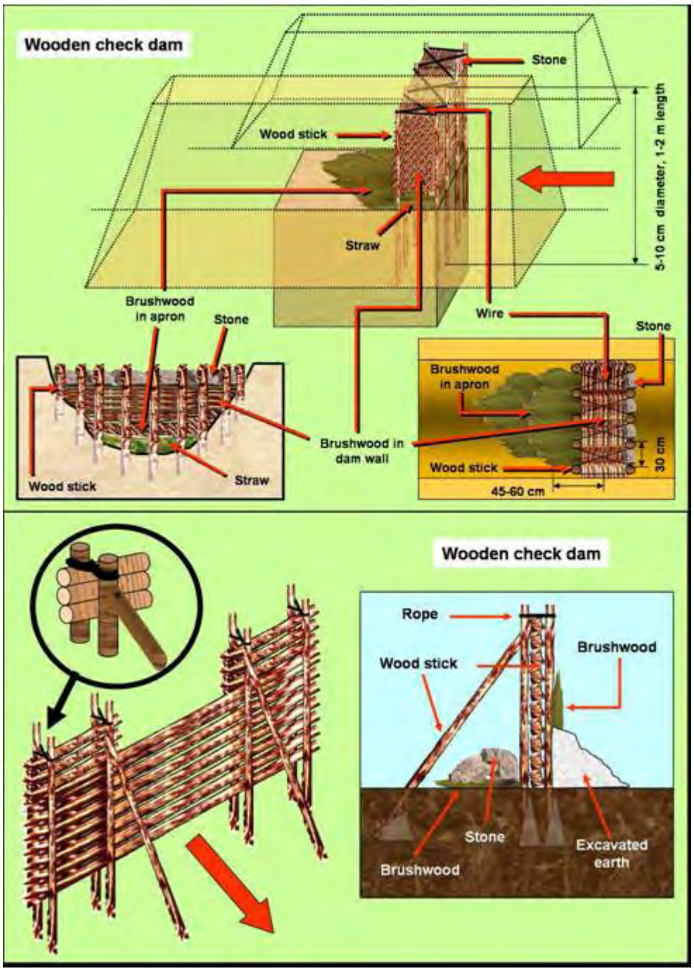
Figure 14 Concrete and Metal Check structure



Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

Checks are structures designed to raise water levels up and divert it from the field ditch to the field. It can be a permanent structure but it also can be portable. There are many different types of checks (Woven bamboo or stick check, Wooden check, Alternative wooden check, Sand bag chack, Stone and wire netting check, Stone check, Metal check, Concrete check). Checks also can be used for canal erosion control for earth canals and gully control.

Figure 15 Wooden Check Dams

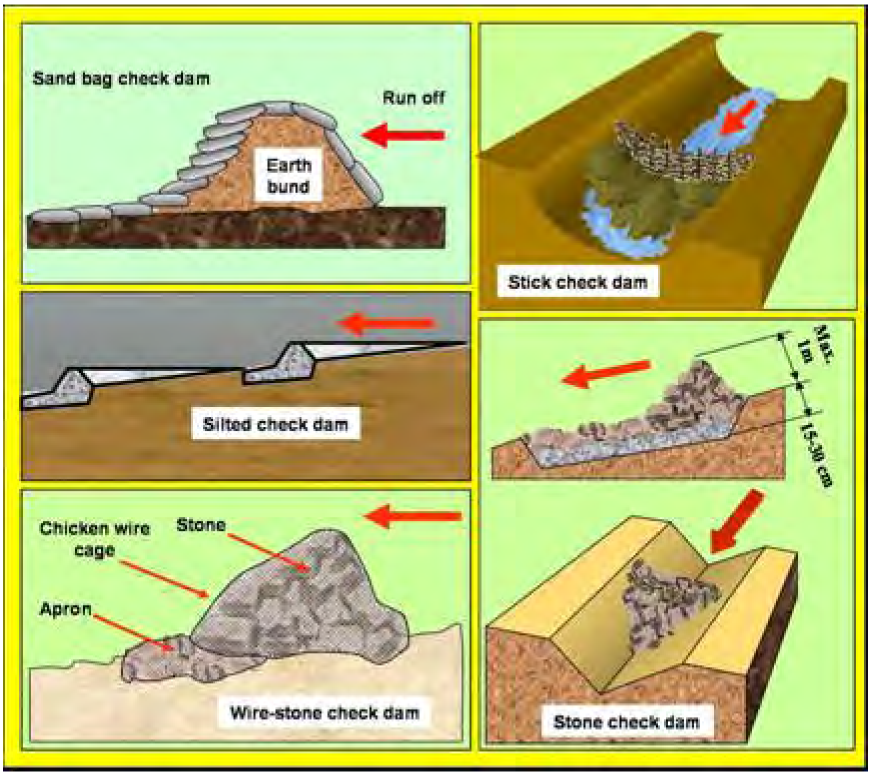


Source: F. Sandor (2007), PRI Prison Farms Manual, Lilongwe, Malawi

4.2 Canal Erosion Control Structures

There are two main types of erosion control: The control of the canal head (inlet) and the control of the canal body. For the canal head erosion control, drop head structures are used, which can be wooden, stone, sand bag or concrete head drop structures.

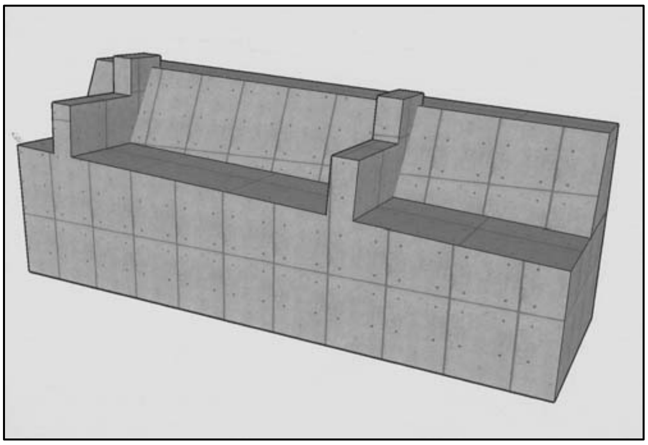
Figure 16 Different types of erosion control methods



Source: F. Sandor (2007), PRI Prison Farms Manual, Lilongwe, Malawi

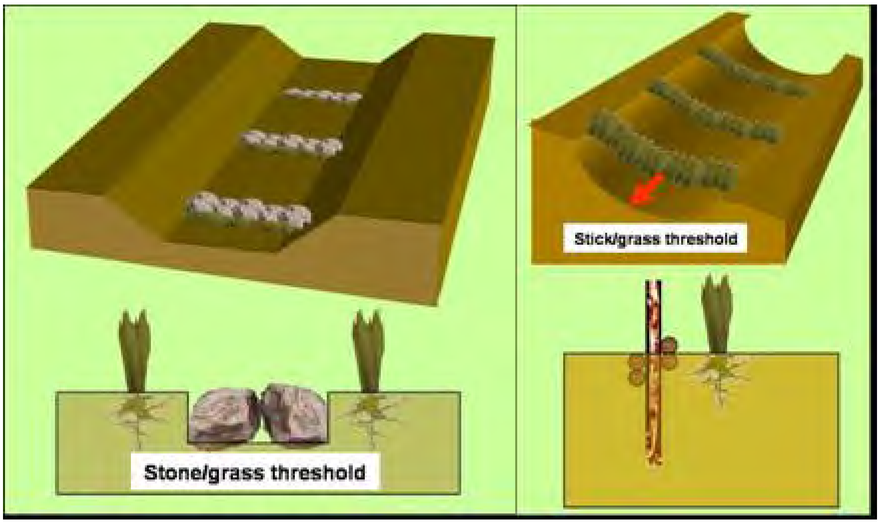
For the canal body erosion control, different methods and structures are used. Thresholds are strips of erosion resistant materials aligned across the water flow. The previously mentioned check dams or live check dams can also be used (Vertiver grass) as well as silted check dams, which make a series of steps down the canal. These series of control structures in the canal form the drop structures. Chutes are steep and lined within the canal sections, where the water cannot drop freely.

Figure 17 Canal drop structure



Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

Figure 18 Thresholds to control the body of the canal



Source: F. Sandor (2007), PRI Prison Farms Manual, Lilongwe, Malawi

5 Irrigation Methods

5.1 Field Application System

Photo 5 Water reserve

Source: F. Sandor (2002), Domasi, Malawi

Irrigation is an artificial way to add water into the soil with the purpose to support plant growth. As an artificial extra water source, it disturbs the natural hydrologic cycle, because it reduces the volume of water in the original source and relocates it on the crop field. Water also carries other components, such as salt, minerals, etc. Therefore with the removal and transfer of the water, these components are also relocated from their original places. Irrigation changes the balance of soil hydration by generating an extra supply of water; this supply is always associated with a contribution of salts. The amount of salts in the water may seem negligible, but the amounts of water brought in by irrigation leads to a cumulative deposit of salts in the soil which can turn out to be considerable. Pure water is lost through evaporation but the salts remain in the soil. Irrigation reduces the flow of water without reducing the flow of salts; therefore it generates a process of salt concentration. Therefore the method, volume, time and frequency of irrigation should be chosen carefully to avoid further degradation in the farm ecosystem. Water and soil conservation are the leading concepts for irrigation practices. There are many ways to irrigate farmland. The following table shows the categories for the different irrigation methods.

Table 9 Summary table of irrigation methods

No.	System	Method	Sub-method
1	Surface irrigation (Flood)	Basin irrigation	Level direct
			Contour direct
			Levee cascade
			Contour levee cascade
		Furrow irrigation	Graded furrow
			Contour furrow
			Level furrow
			Corrugation
			Snake irrigation
		Border irrigation	Graded border
			Level border
			Contour levee
			Contour ditch
2	Localized irrigation	Continuously recharged	Micro-sprinkler irrigation
			Bubbler irrigation
			Drip irrigation
			Subsurface drip irrigation
		Manually recharged	Sanken bed irrigation
			Bottle or pot irrigation
3	Overhead irrigation	Solid set irrigation	Sprinkler Rotor Gun
		Traveling overhead irrigation	
		Center pivot irrigation	Gooseneck sprinkler irrigation
			Sprinkler irrigation
		Wheel line irrigation	Sprinkler
		Manual irrigation	Housepipe
4	Sub-irrigation	Field seepage irrigation	
		Greenhouse sub-irrigation	

Source: F. Sandor (2008), Roots of Peace, Jalalabad, Afghanistan

5.2 Surface Irrigation

Surface irrigation is applied by gravity and the water flows on the surface. There are three types of surface irrigation:

- Basin irrigation technique, where the entire field is flooded
- Furrow irrigation technique, where the water flows in furrow channels between ridges
- Border irrigation technique, where the water flows in long strips separated by bunds. Basins are as long as wide approximately, and borders are several times longer than wide.

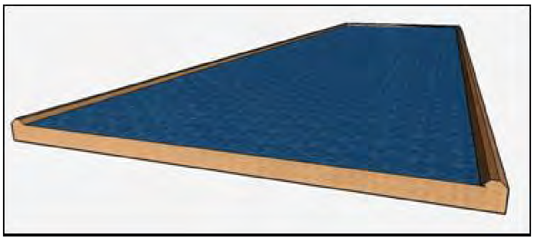
5.2.1 Basin irrigation

Photo 6 Basins for irrigation

Source: F. Sandor (2008), Jalalabad, Afghanistan

Basin irrigation is not suitable for the production of all kinds of crops. Plants, which cannot stand wet and waterlogged conditions for over a period of 24 hours, are not suitable for this irrigation technique. Other plants, like rice, pasture, covering crops like alfalfa, and trees such as citrus trees are perfectly suitable for basin irrigation.

Figure 19 Level basin structure



Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

There are two types of basins. A *level basin* has a regular shaped, leveled surface area, where the water is uniformly distributed up to the same depth across the field. The water level is controlled by the bunds of the basin (*Dikes*).

The *contour-levee basins* are areas bounded by small contour and cross levees following the main contour lines of the field.

Figure 20 Contour-levee basin

Source: SCC (1991), National Engineering Handbook, USA

The shape and size of the basin always depends on the following:

- The topography of the area, especially the land slope and its declination angle
- The soil type and soil texture
- The required depth for irrigation vs. available water
- The agricultural practices

Meanwhile flat lands allow for a bigger basin size; farm lands with a steep slope require terrace-like narrow basins to prevent the movement and relocation of large volumes of soil during layout.

As the slope percentage increases, the length of the basin should decrease gradually. However, the recommended maximum slope percentage should not pass over 4%.

Table 10 Approximate values for the maximum basin

Slope (%)	Length (m)		Slope (%)	Length (m)	
	Range	Average		Range	Average
0.0-0.2	35-55	45	1.0-1.1	15-25	20
0.3	30-45	37	1.2-1.5	10-20	17
0.4	25-40	32	1.6-1.9	10-20	13
0.5	20-35	28	2.0-2.9	5-15	10
0.6-0.7	20-30	25	3.0-3.9	5-10	7
0.8-0.9	15-30	22	4.0	3-8	5

Source: C. Brouwer-A. Goffeau-M. Heibloem, (1985), Irrigation water management, FAO, Rome

The surface area of the basin according to the soil texture and the available water volume per second is the following:

Table 11 Maximum basin areas for various soil types

Volume of water per second (l/sec)	Maximum basin surface area (m^2)			
	Sand	Sandy Loam	Clay Loam	Clay
0-5	0-35	0-100	0-200	0-350
6-10	36-60	101-200	201-400	351-650
11-15	61-100	201-300	401-600	651-1000
16-30	101-200	301-600	601-1200	1001-2000
31-60	201-400	601-1200	1201-2400	2001-4000
61-90	401-600	1201-1800	2401-3600	4001-6000

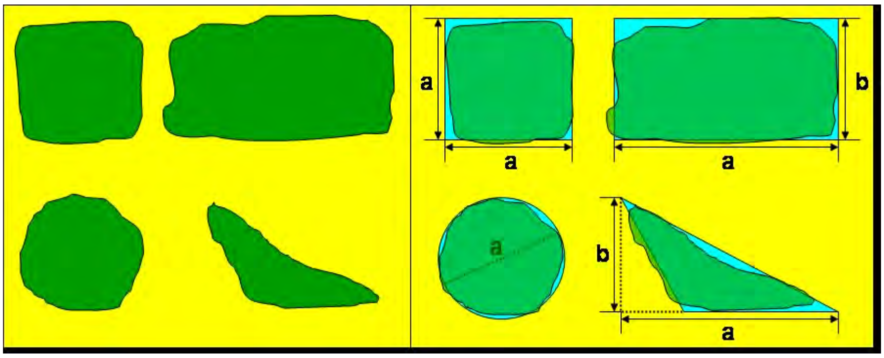
Source: C. Brouwer-A. Goffeau-M. Heibloem, (1985), Irrigation water management, FAO, Rome

The dependence of the basin surface area on the soil texture is related to the soil water holding capacity. Clayey soils water holding capacity is higher than that of the sandy soils. Therefore when using the same volume of water, clayey soil can irrigate more land into the required soil depth, than in the case of the sandy soil, where a larger volume of water will leach out from the irrigated soil layer.

5.2.1.1 Calculate the size of the basin

- Establish the length (a) according to the percentage of slope
- If the shape of the basin is a regular shape the calculation is easier after measuring the length, diameter, etc. according to the regular shape. If the required basin shape is irregular, the first step is to adapt it to the closest regular shape for measurement.
- The most common shapes are: square, rectangular, triangle and circle. The equations for area are the following:

Figure 21 Common basin shapes

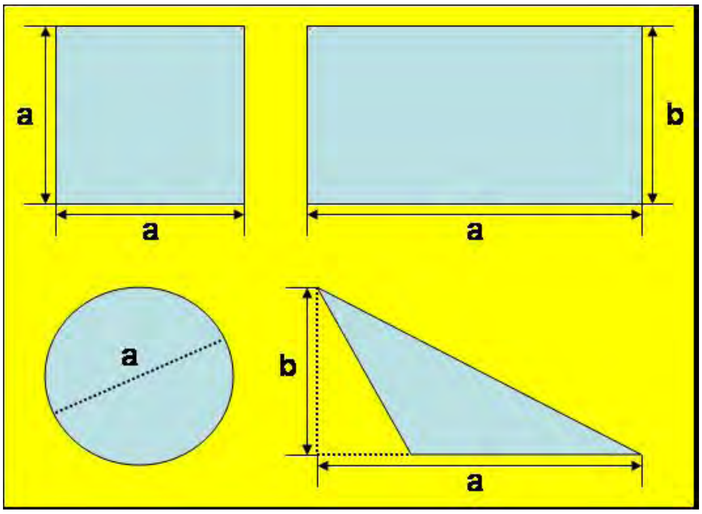


Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

Equation

- Square: $A = a^2$ (m^2), where a = length
- Rectangular: $A = a \times b$ (m^2), where a = length
- Circle: $A = r^2 \times \prod$ (m^2), where r = a/2 and $\prod = 3.14$
- Triangle: $A = (a \times b) / 2$ (m^2), where a = base

Figure 22 Common shapes



Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

- Make a comparison between the recommended surface area, according to the soil texture, and the calculated area (A). Make any necessary adjustments of changing the value of the length (a).

- Make a comparison between the recommended surface area, according to the volume of water per second, and the calculated area (A). Make any necessary adjustments of changing the value of the length (a).

This calculation serves to estimate the maximum size of the basin. The basin can be smaller than this and irrigated efficiently, but cannot be bigger than this.

5.2.1.2 Calculate the bund size of the basin

The calculation begins with the assumption that the necessary amount of irrigation water for the crop is already known. The amount of irrigation water that is needed can easily be converted to find the required irrigation depth and vice versa. Irrigation depth depends on soil texture and rooting depth of the plant. The following table helps to determine the required irrigation depth in the basin.

Table 12 Selection of irrigation methods based on the depth of the net irrigation application

Soil type	Rooting depth	Irrigation	
		Depth (mm)	Method
Sand	Shallow	20-30	Short furrows
	Medium	30-40	Medium furrows, short borders
	Deep	40-50	Long furrows, medium borders, small basins
Loam	Shallow	30-40	Medium furrows, short borders
	Medium	40-50	Long furrows, medium borders, small basins
	Deep	50-60	Long borders, medium basins
Clay	Shallow	40-50	Long furrows, medium borders, small basins
	Medium	50-60	Long borders, medium basins

Source: C. Brouwer-A. Goffeau-M. Heibloem, (1985), Irrigation water management, FAO, Rome

After establishing the required depth of irrigation, the next step is to calculate the irrigation time, which uses the following equation:

Equation

$$\text{Irrigation time} = \frac{2.78 \times \text{Irrigation depth} \times \text{Basin area}}{\text{Discharge of water}}$$

where Basin area = Surface area in m^2
Discharge of water = Volume of water per second

When the irrigation time is known, the necessary total volume of water that will be applied during this time period must be calculated.

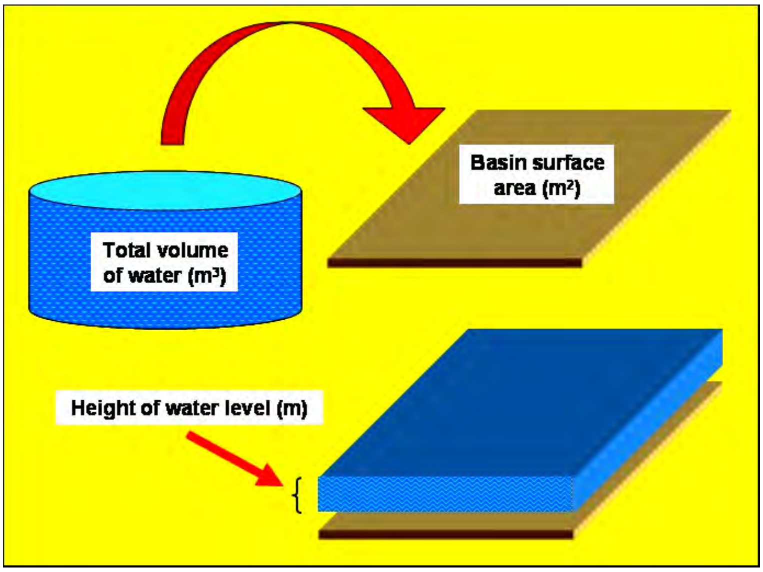
Total water volume = Irrigation time x Discharge of water
where 1 m^3 of water equal with 1,000 liters

Divide the total volume of water (m^3) with the basin surface area (m^2) to find the level inside the basin filled with water (m).

Height of water level = Total volume of water / Basin surface area

Obviously, during longer irrigation periods more water will infiltrate into the soil. Therefore the real water level always will be shorter, then the calculated amount. According to the calculated water level, the height of the basin bund should be 20-30 cm higher to avoid breach and water loss on the bund.

Figure 23 Amount of water expressed in volume and depth



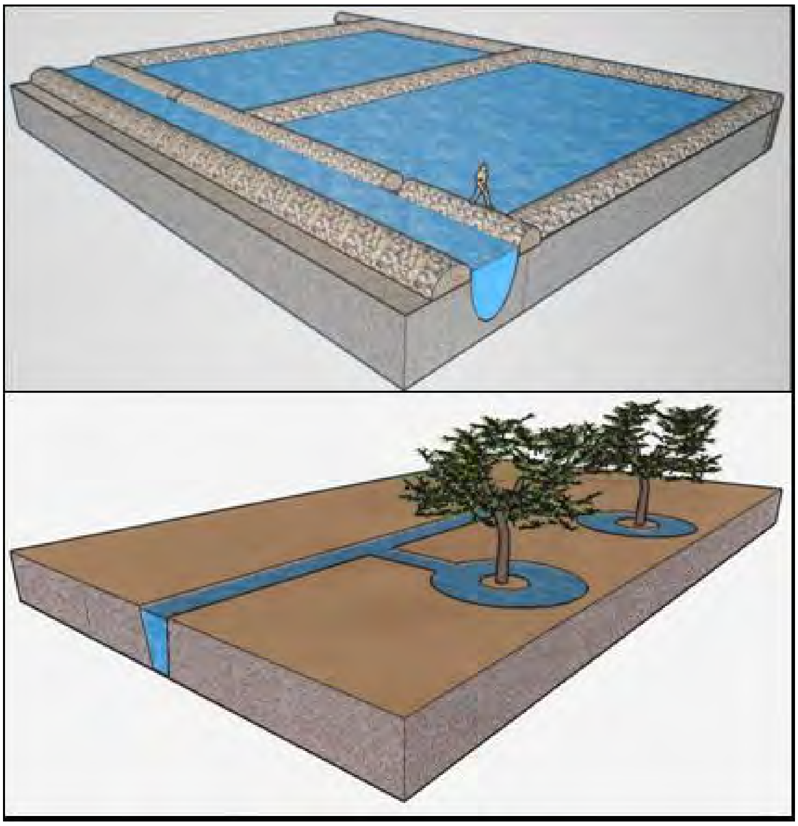
Source: F. Sandor (2008), Jalalabad, Afghanistan

5.2.1.3 Build up a basin

The shape of the basin depends a lot on the topography of the farmland. Building up a basin on flat land is relatively easy. The shape can follow regular shapes, such as square or rectangular. But sloping or undulating landscape often require irregular shapes and the consideration of the direction and descent of the slope. The basin area should be leveled. Therefore terracing is required. The basin bunds establishment varies according to the methods which were used during the bund construction. These are either contour or graded physical layouts. It also can be a mix of the two techniques. The graded physical layouts consist of bunds running on a slight gradient from the land contour, while the bunds of the contour physical layout are located along the contour lines.

The basin is set out by first locating a suitable contour line or graded line across the field. A second line is then set out along further up the slope or flat land. This activity is called “marking a graded or contour line”. In regular intervals, install pegs to show the line where the bund will be built up.

Figure 24 Basin methods for crops and fruit trees

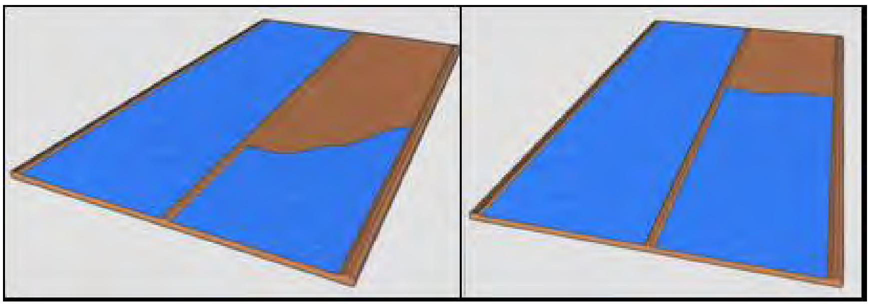


Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

Before building up the bund, the surface soil should be tilled to a 15 cm depth. After building up the bund, smooth and level out the top. Once leveled, there should not be more than 3 cm difference between any two given points of the *bund*'s top.

Finally, make sure that the soil is properly compacted in order to avoid future leakage.

Figure 25 Water flow pattern on poorly and well leveled basin surface

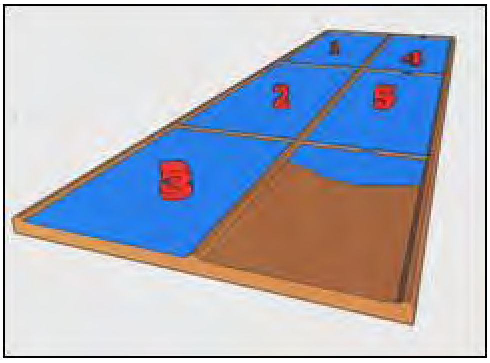


Source: F. Sandor (2208), Jalalabad, Afghanistan

Usually, there are two types of bunds in the common practice. One of them is the temporary bund, which is normally 60-120 cm wide and a height of up to 30cm and is rebuilt in each season. The other one is the permanent bund, which is 130-160 cm wide, 60-90 cm high and permanently remains on the field. Usually, permanent bunds are used for crops such as rice.

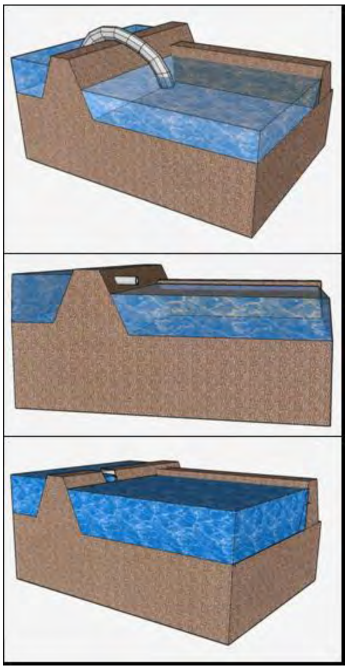
5.2.1.4 Irrigation method

Figure 26 Cascade method



Source: F. Sandor (2008),
RoP Jalalabad, Afghanistan

Figure 27 Siphon, spile and bund breach



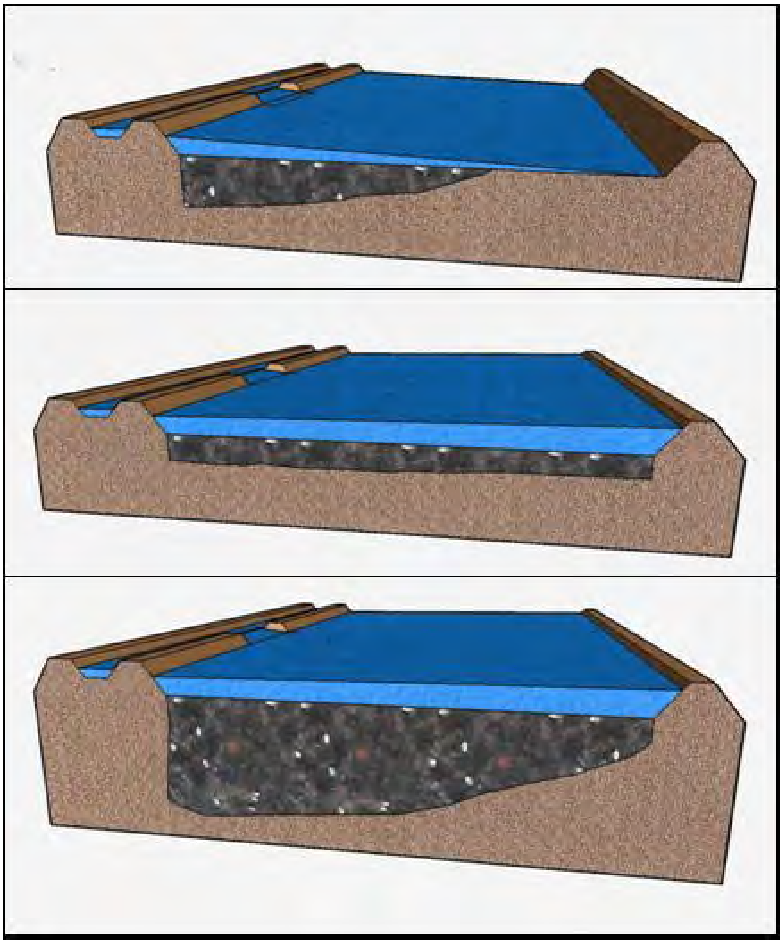
Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

Irrigation for basins can operate in two ways. One of them is called the direct method, where each basin is irrigated separately (the 1st basin is irrigated first followed by the 2nd and so on). The other option is the cascade method, where the highest basin on the slope side is irrigated first. When the water fills the first basin it will overflow and start to fill up the next lower basin and so on. When the lowest basin is filled up, close the water to the 1st basin. Irrigation water can be supplied through *siphon, spile or bund breach*.

5.2.1.5 Wetting pattern

The ideal *wetting pattern* is, when the crop root zone is wetted uniformly. The pattern depends on several factors:

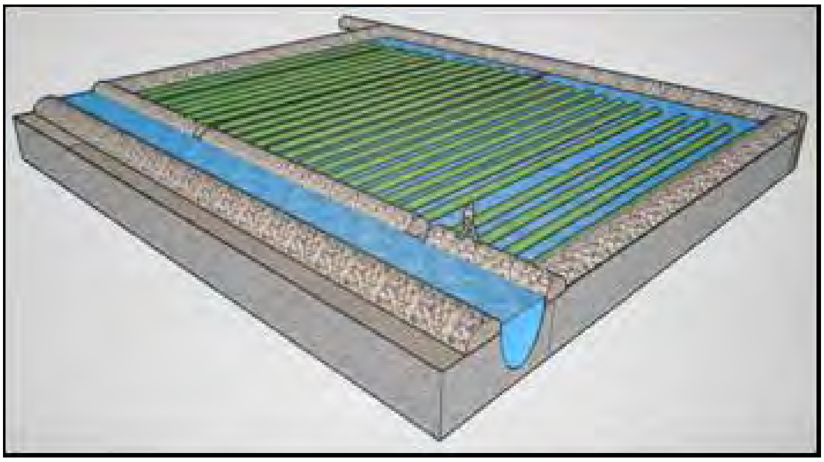
Figure 28 Wetting patterns: Poorly irrigated, uniform pattern and over irrigated basin



Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

- A well leveled surface inside the basin supports uniform wetting patterns. A poorly leveled surface causes irregular patterns, where part of the field or spots will remain dry.
- If a subsoil compacted soil layer is present, the infiltration rate varies causing irregular wetting patterns
- Only an adequate water flow rate will create a uniform wetting pattern. Too low of a flow rate will leave part of the root zone dry and too much water flow will overflow the bund without properly wetting the root zone layer as runoff water is not available for plant irrigation as it does not have sufficient time to sufficiently absorb into the soil.
- In the case of an over-irrigated basin, the percolation loss will be high.

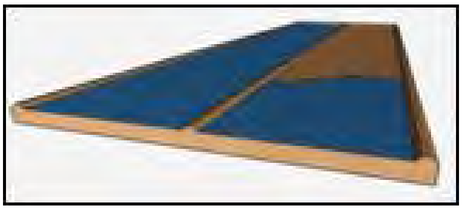
Figure 29 Combination of basin and ridges



Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

5.2.2 Border irrigation

Figure 30 Border irrigation



Source: F. Sandor (2008),
RoP Jalalabad, Afghanistan

The main difference between *border* and *furrow irrigation* is that a border irrigated field is several times longer than wider. Border irrigation is a flooded irrigation method where the surface is controlled by the landscape design and construction. Meanwhile basins are usually leveled fields with border irrigation that differs between graded and leveled methods.

5.2.2.1 Build up a border strip

The width of the *border strip* varies according to the cross slope elevation rate. As the flow depth decreases because of the increasing slope, chances of incomplete water coverage increases. Therefore, when increasing slope, border strip should correspondingly narrow. The limit is around a 5-6 m minimum width, which still allows for efficient use of the strip for production. The following table shows the recommended width of the border strip according to the cross slope elevation:

Table 13 Approximate values for border strip

Elevation per 1 meter length (cm/m)	Width of the border strip (m)
0.0	60
0.1	36-59
0.2-0.5	18-36
0.6-11.0	15-18
12.0-22.0	12-15
23.0-45.0	9-12
45.0-65.0	6-9

Source: C. Brouwer-A. Goffeau-M. Heibloem, (1985), Irrigation water management, FAO, Rome

The length of the border strip depends on the volume of water per second (discharge), the soil texture and the use of the land. Longer strips are easier for farming than shorter strips.

Table 14 Maximum border lengths and widths

Soil type	Slope (%)	Discharge (l/sec)	Border (m)	
			Width	Length
Sand	0.2-0.4	10-15	12-30	60-90
Infiltration rate is higher than 25mm/h	0.4-0.6	8-10	9-12	60-90
	0.6-1.0	5-8	6-9	75
Loam	0.2-0.4	5-7	12-30	90-250
Infiltration rate of 10 to 25mm/h	0.4-0.6	4-6	6-12	90-180
	0.6-1.0	2-4	6	90
Clay	0.2-0.4	3-4	12-30	180-300
Infiltration rate less than 10mm/h	0.4-0.6	2-3	6-12	90-180
	0.6-1.0	1-2	6	90

Source: C. Brouwer-A. Goffeau-M. Heibloem, (1985), Irrigation water management, FAO, Rome

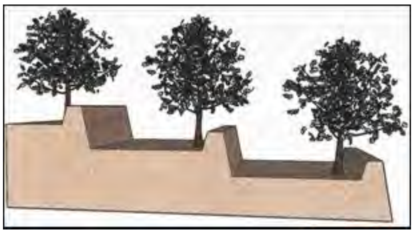
The height of the border bunds should not be more than 30-40 cm, avoiding excessive width. Too big of borders makes it difficult to wet through the bund. The horizontal slope can be a maximum of double the cross section elevation rate - Horizontal slope : vertical slope = 0.5-2.0 : 1.0).

There are five types of border irrigation methods:

1. Graded border irrigation
2. Level border irrigation
3. Contour levee irrigation
4. Contour ditch irrigation
5. Guided border irrigation

5.2.2.2 Graded border irrigation

Figure 31 Border irrigation in terraces



Source: F. Sandor (2008),
RoP Jalalabad, Afghanistan

A border irrigated field is divided into strips closed by bunds or dikes. Water enters at the upper end of the border and progressively covers the whole strip area following the slope in the direction of the irrigation. The optimal slope should be less than 5%, but definitely cannot be more than 2%. The strips are irrigated separately and have little to no cross slope.

It is not suitable for very sandy or clayey soils, where the soil intake rate is very high or low.

One of its specific characteristics is that the time which is needed to apply the gross volume of water into the strip is equal or slightly less than the time period that is needed for the soil to absorb the net volume of water (Gross water equal to the net water volume and deep percolation loss together).

Therefore this type of irrigation is also referred to as advance-recession type irrigation, which means when the water front head reaches the end borders (end of the advance time period), the recession time begins from the upper border of the strip (water moves away from the field channel). This method requires considerable leveling work.

5.2.2.3 Level border irrigation

Photo 7 Level border irrigation structure

Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

The level border irrigation uses the same concept that basin irrigation does except that the length of the strip is much longer than its width. The water is applied rapidly into the strip, which has a completely leveled surface and is closed by bunds or dikes, which retains the water at a uniform depth until it is absorbed by the soil. To avoid reverse grades (The water flow turns back from the end border), at least 5-6 cm overall fall is required in the length of the strip. The water application time into the strip should be short avoiding significant percolation loss. Apply a volume of water which is at least twice of the average intake rate of the soil.

5.2.2.4 Contour – levee border irrigation

This method is a modified version of the level border irrigation. The upper and lower levees follow the contour lines while the other two sides are closed by cross levees. **The area is flooded with excess water comparing to the soil intake rate**. The slope in the direction of irrigation should be less than 1% although the optimum slope is less than 0.5%.

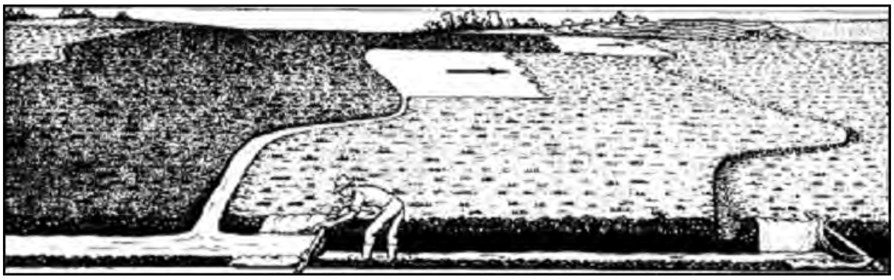
Photo 8. Contour-levee border irrigation structure

Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

5.2.2.5 Contour – ditch border irrigation

Together with the graded border irrigation, the contour ditch method is called controlled surface flooding. This method uses ditches, which follow the contour lines and run across the slope. The upper ditch of the strip discharges the water through the openings of the ditch bund and the lower ditch drains out and collects the excess water. When the strip is irrigated, the lower ditch becomes the water discharge ditch for the next strip and so on. This method is used for areas between 0.5% and 15% depending on soil conditions.

Figure 32 Contour – ditch border irrigation



Source: SCC (1991), National Engineering Handbook, USA

Table 15 Characteristics of border irrigation methods

Method	Slope	Crops	Intake	Soil type
Graded border	<0.5%	Legumes, small grains	Moderate low to moderate high	Most soils except sand and clay
	2%	Non sod forming crops		
	2-4%	Sod crops		
Level border	None or maximum 60 cm overall fall in the length	Alfalfa, legumes, grasses, small grain, rice	Slow to moderate with moderate to high available water holding capacity	Except sandy or fine-textured soils
		Row crops in beds		
		Sugar beet, sorghum, corn, cotton		
Contour levee	None or maximum 1%	Rice, cotton, soya bean, small grains, grasses, hay crops	Moderate to high	Medium to fine-textured soil
Contour ditch	0.5-15^%	Legumes, grasses, small grain	Slow to moderate	Moderately coarse to clay-loam

Source: F. Sandor (2008), Roots of Peace, Jalalabad, Afghanistan

Table 16 Summary table of border irrigation

Method	Advantage	Limitations
Graded border	Suitable for close-growing, non cultivated, sown crops	Not suitable for rice
	Can be used on most soil types	Not suitable for coarse, sandy soils
	Best suitable for slope less than 5%	Not suitable for soils with very low intake
	Good to excellent field application efficiency	Only suitable with relatively smooth topography
	Low labor requirement	Young crop can be damaged
Level border	Suitable for wide range of crops	The borders are too small to use it for soil with low water holding capacity
	Suitable for flat planted and also for bed planted crops	Only for gentle uniform slopes
	No irrigation water loss	Removal of excess rainfall may be necessary
	Little deep percolation loss	Accurate leveling is needed
Contour levee	The best suited for rice	Suitable only for medium to fine textured soils
	Field application efficiency is above 80%	Only for uniform surface soils
	Low labor requirement	It needs drainage facilities
	Controls are simple	It is not suitable for crops, which susceptible to flooding methods
Contour ditch	Low installation cost	Suitable for slowly permeable soils
	Suitable for wide range of topographic conditions	Irrigation efficiency is low 50-60%
	Suitable for annual crops	Young crops may be damaged

Source: F. Sandor (2008), Roots of Peace, Jalalabad, Afghanistan

5.2.3 Furrow irrigation

This method is suitable for a wide range of crops. It is also applicable to grow trees. The water is applied in small *channels* or *ditches* between *ridges* (row). The channels are made through tillage practices. It is also known as rill irrigation.

There are five types of furrow irrigation methods:

1. Graded furrow
2. Contour furrow
3. Level furrow
4. Corrugation irrigation
5. Snake irrigation

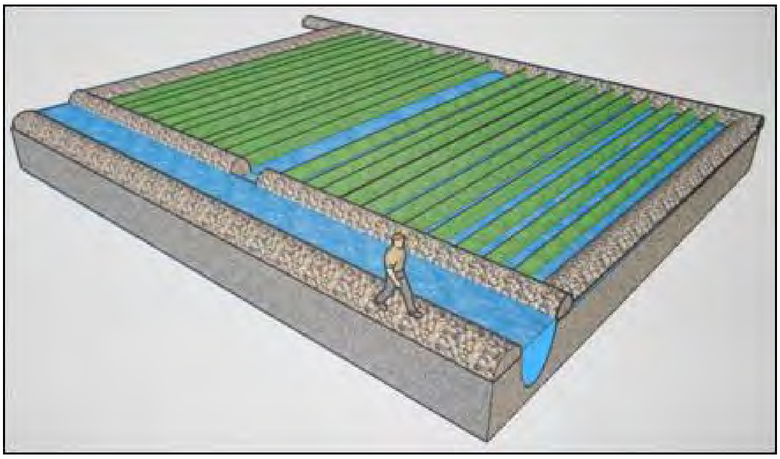
5.2.3.1 Graded furrow irrigation

Photo 9 Graded furrow irrigation structure

Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

This method is used for land with a gentle and uniform slope. The furrows are small channels between rows or bedded planted crops. It can be used for almost all types of soil. The grade of the furrow should not be higher than 1% in most of the cases. The maximum allowed grade is 3%. The preparation of the graded furrows is labor intensive work. This method works with a medium capacity water discharge. Therefore it is not suitable for crops with very light irrigation requirement or for soil types with very high water intake.

Figure 33 Graded furrow irrigation



Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

5.2.3.2 Contour furrow irrigation

It can also be called as contour-level furrow irrigation. This method uses furrows, which follow the contour lines and carry the water across the sloping field instead of down slope. The furrows are nearly leveled. They have a grade only to allow the flow of the water stream. It is suitable for sloping land. This method can be used for a wide range of soil types except very sandy or cracking soils.

The maximum allowed grade is 4%. It should be managed carefully, because overflow and washout is a high risk during irrigation.

Figure 34 Contour furrow irrigation

Source: F. Sandor (2005), Lilongwe, Malawi

5.2.3.3 Level furrow irrigation

This method is similar to the graded furrow except that in this case the water flows in leveled furrows instead of furrows with a grade. The water can be introduced at both ends. There is no water loss with this method; therefore it is a highly efficient irrigation method.

5.2.3.4 Corrugation irrigation

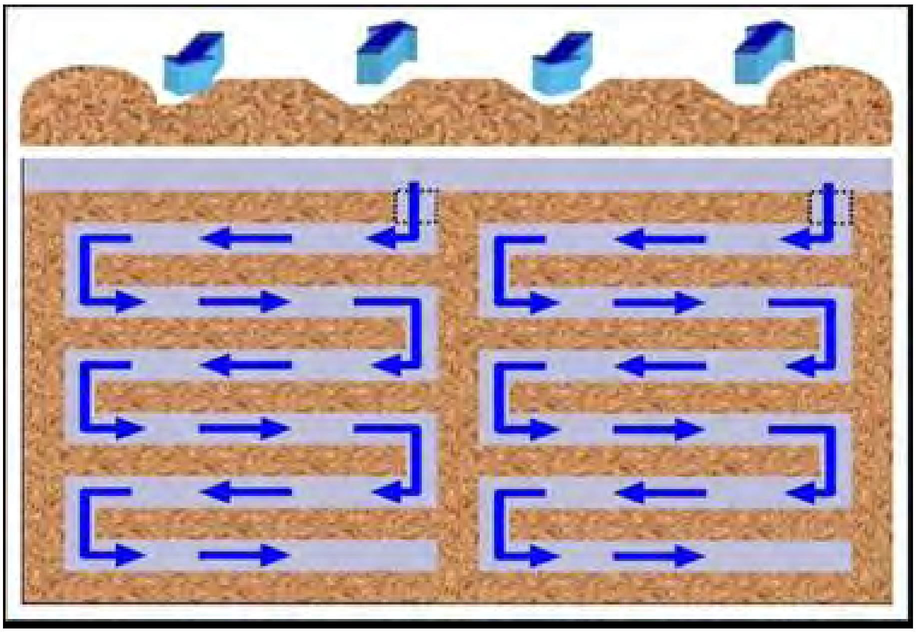
Figure 35 Corrugation irrigation method

Source: SCC (1991), National Engineering Handbook, USA

This method is a kind of mix between furrow and flooded irrigation. It consists of small channels (corrugations) evenly spaced on the field. The water in these small channels spreads laterally on the areas between corrugations. The method is suitable for uncultivated crops (But not for rice). There is a higher slope in the direction of the irrigation and a lower cross slope. The range of the slope needs to be between 1% and 8%. The ideal soil type for this method is coarse textured soil between fine and moderately coarse types. This irrigation method is a highly labor intensive system.

5.2.3.5 Snake irrigation

Figure 36 Water flow using snake irrigation



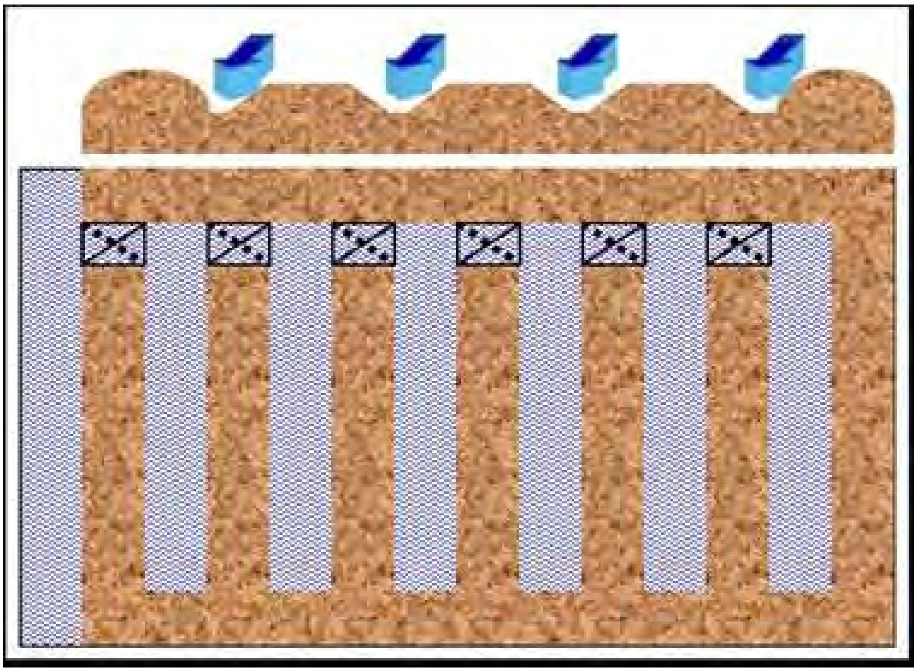
Source: F. Sandor (2008) RoP Jalalabad, Afghanistan

This is a small scale irrigation method, which is a mixed method between basin and furrow irrigation. The field is divided for small basins like in the case of fruit tree basins while inside of each basin small ridges or narrow beds are established.

The ridges are connected in one end so the shallow furrows follow a zig-zag pattern between them. The method received its name from this pattern. The water flowing in the furrows soaks into the soil and spreads laterally. The snake irrigation is very efficient in water use. With very little water, it uniformly irrigates the root zone of the crop. It can save 60-65% of the water that is used for level furrow irrigation. It is suitable for a wide range of cultivated crops. The slope of the land should be between 1% and 3%.

Most of the soil types are suitable for furrow irrigation. It is much more important whether the topographic conditions are adequate or not. The land should be uniform, flat or gentle slope, which should not exceed 0.5%. In case of steeper land, the furrow should follow the contour lines and it should be leveled, which will give it a very similar appearance to the long and narrow level-border or basin irrigation method.

Figure 37 Water flow using furrow irrigation



Source: F. Sandor (2007), PRI Prison Farms Manual, Lilongwe, Malawi

5.2.3.6 Calculate the length of the furrow

The length of the furrow depends on three factors:

- The size of the stream (Liter per second per furrow)
- The slope percentage

The soil texture, which influences the water infiltration rate. In sandy soils the infiltration rate is high according to the high percentage of macro pore space fraction. Clayey soils have high porosity with low percentages of macro pore space volume, but high percentages of small and discontinuous micro pore space, making the water infiltration rate slow. Therefore, the water holding capacity of clayey soils is considerably higher than that of the sandy soils. This allows for a high volume of available water for plant growth.

Photo 10 Furrow irrigated crop

Source: F. Sandor (2003), Domasi, Malawi

Table 17 Maximum furrow length

MAXIMUM FURROW LENGTH (m)					
Slope (%)	Stream size (l/sec)	Irrigation depth (mm)	Soil texture		
			Clay	Loam	Sand
0.0	3.0	50	100	60	30
0.0	3.0	75	150	90	45
0.1	3.0	50	120	90	45
0.1	3.0	75	170	125	60
0.2	2.5	50	130	110	60
0.2	2.5	75	180	150	95
0.3	2.0	50	150	130	75
0.3	2.0	75	200	170	110
0.4-0.5	1.2	50	150	130	75
0.4-0.5	1.2	75	200	170	110

Source: C. Brouwer-A. Goffeau-M. Heibloem, (1985), Irrigation water management, FAO, Rome

5.2.3.7 Calculate the size and shape of the furrow

Photo 11 Furrow irrigation

Source: F. Sandor (2004), Lilongwe, Malawi

Usually three types of furrow shapes can be found in the practice. One of them is the narrow "V" shape, the other two are the trapezium and the curve shapes. The narrow "V" shape is more suitable for sandy soils avoiding unnecessary percolation loss. While for clayey soils it is recommended to use shallow and wide furrows, which have a trapezoid or curved shape. The clay type soils have high water retention rate and the water infiltration is slow, therefore the use of shallow furrow is more desirable. The construction of narrow-deep furrows requires attention from the farmer, because sandy soils are less stable and they tend to collapse.

Photo 12 Shallow type of furrows

Source: F. Sandor (2008), Jalalabad, Afghanistan

It is always useful to calculate the cross section area of the furrow. This information allows us to establish the balance between the discharge capacity, water front advance and wetting pattern. It greatly influences the irrigation efficiency.

Equation

"V" shape furrow cross section area:

$$A\ (m^2 \text{ or } cm^2) = 0.5 \times \text{base} \times \text{height}$$

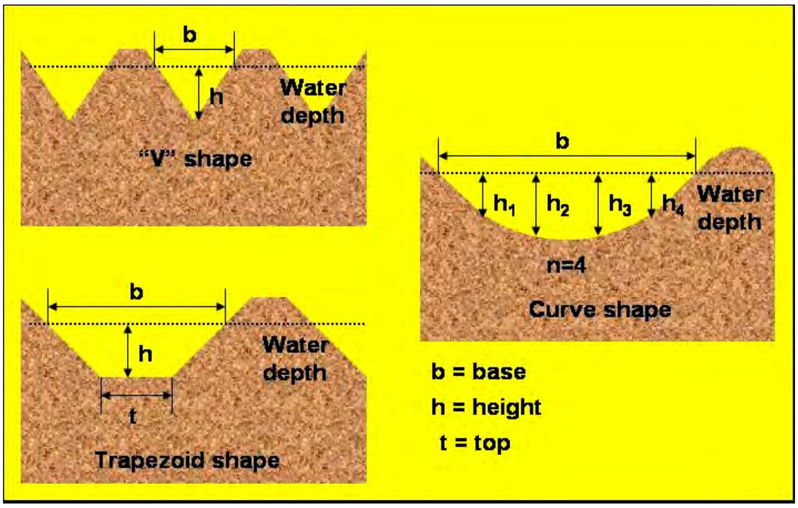
Trapezoid shape furrow cross section area:

$$A\ (m^2 \text{ or } cm^2) = 0.5 \times (\text{base} + \text{top}) \times \text{height}$$

Curved shape furrow cross section area:

$$A\ (m^2 \text{ or } cm^2) = \text{base} \times (\text{height}_1 + \text{height}_2 + \ldots\ldots + \text{height}_n)/n$$

Figure 38 Cross section of different furrow types



Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

The spacing between two adjacent furrows should be the following:

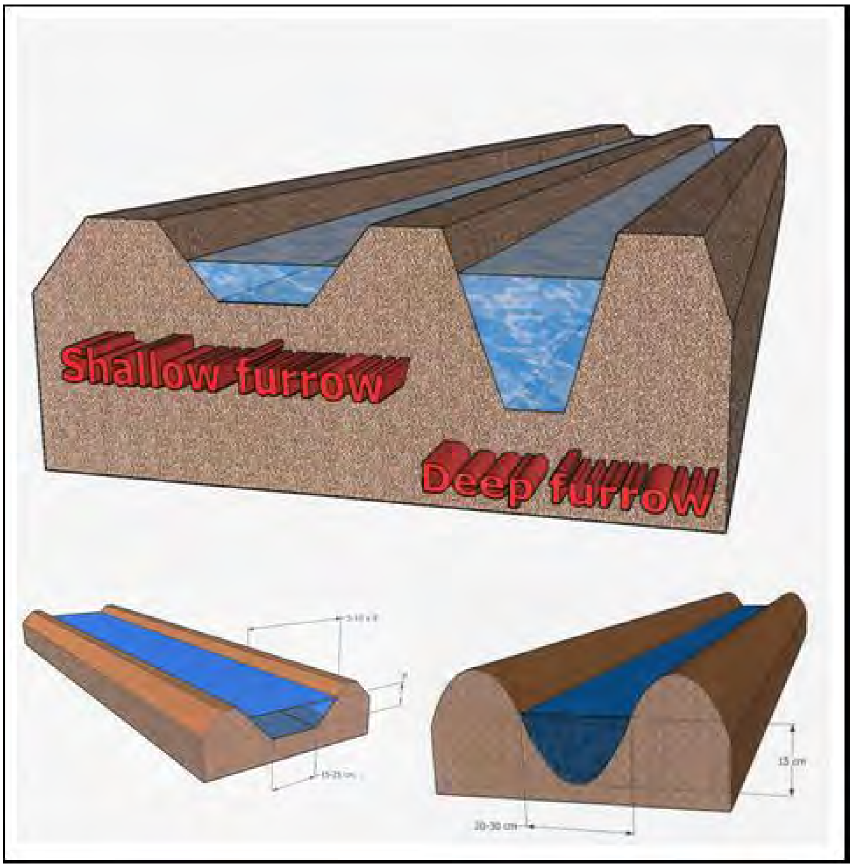
- Coarse sand: 30 cm
- Fine sand: 60 cm
- Loam: 45 – 60 cm
- Clay: 75 – 100 cm
- Heavy clay: 100-150 cm

5.2.3.8 Build up the furrows

The first step is to measure and establish the boundary area. Construct the main water supply channel followed by the water distribution channels. Where necessary (Steep land), establish the main pressure release channel as well as secondary water release channels (drainage system). At the same time the channels are constructed, build up the bunds around the field. The upper bund of the field can be a graded, level or level-contour bund.

Using the upper bund as guidance, establish the guide furrow along the upper edge of the field. Additional guide furrows should be constructed every 5-10 meters depending on the field's topographical characteristics, the planting method and the characteristics of the selected crop. Finally, construct the furrows in the space between the guide furrows.

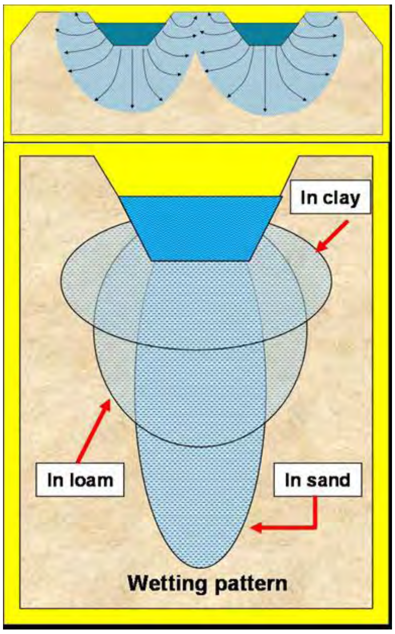
Figure 39 The two main furrow types



Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

5.2.3.9 Wetting pattern

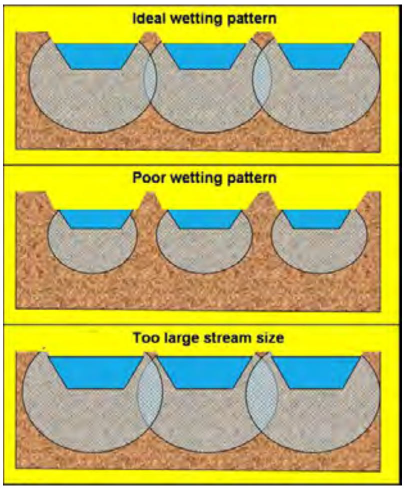
Figure 40 Wetting pattern of furrow irrigation method



Source: F. Sandor (2008)
RoP Jalalabad, Afghanistan

The wetting pattern in the furrows varies according to the soil texture. In sandy soils the water goes through the dominant macro pore space quickly, meanwhile the lateral movement and the upward movement caused by capillarity force is low. Therefore sandy soil has a narrow wetting pattern in the soil. In the case of clayey soil, the tendency is exactly the opposite, as the lateral movement of the water is considerable compared to the slow downward movement through the small and discontinuous micro pore space fraction of the soil. Upward capillarity action is also slow because the discontinuity between the space pores.

Figure 41 Optimal and poor wetting patterns



Source: F. Sandor (2008)
RoP Jalalabad, Afghanistan

The wetting pattern has a wide oval shape. **Heavy clay soils used to be waterlogged, because the water very slowly can penetrate into the soil.** Therefore, careful calculation of the necessary volume of water for irrigation is important. The ideal wetting pattern is when the adjacent wetting patterns overlap each other and the capillary rise wets the entire ridge.

5.3 Localized Irrigation

Localized irrigation is a system where low volume water under low pressure is applied in a pre-determined pattern. There are two main types of localized irrigation systems. One of them is the manually recharged localized irrigation, which uses permeable ceramic pots or perforated bottles. The water volume in the container is filled up manually on a regular basis. The other one is the continuously recharged localized irrigation, where the water supply is pumped or continuously discharged by gravity. It is also called a trickle irrigation system. The water is applied through emitters (Outlet device) as a tiny stream, continuous drops or micro spray. The water infiltrates into the soil from the emission point using gravity and capillary force.

The localized irrigation systems are characterized by the following factors:

- Low discharge pressure
- Low volume of water applied
- Evaporation minimized
- Runoff minimized
- Minimized field layout

5.3.1 Bottle or pot irrigation

Figure 42 Bottle irrigation method

Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

The use of a porous clay pot for irrigation is a very old method and was commonly used by Native American people. The method consists of the installation of clay pots throughout the field spread out at intervals of 0.8-1.0m x 3-4m, which are buried into the soil up to the neck of the pot. Each pot has a capacity to reserve 10-15 liters of water. Through its porous spaces the pot discharges the water gradually into the root zone of the crop. As the water level in the pot decreases, the pot is refilled. The neck of the pot is narrow, avoiding unnecessary evaporation of the water. It is a very efficient and simple method where the climatic conditions are hot and dry.

Photo 13 Bottle irrigation system

Source: F. Sandor (2000), Lilongwe, Malawi

Using bottles and other recipients is a similar approach. In these cases the clay's porous spaces are replaced by little, 5mm diameter holes on the bottom part of the bottle. The bottles are placed between plant rows or around the fruit trees. The bottle is placed in the hole up to the bottle neck with some compost or dry grass being placed around the entire bottle that is used to help retain the moisture in the soil. The bottle should be filled on a daily basis. Surface mulch can help to maintain soil moisture and reduce evaporation.

5.3.2 Sunken bed irrigation

Sunken bed or *box ridges* irrigation is very common in the countries of Sub-Sahara Africa. The bed is sunken beyond the surface level and bounded by small ridges. Inside the bed each plant is placed in a tiny hole. This tiny hole is filled up with water every day by using a water can or house pipe.

5.3.3 Drip irrigation

The water is continuously applied to the surface in a dripping fashion from the emitter. The discharge rate varies according to the distance between the outlets. In case of closed spacing the minimum discharge rate is around 4 liters per hour. The maximum discharge rate is 11.5 liters per hour.

5.3.4 Subsurface drip irrigation

In this case, the drip lines are placed just below the surface. The water discharge rate is the same as the common *drip irrigation*.

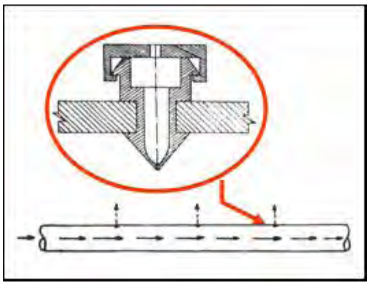
Photo 14 Surface drip irrigation system

Source: F. Sandor (2005), Lusaka, Zambia

5.3.5 Bubbler irrigation

This method uses more water than drip irrigation. The discharge rate goes up to 4 liters per minute. The water is applied to the surface as a tiny stream through an opening of the emitter. The discharge rate is higher than the infiltration rate; therefore a small basin or ring around the plant controls the run off.

Figure 43 Drip emitter cross section



Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

5.3.6 Establish localized irrigation system

Drip irrigation does not require specific physical layout, but if the slope is too steep the wetting pattern not will be uniform. There are many types of systems available from the very cheap to the very expensive. All of them include five main components:

- Control head
- Main and secondary lines
- Manifold
- Laterals
- Emitters

Additionally to the main components, expensive systems also include flow controls and flow pressure regulators.

Photo 15 Drip line on nursery bed

Source: F. Sandor (2004), Dedza, Malawi

The *control head* can have many components. The basic element is the pumping system with filters, but also can be completed with a water measuring device and injector equipment. The injector's main function is to inject fertilizers and other chemicals into the system, which gives to the system multiple uses. The water can be pumped directly into the main line or if the system based on gravity, to be discharged into the water reserve. The filters remove all debris from the water, which can block the emitters. With the water measuring device, the control head is able to automatically turn off the system after the release of the required water volume.

Photo 16 Distributor device in drip irrigation system

Source: F. Sandor (2004), Dedza, Malawi

The main and secondary lines carry out the filtered water on to the field where the laterals will be connected to them. The manifold is the connection between the laterals and the main lines. Both, the main lines and manifold are usually buried beneath the surface. The diameter of the lines varies according to the slope of the land. In case of steeper terrain the size should be smaller to balance the water pressure difference between the upper and lower land. This water pressure difference is caused by gravity, when the slope grade is significant. Uniformity in pressure is important to release the same volume of water into every lateral. If on the upper area the system has lower pressure than on the bottom area, then the manifold will release less water into the upper laterals. When this is happening, the emitters of the upper laterals are not able to release the water, meanwhile the emitters on the bottom area release more water than necessary. The manifold system includes pressure regulators as part of the whole system. The layout of the laterals and emitter spacing varies according to the crop species and water need.

Water flow and pressure control should be controlled during irrigation, which means the on-going adjustment of:

- operation of the equipment
- water distribution
- water application

The following table summarizes the main characteristics for flow and pressure regulation using the available methods.

Manually operated control: Manually used pressure controls and on-off valves or valves preset for a specific pressure or flow rate are incorporated into the system.

Sequential control: Volumetric control valves are interconnected by hydraulic control lines. As each valve closes, the next one opens.

Partial automation control: The volumetric valve opens manually, but it closes automatically by using time clock valves.

Table 18 Flow and pressure characteristics of different methods

Method	Beginning of irrigation cycle	Basis for closing valve	Manner of opening next valve	Order of valve operation	To change irrigation depth	To change the order of operation
Hand valve	Manual opening	Time	Manual	Without restrictions	Change on time or pressure	Without limitations
Volumetric valve	Manual opening	Quantity of water	Manual	Without restrictions	Manually adjust valve	Without limitations
Sequential operation with volumetric valve	Manual opening	Quantity of water	Hydraulic control	Adjoining areas; from low to high areas	Manually adjust valve	Possible only by relocating the control lines
Full automation by	Automatic, planned	Time or volume of	Hydraulic or electric control	Without restrictio	Adjust time or	Resetting at the control

Source: Irrigation (1991), SCS National Engineering, Handbook, USA

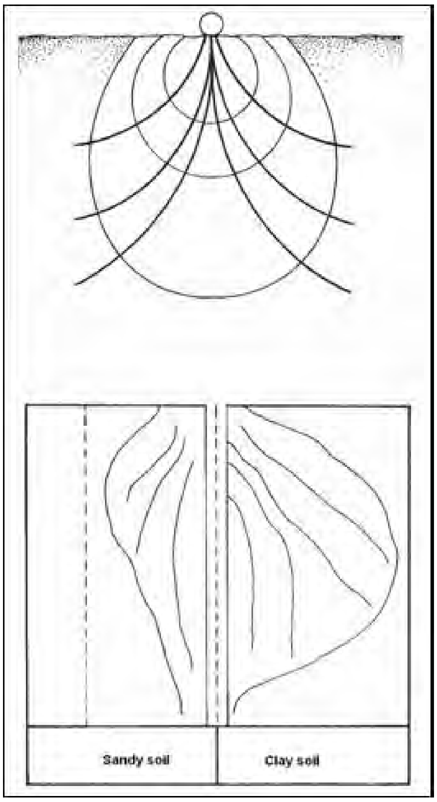
Full automation control: Fully automated system, which can operate in three ways by using a central control board:

- on time basis
- on volume basis
- on soil moisture sensing

5.3.7 Wetting pattern and wetted area

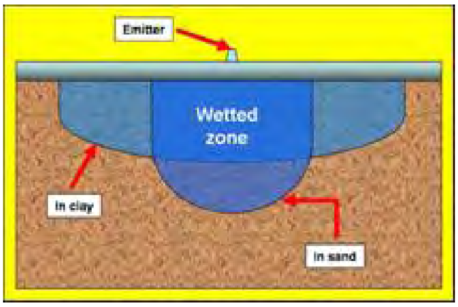
Localized irrigation is designed to wet the top 20-30 cm of the root zone area. The water infiltrates into the soil by gravity and capillary force. Therefore the wetting patterns are similar when the application rate is different but the water volume is the same. In other words, the volume of wetted soil depends on the volume of applied water independent, more or less from the application rate.

Figure 44 Wetting pattern according to the soil texture



Source: D. Brasil Vieira (1989), As Tecnicas de Irrigacao, Sao Paulo, Brasil

Figure 45 Water infiltration pattern according to the soil structure



Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

The wetted area is another issue. Lateral and emitter spacing are very important and should be well calculated to avoid only wetting the soil while leaving the plant root zone dry. The calculation is shown with an indicator called “Percent of Wetted Area

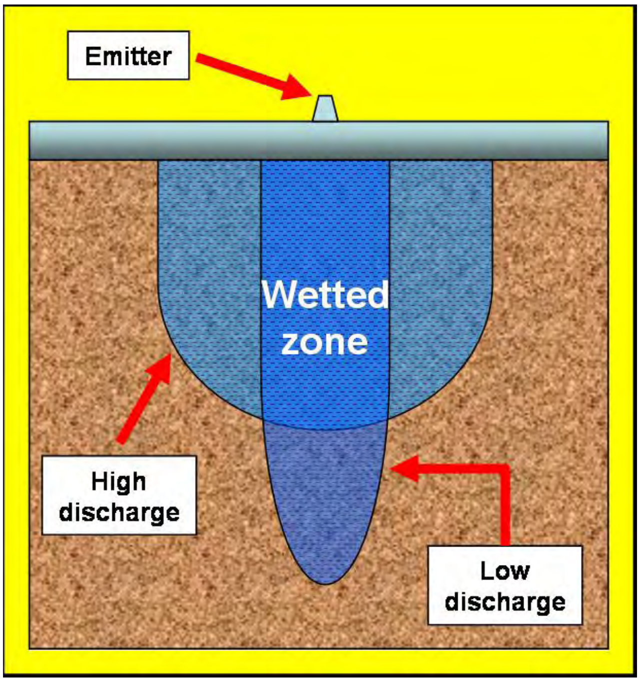
(PWA)”, which describes the average wetted horizontal area in the top 20-30 cm root zone area. The equation is the following:

Equation

$P_{wa} = [(n_e \times S_e \times S_w) / (S_p \times S_r)] \times 100$, where

n_e = Number of water emission point per plant
S_e = Spacing between emitters on a lateral
S_w = Width of the strip wetted at the length of spacing between emitter on a lateral
S_p = Plant distance in a row
S_r = Plant row distance

Figure 46 Wetted area using drip emitter

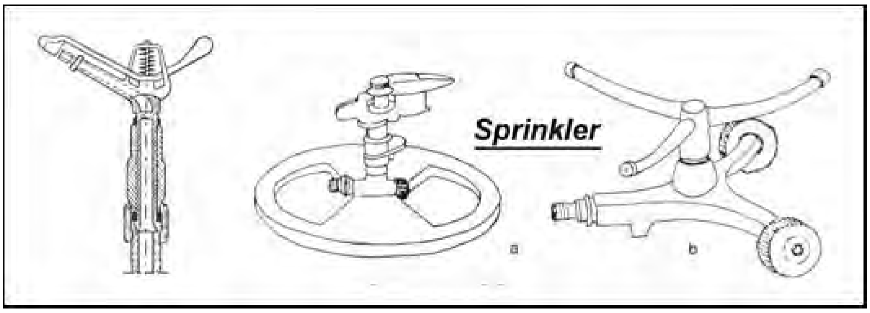


Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

5.4 Overhead Irrigation

In *overhead irrigation* the water is applied to the air and from there falls down in a uniform pattern to the surface where it infiltrates into the soil. The application rate is less than the soil intake rate. The method uses *sprinklers, rotors* (Higher pressure sprinklers that rotate and are driven by a ball drive, gear drive, or impact mechanism. Rotors can be designed to rotate in a full or partial circle.) or guns (Similar to rotors, except that they generally operate at very high pressures) to distribute the water. The water is pumped into the pipe lines and uses high pressure.

Figure 47 Examples of sprinklers



Source: F. Sandor (2007), PRI Prison Farms Manual, Lilongwe, Malawi

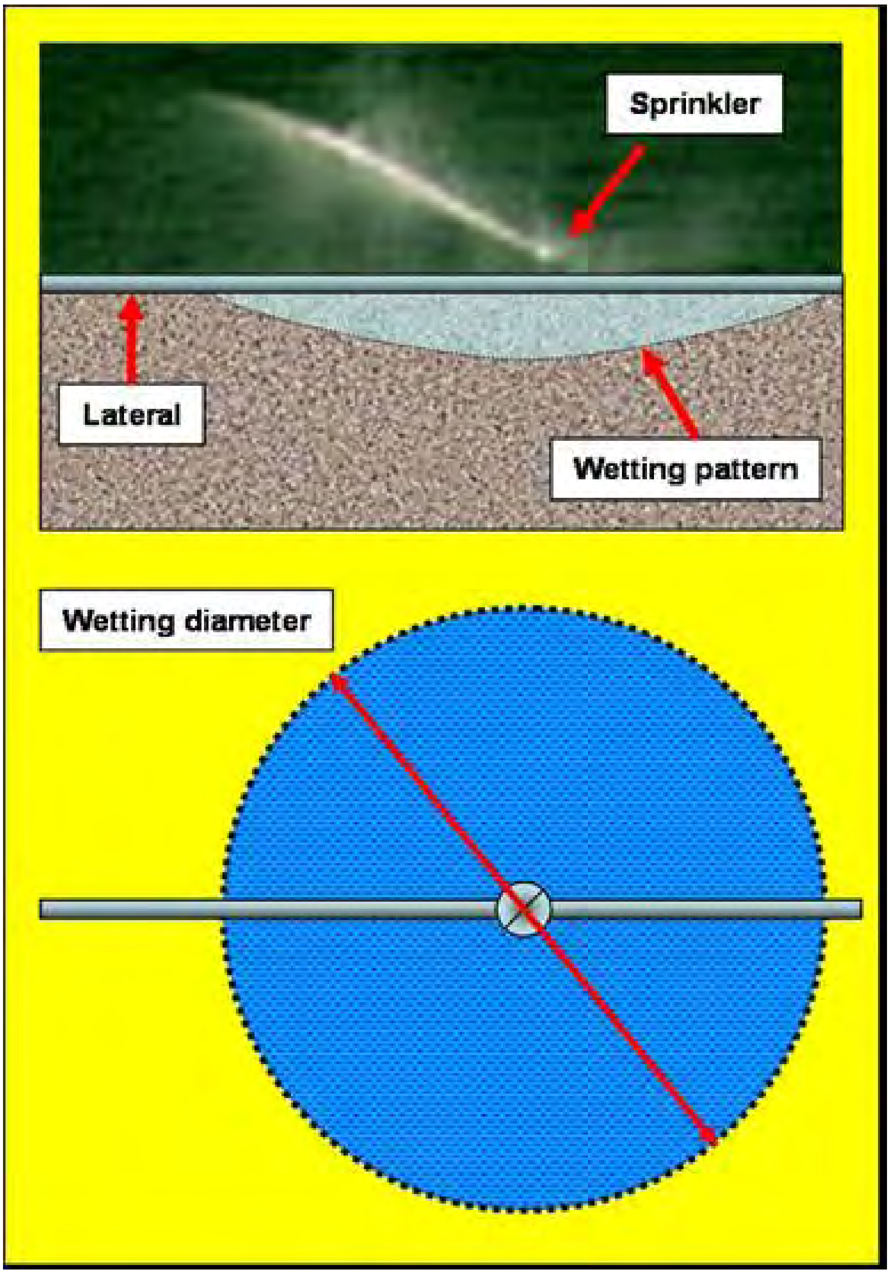
5.4.1 Establish overhead irrigation

The overhead irrigation is suitable for all kind of crops except rice. For coarse sandy soils it is one of the best options for irrigation. With the exception of some special methods, the system does not require extensive land preparations. The land does not need to be leveled at all. It also can be used efficiently for very steep land.

5.4.2 Wetting pattern

Each sprinkler has a circular shape for its wetting pattern. Water is applied to the area closest to the sprinkler more than in the area of the outer part of the circle. Therefore the wetting pattern into the soil cross section looks like a cone. According to this pattern the sprinklers should overlap their patterns partially to achieve a uniform wetting pattern on the field.

Figure 48 Wetting pattern created by sprinkler

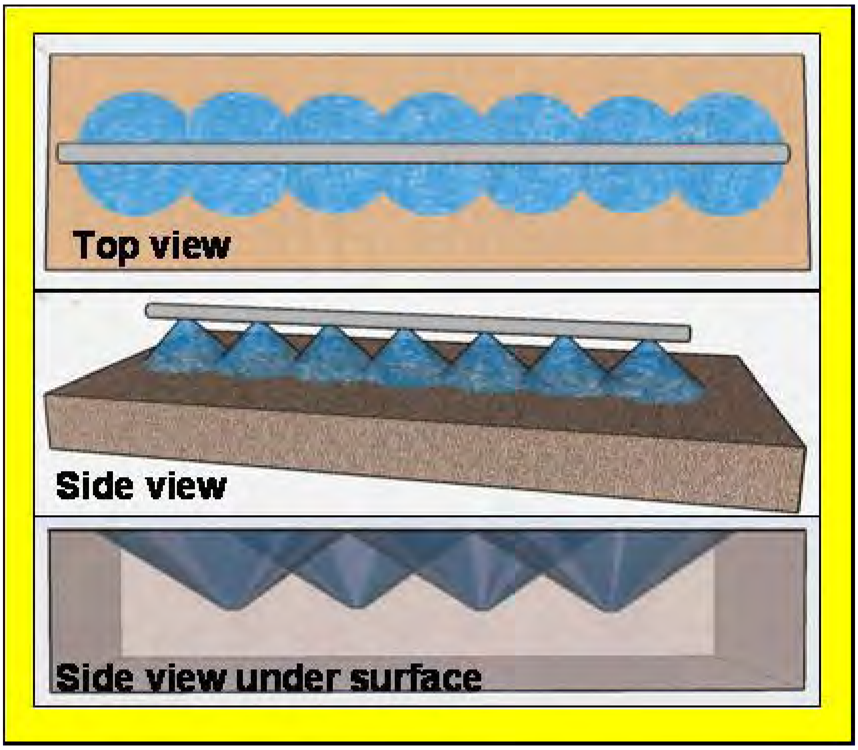


Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

There are five types of overhead irrigation systems:

1. Solid set irrigation
2. Traveling overhead irrigation
3. Center pivot irrigation
4. Wheel line irrigation
5. Manual overhead irrigation

Figure 49 Wetting pattern along the side of a lateral



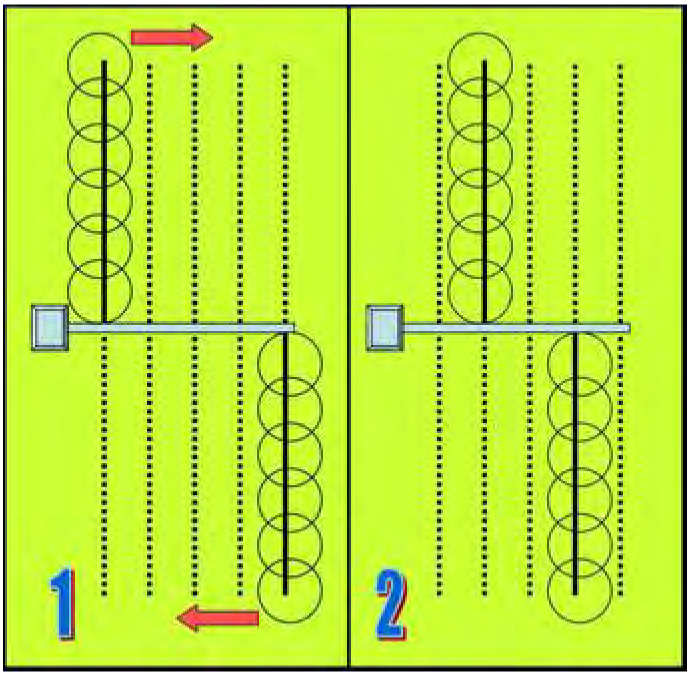
Source: F. Sandor (2008), RoP Jalalabad, Afghansitan

5.4.3 Solid set irrigation

It is also called the *conventional overhead irrigation system*. The main components are the pumping unit, main line, laterals and sprinklers. The system includes three types of methods:

- Mobil: All components of the system can be moved from one area to another. The pump is also mobil and is usually connected to the tractor rotating axe or it has its own motor and is built up on wheels.

Figure 50 Laterals movement on the field

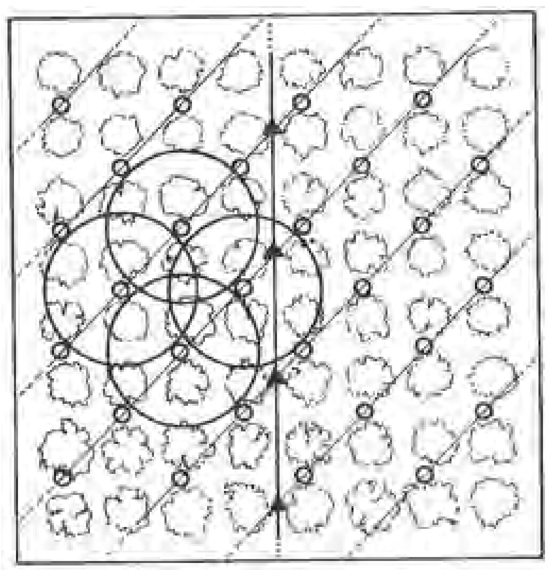


Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

- Semi-mobil: The pump and the main line are fixed permanently and only the laterals and sprinklers can be transferred from one area to the other. It includes three subtypes of methods. The first subtype is when the pump is connected to one end of the main line and the lateral with the sprinklers is alongside the main line. The second subtype is when the pump is connected to the middle section of the main line, but the lateral's movement is the same, from one end to the other end of the main line. The third type is when the main line crosses the middle section of the field and the pump is connected to one end of the main line. In this case two laterals are connected to the two opposite ends of the main line and they move in the opposite direction toward the other end of the main line.

- Permanent: All components are permanently placed, usually buried beneath the surface.

Figure 51 Permanent overhead irrigation system



Source: D. Brazil Vieira (1989), As Technicas de Irrigacao, Sao Paulo, Brazil

5.4.4 Traveling overhead irrigation

These are automatically moved wheel systems. The different mechanisms used to move the components are powered by the *hydraulic pressure* of the irrigation water or use a small gas engine. The *traveling sprinkler* includes the pump, main line, flexible lateral, moving mechanism or traveler (flat rubber hose) and sprinkler. Other systems utilize a length of polyethylene tubing wound on a steel drum. As the tubing is wound on the drum (which is powered by the irrigation water or a small gas engine) the sprinkler is pulled across the field. When the sprinkler arrives back at the reel, the system shuts off. This type of system is known to most people as a "water reel" traveling irrigation sprinkler.

5.4.5 Wheel line irrigation

Photo: 17 Wheel line irrigation system

Source: J. McNee (2001), USDA Idaho, USA

A wheel is fixed permanently at the midpoint of each pipe. The pipes are connected and form the lateral of the system. Basically the lateral is the axel of the wheels. The water runs inside the lateral hose. After the application of the water the lateral will be rotated to the new location.
The pipes of the lateral easily can be disconnected and rebuilt again.

5.4.6 Center pivot irrigation

The system uses joined pipes, which are supported by trusses that are mounted on wheeled towers with sprinklers positioned along its length.

Photo 18 Center pivot irrigation system

Source: USGC (2008), Clemson University, South Carolina, USA

It moves in a circular pattern and is fed with water from the pivot point at the center of the arc. The system can use drop sprinklers or bubblers. Both of them release the water toward the soil surface instead of sprinkling upward to the air. Usually they are hanging from a pipe called a goose neck. The rotating mechanism can be powered by water, a hydraulic system or by an electric motor.

5.4.7 Manual overhead irrigation

This method uses house pipes and is commonly used in household gardens. It is almost impossible to calculate water use and wetting pattern.

5.5 Sub-irrigation

This method can be used when the water table is close to the surface. It artificially raises the level of the water table through water application beneath the ground. In other words, the method creates a perched water table. The water reaches the plant root zone through capillary movement. This method is also called seepage irrigation.

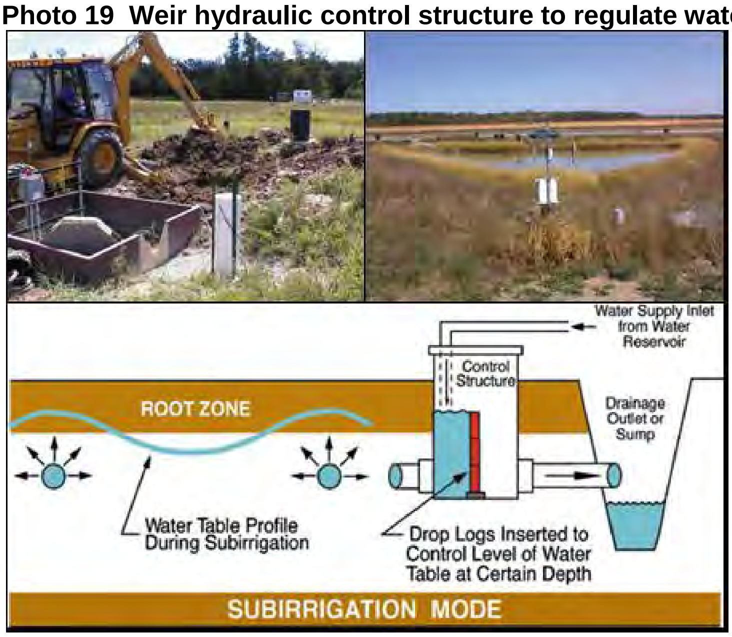
A special type of sub-irrigation is the greenhouse sub-irrigation for potted plants. Water is absorbed from below and the excess water is collected and recycled inside the system. Additional components of the system are the tank, the pump (which pumps the excess water to the tank), and the control system (provide automation).

5.5.1 Establish sub-irrigation

The method requires uniform soil texture with permeability to allow for the rapid horizontal and vertical movement of water. **The soil profile should have a *barrier* (impermeable layer) to avoid excessive water loss or a naturally high water table.**

On a well leveled field the water is introduced through open ditches, tile drains, or mole drains. With the connection to the pumping station, the water flows through the canals, weirs and gates. This regulates the water level in the canal. The water level is usually maintained between 30cm and 60cm according the rooting depth of the crop. The most common ditches in use are the open ditches. Tile and mole drains are expensive. The use of sub-irrigation method is limited, because it requires an unusual combination of natural conditions.

Photo 19 Weir hydraulic control structure to regulate water table depth in sub-irrigated field



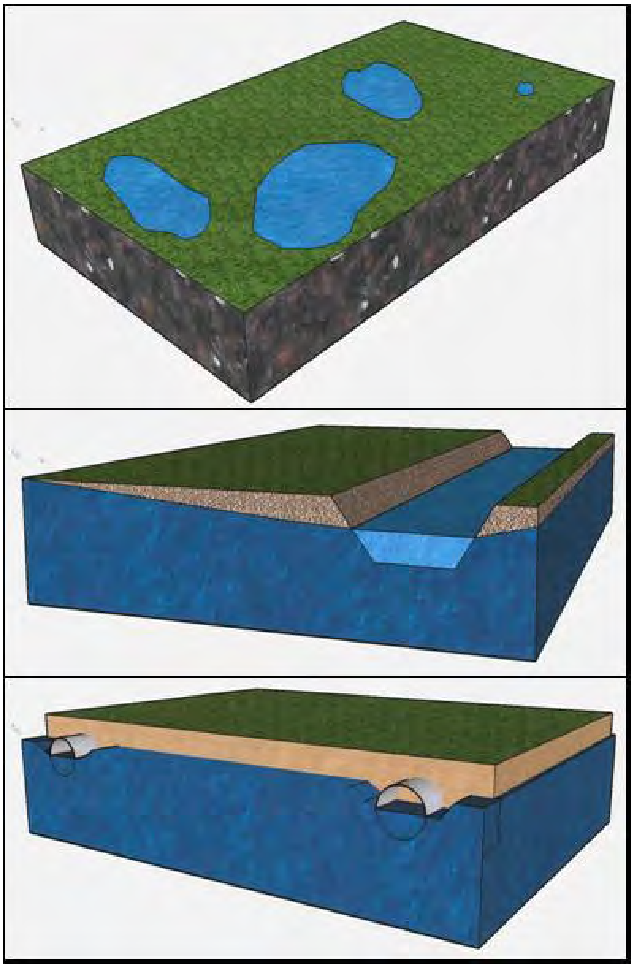
Source: L. Zucker (2007), Ohio State University, USA

5.6 Drainage System

Excess water should be removed from the surface as it comes from rainfall or irrigation practices. Drainage removes excess water from the soil and helps to create a well-aerated root environment that enhances plant uptake of nutrients. Subsurface drainage is often used to prevent buildup of salt in the soil.

A *drainage system* can be placed on the soil surface or the subsurface, or a combination of both. The surface drainage removes the excess water from the surface. The subsurface drainage removes water from the soil profile. Subsurface drainage systems can use deep open drains or buried drain pipes. In some cultivation methods the irrigation distribution ditches also can be used to collect and remove excess irrigation water.

Figure 52 Surface and subsurface drainage structures



Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

6 Irrigation System Management

There are indicators that determine the efficiency of the irrigation practices. By knowing the main contributing factors, all necessary calculations can be made that help obtain efficient irrigation practices. Before designing an irrigation system, it is necessary to acquire the necessary skills and knowledge to calculate the indicators, which will conclude the design and manage the operations.

6.1 Infiltration Rate

The infiltration rate basically measures the soil capacity and how fast it can absorb the water into the soil. It depends on the soil texture, structure and moisture content. Water is absorbed into sandy soil faster than into a clayey soil and the same is true for granular structured soil versus massive soils. This relates to the soil porosity value and the soil micro-macro pore space relationship. The nature of the soil aggregate determines the continuity or discontinuity of the soil space pore content, which influences the soil hydraulic conductivity.

Photo 20 Infiltration test on the field

Source: F. Sandor (2008), Samarkhil, Afghanistan

The infiltration rate is in harmony with the infiltration curve. In the beginning, the water infiltrates quickly into the soil. This is called initial infiltration rate. This process slows down later and finally achieves a steady rate, which is called basic infiltration rate.

The infiltration rate can be measured easily using an instrument called ring infiltrometer, which is a single 30cm diameter and 25-27cm high ring. A 300mm measuring rod is attached to the ring. The ring is placed into the soil up to 15 cm depth. To prevent the later flow of the water, a 60 cm diameter outer ring is installed around the infiltrometer or a soil bund if we do not have an outer ring.

<u>*Test*</u>

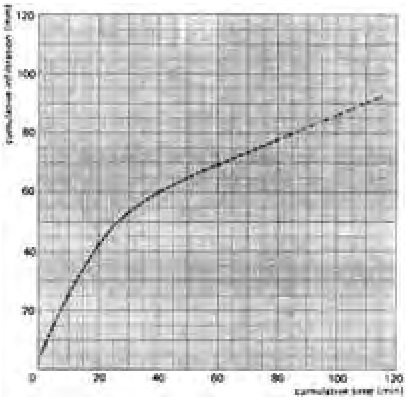
1. Fill up the infiltrometer and the space between the infiltrometer and outer ring or bund with water up to 70-100mm water depth. The water between the two rings will prevent lateral water flow.
2. Measure and record the water level and start running the time recorder.
3. Start recording the water level every 1-2 minutes and add water to bring back the original water level when it is necessary.
4. Maintain the waters in the both the outside space and in the infiltrometer.
5. After the initial phase, increase the recording time period (Every 20-30 minutes).
6. Stop recording when the infiltration rate becomes steady.
7. Conduct minimum 2-3 tests.
8. Use an 8 columns table to record the results:
   - 1st column: Readings on the clock

- 2nd column: Time difference between readings
- 3rd column: Cumulative time since the beginning
- 4th column: Water level readings
- 5th column: Water level differences between readings
- 6th column: Infiltration rate in mm per minute
- 7th column: Infiltration rate in mm per hour
- 8th column: Cumulative infiltration rate in mm per total time period

Equation for Cumulative Infiltration Rate (CIR)

CIR = Ct_n against CIR_n
Where
Ct_n = Cumulative time
CIR_n = Cumulative infiltration
CIR = Will be a curve on the chart
CIR = $CI_b + CI_{C1} + \ldots + CI_{Cn}$, during $Ct_b + Ct_{C1} + \ldots + Ct_{Cn}$
Where
CI_b = Initial Cumulative Infiltration Rate (The total water volume until becomes steady the infiltration rate)
CI_{Cn} = Constant Cumulative Infiltration Rate (The constant water volume when infiltaration rate becomes steady)
Ct_b = Initial Cumulative Infiltration Time (Cumulative time, which needs to reach steady infiltration rate)
Ct_{Cn} = Constant Cumulative Infiltration Time (Constant time period for steady infiltration rate)

Figure 53 Example of Infiltration curve



Source: C. Brouwer-A. Goffeau-M. Heibloem, (1985), Irrigation water management, FAO, Rome

(Example: The test duration was 5 ½ hours. The first 90 minutes we need 120 mm water to reach the steady infiltration rate, which is 80 liter of water for the remaining test period, which was 4 hours. Therefore the basic infiltration rate will be 120 mm water divided by 90 minutes and multiply with 60 minutes, which equal to 79.9 liter per hour.

The constant infiltration rate is 80 liter divided by 4 hours, which is equal to 20 liters per hour.
This translates to the fact that with a 79.9 mm/Hrs basic infiltration rate, 90 minutes and 120 liters of water are needed to reach the constant infiltration rate. After these initial 90 minutes, the infiltration rate will be 20 liters of water per hour (120+20+20+etc) for every hour after.

6.2 Water Flow

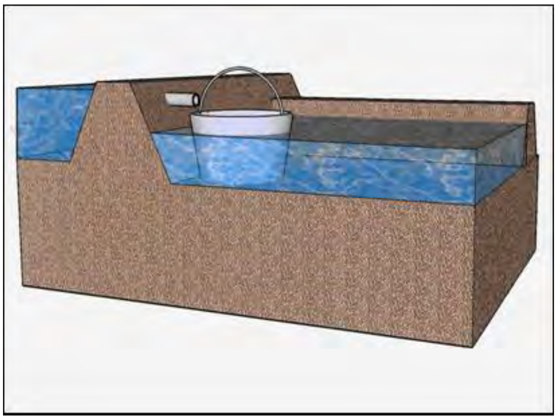
Irrigation systems use different types of field intakes to discharge water to the irrigated area. The main types are open breaches, siphons, spiles, nozzles and low-pressure emitters.

Photo 21: Discharge test of a furrow breach

Source: F. Sandor (2008), Samarkhil, Afghanistan

Open breaches discharge water freely, which means that the head is the difference or there is no difference between water level in the channel and the outlet from the breach. Spiles and siphons can discharge water freely or submerged. When the discharge is free, the head is the difference between water level in the channel and the outlet from the pipe. When the discharge is submerged the outlet may below the water level in the field. This is called submerged discharge.

Figure 54 Water discharge test of a spile



Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

Test - Free discharge

1. Place a bucket behind the bund in a position that the outlet can discharge the water directly into the bucket
2. Measure the time that is needed to fill up the bucket
3. Record the time
4. Repeat the test various times

Equation

Discharge [D in (l/sec)] = Volume of bucket (l) / Time to fill bucket (sec)

Average Discharge [AD in (l/sec)]=(D_1 + D_2 +…+ D_n) / n

Test – Submerged discharged

1. Place a bucket behind the bund so that the bucket lip is at the same level as the water on the field
2. Allow the outlet to discharge water into the hole alongside of the bucket

3. Hold the bucket and allow the water to overflow into the bucket
4. Measure the time that is needed to fill the bucket
5. Record the time
6. Repeat the test numerous times

Equation

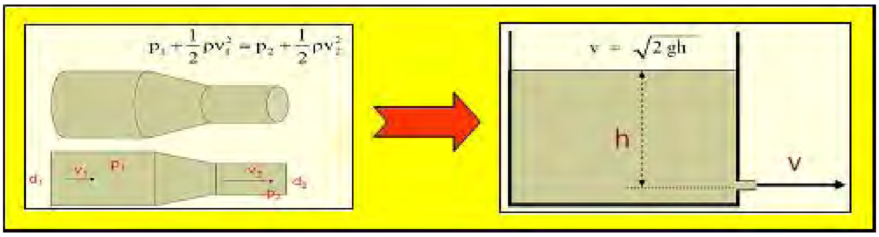
Discharge [D in (l/sec)] = Volume of bucket (l) / Time to fill bucket (sec)

Average Discharge [AD in (l/sec)]=(D_1 + D_2 +…+ D_n) / n

Test – Free discharge from a pipe

The Bernoulli law states that the flow rate inside a tube (or pipe) at any point is the same independently of the diameter of the tube. Therefore as the diameter decreases, the fluid velocity increases and the pressure decreases. Consequently, the Bernoulli law Toricelly established states the equation for the speed of the water from which water flows out from a hole.

Figure 55 Bernoulli law and the calculation of Toricelly using the Bernoulli law



Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

1. Measure the depth of the water in the reserve, tank, canal etc. from the pipe connection middle point (Distance of the fluid mass central point up to fluid's zero static energy level). This is called hydraulic charge.
2. Measure the pipe inside diameter
3. Measure the short pipe length
4. Calculate the rate between pipe length and diameter. This is called Coefficient for discharge
5. Calculate the pipe cross section area
6. Calculate water flow velocity
7. Establish discharge rate

Equation

V_w = √2 x g x h (m/sec)
where
V_w = Water velocity
g = Free gravity fall (0.98 m/sec ≈ 10 m/sec)
h = Hydraulic charge

Dw = A x V_w x C_d
where
Dw = Water discharge
A = pipe cross section area = (∏ x d^2) / 4 and ∏ is equal to 3.14
V_w = Water velocity
C_d = Coefficient for discharge and its value is the following:

Table 19 Coefficient for discharge

Length vs. Diameter	C_d value
10	0.77
15	0.75
20	0.73
30	0.70
40	0.66
50	0.63
60	0.60
100	0.55
300	0.38

Source: W. L. Trimmer (1994), Estimating water flow rates, Oregon State University, USA

Test – US full pipe method for free discharge

1. Place a carpenter rule along the pipe surface
2. Measure the length of the discharge using a 13” vertical drop distance from the end of the carpenter rule to the water drop. Use a plumb to establish a vertical line.
3. Measure the pipe diameter
4. Calculate the surface of the pipe cross section

Equation

$D_w = (3.61 \times A \times X) / \sqrt{Y}$ (gpm = gallon per minute)
where
D_w = Water discharge
A = pipe cross section area = $(\prod \times d^2) / 4$ and $\prod$ is equal to 3.14
X = Horizontal distance
Y = Vertical drop = 13”
Liter per hour (l/Hrs) = gpm x 226.8

Test – US partially full pipe method for free discharge

1. Place a carpenter rule along the pipe surface
2. Measure the length of the discharge using a 13” vertical drop distance from the end of the carpenter rule to the water drop. Use a plumb to establish a vertical line.
3. Measure the pipe diameter
4. Calculate the surface of the pipe cross section
5. Measure the empty portion at the end of the pipe
6. Establish the rate between empty portion and pipe diameter

Photo 22 Outlet to discharge water into the canal

Source: F. Sandor (2002), Domasi, Malawi

Equation

$DF_w = (3.61 \times A \times X) / \sqrt{Y}$ (gpm = gallon per minute)

where

DF_w = Full pipe water discharge

A = pipe cross section area = $(\prod \times d^2) / 4$ and $\prod$ is equal to 3.14

X = Horizontal distance

Y = Vertical drop = 13”

$D_w = DF_w \times F_y$

where

D_w = Water discharge

F_y = Effective area factor and its value is the following:

Table 20 Effective area factor

Empty portion vs. Diameter	F_y value
0.05	0.981
0.10	0.948
0.15	0.905
0.20	0.858
0.25	0.805
0.30	0.747
0.35	0.688
0.40	0.627
0.45	0.564
0.50	0.500
0.55	0.436
0.60	0.373
0.65	0.312
0.70	0.253
0.75	0.195
0.80	0.142
0.85	0.095
0.90	0.052
0.95	0.019
1.00	0.000

Source: W. L. Trimmer (1994), Estimating water flow rates, Oregon State University, USA

Test - Water flow in open channel or stream

To establish water flow rate it is necessary know the cross section area of the flowing water and the speed of the water to run.

1. Water velocity in open channel or stream
    - Measure a representative section of the channel or stream
    - Mark its starting and ending point
    - Place a ball (table tennis) where is the starting point
    - Record the time, which needs the ball to reach the end point

2. Calculate cross section area
3. Calculate water flow

Photo 23 Water flow test for open channel

Source: F. Sandor (2008), Samarkhil, Afghanistan

Equation

$v_w = (S_d / t) \pm 10\%$ (m/min = m/sec x 60)

where

v_w = water velocity

S_d = Section distance

t = time period between the two end of the section

Cross section area:

- V channel = (b x h) /2
- Square or rectangle channel = a x b
- Trapezoid channel = [(a+b) / 2] x h
- Stream channel = $[(h_1 + h_2 + \dots + h_n) / n] \times b$

where,

b = Width of the channel at the level of water

h = Water depth

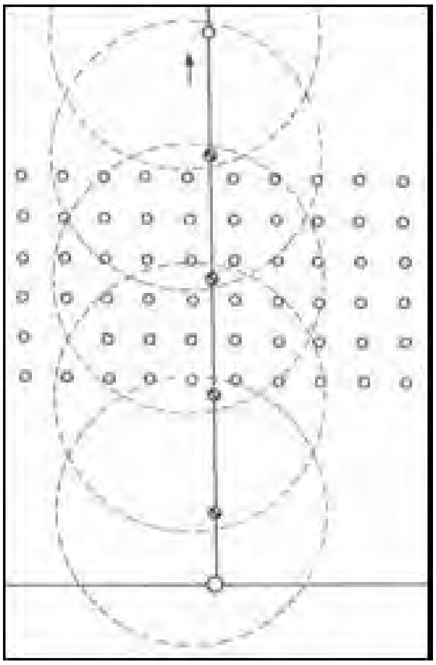
a = Bottom width

Water flow=Water speed x Cross section area   (m^3/min)

Test – Water flow from sprinkler

1. From the sprinkler on a straight line, place containers every 2 m
2. Allow water discharge for some time
3. Measure the volume of water in each container
4. Establish the water distribution curve

Figure 56 Water discharge test of sprinkler irrigation system



Source: D. Brasil Vieira (1989), As Tecnicas de Irrigacao, Sao Paulo, Brasil

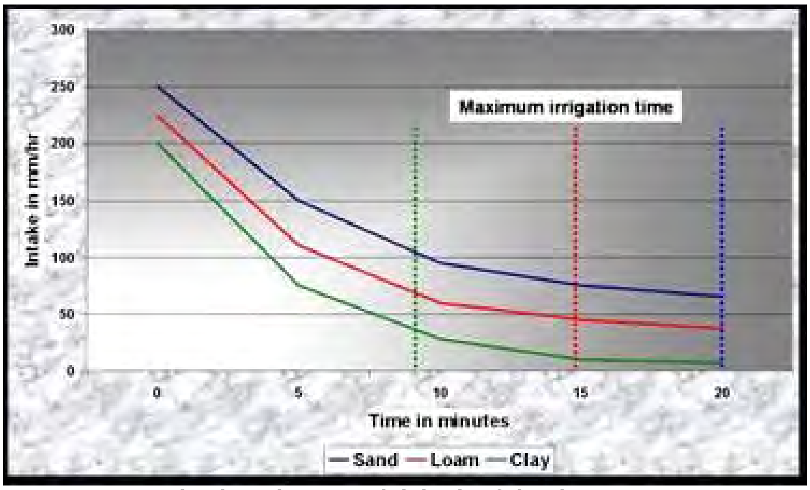
6.3 Wetting Pattern

6.3.1 Analysis - Surface irrigation

To obtain a consistently wet root zone, the surface of the basin must be level and the irrigation water must be applied quickly. It is not possible to have the wetting pattern and root zone coincide completely. The part of the basin nearest to the field channel is always in contact with the irrigation water longer than the opposite side of the basin.

Lateral and downward movement of water depends on soil type. In sandy soil the downward movement is faster than lateral movement; therefore the wetting pattern is long and narrow. While in clayey soils the situation is exactly the opposite. In an ideal situation adjacent wetting patterns overlap each other, and there is an upward movement of water (capillary rise) that wets the entire ridge.

Figure 57 Water intake of differently textured soils



Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

There are two different time periods that are used to describe the water flow. The first time period is measured by the time taken for the water to flow from the discharge point to the opposite side of the field, which is called the Advance of Water Front. The second time period is measured from the time the water supply is stopped to the time taken for the water to infiltrate into the soil, which is called the Recession of Water Front.

When both time periods are the same, an ideal and uniform wetting pattern is produced. However, in most cases the advance period is slower than the recession period, which explains why the part of the field nearest to the water supply receives more water than the opposite side of the field. When the stream size increases, the water distribution improves and the two types of time periods become closer to each other. Therefore the selection of an appropriate stream size is very important, which can be achieved through use of the Quarter Time Rule method.

Test – Quarter time rule

1. Calculate the infiltration rate and establish the infiltration curve
2. Determine the required water depth
3. Check from the infiltration curve the time that is needed to achieve the required water depth
4. Divide this time period by 4. This value will be the required advance time of the water front
5. Test it in practice

The Quarter Time Rule dictates that the water discharge should be large enough for the water to reach the end or cover the field/ furrow in a quarter of the overall time that would be required to fill the water to the needed depth.

Equation

$t_Q = t_I / 4$

where,

t_i = Time to fill the required water depth

t_Q = Quarter time

6.3.2 Analysis - Localized irrigation

The wetting pattern is similar to that of the furrow irrigation and equally differs according to the soil texture. It also shows a similar difference in the water discharge rate. Higher discharge creates a wider pattern than lower discharge. The system only wets part of the root zone.

6.3.3 Analysis – Sprinkler irrigation

The wetting pattern from a single rotary sprinkler is not very uniform. The area wetted is circular from an aerial view and conical from the cross section point of view. The heaviest wetting occurs in the area closest to the sprinkler. For uniform patterns it is necessary to operate several sprinklers close together so that their patterns overlap. The overlap should be at least 65% of the wetted diameter. This determines the maximum spacing between sprinklers.

6.4 Irrigation time

The required irrigation time depends on the water discharge rate, the required irrigation depth and the irrigated surface area.

Test – Irrigation time

1. Establish required irrigation depth
2. Calculate the irrigated area
3. Calculate the water discharge rate

Equation

$T_I = (2.78 \times h_D \times A_I) / D_W$

Where,

T_I = Irrigation time (Hrs)

h_D = Irrigation depth (mm)

A_I = Irrigated area (Ha)

D_W = Water discharge (l/sec)

When dealing with surface irrigation, apply the Quarter Time Rule for the irrigation time, this will give the time that is needed for the water to reach the end of the furrow or cover the basin.

6.5 Field Application Efficiency

The farmer needs to know and determine the performance of basin or furrow irrigation. To achieve that he has to compare his irrigation water need and depth calculation with the actual performance of the irrigation practice. The field application efficiency can be determined through the following equation:

Equation

$$\text{Field application efficiency} = \frac{\text{Required irrigation depth}}{\text{Average irrigation depth}} \times 100\ (\%)$$

When using the surface irrigation method, the Field application efficiency can be measured through the following test:

Test

1. Select a typical basin or furrow and measure its size or length
2. Place posts at 5-10 meters intervals along the furrow or basin
3. Carry out an infiltration test and design the infiltration curve
4. Start to irrigate and record the advance time values (The time period needed for the water to reach each one of the posts).
5. Record the recession time (The time period needed for the water to infiltrate at each one of the posts).

Equation

Tc = Tr – Ta (min)

Where,

Tc = Contact time

Tr = Recession time

Ta = Advance time

Calculate from the infiltration curve the applied water for each post

$h_{AD} = (h_{D1}+h_{D2}+\ldots..+h_{Dn}) / n$

where,

h_{AD} = Average irrigation depth

h_{Dn} = Irrigation depth for each post

$E_A = h_R / h_{AD} \times 100$ (%)

Where,

E_A = Field application efficiency

h_R = Required irrigation depth

h_{AD} = Average irrigation depth (Applied)

7 Irrigation Schedule

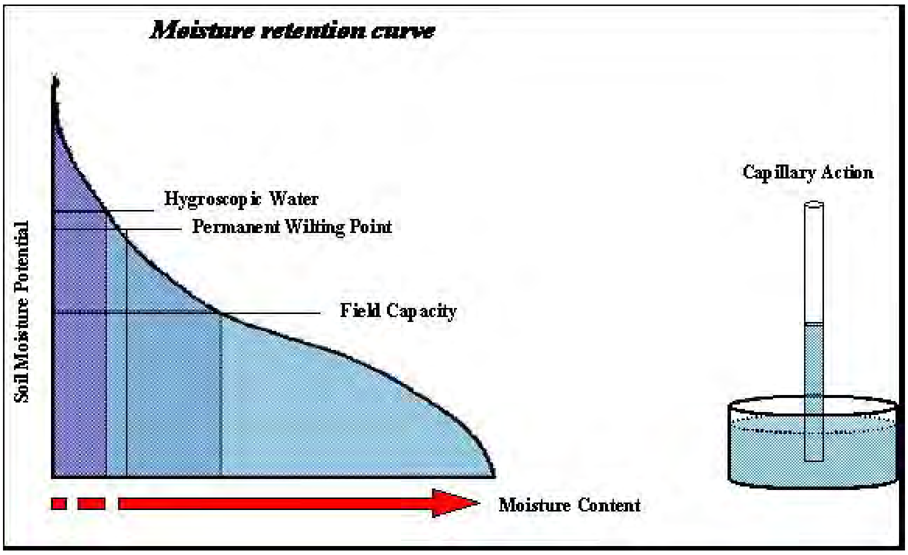
Soil water conditions strongly influence the irrigation scheduling. Knowing the actual water content and the soil water storage capacity allows the technician to determine how much water to apply at one time and the adequate intervals between each irrigation.

7.1 Soil Water Storage Capacity

Soil has three main water condition levels. The *water saturation capacity* (SC) is the moisture content of the soil when all soil pores are completely filled with water. The *field capacity* (FC) is the amount of water that the soil is able to hold after 48 hours. Finally, the *permanent wilting point* (PWP) is the soil water content at which water cannot be extracted from the soil, meaning this amount of water is no longer available for plant growth.

The soil available water content is the amount of water, which can be used by the plant. Its value is the difference between field capacity and permanent wilting point and in mm of water per unit (usually 1 meter) of soil depth.

Figure 58 Water conditions in the soil



Source: F. Sandor (2007), PRI Prison Farms Manual, Lilongwe, Malawi

7.2 Estimate Field Capacity

The estimated maximum field capacity (FC) or *Drained upper limit* (DUL) will be the volumetric moisture content of the soil after 48 hours. The principle of the calculation will be the following:

Gravimetric soil moisture (%) = (Wet soil weight – Dry soil weight) x 100

Volumetric soil moisture = Gravimetric soil moisture x Bulk density*

***Bulk density = See manual: RoP, Soil testing, No. 2008-001-AFG, February 8, 2008**

<u>*Test*</u>

1. Take a soil sample
2. Saturate the sample with water

3. Allow for the excess water to leach out by the force of gravity during a time period of 48 hours
4. Measure the weight of the sample
5. Oven- dry the sample at 105 C° for 24 hours
6. Measure the weight of the oven dried sample

****Test (Soil moisture analysis) = See manual: RoP, Soil testing, No. 2008-001-AFG, February 8, 2008**

Equation

$q_g = (W_w – W_d) / (W_d – W_c)$

Where,

q_g = Gravimetric water content

W_w = Mass of wet soil and container

W_d = Mass of dry soil and container

W_c = Mass of container

$q_v = q_g \times r_b / r_w$

Where,

q_v = Volumetric water content

q_g = Gravimetric water content

r_b = Bulk density of soil

r_w = Density of water

$FC = q_v \times h_s / A_s$

Where,

FC = Field capacity

q_v = Volumetric water content (cm^3 or ml)

h_s = Soil depth unit (1m = 100 cm)

A_s = Soil surface unit ($1m^2$ = 10 000 cm^2)

When testing the actual existing volumetric water content of the soil, it is not necessary to saturate the soil with water. You only need to measure the weight of the wet sample recollected from the field. Soil appearance can indicate the actual water content of the soil. Without accuracy it can indicate the soil moisture status.

Table 21 Determining available soil moisture by feel or appearance

Available water (%)	Coarse (Sand, Loamy sand)	Light (Fine sand, Sandy loam)	Medium (Loam, Silt clay)	Heavy (Sandy clay, Heavy clay)
PWP or drier	Dry, loose, single grained, flows through fingers	Dry, loose, flows through fingers	Powdery, dry, easily breaks into powder when crusted	Hard, baked, cracked, loose crumbs on surface
<50	Appears to be dry, not form a ball with pressure	Appears to be dry, not form a ball with pressure	Crumbly but hold together from pressure	Somewhat pliable, form ball under pressure
50 – 75	Appears to be dry, not form a ball with pressure	Tends to ball under pressure but seldom will hold together	Forms ball, somewhat plastic, slick slightly with pressure	Form ball, will ribbon out between thumb and finger
75 to FC	Slightly stick together, from very weak ball under pressure	Forms weak ball, breaks easily, will not slick	Forms ball, very pliable, slicks readily if high in clay	Easily ribbon out between fingers, has a slick feeling
At FC	Upon squeezing, no free water appears but wet, outline of ball is left on hand	Upon squeezing, no free water appears but wet, outline of ball is left on hand	Upon squeezing, no free water appears but wet, outline of ball is left on hand	Upon squeezing, no free water appears but wet, outline of ball is left on hand
>FC	Free water appears when soil is bounced in hand	Free water will be released with kneading	Can squeeze out free water	Puddles and free water forms on surface

Source: Manitoba Agriculture (2006), Water use and moisture management

7.3 Estimate Permanent Wilting Point

Test

1. Take an air dried and sieved soil sample and fill a cylinder
2. Put the cylinder in a plate and fill the plate with water
3. Saturate the sample with water (leave the sample to wet overnight in the plate)
4. Transfer the plate with the cylinder to a pressure chamber and apply 1.5 MPa (1500 KPa) positive pressure
5. Remove the soil sample after extraction
6. Weigh the sample
7. Oven-dry the sample for 24 hours at 105 C^o

Equation

$PWP_w = M_w / M_s$

Where,

PWP_w = Permanent wilting point on weight basis

M_w = Mass of water

M_s = Mass of oven dried soil

$PWP_v = PWP_w \times r_b / r_w$

Where,

PWP_v = Permanent wilting point on volume basis

PWP_w = Permanent wilting point on weight basis

r_b = Bulk density of soil

r_w = Density of water

7.4 Estimate Available Water Storage Capacity

The soil *available water storage capacity* (AWSC), also known as *available water capacity* (AWC) is the amount of moisture the soil can store between field capacity (FC) and permanent wilting point (PWP).

<u>Equation</u>

$AWSC_w = FC_w – PWP_w$ established on weight basis

Where,

$AWSC_w$ = Available water storage capacity on weight basis

FC_w = Field capacity on weight basis

PWP_w = Permanent wilting point on weight basis

$AWSC_v = FC_v – PWP_v$ established on volume basis

Where,

$AWSC_v$ = Available water storage capacity on volume basis

FC_v = Field capacity on volume basis

PWP_v = Permanent wilting point on volume basis

AWSC in mm per 1m soil depth = AWSC x (h_s / A_s) x 10

Where,

AWSC = Available water storage capacity in cm^3 or ml

h_s = Soil depth unit (1m = 100 cm)

A_s = Soil surface unit ($1m^2$ = 10 000 cm^2)

The pressure outflow method for estimating permanent wilting point is quite an accurate estimation. However, not everyone has a pressure chamber to implement the test. Therefore, the following table shows the average available water storage capacity of the different soil texture classes.

Table 22 Available water storage capacity and infiltration rate

Soil texture	AWSC (mm/m)	Infiltration (mm/Hrs)
Clay	200	6.3
Silt Loam	208	8.9
Clay Loam	200	7.6
Loam	175	8.9
Fine Sandy Loam	142	10.1
Sandy Loam	125	11.4
Loamy Sand	100	16.5
Sand	83	19.0

Source: T.W. Gulik (2005), Landscape irrigation scheduling calculator, IIABC

7.5 Soil Water Storage Capacity

The soil *water storage capacity* (SWS) easily can be calculated from the Available water storage capacity (AWSC) if the *effective root depth* of the plant (RD) is known. It indicates how much water should be applied at one time and which frequency the crop should be irrigated.

Equation

SWS = RD x AWSC

Where,

SWS = Soil water storage

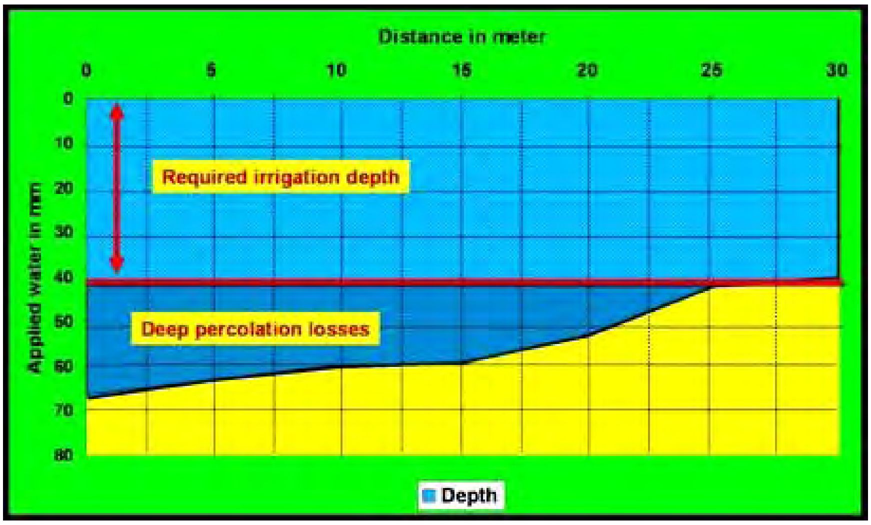
RD = Rooting depth

AWSC = Available water storage capacity

7.6 Maximum Soil Water Deficit

The *Maximum soil water deficit* (MSWD) also known as *Readily available water* (RAW) or *Plant available water capacity* (PAWC) is the amount of water in the soil that is allowed to be removed from the soil prior to irrigation. Ted W. van der Gulik (Landscape Irrigation Scheduling Calculator, IIABC, May 2005) describes it as: "…the amount of water that can be stored in the soil that is readily available to the plant…The MSWD is also the maximum amount of water that can be applied at one time before the risk of deep percolation occurs."

Figure 59 Percolation loss



Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

To calculate MSWD from Soil water storage capacity a factor called Availability coefficient (AC) or Management allowed deficit (MAD), should be applied. The AC is expressed in percentage and it refers to the amount of water that can be extracted by the plant without putting unnecessary stress on the plant. The availability coefficient varies with plant species. For high value crops the AC is 40% or less, meanwhile for low value crop the AC is 60% or more. Usually an average value of 50% for AC represents a reasonable value for most row crops.

Equation

MSWD = SWC x AC

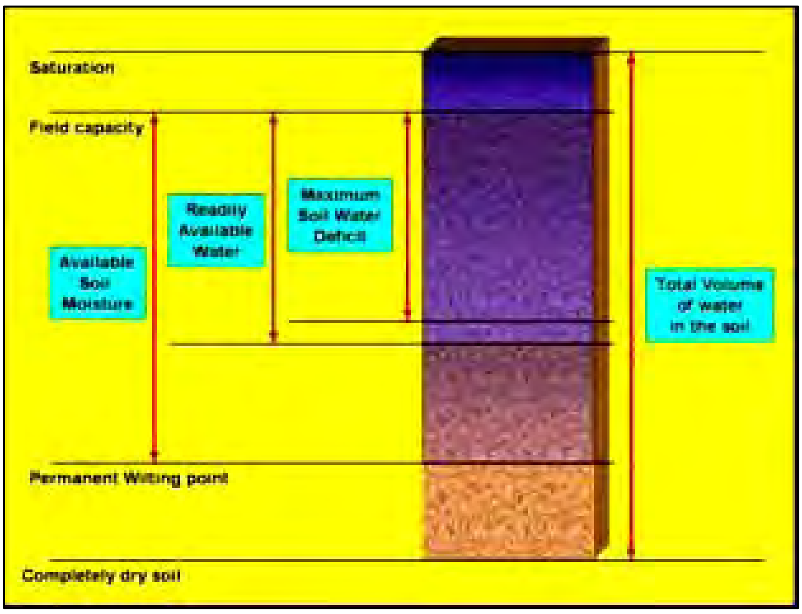
Where,

MSWD = Maximum soil water deficit (MSWD = RAW = PAWC)

SWS = Soil water storage

AC = Availability coefficient

Figure 60 Soil moisture conditions

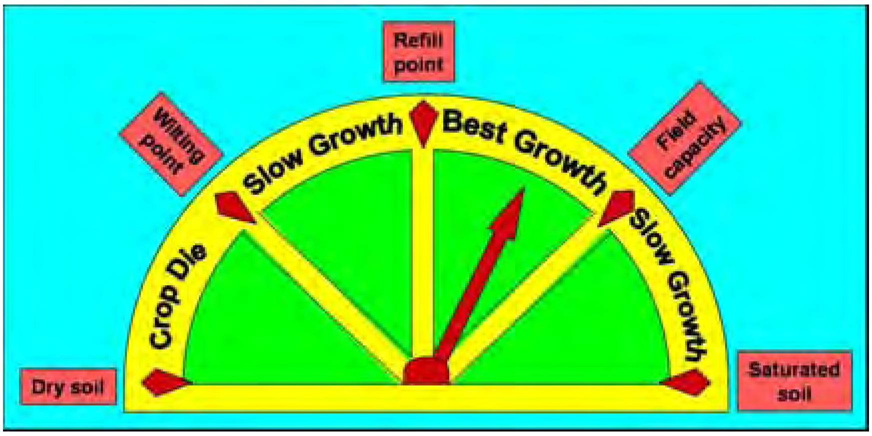


Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

7.7 *Irrigation Interval And Amount Of Water Applied At One Time*

Calculating the *irrigation interval* (I_{Int} =) is one the most critical steps to establish an efficient irrigation system. The simplest way to establish the periods between irrigations is to collect information about the *Maximum soil water deficit* (MSWD) and the *crop water use* (ETcrop). According to the climate and the stage of plant development, the evapo-transpiration and plant water need values are changing during the growing period, therefore, the irrigation interval is calculated on a monthly basis. The irrigation interval is expressed in days. The volume of irrigation water at one time is equal to the amount of water of MSWD.

Figure 61 Irrigation clock



Source: Based on H. Ramsey (2007), Farm note, Waroona, Australia

Equation

I_{Int} = MSWD / ETcrop

Where,

I_{Int} = Irrigation interval

MSWD = Maximum soil water deficit (MSWD = RAW = PAWC)

ETcrop = Crop daily water need

7.8 *Irrigation Time*

There is a specific time period needed to apply the calculated amount of irrigation water. The value of the time period depends on the required amount of water (MSWD) and the water discharge rate per unit time period. It is also calculated on a monthly basis and expressed in minutes or hours.

Equation

T_{Irr} = MSWD / Dw

Where,

T_{Irr} = Irrigation time

MSWD = Maximum soil water deficit (MSWD = RAW = PAWC)

Dw = Water discharge

7.9 Moisture Accounting Method

This method is a day-to-day method, which measures the amount of water coming in and out to the effective root zone. It expresses the balance of total water present in the root zone on a particular day. The following formula describes the total water in the root zone:

Equation

$TW_T = TW_{T-1} + P_e + Irr – ETcrop – DEEP - Flux_{net}$

Where,

TW_T = Total water in the root zone on day T

TW_{T-1} = Total water in the root zone on previous day of T

P_e = Effective rainfall

Irr = Applied irrigation water

ETcrop = Crop water use

DEEP = Percolation loss

$Flux_{net}$ = Any change in total water in the root zone

Basically, the *moisture accounting method* uses this formula to calculate cumulative soil water deficit on a daily basis. Through this information the exact day when we should irrigate can be determined.

Example

Soil texture = clay

Crop = tomato

Effective root depth (RD) = 0.55 m

Available water storage capacity (AWSC) = 200 mm/m

Soil water storage (SWS) = 0.55 x 200 = 110 mm

Availability coefficient (AC) = 40 %

Maximum soil water deficit (MSWD) = 110 x 0.40 = 44 mm

Irrigation water at one time = 44 mm

Irrigation method = furrow irrigation

Discharge rate = 20 l/sec = 1,200 l/min

Length of field = 90 m

Width of furrow = 0.6 m

Number of furrow = 100

Volumetric MSWD = 44 l/m2 (4.4 cm x 100 cm x 100 cm)

MSWD per furrow = 44 x 0.6 x 90 = 2,376 l/furrow

MSWD for total area = 100 x 2,376 =237,600 liter = 237.6 m3

Irrigation time = 237,600 / 1,200 = 198 minutes = 3.3 hours

Table 23 Example of moisture balance sheet

Moisture Balance Sheet								
Day	ETo	Kc	ETcrop	P	Pe	Irrigation	Soil water	Cumulative water deficit
	A	B	C=AxB	D	E=D-5	F	G=(E+F)-C	H
	mm/day		mm/day	mm	mm	mm	mm	mm
1	7.5	0.85	6.4	0	0	44.0	37.6	-6.4
2	8.5	0.85	7.2	2.7	0	0	30.4	-13.6
3	8.9	0.85	7.6	5.4	0.4	0	22.8	-20.8
4	8.8	0.85	7.5	0	0	0	15.3	-28.3
5	7.2	0.85	6.1	0	0	0	9.2	-34.4
6	9.4	0.85	8.0	0	0	0	1.2	-42.4
7	6.9	0.85	5.9	0	0	44.0	39.3	-4.7
8	3.5	0.85	3.0	0	0	0	36.3	-7.7
9	6.2	0.85	5.3	6.0	1.0	0	31.0	-13.0
10	6.5	0.85	5.5	3.2	0	0	25.5	-18.5

ET_{crop} = Crop water need, K_c = Crop factor, ETo = Reference crop evapo-transpiration, P_e = Effective rainfall, P = Total rainfall
Source: F. Sandor (2008), RoP Jalalabad, Afghanistan

7.10 Irrigation System Parameters

After the tests and calculations regarding soil water characteristics, crop and irrigation water needs and the water distribution parameters have been included, it is then time to calculate the parameters of the irrigation system. With surface irrigation, considering its relative simplicity, there is no need to implement further tests or calculations; however sprinkler and trickle systems require more accurate data. For the purpose of this manual we use the formulas recommended by Irrigation Industry Association of BC (IIABC) in its manual: Landscape irrigation scheduling calculator; May 2005.

7.10.1 Equation for Application Rate (AR)

Equation

Sprinkler system AR = (227 x Q) / (S_1 x S_2)

Where,

AR = Application rate in mm/Hrs

227 = Factor to convert gpm to mm/Hrs

Q = Sprinkler flow rate in gpm

S_1 = Sprinkler spacing along lateral in meter

S_2 = Lateral spacing in meter

Drip/Trickle system AR = Q / (S_1 x S_2)

Where,

AR = Application rate in mm/Hrs

Q = Emitter flow rate in l/Hrs

S_1 = Emitter spacing along line in meter

S_2 = Line spacing in meter

Table 24 Parameters for Application Efficiency (Ae)

Application Efficiency (Ae)	
Irrigation system	**Ae factor**
Drip	0.90
Trickle	0.90
Microspinkler	0.80
Rotor sprinkler	0.72
Spray head	0.70

Source: T.W. Gulik (2005), Landscape irrigation scheduling calculator, IIABC

7.10.2 Equation for Irrigation Water Requirement (IR)

Equation

$IR = ET_L / Ae$

Where,

IR = Irrigation Water Requirement in mm

ET_L = Landscape evapo-transpiration in mm

Ae = Application efficiency in %

7.10.3 Equation for Operating Time (OT)

It is the maximum length of time the system should operate for each irrigation event.

Equation

$OT = (ET_L \times 60) / AR$

Where,

OT = Operating time in minutes

ET_L = Landscape evapo-transpiration in mm

AR = Application rate in mm/Hrs

Table 25 Parameters for Management Allowed Deficit/Depletion (MAD equal to Availability Coefficient [AC])

Management Allowed Deficit (MAD)		
Soil texture	**Sprinkler system (%)**	**Drip system (%)**
Clay	70	50
Silt Loam	80	60
Clay Loam	80	60
Loam	100	60
Fine Sandy Loam	100	70
Sandy Loam	100	70
Loamy Sand	100	80
Sand	100	80

Source: T.W. Gulik (2005), Landscape irrigation scheduling calculator, IIABC

7.10.4 Equation for adjusted Maximum Soil Water Deficit ($MSWD_{MAD}$)

Equation

$MSWD_{MAD}$ = MSWD x MAD

Where,

$MSWD_{MAD}$ = Adjusted Maximum soil water deficit in mm

MSWD = Maximum soil water deficit in mm

MAD = Management Allowed Deficit in %

7.10.5 Equation for Irrigation Days (ID)

They are the number of days the irrigation system will operate during the reference time period.

Equation

ID = ET_L / $MSWD_{MAD}$

Where,

ID = Irrigation days

ET_L = Landscape evapo-transpiration in mm

$MSWD_{MAD}$ = Adjusted Maximum soil water deficit in mm

7.10.6 Equation for Total Run Time per Day (T_d)

IT is the amount of time on each irrigation day that the irrigation system will operate during that 24 hour period.

Equation

T_d = OT / ID

Where,

T_d = Total run time per day in min/day

OT = Operating time in minutes

ID = Irrigation days

7.10.7 Equation for Maximum Runtime per Cycle (RC)

It is the time period, that it takes for run off to begin after the irrigation system has been turned on.

Equation

$RC = (CI_{Cn} \times 60) / AR$

Where,

RC = Maximum Runtime per Cycle in minutes

CI_{Cn} = Constant Cumulative infiltration rate in mm/Hrs

AR = Application rate in mm/Hrs

7.10.8 Equation for Cycles per Day (C)

It is applied when the total run time per day is greater than the maximum runtime per day. It prevents run off and allows the water to infiltrate into the soil.

Equation

$C = T_d / RC$

Where,

C = Cycles per day

T_d = Total run time per day in min/day

RC = Maximum Runtime per Cycle in minutes

Photo 24: Surface and underground intake structure

Source: F. Sandor (2003), Dedza, Malawi

7.11 Design Irrigation Schedule

To facilitate irrigation scheduling and calculate the above described formulas IIABC recommended the use of the Base Theoretical Irrigation Schedule Worksheet.

Table 26 **Base theoretical Irrigation schedule**

Base Theoretical Irrigation Schedule Worksheet			
Item	**Source of calculation**	**Value**	**Unit or function**
1. Landscape water requirement			
1.1. Parent material	Landscape plan		Classification
1.2. Reference month	Judgment		Month
1.3. Reference period	Judgment		Irrigation period-days
1.4. ETo (reference period)	$ETo = K_{pan} \times E_{pan}$		mm per period
1.5. Landscape coefficient (ET_L)	$K_L = K_c \times K_d \times K_{mc}$		Plant multiplier
1.6. Management factor (K_m)	K_m = __________		Site multiplier
1.7. Water requirement	$ET_L = ETo \text{ X } K_L$		mm per month
2. Soil properties			
2.1. Soil type (Root zone)	Site inspection		Soil texture
2.2. Water infiltration rate	$CIR = Ct_n$ against CIR_n		mm per hour
2.3. Available water storage capacity (AWSC)	$AWSC_w = FC_w – PWP_w$		mm per m of soil
2.4. Rooting depth (RD)	Site inspection		meter
2.5. Soil water storage (SWS)	SWS = RD x AWSC		mm
2.6. Availability coefficient (AC)	50 % (40-60%)		Expressed in decimal
2.7. Maximum soil water deficit (MSWD)	MSWD = SWC x AC		mm
3. Irrigation system	**System type:**		
3.1. Application rate (AR)	$AR = (227 \times Q) / (S_1 \times S_2)$ or $AR = Q / (S_1 \times S_2)$		mm per hour
3.2. Application efficiency (Ae)	According to system type		Expressed in decimal
3.3. Irrigation water requirement (IR)	$IR = ET_L / Ae$		mm per period
3.4. Operating time (OT)	$OT = (ET_L \times 60) / AR$		Minutes per period
3.5. Management allowed deficit (MAD)	50 % (40-60%)		Expressed in decimal
4. Scheduling requirement			
4.1. Irrigation days (ID)	$ID=ET_L / (MSWD \times MAD)$		Days in period
4.2. Water restrictions	Water purveyor		Days or Hrs in period
4.3. Total runtime per day (Td)	$T_d = OT / ID$		Minutes per day
4.4. Max. runtime per cycle (RC)	$RC = (CI_{Cn} \times 60) / AR$		Minutes
4.5. Cycles per day (C)	$C = T_d / RC$		Repetition

Source: T.W. Gulik (2005), Landscape irrigation scheduling calculator, IIABC

With some modifications, the Base Theoretical Irrigation Schedule Worksheet can be used for surface irrigation.

Table 27 Base theoretical Irrigation schedule for surface irrigation

Base Theoretical Irrigation Schedule Worksheet for Surface Irrigation			
Item	**Source of calculation**	**Value**	**Unit or function**
1. Landscape water requirement			
1.1. Parent material	Landscape plan		Classification
1.2. Reference month	Judgment		Month
1.3. Reference period	Judgment		Irrigation period-days
1.4. ETo (reference period)	ETo = K_{pan} x E_{pan}		mm per period
1.5. Landscape coefficient (ET_L)	K_L = K_c x K_d x K_{mc}		Plant multiplier
1.6. Management factor (K_m)	K_m = __________		Site multiplier
1.7. Water requirement	ET_L = ETo X K_L		mm per month
2. Soil properties			
2.1. Soil type (Root zone)	Site inspection		Soil texture
2.2. Water infiltration rate	CIR = Ct_n against CIR_n		mm per hour
2.3. Available water storage capacity (AWSC)	$AWSC_w$ = FC_w – PWP_w		mm per m of soil
2.4. Rooting depth (RD)	Site inspection		meter
2.5. Soil water storage (SWS)	SWS = RD x AWSC		mm
2.6. Availability coefficient (AC)	50 % (40-60%)		Expressed in decimal
2.7. Maximum soil water deficit (MSWD)	MSWD = SWC x AC		mm
3. Irrigation system	**System type:**		
3.1. Discharge rate (AD or D_W)	AD=(D_1+D_2 + … +D_n) / n		Liter per second
3.2. Area of basin or furrow (A)	A=L x W or A=L x W x Fn		m^2
3.3. Number of furrow (Fn)	Fn=___________		Units
3.4 Volumetric MSWD ($MSWD_{VOL}$)	$MSWD_{VOL}$=MSWDx1000		Liter per m^2
3.5. Irrigation water / one time (IN)	IN= $MSWD_{VOL}$ x A		Liter or m^3
4. Scheduling requirement			
4.1. Irrigation time (T_I)	T_I = (2.78 x h_D x A_I) / D_W		Hours
4.2. Irrigation interval (I_{Int})	I_{Int} = MSWD / ETcrop		Days per period
4.3. Quarter time (QR_T)	QR_T = T_I / 4		Hours
4.4. Application efficiency (E_A)	E_A = h_R / (h_{AD} x 100)		Percentage

Source: F. Sandor (2008), Roots of Peace, Jalalabad, Afghanistan

The traveling gun irrigation system also requires some modification of the Base Theoretical Irrigation Schedule Worksheet.

Table 28 Base theoretical Irrigation schedule for traveling gun irrigation system

Base Theoretical Irrigation Schedule Worksheet for Travelling Gun Irrigation System			
Item	**Source of calculation**	**Value**	**Unit or function**
1. Landscape water requirement			
1.1. Parent material	Landscape plan		Classification
1.2. Reference month	Judgment		Month
1.3. Reference period	Judgment		Irrigation period-days
1.4. ETo (reference period)	ETo = K_{pan} x E_{pan}		mm per period
1.5. Landscape coefficient (ET_L)	$K_L = K_c \times K_d \times K_{mc}$		Plant multiplier
1.6. Management factor (K_m)	K_m = __________		Site multiplier
1.7. Water requirement	ET_L = ETo X K_L		mm per month
2. Soil properties			
2.1. Soil type (Root zone)	Site inspection		Soil texture
2.2. Water infiltration rate	CIR = Ct_n against CIR_n		mm per hour
2.3. Available water storage capacity (AWSC)	$AWSC_w = FC_w - PWP_w$		mm per m of soil
2.4. Rooting depth (RD)	Site inspection		meter
2.5. Soil water storage (SWS)	SWS = RD x AWSC		mm
2.6. Availability coefficient (AC)	50 % (40-60%)		Expressed in decimal
2.7. Maximum soil water deficit (MSWD)	MSWD = SWC x AC		mm
3. Irrigation system	**System type:**		
3.1. Application rate (AR)	AR = 227 x Q		mm per hour
3.2. Application efficiency (Ae)	According to system type		Expressed in decimal
3.3. Irrigation water requirement (IR)	IR = ET_L / Ae		mm per period
3.4. Operating time (OT)	OT = (ET_L x 60) / AR		Minutes per period
3.5. Management allowed deficit (MAD)	50 % (40-60%)		Expressed in decimal
4. Scheduling requirement			
4.2. Irrigation interval (I_{Int})	I_{Int} = MSWD / ETcrop		Days
4.2. Discharge (D_U)	D_U=AD/$Width_W$/$Length_H$		mm per hour
4.3. Speed (v_U)	v_U=AD/$Width_W$/MSWD		m per hour

*** $Width_W$ = Wetted width in meter   ** $Length_H$ = Distance traveled in one hour**

Source: F. Sandor (2008), Roots of Peace, Jalalabad, Afghanistan

7.12 Calculating Requirements to Determine Irrigation Schedule

7.12.1 Surface irrigation:

- Test and calculate infiltration rate into the soil
- Test and calculate the discharge of the water source
- Test and calculate water flow in the main irrigation canal
- Test and calculate discharge to the furrow or basin
- Test and calculate water flow in the furrow
- Test and calculate advance time, recession time and contact time
- Design the infiltration curve
- Calculate field application efficiency
- Calculate irrigation time
- Calculate irrigation interval

7.12.2 Localized irrigation:

- Add up the total number of emitters equivalent to a full circle
- Check the nozzle discharge rate
- Calculate the discharge of all the emitters together in liter per hour
- Obtain the value of irrigation time from the schedule
- Calculate the amount of water applied at each irrigation event (Multiply discharge of all emitters with irrigation time)
- Multiply the amount of applied water at each irrigation event with the total number of irrigation events for the season to have the total volume of water during the season
- Summarize the total volume of water of each season to have the total volume of water for the whole growing period

8 Water Quality

The supply of water is finite. A stable water supply tends to deteriorate annually in quality and quantity, often a result of the following reasons:

- Water pollution caused by gases absorbed from the atmosphere, groundwater contamination due to agriculture, deforestation (forest is a natural filter), eutrophication, suspended particulate matter and/or salinity.

- Water misuse leading to areas becoming waterlogged, streams drying up, and/or a lowering of the water table; overuse of groundwater; over-pumping of aquifers.

The caused effects related to water quality problems are the following:

- Salinity
- Low infiltration rate
- Toxicity
- Water pollution
- Water-logging
- Water loss
- Salt deposition

8.1 Salinity

Salinity problems exist if the concentration of salt in the root zone affects the plant growth and causes loss in the yield.

Even if salts are present in irrigation water in small quantities they have a great impact on crop yield and soil quality. High salinity in irrigation water reduces water availability to the plant and damages the soil.

Water used for irrigation can vary depending upon the quantity of dissolved salt and also by the kind of salt.

Photo 25 Salt deposit on the surface of soil

Source: F. Sandor (2008), Batikot, Afghanistan

Leaching rate is equal to the depth of water leached below the root zone divided by the depth of water applied at the surface. If the leaching rate in the soil is high, the salt accumulation will be less than with a lower leaching rate.

Large-scale irrigation practice often raises the level of the water table, resulting in water-logging; if it is raised to within two meters of the surface there will be high salinity.

The high evaporation rate in arid climates leaves the salt behind in the top layer of the soil, and poor drainage aggravates the salinity problem. Inadequate irrigation practice and wrong land use both contribute to this.

8.2 Low Water Infiltration Rate

The problem of low water infiltration has the same effect as water salinity, but the causes of low water infiltration are exactly the opposite of those of salinity. Salinity affects the water storage capacity of the soil, reducing the water available for the plant to use later. Water with low salinity leaches out the soluble minerals (especially calcium) and salts from the soil, which damages the soil structure and the stability of the aggregates. Soil crusting is a typical symptom of this damage.

Whereas low salinity water has a low infiltration rate, water with high sodium content also creates infiltration problems in the soil. It occurs when the *sodium - calcium ratio* is higher than 3:1. Excess tillage and harrow practice contribute to this problem through soil structure destruction and “plough sole disease” (see above), which also causes a drainage problem.

The problem of low infiltration can also be caused by a clayey or compacted soil surface.

8.3 Toxicity

The presence of excessive amounts of certain elements can cause *toxicity* in the plant. This is a physiological effect, with the particular element accumulating in the plant leaf. This effect differs from that of salinity in that it is caused by the presence of the toxic element in water, rather than by a water shortage. The most common elements found in water that have a toxic effect on plants are chloride, sodium and boron.

8.4 Water Pollution

Intensive conventional agriculture has led to the *contamination* of groundwater through the excessive use of fertilizers and chemicals. Manure and fertilizers pollute groundwater and increase the level of nitrates and other nutrients in it, in the process of eutrophication. *Eutrophication* has affected 30-40% of the global lake and reservoir systems. Nutrients, sewage, industrial and urban wastes, and toxic metals are among the main water pollutants. *Deforestation* leads to erosion and this and other by-products of human activity cause there to be particles floating in the water, making it turbid. Moreover, with deforestation the aquifer loses its natural filter and protection against pollution. Poor drainage and high evaporation, especially in arid areas, can cause salinity problems in water. Around the world about 20-30 million hectares have been severely affected, with another 80 million hectares affected to some degree by salinity problems. This comes from a total of 270 million hectares of irrigated land worldwide.

8.5 Water-logging

Water-logging occurs naturally when the water table level is high and the soil has poor drainage capacity. However, most water-logging problems come from faulty irrigation practice, where the water used for irrigation exceeds the natural drainage capacity. Excess water can raise the underground water level, causing water-logging. The damaging side-effect of water-logging can be secondary salinization.

8.6 Water Loss

Substantial water loss causes the aquifer to dry up, leading to *soil depletion*. The damage can be so severe that the land will be useless for agricultural production. Water loss can occur for different reasons. In dry and hot weather, evaporation is high and the soil dries up through *capillary vacuum pressure*. Pumping too much water from the aquifer causes severe structural damage in the soil. This happens when the irrigation practice is faulty, or when the output from the irrigation system is higher than the input to the water source. Excessive drainage practice removes the water table level and dries up the soil. Structural damage can result in the development of *sodic soil.*

8.7 Salt Deposition

Salt deposition on the surface frequently occurs as the result of irrigation. The water evaporates quickly from the surface before it can penetrate into the soil. The salt content of the water will be deposited on the surface and will damage the soil structure. It can happen in arid, hot areas too, where the upward movement of minerals by capillary force and by intensive evaporation also causes salt deposits on the surface. Generally we can say that in wetland the minerals tends to move downward, i.e. the leaching process dominates, while in dry land the minerals tend to move upward, with salt accumulating in the top layer of the soil.

8.8 Water Management

Efficient water management requires a *problem - solution method*, where the right solution proceeds from a careful analysis of the problem. The following table may serve as a guide to efficient water management.

Table 29 Problem-Solution approach for water management

Problem	Causes of the problem	Solutions
Groundwater polluted from surface sources	Water damaged irreversibly by intrusion of salt water; Fertiliser and other chemicals have contaminated groundwater.	Reduce water pollution; Preserve water quality; Balance timber harvesting with good reforestation practices; Practise adequate tillage; Use less fertiliser and pesticide.
Aquifers lose capacity	The aquifer has been over-exploited and cannot hold water, causing the land to subside.	Use less water more efficiently; Adjust the input-output balance, leaving a renewable portion of water intact in the aquifer (i.e. establish a water reserve in the aquifer); Create a balance between aquifer and streams using hydraulics; Establish water reservoirs;
Waterlogging	Excess water has seeped back into the ground; Inadequate irrigation practice.	Use less water more efficiently; Create a balance between aquifer and streams using hydraulics.
Salinization	Excess water has seeped back into the ground; Inadequate irrigation practice;	Use less water more efficiently; Reduce water pollution; Reduce fertiliser and pesticide use; Regulate pH level by using biocatalysts.

Problem	Causes of the problem	Solutions
	Chemicals have increased salinity.	
Decline in water flow	The land's competence to supply water is exhausted because the water has been misused.	Reallocate existing supply; Ensure more equitable access; Use water more efficiently; Apply water management methods based on engineering and other techniques in order to capture, store, treat and deliver the water; Adjust the input-output balance, leaving a renewable portion of water intact in the aquifer (i.e. establish a water reserve in the aquifer).
Degradation of water resource	Inadequate construction and irrigation management	Use less water more efficiently; Preserve water quality and quantity
Poor irrigation drainage	Excessive water use; Salinity has compacted the soil; Deforestation has destroyed soil structure and increased erosion; Destruction of soil structure through poor farming practice.	Use less water more efficiently; Control salinity; Control erosion; Regulate pH; Practise adequate tillage.
Streams dry up	Water source has been over-exploited	Use less water more efficiently; Adjust the input-output balance, leaving a renewable portion of water intact in the aquifer (i.e. establish a water reserve in the aquifer); Establish water reservoirs.
Water scarcity	Competition between agricultural, industrial and domestic water use; Misuse of water supply	Reallocate existing supply; Ensure more equitable access; Use water more efficiently; Apply water management methods based on engineering and other techniques in order to capture, store, treat and deliver the water; Reduce water pollution; Carry out an assessment of government interventions in water management policy in order to expose the economic and environmental impacts on the country; Food security policy should be linked to the water security policy; Establish water reservoirs.
Water pollution	Decreased water flow has reduced both the assimilation of polluted water and the wildlife habitats; Deforestation has increased the leaching of chemicals into the groundwater.	Preserve water quality; Balance timber harvesting with good reforestation practices; Practise adequate tillage; Use biocatalysts; Control fertiliser and pesticide use.
Groundwater overused	Over-pumping the water results in widespread	Use less water more efficiently; Establish water reservoirs;

Problem	Causes of the problem	Solutions
	structural damage	Create a balance between aquifer and streams by using hydraulics.
Precipitation contaminated	Harmful gases absorbed into the atmosphere; Decreased natural filter system (due to deforestation).	Reduce atmospheric contamination; Introduce reforestation.
High water nitrate level	Use of high levels of nitrogen and manure in intensive farm production.	Reduce water pollution; Reduce the use of nitrogen fertilisers.
Water retention capacity of soil decreased	Deforestation has increased erosion and caused water turbidity, due to matter suspended in the water; Deforestation has increased the leaching of nutrients and decreased water retention capacity, resulting in the destruction of wetland	Apply water management methods based on engineering and other techniques in order to capture, store, treat and deliver the water; Control erosion; Introduce reforestation; Apply compost and biocatalysts intensively in order to keep moisture in the soil and to increase water retention through improving the physical properties of the soil.
Increased amount of suspended matter		
Destruction of wetland		
Eutrophication	Agricultural run-off has enriched the water with nutrients, especially with phosphorus and nitrogen	Reduce water pollution; Control erosion; Apply landscaping methods.
Freshwater pollution	Salinity has polluted freshwater through a combination of poor drainage and high evaporation rates; Agricultural run-off has polluted the water	Reduce water pollution; Improve soil structure; Control pH; Reduce chemical use; Increase biocatalyst use.

Source: F. Sandor (2008), Roots of Peace, Jalalabad, Afghanistan

There are several different ways to avoid or resolve water quality related problems. Therefore when making a production technology design, it should include a water and irrigation management plan. This plan will regulate the use of water and also contain all measurements, which are necessary for water-soil conservation and/or improvement.

Salinity problems can be addressed through some effective interventions enlisted below:

- *Salinity control by irrigation of root zone:* Where there is a shallow and saline water table, the salts may be replaced in the root zone level through irrigation using a capillary system, or simply by water saturation.

- *Salinity control by grading and drainage:* Land grading can control salinity by changing the natural slope. This process may be followed by subsoiling and ploughing to break up the compaction effect of grading. A shallow water table can be stabilised by breaking up the hardpan or clay layer through tillage. This practice is often combined with installing a system to improve the surface drainage of the soil; field, collector and main drains are installed at a shallow depth. If the land is graded to create an artificial downward slope, this will help the water to flow into the collector drain. In order to control waterlogging, install deep open drains or pipelines at a constant depth.

- *Salinity control by deep cultivation:* Temporary improvement can be achieved by subsoiling, where a hardpan clay layer blocks water penetration. Permanent improvement of internal drainage is possible through deep and slip ploughing practice.

- *Salinity control by placement of seed:* In a flat-top bed, double row planting is the recommended method, because the main salt accumulation occurs in the central lane between the beds. In both single and double row planting practice, the best recourse is to build up a sloping bed and position the plants at the side of the rows; this also helps to control the temperature of the soil.

- *Salinity control by leaching reclamation:* Practice pre-planting irrigation by applying 10-20 cm of water; after planting irrigate again to allow the accumulated salt to wash down from the surface layer. Adjust the quantity of water according to the level of the water table. Localized or furrow irrigation is effective for raised beds/rows, otherwise overhead sprinkler irrigation is the best option.

- *Salinity control by changing or blending the water supply:* This practice is necessary when the quality of the irrigation water is a problem.

To solve low infiltration problems use chemical *amendments*. The most common practice is to add gypsum (5 to 40 Mt/Ha) to the water or soil. Another way is to blend two or three different water sources to avoid impurity (Ca, Na, Mg, HCO_3). Amendments reduce the sodium:calcium ratio, thus improving the infiltration of the water into the soil. Some acid-forming amendments may help too, such as by using sulphuric acid or sulphur. These amendments react with the soil's calcium carbonate ($CaCO_3$) and release calcium into the soil with the same effect as is achieved by reducing the sodium - calcium ratio. The following table shows the chemicals recommended for amending soil and water:

Table 30 Soil and water amendments

Chemical	Composition	Use
Gypsum	$CaSO_4 \cdot 2H2O$	Amendment for water or soil
Sulphur	S	Amendment only for soil
Sulphuric acid	H_2SO_4	Amendment for water or soil
Ferric sulphate	$Fe_2(SO_4)_3 \cdot 9H_2O$	Amendment only for soil
Lime sulphur	9% Ca + 24% S	Amendment for water or soil
Calcium chloride	$CaCl_2 \cdot 2H_2O$	Amendment for water or soil
Calcium nitrate	$Ca(NO_3)_2 \cdot 2H_2O$	Amendment for water or soil
Calcium carbonate	$CaCO_3$	Amendment only for soil

Source: R.S. Ayers-D.W. Westcot (1994), Water quality for agriculture, FAO, Rome

Cultivation and tillage may help where the infiltration problem is severe and caused by clayey soil or soil compaction. Tillage improves water penetration into the deeper soil areas, and cultivation before each or every other irrigation allows the water to penetrate into the top layer.

The application of organic matter in the range of 10-30% by soil volume brings a dramatic improvement in water penetration into the soil. The best quality organic matter is fibrous, making the decomposition process slow. Rice hulls and sawdust also give temporary help, but it is better to apply them as charcoal.

Here are some useful tips for irrigation practices:
- Irrigate more frequently

- Irrigate before planting
- Irrigate for a longer period of time
- Use localized, or drip irrigation for clayey soil.

As in the case of salinity problems, the use of leaching techniques and the blending of the water supply are useful methods of counteracting toxicity. When toxicity is a major problem it is better to change from overhead irrigation to a surface method, which prevents the adsorption of toxic ions into the plant leaves. Night overhead irrigation is quite useful, because even though the toxic elements will be absorbed by the plant, there will be no foliar deposition. If an overhead irrigation system has to be used, some regulation methods help against toxicity, such as increasing the sprinkler rotation speed, enlarging the sprinkler orifices, increasing the pressure, reducing the spacing on the sprinkler system or increasing the droplet size.

High wind also contributes to toxicity as it increases concentration, absorption and deposition; therefore irrigation should not be practised in very windy weather. In countries with seasonal rainfall, where the dry season is cool, there is less risk of toxicity because there is less need for water during this cooler part of the growing season. In these places it is good farming practice to grow irrigated winter crops.

Severe toxicity problems can make it necessary to select only the most tolerant crops for production. The table below lists crops by level of tolerance to two potentially toxic elements – sodium and boron.

Table 31 Sodium-Boron tolerance of different crops

Common name	Scientific name	Tolerance to	
		Sodium	Boron
Lemon	Citrus limon	Sensitive	Very sensitive
Grapefruit	Citrus X paradise	Sensitive	Sensitive
Orange	Citrus sinensis	Sensitive	Sensitive
Apricot	Prunus armeniaca	Sensitive	Sensitive
Peach	Prunus persica	Sensitive	Sensitive
Cherry	Prunus avium	Sensitive	Sensitive
Plum	Prunus domestica	Sensitive	Sensitive
Persimmon	Diospyros kaki	Sensitive	Sensitive
Grape	Vitis vinifera	Sensitive	Sensitive
Walnut	Juglans regia	Sensitive	Sensitive
Cowpea	Vigna unguiculata	Sensitive	Sensitive
Onion	Allium cepa	Moderate tolerant	Sensitive
Garlic	Allium sativum		Sensitive
Wheat	Triticum eastivum	Moderate tolerant	Sensitive
Sunflower	Helianthus annuus		Sensitive
Mung bean	Vigna radiate	Sensitive	Sensitive
Strawberry	Fragaria spp.		Sensitive
Bean	Phaseolus vulgaris	Very sensitive	Sensitive
Peanut	Arachis hypogaea	Sensitive	Sensitive
Pepper	Capsicum annuum		Moderate sensitive
Pea	Pisum sativa	Sensitive	Moderate sensitive
Carrot	Daucus carota	Moderate tolerant	Moderate sensitive
Radish	Raphanus sativus	Moderate tolerant	Moderate sensitive
Potato	Solanum tuberosum		Moderate sensitive
Cucumber	Cucumis sativus		Moderate sensitive
Lettuce	Lactuca sativa	Moderate tolerant	Moderate tolerant
Cabbage	Brassica oleracea capitata		Moderate tolerant
Celery	Apium graveolens		Moderate tolerant
Turnip	Brassica rapa		Moderate tolerant
Maize	Zea mays	Sensitive	Moderate tolerant
Squash	Cucurbita pepo		Moderate tolerant
Muskmelon	Cucumis melo		Moderate tolerant
Sorghum	Sorghum vulgare	Moderate tolerant	Tolerant
Tomato	Lycopersicon lycopersicum	Moderate tolerant	Tolerant
Alfalfa	Medicago sativa	Tolerant	Tolerant
Parsley	Petroselinum crispum		Tolerant
Beet	Beta vulgaris	Tolerant	Tolerant
Sugarbeet	Beta vulgaris	Tolerant	Tolerant
Rice	Oryza sativus	Moderate tolerant	
Spinach	Spinacia oleracea	Moderate tolerant	
Cotton	Gossypium hirsutum	Sensitive	Very tolerant

Source: R.S. Ayers-D.W. Westcot (1994), Water quality for agriculture, FAO, Rome

Plant nutrition and irrigation systems should be managed carefully to avoid water pollution. Excessive fertilizer, chemicals or manure application with too much irrigation practice leaches the toxic minerals into the groundwater and also causes eutrophication. Natural forest management and agro-forestry help avoid the problem of polluted, turbid water. These approaches will include erosion control methods and appropriate landscape building, which will counteract the problem of suspended particular matter in the water.

Dry-land farming should be based on weed-free cultivation (weeds soak up water that would otherwise be absorbed by the chosen crops), and creating dust mulch; which would fill the large pores in the soil and limit evaporation.

It is important to introduce a large volume of organic matter into the soil; it will function like a sponge, conserving moisture in the soil.

Summer fallows allow for the replenishment of water reserves depleted by cropping. The alternation of grazing and planting is a sustainable practice in dry-land farming.

Finally, the drainage practice of leaching, mentioned above, should complement the anti-pollution measures.

The wrong irrigation practices often cause a water-logging effect. In other cases the area itself is waterlogged. The volume of water used for irrigation should be commensurate with the soil's drainage capacity. Whereas soil with good drainage and infiltration capacity can absorb a lot of water at once, poorly drained soil needs frequent irrigation with small volumes of water. With this in mind, the regulation of volume and frequency in irrigation can avoid areas becoming water-logged. Other land preparation practices, such as drainage, leaching and landscaping have already been described and play an important part in the development of irrigation systems.

The lack of effective water management and irrigation planning in the technology design often leads to substantial water loss on the farm. Water misuse is one of the most common mistakes in farming practices.

Landscaping allows for the uniform distribution of water on the surface and for the control of excess run-off. Drainage, leaching and water keeping practices help control water penetration or removal. Organic matter application and mulching practice keep the moisture in the soil and reduce water evaporation. The irrigation methods used should maintain a balance between water input and output. Any drainage and leaching practice should avoid quick and drastic changes to soil quality.

Salt deposition can be avoided, if irrigation takes place at night, when heat cannot accelerate evaporation. Mulching the surface controls the temperature and evaporation, allowing the salt content to remain in solution. Organic matter deposition below the top layer of the soil keeps moisture near the surface and slows down the upward movement of minerals.

8.9 Water Quality Guideline

While soil test laboratory analysis is a common practice, water laboratory tests are not very popular between farmers and agriculturists. This is because most agriculturists can interpret soil test results easier than water test results. Water analysis is the lesser known area for practicing agronomy. Most agriculturists are not aware of water standards and water quality limitations. The following guidelines published by R.S. Ayers in 1994 (University of California Davis, USA) indicates the most important parameters and their value ranges.

Table 32 Water analysis standards

Irrigation problem			Unit	Degree of restriction on use		
				None	Slightly to Moderate	Severe
Salinity						
EC_W			dS/m	<0.7	0.7-0.3	>3.0
TDS			mg/l	<450	450-2000	>2000
Infiltration						
SAR	0-3	EC_W	dS/m	>0.7	0.7-0.2	<0.2
SAR	3-6	EC_W	dS/m	>1.2	1.2-0.3	<0.3
SAR	6-12	EC_W	dS/m	>1.9	1.9-0.5	<0.5
SAR	12-20	EC_W	dS/m	>2.9	2.9-1.3	<1.3
SAR	20-40	EC_W	dS/m	>5.0	5.0-2.9	<2.9
Ion toxicity						
Sodium (Na)	Surface irrigation		SAR	<3	3-9	>9
	Sprinkler irrigation		me/l	<3	>3	
Chloride (CL)	Surface irrigation		me/l	<4	4-10	>10
	Sprinkler irrigation		me/l	<3	>3	
Boron (B)			mg/l	<0.7	0.7-3.0	>3.0
Trace elements						
Aluminium (Al)			mg/l			≥5.00
Arsenic (As)			mg/l			≥0.10
Beryllium (Be)			mg/l			≥0.10
Cadmium (Cd)			mg/l			≥0.01
Cobalt (Co)			mg/l			≥0.05
Chromium (Cr)			mg/l			≥0.10
Copper (Cu)			mg/l			≥0.20
Fluoride (F)			mg/l			≥1.00
Iron (Fe)			mg/l			≥5.00
Lithium (Li)			mg/l			≥2.50
Manganese (Mn)			mg/l			≥0.20
Molybdenum (Mo)			mg/l			≥0.01
Nickel (Ni)			mg/l			≥0.20
Lead (Pd)			mg/l			≥5.00
Selenium (Se)			mg/l			≥0.02
Vanadium (V)			mg/l			≥0.10
Zinc (ZN)			mg/l			≥2.00
Miscellaneous effects						
Nitrogen (NO_3 – N)			mg/l	<5	5-30	>30
Bicarbonate (HCO_3) (Only overhead sprinkler irrigation			me/l	<1.5	1.5-8.5	>8.5
pH					Normal range:	6.5-8.4

Source: R.S. Ayers (1994), University of California Davis, USA

A change of 10 to 20 percent above or below a guideline value has little significance. Experience have led to these divisions, but management skill of the water user can alter them. The following table shows laboratory results of common irrigation water quality.

Table 33 Parameters for common irrigation water

Water parameter	Symbol	Unit[1]	Usual range in irrigation water	
SALINITY				
Salt Content				
Electrical Conductivity	EC_w	dS/m	0 – 3	dS/m
Total Dissolved Solids	TDS	mg/l	0 – 2000	mg/l
Cations and Anions				
Calcium	Ca^{++}	me/l	0 – 20	me/l
Magnesium	Mg^{++}	me/l	0 – 5	me/l
Sodium	Na^{+}	me/l	0 – 40	me/l
Carbonate	CO^{--}_3	me/l	0 – .1	me/l
Bicarbonate	HCO_3^{-}	me/l	0 – 10	me/l
Chloride	Cl^{-}	me/l	0 – 30	me/l
Sulphate	SO_4^{--}	me/l	0 – 20	me/l
NUTRIENTS[2]				
Nitrate-Nitrogen	NO_3-N	mg/l	0 – 10	mg/l
Ammonium-Nitrogen	NH_4-N	mg/l	0 – 5	mg/l
Phosphate-Phosphorus	PO_4-P	mg/l	0 – 2	mg/l
Potassium	K^{+}	mg/l	0 – 2	mg/l
MISCELLANEOUS				
Boron	B	mg/l	0 – 2	mg/l
Acid/Alkaline	pH	1–14	6.0 – 8.5	
Sodium Adsorption Ratio[3]	SAR	(me/l)[1], [2]	0 – 15	

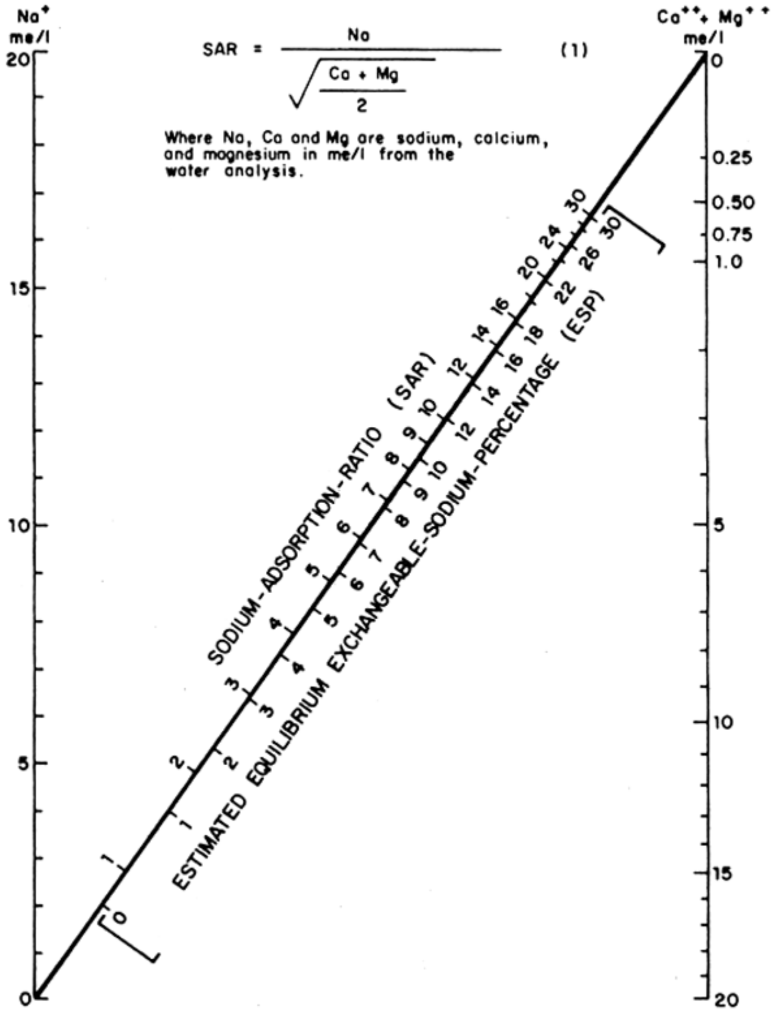
[1] dS/m = deciSiemen/metre in S.I. units (equivalent to 1 mmho/cm = 1 millimmho/centi-metre)

mg/l = milligram per litre ≃ parts per million (ppm).
me/l = milliequivalent per litre (mg/l ÷ equivalent weight = me/l); in SI units, 1 me/l= 1 millimol/litre adjusted for electron charge.
[2] NO_3 -N means the laboratory will analyze for NO_3 but will report the NO_3 in terms of chemically equivalent nitrogen. Similarly, for NH_4-N, the laboratory will analyze for NH_4 but report in terms of chemically equivalent elemental nitrogen. The total nitrogen available to the plant will be the sum of the equivalent elemental nitrogen. The same reporting method is used for phosphorus.
[3] SAR is calculated from the Na, Ca and Mg reported in me/l (see Figure 1).
Source: R.S. Ayers (1994), University of California Davis, USA

The Sodium Adsorption Ratio (SAR) can also be calculated using the following equation:

Nomogram for determining the SAR value of irrigation water and for estimating the corresponding ESP value of a soil that is at equilibrium with the water.

Table 34 Nomogram



Source: Richards 1954

Annex 1: Glossary of Terms

A

Acid	Substance with a pH less than 7.0 (Burt, 1998)
Adjusted sodium adsorption ratio	Index of permeability problems, based upon water quality. (Burt, 1998)
Adsorption	Concentration of a substance at the surface of another, more noticeable with substances of large surface area, such as clay particles. (Hess, 1999)
Advance ratio	Ratio of the time for the water to reach the end of the field to the total set time for an irrigation set on a furrow irrigation system. The ratio should be less than 0.5 to have a good distribution uniformity. (Burt, Surface Irrigation)
Advance time	Time required for a given stream of irrigation water to move from the upper end of a field to the lower end. (ASAE, 1998)
Aeration capacity	To supply or impregnate with air. (Webster, 1981)
Aggregate	Groups of individual soil particles, held together naturally and consisting of particles of sand, silt and clay separated from each other by pores, cracks or planes of weakness. The term, soil structure, refers to this arrangement of the soil in natural aggregates. Various types of soil structure are recognized (Massive, platy, prismatic, blocky, granular).
Alkaline	Soil with pH greater than 7.0. (Soil, 1996) Soil with an exchangeable sodium percentage greater than 15%. (Burt, 1998) Soil that has sufficient exchangeable sodium (alkali) to interfere with plant growth and cause dispersion and swelling of clay minerals... Hess, 1999
Allowable soil water depletion	Portion of plant available water that is allowed for plant use prior to irrigation based in plant and management considerations
Anion	Negatively charged ion, which during electrolysis is attracted towards the anode. The most common anions in soil extracts and waters are bicarbonate, sulphate, carbonate, chloride and nitrate ions. (Hess, 1999)
Application efficiency	The ratio of the water that is stored in the root zone for later use by the plants to the total water applied. [%, decimal]
Aquiclude (Aquifuge)	Impermeable layer for water flow
Aquifer	When the water penetrates into them and finds a layer with very low hydraulic conductivity, the water will be stuck and will create an aquifer. Unconfined aquifer (Phreatic aquifers): Commonly called as water table, because its upper boundry is the surface known as water table, where the pressure head is equal to the atmospheric pressure Confined aquifer: Its upper boundary is an aquitard or aquiclude. We can find the water table above this boundary. These aquifers are much more smaller, than the extensive unconfined aquifers

Aquifer recharge area	Surface area that provides water for an aquifer
Aquitard	The soil layer, which restrict groundwater flow between aquifers
Available soil moisture	Difference at any given time between the actual soil moisture content in the root zone soil and the wilting point. (On-Farm Committee, 1979)
Available water	Portion of water in a soil that can be readily absorbed by plant roots. It is the amount of water released between in situ field capacity and the permanent wilting poin
Available water holding capacity	See available water
Available water storage capacity	See available water

B

Blaney-Criddle Method	Air temperature based method to estimate crop evapotranspiration. (NRCS, 1997)
Border dike	Earth ridge or small levee built to guide or hold irrigation or recharge water in a field. (ASAE, 1998)
Border ditch	Small excavation used as a border of an irrigated strip or plot with water being spread from one or both sides. (ASAE, 1998)
Border irrigation	See irrigation systems
Bubbler irrigation	See irrigation systems
Bubbler	Water emission device that tends to bubble water directly to the ground or that throw water a short distance, on the order of one foot, (300 mm) before water contacts the ground surface. (Smith, 1997)
Bulk density	Mass of dry soil per unit bulk volume ... (generally ranging in value from 1.3 to 1.6 g/cc) (ASAE, 1998)

C

Capillary water	Water held in the capillary, or small pores of the soil, usually with soil water pressure (tension) greater than 1/3 bar. Capillary water can move in any direction. (NRCS, 1997)
Catch can grid	Containers spaced at regular intervals for collecting water for use in a water audit (sprinkler profile test). (Contractor, 1999).
Cation	Positively charged ion which during electrolysis is attracted towards the cathode. Sodium, potassium, calcium and magnesium are the most common cations in waters and soil extracts. (Hess, 1999)
Cation exchange capacity	The sum of exchangeable cations (usually Ca, Ma, K, Na, Al, H) that the soil constituent or other material can adsorb at a specific pH, usually expressed in centimoles of charge per Kg of exchanger (cmol/Kg), or milli equivalents per 100 grams of soil at neutrality (pH = 7.0), meq/100g. (NRCS, 1997)

Center pivot irrigation	See irrigation systems
Check	Structure to control water depth in a canal, ditch or irrigated field. (NRCS, 1997)
Coefficient	Various forms of "k" are used to describe constants, coefficients and factors
Control structure	Water regulating structure, usually for open channel flow conditions. (NRCS, 1997)
Conveyance efficiency	The ratio of the water that is delivered to a field to the total water diverted or pumped into the conveyance system at the upstream end
Conveyance loss	Loss of water from a channel or pipe during transport, including losses due to seepage, leakage, evaporation, and transpiration by plants growing in or near the channel. (ASAE, 1998)
Corrugation irrigation	See irrigation systems
Crop water stress index	Index of moisture in a plant compared to a fully watered plant, measured and calculated by a CWSI instrument. Relative humidity, solar radiation, ambient air temperature, and plant canopy temperature are measured. (NRCS, 1997)
Crop coefficient	A number that is multiplied by the potential evapo-transpiration to obtain the actual crop or plant evapotranspiration. They are crop dependant numbers and change over time with the crop's growth stage
Cumulative infiltration	Depth of water absorbed by soil from the time of initial water application to the specified elapsed time. (NRCS, 1997)
Cycle time	Length of water application periods, typically used with surge irrigation. (NRCS, 1997)

D

Deep percolation	Movement of water downward through the soil profile below the root zone that cannot be used by plants. (ASAE, 1998)
Deep percolation percentage	Ratio of the average depth of irrigation water infiltrated and drained out of the root zone to the average depth of irrigation water applied. (ASAE, 1998)
Deficit irrigation	Irrigation water management alternative where the soil in the plant root zone is not refilled to field capacity in all or part of the field. (NRCS, 1997)
Delivery box	Structure diverting water from a canal to a farm unit often including measuring devices. Also called "turnout". (ASAE, 1998)
Distribution uniformity	Measure of the uniformity of irrigation water over an area. (ASAE, 1998)
Drip irrigation	See irrigation systems

E

Effective rainfall	Portion of total precipitation which becomes available for plant

	growth. (ASAE, 1998)
Electrical conductivity	Measure of the ability of the soil water to transfer an electrical charge. Use as an indicator for the estimation of salt concentration
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". (ASAE, 1998)
Emission uniformity	Index of the uniformity of emitter discharge rates throughout an irrigation system. Takes account of both variations in emitters and variations in the pressure under which the emitters operate. (ASAE, 1998)
Emission point	Location where water is discharged from an emitter. (ASAE, 1998)
Evaporation	Water movement from a wet soil or plant surface which does not pass through the plant. (Burt, 1998). Physical process by which a liquid is transformed to the gaseous state, which in irrigation generally is restricted to the change of water from liquid to vapor. Occurs from plant leaf surface, ground surface, water surface and sprinkler spray. (NRCS, 1997)
Evaporation pan	Pan or container placed at or about crop canopy height containing water. Water levels are measured daily in the pan to determine the amount of evaporation. (NRCS, 1997
Evapotranspiration	Combination of water transpired from vegetation and evaporated from the soil and plant surfaces. (ASAE, 1998)
Exchangeable Sodium Percentage	Percentage of the cation exchange capacity (meq.) of a soil which is occupied by sodium. (Burt, 1998)

F

Field capacity	Amount of water remaining in a soil when the downward water flow due to gravity becomes negligible. (ASAE, 1998)
Flow rate	Rate of flow or volume per unit period of time
Flume	Flow measuring device for open channel flow. Water travels through a restriction and the flow rate is determined using the water height on a staff gauge
Friable	Soil consistency term referring to the ease with which the soil aggregates may be crumbled (in the hand), i.e. a friable soil is easily crumbled in the hand. (Hess, 1999)
Furrow irrigation	See irrigation systems
Furrow	Small channel for conveying irrigation water down slope across the field. Sometimes referred to as a rill or corrugation. (NRCS, 1997)

G

Gated pipe	Portable pipe with small gates installed along one side for

	distributing irrigation water to corrugations or furrows. (ASAE, 1998)
gpm	Acronym for gallons per minute
Ground water	Water occurring in the zone of saturation in an aquifer or soil. (NRCS, 1997)
Growing season	Period, often the frost-free period, during which the climate is such that crops can be produced. (NRCS, 1997)

H

Head spacing	Distance between sprinklers
Horizon (soil)	Layer of soil or soil material approximately parallel to the land surface and differing from adjacent genetically related layers in physical, chemical, and biological properties or characteristics such as color, structure, texture, consistency, kinds and number of organisms present, degree of acidity or alkalinity, etc. (Soil, 1996)
Hydrologic cycle	Model that describes the movement of water between the hydrosphere, lithosphere, atmosphere, and biosphere
Hydrosphere	One of the three components of the global ecosystem, the other two being the atmosphere and the geosphere. The hydrosphere describes the waters of the Earth. Water exists on the Earth in various stores, including the: atmosphere, oceans, lakes, rivers, glaciers, snowfields and groundwater. Water moves from one store to another by way of: evaporation, condensation, precipitation, deposition, run-off, infiltration, sublimation, transpiration, and groundwater flow.

I

Infiltration	Process of water movement through the soil surface into the soil matrix. (Burt et al, 1997)
Infiltration rate	Volume of water infiltrating through a horizontal unit area of soil surface at any instant. (Hess, 1999)
Initial intake	Depth (rate) of water absorbed by a soil during the period of rapid or comparatively rapid intake following initial application. (NRCS, 1997)
Intake rate	Rate at which water percolates into the soil after infiltration has decreased to a low and nearly constant value. (ASAE, 1998)
Inverted siphon	Closed conduit (for conveying water) with end sections above the middle section; used for crossing under a depression, under a highway or other obstruction. Sometimes called a sag pipe. (NRCS, 1997)
Irrigation	Intentional application of water to the soil, usually for the purpose of crop production (reclaiming soils, temperature modification, improving crop quality). (Soil, 1996)
Irrigation efficiency	Proportion of the water that is beneficially used to the irrigation water applied

Irrigation frequency	Measure of the number of irrigations per unit time
Irrigation interval	Average time interval between the commencement of successive irrigations for a given field (or area). (ASAE, 1998)
Irrigation water requirement (net)	Depth of water, exclusive of effective precipitation, stored soil moisture, or ground water, that is required for meeting crop evapo-transpiration for crop production and other related uses. Such uses may include water required for leaching, frost protection, cooling and chemigation. (NRCS, 1997)
Irrigation water requirement (gross)	Total irrigation requirement including net crop requirement plus any losses incurred in distributing and applying and in operating the system. (NRCS, 1997)
Irrigation water requirement	Calculated amount of water needed to replace soil water used by the crop (soil water deficit), for leaching undesirable elements through and below the plant root zone, plus other needs; after considerations are made for effective precipitation. (NRCS, 1997)
Irrigation schedule	Determining when to irrigate and how much water to apply, based upon measurements or estimates of soil moisture or crop water used by a plant. (NRCS, 1997)
Irrigation system	Physical components (pumps, pipelines, valves, nozzles, ditches, gates, siphon tubes, turnout structures) and management used to apply irrigation water by an irrigation method. (NRCS, 1997) Drip/trickle/micro: Micro irrigation system (low pressure and low volume) wherein water is applied to the soil surface as drops or small streams through emitters. Preferred term is drip irrigation. (NRCS, 1997) <u>Bubbler irrigation</u>: Application of water to flood the soil surface using a small stream or fountain. The discharge rates for point-source bubbler emitters are greater than for drip or subsurface emitters but generally less than 1 gpm. A small basin is usually required to contain or control the water. (ASAE, 1998) <u>Surface</u>: Type of irrigation where water is distributed to the plant material by a ground surface distribution network possibly including rows or dikes. <u>Basin irrigation</u>: Irrigation by flooding areas of level land surrounded by dikes. Used interchangeably with level border irrigation, but usually refers to smaller areas. (ASAE, 1998) <u>Border irrigation</u>: Irrigation by flooding strips of land, rectangular in shape and cross leveled, bordered by dikes. Water is applied at a rate sufficient to move it down the strip in a uniform sheet. Border strips having no down field slope are referred to as level border systems. Border systems constructed on terraced lands are commonly referred to as benched borders. (ASAE, 1998) <u>Check irrigation</u>: Modification of a border strip with small earth ridges or checks constructed at intervals to retain water as the water flows down the strip. (ASAE, 1998) <u>Check basin irrigation</u>: Water is applied rapidly to relatively level plots surrounded by levees. The basin is a small check. (Soil, 1996) <u>Corrugation irrigation</u>: Method of surface irrigation similar to furrow irrigation, in which small channels, called corrugations, are used to guide water across a field. No attempt is made to confine the water entirely to the corrugations. (ASAE, 1998) <u>Flood irrigation</u>: Method of irrigation where water is applied to the

soil surface without flow controls, such as furrows, borders or corrugations. (ASAE, 1998)

Furrow irrigation: Method of surface irrigation where the water is supplied to small ditches or furrows for guiding across the field. (ASAE, 1998)

Alternate set irrigation: Method of managing irrigation whereby, at every other irrigation, alternate furrows are irrigated, or sprinklers are placed midway between their locations during the previous irrigation. (ASAE, 1998)

Alternate side irrigation: Practice of furrow irrigating one side of a crop row (for row crops or orchards) and then, at about half the irrigation time, irrigating the other side.

Cutback irrigation: Reduction of the furrow or border inflow stream after water has advanced partially or completely through the field in order to reduce runoff. (ASAE, 1998)

Surge: Surface irrigation technique wherein flow is applied to furrows (or less commonly, borders) intermittently during a single irrigation set. (ASAE, 1998)

Sprinkler: Type of irrigation using mechanical devices with nozzles (sprinklers) to distribute the water by converting water pressure to a high velocity discharge stream or streams.

Center pivot: Automated irrigation system consisting of a sprinkler lateral rotating about a pivot point and supported by a number of self-propelled towers. Water is supplied at the pivot point and flows outward through the pipeline supplying the individual sprinklers or spray heads. (NRCS, 1997)

Lateral (linear) move: Automated irrigation machine consisting of a sprinkler line supported by a number of self-propelled towers. The entire unit moves in a generally straight path perpendicular to the lateral and irrigates a basically rectangular area. (NRCS, 1997) (Soil, 1996)

Traveler (traveling gun) irrigation: Large rotating sprinkler(s) mounted on a trailer to deliver water in a circle. The sprinkler and associated trailer are towed through the field by any of several means. ... (NRCS, 1997)

Gun type: Single sprinkler head with large diameter nozzles, supported on skids or wheels. Periodically moved by hand or mechanically with a tractor, cable, or water supple hose. ... (NRCS, 1997)

Portable (hand move) irrigation: Sprinkler system which is moved by uncoupling and picking up the pipes manually, requiring no special tools. (Soil, 1996)

Side move: Sprinkler system with the supply pipe supported on carriages and towing small diameter trailing pipelines each fitted with several sprinkler heads. (NRCS, 1997)

Side role (wheel line): Supply pipe is usually mounted on wheels with the pipe as the axle and where the system is moved across the field by rotating the pipeline by engine power. (NRCS, 1997)

Towed sprinkler: System where lateral lines are mounted on wheels, sleds, or skids and are pulled or towed in a direction approximately parallel to the lateral. Rollers or wheels are secured in the ground near the main water supply line to force an offset in the tow path equal to half the distance the lateral would have been moved by hand. (NRCS, 1997)

Solid set/fixed: System of portable surface or permanently buried laterals totally covering the irrigated area or field. Typically several adjacent laterals or heads are operated at one time. Portable laterals are typically removed from the field at end of germination, plant establishment, or the irrigation season and are replaced the next irrigation system. (NRCS, 1997)

L

Leaching	Removal of soluble material from soil or other permeable material by the passage of water through it. (ASAE, 1998)
Leaching fraction	Ratio of the depth of subsurface drainage water (deep percolation) to the depth of infiltrated irrigation water (see *leaching requirement*). (ASAE, 1998)
Leaching requirement	Quantity of irrigation water required for transporting salts through the soil profile to maintain a favorable salt balance in the root zone for plant development. (ASAE, 1998)

M

Management allowable (allowed) depletion	Planned soil moisture deficit at the time of irrigation. (NRCS, 1997)
Maximum application rate	Maximum discharge at which sprinklers can apply water without causing significant translocation. (NRCS, 1997)
Moisture deficit	Difference between actual soil moisture and soil moisture held in the soil at field capacity. (NRCS, 1997)

N

Nozzle	Final orifice through which water passes from the sprinkler or emitter to the atmosphere. (Rain Bird, 1997)

O

Operating time	Time that water inundates the soil surface with opportunity to infiltrate. (NRCS, 1997)
Overlap	Area which is watered by two or more sprinklers. (Rain Bird, 1997)

P

Percolation	<u>Beneficial deep percolation-leaching</u>: It is a beneficial use when it leaches salts from the root zone to a level required for acceptable crop production. (Burt et al 1997) <u>Nonbeneficial (excess) deep percolation</u>: If the actual depth of deep percolation at a given location is more than the required beneficial leaching depth, that which is in excess of the requirement is nonbeneficial. (Burt et al 1997)
Percolation rate	Rate at which water moves through porous media, such as soil. (ASAE, 1998)

Permanent irrigation	Irrigation having underground piping with risers and sprinklers. (Soil, 1996) Preferred term is stationary sprinklers.
Permanent wilting point	Moisture content, on a dry weight basis, at which plants can no longer obtain sufficient moisture from the soil to satisfy water requirements. Plants will not fully recover when water is added to the crop root zone once permanent wilting point has been experienced. Classically, 15 atmospheres (15 bars), soil moisture tension is used to estimate PWP. (NRCS, 1997)
pH	Measure of acidity or alkalinity. (Burt, 1998)
Plant available water	Available water located in the root zone. Same as root zone available water
Precipitation	Total of all atmospheric water deposited on the surface. That is rain, snow, hail, dew and condensation. (Hess, 1999)
Profile (soil)	Vertical section of the soil through all its horizons and extending into the C horizon. (Soil, 1966)

R

Relative humidity	Ratio of the amount of water vapor present in the atmosphere to the amount required for saturation at the same dry bulb temperature. (NRCS, 1997)
Root depth (effective)	Depth from which roots extract water. The effective rooting depth is generally the depth from which the crop is currently capable of extracting soil water. However, it may also be expressed as the depth from which the crop can extract water when mature or the depth from which a future crop can extract soil water. Maximum effective root depth depends on the rooting capability of the plant, soil profile characteristics, and moisture levels in the soil profile. (NRCS, 1997)
Root zone	Depth of soil that plants roots readily penetrate and in which the predominant root activity occurs. (ASAE, 1998)
Run off	Portion of precipitation, snow melt or irrigation, that flows over the soil, eventually making its way to surface water supplies. (ASAE, 1998)
Run off rate	Rate at which water flows above ground from a watershed or field

S

Saline soil	Soil that has sufficient soluble salts to interfere with crop growth. ... (Hess, 1999). Non-sodic soil containing sufficient soluble salts to impair its productivity for growing most crops. The electrical conductivity (ECe) of the saturation extract is greater than 4 mmhos/cm, and exchangeable sodium percentage (ESP) is less than 15; i.e., non-sodic. The principal ions are chloride, sulfate, small amounts of bicarbonate, and occasionally some nitrate. Sensitive plants are affected at half this salinity, and highly tolerant ones at about twice this salinity. (NRCS, 1997)
Salinity	Soil containing both sufficient soluble salts and exchangeable sodium to interfere with the growth of most crops. The exchangeable sodium percentage (ESP) is

	greater than or equal to 15, and electrical conductivity of the saturation extract (ECe) is greater than 4 mmhos/cm. It is difficult to leach because the clay colloids are dispersed. (NRCS, 1997). Refers to the amount of salts dissolved in soil water.
Saturation point	Condition where all soil pores / voids are filled with water. (NRCS, 1997)
Siphon	Closed conduit used to convey water across localized minor elevation raises in grade. It generally has end sections below the middle section. A vacuum pump is commonly used to remove air and keep the siphon primed. The upstream end must be under the water surface. Both ends must be under water, or the lower end must be closed to prime the siphon. (NRCS, 1997)
Sodic soil	Non-saline soil containing sufficient exchangeable sodium to adversely affect crop production and soil structure. ... (ASAE, 1998)
Sodium adsorption ratio	Portion of soluble sodium ions in relation to the soluble calcium and magnesium ions in the soil water extract ... (ASAE, 1998)
Sodium adsorption ration (adjusted)	Sodium adsorption ratio of a water adjusted for the precipitation or dissolution of CA^{2+} and Mg^{2+} that is expected to occur where water reacts with alkaline earth carbonates with a soil. ... (NRCS, 1997)
Sodium percentage	Percentage of total cations that is sodium in water or soil solution. (ASAE, 1998)
Soil	Unconsolidated minerals and material on the immediate surface of the earth that serves as a natural medium for the growth of plants. (ASAE, 1998)
Soil moisture (water) depletion (deficit)	Difference between field capacity and the actual soil moisture in the root zone soil at any given time. It is the amount of water required to bring the soil in the root zone to field capacity. (On-Farm Committee, 1979). Amount of water required to fill the plant root zone to field capacity. (Burt, 1998)
Soil water content	Amount of water in a given volume (or weight) of soil. ... (NRCS, 1997)
Spile	Conduit, made of lath, pipe or hose, placed through ditch banks to transfer water from an irrigation ditch to a field. (ASAE, 1998)

T

Total dissolved solids	Total dissolved mineral constituents of water. (NRCS, 1997)

U

Unavailable soil water content	Portion of water in a soil held so tightly by adhesion and other soil forces that it cannot be absorbed by plants rapidly enough to sustain growth. ... (ASAE, 1998)

V

Valve	Device to control flow. Valves used in pressurized systems

W

Water holding capacity	Total amount of water held in the soil per increment of depth. It is the amount of water held between field capacity and oven dry moisture level. (NRCS, 1997)
Water table	The upper surface of a saturated zone below the soil surface where the water is at atmospheric pressure. If you dig a hole deep enough water will start filling the hole at the water table.
Weir	Flow measuring device for open-channel flow. Weirs can be either sharp-crested or broad-crested. Flow opening may be rectangular, triangular, trapezoidal (cipolletti), or specially shaped to make the discharge linear with flow depth (sutro weir). Calibration is based on laboratory ratings. (NRCS, 1997)
Wetted area	Surface area wetted at completion of irrigation. (Landscape, 1996)

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Annex 4: References

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