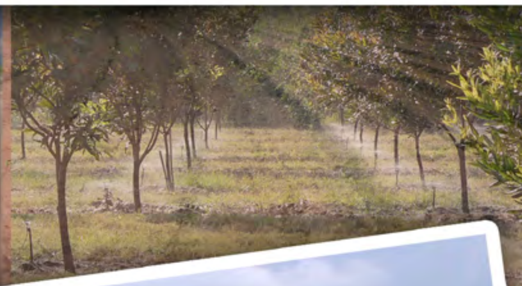
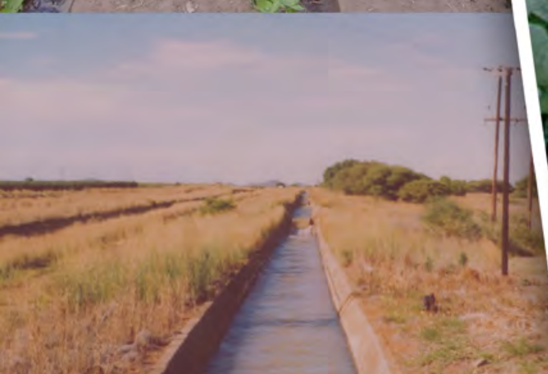
Training material for extension advisors in irrigation water management

Volume 2: Technical Learner Guide
Part 4: Irrigation water management

JB Stevens & F Buys





TT 540/4/12

WATER RESEARCH COMMISSION

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Report to the

Water Research Commission

University of Pretoria

NQF
Level 5

WATER RESEARCH COMMISSION

agriculture, forestry & fisheries
Department: Agriculture, Forestry and Fisheries
REPUBLIC OF SOUTH AFRICA

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This report forms part of the following set of reports:
Volume 1: Main report
Volume 2: Technical learner guide
Volume 3: Extension learner guide

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Before we start...............

Dear Learner ....this learner Guide contains information to acquire the basic knowledge and skills leading to the unit standard:

Title: Develop suitable irrigation systems

US No: 116414 NQF Level: 5

Title: Manage water quality parameters

US No: 116322 NQF Level: 4

Title: Schedule the operation and maintenance of irrigation

US No: 116322 NQF Level: 4

Title: Monitor the operation and maintenance of irrigation systems

The full unit standards are available and can be cited on the SAQA website. Read the unit standards at your own time and if there are any questions or aspects that you do not understand, discuss it with your facilitator.

The unit standards are some of the building blocks in the qualification listed below:

Title	ID no	NQF Level	Credits
National Diploma: Plant Production	49010	5	120
National Certificate: Plant Production	49009	4	120
National Certificate: Plant Production	49052	3	120

Assessment.........

You will be assessed during the course of the study (formative assessment) through the expected activities that you are expected to do during the course of the study. At the completion of the unit standard, you will be assessed again (summative assessment).

Assessment therefore takes place at different intervals of the learning process and includes various activities - some will be done before commencement of the program, others during the delivery of the program and others after completion of the program.

How to attend to the activities.......

The activities included in the module should be handed in from time to time on request of the facilitator for the following purposes:

- The activities that are included are designed to help gain the necessary skills, knowledge and attitudes that you as the learner needs in order to become competent in this learning module.
- It is important that you complete all the activities and worksheets, as directed in the learner guide and at the time indicated by the facilitator.
- It is important that you ask questions and participate as much as possible in order to be actively involved in the learning experience.
- When you have completed the activities and worksheets, hand it in so that the assessor can mark it and guide you in areas where additional learning might be required.
- Please do not move to the next activity or step in the assessment process until you have received feedback from the assessor.
- The facilitator will identify from time to time additional information to complete. Please complete these activities.
- Important is that all activities, tasks, worksheets which were assessed must be kept as it becomes part of your Portfolio of Evidence for final assessment.

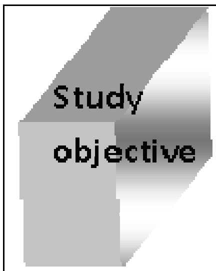
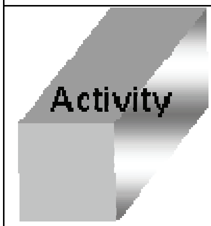
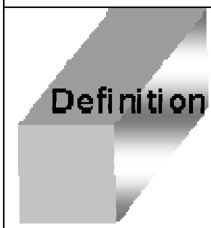
Check your progress.......

Use the following checklist to determine your competency regarding this specific learning module.

Confidence level	**I am sure**	**Still unsure**	**Do not understand and need help**	**Motivate your answer**
Can you identify problems and troubleshoot correctly?				
Are you able to work well in a team?				
Are you able to collect the correct and appropriate information required for decision making?				
Will you be able to perform the observation expected in an organised and systematic way while performing your task as an extensionist?				
Are you able to communicate the information and newly gained knowledge well to experts?				
Can you base your tasks and answers on scientific knowledge that you have learned?				
Are you able to show and perform the activities required in this learning module correctly				
Are you able to link the knowledge, skills and competencies you have learned in this module of learning to specific duties in your job?				

How to use this guide ....

Throughout the learner Guide you will come across certain re-occurring notifications. These notifications each presents a certain aspect of the learning process, containing information, which would help you with the identification and understanding of these aspects. The following will be found in the learning material:

	What are the study objectives for a specific module? This provides an idea of the knowledge, skills and competencies that are envisaged to be
	You will be requested to complete activities, which could either be group or individual activities. Please remember that the completion of these activities is important for the facilitator to assess, as it will become part of your ***Portfolio of Evidence.***
	What does it mean? Each learning field is characterised by unique terminology and concepts. Definitions help to understand these terminology and concepts and to use it correctly. These terminology and concepts are highlighted throughout the learner guide in this manner.

My notes...................................

You can use this box to jot down some questions or notes you might have, concepts or words you do not understand, explanations by facilitators or any other remark that will help you to understand the work better.

What are we going to learn?

For each of the learning modules included in this learning area specific learning outcomes were set, which you need to be able to demonstrate a basic knowledge and understanding of.

Contents

Module 1

Introduction to irrigation management

Study objective

After completion of this module, the learner should be able to have a basic understanding of:

- Irrigated agriculture in South Africa and the trends
- The principles of irrigation
- Concept of irrigation in practice
- A wetting front and methods to observe the wetting front
- General advantages of irrigation
- Basic irrigation terminology
- Definitions and concepts regarding irrigation

Table of contents

Irrigation is an artificial way to supply plants with water to permit farming in arid regions and to overcome drought periods in semi arid regions. As such it plays a key role in feeding an expanding population worldwide. Crops under irrigation create an economic growth point as it increases the need for fertilizers, pesticides, equipment and labour. It triggers a chain reaction of other business developments in the supply of inputs as well as the distribution of produce to various markets and processors. In many countries it forms the centre of economic and social development. In this regard it is extremely important for the state to build infrastructure which can supply and store water for irrigation in order for food production to be sustained and increased even in periods of severe drought.

This module provides an overview of what is understood under irrigation. What happens with water after it landed on the soil?

1. Irrigated agriculture in South Africa

In South Africa 1.5% of the agricultural land or 10% of the cultivated area, is under irrigation, but it contributes to over 30% of the gross value of the country's crop production.[5)] Irrigation in South Africa is essential for the fruit and wine industries, which rank amongst the most important export commodities for the country[7)]. Irrigated agriculture makes an important contribution to the food security of the country. It is generally accepted that only 14 million hectares (or 13% arable land) exists in the country. This includes 3% high potential land, while the rest mainly marginal for crop production. If the international norm of 0.4 ha/person is required for the production of food per person is applied, then South Africa has the potential to feed 35 million people. This is less than the current estimation of the population, a gap that will increase as the population grows[9).] Therefore the South African Food Cost Review (2007)[8)] lists the following measures to promote food security in South Africa:

- Increasing of availability of land
- Increasing the availability of farming inputs like water, fertiliser, etc.

- Improving agricultural support and research systems
- Reinvestment in agriculture on a massive scale, i.e. investing in technology irrigation infrastructure and human capacity
- Establishment of agro-industrial zones in the rural areas

Therefore irrigated agriculture historically has been and in future will be very important regarding the socio-economic development of rural areas in South Africa. The following trends are observed in the irrigated agricultural sector[3)]:

- ***Large scale irrigated commercial agriculture***

  Up to the 1970s the major crops produced under irrigation, especially in the central parts of the country, included grain crops like maize and wheat, industrial crops like cotton and fodder crops like Lucerne. Flood irrigation was mainly used.

  Thereafter a major shift towards high value crops like fruit and wine took place. An area like the Olifants River (west), which is presently essentially one big vineyard, used to produce mainly Lucerne and small amounts of vegetables. Sprinkler, micro and drip irrigation largely replaced flood irrigation. During the same period expansion of irrigation with underground water, using centre picot systems, took place. Crops included wheat, maize, cotton, etc. Presently there is a movement away from labour intensive high-value crops back to less labour-intensive crops because of labour legislation and minimum wages[10)].

  In the lower Orange River (Upington) area there is, for example, some movement back to the production of raisins, from sultanas instead of marketing of table grapes.

  Future trends will most probably be determined mainly by:

  i) the labour situation (availability and affordability) and

  ii) water availability

  iii) deterioration of water quality that may cause high-value crops to become unacceptable to export markets

- **Small scale irrigated agriculture**

  Although small scale irrigation schemes were managed as early as the late 1800s, such schemes were really established only from the 1950s onwards, with most being established in 1970s and 1980s[11)]. Almost all of the latter schemes were highly capital intensive schemes, managed totally top-down by consultants appointed. Annual losses amounted to million of rands[6)].

After 1994 the homeland corporations were disbanded without putting anything in their place. The result was that water supply infrastructure of these schemes collapsed and consequently the schemes themselves collapsed[11)]. A process of revitalisation of these schemes was started, with the major emphasis on the creation of strategic partnerships.

2. Main factors that influence trends in irrigated agriculture

The main factors that influence the trends in the irrigated agriculture sector are:

- International trends: markets, subsidy policies of crop production, biofuel policies, etc.
- Local trends in food preference, e.g. dietary preferences change as income of people increases. Usually it changes from a more starch based to a more protein based diet.
- Local policies, e.g. social and market policies, biofuel policy, food security policy.
- Quality and quantity of local natural resources (e.g. impact of land degradation)
- Cost/benefit squeeze (profitability and risk): macro economic factors (both national and international) have major impacts on the use of irrigation water in agriculture. Commodity prices and export opportunities on the one hand and input costs on the other hand.
- Climate change
- Water availability and pricing

The potential scope for improving irrigation efficiency (water use efficiency) is tremendous. In this way water demand in existing irrigation and in future irrigation (the National Department of Agriculture is looking to an additional 600 000 ha of irrigation under Asia[12]) can be reduced substantially. There is scope for off-farm (i.e. in the supply system) and on-farm improvement of water use efficiencies.

Figure 1 illustrates the potential losses that could occur from the dam wall to the irrigation field.

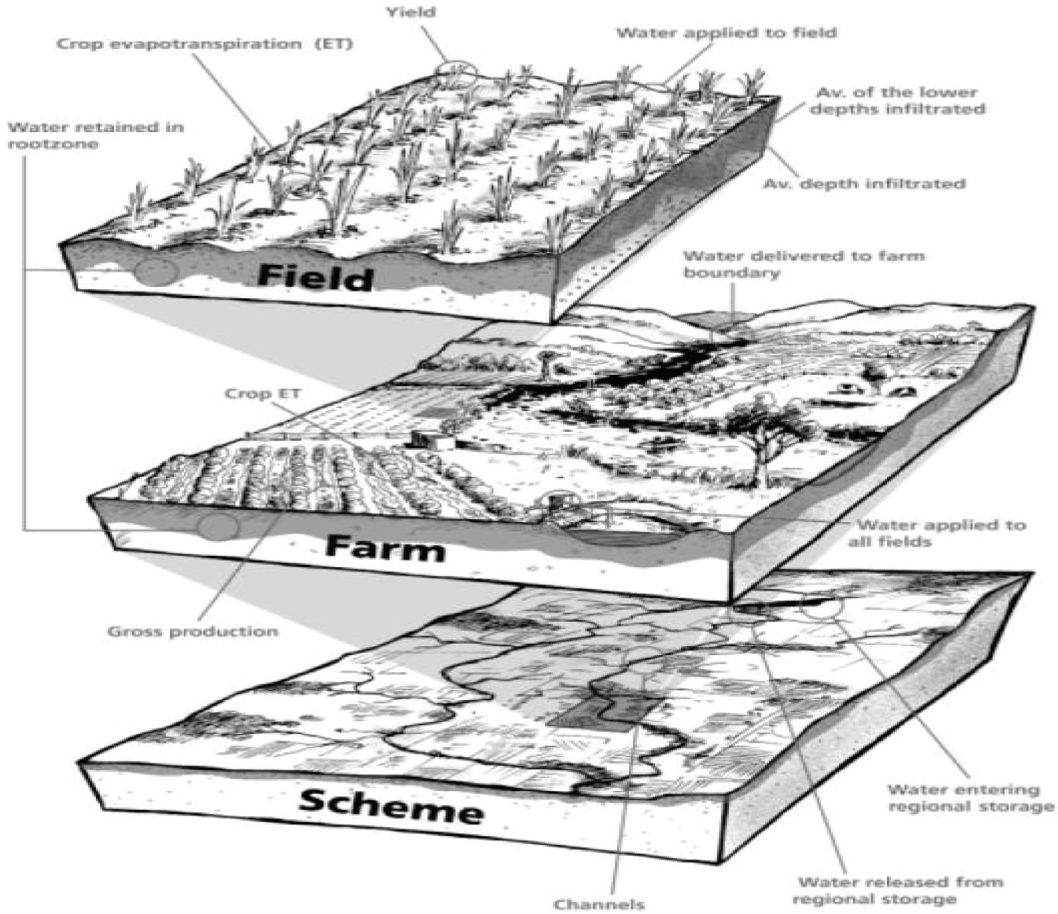


Figure 1. Water Use Efficiency framework [4)]

Improvement of the efficiency of irrigation water supply has two components:

a. Technical component, dealing with the quality and maintenance of water supply infrastructure

b. Management of water supply.

The collapse of many of the irrigation infrastructure in the former homelands after 1994 is an excellent example of neglecting water supply infrastructure and management.

In several irrigation schemes, especially older ones, large water losses occur between the source (e.g. the dam) and the farm gate (irrigation field) due to leaking canals and leaking balancing dams and reservoirs. On many of the older irrigation schemes a major problem is that the supply canals are too small to permit highly efficient flexible supply on demand to farmers. In order to minimise losses in the water supply system between the source and the farm gate, the Water Administration system (WAS) programme was developed with funding from Department of Water Affairs (DWA), Water Research Commission (WRC) and Water User Associations (WUAs).[13)] Field measurements indicated that water savings of 10-20% can be achieved by implementing the water release module of the WAS programme. The management and maintenance of water supply infrastructure is the responsibility of DWA (Department of Water Affairs) and Catchment management Agencies (CMAs).

The rest of the discussion in this module and Part 4 will focus on on-farm improvement of irrigation water use efficiency. In the majority of irrigated areas there is substantial scope for the improvement of irrigation water use efficiency. This could be achieved through:

- Good understanding of the soil-plant-atmosphere continuum
- Appropriate construction and maintenance of on-farm irrigation water supply systems
- Selection of the most appropriate irrigation system for a specific farm, and the proper maintenance and management of the system
- Improved irrigation management on the farm through irrigation scheduling and keeping of irrigation records

3. Principles of irrigation

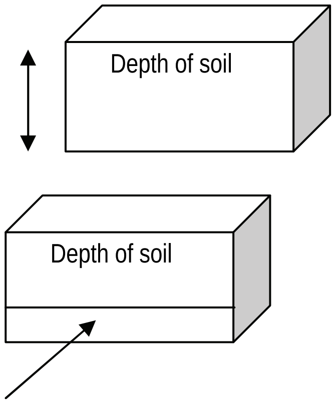
The basic principle of irrigating crops is to supply the plant with the correct amount of water for optimal growth at the right time.

3.1 Soil water balance

Evapotranspiration (ET) or consumptive use, a combination of water evaporated from the soil surface and water transpired by plants, causes soil water to decrease over time. If rainfall or irrigation does not replace this water, soil water falls to the extent that plants reduce growth and ultimately wilt and die.

The *rate of evaporation* from the surface decreases fairly quickly until the soil surface is dry. The remaining of the soil water, which is usually the majority of the available water, is used by plants for *transpiration* and growth. Because the crops we grow need regular and specific amounts of water to grow well, it cannot depend on rain only for this supply. Rainfall in South Africa is in most cases insufficient and erratic. We therefore need to apply water with an irrigation system on a regular basis. Various systems and techniques are being used to apply water to crops. (These systems will be discussed in Module 5).

Rain and sprinkler applications are measured in millimetres. This means that if for example 25 mm of rain falls, if measured in a can, will be 25 mm deep in the can. It does **not** mean that water enters the soil to a depth of 25 mm. It only represents the application of water to the soil surface.



Equivalent depth of water after soil is removed

Using this concept:

100 mm=100 l/m^2 =10 m^3/ha

Figure 2 indicates how an application of 25 mm infiltrates to a depth of 400 mm in a sandy soil, but it takes an application of 75 mm to wet the same depth of a clay soil. This is because water is held in soil by clay particles, and therefore more water can be stored in soils with higher clay content. It can also be expressed that 75 mm can be stored in the clay soil where only 25 mm can be stored in the same depth of sandy (less clay) soil. This will have an impact on the way the different soils are irrigated.

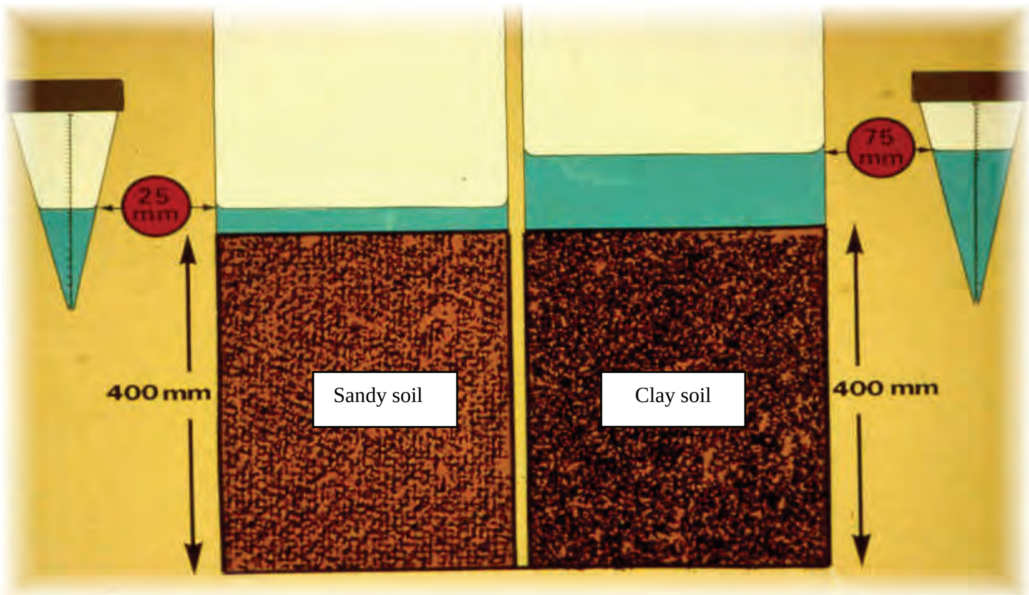


Figure 2. Indication of the infiltration depth of two different water applications according to the texture (clay content) of the soil[2)].

Rule of thumb

A general rule of thumb which is decades old, is that one inch (25 mm) of water wets about one foot (300 mm) of soil. As illustrated above however, it is highly subject to clay content.

3.1.1 Calculating the volume of water in the soil

If you have a measure of the volumetric water content at any point in time, then the volume of water in the crop root zone can be calculated by multiplying the volumetric water content by the depth of the root zone. For example – if the volumetric water content is 25% and the root zone is 300 mm deep:

Volume of water= 0.25 x 300 mm=75 mm

Important is to remember that only a mall portion of this water is available to the plant.

3.1.2 What happens in the soil when you irrigate?

In practice the following happens when one irrigates:

- Water is applied to the soil surface and enters the soil through the process of **infiltration** (seeping into the soil). Depending on the soil texture and other soil factors, the water infiltrates at a certain tempo – the **infiltration rate** (Part 2: Soil). This rate is measured as depth in mm of water applied per hour. When water is applied to a crop, water will soak into the surface of the soil.
- The infiltration rate will vary as it is influenced by:
  i. Compaction of soil surface
  ii. Soil texture and structure
  iii. Amount and type of vegetation cover
  iv. Soil water content status, whether the soil is wet or dry
- Water fills the macro and micro pores of the soil and displaces the air in those spaces. Water is adsorbed (sticks onto) to the clay particles in the soil and excess water moves freely in the macro pores down the soil profile with gravity to fill the pores deeper in the soil. This movement of water takes place in a relative horizontal line called the **wetting front**. The depth of infiltration of the wetting front is a function of the amount of water irrigated, as well as the soil texture (clay content). At field capacity the soil particles have adsorbed its maximum amount of water, with enough air molecules in between necessary for root functions and micro organism activity. The soil then contains no free water. Any additional water will leach (drain) at the bottom of the soil profile – if the soil is well drained. If there is a drainage problem the profile will fill up and additional water will run off from the surface and the soil will stay water logged (over saturated).

  In sandy soils the percolation rate (downwards movement of water through soil) is higher than in clay soils, while water percolates readily through sandy loam and loam.

- Nutrients are dissolved in the soil water and absorbed by plant roots together with the water. It is therefore important to irrigate only up to the depth where the roots are active to ensure nutrient uptake and prevent leaching (draining) of plant nutrients. We therefore need to know how deep the irrigation (wetting front) infiltrates with a certain amount of irrigation application.

3.1.3 What is a wetting front?[2)]

As mentioned above, water infiltrates the soil profile along a **wetting front**. This can be defined as the visible line of wetting in the soil profile caused by water infiltration from rain or irrigation.

The wetting front can physically be seen by digging a soil profile hole. This is an exercise that every irrigation farmer should do to see how deep a certain amount of irrigation infiltrates into his soil. This is also the basis for irrigation scheduling on a specific field. By digging this profile the farmer or extension advisor can practically see the depth of infiltration of a specific amount of irrigation, and can therefore determine the amount of millimetres that should be irrigated on that field for a certain root depth.

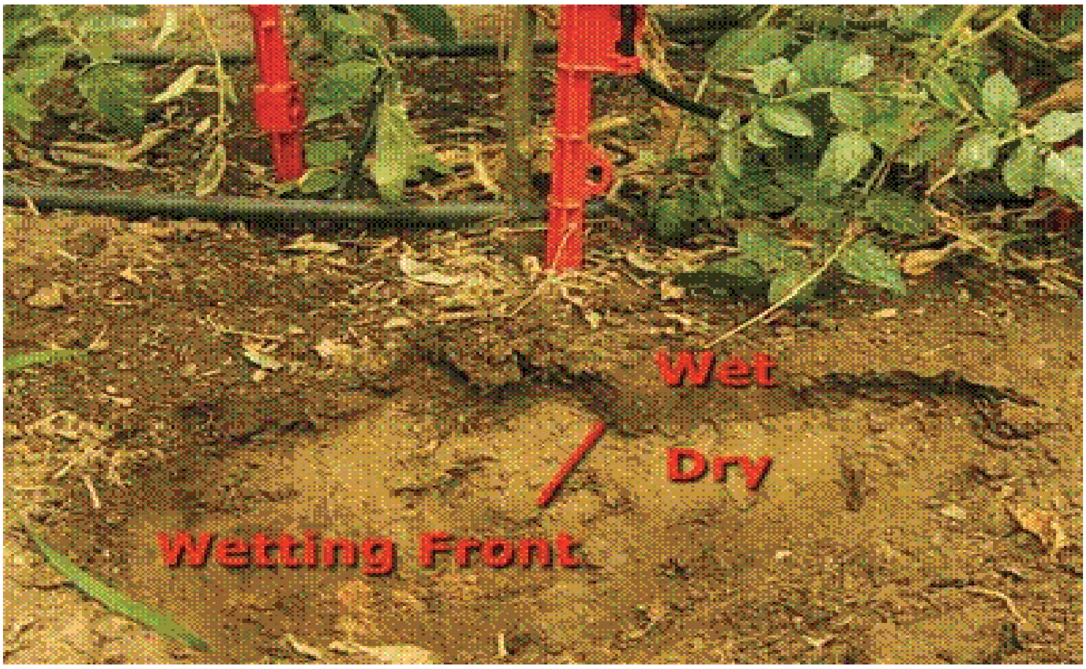


Figure 3. Soil profile indicating the wetting front[2)]

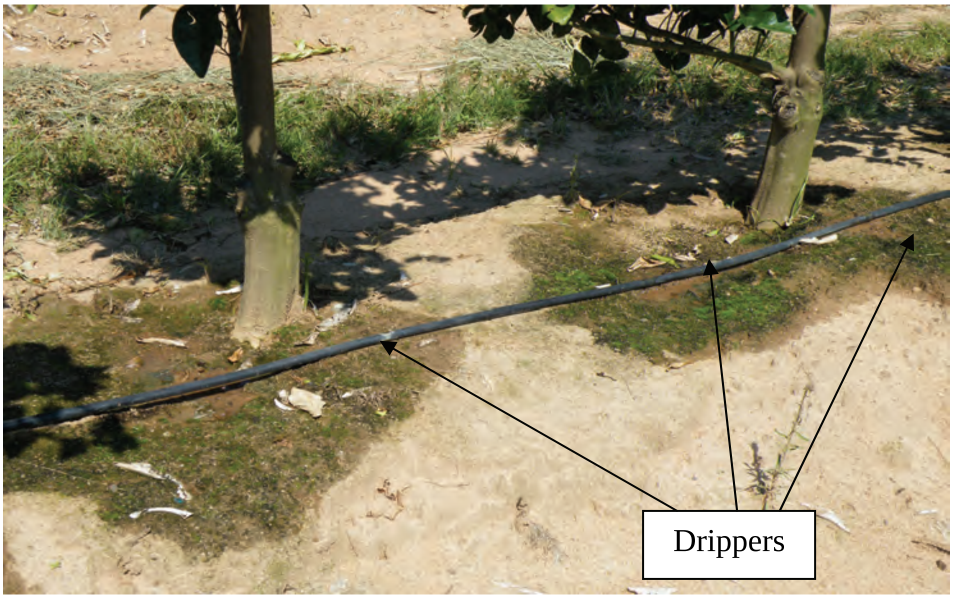


Figure 4. Wetting front visible from above

As the soil dries out, the rate of evaporation from the surface falls fairly quickly until the soil surface is dry. The remaining soil moisture, which is usually the majority of the available water, is used by the plant for transpiration and growth. After a while the soil surface becomes dry enough to slow down the plant growth. The soil moisture level at this stage is called the *critical deficit.*

Definition

Full point or Field capacity: is the maximum quantity of water that soil can retain which cannot drain from the soil under the force of gravity. Thus it is the quantity of water retained in the soil after all free water has drained from the macro pores under the force of gravity. Field capacity is the upper limit of plant-available water in a soil.

Refill point: when the soil has declined to point where the plant becomes stressed. Active growth stops as the plant finds it harder to extract the remaining soil water.

*Permanent wilting point (PWP***)** *or just wilting point:* is supposed to indicate the lower level of plant-available water in the soil where soil water is no longer available to the plant because adsorption forces exceed the plants' suction ability.

Readily available water (RAW) or Plant available water (PAW): A plant cannot use all the water held in the soil. The amount of water between Field Capacity and Permanent Wilting Point is called **Readily Available Water (RAW).** This is the amount of water the plant can readily use before growth rates become affected. Irrigation should aim at replacing this volume of water.

3.1.4 How can I use these principles to manage irrigation?

The less RAW a soil holds, the more frequently it needs to be irrigated. For instance, 80% of PAW in sandy soils is readily available. In clay soils, only 40- 50% of PAW is readily available. Because of this attribute of clay soils, they have approximately twice the amount of RAW as sandy soils, and should therefore require less frequent irrigations.

Activity

Activity 1

Group activity

1. Measure the infiltation rate of water into two different soil types by digging a soil pit or using of a soil auger. Measure the depth the water moved through the soil surface and record the time that water takes to be absorbed by the specific soil type.

   Soil type 1

   ....
   ....
   ....

   Soil type 2:

   ....
   ....
   ....
   ....
   ....

2. Your trainer will have the infiltration rates of a range of soils – use these to determine the specific soil type you are working with (sandy, loam or clay).

   Soil type1: What soil type is this?

   ....
   ....
   ....
   ....
   ....
   ....
   ....

Soil type2: What soil type is this?

....
....
....
....
....

3.2 Measuring Crop Water Use

Answering the basic questions of how much water crops need and when it is required depends on the understanding of crop water use. Without proper knowledge of being able to estimate what the current water status of the soil is, or whether the crop is under stress or likely to be under stress in the near future (critical growth periods), it is impossible to irrigate efficiently.

There are basically three fundamental ways of measuring crop water use, namely:

- Soil water measurements (observe and feel; tensiometers; capacitance meters, electric resistance meters, etc.) This method measures soil water content and allows the irrigator to determine how much water to apply, and with the proper knowledge about the crop requirements, when to apply the water).The relative low cost devices like tensiometers, electric resistance meters, etc. are used by farmers while the more sophisticated and expensive devices like capacitance meters are mainly used by irrigation consultants[6)]. Some of these methods are used for taking readings manually, while other record soil water content on a continuous basis.
- Plant water measurements (leaf water potential, heat pulse method, stem diameter measurements, infrared thermometry, etc.) The general idea behind the plant measurements is measure the water status of the plant rather than the soil. The plant is an important link between the soil and the atmosphere, and its water status can give an accurate indication of when to irrigate.
- Evapotranspiration estimations and measurements (weather stations, evaporation pans, computer programs like SAPWAT, etc.) Evapotranspiration is giving an estimation how much water has been taken from the soil, and therefore how much irrigation is required. Water budgets are used to calculate soil water indirectly by adding rainfall and irrigation and subtracting ET to determine the soil status.

4. Why irrigation?

Irrigation is done to optimise yields by providing plants with dissolved nutrients and to manipulate the growth stages of the plant through irrigation scheduling. The purpose is therefore to ensure, from a water perspective, that the most optimal economic yield is produced.

a. *Crops can be grown that would not naturally adapt to local climatic conditions (rainfall)*
Perennial crops grown in this country not only need more water than the average rainfall, but also need water throughout the year. These crops would therefore not be grown without irrigation.

b. *Water can be applied according to **crop requirements**.*
Many crops like citrus, mangoes, grapes and avocado's flower in the winter and spring months when very little rain occurs, and this is a critical stage where moisture stress in plants should be avoided. Correct water application in this stage is critical. Theoretically the less rainfall occurs the more accurate water application can be done according to crop requirements.

c. Irrigation is used as a manipulation tool in the crop growth stages and gives farmers a degree of control over flowering and ripening stages of fruit crops. Many crops tend to flower more profusely and evenly when experiencing a mild stress just before flowering. In some crops like citrus the sugar content in the fruit can be increased by applying less water or decreased by applying more.

d. A further advantage of irrigation is that planting dates for seasonal crops can be determined by the farmer and not by the rainfall pattern. This can give a farmer a competitive advantage to other farmers in his area that are only dependant on rain. For example a farmer who plans to sell green mealies in December, needs to plant in August or September when usually very little rainfall occurs.

Note: *It is also important that irrigation is economically sustainable. Therefore not only water application but also all other resources need to be optimally utilised and that the crops are marketed profitably.*

5. Consequences of under or over irrigation

Under irrigation usually lead to:

- Plants suffering during certain critical physiological stages which can lead to reduced crop yields or lower crop quality
- Some of the nutrients will become out of balance and the plant could experience an oversupply of some nutrients and a shortage of other nutrients.

Over irrigation leaches nutrients out of the soil and the plants experience an imbalanced supply of nutrients. Some nutrients are more difficult to leach out of the soil and will become toxic, while others leach quickly and the plant will have a lack of these nutrients (Part 2, Module 6).Therefore the importance of irrigation scheduling and the consequences of starting and stopping irrigation at times is very important. Over irrigation results in causing an imbalanced mineral supply to the plant and also in clay soils result in water logging, compaction and fungal root diseases.

To prevent these consequences of ill irrigation management, the irrigators should have the necessary knowledge to make the correct decisions at critical times. The necessary system maintenance is a prerequisite to prevent that part of the irrigation system being over loaded and eventually breaking.

6. Concepts used in irrigation management

6.1 General concepts

- **Volume**

  In South Africa the metric system is used, and volume of water is measured in litres (L) or cubic meter (m^3).

  1 m^3 = 1000 L

- **Application**

  Water application to the soil as well as rainfall is measured in millimetres (mm).

  If one litre is applied to one square meter, an application of 1 mm is done.

  1 L/m^2 = 1 mm therefore 20 L/m^2 = 20 mm

  The same is true for larger areas and volumes: **mm =** $\frac{\mathbf{m^3}}{\mathbf{ha \times 10}}$

  If 10 m^3 is applied to one hectare it represents 1 mm application.

  1 mm = 10 m^3/ha. 200 m^3/(1 ha x10) = 20 mm.

  4000 m^3 applied on 10 hectares means an application of 40 mm.

  $$\frac{4000\ m^3}{(10\ ha \times 10)} = 40\ mm$$

  If the 40 mm is applied with a sprinkler system in a time of 8 hours, the **application rate** of the system is 5 mm/h (40 mm/8 hours).

- **Application rate**

  The rate of water application on a total area is measured in millimetres per hour (mm/h).

  If a sprinkler system is spaced 18x18 m, and a sprinkler nozzle delivers 1500 L/h, then the application rate can be calculated as follows:

  (Keep in mind that L/m^2 = mm): 1500 L/324 m^2 (18x18) = 4.6 mm.

  The nozzle delivers 1500 L per hour; therefore it applies 4.6 mm/h

- **Application Efficiency**

  In 6.1 where application of water is discussed where a certain volume of water is applied to a specific area to obtain a certain application in millimetres. This is however a theoretical figures because no irrigation system is 100% efficient in the application of water. To a certain extent some losses always occur and this varies according to the irrigation system and is also influenced by the climatic conditions.

  A system with application efficiency of 80% can therefore successfully apply to the soil 80% of the pumped volume of water. The other 20% is lost through direct evaporation, wind drift as well as (evaporation from) crop interception.

  The example in 6.1 can then be adapted as follows:

  4000 m³ applied on 10 hectares by a system with 80% application efficiency equals an application of:

  $$\frac{4000\ m^3}{(10\ ha \times 10)} = 40\ mm \times 80\% = 32\ mm \qquad (also\ 40\ mm - 20\%)$$

  If 15000 m³ is applied by a centre pivot system with 85% application efficiency on an area of 30 ha, the application achieved is:

  $$\frac{15000\ m^3}{30\ ha \times 10} = 50\ mm \times 0.85 = 42.5\ mm \qquad (50\ mm - 15\%)$$

- **Pressure**

  To understand pressurized irrigation we need to appreciate the concept of energy supply to drive the water through a pipe to be applied by a sprinkler or dripper.

  This energy is provided in two ways namely:

  i. **gravity** where water moves down a slope with natural gravitational force
  ii. **pumping** water against gravity and pipe friction to a certain height.

  A basic presentation of these concepts is given in the following diagrams:

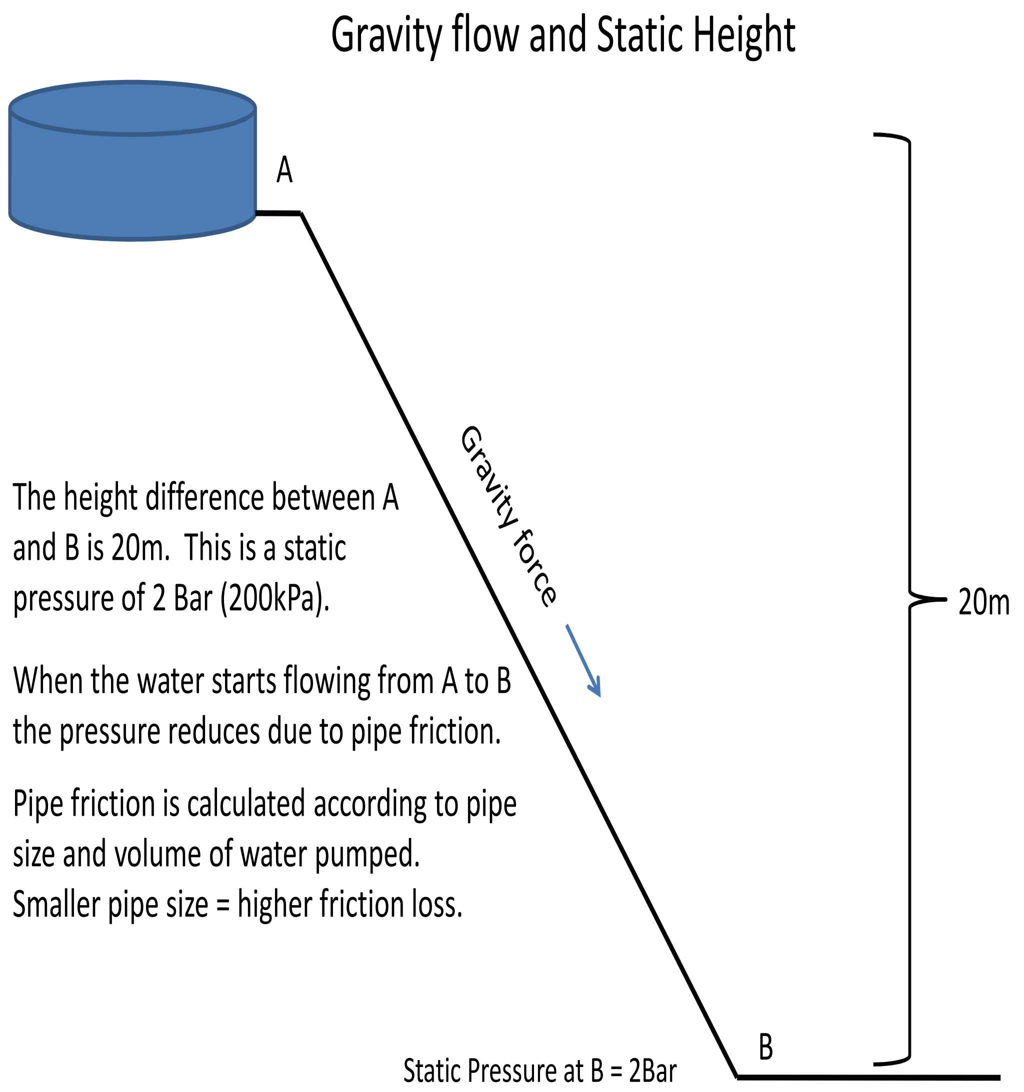


Figure 5. Gravity flow and static height

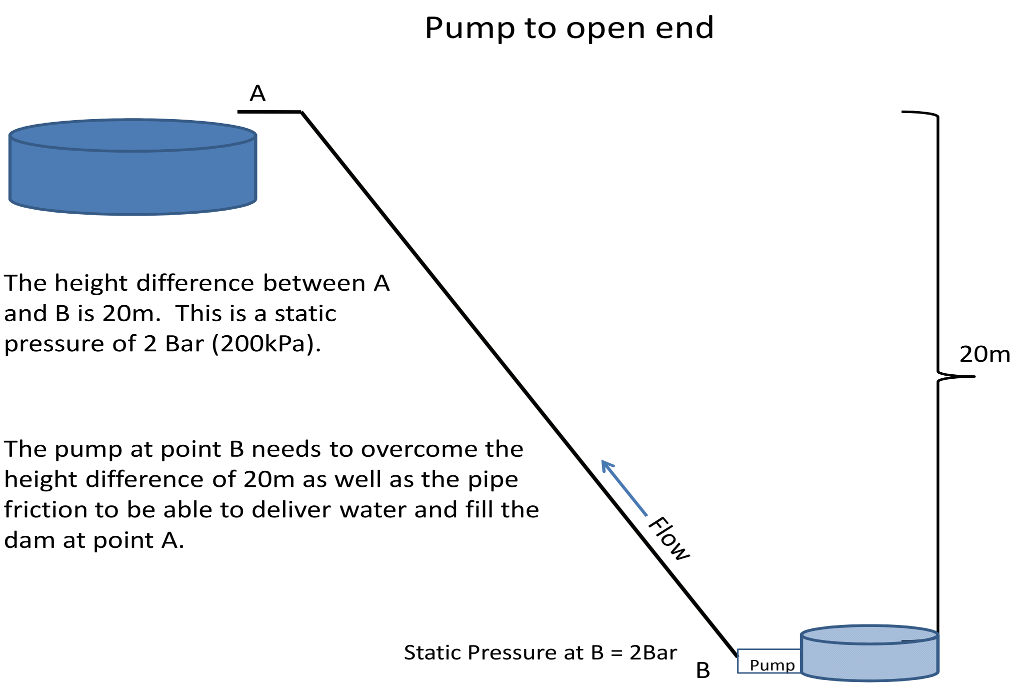


Figure 6. Pressure pumping to an open end

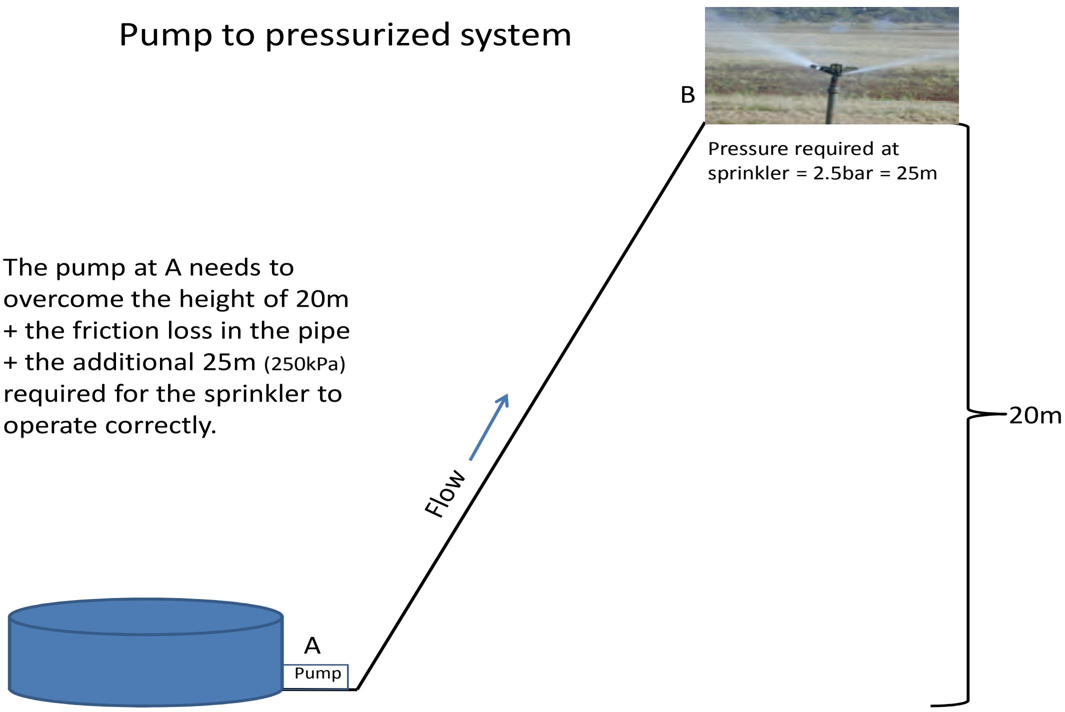


Figure 7. Pumping to pressurized system

From the above diagrams it can be understood that the standard unit for water pressure is meter (m). Bar (B) and kilo Pascal (kPa) are generally used for measuring pressure with instruments.

1 bar =10 m =100 kPa

- **Flow rate**
  The flow of water inside a pipe or in a canal is expressed and measured in volume of water per time unit. The standard units for flow rate are cubic meters per hour (m^3/h), litres per hour (l/h) and litres per second (l/s).

- **Flow velocity**
  Flow speed in a pipe or canal is expressed in meters per second (m/s). It is the physical distance the water flows per second.

6.2 Irrigation management definitions and concepts

- **Irrigation**
  The artificial application of water to the soil to meet **crop water requirement (CWR)**.

- **Irrigation system or only system**
  The physical components and water bearing structures specially established for the transportation of irrigation water from the source to the crop in order to apply it to the benefit of the crop.

- **Distribution lines**
  a. Main line
  The part of the pipeline from the pump to the inlet to a field.

  b. Sub-main line
  The part of the pipeline connecting the main line to the manifolds. (Owing to the many different pipeline layouts found in practice, it is often neither easy nor important to distinguish between main lines and sub-main lines.)

- **Manifold**
  The pipeline from which the laterals branch off.

- **Lateral**
  The pipeline on which the emitters occur.

- **Emitter**
  A device designed to distribute water onto the soil according to a specific application rate and distribution pattern at a given pressure. (Examples are drippers, microjets, micro sprinklers, sprinklers and big guns).

- **Emitter discharge (qe): [volume/h]**
  The amount of water per hour leaving the emitter at a given pressure.

- **Irrigation block**
  Part of an irrigation system designed as a unit and controlled by a single valve. The whole block is always irrigated during one standing or irrigation time.

- **Irrigation set**
  A group of irrigation blocks which can be irrigated at the same time.

- **Design application: [mm]**
  The maximum application for which the system is designed.

- **System capacity: [m3/h of l/s]**
  The maximum rate of delivery of the system.

- **Irrigation scheduling**
  The process of management of an irrigation system with the purpose of applying the correct amount of water at the correct time to meet the crop water requirement (CWR) optimally.

- **Cycle length: [days]**
  The actual time lapse between the commencement of two successive applications for a specific irrigation set.

- **Theoretical cycle length: [days]**
  The calculated time lapse between the commencements of two successive applications by a specific irrigation system when it has to satisfy the peak water requirement of the crop.

- **Standing time: [h]**
  The actual period of time needed by a static irrigation system for a certain net application (NA).(Actual hours irrigating).

- **Theoretical standing time: [h]**
  The calculated period of time for which a system has to irrigate to apply the design application.

- **Rotation time: [days of h]**
  The actual time that a mechanized irrigation system must irrigate for a certain net application (NA).

- **Inflow time: [minutes]**
The actual period of time necessary for the water supply of a flood irrigation system to be diverted into a flood bed for a certain net application (NA).

- **Pressure (p or H): [kPa or m]**
The pressure of the water inside the system relative to atmospheric pressure

- **Pressure variation (.H): [kPa or m]**
The difference in pressure between the highest and the lowest pressure in a unit, such as an irrigation set, an irrigation block, a lateral or a filter.

- **Pressure loss (äH): [kPa or m]**
The difference in pressure between two points in a system as a result of the static pressure and pipe friction.

  - **Static head (hs): [kPa or m]**
  The difference in altitude between two points in a system.

  - **Pipe friction (hf): [kPa or m]**
  The head loss as a result of laminar and turbulent flow of a viscose liquid (in this case, water) through the different components of a system.

- **Hydraulic gradient: [m/m]**
The slope on the line (which would have been followed by a free water level) representing the total energy head in a closed or open conduit.

- **Pipe diameter: [mm]**
The internal or external diameter of a pipe.

  - **Internal diameter (d): [mm]**
  The real internal diameter of a pipe.

  - **Nominal diameter: [mm]**
  The diameter in terms of which a pipe is popularly spoken of.

- **Pipe length: [m]**
The length of a specific section of pipe of constant diameter, class and material.

- **Equivalent pipe length: [m]**
The length of a specific diameter of pipe producing the same head loss as a specific component of the same diameter under the same flow conditions.

- **Application**
  - **Gross application (GA): [mm]**
    The average depth of water that is theoretically applied by the emitter to the wetted area during one standing, irrigation or inflow time at its emitter discharge.
  - **Net application (NA): [mm]**
    The depth of water applied to the soil surface during one standing, irrigation or inflow time. *Alternative:* It is calculated by multiplying the gross application (GA) by the application efficiency (ça).
    $$NA = ça\ GA$$

- **Application rate**
  - **Gross application rate (GAR): [mm/h]**
    The rate at which the water is theoretically applied by the emitter to the wetted area.
  - **Net application rate (NAR): [mm/h]**
    The rate at which the water is applied to the soil surface by the emitter.

    Alternative: It is calculated by multiplying the gross application rate (GAR) by the application efficiency (ça).
    $$\text{NAR} = \text{ça GAR}$$

- **Emitter discharge (qe): [volume/h]**
  The volume of water per hour leaving the emitter at a given pressure.

- **Distribution pattern**
  The water pattern according to which the irrigation water is distributed onto the soil surface by the emitter.

- **Spacing: [m]**
  - **Emitter spacing: [m]**
    Distance between two emitters along a lateral.
  - **Lateral spacing: [m]**
    Distance between two laterals.
  - **Sprinkler positioning: [m x m]**
    Distance description of an emitter positioning: (Distance perpendicular to laterals) × (distance parallel to laterals).
  - **Plant spacing: [m]**
    Distance between two plants in the same row.

- **Row spacing: [m]**
  Distance between two adjacent rows in a field.

- **Orchard spacing: [m x m]**
  Distance description of the trees in an orchard: (Plant spacing) × (row spacing) or in the case of a tramline spacing: (row spacing) × (row spacing) × (plant spacing)

- **Tramline spacing**
  Where two different row spacing are alternated in the same field.

- **Effectively wetted area**
  That part of the emitter's distribution pattern that may be considered effective for scheduling calculations. (A net application rate (NAR) of 1 mm/h and higher is mostly considered effective).

- **Wetted strip width: [m]**
  The width of a strip effectively wetted by a row of emitters. (It does not include the lateral distribution of the water in the soil).

- **Coefficient of variation (CV): [%]**
  A statistical parameter determined by the variation of manufacturing of different components in the same model.

- **Christiansen Uniformity Coefficient (CU): [%]**
  A statistical parameter giving a description of how evenly the irrigation water is distributed in an irrigation block, based on measurements of the net application (NA) on a grid over the given area. The description of Christiansen (1942) is being used.

- **Distribution uniformity (DU): [fraction]**
  The criteria of the uniformity of distribution determined by measuring and giving an indication of the measure in which under-irrigation is taking place in an irrigation block by calculating the relation between the average of the lowest 25% of the measurements and the average of all the measurements in the block.

- **Emitter Uniformity (EU): [%]**
  A static parameter determined by measuring (metering) of delivery and giving an indication of how equally emitters deliver water within an irrigation block. There is a differentiation between design uniformity (for design purposes) and actual emitter uniformity (for evaluation purposes)

- **Operational losses**
  That portion of irrigation water that does not reach its destination at a specific point in the process. The ideal is to minimize the losses through optimal design, proper installation, operation and maintenance of the irrigation system.

- **Chemigation**
  The application of chemical substances, dissolved or in suspension, to the irrigation water by means of the irrigation system. A distinction can be made between the following:
  - **fertigation**, by means of fertilizer application;
  - **herbigation**, by means of herbicide application;
  - **fungigation**, by means of fungicide application;
  - **insectigation**, by means of insecticide application

- **Filter**
  A device removing solid and organic material exceeding a certain size from the irrigation water during irrigation.

- **Valve**
  A valve is a device in a pipe line that shuts off or controls the flow of water.
  - **Shut-off valve**
    That mechanism in a valve that physically shuts off or controls the flow of water.
  - **Gate valve**
    Valve in which the sealing disc is opened and closed in a linear action by means of a threaded spindle. When open, the water flows horizontally past the bottom end of the sealing disc.
  - **Diaphragm valve**
    Valve in which the flow opening is shut off with an elastic membrane by means of a positive threading action.
  - **Butterfly valve**
    This valve is opened or closed by rotating a sealing disc through 90º by means of a lever or gearbox.
  - **Ball valve**
    The flow is shut off by means of a quarter rotation.

- **Control mechanisms**
  That unit that controls the sealing mechanism to have a threaded mechanism or a lever to control the valve.

- **Mechanical control**
  Mechanical, manually controlled valves have a threaded mechanism or a lever to control the valve.

- **Hydraulic control**
  - **Single chamber control:** Hydraulic valve with a single chamber inside which the pressure can build up to shut off the flow by means of a diaphragm.
  - **Double chamber valve:** Hydraulic valve consisting of two chambers and which seals relatively slowly over the last 30% of the closing action.
  - **Manual control of hydraulic action:** Hydraulic valve with simple three-way valve that controls the opening action.
  - **Hydraulic remote control:** Hydraulic valve which is operated by means of a remote controlled hydraulic signal.
  - **Electric remote control:** Hydraulic valve which is operated by means of a remote controlled electric signal.
  - **Automatic pilot controlled hydraulic valve:** Consists of a diaphragm with adjustable spring which serves as the control unit for the hydraulic valve.

- **Air valve**
  Valve that lets out air through a pipeline while it is under pressure and also when it is filled with water, and which lets air into a draining system to prevent the forming of vacuums.

- **Foot valve**
  Valve that shuts off the inlet openings to prevent water from flowing backwards from the suction pipe – e.g. when the pump is switched off.

- **Non-return valve**
  Valve that prevents the backwards flowing of water in a pipe.

- **Float valve (sometimes wrongly called ball valve or ball lever valve)**
  Valve which can maintain a constant free water level by means of a floating ball attached to a lever.

- **Efficiency (ç): [% or fraction]**
  The output of a specific operation in relation to the input.

- **Transportation efficiency (çt): [% or fraction]**
  The efficiency of transportation of water from the source to the irrigation dam or draw-off point on the farm boundary.

- **Distribution efficiency (çd): [% or fraction]**
  The efficiency of distribution of water from the irrigation dam or draw-off point on the farm boundary through the irrigation system to the point where it leaves the emitters. Losses from the irrigation dam are included here.

- **Conveyance efficiency (çc): [% or fraction]**
  The efficiency of conveyance of the water from the source to the point where it leaves the emitters.

- **Application efficiency (ça): [% or fraction]**
  The efficiency with which the water leaving the emitters of the irrigation system falls onto the soil surface.

- **System efficiency (çs): [% or fraction]**
  The efficiency with which water from the irrigation dam or draw-off point on the farm boundary is delivered through the irrigation system to the point where it falls onto the soil surface.

- **Storage efficiency (ço): [% or fraction]**
  The efficiency with which the water that falls onto the soil surface, infiltrates the soil and becomes available in the root zone of the plant.

- **Field application efficiency (çf): [% or fraction]**
  The efficiency with which the water leaving the emitters, infiltrates the soil and becomes available in the root zone of the plants.

- **Irrigation efficiency (ç*i*): [% or fraction]**
  The efficiency of the total process of irrigation from the source of the water to the point where the water becomes available in the root zone of the plant.

- **Evaporation (E): [mm/day]**
  The loss of water from the soil surface and the top layer of soil before the water is able to penetrate the soil deeply enough to be useful to the crop. (It forms part of evapotranspiration (ET)).

- **Transpiration (T): [mm/day]**
  The loss of water into the atmosphere from the growing plant regulated by physical and physiological processes in the plant.

- **Crop evapotranspiration (ETc): [mm/day]**
  The loss of water through transpiration (T) of the growing plant plus evaporation (E) from the soil surface.

- **Reference evapotranspiration (ET0): [mm/day]**
  The crop evapotranspiration (ETc) of a reference crop - green grass of uniform height (80 to 150 mm tall), growing actively, completely shading the ground and not short of water.

- **Evaporation pan**
  A device used for the measurement of the amount of water lost through evaporation from an open water surface during a specific period. (The American class A pan, which is the standard in South Africa, the Symons pan, the Scheepers pan and the Nelspruit pan are a few examples.)

$$ETc = E + T$$

- **Pan evaporation (E0): [mm/day or mm/month]**
  The amount of water that evaporates from an evaporation pan during a certain period.

- **Crop factor (f): [fraction]**
  The ratio of crop evapotranspiration (ETc) to pan evaporation (E0) for a crop of a given age, in a certain growth phase, with a certain canopy size, in a certain climatic zone.

- **Pan coefficient (kp): [fraction]**
  The ratio of reference evapotranspiration (ET0) to pan evaporation (E0) for the same period.

- **Crop coefficient (kc): [fraction]**
  The ratio of crop evapotranspiration (ETc) to reference evapotranspiration (ET0) for a given crop when growing in large fields under optimum growing conditions.

- **Rainfall or precipitation (R): [mm/period]**
  The depth of precipitation or rainfall registered during a given period by a correctly mounted rain gauge.

- **Effective rainfall (Re): [mm/period]**
  The rain that falls during a given cycle and that can be used profitably by the plants and that partially or completely replaces scheduled irrigation. (This excludes surface run-off, deep percolation and a portion of interception).

- **Surface run-off**
  That portion of rainfall or irrigation which runs off without infiltrating the soil.

6.3 Plant-related definitions and concepts

- **Root zone**
  The area around the plant below the soil surface delimited downwards by the effective root depth (ERD) and sideways by the lateral extension of most of the plant's nutritive roots. Alternative: The root volume of the crop.

- **Crop water requirement (CWR): [mm/period]**
  The depth of water required by a given crop for evapotranspiration (ET) over a specific period. Alternative: Net irrigation requirement (NIR) of a given crop plus effective rainfall (Re). (Operational losses of the system are excluded from the crop water requirement (CWR)).

- **Seasonal crop water requirement: [mm]**
  The crop water requirements (CWR) for an entire growing season.

- **Peak crop water requirement: [mm/day]**
  The average daily crop water requirement (CWR) for the period during which it is the highest.

- **Irrigation requirement**
  - **Net irrigation requirement (NIR): [mm/period]**
    The depth of irrigation water necessary to meet evapotranspiration (ET) of the crop during a certain period and in a specific growing phase of the crop.

    Alternative: Gross irrigation requirement (GIR) of a given crop minus operational losses of the system.

  - **Gross irrigation requirement (GIR): [mm/period]**
    Net irrigation requirement (NIR) of a given crop plus operational losses of the system. (The contribution of effective rainfall (Re) is excluded.)

- **Effective root depth (ERD): [m](Effective root zone)**
  The soil depth within which most of the nutritive roots of a plant occur. (It is the smaller of the natural root depth and the effective soil depth.)

  - **Natural root depth: [m]**
    The soil depth within which most of the nutritive roots of the relevant crop would have occurred if no soil restrictions were present.

  - **Effective soil depth: [m]**
    The soil depth to a level at which the growth of the nutritive roots of the plant is restricted by soil-related conditions.

- **Equivalent application: [mm]**
  The average **application** where all the irrigation water actually applied to a limited area, to be applied uniformly over the total area.

- **Shaded area** or **drip area: [m²]**
  The area of the shade cast by a plant on the ground when the sun is directly overhead.

- **Interception**
  That part of rainfall and irrigation that does not reach ground level as a result of interception by foliage.

6.4 Water-related definitions

- **Hydraulics**
  The science that deals with liquids in motion (hydrodynamics) or at rest (hydrostatics). In irrigation the principles of hydraulics are applied to the behaviour of water in pipes and other components of irrigation systems such as pumps, valves, filters, canals and dams.

- **Hydrology**
  The science of the waters of the earth. The study of the distribution of rainfall, run-off and water quality in rivers, and the occurrence and quality of groundwater.

- **Water quality**
  The occurrence and concentration of physical, chemical and biochemical substances and of biological organisms in irrigation water.

- **Dam** (or **dam wall)**
  Any structure capable of storing water.

- **Basic types of structures**
  - **Earth dam:**
    Earth dams are embankments of rock or earth with an impermeable core or upstream blanket for controlling seepage.
  - **Gravity dam:**
    A gravity dam depends on its own weight for stability.

- **Dam capacity: [m3]**
  The amount of water that can be stored in a dam.

- **Dam surface area: [ha]**
  The area of the water surface of a dam.

- **Spillway**
  The section of the structure built for the safe passage of flood water.

- **Discharge structures**
  The structures and equipment built into the dam for the discharge of water.

- **Diversion weir**
  A low dam built in a stream in order to raise the water level sufficiently for diversion of all or part of the water into a canal or furrow, and to control the flow.

- **Canal**
  An open furrow in which the water flows under gravity. (It may consist of soil, or it may be lined with concrete or any other impervious material).

- **Sluice-gate**
  A sliding structure for the control of the flow of water in an open conduit.

- **Flow rate** or **flow: [m³/s]**
  The rate of flow of water past a certain point.

- **Water meter**
  A device measuring the cumulated amount of water that flowed past a certain point in a pipeline.

- **Flow meter**
  A device with which the flow rate in a pipeline or canal is measured.

- **Flow measuring weir**
  A structure used exclusively for measuring the flow rate in a canal or stream.

- **Basic types of weirs**
  - Rectangular sharp-crested or broad-crested weir
  - V-notch or Cipoletti weir
  - Crump or Parshall flume

- **Irrigation stream: [m³/h]**
  The flow rate at which an irrigator may take water from a canal or furrow shared with other irrigators.

- **Water Act**
  The National Water Act (Act 36 of 1998) as amended, and the regulations and proclamations promulgated there under.

- **Soil Conservation Act**
  The Soil Conservation Act (Act 43 of 1983) as amended and the regulations and proclamations in terms thereof, or any act with which it is replaced.

- **Contour channel**
  A gently sloping channel with a raised bank built across lands of steeper gradient. The gradient of the contour ridge is gentle enough to prevent erosion.

- **Waterway**
  A broad artificial channel which collects the water from several contour ridges and carries it straight down the steepest slope to a natural watercourse.

7. Glossary: Abbreviations and Symbols

A = Area
AWD = Allowable water depletion**CU** = Christiansen Coefficient of Uniformity
CV = Coefficient of variation (of manufacturing)
CWR = Crop water requirement
d = Diameter
ç = Efficiency
ç**f** = Field application efficiency
ç**i** = Irrigation efficiency
E = Evaporation
E0 = Pan evaporation
ERD = Effective root depth
ET = Evapotranspiration
ET0 = Reference evapotranspiration
f = Crop factor
g = Gravitational constant (9,81 m/s²)
GA = Gross application
GAR = Gross application rate
GIR = Gross irrigation requirement
H = Head or pressure head
kc = Crop coefficient
L = Length
m = Mass
NA = Net application
NAR = Net application rate
NIR = Net irrigation requirement
p = Pressure
P = Power
PWP = Permanent wilting point
Q = Flow rate
qe = Emitter discharge
r = Radius
R = Rainfall or precipitation
Re = Effective rainfall
RAW = Readily available water
SWC = Soil water capacity
t = Time
T = Transpiration
v = Velocity
V = Volume

8. Basic units and calculations

Description	Abbreviation	Unit	Symbol
Length	*L*	meter	m
Area	A	square meter	m^2
Volume	V	cubic meter	m^3
Time	t	seconds	s
Velocity	v	meter per second	m/s
Flow rate	Q	cubic meter per second	m^3/h
Mass	m	kilogram	kg
Force and weight	F	newton	N
Pressure	p	pascal	Pa
Power	p	watt	W
Temperature	T	degrees Celsius	ºC
Electric current	I	ampère	A
Electric potential	V	volt	V

9. Common irrigation unit conversions

Area	1 Hectare (ha) = 100 m x 100 m = 10 000 m² 12 ha = 12 x 10 000 m² = 120 000 m²
Volume	1 Cubic meter (m³) = 1 m x1 m x1 m = 1000 L 50 m³ = 50 x 1000 = 50 000 L 200 000 L = 200 000/1000 = 200 m³ 3000 m³ = 3000 x 1000 = 3000 000 L
Distance	1 km (kilometre) = 1000 m 2.7 km = 2.7 x 1000 = 2700 m
Time	1 min = 60 seconds 0.8 min = 0.8 x 60 = 48 sec 6.4 min = 6 min 24 sec (0.4 x 60) 1 H = 3600 sec
Velocity	Water flow in a pipe/river/canal is measured in meters per second. 12 m in 10 sec = 1.2 m/s 50 m in 60 sec = 0.83 m/s
Flow Rate	1 m³/h = 1000 L/h 1 m³/h = 3600 L/s (60 min x 60 s) 100 000 L/s = 100 000/3600 = 27.77 m³/s 1 m³/s = 1000 L/s (1 m³ = 1000 L) 60 m³/h = 60 000 L/h 15 m³/s = 15 000 L/s 7200 L/s = 2 m³/s (7200/60/60)
Application	Apply 1 L to 1 m² =1 mm application (depth) 1 L/m² = <u>1 mm</u> 25 mm/5 ha = 25 x 5 x 10 = 1250 m³ 500 m³ per ha = 500/10 = 50 mm Apply 10 m³ on 1 ha = 1 mm application 10 m³ per ha = <u>1 mm</u> 20 mm applied on 1 ha = 20 x 10 = 200 m³ 2000 m³ on 5 ha = (2000/5/10) = 40 mm
Pressure	1 Bar = 10 m = 100 kPa (kiloPascal) 25 m = 2.5 bar 650 kPa = 65 m = 6.5 bar 3 Bar = 300 kPa 150 kPa = 15 m 40 m = 4 bar = 400 kPa
Electric Power	Power (W) = volt (V) x ampère (A) Ampère (A) = power (W)/volt(V) 380 V x 150 A = 57 000 W = 57 kW 37 000 W (37 kW)/380 V=97 A
Application Rate	2 mm applied per hour = 2 mm/h 2.5 mm applied in 30 min = 5 mm/h 30 mm applied in 8 hours = 3.75 mm/h 2 5 mm applied in 6 hours = 4.16 mm/h

Activity

Activity 2

Group activity

1. Explain what it practically means if you measure 20 mm in your rain gauge after a rain storm.

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2. How many litres fall on one hectare if you apply 5 mm on that area?

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3. If the application efficiency of an irrigation system is 80%, calculate the net application when a gross application of 30 mm is applied.

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4. If 5000 m^3 is applied on 15 ha, what is the gross application?

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5. If the system efficiency is only 75%, what is the net application?

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6. How many cubic meters (what gross volume) should be pumped to apply 34 mm to a 5 hectare field, with an irrigation system that has 85% application efficiency?

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7. According to the label on your pump it delivers 8 litres per second (L/s) at a pressure of 40 m. What is the delivery in cubic meter per second m^3/s)?

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8. What is your pump delivery in cubic meter per hour (m^3/h)?

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9. What pressure – measured in bar – can your pump deliver?

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10. A specific sprinkler irrigation system is able to apply a gross application of 5 millimetres per hour (5 mm/h). The application efficiency of the system is 75%.

    How many hours should you irrigate (stand time) to apply a net application of 30 mm?

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References

1 ARC Institute of Agricultural Engineering (ILI) Irrigation User's Manual, 2009

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Technical Learner Guide

Irrigation Water Management

Level 5

Module 2

Assessing of water resources

Study objective

After completion of this module, the learner should be able to have a basic understanding of:

- Identifying the potential water resources on a farm
- Difference between private and public water
- The major river systems of South Africa
- Riparian rights to the use of water from a river that runs through or on the boundary of the farm
- Requirements and conditions which should be met for the building and using of dams with a safety risk
- Sustainable use of groundwater
- How to calculate the water requirements for a specific farm?

Table of contents

An irrigation system must meet the farmers' goals. In the designing of a new irrigation system, there are a number of basic questions that need to be answered relating to water supply, application depths and rates and equipment selection.

The typical questions relating to water supply and irrigation system capacity to be answered are:

- How much water is need?
- What maximum supply rate is required?
- Where is the water to come from?
- How much water is required per season or per hectare?
- Is storage required and what capacity is required?

These and other aspects of the water supply system are discussed in this module.

1. Water resources for irrigation purposes

The evaluation of water sources on the farm includes the determination of water availability, quality, legal aspects and suitability for irrigation purposes.

The National Water Act (1998) determines the use of water on the farm and is aimed at equal and fair allocation of water to all users and the protection of these rights. The right to use water on the farm is linked to two aspects namely:

- the link between the right to use water and land ownership or also known as riparian rights, and
- the separation between public and private water.

Public water refers to water in public streams. A public stream is defined as a natural stream, which flows in a known and clearly defined channel, from which two or more riparian areas, with separate title deeds may be irrigated.

Private water includes surface or underground water. Surface water is water that falls on a piece of private land or comes from a natural spring on the farm. Underground water coming from a borehole is a typical example of private water. The owner of the land has the sole right to use the surface and underground water and may not sell or transfer those rights across the borders of the property from which it originates without a permit in terms of section 5 (2) of the Act.

Water resource options for use include:

1) Pumping from rivers and streams
2) Use of irrigation dams
3) Groundwater resources
4) Government and community (private) irrigation schemes

1.1 Pumping from rivers and streams

Globally rainwater is the primary source of irrigation water. Rainwater that runs off from soil and other surfaces naturally forms little streams, which meet to form larger streams. A river is a network of streams that is formed by the topography of an area. The constant flow of a river depends firstly on the amount of rainfall, but also on the duration time of the rainy season, the length of the river, the slopes and the vegetation of the catchment area. Shorter rivers with steep catchment slopes will runoff quicker than a longer one (with the same rainfall) with less steep slopes. The latter will therefore take longer to drain the same amount of water with slower flow speeds.

In terms of article 9 (1) of the Water Act, each owner has the right to the reasonable use of his portion of the normal flow of a public stream, which borders his farm. Normal flow of a public stream is the volume of water, which clearly flows in the public stream and which, without the use of storage, may be used advantageously for irrigation of the riparian areas. Normal flow, available for direct irrigation from a public stream is that which is available for 70% of the time during critical periods. The principle of fair share applies the normal flow, and the rights are usually not determined or published. The only control that Department of Water Affairs and Forestry has over the abstraction of water from these areas, is in terms of article 9B(1) of the Water Act, which determines that anyone who draws more than 110 litres per second or stores more than 250 000 m^3 per separately registered portion of land, as existed on 28 May 1975, must obtain a permit from the Minister of Water Affairs. Article 9b(1c) however empowers the Minister to adjust abovementioned storage and abstraction limits to provide for the local circumstances. In the Umgeni River in KwaZulu-Natal farmers may only store 20 000 m^3 and abstract 5 litres per second, before permits are required.

Not all farms that border public rivers or streams have automatic riparian rights. Previous subdivision of land may have left the specific farm without the riparian rights and therefore it is necessary to confirm these rights as described by the title deeds, before you start planning irrigation. Riparian owners do take priority at all times over the abstraction of water for household and livestock use, while the irrigation farmer will identify the limitations applicable to the specific property. In some irrigation districts these responsibilities are taken over by the local Irrigation Board has been indicated in the National Water Act (1998). If the property is situated within a government water control area, the Department of Water Affairs and Forestry publishes the riparian rights of individual properties in the Government Gazette. If riparian owners irrigate more than their rights allow, immediately after promulgation, they must cut back on irrigation, or they may be allowed to create storage facilities for surplus water.

Rivers are main sources of water, but only a small percentage of rainfall (9%) reaches the rivers in South Africa. The Orange River Basin is the largest river basin in the country, with 600 000 km^2 of its total catchment of 1 million km^2 falling inside the borders of South Africa. The fact that rainfall is variable has led to the fact that major rivers like the Limpopo, Orange, Vaal, Inkomati and others are dammed or modified to meet the demand for water use. The following map in Figure 3.7 illustrates the major rivers and catchment areas of South Africa.

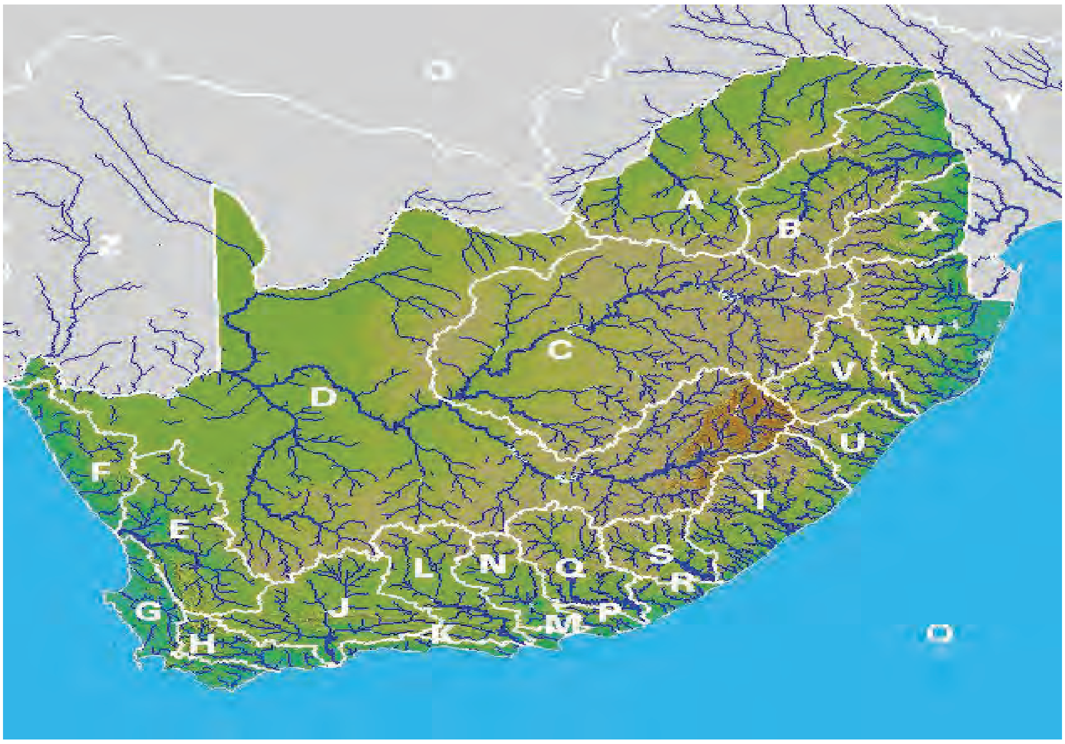


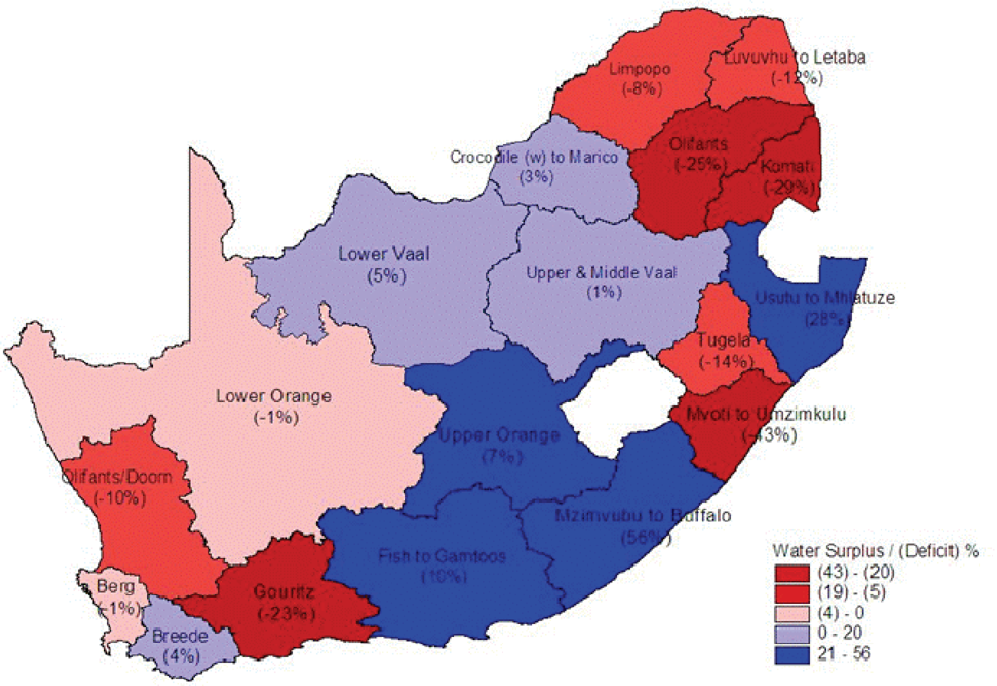
Figure 1 Major rivers of South Africa (www.dwaf.gov.za)

Legend

A	Limpopo	J	Gouritz	S	Mzimvubu
B	Olifants	K	Tsitsikamma	T	Umtamvuna
C	Vaal	L	Sondags	U	Umzimkulu
D	Orange	M	Swartkops	V	Tugela
E	Olifants	N	Fish	W	Pongola
F	West Coast	P	Buffalo	X	Nkomazi
G	Berg	Q	Kei		
H	Breede	R	Keiskamma		

Four major rivers in South Africa namely the Limpopo, Inkomati, Pongola and Orange drain about two thirds of the total land area and therefore contribute significantly to the total surface run off.

1.2 Water Management Areas



Water Management Areas percentage surplus/deficit for the year 2000 (Source: NWRS)

Figure 2. Water Management Areas in South Africa[2)]

In terms of water management, the country is subdivided in the following nineteen **Water Management Areas:**

1	Limpopo	11	Mvoti to Umzimkulu
2	Luvuvhu & Letaba	12	Mzimvubu to Keiskamma
3	Crocodile West & Marico	13	Upper Orange
4	Olifants	14	Lower Orange
5	Incomati	15	Fish to Tsitsikamma
6	Usutu & Mhlatuze	16	Gouritz
7	Thukela	17	Olifants / Doorns
8	Upper Vaal	18	Breede
9	Middle Vaal	19	Berg
10	Lower Vaal		

Within the above management areas, water is managed by Catchment Management Agencies (CMAs). CMAs must develop and implement a catchment management strategy for the water resources within their Water Management Area which complies with the National Water Management Strategy. Each Water Management Area is different and has specific requirements.(more detail regarding these water management institutions in Part 6: Module 3).

1.3 Irrigation dams

There are two types of irrigation storage dams namely:

- Catchment dams
- Farm irrigation storage dams

i) Catchment dams

Catchment dams are reservoirs that are human made structures built in rivers (drainage lines) to store water in. The main purpose of a dam is to stabilize water supply over the whole year by catching water in the rainy season and releasing it over the rest of the time. In a dry country like South Africa that receives less than the global average rainfall, it is important to have large water storage capacity to support sustainable irrigation agriculture.

In order to meet the water requirements of SA, large catchment dams were built to regulate the natural variable flow of rivers and to help with the large-scale transfer of water across catchments like the Lesotho Highland Scheme. In South Africa there are 550 government dams, with a total capacity of 37000 million m^3.

Most dams are built within the drainage lines with a physical concrete or earth wall to catch the water. The capacity of a dam depends on the topography of the location where it is built. An efficient dam is one with a relatively small wall, but large and deep storage space. In South Africa many of the dams are relatively shallow with a large surface area, which results in relatively high levels of evaporation losses.

Catchment dams are the main sources for many irrigation schemes where water is supplied to farms in a network of canals or pipelines. In some cases the dam is built high up in the catchment and water is released into the stream flow for farms lower downstream. It is then pumped directly from the river for irrigation. In some cases a storage dam is built outside the drainage line (off stream dams) and then water is channelled or pumped into the dam.

ii) Farm Irrigation Storage Dams

The Water Act of 1998 includes requirements and conditions which must be met regarding the classification, design, construction, registration, commissioning, operation, maintenance and abandonment of dams with a safety risk. A dam with a safety risk is defined as a dam with a storage capacity in excess of 50 000 m^3 and a vertical wall height, measured on the downstream side in excess of 5 meters. Furthermore, any dam not fitting the above description may be declared a dam with a safety risk if, in the

Minister's judgment, the structure is such that it poses a threat to human lives or public safety.

The following thumb rule can be used effectively to provide estimates for dam capacity or to estimate the possible capacity of a proposed dam:

$$\text{Capacity } (m^3) = \frac{\text{surface area (hectares) x maximum depth (meters) x 10}}{3}$$

The best method of determining the capacity of a dam is by detailed topographic and hydrologic surveys, which is recommended for the planning of large dams. The reliability of sufficient runoff is important. Other factors like the delay time of runoff, intensity of rainfall, the ratio between peak and constant flow are a few additional factors that are considered when planning dams and irrigation schemes. The percentage of rainfall that runs off varies according to the annual rainfall and soil types (lower runoff in areas with sandy soils).

Requirements arising from the Act (1998) are the following:

- An owner of a dam must register it within 120 days from the date it is ready to store or release water
- An owner must ensure that he/she complies with the regulations regarding the design, construction, commissioning, modification and enlargement of the dam.

1.4 Government and private irrigation schemes

One of the main objectives of the Act (1998) is to decentralize responsibility and authority of water resource management to appropriate local and regional institutions like the 19 Catchment Management Agencies (CMAs) operating in the respective Water Management Areas (WMAs). However, there are still some water management institutions like the Department of Water Affairs and Irrigation Boards that have to be changed in order to implement the Act.

South Africa has three general types of irrigation schemes that are linked to the different economic development phases experienced in the country (FAO, 2000):

- *Private irrigation schemes* (approximately 450 000 ha). Private schemes exist where the water source can be privately owned and owners extract water directly from weirs, boreholes, and farm dams. The farmer carries all costs and the registering of these water sources are currently in process.

- *Irrigation Board schemes (approximately 400 000 ha).* The statute under the earlier water legislation established irrigation boards. They are autonomous, democratically run institutions elected by participating irrigation farmers from within their own ranks. They are empowered to provide their own infrastructure and levy fees to cover full costs. An irrigation board may not infringe upon existing rights of riparian owners, and may only regulate water usage. Historically they had access to subsidy in respect of capital works and also state loans, which is no longer available. Under the Act (No. 36 of 1998), all irrigation boards will eventually be converted to WUAs (Water User Associations).

- *Government (state) controlled irrigation schemes:* These are the areas promulgated in the Government Gazette. In SA there are 350 000 ha where the infrastructure was provided by the state. Management and maintenance of the distribution system is a state function and farmer involvement is limited to the participation on advisory committees. Water charges are levied for operation and are charged to farmers. Membership of these schemes will also be transferred to WUAs in due course.

1.5 Canal systems

The success of on farm irrigation management depends largely on the degree of flexibility and reliability of water delivery to the farm. Water must therefore be delivered in a manner (i.e. flow rate, expected time and duration) that will enhance good farming practices.

Figure 3. Canal water delivery system, Rietriver Irrigation Scheme

Figure 4. Canal water delivery system, Klawer Irrigation Scheme

The majority of irrigation schemes in South Africa make use of a canal system. Canals are furrows designed to carry water from a stream or dam to a field or number of fields for irrigation. It can also carry water from a large storage dam to small storage dams on farms from where the farmer can irrigate. Irrigation schemes like Loskop (Olifants River) and Rietriver (Orange River) are examples where canals serve to carry water over long distances to farms downstream. Such a network of canals enables a much bigger area to benefit from the water for irrigation than the immediate farms along the river. It also reduces pumping costs dramatically because water is carried to the farm and does not need to be pumped from the river.

Canals are built on a specific and constant slope to ensure stable water flow. To avoid sand and silt build up in the canal the water flow should be above a certain flow speed to prevent suspended material being deposited in the canal. In other words water that flows too slowly will deposit its suspended material at the bottom of the canal. This is the reason that dams built in streams and rivers often have problems with silt deposits.

A pressure pipe water delivery system is found in Blyde River Irrigation Scheme, which have the main advantage of eliminating seepage losses. However, the main constrain with this type of delivery system is the relative high cost of operation especially when the distance is long and the large flow rates are required.

1.6 Ground water (Boreholes)

Boreholes are holes that are drilled vertically into the earth to find ground water – underground natural streams and cavities where water is stored. Steel casing is inserted into the drilled hole – especially when drilling through sandy soil – to prevent soil falling and closing the hole. A submersible pump is then installed into the hole and water is pumped up to soil surface and out to a field or reservoir. Boreholes usually deliver fairly clean water, but the depth, flow and quality of the groundwater should be determined.

South Africa has about 10 000 million m^3/annum of groundwater available (under normal rainfall conditions) of which only 200 m^3/annum is being used. The role of groundwater is usually underestimated in South Africa; two thirds of our population depend on groundwater for their domestic needs.

Generally borehole water delivery is not enough for commercial irrigation, but a few locations in the country have very strong underground water and boreholes yield up to 120 000 litres per hour. Great care should be taken not to over utilize boreholes, and to follow the testing procedures are recommended by the Borehole Water Association of South Africa. Continual pumping for at least 24 hours, to determine whether the water levels fall and flows decline should be conducted to test the yield of the borehole. The drilling contractors usually have the equipment to test boreholes, without which you cannot be confident that the flow will be sustainable.

The step withdrawal test is conducted by drawing water for one hour at a rate lower than the drilling contractor's blow test. This is followed by three similarly hour tests at an increased rate, during which the supply, drop in water level and elapsed time are noted. These readings are plotted and this provides an idea of the abstraction rate of the water from the borehole. The drilling contractor issues a test certificate and a good practice is to install a pump with 50% of the tested capacity. This will help to ensure sustainable use of the source. The SABI (South African Irrigation Institute) norm however is less than 66%.

Table 1. Recommended testing hours for boreholes. (SABI)

Borehole Testing Hours	
Area of use	**Testing Hours**
Urban	4
Agricultural holding	9
Extensive Irrigation	72

- *Pump delivery rate discharge capacity should be <66% of tested delivery.*

The following table gives recommendations of the abstraction tests for certain running times for which water is pumped for use.

Table 2. Recommended abstraction testing time for boreholes

Service time (h/day)	Testing time (h)
0-2	4
2-4	6
4-11	24
11-17	48
17-24	168

Underground water is private water and therefore the state has little control over groundwater, except in certain areas where groundwater has been declared part of the subterranean government water control area proclaimed by the Minister if substantial reasons exist for the control of abstraction in the public interest. The intention of DWAF is to develop a Groundwater Strategy that would be included in the National Water Resource Strategy (NWRS) to ensure the sustainable use of groundwater in South Africa.

Activity 1

Individual activity

1. Describe the difference between private and public water.
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2. Identify the main water resources that could be taken into account for the planning of irrigation development in your area.
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3. Explain the difference between government and private controlled irrigation schemes by the using of an appropriate example.
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4. Explain the water rights of a landowner who is farming adjacent to a river and who wishes to make use of water for irrigation purposes.
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5. A farmer wants to build a storage dam on his farm. Explain the safety risk conditions and requirements that he should take into consideration regarding the design, construction and registration of the dam.
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6. Discuss the general principles that should be kept in mind with the sustainable use of groundwater.
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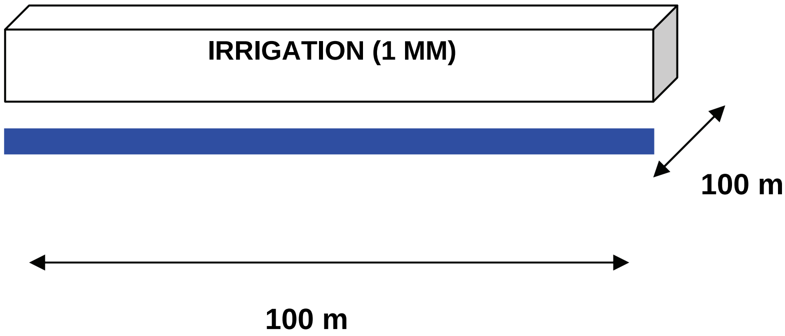
2. Calculations of water required for various irrigation enterprises

According to the water allocation to a farm, planning can be done for planting of crops, choice of irrigation systems and areas that can be cultivated. These calculations are done before development, but also before each planting season especially in times of drought to ensure that the area planted does not exceed the available water supply. When the crop water requirement is determined, the farmer should make sure that there is enough water available from the water source (in volume) for the specific crop requirement.

For every millimetre of application per hectare, 10 m^3 (cubic meters) of water is required from the source.

1 mm / ha = 10 m³.



This equation can also be expressed as: **mm = m³ / m² x 1000**

or **m³ = mm x ha x 10**

Example

Example 1: If a crop with a seasonal water requirement of 340 mm is to be planted on 5 hectares the volume of water needed is calculated as follows:

Volume (m³) = mm x ha x 10

= 340 mm x 5 ha x 10

= 17 000 m³ *(This is the net volume)*

No irrigation system is 100% efficient in application because water losses occur during operation. This loss of water should therefore be taken into account when calculating the water volume required. For a system with efficiency of 80% (0.80) the volume is divided by the efficiency rate:

Gross volume = 17000 m³ / 0.8 = 21 250 m³

In practice this means that when 21250 m³ of water is pumped to 5 hectares a net application of 340 mm (17000 m³) will be chieved after 20% of the water is lost through evaporation and other losses.

Example 2: The annual water requirement of sugar cane (perennial crop) is 1200 mm. The volume of water needed to irrigate 40 hectares is:

Volume (m^3) = mm x ha x 10

= 1200 x 40 x 10

= 480 000 m^3 *(This is the net volume)*

The crop is irrigated with a sprinkler system and the efficiency is 70%.

The gross volume is therefore: 480 000/0.70 = 685 700 m^3

Knowing the water allocation, calculations can be done on the amount of hectares of a crop that can be planted on a farm. The examples above are now reversed to calculate area (ha).

Example 3: The annual water allocation to a farm on the lower Crocodile River is 13000 m^3/ha/year. If the farm has an allocation of 30 hectares for irrigation then a total of 13000 x 30 = 390 000 m^3 *(gross volume)* is available annually. The farmer wants to plant potatoes with a water requirement of 560 mm for the season. He uses a centre pivot system with an efficiency of 75%. The net volume available for crop production is therefore:

(Gross) 390 000 m^3 x 75/100 (account for losses) = 292 500 m^3

The area is then calculated by adapting the formula
m^3 = mm x ha x 10 to:

$$\text{Ha} = \frac{m^3}{(mm \times 10)} = \frac{292\,500}{(560 \times 10)} = 52.2 \text{ ha}$$

In other words the farmer can theoretically plant 52.2 hectares of potatoes using his centre pivot while receiving an annual water allocation of 390 000 m^3.

Note:

a) *In practice it should be confirmed that the total of this volume of 390000 m^3 is available during the specific growing season for potatoes.*

b) *Many times on farms and irrigation schemes there is a limit to the storage capacity on the farm or the canal system, and the allocation can only be delivered to the farm over a 12-month period. In this case the monthly allocation – as supplied by the irrigation board – should be used for planning.*

Evaporation losses from storage dams must also be taken into account with the planning of irrigation. This can be a significant amount of water lost from any dam per annum. If the annual evaporation figure for a given area is 600 mm, the volume of water lost from a farm dam with a surface area of 2 hectares can be calculated as follows:

$$\mathbf{m^3 = mm \times ha \times 10}$$
$$= 600 \times 2 \times 10$$
$$= 12\,000\ m^3$$

From large dams like the Vaal or Gariep dam these figures amount to millions of cubic meters. Despite this fact South Africa has a shortage of water storage and dams are critical in ensuring a reliable supply of irrigation water for food production and human consumption.

Activity

Activity 2

Individual activity

1. A sugar cane crop in the Komatipoort area has an annual water requirement of 1400 mm. Calculate the number of hectares that can be planted on a farm with water allocation of 900 000 m³ using an irrigation system with 85% water application efficiency.
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2. What advantages exist in using a canal system to distribute water to different farms on an irrigation scheme?
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3. What is the purpose of having water allocations for different farms on a river or canal system?

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WATER RESEARCH COMMISSION

agriculture, forestry & fisheries
Department: Agriculture, Forestry and Fisheries
REPUBLIC OF SOUTH AFRICA

Technical Learner Guide

Irrigation Water Management

Level 5

Module 3

Assessing water quality for irrigation

Study objective

After completion of this module, the learner should be able to have a basic understanding of:

- The importance of water quality for irrigation.
- To be able to do a basic interpretation of a water analysis and
- Classify irrigation water into a specific class
- To apply practices to manage lower quality water and soils

Table of contents

The effects of polluted water on human health, on the aquatic ecosystem and on various sectors of the economy, including agriculture can be disastrous. Water quality has a number of effects on water use in irrigated agriculture. Most important is that the leaching requirements increase as the salinity and/or sodicity of the irrigation water increases. The leaching requirements is the amount of water that must be applied over and above the crop requirement to avoid salinisation and/or sodification of the irrigated soil to the point where it has extremely severe negative effects on crop yields and even becomes unfit for crop production.

Pollution of irrigation water by harmful organisms to humans is mainly caused by human excreta, or toxic heavy metals, due to acid mine drainage. This has serious implications for the production and exporting of high value crops.

1. Water quality and common problems

Definition

Water quality is a term used to describe the chemical, physical and biological characteristics of water, usually in respect to its suitability for an intended purpose.

In general the quality of South Africa's irrigation water is generally considered to be good. The situation is deteriorating due to the effects of:

- Irrigation
- Mining
- Industrial
- Urban development.

In many areas irrigation expansion plays a major role in lowering the quality of irrigation water downstream. At a measuring point in the Great Fish River the salinity of the water for a period decreased after transfer of high quality water from the Orange River. Thereafter it started increasing again. This increase was directly correlated with the increase in the irrigated area upstream from the measuring point – leading to increased return flow.

Significant areas have surface waters, which are classified as "Mostly unsuitable". These are mainly in the Karoo and Eastern Cape rivers draining from the Karoo. The latter receive water from the areas with mudstones and shales of the Beaufort group. These mudstones and shales have high salt contents and also high sodium and magnesium contents. Rivers like the Great Fish River receive many salts from these materials as ground water flow after heavy rains. Base flow water in the rivers during dry periods is also highly saline and sodic. The worst scenario is where farmers have to pump highly saline water from pools in these rivers during prolonged droughts. Water quality furthermore decreases downstream, as indicated above.

Regardless of the source, irrigation water always contains impurities in the form of dissolved or suspended materials. The amount and nature of impurities under specific environmental, climatic, soil and plant conditions determine the relative quality of the water. Water quality is influenced by the combined effects of the substances present in the water. These may include organic as well as inorganic materials. Organic matter includes all plant and animal rests as well as fish and other microscopic water living organisms. Inorganic materials are chemicals like salts and elements that influence the pH of the water.

Among the factors to be considered when judging the suitability of water for irrigation are salinity, sodium, carbonates, chloride, boron, suspended materials and pesticide hazards. These indicators are hazards from a soil point of view because there is a danger of them accumulating in the soil to a point of crop reduction or even plant toxicity. Carbonates and suspended materials have an adverse effect on irrigation systems because carbonates cause deposits in pipes, and suspended materials cause blockages, which need to be removed from (filtered out of) the water. Irrigation systems should be developed only in cases where there is a low hazard.

The extensionist must be able to help with the interpretation of the analysis and provide recommendations to put some changes into practice. How often water should be tested depends on the source, flow rates and history of water quality problems. Iron levels in water for instance do not change rapidly, while salinity; pH, pesticides and nutrient levels can fluctuate with the changes in flow rates.

2. Causes for deterioration of water quality

The following factors contribute to the deteriorating of water quality – some of which are ascribed to man's activities and others are inherent in the geological characteristics of the source area[1,2)]:

- *Salination:* this implies the accumulation of salt in water. A persistent water quality problem is salination, which has two major causes namely: natural and anthropogenic. The origin of natural salination of river water is often geological. Man made causes are associated with increased release of salts, either short or long term.
- *Eutrophication:* This implies the enrichment of water with nutrients like nitrate and phosphate. These encourage the growth of microscopic green plants termed algae-causing dams and rivers to become silted in, causes a lack of oxygen for water plants and animals.

- *Micro pollutants:* this is a water quality issue that receives prominent attention amongst industrialised nations, where the pollution by metals and manmade organic compounds, like pesticides, causes serious effects on the health of man and animals.
- *Microbiological pollutants:* water contamination by faecal matter is the medium for the spread of diseases such as dysentery, and cholera.
- *Erosion and sedimentation:* the average sediment yields in South African catchments range from less than 10 to more than 1 000 tonnes/km^2/annum. In some parts of South Africa erosion has increased by as much as tenfold as a result of human impacts. Apart from the loss of fertile agricultural soil, off-site damage like loss of valuable reservoir storage, sediment damage during floods and increased water treatment cost, have tremendous effects on total impact.

3. Factors that determine water quality

The following factors determine the water quality of irrigation water on the farm:

1. Physical water quality: The physical water quality on the farm is determined by foreign materials that do not dissolve in the water, and that can usually be seen with the naked eye. These materials usually cause problems primarily to the irrigation system. Drippers and micro sprayers have very small openings (0.25-2.5 mm diameter) and are easily blocked by any material that is too large to pass through.

   The following materials can influence the physical quality of irrigation water and are often responsible for clogging the drippers and micro sprayers:

   - Inorganic materials like clay, silt and sand;
   - Organic debris, such as remnant of plants, seeds, animals, aquatic fauna and flora;
   - Living aquatic plants and animals, such as algae and snails;
   - Plastic cuttings from irrigation pipes and equipment;
   - Lubricant residues like old motorcar oil,etc

Figure 1. Debris that have been removed from a canal at Tugela Ferry

2. Chemical water quality factors: usually refer to the non-visible components in the water. Instruments are used to determine their presence and concentration. Chemical quality factors usually affect the :
    - Crop production
    - Sustainability of the productivity of the soil (Part 2)
    - Effective operation of the irrigation system

The most important chemicals influencing water quality.......

Total soluble salts	*Boron*
Iron	*pH*
Manganese	*Chloride*
Bicarbonate	*Calcium*
Sulphides	*Nitrates*
Nitrites	*Carbonates*
Magnesium	*Sodium*

4. Classes of Irrigation Water

Irrigation water is classified in four classes according to the following norms[1,2)]:

- The effect of irrigation on profitability and **crop yield**
- The effect on **soil degradation** which will influence sustainable production
- The degree to which different **management options** need to be employed to avoid undesirable effects.

Table 1 gives a summary of the classification of water in terms of suitability to use for irrigation[1)].

Table 1. Classification of water for irrigation

Class	Suitability for use
Class 1	The water can be used for even the most sensitive crops and soils without any reduction in yield or need for special management practices.
Class 2	Water can be used for all but the most sensitive crops and soils without any reduction in yield or need for special management practices.

Class 3	Some yield loss is experienced even though special management practices are implemented but reasonable profit is realized.
Class 4	Yield losses and/or the need for special management practices are such that economic viability is questioned.

5. Salinity

Salinity (salt content) of irrigation water is important because it has an effect on the uptake of water (osmotic effect). The presence of dissolved salts in soil water reduces its availability to crops. Salinity hazard is determined by measuring the electrical conductivity (EC) of the water.

Testing of the water will indicate whether the water is suitable for irrigation or if dilution with freshwater is required before use. Salinity can be measured with a pocket sized salinity meter or by sending samples to a laboratory for analysis.

The salinity is measured by reading the electrical conductivity of the water. A guideline for electrical conductivity (EC), and therefore also the salinity of water is provided in Table 2.

Figure 2. Pocket size pH meter

Table 2. Guideline for electrical conductivity (EC) in irrigation water[1)]

EC range (mS/m)	Effects
< 40	Should ensure that salt-sensitive crops can be grown without suffering a yield decrease.
40-90	A 95% yield of moderately salt-sensitive crops can be maintained. Leaching may be required and wetting of foliage of sensitive crops be prevented.
90-270	A 90% relative yield of moderately salt-tolerant crops can be obtained. Moderate leaching may be required and wetting of foliage of sensitive crops be prevented.
270-540	An 80% relative yield of moderately salt-tolerant crops can be obtained. Moderate leaching may be and wetting of foliage of sensitive crops be prevented.

Water salinity measurements are expressed in deci-Siemens per metre (dS/m), milli-Siemens per metre (mS/m) or sometimes in mS/cm.

Conversion:

1 dS/m= 1000 mS/m

To convert dS/m to mS/m: multiply by 1000; 1.2 dS/m = 1200 mS/m

To convert mS/m to mS/cm: multiply by 10; 250 mS/m = 2500 mS/cm

The old units for measuring salinity were mg of salt per one litre of water often expressed as parts per million (ppm). Conductivity is however a more accurate indication of salinity than the number of soluble salts.

To convert conductivity readings to parts per million (ppm):

DS/m x 640 = parts per million (ppm) or, mS/cm x 0.64 = ppm

Irrigation water can be classified in six different salinity classes ranging from low to excessive salinity. Table 3 provides an indication of salinity classes.

Table 3. Salinity classes of irrigation water [7)]

Salinity classes measured in mS/cm					
Low salinity	**Moderate** salinity	**Medium** salinity	**High** Salinity	**Very high** salinity	**Excessive** salinity
< 250	250-750	750-2250	2250-4000	4000-6000	> 6000

The following problems can occur depending on the level of water salinity[5,6,7)]:

- **Irrigation systems**: Corrosion on steel parts in irrigation systems as well as carbonate deposits in pipes, which can be so severe that, the inside diameters of pipes are reduced dramatically.

- **Soil's ability to drain:** In the soil salts can build up to levels that are detrimental to plant growth and to soil organisms. The physical condition of soil resulting from irrigation is one characterized by a general loss of porosity (and permeability) and increase in dry strength (crusting). Additional mechanical stresses on soils include the impact due to water drops as well as cultivation and traffic. Soil crusts typically form when water drop impact combines with clay dispersion and deposition. All the above processes are influenced significantly by the salt concentration of the soil solution, the level of soil sodicity and their interaction with the clay fraction of the soil.

- **Crop performance:** Plants vary in their response to soil salinity, but the general effect of soil salinity on plants is called an **osmotic effect**. This means that salts increase the energy with which water is held in the soil. In other words, the soil must be kept wetter to supply the same amount of **plant-available water** as would be present without the salts. Plants must then increase the energy they use to obtain water from the soil, using energy that would otherwise be used for growth, flowering, or fruiting. As salt concentration increases, water becomes increasingly difficult for the plant to absorb. Symptoms of salt injury in plants resemble drought, with symptoms of wilting and stunted growth. A plant can actually die from water stress or drought in a moist soil if the salt concentration becomes high enough. Other effects of salts on plants are toxicities of specific salts and nutritional imbalances. Some elements, such as sodium, chlorine, and boron, have specific toxic effects on plants. Plants sensitive to these elements may be affected at relatively low salt levels if the soil contains enough of the toxic element.

6. pH of irrigation water

pH is a measure of relative acidity or alkalinity of the water. It is measured on a scale of 0-14, with 7 being neutral. Readings above 7 are alkaline while readings below 7 are acidic. pH is seldom a problem by itself, but influences the availability of plant nutrients. Water with readings between pH 6.5 and 8.5 is generally suitable for irrigation.

High alkaline waters caused by soluble salts in the rock, as well as from pollutants and fertilizers leached and transported to rivers. Water lower than pH 6 or higher than pH 8.5 when used in spraying mixes, can reduce the effectiveness of many pesticides commonly being use. The biggest effects of high or low pH are that firstly nutrients become less available to plants below or above certain pH levels. Secondly some elements (in fertilizers) may react at low or high pH and form other substances, which are also not available for the plant.

7. Sodium

Because of the effect on the soil and on the plant, the concentration of sodium (Na) is considered one of the major factors governing water quality. Sodium carbonate is mainly responsible for soil alkalinity[7)].

According to Rhoades (1984)[5)] and Loveday (1984)[3)] in sodic, non-saline soils, the total salt concentrations are low and consequently Ca and Mg concentrations may be nutritionally inadequate for certain crops. This is because sodium in soil has a negative effect on the availability of other cations namely calcium and magnesium. Sodicity may therefore induce Ca, Mg and various micronutrient deficiencies because the associated high pH and bicarbonate levels repress their solubility and concentrations. A high concentration of sodium ions causes yellowing of the leaves and eventually leaf loss.

Imbalances between sodium ions and calcium and magnesium ions are referred to as the Sodium Adsorption Rate (SAR). The classification of water according to the SAR is divided into 4 groups: Low, Medium, High and Very High [7)]. High SAR levels will affect the soil structure and cause poor water penetration through the soil, poor drainage and low aeration levels. Soils affected, will show typical symptoms like hard, blocky structure and surface crusting.

Water quality directives for sodium are illustrated in Table 4.

Table 4. Water quality directives for sodium[14)]

Ion	Degree of problems with sodium		
	None	Mild	Serious
Sodium (mg/L)	<70	70-160	>160

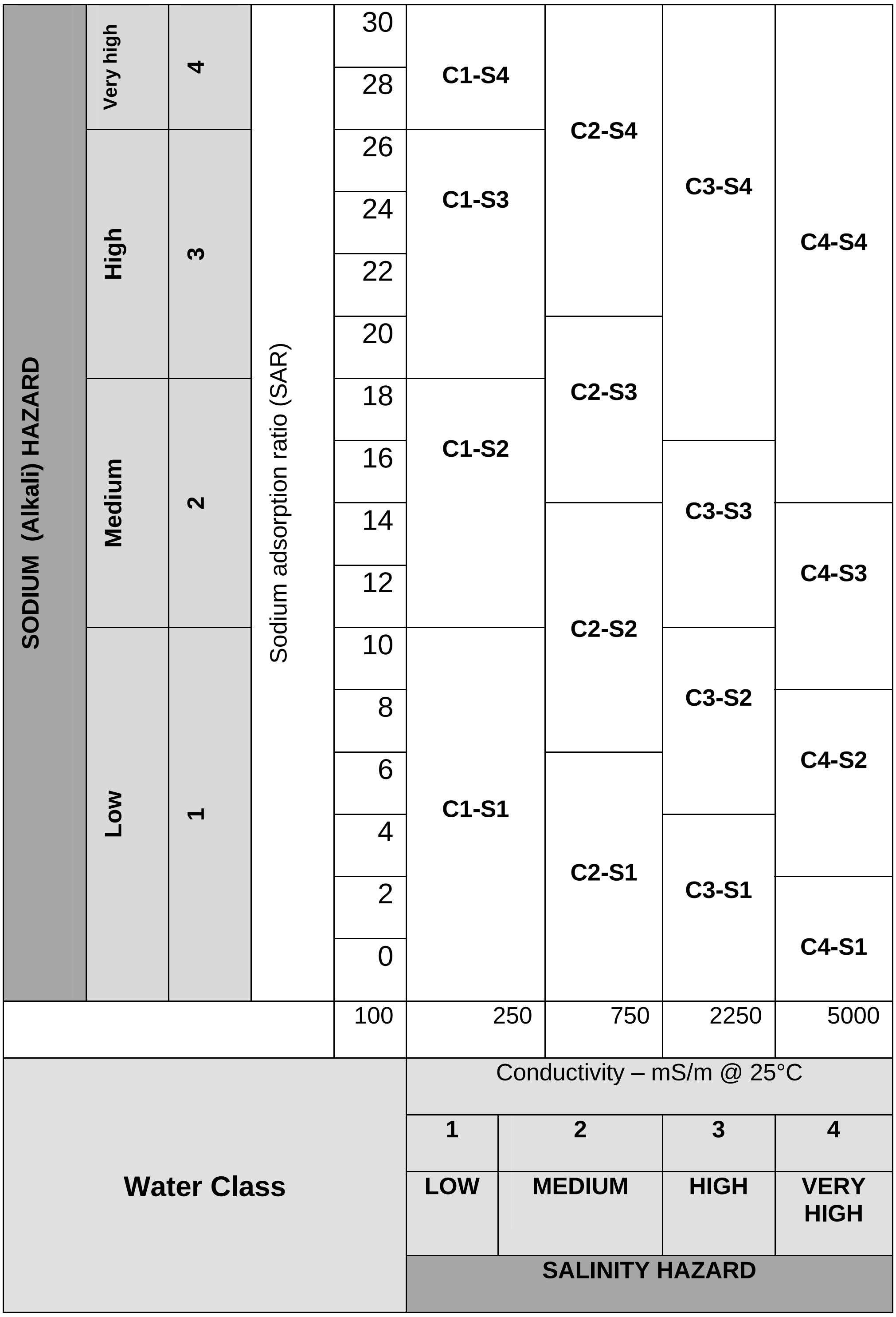

Figure 3. Classification of irrigation water[1)]

Adapted from U.S. Salinity Lab, 1954.

Figure 3 reveals the classification of water according to both sodium hazard (SAR) as well as the salinity hazard (Conductivity).

The following are general guidelines for the use of sodic water for irrigation:

- Low sodic water (SAR <3): can be used for irrigation on all soil types with little risk of developing or aggravating a soil sodicity problem
- Medium sodicity water (SAR 3-12): may cause problems in both sodic and non-sodic clay soils. Water in this category can be used on coarse textured soils (sand and loam) or organic soils. The application of gypsum will promote the leaching of sodium in clay soils.
- High sodicity water (SAR >12): generally unsatisfactory for irrigation except at medium salinity levels as illustrated in Figure 3.2. However, although the salinity level will counteract the high SAR, the irrigation water will still affect the yield and growth of crops and pastures. The addition of gypsum will reduce the impact of the high concentration of sodium.

Sodium toxicity is common in avocado, citrus and stone fruit. Sodium is often retained in the roots and lower bases of trees, but over time enough may accumulate to be transported to the leaves to cause leaf burn.

8. Bicarbonate (HCO_3^-) and carbonate (CO_3) levels

Residual sodium bicarbonates (RSC) value of irrigation water is defined as the difference between bicarbonates and calcium, as well as magnesium ions. The bicarbonate (HCO_3^-) and carbonate (CO_3) concentrations are important in irrigation due to its tendency to precipitate calcium and magnesium from the soil in the form of calcium and magnesium carbonates. This brings about a change in the ratio between sodium (Na) and the other cations. High carbonate and bicarbonate concentrations increase the exchangeable sodium percentage and therefore cause problems associated with sodicity. A relative high residual sodium carbonate value influence crop cultivation and soil structure negatively e.g. dispersal of soils.

Carbonate and bicarbonate levels up to 90 mg/L should be acceptable, while >90 mg/L would raise concern. Bigger than 90 mg/L levels cause white deposits on the plant leaves (whitewashing), especially with overhead irrigation systems.

9. Chloride (Cl^-)

High chloride (Cl^-) levels have negative and sometimes detrimental effects on sensitive crops. In some woody crops, Cl may accumulate in the plant tissue to toxic levels. Chloride is however not absorbed by the soil complex and has no effect on the physical properties of the soil. Chloride hazard is not found commonly, so no official classification system exists. The chloride hazard for r a specific area and a specific crop should be calculated. The limits for Cl tolerance are available for a range of crops and cultivars. In general the limit for sensitive crops is as low as 15 mg/L. If chloride water is applied by drip irrigation and not on the plant, levels below 140 mg/L (ppm) are generally acceptable. Above 350 mg/L should be treated with caution.

Water quality directives for chloride in irrigation water for drip and sprinkler irrigation systems are illustrated in Table 5.

Table 5. Water quality directives for chloride (mg/L) for different irrigation systems[12)]

Ions	Degree of loaf scorch problems with chlorine		
	None	**Moderate**	**Serious**
Drip irrigation	<140	140-350	>350
Overhead irrigation	<40	70-150	>150

Fruit trees, which are specifically sensitive to both chloride and sodium, but also sensitive to total salinity, show large differences in tolerance according to variety and rootstock (Table 6) [4,10)].

Table 6. Chloride tolerances for different crops [4,10)]

	Tolerance class			
	Sensitive	**Mildly sensitive**	**Mildly tolerant**	**Tolerant**
Chloride concentration (mg/L)	≤ 175	175-350	350-700	>700
Crops	Almonds, apricots, citrus, plums, grapes	Peppers, potatoes, tomatoes	Barley, maize, cucumber, lucerne, sorghum	Cauliflower, cotton, sugar, sunflower

10. Boron (B)

Boron (B) is also one of the microelements in irrigation water that harms plant growth. The boron content of irrigation water is classified on the basis of plant tolerance. It is toxic to plants at levels only slightly higher than the level required for optimal growth.

Boron is very difficult to leach out of the soil, and therefore the use of irrigation water containing high concentrations should be avoided. Very high levels of boron cause malformation of leaves and flowers as well as leaf burn. As indicated in Table 6, citrus, avocado, grapes and stone fruit are very sensitive to high B levels, while sorghum, cotton and asparagus are in general more tolerant.

Table 7. Boron tolerance of different crops [9)]

Boron tolerance levels of different crops		
Sensitive **0.3-1.0 ppm of boron**	**Semi-tolerant** **1.0-2.0 ppm of boron**	**Tolerant** **2.0-4.0 ppm of boron**
Avocado	Lima bean	Carrot
Grapefruit	Sweet potato	Lettuce
Lemon	Pepper	Cabbage
Orange	Pumpkin	Onion
Stone fruits	Maize	Broad bean
Apple	Olive	Asparagus
Pecan	Tomato	Cotton
Grapes	Potato	Sorghum
	Sunflower	

Table 8 provides a guideline for the use of irrigation water in terms of the boron content. These figures are used for crop planning according to the boron values in a water analysis.

Table 8. Guideline for boron in irrigation water[1,6)]

Boron range (mg/ℓ)	Effect on crop yields
0-0.2	Should ensure that boron sensitive crops can be grown without suffering a yield decrease given moderate leaching.
0.2-0.9	A 95% yield can be maintained for moderately boron sensitive crops provided moderate leaching is maintained.
0.9-1.5	Moderately boron-tolerant crops can obtain a 90% yield provided a moderately high leaching fraction is maintained.
1.5-3.0	80% yield can be obtained for moderately boron-tolerant crops given a high leaching fraction are maintained.

11. Effect of algae and pesticides on irrigation efficiency.

Pesticides include both organic and inorganic compounds that can have a direct influence on the biological activity in the water as well as in the soil. Synthetic insecticides developed over the past few decades produce most of the hazard potential. These include hydrocarbons, organo phosphates, carbonates and more. These pesticides end up in water sources through runoff and by leaching, and some of these persist in the soil environment. Irrigators should follow best management practices in pesticide use and disposal to minimize the chance for contamination of water sources.

Water organisms like algae and aquatic weeds increase in the presence of nutrients. Blue-green algae rely on sufficient nutrients (particularly phosphorus), still, warm conditions, enough sunlight and relative low turbidity. Because of the slimy nature of algae it causes blockage problems in pumps, pump suctions, pipes, sprinklers, canals and dams. Prevention of the formation and growth of algae in water sources is extremely difficult. In canals the water supply can be stopped to let the canal dry out from time to time. The most effective way to prevent algae entering an irrigation system is to ensure that the point of water extraction for example pumping from a dam is far from the inflow and not close to either the bottom of the dam or the water surface where algae tend to grow. It is especially in drip irrigation systems that water quality is critical for successful system operation.

Table 9 shows the classification of water used for drip irrigation in terms of the hazard rating.

Table 9. Hazard rating of water for drip irrigation [10)]

WATER QUALITY CLASSIFICATION FOR DRIP IRRIGATION BLOCKAGES			
Clogging factors	Hazard rating		
	Minor	**Moderate**	**Severe**
Physical (mg/ℓ)			
Suspended solids	< 50	50-100	> 100
Chemical (mg/ℓ)			
pH	< 7,0	7,0- 8,0	> 8,0
Dissolved solids	< 500	500- 2 000	> 2 000
Manganese	< 0,1	0,1-1,5	> 1,5
Total iron	< 0,2	0,2-1,5	> 1,5
Hydrogen sulphide	< 0,2	0,2-2,0	> 2,0
Biological (no./mℓ)			
Bacterial number	< 10 000	10 000-50 000	> 50 000

12. Control of factors causing blockages

A water analysis against the appropriate water quality guidelines can be useful to identify problems like blockages, corrosion and sedimentation.

The following table provide possible factors that can cause drippers to block.

Table 10. Physical, chemical and biological factors that cause dripper blockage [11)]

Physical	Chemical	Biological
Inorganic materials Sand (50-250 µm) Silt (2-50 µm) Clay (<2 µm)	**Alkaline heavy metals** *Cations:* • Calcium • Magnesium • Iron • Manganese *Anions:* • Carbonates • Hydroxides • Silicates • Sulphides *Fertilisers:* • Ammonia • Iron • Copper • Zinc • Manganese • Phosphate	**Algae** **Bacteria** • Filament • Slime **Microbiological activities** • Iron • Manganese • Sulphates

- *Physical factors:* the blockage is the result of suspended solids. Very fine particles tend to remain in suspension but may flocculate out in place where the water velocity is low or the water turbulence drops. The most common place for sedimentation is to occur at the end of laterals, causing these emitters to be blocked first.

- *Biological factors:* algae growth and microbiological activities may cause blockages, often originating in storage dams that are enrich with nitrate. Algae residues may come through the filters with the clay particles, serving as food for the bacterial slime. Fertiliser applications through irrigation systems, especially where laterals are exposed to direct sunlight, will lead to an increase in the growth of bacterial slime. These algae can block emitters, or can serve as a binding agent that combines silt and clay particles, leading to blockage.

- *Chemical factors:* Blockages can also occur due to a chemical reaction in the water, resulting in a deposit. Calcium, magnesium carbonate, iron, manganese oxides and magnesium sulphides are all possible chemical deposits in the dripper line or irrigation line.

	
Organic sedimentation	Silt buildup
Bacteria, slime and algae	Carbonates, hydroxides and phosphates
Oxidizing treatment Chlorine or Hydrogen Peroxide	Acid treatment

- *Control of factors causing blockages*

The control of algae and cleaning of the irrigation system comprises chemical treatment to stop growth and clean equipment from bacterial slime and algal growth. Treatment is done mainly with acid, peroxide as well as chlorine, and is discussed in detail in the module on system maintenance.

In alkaline water or due to fertilizer deposits, **carbonates** are dissolved with the aid of hydrochloric or phosphoric acid. **Iron** and **manganese oxides** are also removed with acids. **Organic** and **biological** sediments are cleaned with the use of peroxide. Chlorine is also used to stop growth of organic and bacterial organisms in water, and can be used as preventive measure.

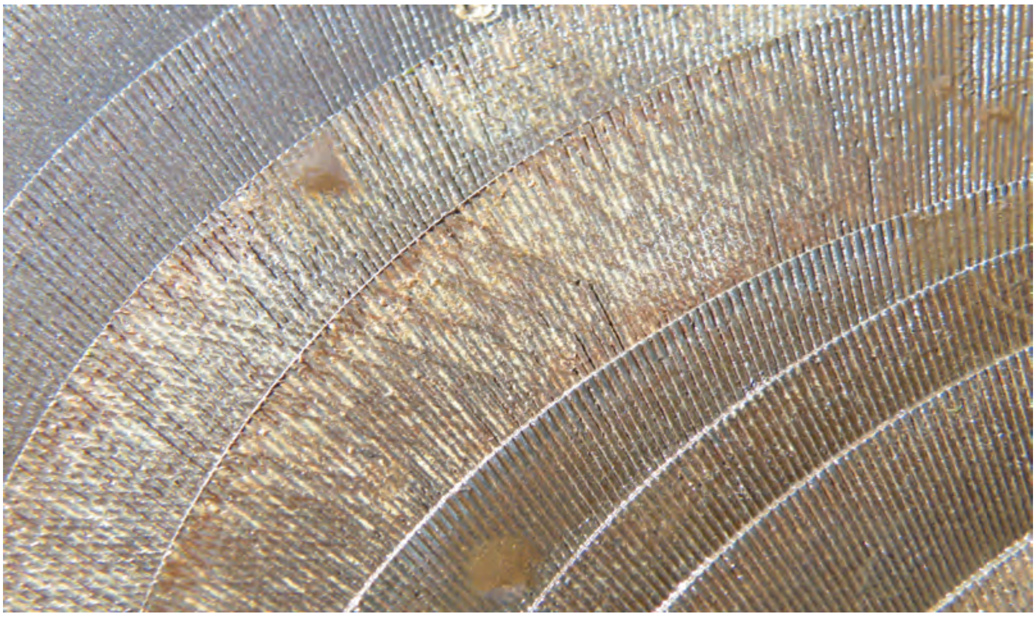

Figure 4. Filter rings blocked by sediments due to high manganese and organic content[8)]

13. Testing and interpreting of water analysis for irrigation.

With the necessary knowledge and competence, there is a lot of information that irrigation extensionists can obtain from a water analysis. Together with a soil scientist water can be analyzed and predictions can be made regarding choice of crop, cultivars, and yield potential and management practices which may be necessary to maintain full production ensure sustainability and prevent possible soil degradation.

Step 1: Take water sample

To measure water quality you will need to take a proper sample by using a thoroughly cleaned plastic or glass container with tight seals. The results of the analysis on water samples can only be as good as the sample submitted to the lab. Care must be taken to ensure that the sample is as representative as possible and that it is properly cared for prior to reaching the lab. The most important aspect is to clearly mark the different samples with information regarding farm name, location, date and specific water source for interpretation purposes.

Step 2: Hand in sample for analysis

As soon as possible after taking the sample from the source, hand it in at the soil science lab. Find out if a standard analysis includes all the aspects you require, and if not then ask for specific analysis of for example Boron or Chloride. Make use of accredited laboratories with proven track records.

Step 3: Interpretation of water analysis

Step by step go through each item on the analysis and compare with known levels of danger and plant tolerance.

According to the level of salinity, pH, bicarbonates, sodium, boron, etc, determine whether it is safe to continue planting a certain crop.

Example

Table 11. Example of water analysis

				Address of laboratory	
				Date	
Sample identification/no	Borehole 1 or Pivot 2			Lab No:	W00378/2000
Results	**mg/L**	**ppm**		**mg/L**	**ppm**
Fluoride	0.00	0.00	Sodium	1.1.3	25.90
Nitrite	0.00	0.00	Potassium	0.01	0.50
Nitrate	0.27	16.53	Calcium	3.48	69.50
Chloride	0.34	12.19	Magnesium	3.09	37.53
Sulphate	0.46	22.08	Boron	0.02	0.08
Phosphate	0.00	0.00			
Carbonate	0.00	0.00			
Bicarbonate	6.65	405.65			
Subtotal	7.72	456.45	Subtotal	7.73	133.55
			Total	590.00	
			Minimum*	202.80	
			Total Dissolved Salts (TDS)	387.20	
Na CO_3	0.00	0	Temporary hardness	6.59	330
Na HCO_3	0.00	5	Permanent hardness	0.00	0
Alkalinity	6.65	333			
pH	7.56		SAR	0.62	
PHS	7.08		EC (mS/m) at 25ºC	56	

- *Correction factor incorporated in case of volatile substances*

14. Guidelines for interpretation of water analysis

The following notes give some general guidelines to assist with the interpretation of the analysis:

Table 12. Guidelines for interpretation of water analyses[1,2)]

Water quality constituent	Remark
pH	The normal range of pH for irrigation water is from 6.5 to 8.4. An abnormal value is a warning that the water needs further evaluation. Irrigation water outside the normal range may cause nutritional imbalance or may contain a toxic ion.
Salinity indicators: **EC and TDS**	Salinity (EC or TDS levels) indicates the build up of salts in the soil. Tables 2 and 3 provide general guidelines for interpretation.
SAR indicator:	Sodium Adsorption Ratio (SAR) as an indicator of sodicity: o Low SAR: <3 o Medium SAR: 3-12 o High SAR : >12
Bicarbonates	Bicarbonates cause changes in SAR and also precipitate in irrigation systems. Bicarbonate levels higher than 350 mg/L can start to cause problems. Monitor frequently to prevent damage to plants.
Trace elements **(Minor plant nutrition elements)** [So called just because plants require it in smaller quantities, but are essential for plant growth]	Trace elements, which could affect plant growth or accumulate to concentrations harmful to humans or animals, can be assessed. These include mainly **Boron** and **Chloride** but **Manganese** (Mn), **Copper** (Cu), **Molybdenum** (Mo), **Zinc** (Zn), **Aluminium** (Al), **Iron** (Fe) and others can also occur in levels that vary from deficient to toxic. o Boron (B): Look at Tables 7 and 8 for general guidelines. o Chloride (Cl): o Low level: < 140 mg/L o Moderate level: 140-350 mg/L o High level: >350 mg/L Optimum levels for trace elements are crop specific. See Table 6.

A summary of water quality guidelines for irrigation is given in Table 13, which can be used to evaluate water quality from an analysis for the purpose of irrigation development planning.

Table 13. Summary of water quality guidelines for irrigation[1)]

Water quality constituent	Water quality guideline			
	Class 1	Class 2	Class 3	Class 4
	Salinity & Sodicity			
Salinity (EC) (mS/m)	0-40	40-90	90-270	270-540
Sodicity (SAR)	0-1.5	1.5-3.0	3.0-5.0	5.0-10.0
	Potentially toxic elements (mg/ℓ)			
Boron (B, mg/ℓ)	0-0.2	0.2-0.9	0.9-1.5	1.5-3.0
Chloride (Cl, mg/ℓ)	0-105	105 -140	140-350	> 350
Sodium (Na) **SAR (mmol/ℓ)**	0-3	3-5	5-7	7-9
	Trace elements (mg/ℓ)			
Aluminium (Al)	0-5.0	0-5.0	5.0-10	10-20
Copper (Cu)	0-2.0	0-2.0	2.0-2.5	2.5-5.0
Iron (Fe)	0-5.0	0-5.0	5.0-10	10-20
Lead (Pb)	0-0.2	0-0.2	0.2-1.0	1.0-2.0
Manganese (Mn)	0-0.2	0-0.2	0.2-5.0	5.0-10
Molybdenum (Mo)	0-0.01	0-0.01	0.01-0.025	0.025-0.05
Zinc (Zn)	0-1.0	0-1.0	1.0-2.5	2.5-5.0
	Miscellaneous problems			
Nitrogen (mg/ℓ)	0-5	5-30	> 30	
pH (acceptable range)	6.5-8.4 (H2O)			

15. Practices to control salinity in irrigated fields

The following practices are recommended to control salinity in irrigation fields[6)]:

- **Crop management**
  Because crops and different cultivars vary considerably in their tolerance to salinity, crops can be selected which produce satisfactorily in the particular conditions in the root zone. Because seedling development is often the most sensitive growth stage, it is important to consider the crop's salt tolerance during seedling development (Table 2).

  Salts accumulated in the seedbed reduce the rate of germination, and increases time required for emergence. The stand may also suffer as a consequence of crusting. When a crust is likely to develop, sowing rate may be increased to facilitate seedling emergence.

  Other techniques to combat crusting include mulching, and in sodic soils, application of amendments likes gypsum. Plant density may be increased to compensate for smaller plant size that exists under saline conditions.

- **Soil management**
  Salt accumulation can be especially damaging to germination and seedling establishment when raised beds or ridges are used with furrow irrigation. The salt accumulates progressively in the centre of the surface of the bed and is most damaging when a single row of seeds is planted in the central position. Seeds can therefore be planted in double rows on the shoulders of the ridge to germinate in a region of relatively lower salinity.

  The same is true for the wetting border of dripper lines and seeds can be planted right along the dripper line to avoid high salt concentrations on the edge of the wetting pattern.

  During irrigation, sodic soils are especially prone to clay dispersion and crusting. As mentioned various amendments can be applied including green manuring, thus enabling better seedling emergence, improved water infiltration and storage, and greater flexibility on other operations. More frequent irrigations may also be applied to soften crusts.

  For sodic soils that are particularly liable to structural damage, but also other soil, it is important to avoid tillage at high water contents. The most suitable water content for tillage is usually described as "moist".

- **Irrigation management**
  The primary elements in irrigation management for salinity control are frequent irrigation, adequate leaching, drainage and control of the water table. However the delivery system as well as the manner of irrigation also plays important roles. Where leakages on pipes and seepage occur in main canals of furrow systems, it leads to development of high water tables and excessive soil salinity. Leakages should

therefore be repaired timely and seeping losses may be reduced by compacting the floors and walls of canals or by lining them with less permeable materials.

For efficient control of irrigation system water applications should be monitored to know the amount and depth of application. This demands measuring of water flow to irrigation blocks as well as measurement of soil moisture in different soil depths.

Salt accumulation in the root zone can be prevented with pre-emergence irrigations using overhead sprinklers temporarily on furrow systems. The total area is irrigated and thereby reducing salinity levels. Once the seedlings are established the sprinklers can be removed and furrow irrigation can continue. According to Rhoades (1984)[5)] and Loveday (1984)[3)], the ideal irrigation system would provide water more or less continuously to the plant to match evaporation and to keep water content in the root zone within narrow limits with adequate aeration and minimum loss in deep percolation. By this means the salinity of the soil water is prevented from increasing significantly between irrigation events as evapotranspiration proceeds. The availability of water to the crop is maximized since the osmotic potential is maximized.

For any irrigation area to be viable in the long term, drainage (either natural or artificial) must be able to cope with waters percolating beneath the irrigated land. Without such drainage groundwater will eventually rise to levels that allow salts to accumulate in the soil and the root zone to become water logged. Measures to prevent these situations include increase in irrigation efficiency, minimized leaching and interception of subsurface water drainage flow. With the minimized leaching approach, the aim is to make maximum use of all the applied irrigation water through root uptake and evapotranspiration, thus producing minimum drainage and salt return.

Activity

Activity 1

Group activity

1. Discuss the importance of water sampling for the purpose of irrigation.

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2. A farmer takes a water sample to a lab for analysis. The pH measured from his water source is 8.5, and the water has an EC of 2000 mS/cm. Advise this farmer on the possibility as well as the dangers of irrigating from this source.

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3. Which types of crops can be considered by the farmer in the specific circumstances, and what type of irrigation system would you recommend?

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4. Farmer John receives an analysis, which classifies his water as C1-S2. What does it mean and what advice can you give farmer John on using this type of water for irrigation?

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5. What is the relevance of pesticides and leaching fertilizers with regard to irrigation water?

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6. Which practices would you recommend to control salinity if it occurs in a specific irrigation field?

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Module 4

Planning for irrigation development

Study objective

After completion of this module, the learner should be able to have a basic understanding of:

- Objectives of planning
- Factors affecting the planning of irrigation on the farm
- The process followed in the planning of irrigation
- Principles that apply in the theoretical investigation on a proposed irrigation development.
- Application efficiency of various irrigation systems
- Cost estimation of irrigation development

Table of contents

Planning of an irrigation system for a specific farm should take the natural resources available and the management requirements of the farmer or irrigator into account. The natural resources include the soil, water and climate of the specific location, while the management requirements include the agronomic practices applicable to the specific crop, the time and labour requirements for the specific farm, and the water application characteristics of the specific irrigation system adopted.

In this module a detailed checklist is given of all the factors affecting the planning of an irrigation development. Before an irrigation system is installed, certain questions should be asked and factors be investigated to ensure sustainable operation of the system.

1. Objective of planning

1.1 What is planning?

Planning is to develop a diagram or a strategy to achieve a target or goal. We need to determine our goals and then analyze what we have and how best to use it in achieving those goals.

1.2 Benefits of planning

Planning creates certain goals and milestones, which need to be achieved through the implementation process. It also sets a budget and time frame in which to complete the project.

1.3 Establishing goals

This process sets up short term and long-term goals to which progress and performance can be measured.

1.4 Development controls

Control is an important function in the implementation phase of a project and it involves the measurement of performance as well as to take care that the right actions are taken.

1.5 Situation analysis

Analyzing the situation in terms of strengths and weaknesses can provide the necessary background to identify opportunities in the planning framework. Gathering as much information as possible on the current situation enables you to have a clear picture of the present state, and to plan the way forward.

2. Factors affecting system planning

2.1. Physical factors

- **Availability of water**

It must be ensured that the water is from a sustainable and reliable source to enable uninterrupted irrigation and crop production. Furthermore the water must be used legally from the source in quantities allowed by the water location to the farm/area.

- **Water Quality**

Water quality includes the combined effects of different substances present in the water. The possibility of using a given water supply for irrigation is largely dependent on its constituents. These may include organic as well as inorganic materials. Organic matter includes all plant and animal rests as well as fish and other microscopic water living organisms. Inorganic materials are chemicals like salts and elements that influence the pH of the water. Hazard levels for salinity, sodium, chlorine, boron, pesticides as well as suspended solids need to be determined. Different crops show different levels of sensitivity or tolerance to the given chemicals, and care should be taken that the planned crop and irrigation system is suited to the available water quality.

- **Soil texture**

The soil texture is the physical composition of the soil in terms of sand, clay and silt particles. Because the water holding capacity of a soil is largely dependent on the clay content, it is important to define the soil texture. A high clay percentage will lead to higher water holding capacity (bigger reservoir). This can guide the choice of irrigation system as well as its delivery rate. It will therefore also influence the choice of crop as well as management of both crop and irrigation. Soil texture together with other factors has an influence on permeability and infiltration rate of soils. These have an impact on choice of system and application rate, which should always be lower than the infiltration rate.

- **Soil depth, drainage and colour**

Soil depth is often a limiting factor in the planning of irrigation systems. On shallow soils management of irrigation is extremely difficult, and thorough planning is very important. Soil depth is in most cases more important than soil texture in the planning to develop irrigation. When shallow soils are irrigated it often leads to drainage problems especially in heavy rainy seasons. In very simple terms the most suitable soil for irrigation is a deep red or brown soil. Where grey and yellow colours occur in soil it is an indication of current or previous anaerobic conditions due to water logging.

- **Topography and shape of land**

The slope of land is often a determining factor in the choice of irrigation system. Steep slopes are limiting for irrigation systems like furrows, centre pivots and to a lesser extent also micro and drip irrigation. The shape and size of fields can also limit applications like centre pivots and other mechanized systems. Natural surface drainage of a location is also influenced by the topography, and can cause water logging as well as erosion problems on irrigated (cultivated) fields.

The soil characteristics such as soil depth, texture, and type should be presented on an individual or combined map to determine those parts of the irrigation development in which there are special attention required.

- **Climate**

The local climatic conditions (rainfall, temperature, frost, humidity, wind and evaporation) are important factors to consider in crop planning, and therefore also in irrigation development and choice of irrigation systems. Wind is often a limiting factor regarding choice of system because of possible damage and sprinkler inefficiency.

- **Crop**

The type of crop, crop rotation, height of the crop, tilling practices, pest control requirements, crop water requirements and climate control will influence the selection of an irrigation system. Water uptake of crops depends on:

- Size of leaf canopy
- Evaporative power of the atmosphere or atmospheric evaporative demand
- Resistance in the soil-plant system to water uptake.

Germination of seeds is an especially important factor where very small seeds are sown very shallow. In these cases small droplets are required to enable seedlings to emerge and develop.

- **Energy sources**

The proximity of electricity is an important factor in considering electric driven pump and irrigation systems. To some extent pump systems can be driven by diesel driven motors, but systems like centre pivots are electrically driven. Diesel motors however are not only more expensive in the initial capital layout, but also regarding the running cost as well as maintenance. The practical issue of storing and handling diesel is also a factor to consider.

2.2. Economical factors

- **Capital investment and period**

Micro irrigation systems are generally more expensive per hectare than for instance movable irrigation systems. The farmer may for economic reasons rather select the cheaper movable irrigation system, even though it may not be ideal for the specific situation.

- **Expected life span of system**

This is an important factor where the system is bought through loans to determine the financing period. This also determines the replacement time frame of a system. Usually average values are used, and banks work very conservatively when lending money for such assets. The life span is therefore usually far greater than the financing period. With careful operation and maintenance it can be several times the payment period.

This enables a farmer to spend the money on other equipment or to expand his operation.

- **Cost Items**
  1. Maintenance
     This includes the lubricants and spare parts as well as the additional equipment that must be available on the farm to carry out replacements and repairs.
  2. Labour
     This includes the workers responsible for all aspects of the operation as well as the maintenance of the system.
  3. Energy/operating costs
     Energy requirements and therefore operation costs of systems such as the big gun, travelling gun and high–pressure-travelling boom are considerably higher than low-pressure systems such as for e.g. drip irrigation. Application efficiency further more plays an important role in the cost per millimetre applied.

- **Efficiency of irrigation system**

The application efficiency – percentage of water that reaches the soil in relation to the volume of water pumped – is one of the most important factors to consider when planning an irrigation development. This directly impacts on the cost of applied irrigation. A more efficient system will have a lower cost in Rand per millimetre applied because a higher percentage of water reaches the soil, and less is lost through evaporation.

The irrigation system efficiency value is very important to take into consideration during the planning of an irrigation system, as it makes provision for possible losses that may occur between the inflow to the irrigation system and the point where the irrigation water is available to the crop root zone. The losses may include aspects like back flush of water, non-beneficial spray evaporation losses and wind drift, in-field conveyance losses, etc.

Table 1 gives the norms for system application efficiency given by the South African Irrigation Institute (SABI).

Table 1. Application efficiency of various irrigation systems

	System	Application Efficiency [3] (%)	Application Efficiency [4] (%)
1	Drip	90	95
2	Micro sprinklers	80	85
3	Permanent Sprinklers	75	90
4	Movable Sprinklers	70	83
5	Moving systems – centre pivots	80	98
6	Boom sprays & Travelling guns	65	78
7	Flood – pipe supply	80	98
8	Flood – ground canal supply	60	86

**The figures illustrated in the last column are newly released figures as proposed by the WRC Report TT 466/10. Main difference between the new recommended values and previous recommended values is that it does not include an adjustment for non-uniform water applications.*

Definition

Irrigation system efficiency is therefore the ratio between the nett and gross irrigation requirements (NIR and GIR)

Nett irrigation requirements (NIR) is the amount of water that should be available to the crop as a result of the planned irrigation system

Gross irrigation requirements (GIR) is the amount of water supplied to the irrigation system that will be subject to the envisaged in-field losses

- **Viability of irrigation development**

When planning an irrigation development and calculating operating and profit margins a very conservative approach is advisable. It should be accepted that the people involved may be in a learning phase regarding irrigation management, commercial crop cultivation and marketing, and that crop prices mostly do not realize as planned initially. The cost of irrigation systems, inputs, energy and maintenance cause small-scale irrigation development to be cost in efficient especially for subsistence farming. Repayment of an irrigation system is highly dependent on profitable crop production.

2.3 Institutional factors

- **Management requirement of irrigation system**

In planning an irrigation system it is important to assess the level of skill of the people who will manage and operate the system. In many cases systems are developed that is not suited to the level of technical development of the people. In traditional cultures where new technology is not readily accepted, a new system could be rejected even before it has had time to operate.

- **Labour and supervision**

The requirements of irrigation systems in terms of labour will always be a factor in the choice of systems. A shortage of labour or skilled labour, or the cost of labour may force a farmer to use self-propelled or permanent irrigation systems rather than moveable systems. Labour laws as well as the reliability of workers may also compel farmers to implement more automated systems. The additional benefit of this is that the farmer is more actively involved in the operation of the system.

- **Availability of support services (extension, technical, etc.)**

In the choice of irrigation system it is important to look at well-established companies and brand names with adequate service backup and spare parts available. It is equally important to identify people who can assist in the operation as well as the management of the crop-soil-system combination. In some cases specific systems – like drip systems – are used in areas simply because of the presence of a very competent technical advisor in the area. Another important factor is that advisors should be timely available to assist farmers with problems when necessary.

- **Water legislation**

The National Water Act Nr. 36 of 1998 governs all water use in South Africa. Any proposed irrigation development should have permission from the Department of Water Affairs and Forestry (DWAF) to proceed with water extraction from a source. Only when there is available capacity from a source can water be allocated for new developments. This will change from area to area, and may also depend on the possibility of increasing the capacity of the source.

In each area a Catchment Management Agency (CMA) is responsible for the control of water allocations of the specific source. The CMA is also responsible for demand management and conservation of the source to ensure correct and sustainable water use.

- **Maintenance and operation requirements of system**

Many irrigation systems in South Africa had become inefficient or even totally useless, because of maintenance which had not been done during operation. In most cases system maintenance is very simple, but designers and suppliers often fail to implement a well laid out maintenance plan. The operators of irrigation schemes are also guilty of not following the maintenance schedule correctly for the full duration of the system operation. All pump systems for example should be lubricated in order for the bearings to run smoothly and stay cool. With drip systems the correct flushing and cleaning procedures should be followed to prevent blockages. Failure to do this will result in a situation where the system needs to be replaced prematurely.

2.4 Socio economic issues

It needs to be established whether the planned irrigation development will benefit a community as a whole, or only a few individuals. Care should be taken that beneficiaries as well as the community they live in accept ownership of such development. Crime in the form of theft or sabotage often leads to the end of an irrigation development. The impact of water use from a shared source should also be assessed in terms of influence on the surrounding communities. Theft of cables and other equipment can be a very bad problem and can permanently damage the pumps and electrical equipment.

2.5 Personal consideration

Each type of irrigation system has an ideal field of application, but the final choice is with the user of the system, the farmer. Each user has its own preferences that are influenced by various factors like for instance, is the irrigation system adaptable to his current farming system, what are the managerial and operation skills that are required, can the system be adapted for other uses and are the supplier of the irrigation system reliable.

2.6 Environmental impact

The environmental impact of any development cannot be ignored, and the same holds for irrigation. With new developments on virgin land permission should be obtained from the Departments of Agriculture and Environmental Affairs. The possible impact on neighbouring farmland, dams, wetlands and rivers should be estimated and identified. Irrigation development brings increased salt deposits in soil as well as more than natural water drainage. These factors should be incorporated and accounted for in planning of irrigation development.

3. Planning checklist

Table 2. Planning checklist for development

	Subject	Assessment
1	**Availability of water**	- What is the expected delivery of the water source? - Permission for the use of the water source obtained as prescribed by the National Water Act. - Is the source seasonal or is water available throughout the year?
2	**Water quality**	- Determine the water quality – physical & chemical. - Is leaching of the soil a requirement? What percentage must take place? - Is additional water capacity required for the leaching of soil? - Is the water-soil combination suitable for the specific crop?
3	**Soil texture**	- What is the estimated clay percentage of the soil? - What is the expected water holding capacity of the soil? - What is the maximum application rate without exceeding the infiltration rate ability of the soil?
4	**Soil depth, drainage & colour**	- Is drainage necessary and how intensive? - Should the soil be trenched and how? - What soil improvement agents or actions are required, how much and at what depth?
5	**Topography**	- What is the shape of the land? - Are there any obstructions that occur? Will it influence the design of the irrigation system? - Planting direction (eg. N-S) vs. direction of slope – how will it have an influence, and how will erosion be prevented? - Slope of the land and the possibility of flood? - Influence of slope on water tables of the land? - Access routes to the irrigation field?
6	**Climate**	- What are the number of wind days per year, prevailing wind strength and direction? - What is the long-term average rainfall, evaporation and temperature per month? - Does frost and hail occur? How often?

7	**Electricity / Energy**	- Type of energy available and appropriate? - Reliability of energy source? - Any specific precautions required? - Maintenance and operation of energy source? - Costs of energy source?
8	**Management skill**	- What knowledge is necessary to manage the system in terms of costs, maintenance schedule and crop requirement? - What level of farming skills are available with the present prospective farmers – can they be trained according to the requirements? - Who will ultimately be responsible and accountable for the management of the total operation?
9	**Operation & maintenance**	- What level of skill is required to operate system? - Are technical skills & know how necessary? - Is the maintenance simple and easy to do? - Is special equipment required for maintenance work?
10	**Advisory services**	- What kind of back-up is available in terms of advice on irrigation, fertilizer and crop production? - How accessible is the advisory services in the area and what costs are involved? - Are these services reliable and do they have proven track records?
11	**Socio economic issues**	- Is the proposed development on tribal, state, municipal or private land? - Will the community benefit from the development in terms of job and business opportunities? - Will the development have any disadvantages to neighbouring communities? - Is security an issue and how will it be handled? - How will project ownership be ensured & sustained?
12	**Crops**	- Which crops are cultivated in the area? - What types of crops could be cultivated? - What crop rotation is followed on the farm? (seasonal crops) - What is the expected effective root depth of the crop? - What is the general plant direction, spacing, sowing density and trellising system followed? - Identify critical crop growth stages when the crop is sensitive for soil water deficiencies, heat or cold. - What are the peak water requirements of the crop, when does it occur and what is the total crop water requirement per season? - What is the spacing of trees/vines between and in plant rows for the design of emitter positions and manifold spacing?

13	**Irrigation System**	- Is the purpose of the irrigation system also to combat frost or cooling of area? - What are the available number of days per week and hours per day in which irrigating can be done? - What are the particulars of the available energy source? - What must the flow rate of the system be to supply the peak demands of gross irrigation? - Will the system also be used for chemigation? - Is there a specific crop preference to be irrigated overhead, or specifically on soil level to prevent foliar diseases?
14	**Viability of development**	- What kind of crops can be grown successfully and profitably taking in mind the climate, soil, water, crop value, security, marketing issues, etc? - Can a marketing system be established before development begins? - What financial and general management skills are necessary to run the project strategically as well as day to day? - What is the life span of proposed (permanent) crops and that of the planned irrigation system? - The scale of plantings should also be considered especially where profit margins are known to be small.
15	**Environmental impact**	- Will the development have any negative impact on the environment? - How will the soil and ground water be influenced by the water quality in terms of salinity? - Will the subtraction of water negatively influence wetland areas or forests? - How will the ecology change with the establishment of a mono culture crop? - What measures can be taken to sustain ecological diversity?

4. Cost Estimate

If the proposed development meets all requirements as set out in the checklist above, estimation can be done regarding the costs to determine the scale (size) of development. On large scale developments tenders are usually invited but with smaller developments individual companies are requested to quote for the design, supply and installation. This is mostly done through advertisements in the printed media.

Table 3 gives an indication of the cost items as well as the specific costs of a new irrigation development on sugar cane with centre pivot irrigation in the Nkomazi area of Mpumalanga. (2009).

Table 3. Establishment costs for sugar cane on centre pivot, 2009 (SASA)

Category	Cost Items	Cost: Rands / ha
A	**Land preparation**	
1	Land clearing & debushing (new fields)	R 650
2	Ripping	R 760
3	Ploughing	R 685
4	Harrowing (disc)	R 290
5	Disc and drawing lines (sugar cane)	R 408
B	**Installation of system**	
6	Trenching	R 4,000
7	Laying of main line, sub mains & valves	R 2,000
8	Cost of irrigation system	R 15,000
C	**Planting**	
9	Manual planting of cane	R 1,670
		R 25,463

5. Design

When all factors have been considered, the planned area can be surveyed and an irrigation system can be designed according to norms set by the South African Irrigation Institute (SABI).

The complete design includes the following:

- A detailed map of the irrigation system should be supplied for installation of the irrigation system as well as for operational purposes.
- The designer also needs to supply a management plan as well as operating manual. The operating manual indicates the combination(s) of blocks that can simultaneously be irrigated, as well as start up procedures; filter cleaning valve opening and system operation.
- A detailed technical report, which includes safety factors as well as expected life span of the system, and also the possibility of expansion.

6. Installation

Installation of irrigation systems is a vital part of the successful implementation of irrigation development. Installation is done according to the design, and should be done by skilled contractors.

Installation should be done neatly and exactly according to the design. It is important that pipe sizes and distances exactly follow design parameters.

During installation care should be taken that no soil, tools, plastics and other objects or animals like rodents can enter pipes and cause blockages. After installation is done the system should be commissioned and tested by the installation contractor together with the designer before it can be handed over for operation.

7. Summary of planning and implementation process

Table 4. Summary of planning and implementation process

Five steps of the planning and implementation process	
Step 1: Use planning checklist	A detailed overview of the proposed development considering all aspects of the impact of irrigation development.
Step 2: Cost estimate	Summary of all costs involved for budgeting and planning to determine the scale of development.
Step 3: System Design	A detailed design of the total system with a comprehensive list of material cost of installation, scope of work, labour required and time frame. The design includes all the parameters of topography, system delivery pipe sizes and pump details
Step 4: Installation	The physical supply of materials and the installation of all pumps, connection of pipes, filters and valves and according to the design.
Step 5: Commission & operation	Start up of system, setting of valves and training of staff to operate the system. According to the design, certain pressures will be measured at specific points in the system. During commissioning these points are checked. A specific number and combination of valves are also set out in the design and the operation manual. The flow and pressure values are calculated on these combinations, and it should be used at all times.

8. Programs that support planning of irrigation development

SAPWAT is generally recommended for the planning of irrigation requirements on a wide range of crops in South Africa. The programme has at its core the procedures contained in the internationally accepted guideline for estimating irrigation requirements namely the United Nations food and Agricultural Organisation Irrigation and drainage Report No 56 (FAO56), which uses the Penman Monteith equation[4)]. This program uses a comprehensive weather data base and the FAO four stage crop development curve procedure to calculate the irrigation requirements of a crop for a specific area. The program can estimate irrigation requirements for a single crop or a field of multiple crops, for a single farm, or for a group of farms or Water User Association or for a Water Management Area. The program is available from the WRC, who funded its development.

Activity

Activity 1

Individual activity

An 85 hectare farm is bought by a farmer in the Loskop area with the aim of developing an irrigation farm. The farm is situated 12 km from Groblersdal on the road to Marble Hall.

It has a water allocation of 40 hectares from the Loskop Dam Irrigation Scheme, and the canal forms the border at the bottom end of the farm. Currently no crops are being cultivated, but previously 40 hectares of dry land maize was planted and the farm carried 20 head of cattle.

Export citrus is grown on large scale in the area, and a variety of seasonal crops and grains are also cultivated. The average slope of the farm is 4% (4 m/100 m) and there is an existing 3-phase ESKOM power supply. There is a three-bedroom house as well as a 12x30 m tractor shed on the farmyard.

No irrigation system is implemented but there is a storage dam of 6 000 m³. The climate in the area is being described as hot dry summers and cool winters, with frost occurring every winter for at least 15 days.

The soil on the farm is fairly uniform red soil with 23% clay and an average depth of 600 mm with permeable gravel layer from 600 mm to 900 mm. However the top 20% of the arable area is shallower with a depth of 350 mm and less clay.

1. Use the planning checklist to evaluate the viability and impact of the proposed irrigation development.

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2 Advise on crop(s) and irrigation system(s) and provide supporting motivation for the specific recommendations.

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3 Give a summary of all the aspects of planning of the project up to implementation of the irrigation system.

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Authenticator:

- Mr A vd Merwe

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Technical Learner Guide

Irrigation Water Management

Level 5

Module 5

Introduction to different irrigation systems

Study objective

After completion of this module, the learner should be able to have a basic understanding of:

- Different irrigation systems
- Factors to take into consideration with selection of an irrigation system
- The different kinds of irrigation systems
- The application potential and limitations of each
- Cost structures for the various irrigation systems
- Energy cost for irrigation systems

Table of contents

1. Irrigation systems

There is a wide range of irrigation methods, each with advantages and disadvantages. As Module 4 illustrated, the following factors are taken into consideration with the selection of a specific irrigation system:

- Water availability
- Soil characteristics
- Topography
- Climate
- Energy costs
- Crop
- Labour
- Capital cost
- Personal preference
- Economical factors
- Institutional aspects like labour requirement, etc.

With the selection of an *appropriate irrigation system for a specific farm, the irrigator* takes the following factors into consideration:

- to apply the right amount of water,
- to apply water of a suitable quality,
- at the correct application rate,
- as uniformly as possible to the whole field,
- with the least amount of non-beneficial water consumption (losses), and
- as economically as possible

The most efficient irrigation system is that one designed according to sound design principles based on limiting discharge variation and energy requirements in the field[5.)]

There are mainly two types of irrigation system namely:

1) Pressurised irrigation systems
2) Surface irrigation systems

1.1 Pressurised irrigation systems

Pressurised irrigation systems include all systems where the irrigation water is supplied under pressure in pipelines to emitters, through which the water is applied to the soil surface or below the soil surface to the root zone e.g. centre pivot, sprinkler, micro and drip irrigation systems. The emitters are mounted on connection pipes, usually called laterals, while the laterals are connected to each other with pipe called manifolds like in the case of micro and drip irrigation systems. It can also be directly being connected to the mainline like in the case of sprinklers. The aim with the emitter is to apply water at a specific flow rate (called the emitter discharge rate) over a specific area in the field. The emitter discharge is determined by the pressure of the water in the emitter- called the *design operating charge.* At pressures higher than the design operating pressure, the emitter will discharge more than the design discharge, while at pressures lower than the design operating pressure; the emitter will discharge less than the design discharge.

An efficient pressurised irrigation system is therefore one that applies irrigation water as uniformly as possible across the whole field.

1.2 Surface irrigation systems

This type of irrigation systems refers to where irrigation water flows over the soil surface under controlled conditions with the purpose of delivering the desired amount of water to infiltrate the soil. Surface irrigation consists mainly of three types:

- Basin irrigation
- Border strip irrigation
- Furrow irrigation.

The aim with surface irrigation is to ensure that relatively even amounts of water are applied to all areas of the field in amounts that match well to soil characteristics like soil water holding ability and also to the crop water requirements.

Therefore the performance of surface irrigation systems are influenced by infield factors like:

- inflow rates
- field lengths
- furrow shape
- field slope
- surface roughness
- soil infiltration properties.

Figure 1 presents a classification of the various irrigation methods, and this module will elaborate on several of these irrigation systems, together with the advantages and disadvantages.

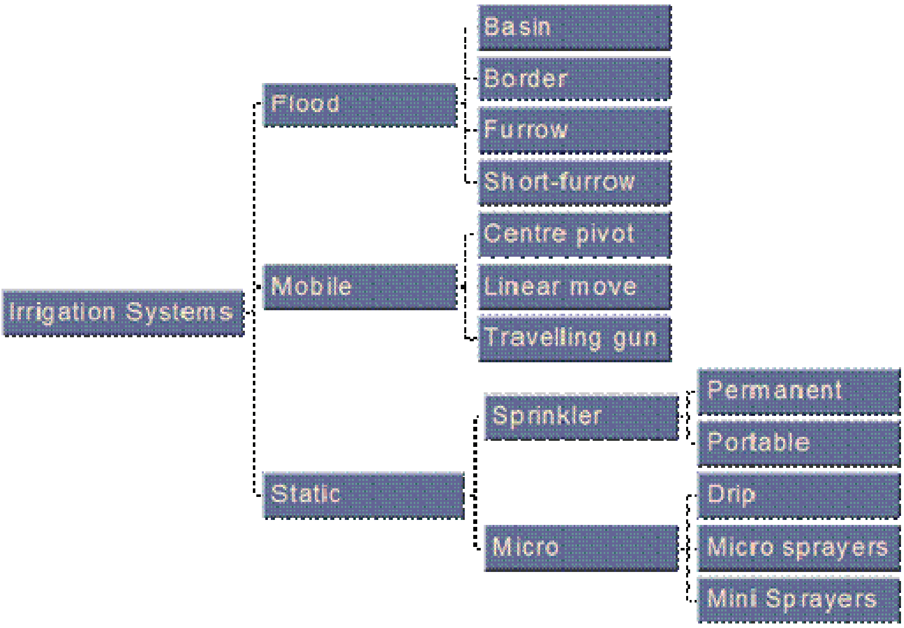

Figure 1. Classification of irrigation systems[2,6)]

In South Africa the implementation of the various irrigation systems vary between the various irrigation areas. Figure 2 illustrates the popularity of sprinkler and movable irrigation systems in the country.

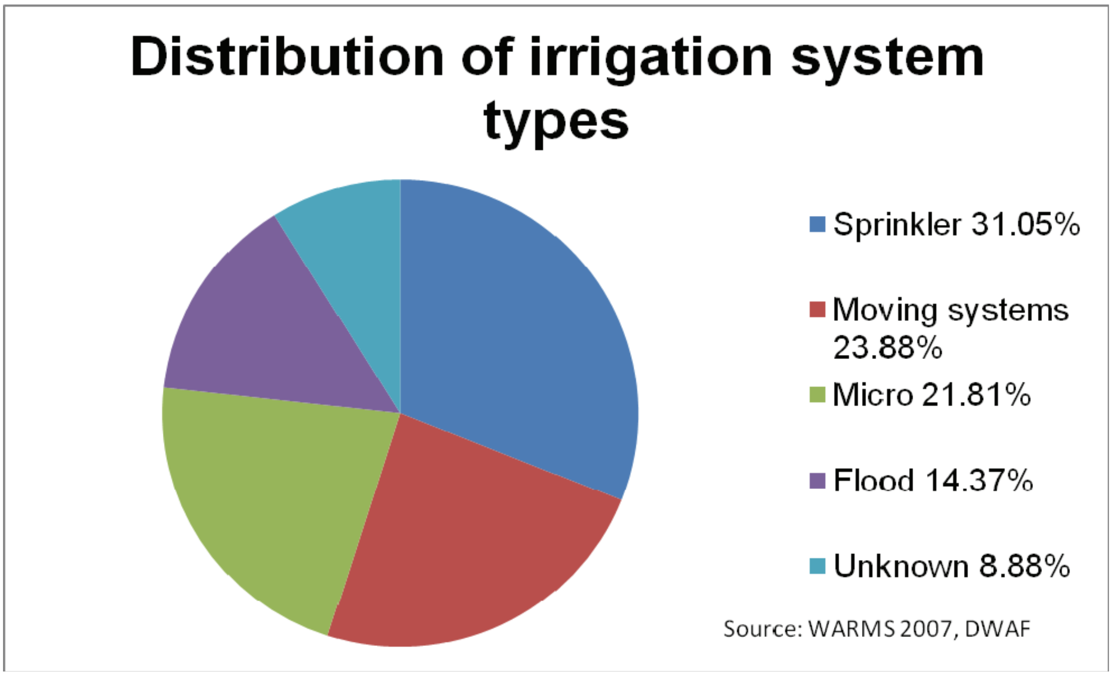

Figure 2. Implementation of various irrigation system types in South Africa.

2. Static irrigation systems

This type of irrigation systems includes all types that remain stationary while water is applied. The diameters of the nozzles can vary between 1 mm with micro irrigation to 25 mm with travelling guns, but the nozzle of ordinary sprinkler irrigation are from 3 mm to 7 mm.

2.1 Sprinkler Systems

Definition

A **sprinkler system** delivers water under pressure with the assistance of sprinklers that spray the water over a certain area. The wetting pattern of each sprinkler is usually a circle, and the design of a sprinkler system makes provision for the circles overlapping to create an equal water distribution over the area.

Sprinkler irrigation is well known for the last 50 years, but for the farmer it has only been economically usable for the last 30-40 years. The spray is developed by the flow of water under pressure through small orifices or nozzles. The pressure is usually obtained by pumping, although it may be by gravity if the water source is high enough above the area to be irrigated. The irrigation water is distributed to the field through pipelines. Sprinkler irrigation is adaptable to most crops, soils and topographical circumstances. However for even water distribution over the total land surface, careful designing is required. With careful selection of nozzle sizes, riser heights, operating pressure and sprinkler spacing, water can be applied uniformly at a rate lower than the infiltration rate of the soil, thereby preventing runoff and the resulting damage to land and crops.

- **Sprinkler Types**

Many different designs and styles of sprinklers are designed and used in practice. Low angle sprinklers are used in orchards (sprinkler angle ± 20º); a rain gun type of sprinkler for crops where large spacing is possible (sprinkler angle ± 26º) and type that is mainly used for cash crops (sprinkler angle ± 25- 26º)[1)].

The rotation of sprinklers is brought about by different ways such as:

- By means of a hammer action
- A turbine that drives a gear that causes rotation
- Where the jet direction is tangential to the sprinkler shaft, it causes the sprinkler to rotate

i) **Impact sprinklers** use a spring loaded hammer to break the stream of water from the nozzle to distribute the water and to enable rotation.

Figure 3. Impact sprinklers

i) The **Floppy** sprinkler utilizes a silicone tube which snakes to and fro through 360º to irrigate a circle pattern.

Figure 4. Floppy irrigation system

ii) **Gear driven** sprinklers rotate by using a set of gears driven by the water stream.

iii) **Wobblers** are sprinklers that has a part where the nozzle is located which wobbles and thereby rotates the spray pattern.

iv) Rotor-sprinklers utilize the water stream to rotate, and has a silicone filled drive section that considerably slows down the rotation speed.

2.2 Permanent sprinkler system

The term permanent refers to a solid set of sprinklers that is installed to irrigate 100% of an area, for the duration of the life time of the system. The sprinklers can either be mounted on stand pipes of various lengths and types, or on an overhead cable system that supports the pipes and sprinklers. No parts of the system are being moved during normal operation. The type of sprinkler is determined by the specific application, customer preference as well as price.

Application

The system is used for all types of crops including vegetables, sugar cane, grains, potatoes, bananas and trees where overhead wetting is not a problem.

Advantages

- Low labour requirement as no moving of pipes is necessary.
- Easy to operate as one valve opens a block of sprinklers.
- Makes water management easier because a block of sprinklers is operated simultaneously, and it is easier to apply small applications.

Figure 5. Permanent Sprinklers: Floppy sprinklers

Disadvantages

- High cost due to the high number of sprinklers per hectare and high construction cost in the case of the cable system.
- Larger supply pipes needed because of the high volume required;
- Consequently impractical to have large irrigation blocks due to the high volume.
- Requires careful management in terms of soil preparation and other cultivation practices to prevent damage to stand pipes and hydrants.

2.3 Semi-permanent system

This sprinkler system consists of a set of sprinklers that is being moved from one position to another for a number of positions per sprinkler depending on the design. The sprinklers are connected to a supply pipe which is moved from one fixed hydrant to another.

Two varieties are found on this concept:

a. Dragline system

Each sprinkler is connected to a flexible pipe which is connected to the supply pipe. This enables the sprinkler to be moved from one position to another without moving the supply pipe. Sprinkler spacing is usually 18 x18 m with between 1 and 5 positions on each side of the supply pipe.

Application

The system is used for all types of crops including vegetables, sugar cane, grains, potatoes, bananas and trees where overhead wetting is not a problem.

Advantages

- Low capital cost due to the low number of sprinklers per hectare.
- Consequent smaller main line pipe diameters required.
- System can adapt to field size and shape.

Figure 6. Dragline system

Figure 7. Sprinklers with dragline pipes

Disadvantages of draglines

- High labour requirement to move pipes during operation.
- Low efficiency with high risers when irrigating in warm windy conditions due to high evaporation losses, and also because sprinklers stand isolated when irrigating – overlapping is theoretical and not achieved in practice.
- Damage to crops is inevitable due to the movement of pipes and sprinklers.
- Difficult and impractical to apply irrigation in a short cycle due to the practical constraints of the system.
- High pressure losses due to friction in small diameter (20 mm) dragline.
- Supervision & management can be difficult on irregular fields where unreliable labourers often fail to shift sprinklers correctly.

Diagram showing the moving of sprinklers on dragline system (Figure 8).

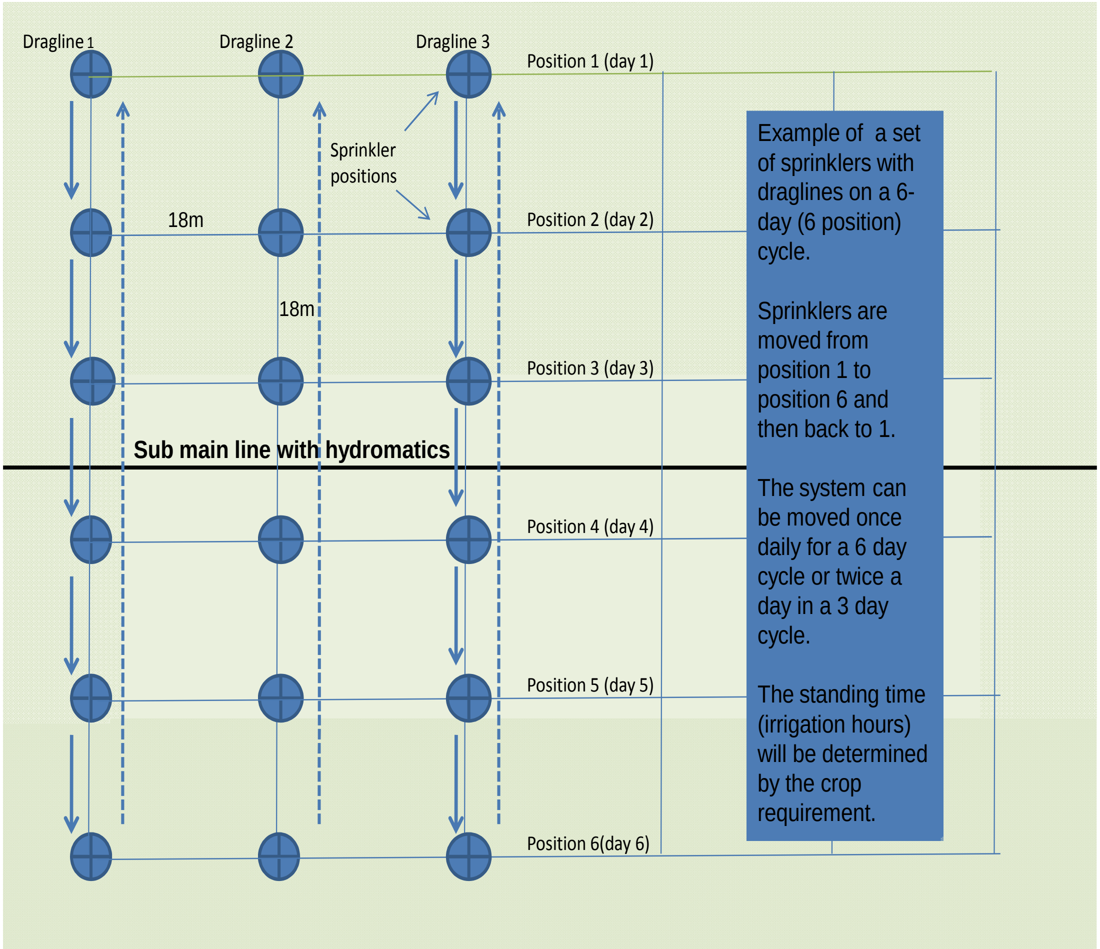

Figure 8. Diagram showing moving of sprinklers on dragline system

b. Quick coupling or fixed line system

Like with the dragline system the quick coupling pipes are also connected to fixed hydrants in the field. The sprinklers in this case are situated directly on the supply pipe. After irrigating on one position the supply pipe needs to be moved, complete with sprinklers, to the next position.

Application
The system is used for various types of low growing crops including vegetables, grains, potatoes, pasture crops.

- *Spacing:* The spacing can vary from 6x6 m to 18x18 m spacing, depending on the usage. However, various factors determine which spacing is the best in any given situation. If the spacing is small, sprinklers with small jet sizes and lower pressure can be used. However, with narrow spacing, the labour requirements and capital cost per hectare will be higher than with wide spacing. The uniformity of the rotation speed is of vital importance seeing that variation there in will also result in a variation of the application uniformity.

- *Uniformity:* With the exception of specialised nursery nozzles, the wetting pattern of sprinkler emitters is circular. Wind conditions have a great influence on the application uniformity. Wind influence the general distribution pattern (Figure 9), and thus the larger the spacing, the better the changes that wind can reduce the distribution efficiency.

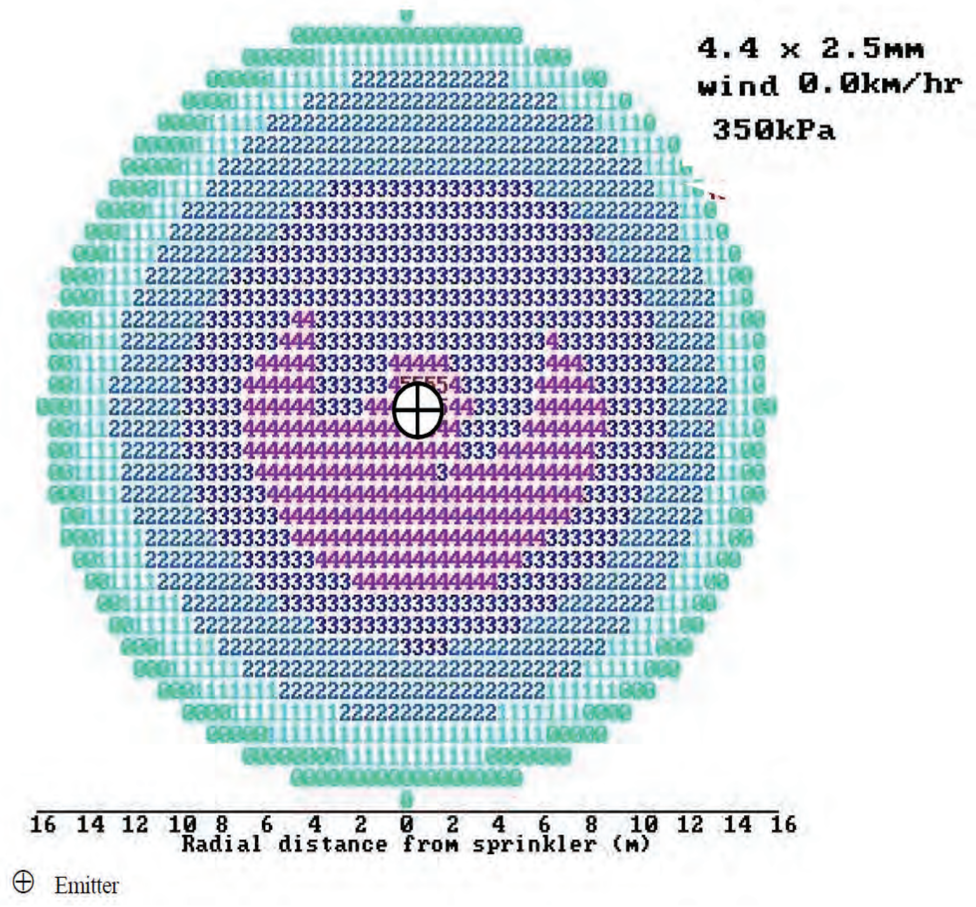

Figure 9. Wetting pattern of a sprinkler emitter[8)]

**Note: the numbers on this chart represents the amount of water falling at that point in millimetres per hour.*

There is however no single answer to which sprinkler spacing is the "correct" or the "best", The final decision in this regard depends upon factors such as the discharge of a sprinkler.

There are many factors that determine the uniformity of distribution with sprinklers:

- Wind conditions
- Pressure variation in the system
- Plant growth (with low angle sprinklers)
- Spacing
- Application rate

Figure 10. Quick coupling hydrant and pipe

Figure 11. Quick coupling pipes and sprinklers

Advantages

- Low capital cost due to low number of sprinklers per hectare.
- Consequent smaller pipe diameters required.
- System can adapt to field size and shape.

Disadvantages

- High labour requirement to move pipes during operation.
- Low efficiency with high risers when irrigating in warm windy conditions due to high evaporation losses.
- Damage to crops is inevitable due to the movement of pipes and sprinklers.
- Difficult and impractical to apply irrigation in a short cycle due to the practical constraints of the system.

2.4 Micro sprinkler system

The micro sprinkler is developed to apply small diameter circles emitting small droplets. Micro sprinklers are mounted on short (300-600 mm) stakes and water is applied under the tree not wetting the tree canopy. Wetting patterns overlap to create a wetting strip under the tree row, leaving a dry area between tree rows[2,6,)].

Depending on pressure, nozzle size and spreader type, micro sprinklers can wet circle diameters ranging from 0.3 m to 8 m.

Application

The system is used for all types of tree crops and in some cases as overhead irrigation for vegetables and crops that need cooling during the day.

Micro sprinklers are also used in nurseries because of small droplets that gently wet plants and seed trays containing small seeds and fragile seedlings.

Figure 12. Micro sprinklers under trees and examples of different types

Figure 13. Sprinklers operating under trees

Figure 14. Micro sprinklers irrigating

Advantages

- Operation is easy as the sprinklers function in blocks which means large groups of sprinklers operate simultaneously.
- Makes water management easier because it is easier to apply small applications with a relative large block of sprinklers.
- Strip irrigation possible which saves water and encourages orchard practices to take place while irrigation continues.
- Relatively low pressure required to operate the system – saves energy costs.

Disadvantages

- Requires careful design & pressure regulation.
- Requires relatively fine filtration to prevent blockages of small emitters.
- Relatively high cost due to high number of sprinklers and pipes per hectare.
- Equipment easily damaged by people during orchard practices.
- Limited life span of poly ethylene pipe exposed to sunlight.
- Over irrigation on parts of the root zone because of uneven root distribution.

2.5 Drip Systems[1)]

Drip irrigation is developed with the primary aim of saving water. It originated in the 1960s in Israel where arid climatic conditions, sandy soil types and critical lack of water availability cause sprinkler irrigation to be highly ineffective and costly due to high evaporation losses. When holes are simply made in a pipe, the water will spray out according to the size of the hole and the water pressure. It was therefore necessary to develop a device that reduces the flow and pressure to give a very low water delivery – namely the dripper.

Definition

A **dripper** is a small device that consists of a small inlet, a very small flow path that reduces the flow and pressure in the dripper, and an outlet that delivers a certain amount of litres per hour according to the rating of the specific dripper.

With the developments in the plastic technology it became possible and cost effective to incorporate the dripper in the pipe manufacturing process resulting in a drip pipe with integral drippers.

- Pressure compensating drippers differ from conventional drippers in that it has a constant delivery even with an increase in pressure.
- CNL or Non-leakage drippers close at a certain low pressure level to ensure the pipe remains filled with water for immediate reaction once irrigation starts again.

Applications

Two types of drippers are commonly used:

i. **Integral drippers** – Also referred to as inline drippers. It consists of a poly pipe where the dripper device is plastic welded on the inside of the pipe wall with a hole in the pipe where the outlet of the dripper is. Inline drippers come in standard dripper spacing, but can also be ordered with spacing according to customers' specifications.

Figure 15. Examples of in line drippers

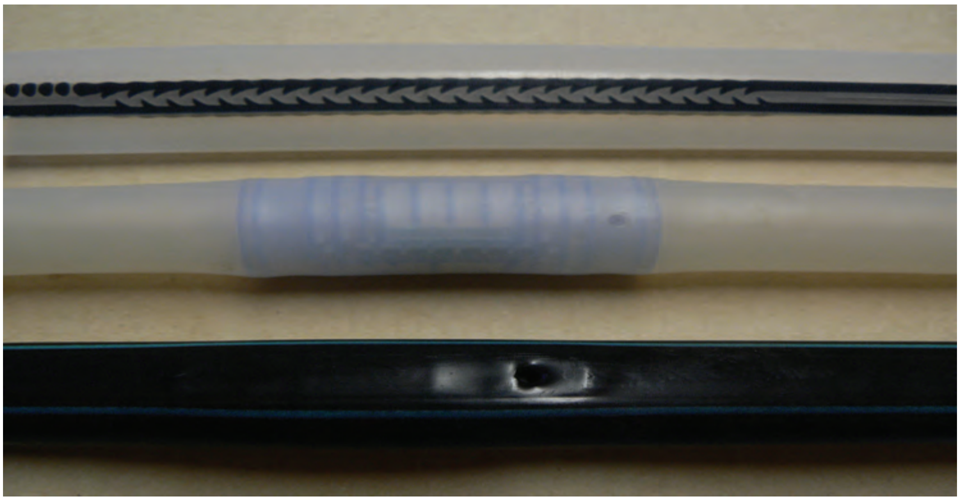

Figure 16. Different in line dripper pipe

Figure 17. Cut open drip pipe

- Drippers are externally invisible thus allowing easy mechanic handling of drip lines (layout and retrieving).
- Especially suitable for row crops (vegetables, sugar cane, potatoes, sweet corn, bananas, cotton, orchards, etc.) but also widely used on tree crops and vines. Drip pipes can be re-used for several seasons with proper maintenance and depending on the pipe's wall-thickness.
- In some cases it is installed subsurface where harvesting and cultivation practices do not allow for pipes to be installed on the soil surface, e.g. sugar cane, lucerne.

The decision on dripper spacing and delivery is influenced by the crop as well as the soil in terms of infiltration and water holding capacity. Figure 18 indicates the difference in water infiltration for two different soil types.

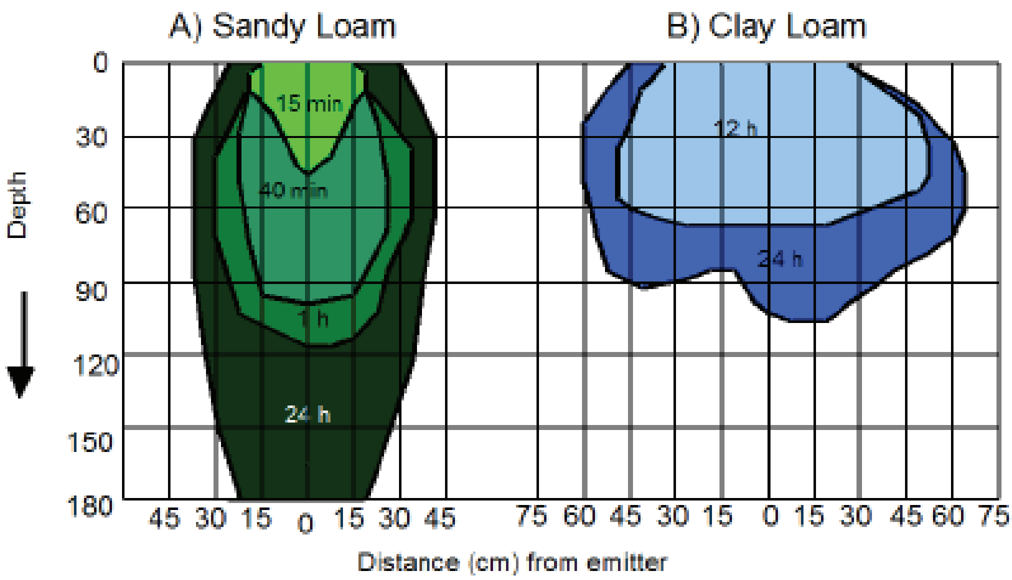

Figure 18. Effect of soil texture on lateral water movement

- ***Situation A*** is a Sandy loam where infiltration is fast, but lateral movement is limited. In this situation a low delivery dripper will be used at a narrow spacing. Example: 2 L/h drippers spaced at 300 cm on the drip line.

- ***Situation B*** is a Clay soil where infiltration is slow but lateral movement is good. Wider spacing can therefore be applied, using drippers of a higher delivery rate, for example: 4 L/h drippers on 500 mm spacing.

Note: *A practical field test is advised to determine the correct dripper specification.*

ii. **Button drippers** – Also known as online drippers. It is a dripper unit which is mounted manually on the outside of the pipe wall at any desired interval. Online drippers are used in greenhouses – mostly delivering water to 4 plants via a manifold and spaghetti tubes (figure below). It is also used for trees with a wide spacing where it is not practical to use inline drippers, or where lateral movement of water is restricted due to very sandy soil.

- Can be placed precisely according to plant or tree spacing, or as desired to meet the grower's requirements.
- Additional drippers can be added at a later stage (e. on tree crops) to increase water application due to increased demand as a result of the plant's growth rate.

Figure 19. Button drippers in greenhouse

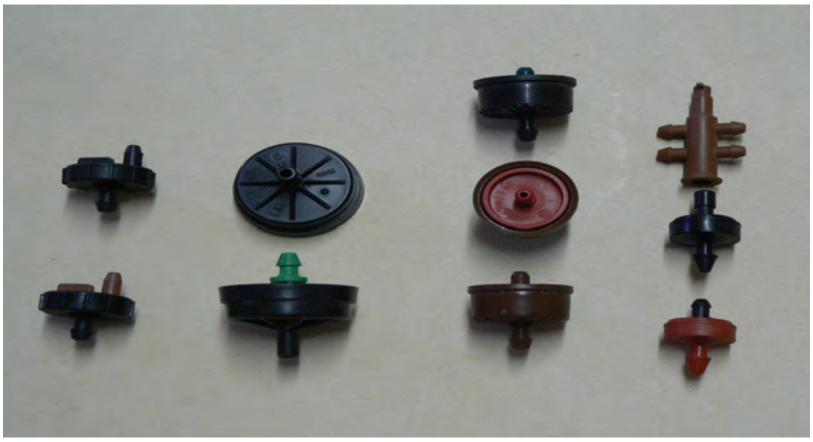

Figure 20. Examples of button drippers

Figure 21 Button dripper irrigating tree

Advantages

- High application efficiency is obtained because water is applied directly to the soil surface and only a small percentage of surface area is wetted.
- Layout of large blocks is possible where low flow rates and wide dripper spacing are used.
- Labour and energy costs are low.

Disadvantages

- Needs very fine filtration due to the high danger of blockages.
- Physical and chemical impurities can create blockages, and therefore chemical treatment and rinsing of pipes are essential.
- High investment cost especially with pressure compensated systems.
- Monitoring is difficult because blockages cannot be easily detected.
- It is easy to over irrigate because the surface soil is not saturated as with overhead irrigation.

Figure 22. Planting of cabbage seedlings with drip lines

Calculation of drip application

Because of the fact that drip irrigation only wets a strip of land, the application cannot be measured in millimetres like with overhead irrigation. Recommendations and figures in literature are however made in millimetre, and therefore one should be able to convert the litres per hectare to millimetres applied.

Example

A sugar cane field has drip lines with a spacing of 2 m between lines. Drippers deliver 2 L/h and drippers are spaced 0.6 m in the line.

The theoretical application of 6 hour irrigation is calculated as follows:

- Number of drip lines per hectare is 100 m / 2 m = 50 lines
- Number of drippers per line is 100 m / 0.6 m = 166 drippers
- Number of drippers per hectare is therefore 166 x 50 = 8300
- Dripper delivery per hour is 8300 x 2 L/h = 16 600 L/h
- Delivery in 6 hours is 99 600 L = 99.6 m^3[1 L/m^2 = 1 mm] and [10 m^3/ha = 1 mm]
- Therefore 99.6 m^3 = 9.96 mm = 10 mm

[For every 10 m^3 pumped per hectare, one millimetre is applied]

3. Mechanized Sprinkler Systems

Definition

A **mechanized** system refers to a system that moves on wheels while irrigating the area. Mechanized systems utilize a mechanical framework or vehicle that carries either one large sprinkler or a set of smaller sprinklers that irrigate while the system moves along

These systems generally have a number of requirements including high pressure, relatively flat land and soils with high infiltration rate. The following are examples of *Mechanized systems:*

3.1 Centre pivot[1)]

The centre pivot consists of a centre piece where the water supply and controls are, and a number of spans housing the sprinklers. A span is a steel structure supporting the supply pipe to which the sprinklers are connected. At the end of each span is a set of two electrically driven wheels which drive the span to rotate (pivot) around the centre piece. Additional spans can be added to create a much larger area while reducing the cost per hectare of the system. Span lengths differ between manufacturers, but lengths of 33 m to 62 m are available, and these are used in combination to fit a number of spans on a field depending on the area. An overhang or a big gun sprinkler can be added to the end span to further increase the circle radius at relatively low cost.

The average centre pivot consists of 4 to 12 spans covering up to 100 hectares. Larger pivots are also found – up to 200 hectares, but are seldom practical due to land and soil constraints. The size of a pivot is determined by cost, availability of land & water, the crops, soil infiltration capacity and topography.

The centre pivot system is increasingly popular because it is easy to operate, can be programmed for different crops and its ability to irrigate large areas at high efficiency.

i) Two types are generally seen namely high clearance pivots (for high growing crops like bananas, sugar cane) and low profile pivots for grains, vegetables etc.
ii) Towable centre pivots are available in the low profile range and are equipped with a set of wheels at the centre as well as adjustable wheels that can change angle that it can be towed to a different area to irrigate.

Figure 23. Centre pivot in line

Figure 24. Centre of pivot with fertilizer tank

Figure 25. Electric motor and drive shafts

Figure 26. Drive shaft and wheel

Application

Centre pivots are widely used for all types of crops including grains, vegetables, sugar cane, potatoes, bananas etc.

Operation

The system can run either clockwise (forward) or anti-clockwise (reverse). The speed at which the system runs to complete the circle can be set at the speed setting indicator. The speed setting also controls the water application of the system. The application at 100% setting for example can be 8 mm. If the percentage is set to 50% it runs at half the full speed and will therefore apply twice the application = 16 mm. If a farmer wants to apply 30 mm, he has to know at what percentage to set the system. This is calculated as follows:

$$\textbf{\% setting} = \frac{\textbf{100 x minimum application (mm)}}{\textbf{required application (mm)}} = \frac{100 \times 8}{30} = \textbf{26\%}$$

Note:

- *It is therefore critical to know what the application at 100% setting is. This can be measured with rain gauges at 100% setting.*
- *Fertilizer is also applied through the system which further improves productivity and saves costs.*

Figure 27. Centre pivot control panel

Figure 28. Aerial view of centre pivot circles

Advantages

- Low labour requirement because the system is fully automated – a single operator per system.
- Irrigation can be done at night which increases efficiency and productivity.
- High application and distribution efficiency can be achieved.
- Fertigation is applied easily and accurately.
- Saves on labour costs and easy to operate and manage.

Disadvantages

- Ineffective use of land because of the circle pattern of operation.
- Planting in sectors of the circle can be difficult when having to irrigate different crops and growth stages.
- High initial investment cost, and totally dependent on electricity supply.
- Gale force winds can cause severe damage when towers are blown over

3.2 Travelling Gun

This system utilizes a single large gun sprinkler on a trailer which travels in a straight line while irrigating. The sprinkler is pulled mechanically either by using a cable which is rolled up by a hydraulic pump, or by rolling up the supply pipe as it travels forward.

The system has a number of requirements and limitations including high pressure, square or rectangular fields, labourers and tractors to move the system and flat land. The system is not suitable for sensitive crops, can cause soil compaction and high water losses due to the large distance water has to travel through the air.

Figure 29. Travelling gun with rigid pipe

Application

The system is used for crops like sugar cane, some grain crops and pasture crops where the impact of large droplets does not have a negative effect on the crop. The widest application is on pastures, and its biggest disadvantage is the high water losses and high pressure requirement.

Figure 30. Travelling gun with lay flat hose

Advantages

- Relative low capital cost.
- Easy to operate on narrow rectangular fields

Disadvantages

- Can cause soil surface compaction because of large droplets.
- Needs a tractor and labourers to move from one position to another.
- Needs high to very high water pressure to operate = high energy cost.
- A high evaporation loss due to the long distance water is projected through the air.
- Is not practical to irrigate small applications.
- Uneven application due to variation in running speed and wind drift.
- As a result of the large circle, a large amount of water is wasted outside the field at the starting and ending point.

4. Flood Irrigation

Flood irrigation can be described as the method of channelling water into a series of canals, furrows or basins through the utilization of gravity flow. It is the oldest and still most widely used method of irrigation worldwide. It originated thousands of years ago in the flood plains of rivers like the Nile where it was easy to divert the stream flow into manmade canals and furrows. Today a number of types of flood irrigation are practiced to irrigate a wide variety of crops all over the world.

Theoretically a well planned and laid out flood irrigation can be very effective, but in practice it is mostly found that the uniformity of application and distribution is very poor, and a lot of water is wasted through over irrigation. Irrigation cycles are also too long, resulting in the crop experiencing a period of drought followed by over saturation.

Application

Flood irrigation is used in conditions where water is easily available, soil is relatively flat, energy sources like electricity are not readily available and where there is a lack of capital to invest in more efficient distribution systems. It can be used on basically any type of crop that allows the flow of water in furrows or basins like trees, sugar cane, bananas and vegetables. It is difficult with creeping crops like pumpkins and water melons.

Advantages

- Low energy cost – no cost in some cases.
- Low capital layout even with mechanical landscaping.
- Low occurrence of plant diseases where plant leaves are not wetted.

Disadvantages

- Low distribution and application uniformity.
- Labour intensive
- Difficult to measure & control the application amount.
- Short cycle length mostly not practical.
- Not advisable for sandy and rocky soil types or high clay soils.
- Soil erosion is often seen without the necessary rehabilitation.

Types of Flood Irrigation

- Furrow irrigation (Short furrow irrigation)
- Border irrigation
- Basin irrigation

4.1 Furrow irrigation

Furrows are ploughed parallel to each other and row crops are established on the embankments. Streams of water are for a specific time [cut-off time] led out of a main furrow with a spade, into the furrows that are spaced at 1 to 2 meters and 30 to 500 meters long. The water reaches the plants by seeping through sideways. The water can also be led out of a canal by using a siphon. Sometimes water is only applied to alternate rows.

Limitations

1. To obtain uniformity of distribution of the water, it is important that the system is designed so that:
    - o the slope in the furrows stays constant;
    - o to combat erosion, the slope is not too steep;
    - o all the rows are of the same and correct length; and
    - o the stream has the correct flow rate.

    (A field must therefore be even [<6% slope], the slope must be uniform and it must have a rectangular shape.)

2. The soil must not be too sandy so that:
    - o sufficient lateral movement of the water occurs to wet the root-zone in the embankment; and
    - o the furrows can be long enough (100-200 m).

Application

1. Agricultural crops and vegetables planted in rows can be irrigated in this way, if the plants don't fall over and lie in the furrow and obstruct the flow of water.

2. Orchards, if the weed control is such that the roughness factor in the furrows stay constant.

Figure 31. Furrows well laid out on contours

Advantages

- On even fields, the investment cost is low.
- Energy cost is low because the water does not require pressure.

Disadvantages

- The design is difficult and the application depth cannot easily be adapted.
- A lot of water is wasted where soil main furrows are used and the controlling of water with a spade is difficult.
- A lot of labour is necessary to control the stream.
- Management is difficult where the roughness of the furrow surface varies during the season, or where crop rotation is practised.

One way to optimize furrow irrigation especially on small scale is to use dragline pipes for water supply to each furrow. The figure below (Figure 33) explains the use of short draglines for furrow irrigation, and can be utilized on small scale, but also on fairly large scale.

Figure 32. Short but deep furrows on steep slope

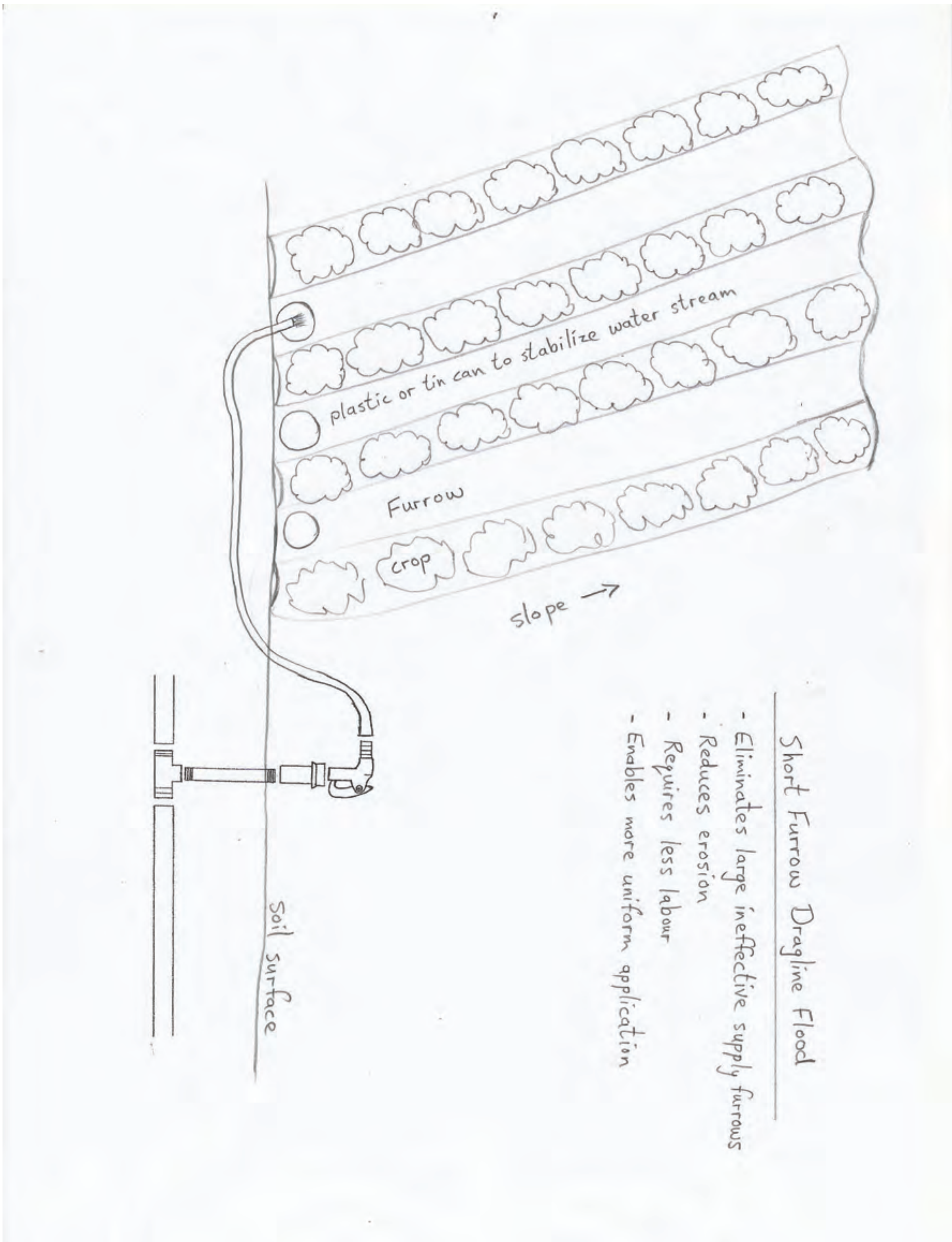

Figure 33. Short furrow dragline flood

4.2 Border irrigation

Water is, for a certain length of time, led out of a canal by siphon pipes, valves or sluices, into border strips that can be 2 to 20 m wide and 40 to 800 m long. In the R.S.A. siphon pipes or sluices are controlled manually, but in the U.S.A. there are systems where the valves are controlled automatically. (Border irrigation = strips of land bordering a canal)

Limitations

a. To obtain uniform distribution of water, it is important that the system is designed in such a way that:

i. the slope along the length of the bed is constant
ii. to combat erosion, the slope is not too steep
iii. the cross section surface is level and horizontal
iv. All the rows are of the same and the correct length
v. the texture, and thus also the infiltration rate of the soil does not vary too much
vi. the stream is just the correct flow rate

Note: *A limited flow rate also limits the length and/or width of the border strips. The field must be fairly level (<6% slope), the slopes must be even and the field must have a rectangular shape. If the gradient slopes gradually enough, the system is designed in such a way that the length of the border strip is perpendicular (90°) to the contour. If the slope is too steep, the beds can cross the contour at an acute angle, but then terraces will have to be formed and this will increase the cost.*

b. The soil must not be too sandy so that:

i. sufficient lateral movement of the water occurs underground, considering that the soil surface is never so level that the flow depth can be 100% uniform;
ii. beds can be long enough (100 to 300 m).

c. The system is limited to crops that will not influence the flow of the water dramatically, as the plants grow higher.

Applications

The border strip system is especially suitable for crops such as Lucerne that covers the whole area, but can also be used with row crops and orchards.

Advantages

- On even and level fields, the investment cost is low.
- Energy cost is low because water does not require pressure
- With a well-designed system where a large stream of water is handled by sluices, or especially with automated systems, less labour is used than with a furrow system.

Disadvantages

- The design is difficult and application depth cannot be adapted very well.
- Especially on slanting and uneven fields, the construction of the beds is expensive and difficult.
- Management is difficult especially where the roughness of the bed surface changes during the season or because of crop rotation.

4.3 Basin irrigation

Basin irrigation is especially applicable in the case of rice cultivation where large level basins are irrigated. In South Africa, this method, to irrigate orchards, is of importance. Around every tree a basin with a horizontal bottom is formed. A stream is led out of a branch furrow or low pressure pipeline, into furrows that run next to each row of trees. The basins are filled up to the desired depth out of these furrows. A labourer using a spade controls the water.

Limitations

Although flood irrigation in basins is possible on slanting fields, it is not advisable because the slanting slopes complicate the construction of the basins.

Figure 34. Basin irrigation

Advantages

- On even level fields, the investment cost is low.
- Energy cost is low because the water does not require pressure.

Disadvantages

- Where weeds are not chemically controlled, the upkeep of the basins requires a lot of labour.
- There is a large amount of water lost when the rows are too long and the infiltration rate is high (excessive seepage).
- Controlling the application depth is difficult.
- A lot of labour is necessary to control the water.

5. Cost analysis of various irrigation systems

The costs of irrigation systems are mainly determined by the capital cost, energy costs required for operation and the labour cost involved where labour is required for shifting of moveable irrigation systems. Table 1 provides the cost analysis of various systems that are used for irrigation of sugarcane in the Lowveld (Onderberg area).

Table 1. Costs analyses of various irrigation systems used for the irrigation of sugarcane in Lowveld which include all direct costs involved from the pump up to the irrigation field (2009)

Type of irrigation system	Design norms	System efficiency (%)	Installation cost/ha
Total irrigation requirement: 1400 mm/annum			
Floppy	1.1 L/sec (9.5 mm/day)	75	33 000-35 000
Permanent overhead	1 L/sec (8.64 mm/day)	70	30 000-33 000
Centre pivots	1 L/sec (8.64 mm/day)	80-85	15 000-22 000
Drag line sprinklers	1 L/sec (8.64 mm/day)	50-55	15 000-17 000
Drip system	0.76 L/sec (6.57 mm/day)	90	19 000-23 000
Subsurface drip		>95	27 000-30 000

Table 2 provides a summary of the most important aspects of the different irrigation systems to take into consideration when selecting an appropriate irrigation system for a specific irrigation farm.

Table 2. Summary of irrigation systems 2003 (ILI)[2)]

Irrigation group		Irrigation system	Estimated capital cost [R/ha] ($\times 10^3$) 2003	Application efficiency [%]	Life expectancy [years]	Labour requirements [ha/labourer]	Annual maintenance cost [% of capital cost]
Flood		Furrow	5 - 6	60 - 80	10	15	5
		Border	7 - 9	60 - 80	15	10	5
		Basin	6 - 9	60 – 80	20	12	5
Static	Sprinkler	Permanent	14 - 16	75	15	50	1
		Dragline	10 - 12	65	10	25	4
		Quick-coupling	9 - 12	70	12	20	3
		Hop-along	11 - 13	65	12	25	2
		Big gun	8 - 9	65	10	20	4
		Side-roll	11 - 13	65	12	25	2
		Boom	8 - 10	65	15	25	4
	Micro	Drip	18 - 20	90	5- 15	30	2*
		Subsurface drip	20 - 22	95	10	25	3
		Microsprinkler	14 - 17	80	10	30	3
		Microsprayer	22 - 25	80	15	30	3
Moving		Travelling gun	9 - 11	65	10	25	6
		Travelling boom	10 - 12	65	12	30	6
		Centre pivot	18 - 20	80	15	100+	5
		Linear	30 - 35	80	15	100+	6

Note: *The estimated capital costs include the costs of the pump station, supply system, distribution system and installation of equipment. Drip and micro systems were calculated for vineyards.*

5.1 Energy requirements and costs to irrigate

The location of the pump station should be as near as possible to the centre of design area. This is to ensure that water is distributed as economically as possible from the farm edge to the field edge. The energy need to distribute water over the field is of critical importance regarding the relative high ESKOM tariffs and the in endeavour to use electricity efficiently on the farm.

The following factors determine the energy requirements of a specific irrigation system:

- *Flow rate of irrigation system*
The higher the flow rate required for a specific irrigation system, the greater the amount of power needed to supply it, and therefore a higher energy cost implied[5)]. The flow rate required is influenced by:

    - the irrigation requirements of a specific crop,
    - type of system and number of emitters operating simultaneously
    - the application efficiency of an irrigation system,
    - the number of hours per day that a system is used
    - and the irrigator's irrigation schedule strategy followed on the farm.

- *Pressure requirements of an irrigation system*
The higher the pressure requirement to operate an irrigation system, the higher the energy requirement of the system. The pressure requirement of a system is determined by the operating pressure of the selected irrigation system, the topography of the farm, the pipe sizing strategy used to design the distribution system, the length of the pipes distributing water on the farm, and the friction loss through the other components such as valves and filters[5)].

- *Efficiency of motor and pump*
The higher the pump efficiency, the lower the energy requirement. Different pump brands and types of pumps can influence the efficiency though they are pumping the same amount of water[5)]. The key to an efficient pumping system is to select the best motor/pump combination at the design stage. Therefore it is important to compare initial capital cost with the operational cost of a specific combination[5)]

  ESKOM launched a specific programme called "Energy Efficient Motors programme" in 2007, where a subsidy is paid to users replacing older, inefficient motors with premium efficient motors. *More details available at www.eskom.co.za/dsm.*

- *Tariff structures*
Irrigators do not have much influence over the electricity prices or the reliability of supply. In the past electricity costs in South Africa was rated amongst the cheapest in the world [7)]. Due to an increase in the population, the increase in cost of fossil fuels and

the general economic growth in the country, ESKOM a sole energy provider have struggled to meet the electricity demands. As a result, a number of electricity increases since 2008 have impacted seriously on the profitability of an irrigation farmer. Where cheaper night rate electricity options are available, irrigators should make use of it. This however requires designing the irrigation system to operate within those hours. For a ten hour night rate period, an irrigation system has to be designed with more than twice the capacity compared to a system that is operating over a full day (24h). This adaption to design usually involves consideration of bigger pipes, pumps and system components, and a much higher cost system[5)].

There are various energy cost saving structures available from ESKOM. All tariff options include:

- a fixed cost, for the end use of infrastructure irrespective of whether electricity was used or not,
- and variable costs for the actual consumption of electricity.

Table 3 illustrates the options for the rural user, which implies different tariffs according to the time of use.

Table 3. ESKOM Tariff options for rural users[4)]

Tariff Plan	Description
NIGHTSAVE Rural	This is for customers with a notified monthly demand of at least 25kW/kVA. With a supply voltage ≤22kV, who can move all or part of their demand to off-peak periods (22:00-06:00 on weekdays as well as Saturdays and Sundays).
RURAFLEX	This tariff is applicable to 3-phase customers with a supply voltage from 400V up to 22kV and who can shift their loads to defined time periods.
LANDRATE	This is for rural customers with a notified monthly demand of 100kVA or less. LANDRATE is subdivided into 5 categories.

Ruraflex and Nightsave options are designed to promote the use of electricity during low demand season and off peak hours: after 22h00 until 6h00 during weekdays and during the weekend.

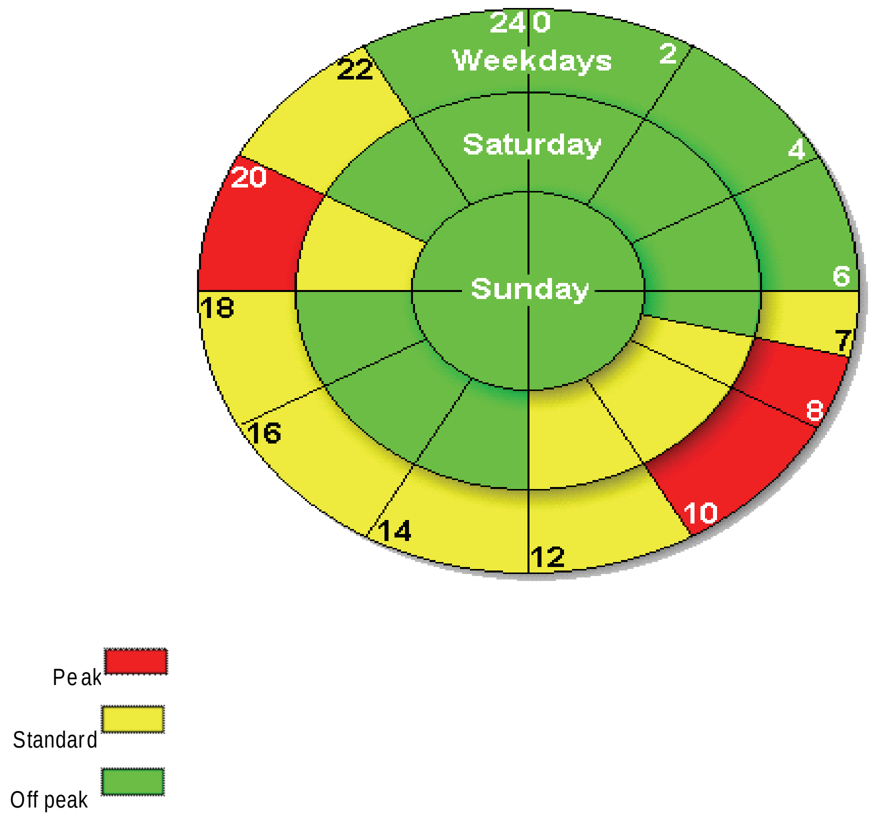

Figure 35. Tariff periods for Ruraflex

Table 4 illustrates the Landrate options that are available for irrigators to consider. More information on these options can be obtained from ESKOM website www.eskom.co.za

Table 4. Landrate options[4)]

	Service Charge [R/POD/day]	**VAT incl**	**Network Charge** [R/POD/day]	**VAT incl**	**Energy Charge** [c/kWh]	**VAT incl**	**Environmental levy** [c/kWh]	**VAT incl**
Landrate 1	**R 8.29**	*R 9.45*	**R 10.12**	*R11.54*	**46.27**	*52.75*	**1.97**	*2.25*
Landrate 2	**R 8.29**	*R 9.45*	**R 15.56**	*R17.74*	**46.27**	*52.75*	**1.97**	*2.25*
Landrate 3	**R 8.29**	*R 9.45*	**R 24.88**	*R28.36*	**46.27**	*52.75*	**1.97**	*2.25*
Landrate 4			**R 8.06**	*R 9.19*	**90.86**	*103.58*	**1.97**	*2.25*
Landrate Dx *	**R 17.94**	*R 20.45*	**** Landrate Dx charge includes the Environmental levy***					

6. Automation

The different irrigation systems can all too some extent, be automated for easier operation or for the purpose of very frequent and accurate applications. In some cases the total system can be automated, but some systems like flood irrigation, only pump and possibly some main valves can operate automatically.

The following functions can be automated:

- Pump start / stop
- Valve opening
- Back flushing of filters
- Injection of fertilizer / chemicals

In modern greenhouses all the functions are automated because of the complexity of inputs. These include the functions above as well as the following:

- Opening of ventilation
- Cooling / starting of fans
- Heating
- Misting
- Drainage
- Flow monitoring
- Tank level control
- Control of EC and pH of irrigation water
- Reaction on alarms according to flow, pressure, humidity or temperature

With centre pivots (mechanized systems) the start / stop functions are also controlled by the onsite control panel.

6.1 Requirements for automation

Apart from the normal system components, automation requires a number of specific items:

- o *Controller*[1,2,6)]

The controller can be a PC with the necessary software to control a number of outputs like opening of valves, starting of fertilizer pumps, etc. as well as to interpret a number of inputs received from EC, pH and moisture sensors, flow meters and other sensors.

It can also consist of a very simple timer or household garden irrigation controller which can only open a limited number of valves (stations). Most entry level controllers are able to open and close between four and six valves up to 4 times per day. These controllers however are not able to receive inputs from sensors to make adjustments to the program. With irrigation systems the controller primarily opens and closes a number of valves (stations), but may also be used to start the pump, flush filters and open fertilizer valves.

As mentioned above, with greenhouses the functions are numerous, and more advanced controllers are necessary for total control of irrigation, climate and fertilizers. It is also necessary to receive inputs (feedback) from sensors and react according to certain pre-set conditions. For example if the humidity / temperature in the greenhouse rises above a certain point the fans should start or the ventilation should start opening. With open field irrigation the moisture sensor will signal to the controller to start irrigating at a certain moisture level. A rain sensor can for example stop the irrigation.

Figure 36. Multi output controller

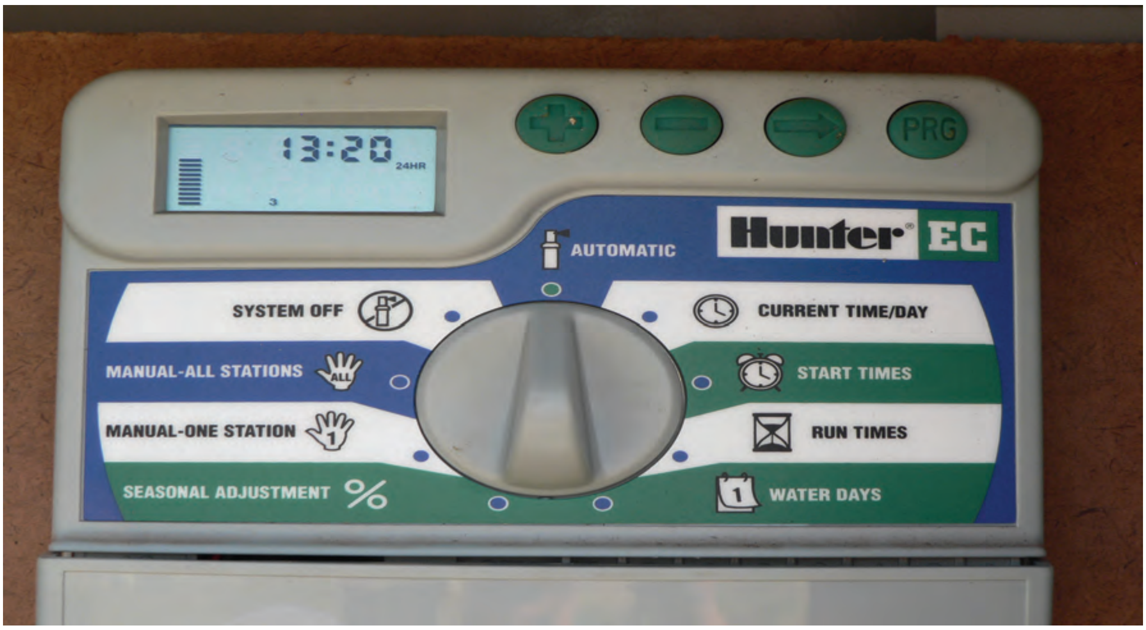

Figure 37. Four-station irrigation controller

Note: Where a controller (flush timer) is used to flush filters, it is used only to open and close the flush valves and not to control irrigation

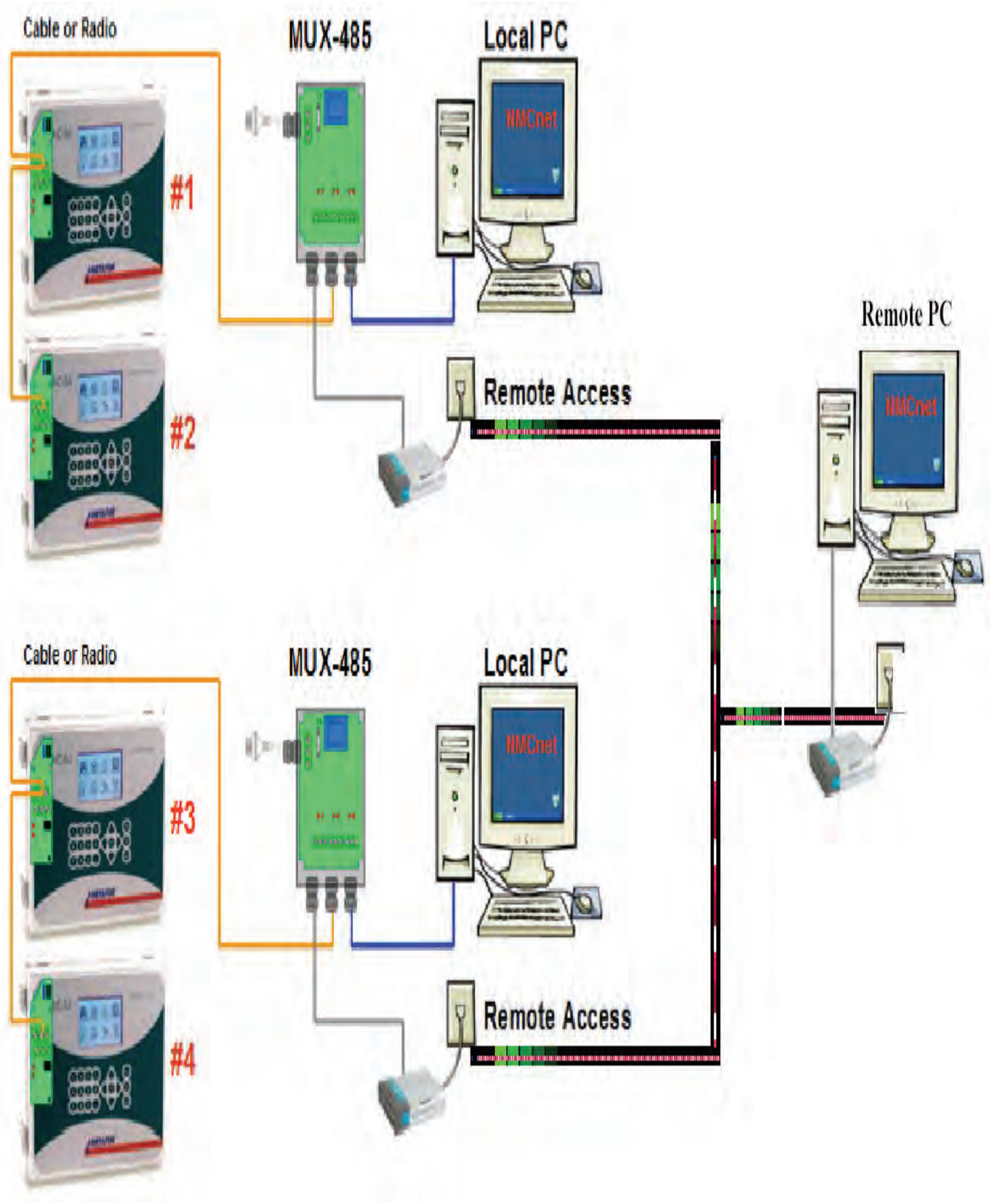

Figure 38. Schematic diagram of controllers linked to PC as well as remote PC

The above example is where four controllers are used to control the irrigation and climate respectively in two greenhouses. The controllers are connected to an onsite PC at the two different locations. Both PC's are connected to a remote PC (manager's office) via internet with a modem.

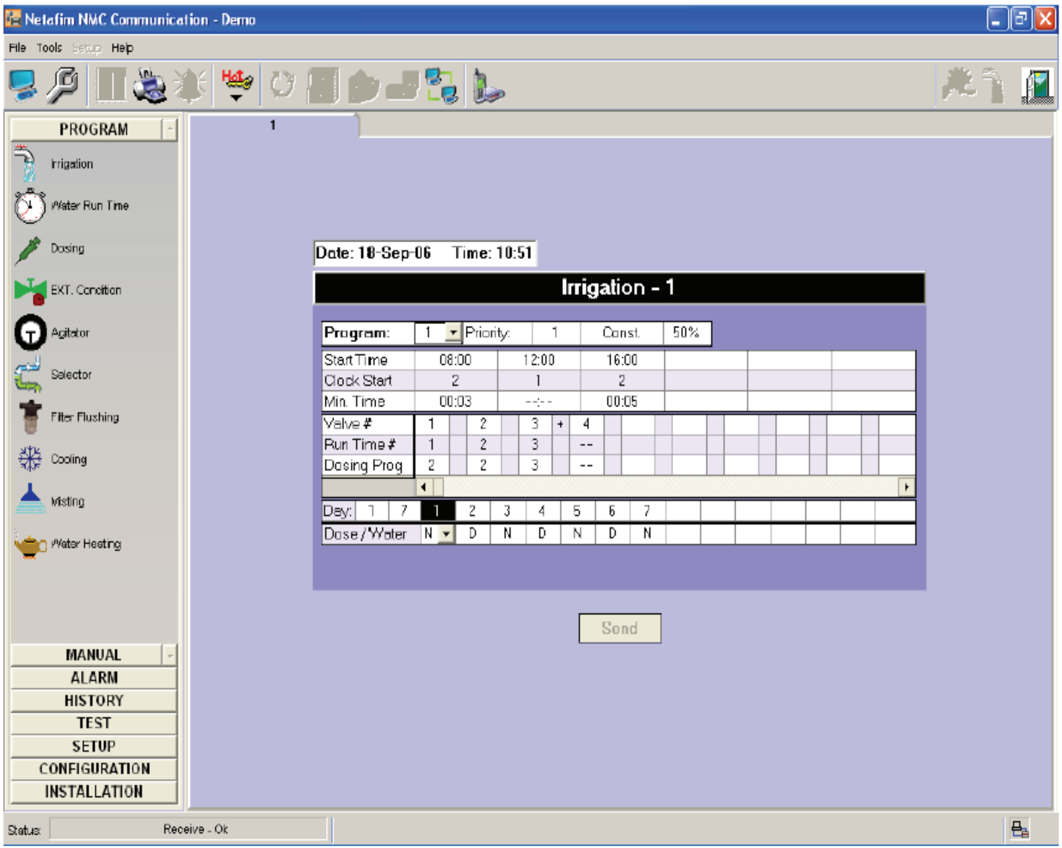

Figure 39. Example of PC screen of irrigation program

- *Electric Valves*

Electric valves can either be a specifically designed valve that has a built in solenoid which opens the valve, or it can be a normal hydraulic valve with a solenoid added for the same purpose. The solenoid is connected to the controller with two wires, and receives a low voltage current – usually 24V – from the controller[1,6].

Figure 40. Electric valve in greenhouse

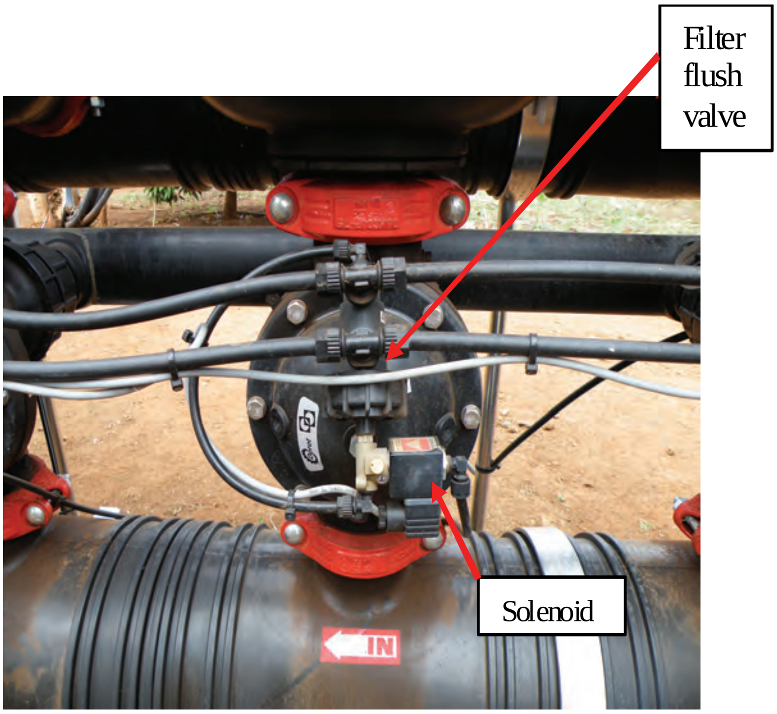

Figure 41. Hydraulic flush valve with solenoid

Wireless systems also exist with small battery powered radio receivers at the different stations. Especially on large farms and areas with lightning problems the wireless system is more users friendly. It also enables the user to receive inputs from the fields on a regular or even continuous basis without physically going out in the field to do the measurements.

Figure 42. Radio transmitter

- *Electronic Switches*

For the purpose of starting pumps for irrigation as well as fertigation, electronic switches are necessary to receive the command from a controller and start the pump, motor or specific greenhouse function[1)].

These switches connect the main electricity supply (Usually 240V) to the specific function, like the motor of a pump or fan to be able to work. Each feature therefore has its own switch to be able to work independently.

Note: *The switch gear is connected and serviced by an electrician, and should always be treated as live and dangerous.*

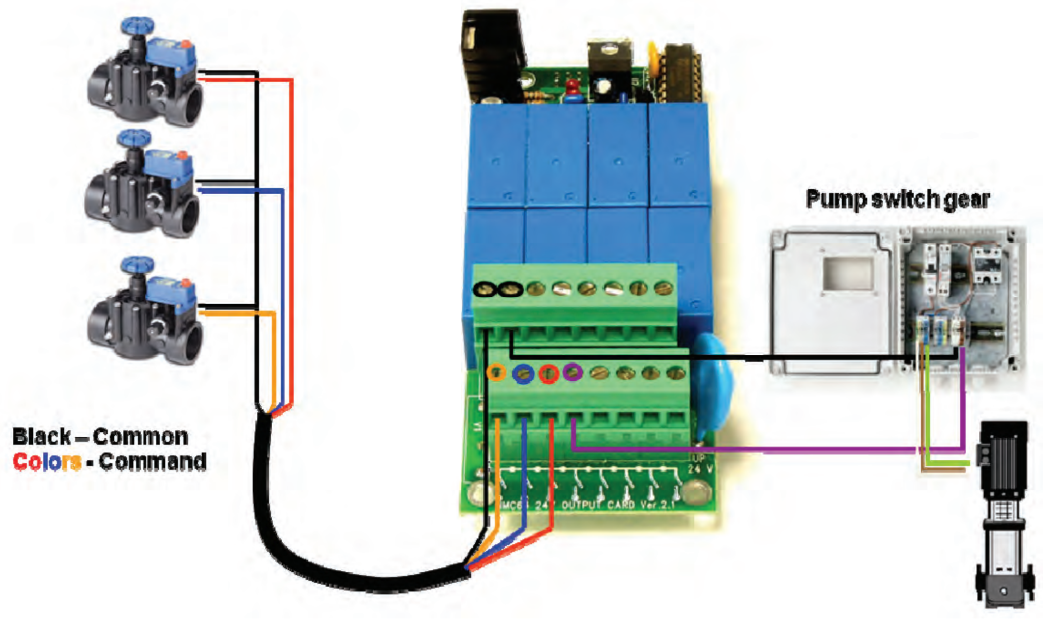

Figure 43. Schematic presentation of controller with connection to pump and valves

Activity

Activity 1

Individual activity

Case Study

Farmer Mamba has acquired a 20 hectare farm with 8 ha mango trees, 8 ha avocado as well as 4 hectares where vegetables had been planted each year. Mangoes are planted on sandy soil, the avocado trees on heavy clay soil, and the vegetable area is a sandy loam but shallow soil. The farm is in a hot area with low rainfall, but is situated close to a large river. The farm has a water allocation from a canal system that supplies water to an outlet on the farm. For the past 30 years all the crops were irrigated by flood irrigation. After receiving a very negative report on an assessment of the system efficiency by the Institute for Agricultural Engineering, the new owner decided to invest in new irrigation systems for the farm.

1. Make a recommendation on the irrigation system(s) that farmer Mamba can consider, and supply him with good reasons for the choice.
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2 Give a cost estimate of the proposed irrigation development regarding cost per hectare as well as maintenance cost.

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3 Supply a summary of how the new system(s) may impact on the management of the farming operation compared to the current flood irrigation.

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Activity

Activity 2

Individual activity

Case Study

A 40 ha farm in a banana producing area is for sale, and farmer Jackson asked you to advise him on the farm situation. He plans to establish sugar cane because the farm is located within 50km of a sugar mill. During a visit to the farm you find that there are two different types of soil. The largest part of the farm is a deep red soil with high clay percentage, and about 15% of the arable area is a relative shallow rocky and gravel soil.

1 What irrigation system(s) can you recommend, and give reasons for your choice?

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2 What is the expected life span of the specific system(s)?

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3 A centre pivot delivers 4 mm at a percentage setting of 100% (minimum application). At what percentage should the setting be to apply 20 mm?

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1 Netafim Hardware Installation Manual, 2008.

2 ARC Institute of Agricultural Engineering (ILI) Irrigation User's Manual, 2009.

3 Lowveld College of Agriculture Water Management 1A Study Guide, 2008.

4 ESKOM, 2009. ESKOM Tariffs and charges. 2009/201. ESKOM, Johannesburg. Available at: www.eskom.co.za

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7 Jumman A, 2009. A framework to improve irrigation design and operating strategies in the South African sugarcane industry. MSc dissertation, University of KwaZulu-Natal, Pietermaritzburg, South Africa.

8 Waterwise on the farm, 2001. Introduction to irrigation management: Evaluating your pressurised system. NSW Agriculture, Australia.

My notes…........

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Authenticator:

- Mr A vd Merwe

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Technical Learner Guide

Irrigation Water Management

Level 5

Module 6

Layout of irrigation systems

Study objective

After completion of this module, the learner should be able to have a basic understanding of:

- Layout of an irrigation system
- Basic components of an irrigation system
- Factors to take into consideration with the planning of an irrigation system
- Functioning of a pump
- Types of pumps
- Different types of impellers
- What to observe in a pump house (components and aspects)
- How to calculate net positive suction head
- Reasons for pre filtering
- Components of a filter system
- Different types of filters
- Management of a filter system
- Different pipes used for main and sub main lines
- Different types of valves that can be used and their respective functioning
- Different types of water meters that can be used

Table of contents

After the appropriate irrigation system has been selected and installed, it is important to attend to the layout of the irrigation system and to have a basic understanding of the working of the different system components.

1. Layout of irrigation systems

1.1 System components

The design and layout of an irrigation system is done by engineers and professional irrigation designers. It is a balance of the pump and system delivery with the system requirement as well as the topography and size of the area.

A schematic drawing of the basic components of an irrigation system can be seen in the figure below.

- Pump
- Filters
- Main line
- Main valve
- Block Valves
- Sub main pipes
- Laterals
- Emitters

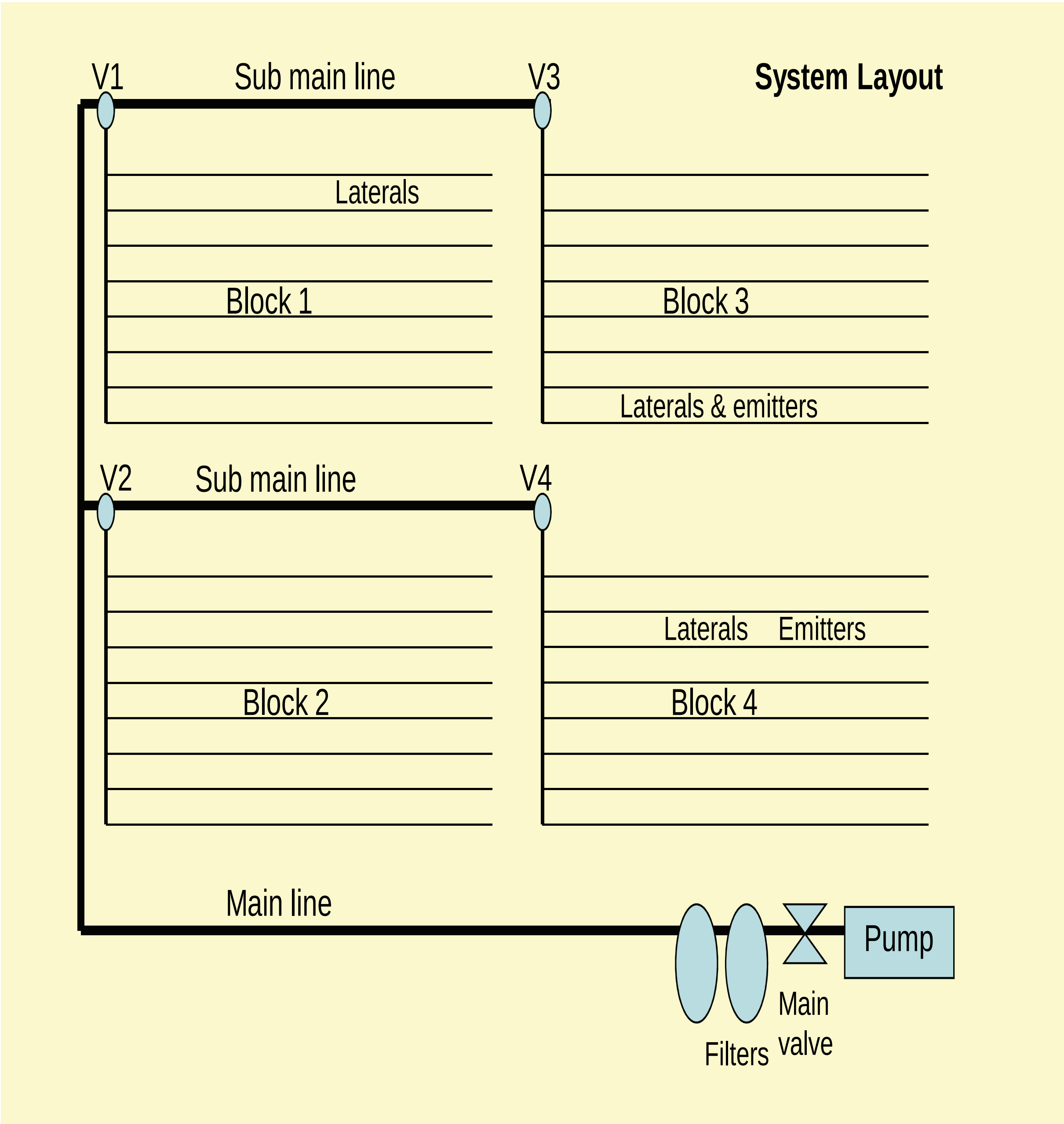


Figure 1. Typical system layout

1.2 Planning of layout

The irrigation designer has the task to do a full scale investigation of the farm layout and topography to be able to do a meaningful planning of the irrigation design. New developments need to be laid out in block groups, and these need to be divided into blocks. The sizes of these blocks are determined according to the pipe sizes and flow rates of the specific irrigation system.

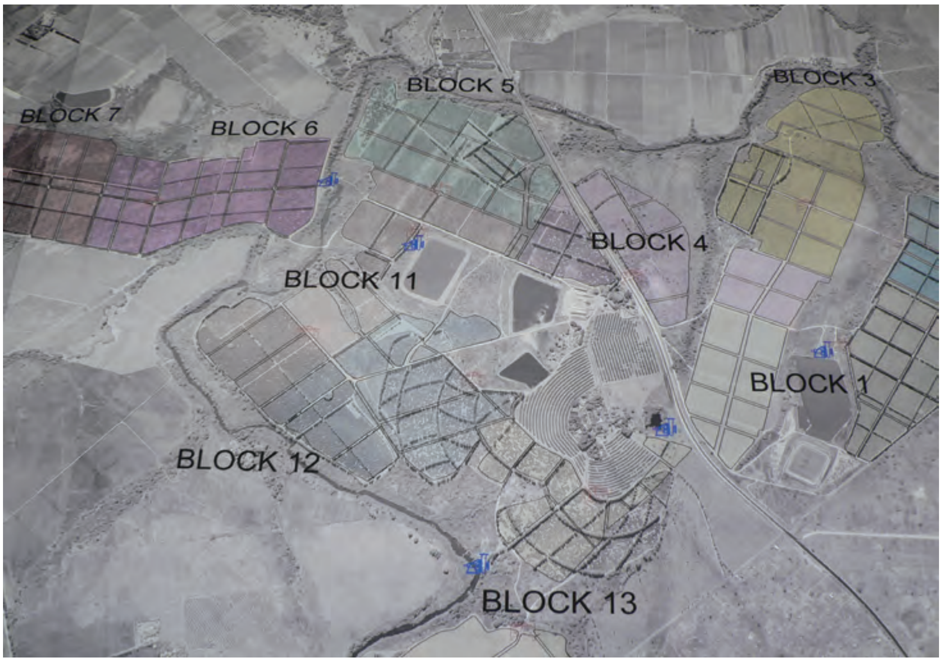


Figure 2. Photograph showing farm layout with blocks and fields in each block

Figure 3. Irrigation plan of a number of fields with dragline systems

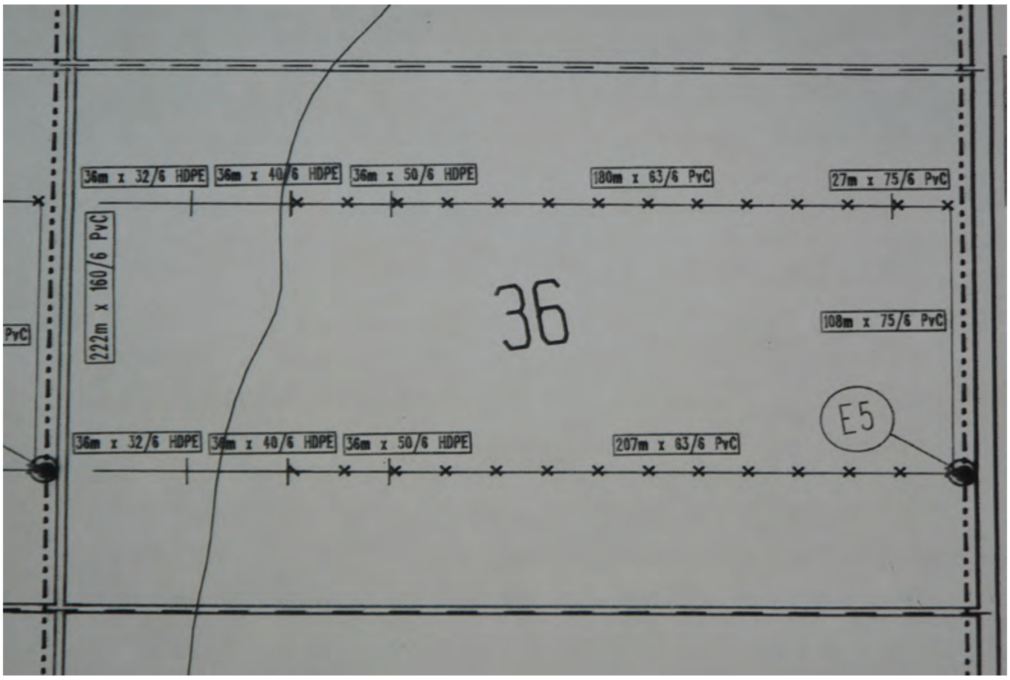


Figure 4. Irrigation plan of a single field with dragline systems. (Field Nr. 36 and valve E5.)

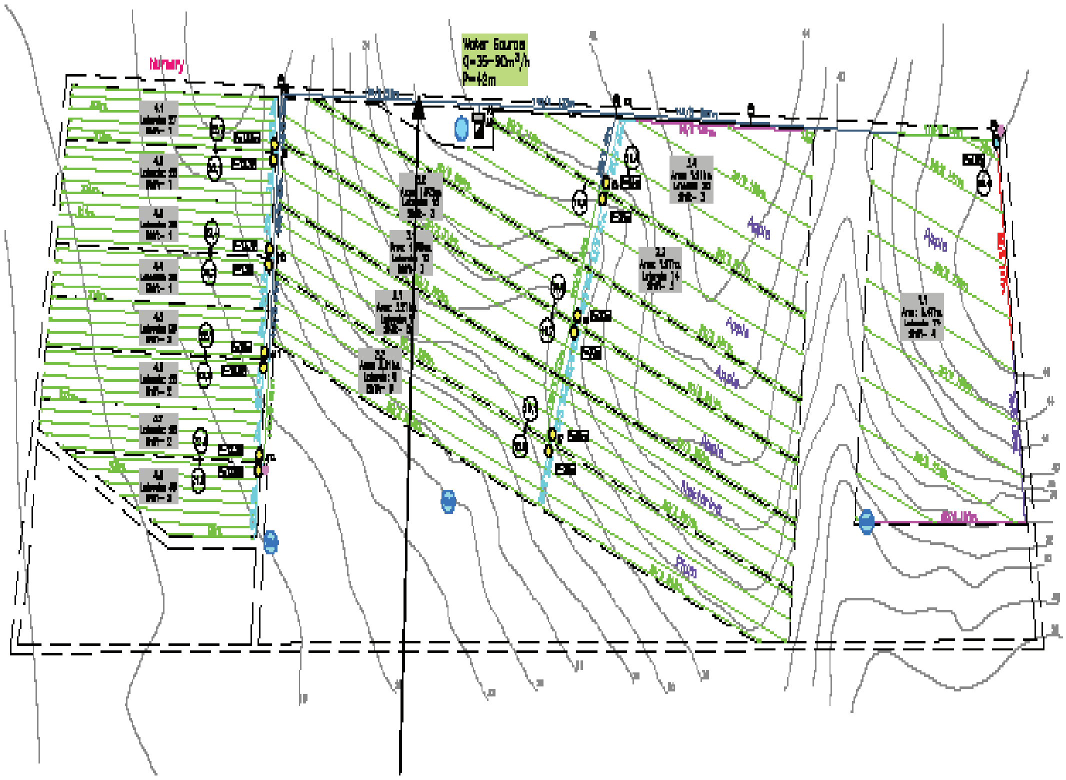


Figure 5. Irrigation plan with contours indicating topography

Contour maps are important because it expresses the topography of an area by indicating the height of different points on a map. This is important to determine the pumping height (pump head) or the static height for gravity flow. The physical difference in height above sea level is one of the aspects used to determine the total head the pump should deliver.

2. Pumps

2.1 Hydraulic energy[2,4,3,)]

The function of a pump in any hydraulic system is to add energy to the system. Figure 6 clearly shows that without a pump it would be impossible for the water to flow from point A to point B. If a pump should, however, be added to the hydraulic system between points A and B, as indicated in Figure 6, and sufficient energy is added to the system, the water will flow from point A to point B.

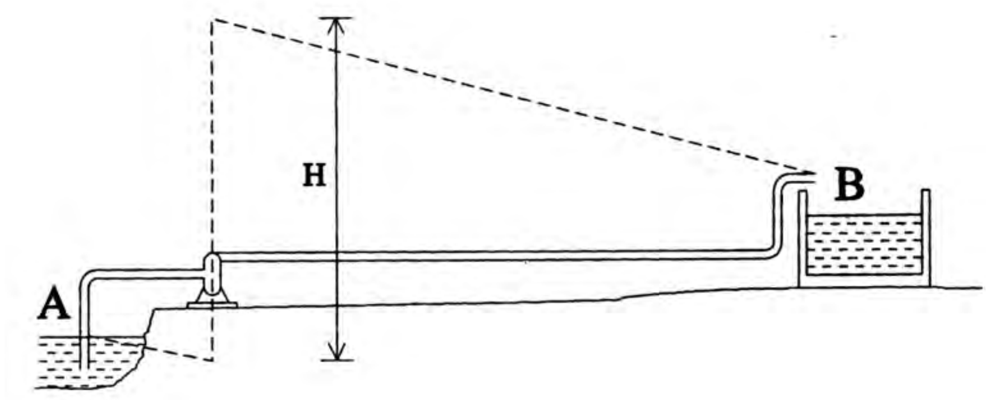


Figure 6. Addition of energy to a hydraulic system[2)]

The amount of energy added to the hydraulic system in the form of pressure head will determine the slope of the hydraulic gradient, which in turn will determine the flow therein. In Figure 6, H and the hydraulic gradient represent the **total energy** added to the hydraulic system by the pump by the dotted line. A pump is included in a hydraulic system for the purpose of adding sufficient energy to the system. This energy, which is supplied in the form of pressure head, must equal the static head, emitter pressure (for e.g. in overhead irrigation systems) and friction and other losses to have the desired effect.

The energy that is added to a hydraulic system in the form of pressure head is dependent on the flow in the system. However, a balance should be maintained between the pump head and the pump delivery on the one hand and the energy that has been added to the hydraulic system and the flow therein on the other.

All irrigation systems need water to be transported from a source to the area that needs to be irrigated. The systems also require pressure for the sprinkler or dripper to function correctly. This pressure required depends on the specifications of the specific system. The energy (pressure) that is required to transfer the water through a pipe or canal is supplied by a **pump**. The pump is in turn being driven by an electric motor or fuel driven engine. The only situation that does not require pumping is where the water source is situated significantly higher than the irrigation area. Then **gravity** forces provide the energy to carry water down to the field or dam, and to supply the irrigation system with water pressure. In agriculture centrifugal pumps are mostly used (see Module 1).

2.2 Functioning of pumps[4)]

All pumps basically consist of a casing (body), a shaft that turns inside the casing, and a single impeller or number of impellers (rotating inside the casing) that is responsible for creating the pressure delivered by the pump. The centrifugal movement of the water through the impeller creates velocity in the water which builds up pressure in the pump. The pump has an inlet (suction) and an outlet (delivery) and delivers water at a certain pressure head [H] (m) and volume [Q] (m^3/h). These two are the pump characteristics and are determined by factors like impeller size (diameter and width) and rotation speed. The specific pump is therefore selected according to the system requirements in terms of pressure and flow volume.

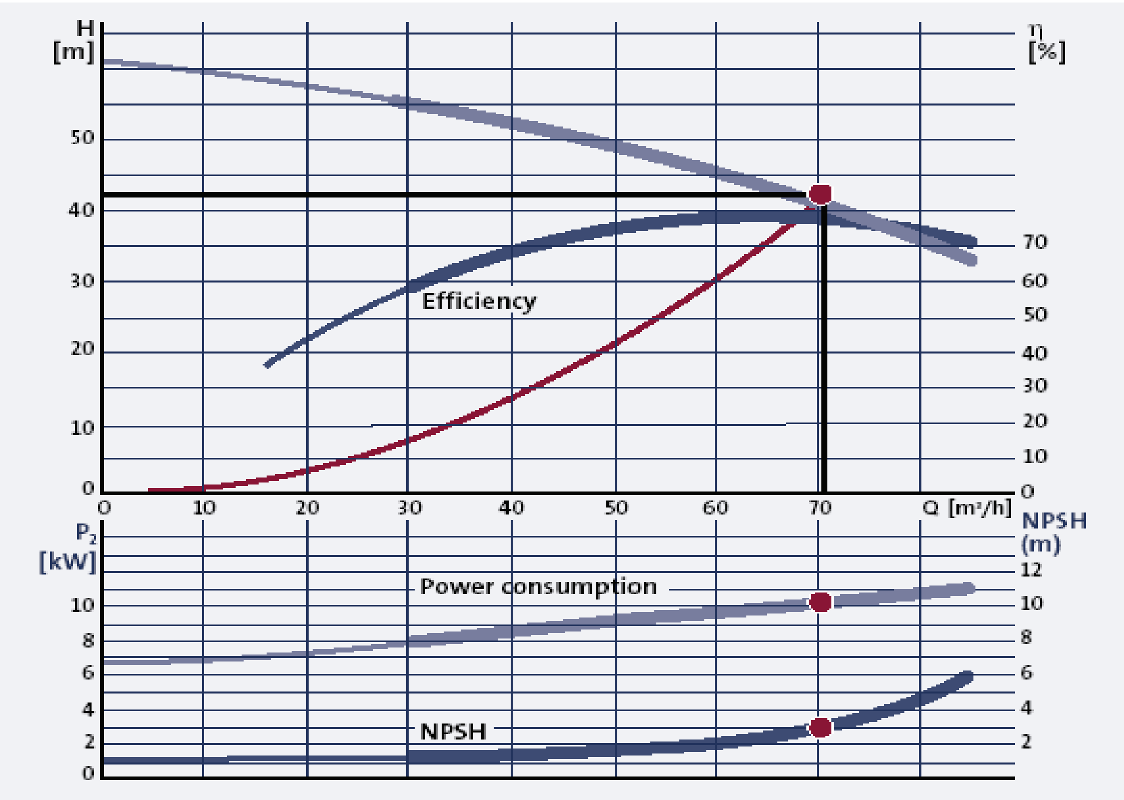


Figure 7. Typical performance curve of a centrifugal pump: Head (pressure) power consumption, efficiency and NPSH are shown as a function of water flow.[4)]

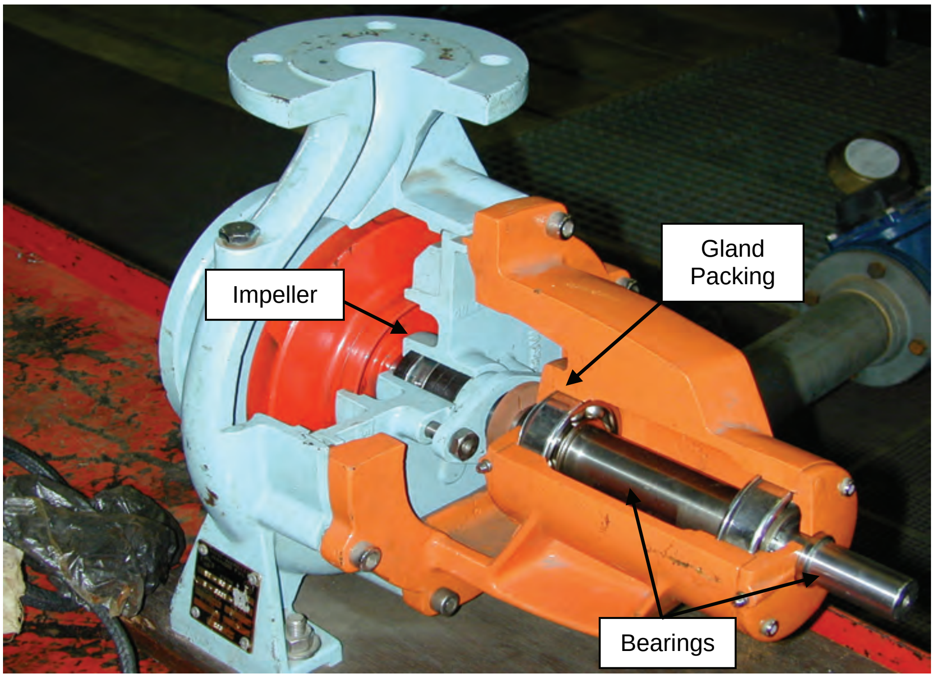
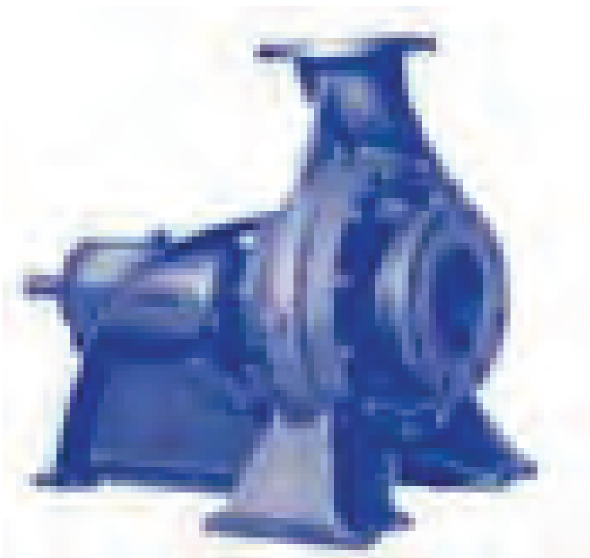


Figure 8. Cross section of centrifugal pump showing shaft, impeller and outlet

2.3 Types of pumps

The following types of centrifugal pumps are generally used in agriculture[1,2,4)]:

a) Single stage pump for low pressure



b) Multistage pumps for high pressure.

Figure 9. Multi stage pump (Multiple impellers)

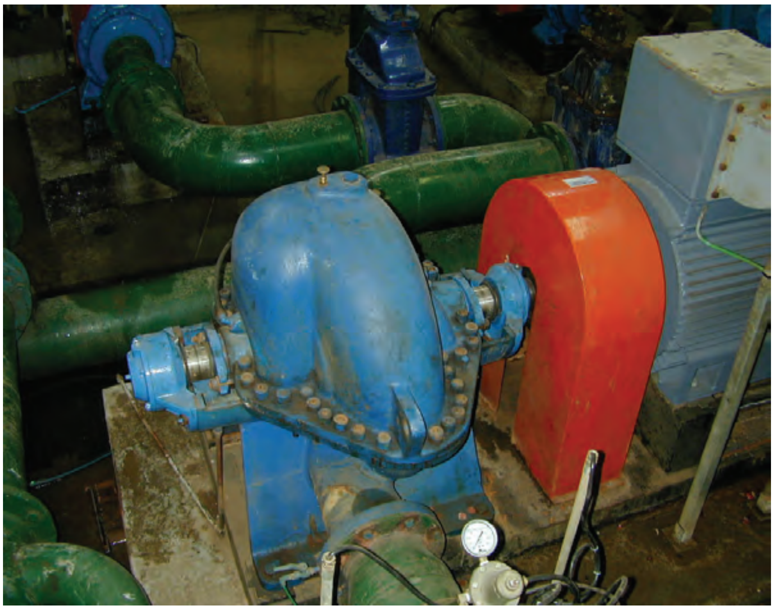


Figure 10. Split casing pump

c) A **submersible** pump is a close-coupled pump unit with a waterproof motor. It is used, mainly, for pumping water from boreholes but also where the flood level of a river is much higher than the normal water level.

The submerged borehole pump with a submersible motor is made to be installed in deep and narrow boreholes and have thus a reduced diameter, which makes them longer than other pump types. The borehole pumps are specially designed to be submerged in a liquid and are thus fitted with a submersible motor, which is rust protected. The pump comes in both a single-stage and a multistage version (the multistage version being the most common one), and is fitted with a non-return valve in the pump head. Because the submersible pump cannot handle high temperatures, it is not used industrially where warm water is often pumped. This is because the motor is submerged in the liquid, which has to cool it.

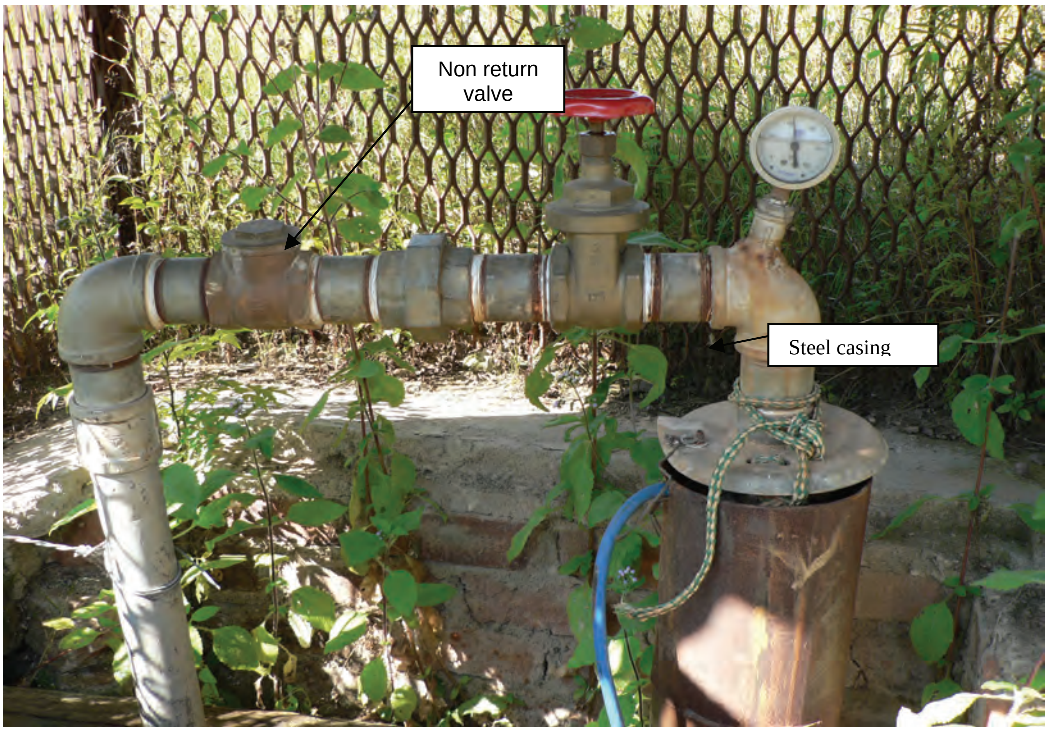


Figure 11. Borehole pump installation in protective cage.

d) A **vertical spindle** pump, mounted with a long shaft, is also used for boreholes. However, today the vertical spindle pump has been more or less replaced by the submerged pump type. The long shaft of the deep well/spindle pump is a drawback, which makes it difficult to install and carry out service. Because the deep well pump motor is air-cooled, the pump is often used in industrial applications to pump hot water from open tanks.

e) Self priming pumps are usually used for swimming pools and for smaller irrigation systems [nurseries] where the pump is frequently started automatically by a timer and a priming problem could arise.

f) A **close-coupled** pump unit is also a single stage centrifugal pump that is coupled as a unit with the electric motor and is usually used in smaller systems. These pumps are however available in units of up to 50 kW and more. This pump has the advantage that no alignment problems can occur using a single shaft to drive both pump and motor.

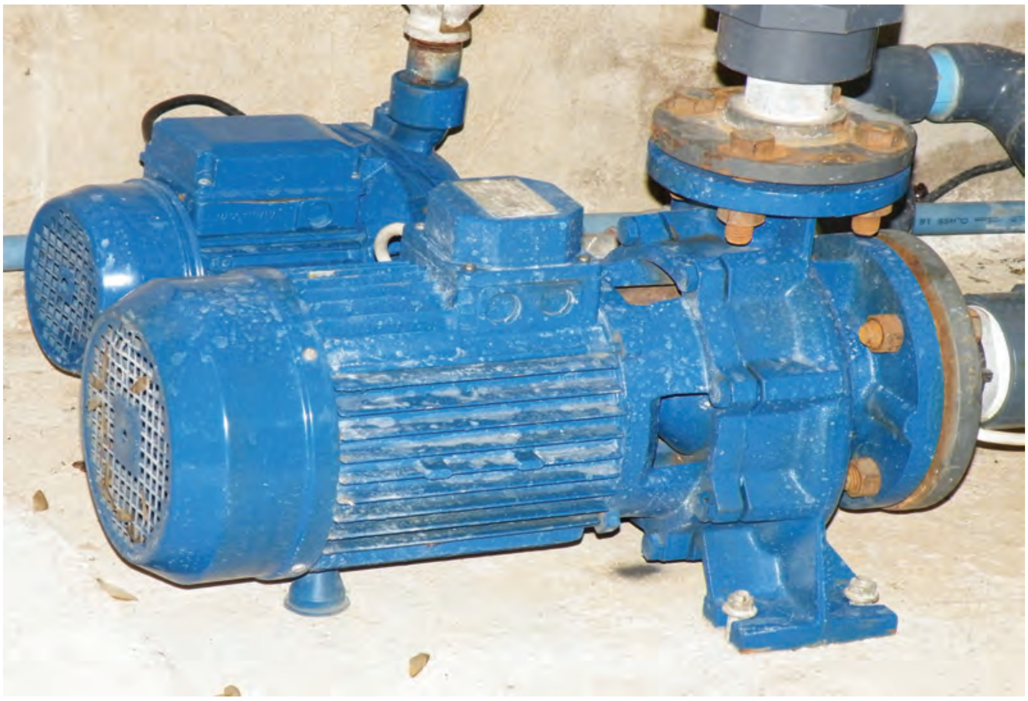


Figure 12. Close coupled pump and motor

2.4 Pump characteristics[2,4,6)]

When a pump system type is to be chosen, the following characteristics of centrifugal **pumps** must be taken into consideration:

- It is limited in the installation height above water level according to the pump specifications regarding NPSHr, height above sea level, vapour pressure and size of suction pipe.
- Less wear and tear takes place at low rotation speed.
- Contrary to the positive displacement pump, this pump cannot be damaged if it pumps against a closed valve. The liquid just rotates inside the casing. The friction does however cause heat and, if it continues for too long, it could be detrimental.
- The pump can work at different duty points but is most efficient at a specific point.
- Centrifugal pumps can pump water containing solids if special impellers are used. These pumps are less subject to wear and tear, because of sand or silt, than positive displacement pumps.

Figure 13. Electric motor with covered coupling, single stage pump and outlet through filter

Figure 14. Motor and pump, inlet [right], outlet with main valve, non return valve with bypass and water meter

Different types of impellers

Different impeller types are used for different purposes. The radial flow impeller is the most commonly used type. The single vane, or two or three opening, impellers are often used where very dirty water, containing solid material, is pumped for irrigation with a rain gun. Bronze impellers are better and more resistant to sand damage, but more expensive than the cast iron type.

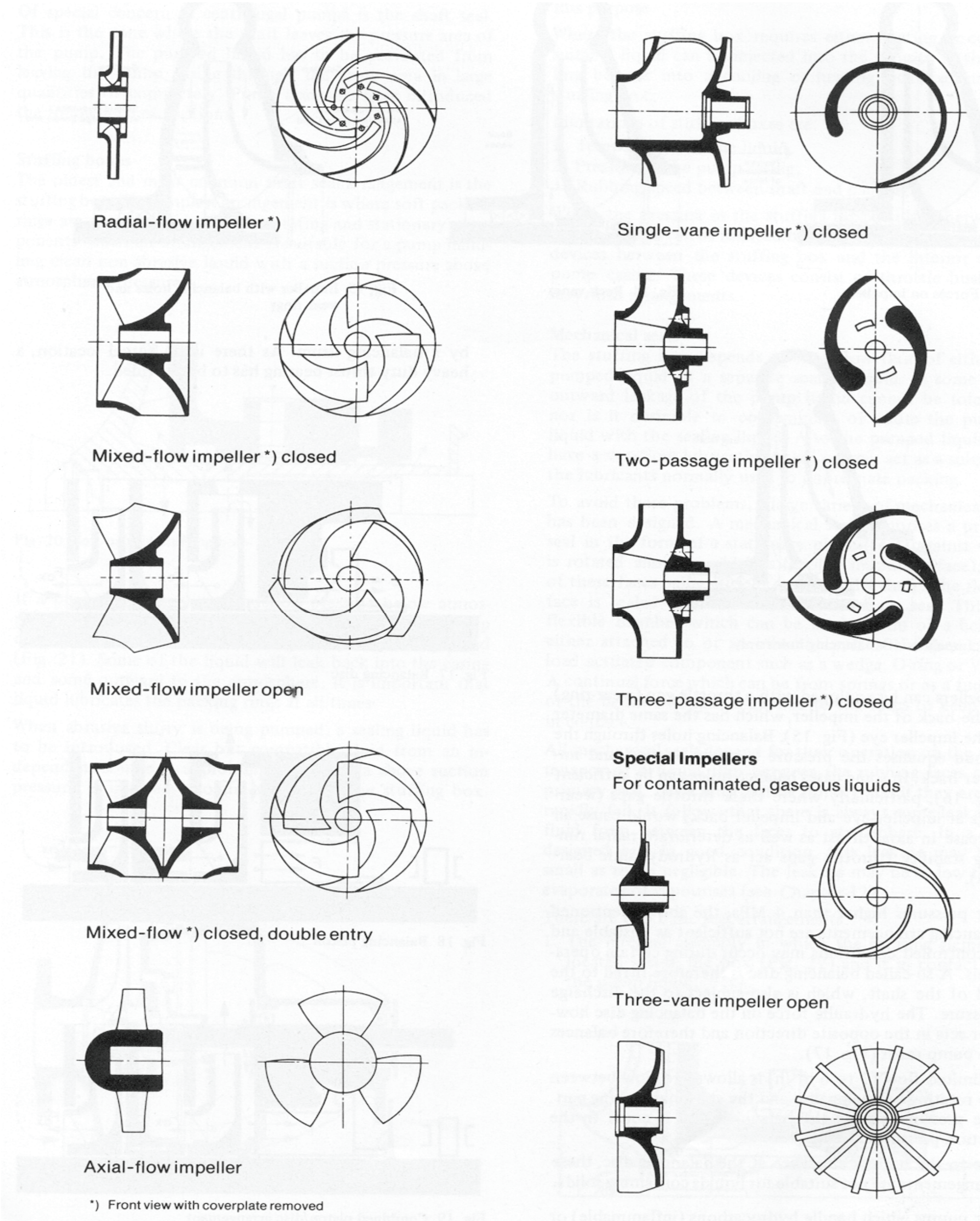


Figure 15. Different types of impellers[2)]

2.5 Pump house checklist

The following components are found inside a pump house:

1. Pump – connected to the suction and delivery pipe
2. Motor – driving the pump at a certain rotation speed
3. Pump coupling – connecting pump and motor shafts – should be covered for safety.
4. Mechanical seal on pump shaft – sealing and lubricating shaft
5. Electrical switches – start and stop pump
6. Volt meter – Indicates the voltage of electricity supply (optional)
7. Amp meter – Indicates the electric current drawn by the electric motor (the reading increases when the load [pump volume] is increased)
8. Pressure gauge – Indicates the pressure delivered by the pump
9. Main valve – gear box type butterfly valve for slow but easy opening
10. Air valve – highest point of pipe system to release air
11. Base plate – steel frame where pump & motor is mounted on

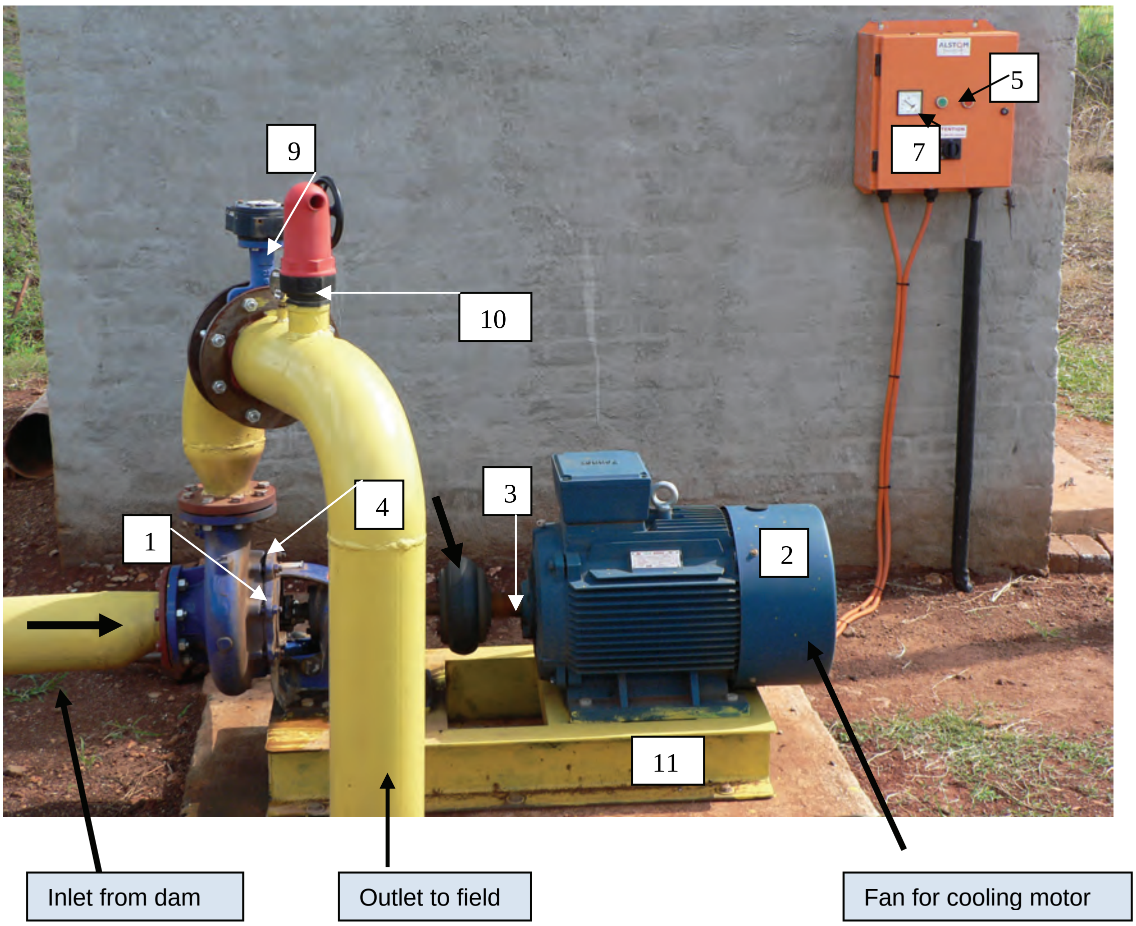


Figure 16. Components of pump house setup

The following figures provide a closer look at the volt, amp meter and the pressure gauge showed in Figure 16.

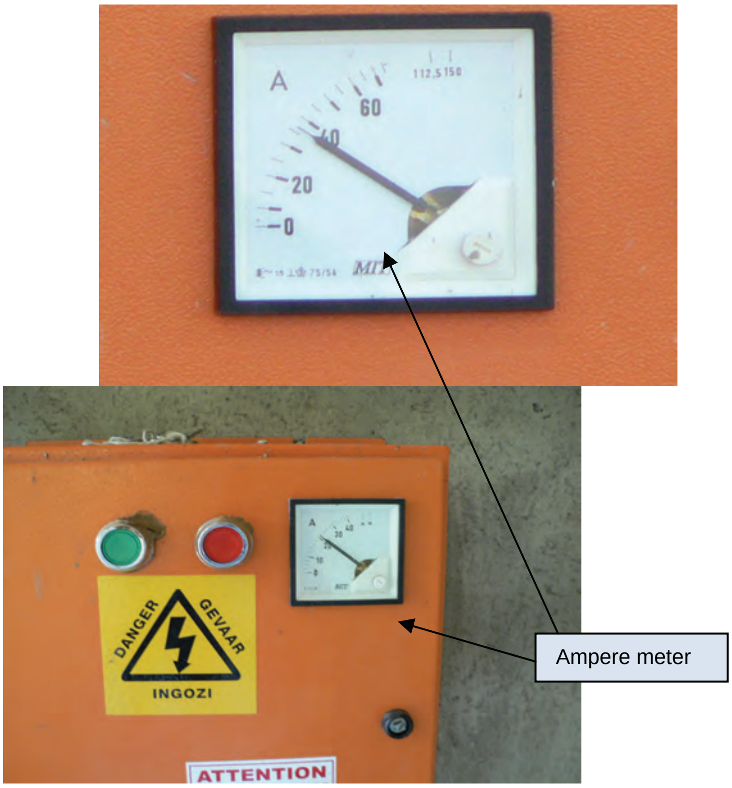


Figure 17. Switch box with amp meter

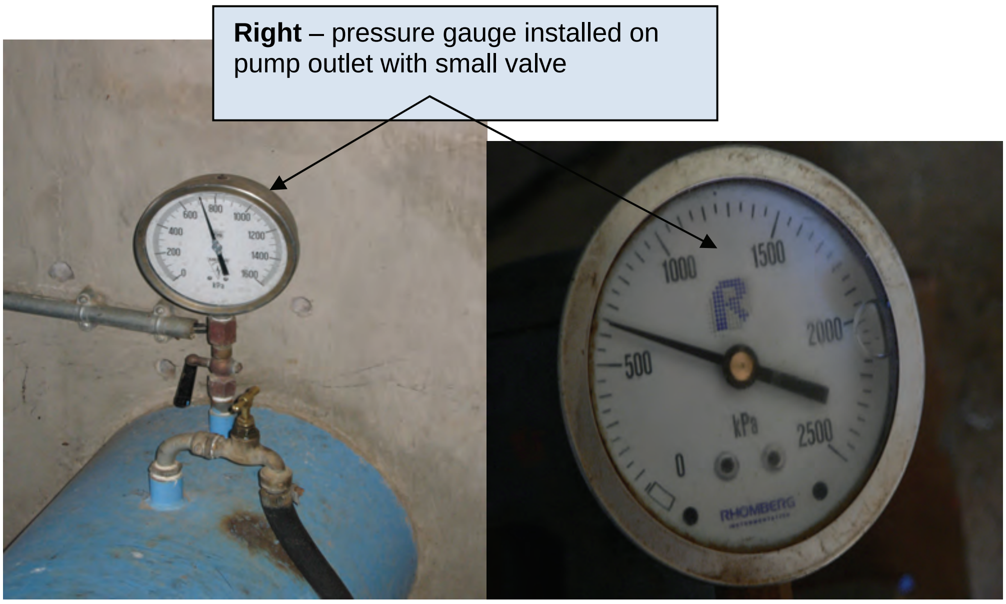


Figure 18. Pressure gauge

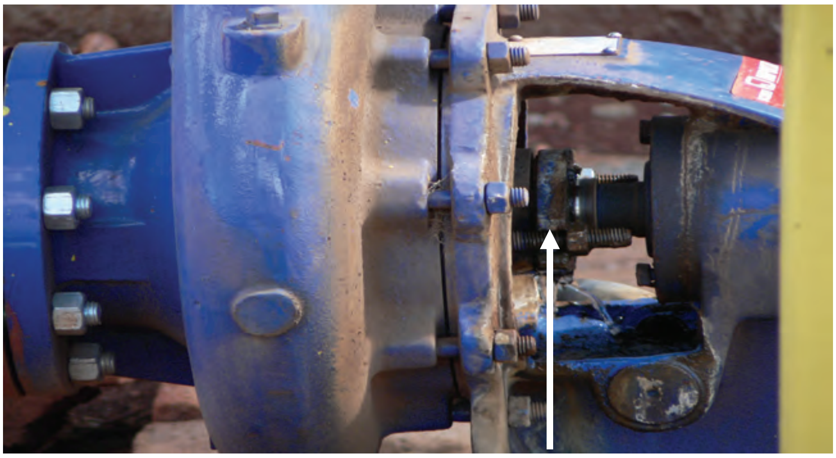


Figure 19. Pump with mechanical seal leaking water

Figure 20. Pump outlet with main valve (top) and shut off

2.6 Net positive suction head [NPSH][2,4)]

As such a centrifugal pump is unable of suction, but it makes use of atmospheric pressure to push the liquid up into the suction pipe. Due to the displacement of water in the eye of the impeller a partial vacuum develops, and the **pressure** needed to "push" the water into the impeller is called the **Net positive suction head** (NPSH). If this pressure is insufficient cavitation is caused basically because the water is pumped faster than it can be sucked into the pump. Cavitation is a cracking noise caused by the implosion of the little vacuum pockets in the pump impeller.

An acceptable suction head is calculated as follows:

- The required net positive suction head [NPSHr] is usually given in the graph supplied by the manufacturer. It is the pressure head needed to give water the required kinetic energy when maximum flow velocity is reached inside the pump impeller. It is a characteristic of the pump and depends on the design.
- When air is sucked out of a suction pipe at sea level, air pressure will force water into the pipe to a height of 10,3 m, provided the water is cold enough to prevent vaporisation [boiling]. If the height above sea level is known, the atmospheric pressure, H(atm), can be obtained from the relevant graph [see Figure 21]

THE AVAILABLE NET POSITIVE SUCTION HEAD [NPSHA] IS CALCULATED AS FOLLOWS:

NPSHa = Hatm – Hf – Hvp – Hss [Eqn.1]

Where Hatm = atmospheric pressure [m water] (see Fig.21)

Hvp = vapour pressure [m water] (see Fig.22)

Hss = static suction head [m] (the height of the pump above the lowest possible water level of the source)

Hf = Friction loss in suction pipe [m]

Furthermore: Hss = Hatm – Hf – Hvp – NPSHr [Eqn. 2]

Where: NPSHr = REQUIRED NET POSITIVE SUCTION HEAD

Note: NPSHr is a pump characteristic and is read from the pump curve.

- **FOR EFFECTIVE OPERATION OF THE PUMP:**

NPSHa > NPSHr

When pumping from a river, pump systems are usually placed as high as possible in an attempt to prevent flooding of the installation. Should the pressure reduction [suction] inside the pump be excessive, the following problems could arise:

- The possibility of air being sucked in at the stuffing box gland increases as the suction head increases.
- The pump stops working because of water vapourising in the eye of the impeller.
- The impeller is damaged by cavitation. It is thus advisable to have the suction head as low as possible.

Example

Example 1:

A centrifugal pump is installed alongside a river, 1200 m above sea level, [Hatm]. The average water temperature is 20°C [= Hvp]. The 150 mm suction pipe is 185 m long and has a friction loss [Hf] of 1,8 m/100 m. The intention is to install the pump 4,5 m [= Hss] above the river water level, in the existing pump house.

Determine whether the NPSHr of the pump, which is 3,3 m [read from the pump curve], is available, (in other words if the pump can function according to above information).

Calculate the NPSHa [using Eqn.1]

HATM = 9 m (point A in Figure 20)

HVP = 0.2 m (point B in Figure 21)

HF =1.8 m/100 m x 185 m

=3.3 m

Therefore:

NPSHa = Hatm – Hf – Hvp – Hss

= 9 m – 3.3 m – 0.2 m – 4.5 m

= 1.0 m

The available NPSHa [1,0 m] is thus smaller than the required NPSHr of 3.3 m.
(Installation height of 4.5 m is therefore too high and the pump will not function correctly.)

The following actions can be taken to ensure that the $NPSH_a$ is > $NPSH_r$

- Shorten the suction pipe [reduce Hf] – Mostly not practical
- Install a suction pipe with a larger diameter [reduce Hf] – Small improvement
- Lower the pump installation level [lower Hss] – Recommended
- Purchase another pump requiring a lower NPSHr – as a last option.

Note: *Hatm and HVP are fixed values for these conditions and cannot be changed*

Example 2.

Using all the information of Example 1, calculate the maximum height, above the river water level, at which the pump can be installed in order to ensure the efficient functioning of the pump.

Therefore calculate Hss [using Eqn.2].

$$Hss = Hatm - Hf - Hvp - NPSHr$$
$$= 9\ m - 3.3\ m - 0.2\ m - 3.3\ m$$
$$= 2.2\ m$$

The pump must therefore be installed at a maximum of 2.2 m higher than the minimum water level, measured from the minimum water level to the centre line of the pump shaft.

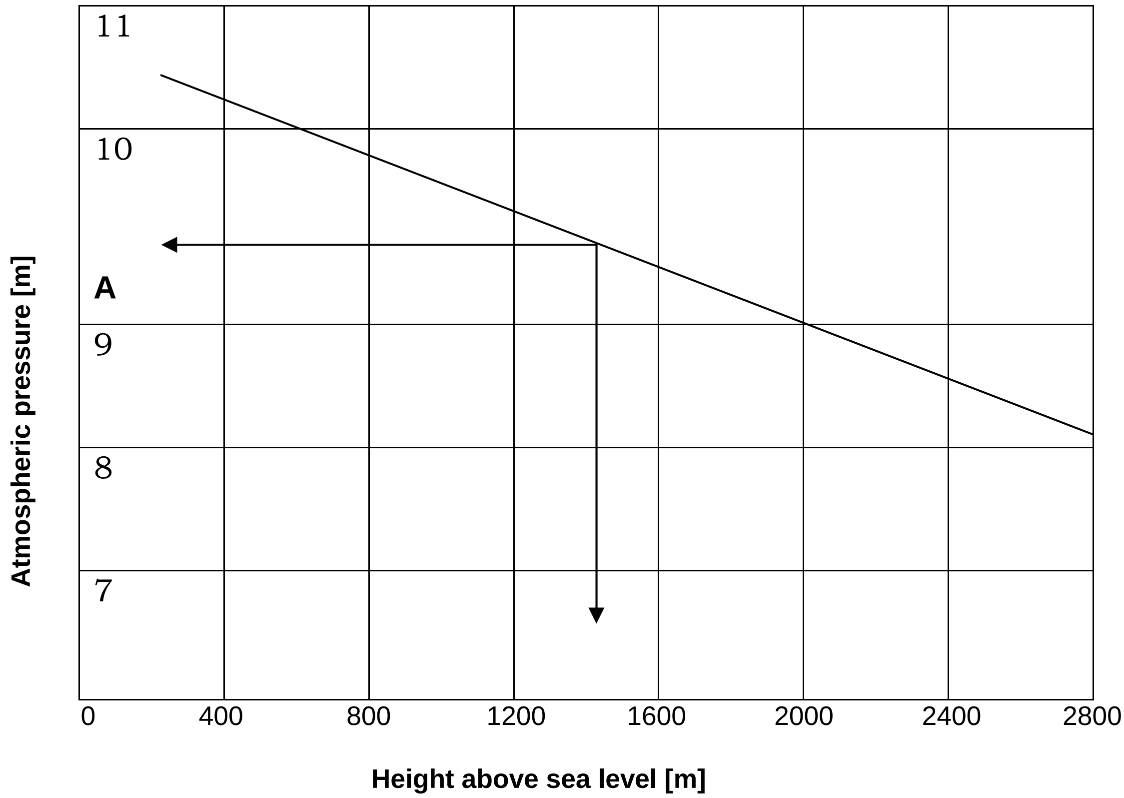


Figure 21. Relationship between atmospheric pressure and height above sea level

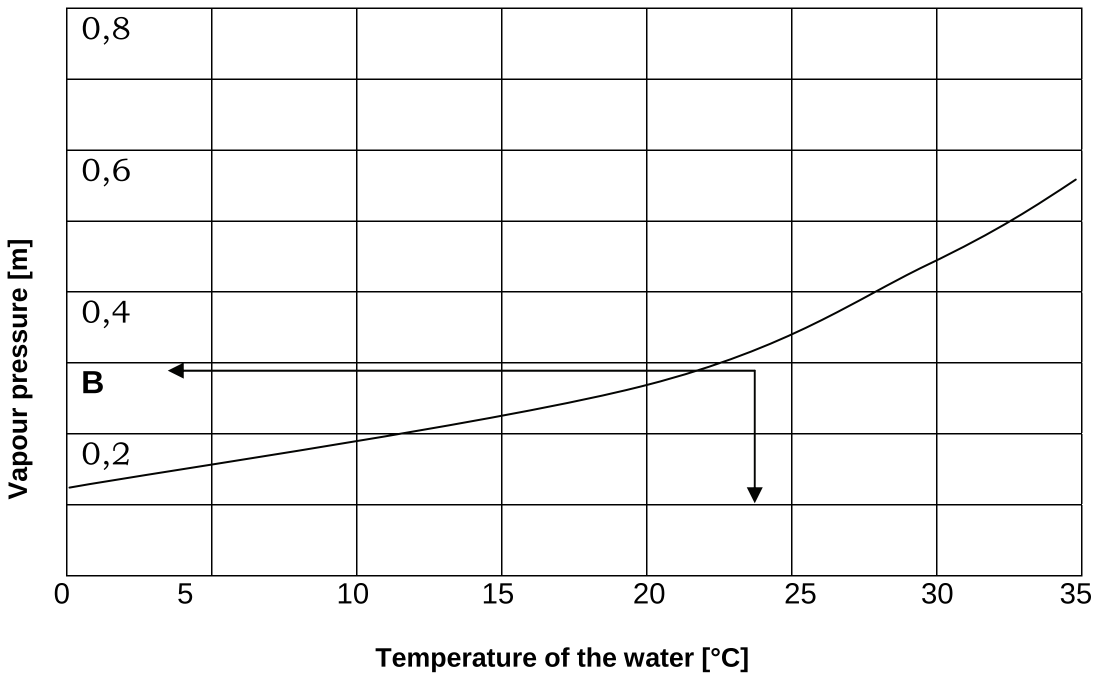


Figure 22. Relationship between vapour pressure and water temperature.

3. Filtration[2,4,6)]

With the exception of flood irrigation, all irrigation systems need filtration to a certain degree to prevent blockages of emitters. A filter is any device or method used to separate impurities from the irrigation water. These include screens, traps and strainers used to prevent fish, water animals, leaves and branches from entering the irrigation system through the suction pipe. It also involves settling dams and sand separators to prevent sand being pumped into the system as well as physical filters which provide the final filtration before water enters the system.

3.1 Pre-filtration

Very dirty water can cause filters to:

a) get clogged very quickly by suspended material such as leaves and sand;

b) function inefficiently because of the need for too frequent flushing causing waste of water and system running under pressure.

The following pre-filtration methods can be utilized:

- **Grid, screen or in-line strainer**

Only the bigger particles that can cause clogging of the pump are removed, either by putting a grid at the opening of the suction pipe inlet or an incline strainer into the suction pipe. This is to prevent fish and frogs to enter the pump inlet. The final filtration of water with regard to solids that can cause clogging is not usually completed between the source and the pump, because of the problems created with the pump suction. In running water, such as a canal, a screen with grooves parallel to the flow direction of the water, is placed at the suction pipe inlet in such a way that it is continuously flushed clean by the current. If the screen is fine enough, the water is usually clean enough for ordinary sprinkler irrigation. For micro irrigation additional filtration is required and placed after the pump.

- **Sand separator**

Sand, which has a higher density than water, can be removed by using a sand separator. The water enters in an off centre connection so that it rotates causing a centrifuge (cyclone). The heavier particles are separated by this centrifuge and accumulate at the bottom from where it is periodically flushed out. Two types of sand separator from Burt & Styles (1994) are indicated below:

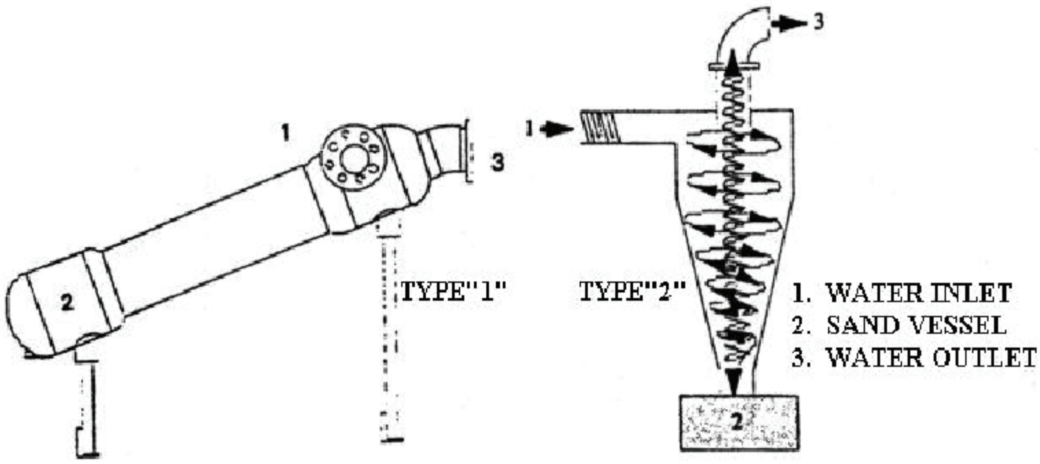


Figure 23. Sand separators

- **Silt dam**

Running water is let into a dam and left for some time. Water is then withdrawn from just below the surface. Using a flexible suction pipe does this. A float suspends the inlet of this pipe. Iron bacteria, with an iron concentration of 0,3 parts per million, produce enough slime to clog the emitters. Oxidation and precipitation (aerating and allowing enough time for the oxidized iron to settle at the bottom) can remove iron.

3.2 Types of filters[2,4)]

- **Disc or Ring filters**

A ring-filter element consists of a cylinder with lid, inlet, outlet and backwash outlet. Another cylinder on the inside is formed by flat plastic discs (rings), which are pressed onto each other by a cap, or tightened by a butterfly nut. The water filters through the grooves in the discs. The fineness of the filter, measured in micron (µm), is determined by the size of the grooves in the discs and is indicated by the colour of the discs. The inlet is tangential (off-centre) so that the filter becomes a sand separator as well. Heavier material accumulates at the bottom near the outlet and is flushed out with the lighter material (that is retained by the discs) during the back-flush action.

Figure 24. Disc filter element with black rings

Figure 25. Automatic flushing disc filters

Figure 26. Disc elements of filter unit (100 micron filtration size)

Figure 27. Arkal Spin-Klin® filter bank

- **Screen filters (Mesh filter)**

The element of the cylindrical shaped type of mesh filter consists of a steel cylinder, but the inner cylinder through which the water filters is made of nylon cloth or stainless steel mesh. The flow direction is inside out and the dirt accumulates on the inside of the mesh cylinder. Back flush is not possible, and it should be cleaned manually by brush on inside of element, or automatically by suction points that rotate up and down on a spindle inside filter element. To clean it, the mesh cylinder must be flushed out, either by taking it out or by opening a flush valve at the end of the cylinder. The mesh is not as strong and durable as the discs of a ring filter and cannot withstand a great difference in pressure.

Figure 28a. Screen filter cleaned manually with brushes [4)]

Figure 28b. Automatic flushing screen filter[4)]

- **Sand filters**

A sand filter element consists of a cylinder that is partly filled with sand, graded according to specifications. The fineness of the filter is determined by the size of the sand particles. Filtration fineness of 75 µm is obtained with sand with an effective particle size of 0.6 mm.

Note:
The effective size of the sand particles is determined by the average diameter of the smallest particles that form 10% of the total. Water enters the sand-bed from above at an even rate and flows through the sand. The arresting of dirt occurs on the surface of the sand as well as inside. At the bottom the clean water flows through a drainage system, consisting of perforated pipes to the outlet. The bottom drain of most sand filters consists of a false bottom with short pipes through it. The pipes, through which water flows to the bottom level, are covered with perforated plastic caps to prevent sand flowing through. Seeing that dirt can pass through a sand filter, it is necessary to place a ring or mesh filter after the sand filter. The purpose of this filter is not to remove large amounts of dirt but to serve as a warning that the sand filter does not function effectively.

Mostly the disc filter behind the sand filter only serves as backup in case the plastic caps collapse and sand moves into the filter outlet.

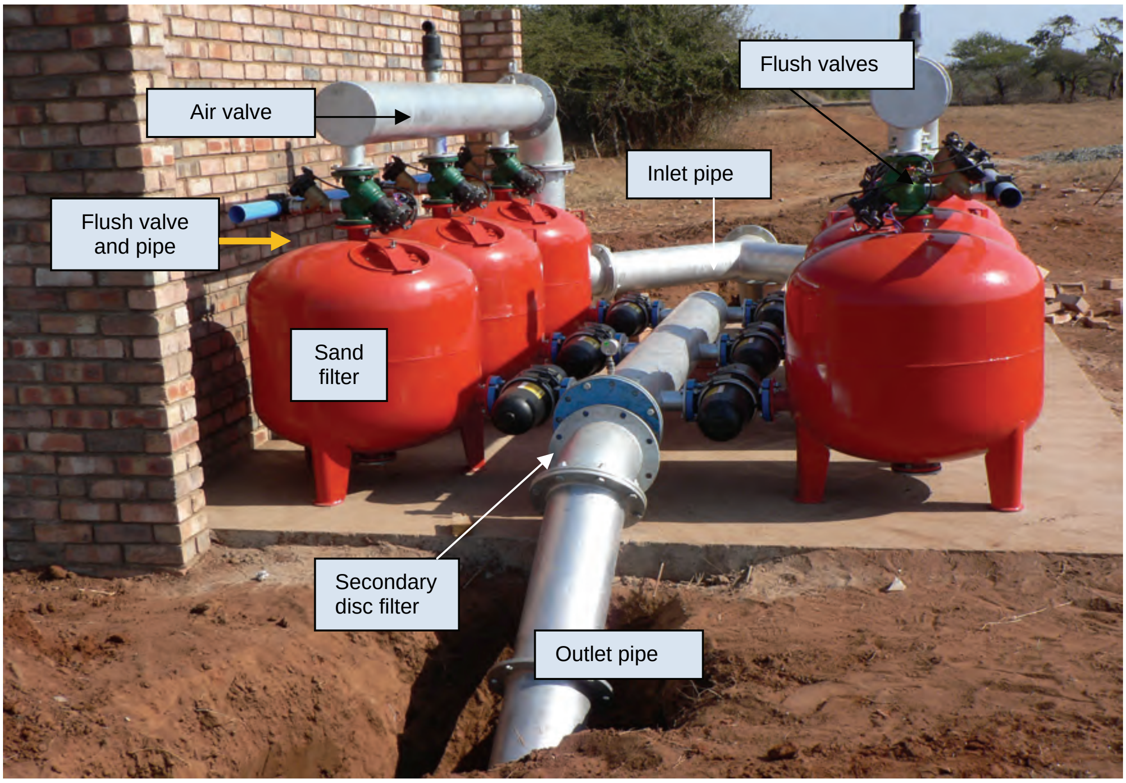


Figure 29. Sand filters with secondary disc filters

3.3 The design of a filter system[4)]

The designer of a filter system must know:

- how dirty the water is (dirt load in the water);
- the nature of the dirt – organic, sand, silt, etc;
- which type of irrigation system is being used;
- the flow-rate of the system;
- what the working pressure is; and the allowable maximum pressure difference between the inlet and outlet of a filter element.

Note: The irrigation system is usually designed as an entirety and the maximum, pressure loss (before back flush) of 50 kPa for ring filters and 30 kPa for sand filters is considered the norm. The pressure loss over a clean element must be 10 kPa for clean water, but for a ring filter and reasonably clean water, 30 kPa is permissible.

- **Dirtiness of the irrigation water**

The degree of dirtiness of the water can be measured with a dirt index meter and this determines how often a back flush is needed. If the dirt index is so high that the period between back-flush actions is too short, the following measures can be taken:

- Pre-filtering with larger size filtration;
- Enlarge the filter bank capacity to handle a larger volume;
- Use a settling dam for sand and chemicals like iron and manganese.
- Adjust the suction point so that the suction pipe is lifted from the bottom of a dam or river.
- Choose a type of irrigation system that can function with a not too fine a filter (e.g. 200 instead of 100µm).
- Use an automatic filter bank where short intervals between back-flush actions can be programmed.
- Knowledge of the chemical composition of dirt in the water is necessary to consider techniques such as chlorination, flocculation and aeration.

In practice a dirt index meter is seldom available, and the designer usually obtains information from the farmer or Irrigation Board regarding the water quality. Because of the fact that water quality varies between seasons, the filter system is designed for the "worst case" scenario regarding dirt. The so called "over design" of a filter system regarding volume is recommended, as it lengthens the time intervals between flushes whereby irrigation continues for a longer time without interruption. A save in water and energy is also obtained.

- **Choosing a type of filter**

To comply with the requirements with regard to the water quality and the type of irrigation system, the characteristics of each type of filter must be reviewed.

The choice of filter is determined by a number of factors such as the irrigation system, chemical and physical water quality, type of dirt in water and even personal preference.

A summary of filter characteristics according to filter type is given in the table below.

Table 1. Filter characteristics[4)]

ITEM	SAND	RING	MESH
Cost	high	average	low
Dirt capacity	high	average	low
Filter efficiency	97%	85%	53%
Flow rate/m² (10 kPa)	25 m³	28 m³	38 m³
Reliability	fair	good	weak

- **The different types of filters can be utilized as follows:**

1) Mesh filters are usually used where dirtiness of water is low, such as after a sand filter for borehole water or installed in micro-jets, hydraulic valves and solenoid valves. A rough mesh can also be used as a pre-filter to remove large particles.
2) Ring filters are used in all types of irrigation systems using the applicable filtration rings. Rings with a filter fineness of 200 micron (µm) are mainly used in micro-irrigation systems while for drip irrigation rings of 100µm is usually used. If dirt is inclined to wedge tightly in-between the rings (discs), an aggressive back flush is required.
3) The filtration of sand filters is very fine and is therefore mainly used in drip irrigation systems where fine filtration is critical and filtration capacity is relatively high. It can also be used with micro irrigation where the water contains a fair amount of sticky dirt.

- **The capacity of a filter system**

A filter-bank must be large enough to:

1) be able to maintain the desired flow-rate without the friction loss becoming too high.
2) accommodate the amount of dirt that accumulates in-between back flush actions without pressure loss becoming too high.

To determine the size of the filter-bank, the designer has to decide on the size as well as the number of elements to be used. The fewer the elements, the lower the cost will be. If only two elements are used, the size of the elements must be such that the flow through each one falls below the flow-rate specification. The total flow-rate must meet the requirements of the system. The flow and pressure loss specification can be obtained from the relevant supplier. It is usually the flow-rates between pressure loss of

10 and 30 kPa over a clean element. It is always advisable to over design filters in terms of water flow so that the influence of a decrease in flow-rate during frequent back-flush actions does not become too big.

3.4 Management of a filter system

The most important function is to clean the filters on time and effectively.

3.4.1 The pressure loss and period between back-wash actions

When the pressure loss becomes too high as a result of clogging then:

1) mesh filters can give way;
2) dirt is pressed so tightly in-between the rings (discs) that it is not released during back-flush; and
3) dirt that is forced into sand-filters form lumps which will eventually limit the flow area.

The pressure loss must be measured regularly. When it is abnormal, the following actions must be taken:

- When the pressure loss of a filter becomes too high (>50 kPa) it can mean that the dirtiness has increased and that the period between back-flush actions must then become shorter. The back-flush cycle can be lengthened as soon as the water becomes cleaner, so that less water is wasted. [Pressure loss should be measured according to specifications of the specific type of filter].
- Whenever the drop in pressure across a ring filter becomes too high immediately after a back-flush action, it can mean that:
  a. dirt is pressed so tightly in-between the rinse (discs) that it cannot be flushed out and therefore the rings must be cleaned by hand; or
  b. the rings are so clogged that the smaller flow area becomes so small and friction loss so high that the clogging has to be removed by using acid.
- Whenever pressure loss across a sand filter becomes too high after a back-flush action, it can mean that the friction loss has increased as a result of clods formed in the sand-bed that is not flushed out.

- Whenever the pressure loss across a mesh filter after a sand filter increases, it must be washed and if it occurs often, it means that too much dirt has passed through the sand filter and the sand must then bereplaced. The filtering ability of the sand decreases as the particles become rounder and smoother.

4. Pipes for main lines and sub main lines

The most widely used type of main and sub main pipes are PVC pipes. In general this is also the most economical choice for most application sizes. In some cases, for example where the main line cannot go underground like over or under a road or bridge, steel pipes may be used for sections of the pipe line. Steel pipes are however mainly used for the immediate pipe work in and outside the pump house.

Concrete pipes are used in cases where very large diameter pipes (>600 mm) are required because of relatively lower cost.

In smaller systems low or high density poly pipes (LDPE or HDPE) are used for main and sub main lines (<80 mm). These pipes come in rolls of 100 m, and are easy to install. For the smaller sizes it is also cheaper than the other types.

Figure 30. PVC pipe connected to asbestos cement (AC) pipe

Figure 31. Script on PVC pipe – 315 mm (outside diameter) class 6 (pressure capacity of 6 Bar)

Figure 32. Laying of main lines from pump house

5. Valves[2,3,4)]

Many types of valves are used in irrigation systems to operate and also protect the system. Valves perform different functions including:

- Opening and closing of water flow
- Pressure reducing
- Pressure sustaining (upstream from valve)
- Pressure release
  - Air outlet
  - Air inlet
  - Flushing of filters and pipes

Shut off valves may be subdivided according to the type of mechanism used to cut off or control the water. Five types of sealing mechanisms are used in agriculture – sluice, diaphragm, saddle, ball and butterfly valves.

5.1 Air valves

- **Air release**
  Air valves are the breathers of an irrigation system and responsible to release air from pipe systems. Air in pipes can cause air locks which inhibits smooth water flow in the pipe. Because of the fact that air can be compressed, it can also cause water hammer which can lead to damaged pipes and systems.

- **Air inlet**
  In cases where one part of a pipe drains while another section stays filled, air also needs to be allowed into the pipe to prevent negative pressure causing pipes to collapse as well as dirt being sucked into the system causing damage to rubber seals. Air inlet valves serve as vacuum breakers and restore the atmospheric pressure in the pipe.

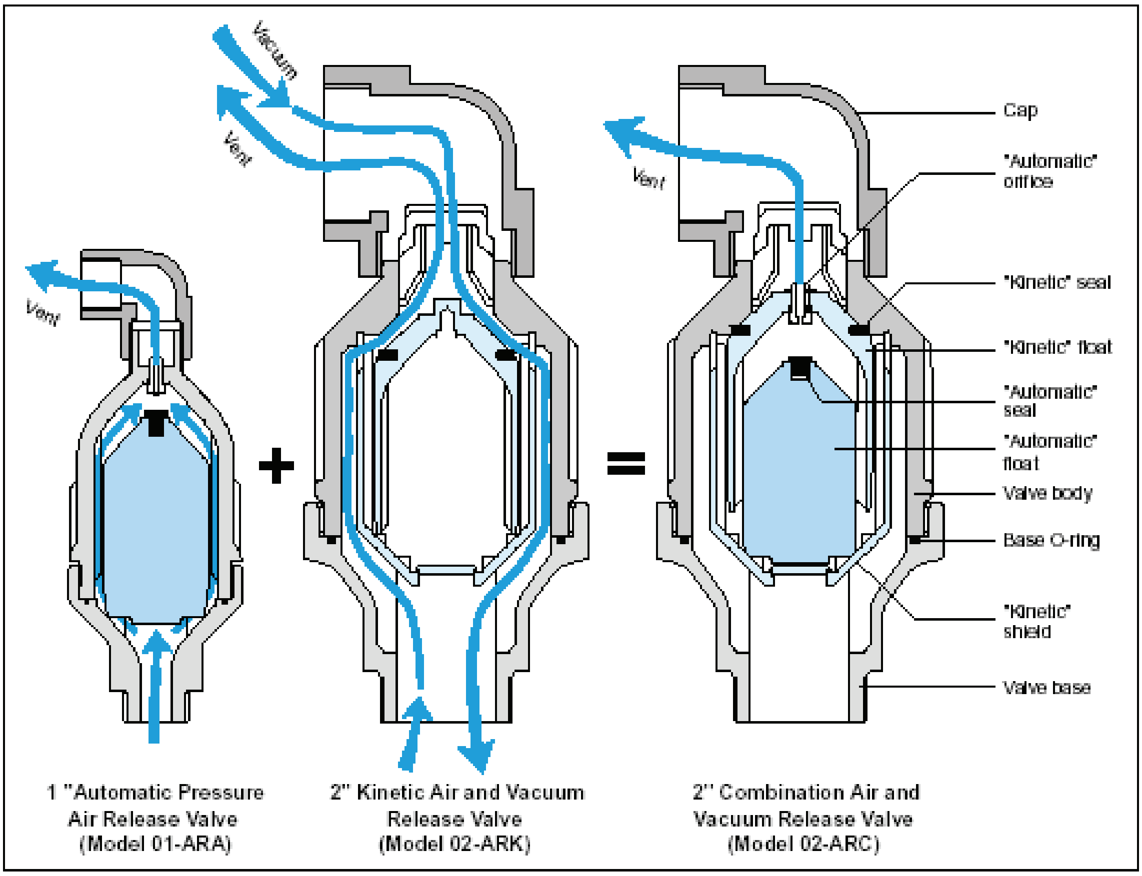


Figure 33. Operation of air valves[4)]

- **Air inlet and outlet (Double purpose)**

When filling an empty pipe line air needs to escape from the pipe via air valves to enable smooth filling and water flow. When shutting down the pump or closing a main valve, some downhill sections of a pipe may run empty in which case air needs to be let into the pipe to prevent formation of a vacuum. The double purpose air valve does both these functions, and is forms a critical component in any pipe line.

Correct placement of air valves on a pipe line enables air to be released from a pipe for smooth operation of the hydraulic system. This is indicated in the figure below.

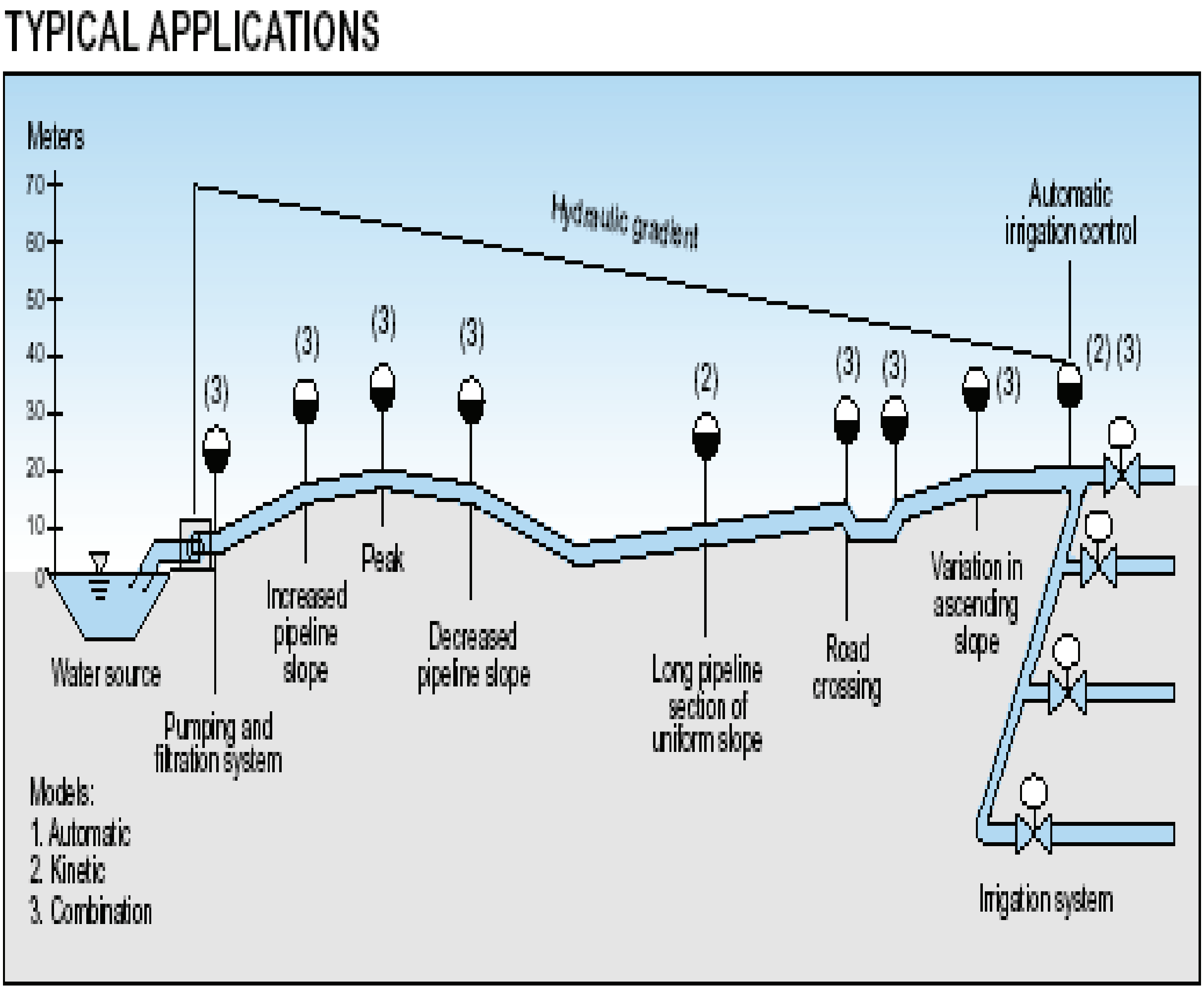


Figure 34. Placing of air valves on a pipe line[4)]

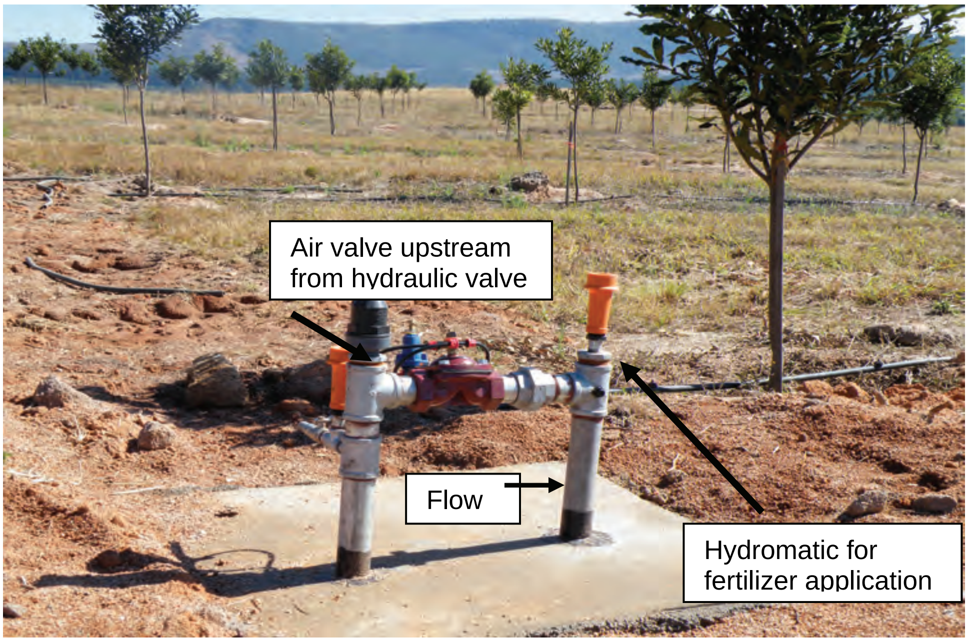


Figure 35. Placement of air valve on valve cluster

The air valves need to be checked for proper operation – audibly and visibly letting air out at start-up of pumps, and letting air in when system shuts down. Air valves need to be removed and cleaned by a trained technician.

Air valves also have the function of protecting the hydraulic valve by letting air out before water reaches the valve to protect it from pressure surges.

5.2 Hydraulic valves

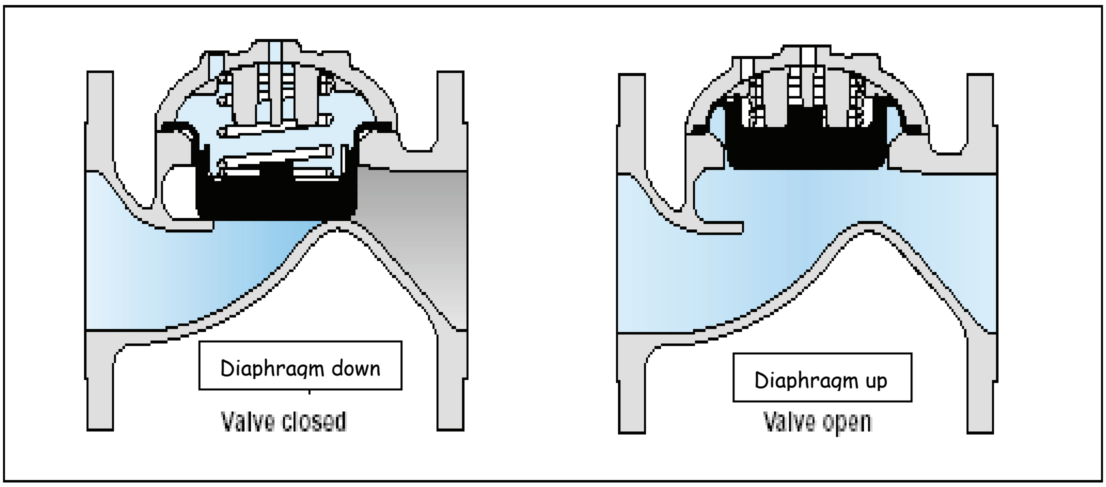


Figure 36. Basic operation of hydraulic valve[4)]

- **Pressure reducing**

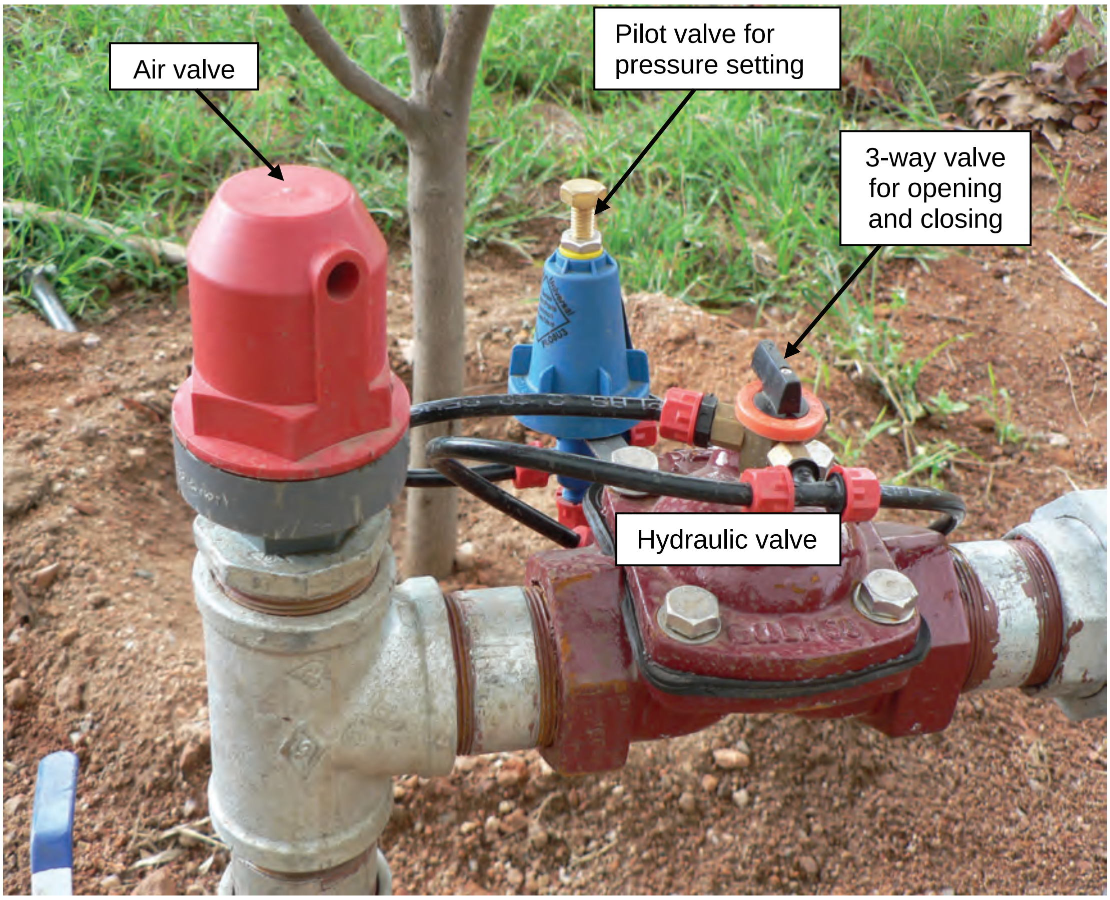


Figure 37. Pressure reducing valve setup

Pilot valves are used together with hydraulic valves to create certain conditions for the hydraulic valve to open, close or control pressure. With the correct connection the hydraulic valve and pilot combination can be used for the following functions:

- o Pressure reducing (control)
- o Pressure sustaining and reducing
- o Pressure relief

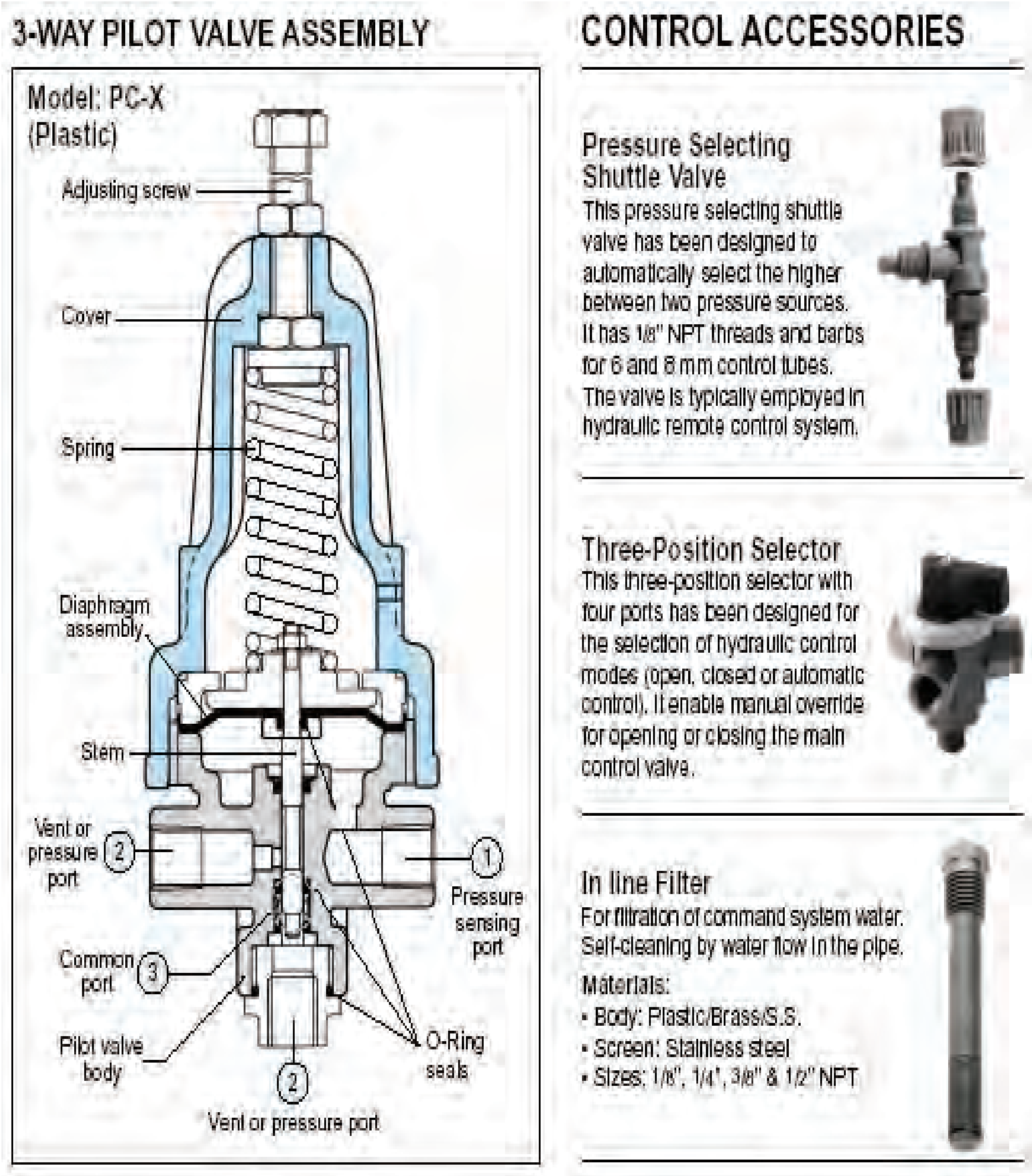


Figure 38. Presentation of pilot valve with accessories[4)]

- **Pressure sustaining**

Where pumps are used as booster pumps on downhill pipe lines, it may be necessary to control the pressure upstream from a hydraulic valve. In other words the pressure is sustained to prevent “over pumping” and cavitation in the pump. For this purpose a hydraulic valve is set up in combination with pilot valves to form a pressure sustaining and control valve as seen in the above picture. The pipe stays filled with water, and the valve gradually opens to sustain the upstream pressure.

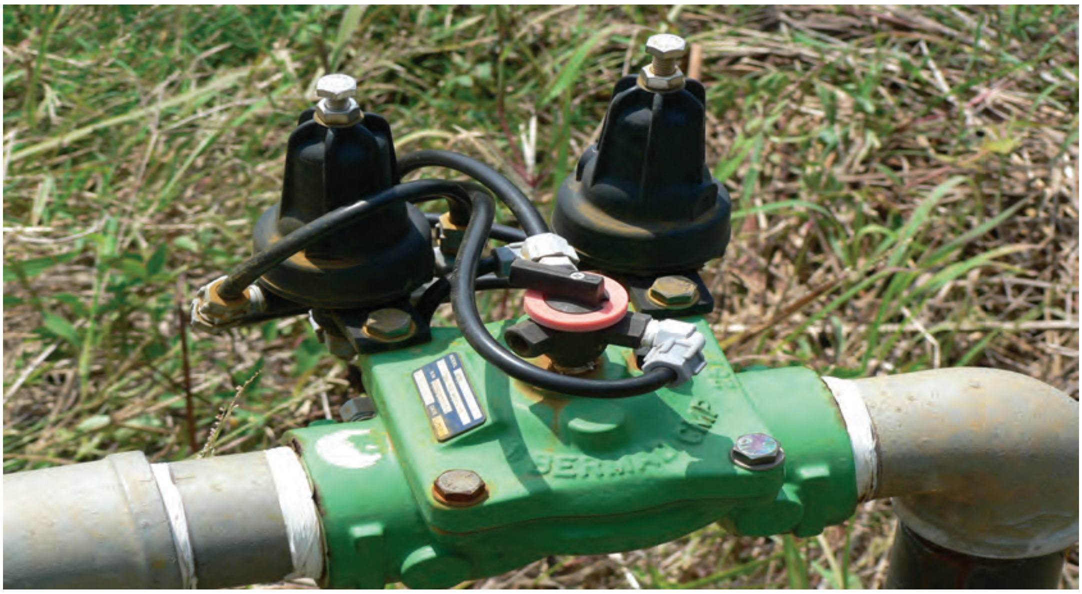


Figure 39. Pressure sustaining and control valve setting

- **Pressure release**

When a pump is started and the pipe lines fill up, water is under low pressure up to the time that the pipes are filled. At that moment there is a pressure surge before sprinklers start emitting water or drippers start dripping. This surge is called water hammer because of the destructive effect it could have if not prevented or controlled. Pressure release valves perform the task of releasing the sudden surge of high pressure to protect pipes and prevent damage to systems. The release valve can be spring tensioned or hydraulically operated and is set according to pipe pressure rating. It needs to be fully closed at normal operating pressure, but to open well before a critical pressure level is reached. Water hammer also occurs when there is a power failure and water runs back in the direction of the pump. In this case release valves are also essential to prevent damage. Hydraulic type valves can also be arranged to release pressure at certain points.

- **Cut off valves**

With pressure reducing or sustaining valves water flow is allowed but controlled to have the correct pressure. A cut off valve (stop valve) is any type of valve that stops water flow in a pipe line. It can be a hydraulic valve, a gate valve, butterfly valve or ball valve. These valves are usually not used to control pressure, but are used in the open or closed position. It is usually installed in pipe lines as stop valves to be able to do repairs on a pipe section. It can be installed before or after a pump, at a dam outlet, at an air valve or any component which needs to be removed while the system is in operation.

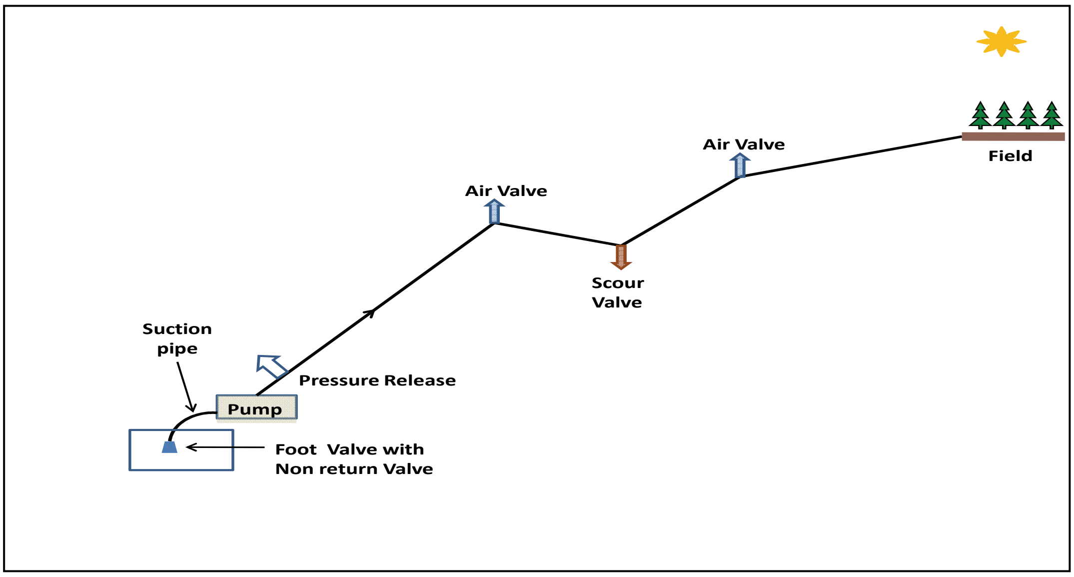


Figure 40. Diagram of valve placement on a pipe system

- **Scour valves**

The term scour valve refers to the function of a valve situated at the lowest point of a pipe line where the topography first rises then falls and then rises again. Where the pipe goes through the lowest point a valve is installed on a T-section to be able to flush out dirt which settles and accumulates at the lowest point because of its weight.

- **Foot valves**

A foot valve is situated at the end of the suction pipe of the pump and water enters through the foot valve into the suction pipe. The foot valve consists of a sieve and usually also a one way (non return) valve. The reason for the non return is that the pump and suction pipe must stay filled with water (primed) to be able to extract and pump water from a lower point. The importance of the sieve is to prevent material from entering the suction pipe and pump which may block or cause damage to the pump.

6. Emitters

Emitters include drippers, sprinklers, micro sprinklers and any other nozzle or device that delivers water from the pipe system. The specific types and application of different emitters are discussed in detail in the introduction to irrigation systems – Module 5.

7. Water meters

Water meters are increasingly being used in the field of irrigation. The high water and pump costs make it essential for the producer to know how much he irrigates. The National Water Act also requires that the producer's water be measured to ensure that the allowed extraction volume is not exceeded. Water meters are therefore usually installed directly after the (main) pump on a farm where water is subtracted from the source. Computerized systems also make use of the impulses from the water meter to allow the correct volume of water to the block. The water meter however does lose its function if it does not measure correctly. The manufacturer's prescriptions must therefore be strictly adhered to, to ensure that the conditions are suitable to the specifications of the specific type of water meter.

Figure 41. Propeller meter

Figure 42. Ultrasonic meter

In general, irrigation water contains a large amount of physical impurities such as silt and water grass, which can influence the operation of the meter. Different types of meters are available and the most appropriate type should be selected for the situation. Ultrasonic meters are most suitable for dirty water because there are no movable parts in the flow area of the pipe. Residential water meters are usually impeller type meters because of lower unit cost.

Except for bulk water metering, water meters are also used to measure the injection of fertilizer and chemicals into a system. Injection controllers are programmed to apply a certain amount (litres) of chemical per volume of irrigation water. This injection is then controlled by flow meters, the water EC is measured and registered on computer. The computer then continually makes adjustments regarding the chemical injection to correct the EC or pH whatever the case may be.

Activity

Activity 1

Individual activity

1. Explain in which ways pressure is created for irrigation systems to operate.

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2. Explain why contour lines on maps are important for planning of irrigation systems.

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3. Describe the functions of pressure gauges, Ampére meters and voltage meters in a pump house.

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4. Under what condition is pre-filtration necessary for irrigation systems?

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5. Which factors influence the size and type of a filter system?

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6. What functions do air valves have in a pipe system?

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7. Different valves have different functions in irrigation systems. Pressure sustaining valves are installed to maintain a specific pressure upstream from an irrigation block. What is the purpose of this?

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8. Why is water meters important in an irrigation system?

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My notes............

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Authenticators:

- Mr D Mynhardt
- Mr G Mostert

Technical Learner Guide

Irrigation Water Management

Level 5

Module 7

Irrigation scheduling

Study objective

After completion of this module, the learner should be able to have a basic understanding of:

- The concepts and principles of irrigation scheduling.
- The calculations for water requirement
- Different irrigation strategies
- Various devices and methods for monitoring soil water, and
- Alternative methods of irrigation scheduling.

Table of contents

After the appropriate irrigation system has been selected and installed, it is important to manage the system correctly to ensure sustainable and cost efficient production of the selected crops. System management includes the correct procedures in operation and maintenance as well as the correct application of water according to the crop requirement at different growth stages (mm/day or L/plant/day). This is done through irrigation scheduling.

1. What is irrigation scheduling?[7,9)]

Definition

Irrigation Scheduling is the compilation of an irrigation program according to crop, soil and climatic factors, and the continuous adjustment according to daily or seasonal changes.

The purpose of irrigation scheduling is to determine the exact amount of water to apply to the field and the exact timing for application. The amount of water applied is determined by using criteria to determine irrigation need and a strategy to prescribe how much water to apply in any situation.

Quick facts............

- Irrigation scheduling is the decision of when and how much water to apply to a field.
- Its purpose is to maximize irrigation efficiencies by applying the exact amount of water needed to replenish the soil moisture to the desired level.
- Irrigation scheduling saves water and energy.
- All irrigation scheduling procedures consist of monitoring indicators that determine the need for irrigation.

The basis of scheduling is to irrigate the correct amount of water when the plant needs it.

2. Irrigation criteria [7)]

Irrigation criteria or indicators are used to determine the need to irrigate. The most common indicators or criteria used are soil water content and soil water tension. Less common are the scheduling to maximise yield and to maximise the net return. The final decisions depend on the irrigation criteria, strategy and goal.

Example

Example 1.

- To illustrate the use of criteria in irrigation scheduling, consider a farmer whose ***goal is to maximize yield.*** Soil moisture content is the irrigation criterion. Different levels of soil water trigger irrigation. For example, when soil water content drops below 70 percent of the total available soil moisture, irrigation should start.

  Soil water content to trigger irrigation depends on the irrigator's goal and strategy. In this case, the goal is to maximize yield. Therefore, the irrigator will try to keep the soil moisture content above a critical level. If soil moisture falls below this level, the yield may be lower than the maximum potential yield. *Thus, irrigation is applied whenever the soil water content level reaches the critical level.*

- ***How much water to apply depends on the irrigator's strategy***. For example, the irrigator can replenish the soil moisture to field capacity or apply less. If no rain is expected and the irrigator wishes to stretch the time between irrigations, it is advantageous to refill the soil profile to field capacity. If rain is expected, it may be wise not to fill the soil profile to field capacity, but leave some room for rain.

- ***If the irrigator's goal is to maximize net return***, an economic irrigation criterion is needed, such as net return. This is the income from the crop less the expenses associated with irrigation.

The importance of irrigation scheduling is that it enables the irrigator to apply the exact amount of water to achieve the goal. This increases irrigation efficiency. A critical element is accurate measurement of the volume of water applied or the depth of application. A farmer cannot manage water to maximum efficiency without knowing how much was applied. Another important monitoring action is to determine if water distribution across the field is uniform, in order to prevent under or over irrigation.

Important to note: *Plants do not actually use water to grow, but rather needs water to cool down [transpirate] and to transport nutrients for all the growth functions and processes within plant cells. It is therefore important to apply the correct amount of water to the soil to be accessible to the plant.*

- **Crop water requirement** is therefore a combination of water used (lost) through transpiration and evaporation from the soil surface.

  (ET: Evapotranspiration)

  Irrigation scheduling comprises two questions:

  - **When** to irrigate (how often)?
  - **How much** to irrigate (how deep)?

- The **interval** or **cycle length** of irrigation is determined by the **size** of the reservoir (soil) and the **rate** at which the plant extracts water from the reservoir. It can be compared with the fuel consumption rate of a car and the fuel tank size. The "consumption rate" of water by plants can be measured accurately with high tech equipment, and is measured in litres per day (L/d) or millimetres per day (mm/d). However water requirement figures are generally taken from literature, and applied in practice as a guide to the crop water requirement and schedule planning. When this guideline is implemented in the irrigation program, adjustments are being made by the farmer according to his specific conditions regarding soil, climate and cultivation practice. He gains experience and knowledge of his field by feeling the soil and visually monitoring the development of his crops.

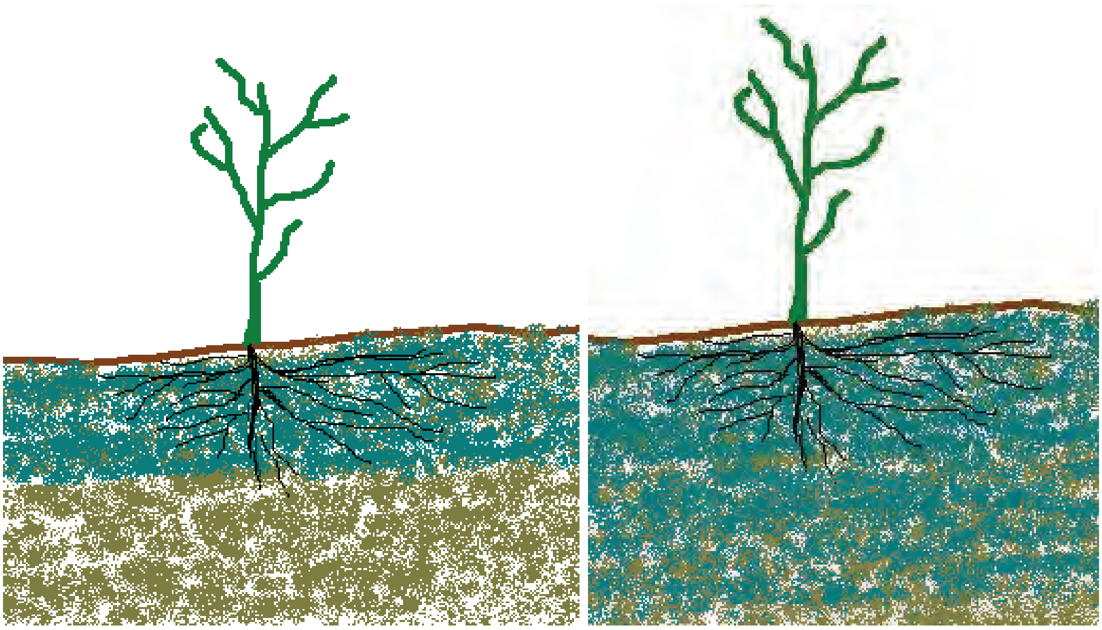
- **Depth** of irrigation, or how long time to irrigate, is determined by the depth of the **root zone** in the soil reservoir, together with the water holding ability of the soil.

Figure 1. Profile of effective root zone under a citrus tree

Irrigation depth is related to irrigating **time** – the longer irrigation takes place, the deeper water will infiltrate the soil. Too deep irrigation will result in nutrients being carried (leached) below root zone, as well as water logging in cases of poor drainage. This leads to root diseases and roots suffocating and dying due to low oxygen levels in the root zone.

In practice the root depth can be physically determined by digging soil profile holes, and the depth of application be adjusted accordingly (Part 2).

Good irrigation depth **Too deep application**



3. Principles of irrigation scheduling[7,9)]

The following principles are applied:

a) Soil moisture shortage must be replenished before drought stress causes a drop in production – **stress prevention**;

b) Seeing that an irrigation cycle must be completed before moisture stress occurs, the system capacity must be taken into consideration when the allowable percentage soil moisture depletion is determined. After rain has wet the total area simultaneously, the following irrigation cycle must start in time not to lack behind on the cycle.

c) To restrict evaporation loss, the application must be as large as possible but unless salts have to be leached out, it must not be so large that water moves lower down beyond the root zone.

d) It is safer to maintain high moisture content but the greater the depletion, the more storage space available, the better the rainfall will be utilised and therefore storing it in a dam can save more water.

e) With most crops it is usually the case that the **maximum production per hectare** is obtained when there is no moisture stress is experienced during the growing period. The ideal moisture condition will be obtained when the soil is kept at field capacity throughout.

f) Whenever the water supply is less than needed for the allotted area and the cost of water is high, **the production per m^3** water consumption must be taken into consideration.

g) The scheduling program, which aims at an optimal water utilisation to obtain maximum profit, therefore lies between choosing the area to be irrigated in such a way that:
   i) **optimum production per hectare** is obtained; and
   ii) **optimum production per m^3** water consumption is obtained.

h) Whenever there is a severe drought, actions can be taken to:
   i) save the biggest possible part of the crop; or
   ii) in the case of permanent crops, try to save the plants

4. Scheduling planning[7,9)]

An irrigation schedule is a program which is drawn up before establishment of the crop using information and long term data regarding the crop, climate, soil and irrigation system. It is a planning exercise that is done with irrigation design and crop planning. Using the same information it can also be done after crop establishment to have a framework for irrigation management. In many cases this is more accurate because root depth (and soil depth) for example can be physically measured instead of using data from literature.

Inputs into schedule planning

a. Crop

The specific crop characteristics which influence water requirement are the root depth, leaf area, sensitivity to stress and length of growth cycle (seasonal crops). The inherent ability of the crop both to absorb water and to protect itself (close stomata) during heat waves also plays a major role in water requirement.

b. Climate

The climatic conditions have a great influence on water requirement and this is a combination of temperature, humidity, wind and day length. The effect the climate has on plants is called the atmospheric demand. Plants use water to cool off, and the greater the atmospheric demand, the higher the rate of transpiration will be.

c. Soil

The water holding capacity and depth of the soil are the most important factors regarding scheduling planning for crop irrigation. These two characteristics determine the water reservoir available to the crop.

If the water holding capacity (WHC) of a soil is 120 mm/m and the depth of the soil is 0.6 m then the reservoir of the soil is 120 mm/m x 0.6 m = 72 mm. This will be the total amount of water contained in that soil depth of 0.6 m. Through the utilization of soil moisture measurement this schedule can be continuously refined to apply irrigation more accurately according to the crop's real water requirement.

d. Irrigation System

The application delivery and cycle length are determined using the above factors. The delivery of an irrigation system is a function of the design and characteristic of the system and is usually a fixed value for example 4 mm/h. In practice you may therefore have a system which, according to the design, delivers for example 4 mm per hour for 8 hours in a cycle of every 7 days. This application can however be applied in different cycle lengths according to soil, crop and management requirements.

Example

Example 2. Scheduling of block groups with different application times and cycle lengths

On farmer John's farm bananas and citrus are panted on a variety of soil types and are irrigated out of the same source with micro sprinklers. Because the orchards are situated on a reasonably level slope, a single pipe system supplied by one pump station is being planned. The block grouping, with information, is shown in Table 1.

Table 1. Block schedule

Block group No.	Cycle length [days]	Application time [hours]	Flow rate / ha / h [m³/h]	Area [ha]	Block group flow rate [m³/h]
B 1	2	4	45	1.80	81
B 2	2	4	45	1.75	79
B 3	2	4	45	1.65	74
B 4	2	4	45	1.60	72
B 5	2	4	45	1.55	70
B 6	2	4	45	1.40	63
B 7	3	8	27	1.95	53
B 8	3	8	27	1.90	51
B 9	3	8	27	1.84	50
C 1	6	12	32	1.88	60
C 2	6	12	32	1.94	62
C 3	4	8	35	1.95	68
C 4	4	8	35	1.98	69
C 5	4	8	35	2.06	72
C 6	4	8	35	1.92	67
C 7	4	8	35	2.03	71
C 8	4	8	35	2.18	76

Note:

1] Blocks with similar irrigation requirements are grouped together to be irrigated simultaneously. This is done by the irrigation designer according to volumes and pressure requirements of different blocks.

2] Blocks B1 to B9 are bananas and C1 to C8 citrus.

According to the above schedule block B1 to B6 are on the same soil type because the cycle length and application times are the same. B7 to B9 have a longer cycle length and it can be accepted that the soil has higher water holding capacity. Similarly there are different cycle lengths and irrigation times for the citrus blocks.

5. Reasons for scheduling (monitoring).

a) water, labour and energy are used more efficiently

b) losses of plant nutrients as a result of over irrigation are prevented

c) reduced danger of water logging

d) damage to crops as a result of drought stress is prevented;

e) costs are saved due to the above increase in efficiencies, and

f) less root diseases because of better soil conditions, and

g) more sustainable use of resources has less impact on the environment.

6. Irrigation water requirement[7,9)]

6.1 Calculation of water requirement

The first point in compiling an irrigation program is to know how much water the crop needs per day, per week, per season, etc. Crop water requirements are published in the "Estimated Crop Water Requirements in South Africa" (Green Book), as well as the SAPWAT program developed by the Water Research Commission. It is also published in various crop production manuals from Research Institutes and crop Growers' Associations.

The Green Book's requirement figures are based on the correlation between the Evaporation of water from an evaporation pan (A-pan) and the water use of plants, while the SAPWAT figures incorporate the Penman-Monteith equation which uses reference evaporation which gives more accurate correlation to crop water use. These figures may however be quite high for some areas and crops, and should be used as planning estimates.

Water Requirement (ET) basically consists of:

- Evaporation (from soil surface)
- Transpiration (water transpired by the plant to cool – from plant stomata)

It is then calculated by the Evaporation (E_0) figure multiplied by the crop factor (f)

$$ET = E_0 \times f$$

Example

Example 3

For example the crop factor for citrus in January is 0.6. The pan evaporation for Eshowe is 223 mm for January.

The water requirement (ET) is then: 223 mm x 0.8 = 178.4 mm / (Jan)

Because January has 31 days 128 mm is divided by 31 = 5.75 mm/day

***Note**: The Penman-Monteith equation uses variable crop factors to calculate crop water requirements using reference evaporation.*

6.2 Irrigation requirement

The Nett Irrigation Requirement (NIR) is calculated by subtracting the effective rainfall (Re) from the Evapotranspiration (ET)

NIR = ET – Re

[We need to irrigate the requirement not met by rainfall]

Because of the fact that not all rainfall (R) is effectively infiltrated (absorbed) by the soil, the effectiveness of rainfall (Re) is calculated as follows:

Re = (R – 20)

Example

Example 4
The average rainfall for January in Eshowe is 146 mm.

Effective rainfall (Re) is calculated by: Re = (146 – 20) / 2 = 63 mm

In Example 2 ET was calculated as: 178.4 mm

Net irrigation requirement (NIR) is then calculated:

NIR = ET – Re = 178.4 mm – 63 mm
= 115.4 mm

(Net irrigation requirement per day (NIRd) = 115.4 / 31
= 3.72 mm/day

At this point the **efficiency** of the irrigation system is brought into account. The **Gross Irrigation Requirement** (GIR) for the month is calculated by dividing the NIR by the system efficiency % (η).

GIR = NIR / η

GIR = 115.4 / 0.80 = 144.25 mm (Jan)
Calculate the GIR /day: 144.25 mm / 31 = 4.65 mm/day

If a 7-day cycle is then used, a gross application of 4.65 mm x 7 days = 32.5 mm is required.

After the cycle length is calculated (a function of root depth, soil water holding capacity and wetting % [W] it is possible to work out an irrigation schedule for the month.

The **cycle length** (CL) is determined by using a certain depletion percentage of the Readily Available Water (RAW) in the soil (Chapter 2). This percentage is decided on according to crop sensitivity and management inputs but is usually 50% or less. Available water (AW), also called **Total Available Moisture** (TAM), is the difference between soil or field capacity and permanent wilting point, and is calculated for the depth of the root zone.

The **available water** (AW) in the root zone is for example 100 mm.

If 50% depletion is allowed, the **readily available water** (RAW) is 100 mm x 0.50 = 50 mm.

Using a micro sprinkler system with a wetting percentage of 60%, cycle length can be calculated.

Cycle length (CL) is: $\dfrac{\textbf{RAW x W\%}}{\textbf{NIRd x 100}} = \dfrac{50 \times 60}{3.72 \times 100}$ = 8 days

This is the maximum theoretical cycle length according to the soil and crop requirement.

** In practice most growers prefer to schedule their irrigation on a week- based program: 7 days, twice a week, daily irrigation, etc.*

6.3 System design application

Daily or real time readings are used where scheduling is applied and adjusted on a day to day basis. When the total available water capacity (TAW) and the effective root depth

(RD) are known, and if the allowable moisture depletion percentage (DPER) is decided, the design application (DAPP) can be determined. This is basically the amount of irrigation water that will wet the root zone.

The following procedures are followed:

a) The **design application** (DAPP) is calculated so that the root zone reaches field capacity after irrigation and no deep leaching occurs. When it becomes necessary to leach out salts, the application must be increased.

b) An irrigation cycle starts as soon as **allowable soil moisture depletion** (DPER) takes place (DAPP = DPER x RD x TAM/100). [mm]

This is usually when 50% of the plant available soil moisture in the root zone is withdrawn as a result of evapotranspiration (ET = evaporation from the soil and transpiration by the plant). In some cases as little as 20% depletion is allowed depending on management policy.

This daily evapotranspiration (ET) is calculated by using an evaporation pan and a formula:

	ET	= Eo x f [mm]
	RD	= root depth [m]
where	Eo	= pan evaporation (mm)
and	f	= crop factor (determined empirically)

This is added and as soon as the sum thereof equals the design application, the next cycle must begin.

c) The total available water (moisture) capacity (TAM) of the soil is the amount of moisture [mm/m] between field capacity and wilting point and can be determined by way of a field test or soil water measurement.

d) To determine the allowable, soil moisture depletion (DPER) the following must be taken into consideration:

i) The higher the soil moisture depletion, the more effective the utilisation of rain will be considering that the available storage space in the root zone will be larger.

ii) The sensitivity of the crop to drought stress determines the amount of soil moisture depletion that is allowed before replenishment is necessary. With 50% depletion, there is little danger of crop loss but if it takes a few days to complete a cycle, there is a possibility of crop loss at the last blocks, considering that by then there may already be a noticeable moisture shortage.

iii) With a large system capacity, a greater amount of depletion can safely be allowed as the cycle is completed in a shorter time.

iv) In the early stages of growth of a crop, the crop factor is low but the root zone may be very shallow, and the root depth should be reduced when calculating the TAM and the irrigation cycle.

e) Because factors such as wind speed, humidity, temperature and the leaf coverage of the crop influence the crop factor (f), the ET value derived from the evaporation pan is not very accurate. It is therefore necessary to monitor the crop factor by using instruments such as a tensiometer or a neutron probe or hydro probe, and where necessary, to adapt the crop factor to obtain a more accurate ET value.

7. Scheduling strategies

The scheduling program can be approached as follows:

1. **Very little moisture depletion** is allowed.

Therefore small amounts are applied at short intervals to keep the soil moisture at or near field capacity. This method is advantageous where:

i) rainfall utilisation does not play a significant role;

ii) abundant irrigation water is available

iii) the system capacity is low and the fear exists that the moisture reserve will be depleted if the peak requirement continues;

iv) a permanent automated system exists; and

v) the crop is sensitive to water shortages.

If this approach is compared to the method where more moisture depletion is allowed, it has disadvantages because:

i) with heavy rain, more plant nutrients are lost and the chances of water logging becomes higher, or erosion as a result of run-off is possible; and

ii) more energy and labour are used for irrigation.

2. **Largest possible extraction** of soil moisture is allowed.

To utilise rainfall as much as possible, maximum moisture depletion is allowed without stressing the crop. Irrigation therefore has to start on time, so that no drought stress takes place before the completion of the cycle. The depletion which is permissible depends on the capacity of the system and how risky it will be. Calculating the depth of the application is approached as follows:

i) To save on labour and to keep evaporation loss low, the application has to be enough so that the total root zone is brought to field capacity;

ii) If the chance of rain is good, the application can be small so as to leave enough space in the root zone to absorb the rain. This method can be advantageous, especially with a dripper system where evaporation loss and labour do not make a big difference.

Note: *The aim with maximum rainfall utilisation is primarily to save on energy, labour and plant nutrients and not so much to save water. Seeing that enough water is available, the depletion must not be so high that crop reduction becomes a risk.*

3. Drought conditions.

In case of water shortage a degree of **crop reduction because of insufficient irrigation** must be accepted. In the event of below normal rainfall, the objective must be to obtain maximum production per m³ water on a part of the crop. The rest of the crop is written off, but if it is a permanent crop, it can be decided to schedule for the sake of survival.

Drought strategies include the following:

1. Apply deep irrigation and stretch the cycle as long as possible.
2. Decide which crops or fields can be discarded because of age, diseases or outdated cultivars.
3. Irrigate and concentrate only the crops or cultivars with the highest potential in profit.
4. Apply mulch to soil surface to prevent evaporation and conserve soil moisture. (mulch = soil cover with organic material or even plastic)
5. In case of micro sprinklers pressure as well as irrigation radius can be reduced to achieve deeper irrigation on a smaller area.
6. Micro sprinklers can also be replaced with drip irrigation to further reduce application area and improve efficiency.
7. Where serious drought is experienced trees can be pruned back severely and painted white to stop water use completely.

If the climate changes to the normal or even above normal rainfall, a water balance is done and the schedule is adapted to obtain a higher yield.

8. Irrigation Scheduling / Monitoring Tools [2,5,6,7,8,9)]

As discussed earlier the depth of irrigation, or how long time to irrigate, is determined by the depth of the root zone in the soil reservoir, together with the water holding ability of the soil. The interval of irrigation frequency is basically determined by the rate of water use of the crop. It is always advisable to measure soil water status to be able to correctly adjust the current irrigation schedule. Continuous monitoring offers the advantage of making quicker corrections to the irrigation program.

To measure or estimate crop water use a number of tools are used in practice. The application of the different tools and appliances used in irrigation scheduling will be discussed briefly.

8.1 Weather and climate forecasting

Weather and climate forecasting is a valuable tool for irrigation management. Irrigations are less effective if followed by large rainfall events; waiting for rain can on the other hand lead to loss of production due to water stress.

There is plentiful supply of weather and climate information available to crop producers in the form of long and short term forecasts. Real time and historical weather data can be obtained from a number of **web sites** including:

http://sasex.sasa.org.za/irricane/tables/index.asp

www.windreport.co.za

www.spaceweather.co.za/RomanRock.htm

http://foreca.net/South_Africa

www.weathersa.co.za

www.weather.com

www.wxmaps.org

www.yr.no

8.2. Automatic weather stations

Automatic weather stations (AWS) are widely used to continuously monitor the climate in a specific area. Rainfall, wind speed, wind direction, relative humidity as well as solar radiation are all factors that can be measured at specific time intervals.

Weather stations tend to be expensive, require high maintenance and may be difficult to use. There are three options available to an irrigator who is after the climatic data:

- Purchase an on-farm weather station and hire a consultant to service it
- Purchase data from a nearby weather station
- Obtain free regional data from sources mention above.

With telemetry data is transmitted to a local computer and in many cases then logged into a web site where it can be viewed by users.

Figure 2. Automatic weather station and AquaCheck ™ PRO Combo Automatic Weather Station

AWS are also used together with irrigation control equipment to be able to react quickly to sudden changes in weather. In such a case it is then linked to the irrigation control unit which has some pre set values by which it can stop or start irrigation. For example, after or even during a quick thunder storm the water will take time to infiltrate the soil, but the measured rainfall can be enough to cause irrigation to be stopped quickly. This may prevent over irrigation and leaching.

8.3. Evaporation pan

Evaporation readings are used to plan and design an irrigation system, but can also be used to manage it. Long-term average evaporation pan readings statistics are used where a fixed scheduling program is calculated. Evaporation figures are used to relate to crop evapotranspiration *via* a crop factor. A crop factor is related to the percent of ground covered by the crop canopy and therefore varies depending the crop stage.

Figure 3. Evaporation pan (Class A pan)

The following crop factors for a medium potato growth cultivar (e.g. Up-to Date) during spring planting at Roodeplaat[4)]

Weeks after planting	f
0-2	0.4
2-4	0.5
4-6	0.6
6-8	0.7
8-10	0.8
10-12	1.0
12-14	0.8
14-16	0.7
16-18	0.6

Example

Example 5.

A potato farmer wants to know how long it takes for a 30 mm irrigation to be used by the crop. The stage of the growth is 14-16 weeks. Currently the average daily evaporation is 5 mm/day.

To determine the crop water use, multiply daily crop evaporation by the crop factor. In this case, the crop factor 0.75

5 mm/day x 0.75 =3.75 mm/day crop water use.

The crop is using 3.75 mm/day, and to determine how long the irrigation of 30 mm will last, divides the irrigation amount by the crop water use:

30 mm/3.75 mm per day=approximately 8 days

This calculation indicates that an irrigation of 30 mm will be used by the crop in 8 days. The farmer can now forecast, given stable weather conditions, when the specific field will need irrigation again.

8.4 Soil water content monitoring

Since irrigation scheduling is the process of making decisions about when to irrigate and how much, three important questions that must be answered in order to schedule effectively are:

1. What is the soil's Readily Available Water Content?
2. How much water is in the soil at a given time?
3. How fast is the crop using the available soil water?

In Figure 4 it is clearly illustrated that Readily Available Water (RAW) is the amount of water stored in the soil between Full Point and Refill Point (or irrigation point). Irrigation should aim to replace the volume of water between the refill point and the full point. After the RAW has been used, plant roots cannot easily extract water from the soil.

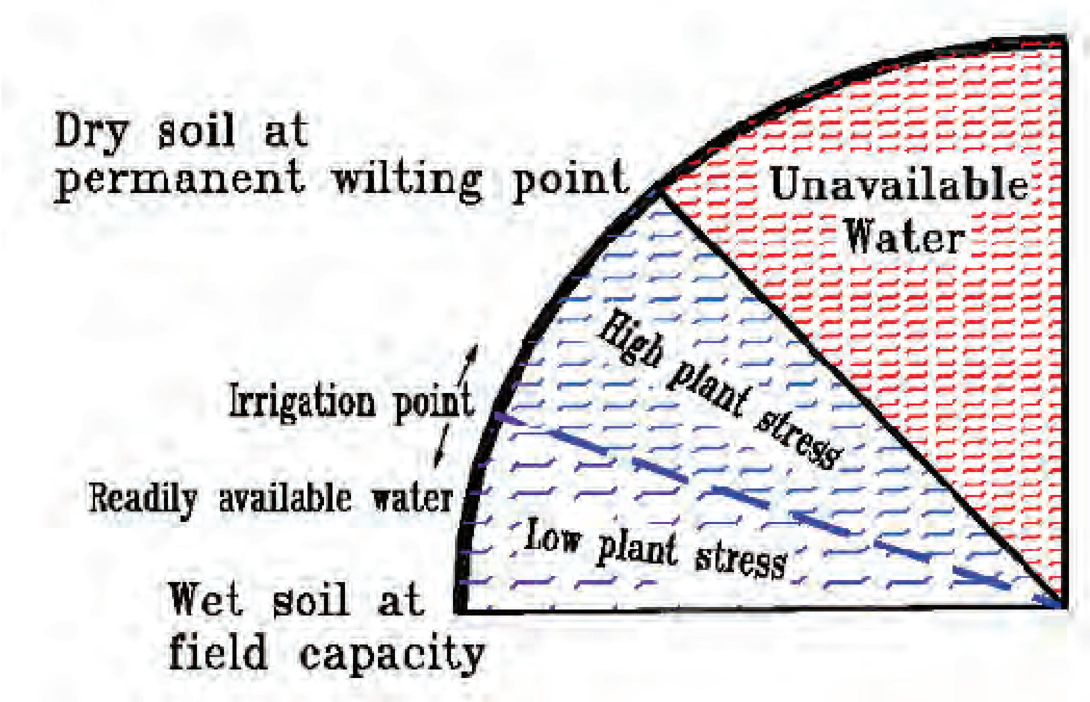


Figure 4. Soil water "fuel gauge"[9].

It is recommended that at least two soil water content measurements should be made in the soil profile – namely one in and one below the effective root zone. By monitoring of the soil water content in the effective root zone- the irrigator ensures that adequate water is available for the crop roots. By measuring the root zone below the effective root zone, the irrigator controls excessive irrigation and also manages soil health.

Soil water content can be divided into gravimetric and volumetric soil water content. *Gravimetric soil water content* is a description of the weight of water for a given soil weight. Gravimetric methods of measuring soil water content involve the removing of soil water from the soil sample, which is a method that requires laboratory facilities.

Volumetric soil water content is a description of how much water is present in a given volume or depth of soil, generally expressed in mm water per m soil. The volumetric soil water content is generally determined directly or estimated indirectly, by measuring various parameters. There are three ways of measuring availability of soil water for plant growth:

- Measuring how strong the water is retained through measurement of the soil water potential.
- Measuring the soil water content
- Measuring the depth of the wetting front after irrigation

Soil water potential: in simple words is the energy required to remove a finite increment of water from the soil. Soil water content does not tell one how “happy” the plant is, but suction indicates the water availability to the plant. Some devices are set into the soil permanently (tensiometers), while others are portable and could be moved around from point to point to take readings (gypsum blocks and granular matrix sensors)

Soil water availability: is usually expressed as a fraction of available water. This fraction is given by the ratio of available water content over the available water capacity, which is defined as the difference between field capacity (“full point”) and wilting point. Whatever the specific irrigation scheduling method *used to determine this measurement, one has always to deal with spatial variability.*

Wetting front detector: as infiltration from irrigation and rainfall occurs, a wetting front develops. This wetting front is measured by a wetting front detector.

Table 2 compares different methods of irrigation scheduling by monitoring soil water content or tension. The methods described in the table measure or estimate the irrigation criterion.

Table 2. Different methods of irrigation scheduling measuring soil water potential and content[7]

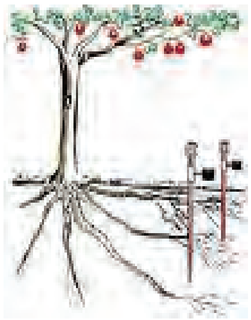
Method	Measured parameter	Equipment needed	Irrigation criterion	Advantages	Disadvantages
Hand feel and appearance of soil.	Soil water content by feel.	Hand probe.	Soil water content.	Easy to use; simple; can improve accuracy with experience.	Low accuracies; field work involved to take samples.
Gravimetric soil moisture sample.	Soil water content by taking samples.	Auger, caps, oven.	Soil water content.	High accuracy.	Labour intensive including field work; time gap between sampling and results.
Tensio-meters.	Soil water tension.	Tensiometers including vacuum gauge.	Soil water tension.	Good accuracy; instantaneous reading of soil moisture tension.	Labour to read; needs maintenance; breaks at tensions above 0.7 atm.
Electrical resistance blocks. (Poreus matrix sensors)	Electric resistance of soil moisture.	Resistance blocks like gypsum block, granular matrix sensors (Watermark, Aquaprobe).	Soil water tension.	Instantaneous reading; works over larger range of tensions; can be used for remote reading.	Affected by soil salinity; not sensitive at low tensions; needs some maintenance and field reading.
Neutron thermalisation	Percentage moisture through the measurement of neutron scattering	Neutron probe	Soil water content	Accurate, clear picture of soil water measurements at different depths	Expensive, limitations related to safety rules that have to be followed, labour intensive.
Di-electric sensors (Capacitance)	AC field applied to soil in order to detect changes in soil dielectric properties linked to variations in soil water content.	C probes, Envioscan, Diviner, Gopher	Soil water content	Real time continuous logging	Relatively expensive

8.4.1 Tensiometers [8)]

A tensiometer (also known as a moisture tensiometer or irrometer) consists of a tube with a ceramic point at the bottom end and a negative pressure gauge (suction pressure meter) at the top. Instruments are available in lengths of 300 mm, 450, 600 and 900 mm. The instruments are filled with water and then installed into the soil at different depths.

It functions on the principle that the plants absorb (suck) water from the soil and, as a result of surface tension also out of the tube through the porous ceramic point. The tensiometer measures this suction pressure and gives a reading of between 0 and 100 kPa (negative). The drier the soil is, the higher the suction pressure that is registered. Usually two tensiometers are installed at a measuring station to measure the moisture tension in the root zone as well as in the sub soil.

The reading on a tensiometer should be 0 in water. Depending on the clay contents of the soil, it can rise up to between -5 and -10 when the soil is at field capacity. Field water capacity is the ideal condition for plants because water and air are available in favourable relations, but if after irrigation, the reading remains at 0 (zero) for too long, it might indicate a waterlogged condition. Tensiometers can only function up to ± 80kPa before the connection between soil and instrument is broken and air is sucked in. The reading will then also indicate 0 kPa. After irrigation, the air must be removed with a suction pump to “reset” the tensiometer.

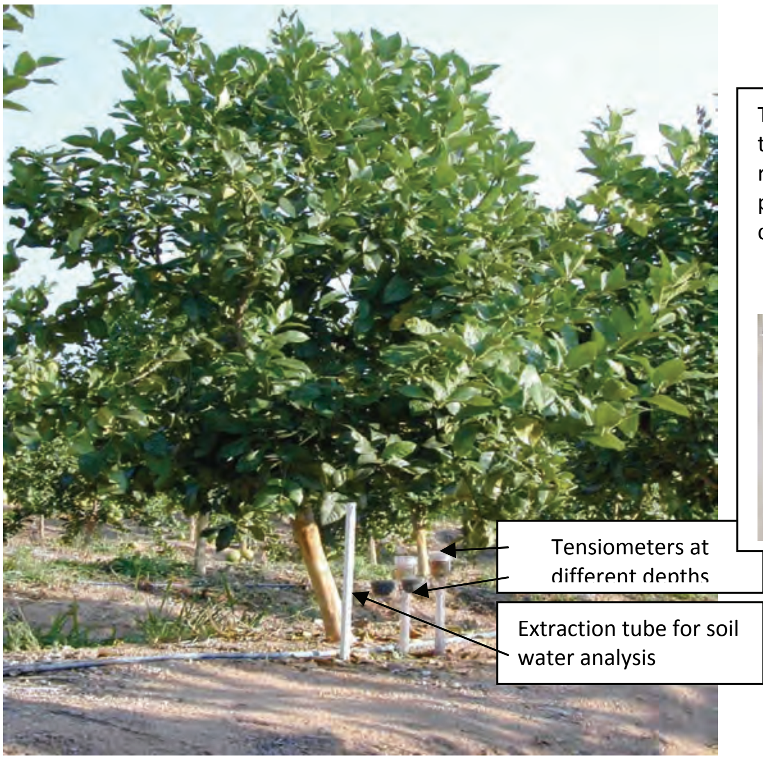


300 mm and 600 mm Tensiometers are usually used to measure soil moisture in the root zone and sub soil respectively.

Figure 5. Tensiometer installation on vegetable crop

Tensiometers are used as follows....

a) Considering that there is a correlation between moisture tension and drought stress in plants, tensiometers are used to determine when to irrigate.



Tensiometer with transparent tube, water reservoir at the top, pressure gauge and ceramic tip at the bottom.

Whenever the reading reaches a certain value, according to crop requirement, irrigation has to start. After rainfall, when the blocks are equally wet simultaneously, irrigation has to start before the moisture contents reach a critical state because the system capacity is usually not sufficient to irrigate all the blocks simultaneously.

The suction pressure, with which plants withdraw water from the soil, varies from plant to plant. Citrus can, for instance, withdraw moisture up to -40 kPa without stress, while the same moisture tension will have a negative influence on the production of bananas.

Tensiometers can also be used with automated systems where the readings are logged electronically.

b) Over irrigation, that can be a waste of water and fertiliser can be indicated by a tensiometer in the sub soil. As previously mentioned one instrument is placed in the root zone and another just below the root area. The reading of the deep tensiometer is the indicator for over irrigation (too deep), which causes leaching of fertilizer and water loss. This is especially true if the reading on deep tensiometer remains low (wet) for a long time. It is good practice to keep the subsoil fairly “dry” to create absorption space for rainfall.

Note: *The ceramic tips of tensiometers need to make very good contact with the soil in order to work properly, and can therefore not be used in very sandy and gravel soils.*

READINGS	IMPLICATIONS
0-10	Saturated soil. Low soil-moisture tension i.e. soil is wetter than field capacity which implies a state of oxygen deficiency or water clogging.
10-20	Soil-water content at field capacity implying ± 20 % available oxygen. This is the ideal condition for optimum growth.
20-40	Water is still easily accessible for most crops.
40-60	Indicate that the water available to the plant is not as easily accessible but still available i.e. time to irrigate.
70-	Indicate that the water available to the plant is dangerously low for the plants and inhibiting growth. Most crops are starting to wilt.

8.4.2 Wetting Front Detector

One of the most important aspects when irrigating is how much (depth) to irrigate. During the course of a season the moisture status of the soil changes, and therefore a specific application do not always infiltrate to the same depth. The Wetting Front Detector indicates to a farmer that the water has reached a certain depth. The farmer can consequently know the amount of millimetres or hours to irrigate on a specific field.

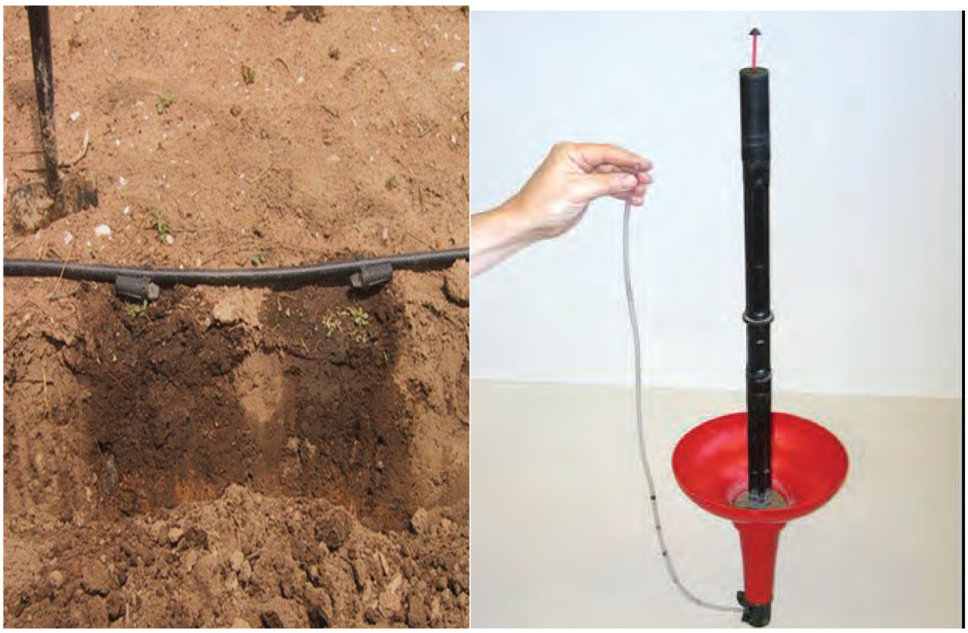


Figure 6. Wetting front detector and wetting front[5)]

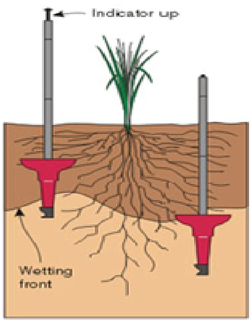


Figure 7. Installed wetting front detector in a citrus orchard

8.4.3 Capacitance type moisture sensors

- ***AquaCheck™ and DFM™*** are manufacturers of moisture sensors that work on the basis of electric conductivity of soil. These soil moisture monitoring devices measure soil moisture over the entire depth of a crop's root zone. It consists of a soil probe and data logger allowing the grower to measure soil moisture content over several depths every 30 minutes. The most common probe lengths offer 6 sensors.

  The AquaCheck™ and DFM™ systems also offer short distance telemetry options. These allow the grower to download data remotely via a handheld logger. The telemetry version of the probe can also be connected to an automatic rain gauge as well as one additional analogue sensor such a dendrometer (stem diameter gauge) or temperature sensor. The probes are available in lengths of 400, 600, 800, 1000 and 1200 mm, and have the option of short distance telemetry with internal or external antenna.

  Method

  To take a reading, the handheld logger is held over the permanently installed probe to download the latest continuous readings. Readings can then be downloaded to your PC and the data being shown on the AquaCheck software.

AquaCheck ™ BASIC **AquaCheck ™ BASIC Handheld Logger**

- ***C-Probe*** utilizes the same technology as the AquaCheck™ and is permanently installed soil moisture monitoring device measuring soil moisture over the depth of a crop's root zone. C-Probe consists of a soil probe and data logger connected to a radio transmitter, allowing the grower to measure soil moisture content. Water management information is automatically downloaded to a PC for closer analysis with the Plant Plus software. The software graphically presents the state of the soil moisture, allowing accurate and timely decisions to be made on when and how much to irrigate.

  Operation

  Data is transmitted via a radio network to the local base station connected to your PC. Data is captured every 15 minutes ensuring real time continuous data of the soil moisture content of the specific profiles.

Figure 8. C Probe installed[6)]

8.4.4 Granular matrix sensors: Watermark

The Watermark sensor (granular matrix sensor) is an indirect, calibrated method of measuring soil water. It is a hand held electrical resistance type sensor, which converts the electrical resistance reading to a calibrated reading of Centibars or kilo Pascal (kPa) of soil water tension. It has been used in science and agriculture since the mid-1980's, and is an affordable and practical substitute for tensiometric measurement in most agricultural and landscape irrigation environments. Readings from the Watermark can be drawn on a graph to interpret soil moisture readings and to assist in the management of soil moisture.

Figure 9. Watermark sensor and data logger[6]

8.4.5. Gypsum block

The gypsum block is relatively inexpensive, and slowly dissolves providing a saturated solution of Ca and SO_4 ions in the porous matrix. This type of sensor is suitable for situations where irrigation applications are required at "full" or "refill "points. A major problem is that the gypsum blocks break down and dissolves over time. The calibration relationship between gypsum block readings and soil water potential is therefore not fixed. The calibration of the instrument must be adapted to the change in the salinity of the water, considering that this will influence the reading. This method is not very accurate where the soil is wet, and is rather used at potentials -< 100 kPa.

8.4.6 Neutron probe (hydro probe)

The neutron probe or hydro probe is an electronic apparatus, which with the help of a radioactive source, counts hydrogen molecules at different depths in the soil – as water is the only substance in the soil containing hydrogen. With calibration it determines the percentage soil moisture at each specific depth. The apparatus is fairly expensive and is presently used mainly by researchers, consultants and large scale farmers. A single apparatus can serve a number of test points and it is possible for one apparatus to serve quite a number of farms. A test point consists of a piece of pipe (usually aluminium) that is installed into the soil vertically. At each test point the instrument is put onto the pipe and the measuring head is lowered into the pipe to take a reading at seven different depths from 100 mm to 1 m. The count can be read directly on the instrument, but the moisture indication can only be obtained from the software after processing.

The data is then downloaded and processed and graphs are produced showing the soil moisture through the soil profile (depth graph). The previous reading on a specific point is also shown, and the difference in moisture can be visually observed from one reading to another. It also gives the moisture in mm of the current reading and the difference from field capacity. A very accurate irrigation recommendation can be made in terms of millimetres to be applied to the profile.

The time graph shows the history of soil moisture readings at each point. Meaningful information can be obtained by looking at the time graph for a season – times of over or under irrigation can clearly be observed, and it can be related to crop yield or quality.

Figure 10. Neutron probe

8.5 Soil water balance scheduling approaches

Soil water budgeting can be predicted by direct measurements or by water budgeting. The soil water balance approach is based upon either the soil water balance models and/or crop growth models to calculate evapotranspiration. Many of the computer programs and models allow the user to choose the method of ET calculation. The data required calculate evapotranspiration.

Two approaches of integrated soil water balance irrigation scheduling are found, namely *pre-programmed irrigation scheduling* and *real time irrigation scheduling*.

- ***Pre programmed irrigation scheduling program****:* the decision on how much to irrigate and when to irrigate is determined in advance and a few corrections usually depend on the rainfall during the season.
- ***Real time irrigation scheduling approach:*** where the decision on when and how much to irrigate is based on actual daily conditions, usually soil water content or atmospheric demand. In real time irrigation scheduling the ETref for forthcoming days is sometimes directly estimated from meteorological services or forecasts.

Various models exist regarding irrigation scheduling that incorporates various factors of the crop and environment. Most of the programs are generic for all crops while others are crop specific and is developed by researchers in a certain crop association or institute.

i) Pre programmed irrigation scheduling methods and models

The following methods and models are applied by irrigators for pre programmed irrigation scheduling:

a. *Seasonal calendar:* for instance a fixed irrigation schedule or irrigation calendar that is based on historical data and developed for specific crops and planting dates, soil types and initial water contents. This type of calendars are usually developed base on daily soil water balance crop yield models to express most appropriate dates for irrigation.

b. *Checkbook irrigation method:* where daily soil water balance (in terms of soil water deficit) are used for the planning of the next irrigation. The checkbook method is an irrigation record keeping model, which accounts for water inputs and outputs. For instance the Griekwaland Wes Coop (GWK) is rendering a scheduling service where the farmer receives information once a week on the current level of the soil water content of the profile as been measured. Based on checks and balances, the recommendation to either reduce or increase the irrigation application during the following week is made.

c. *Computer programs like BEWAB, SAPWAT and Vinet 1.1* are developed for estimating crop water requirements and for the planning of irrigation strategies.

ci. BEWAB (Besproeiingswaterbestuursprogram/Irrigation water management program)

The BEWAB (Besproeiingswaterbestuursprogram) is pre-programmed a soil-water balance model to assist farmers with decision-making by supplying them with pre-plant recommendations on how much water should be applied throughout the season and when to apply it. Irrigation scheduling is practiced through the applying of pre-determined irrigation amounts at prescribed intervals.

The program is based on soil-water budgeting principles. Upper and lower limits of plant available water for different soils are estimated from textural properties. Built into the model are crop water production functions and non-linear crop water demand functions for different crops and planting dates for each locality, based on water use measurements.

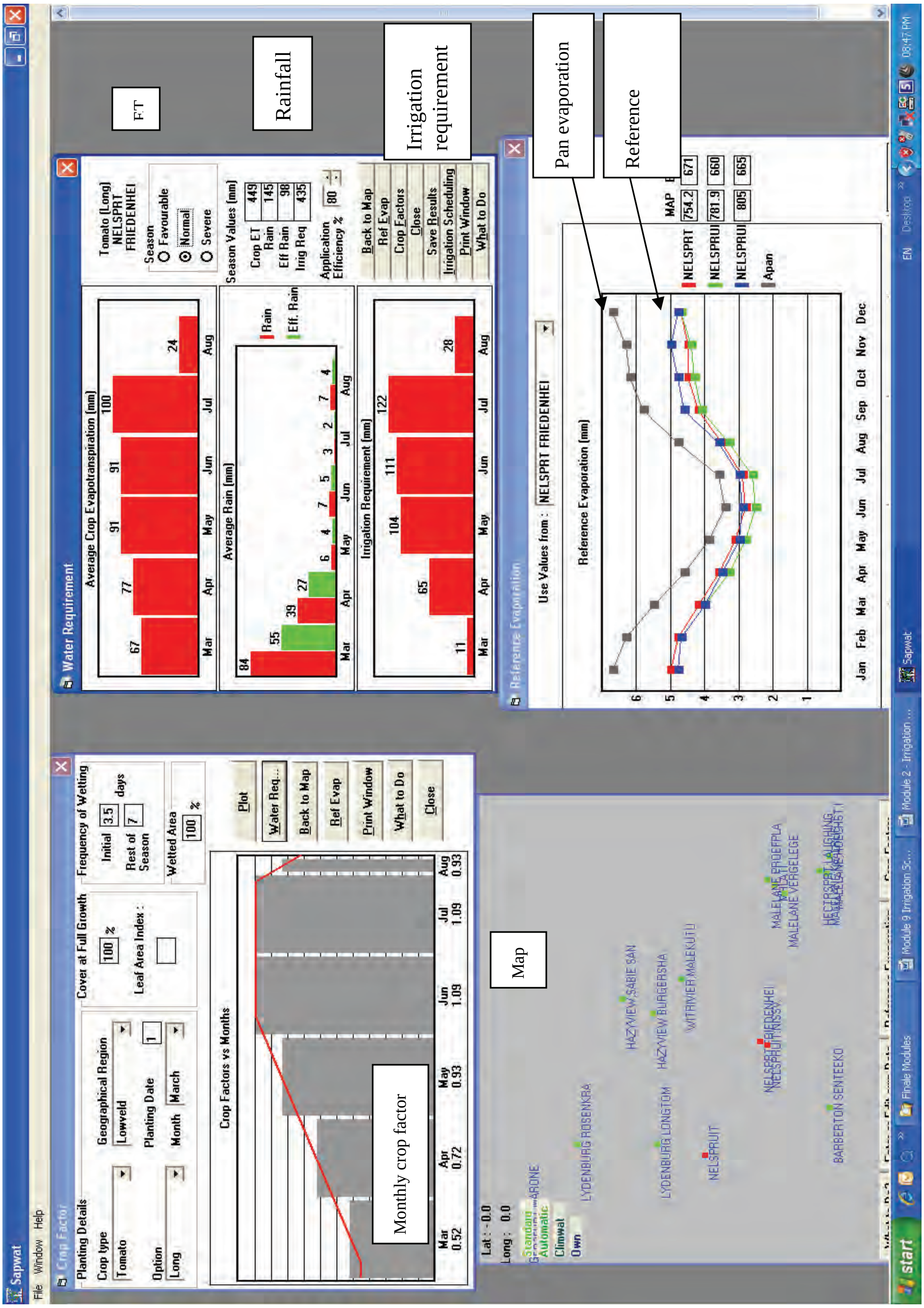
cii. Vinet 1.1 (Estimated Vineyard Evapotranspiration for irrigation system design and scheduling)

Vinet1.1 was designed specifically to help the grape producer in decision making on when and how much and for how long to irrigate. The great variation between vineyards due to the differences in foliage, soil and climate makes decision-making very difficult. This model makes use of an empirical model to simulate the water use of the plants. Parameters like vine spacing, soil type, trellising system, leaf area, ET0 and a constant factor that represents evaporation losses from different soil types are used as parameters in the model. This model was developed by Dr PA Myburgh from the ARC Infruitec Nietvoorbij.

ciii. SAPWAT

SAPWAT is a program developed by the Water Research Commission and is based on evapotranspiration figures calculated through the Penman-Monteith equation. It is the official program used by the Department of Water Affairs to calculate crop water requirements and water allocations. SAPWAT3 was developed to establish a planning and management tool for irrigation engineers, planners and agriculturalists. SAPWAT is also used to estimate the total annual and monthly crop irrigation requirements, which can be compared to the water available to the area.

It also is used to identify possible limitations in the conveyance and delivery infrastructure, which could have negative consequences, associated with the crops being stressed during certain periods resulting from the limitations. It is also used to estimate the crop water use requirements of different crops under different irrigation systems and different irrigation management regimes. SAPWAT is freely available to irrigators, and can be obtained from the Water Research Commission www.wrc.org.za.


FT
Rainfall
Irrigation requirement
Pan evaporation
Reference
Map
Monthly crop factor
Water Requirement
Average Crop Evapotranspiration (mm)
Average Rain (mm)
Irrigation Requirement (mm)
Reference Evaporation (mm)
Crop Factors vs Months

The figure above shows different SAPWAT screens in clockwise order showing **crop factors** (growth stages), **irrigation requirement**, **reference evaporation** and a map of the selected **weather stations**.

Calculation of water requirement

- The water requirement for tree and perennial crops is calculated according to the monthly water requirement of that crop.
- For seasonal crops water requirement is calculated according to the four (4) stages of crop development:
  - Germination & early growth
  - Rapid vegetative growth
  - Flowering and fruiting stage
  - Ripening stage

Note: *Perennial crops like sugar cane also have four stages because it is harvested and needs to repeat the growth cycle.*

ii. Real time irrigation scheduling approach

Real time irrigation scheduling methods and programs have three main elements in common:

- Soil water content as determined through regular measurement of soil water status
- The use and availability of weather data
- A decision support system which relies on field soil water content, weather forecast and crop cultural practices to select the most appropriate course of action in scheduling of crops.

The following real time irrigation scheduling programs are commercially available in the sector:

i. Soil Water Balance model (SWB)

The SWB model is a user friendly, generic crop irrigation scheduling model that incorporates environmental factors with soil moisture conditions including drainage and runoff. It is used to simulate the crop growth, the soil water balance and crop water use. Daily weather input data is required for the model. Soil layer thickness, soil water contents at field capacity, wilting point and soil bulk density need to be supplied for each field. As the name indicates it balances the inputs and losses of soil moisture.

In an approach to make the implementation of SWB more user-friendly to small-scale farmers and even commercial farmers, SWB Irrigation calendars were also developed as an alternative for real time irrigation scheduling. This is where the irrigator has not access to daily weather data or computers. In such instances the long-term temperature, as well as soil and management inputs for a specific locality are used to generate site-specific irrigation calendars. This can be printed and supplied to farmers. The research team does not promote the replacement of real time irrigation scheduling with irrigation calendars, but rather as a site specific simplified application of the SWB model.

The model has been renamed in 2008 after some definite adjustments and improvements were made which included the changing of the database to Firebird instead of Paradox, development of a single setup input screen, development of a Quick setup screen for default soils, weather database improvements, and the extending of the use of SWB for planning purposes. The model has been renamed to SWB-Pro to differentiate from the previous version.

The SWB model is freely available to irrigators, and can be downloaded from www.up.ac.za/UPWI/SWB.

ii. My Canesim/SASched and Irrigation Scheduling Calendar Decision Support (ISCDP)

These programs are available from South African Sugar Research Institute. The aim with these programmes and models are to help with scheduling decisions for the irrigation of sugarcane.

MyCane sim is an internet based simulation model that is developed for management of sugar cane. It uses climatic data from weather stations in a specific area, and can make predictions on yield and sucrose levels at different scenarios. It is configured to provide scheduling advice via SMS's.

Irrigation Scheduling Calendar Decision support Program (ISCDSP) provide printouts that can be used for the showing of optimum irrigation cycle times for cane cut at different times during the year, depending the various agronomic and irrigation conditions. It includes features like the "rain delay calculator", which shows recommendations for the delaying of irrigation following different amounts of rain at different times during the production season.

iii. **Irricheck**

Program initially called BBP17, which was upgraded through feedback from farmers and field experience. This scheduling program is used in various provinces in South Africa.

iv. **Probe for windows (PRWIN):** program that uses data from soil water sensors and schedules irrigation and management of crops.

v. **Donkerhoekdata Irrigation Program (DFM Software Solutions):** This program is a combination of scheduling, water budgeting, soil moisture sensor logging, automated control, fertiliser management and logging of fruit and plant growth.

8.6 Alternative Scheduling methods

The following methods to indicate drought stress can also be used:

a) Indirect method of soil water measurement: the use of a shovel or a soil auger – also known as the "feel method". This implies the use the "hand-feel-method" for the determination of soil water. Soil samples are collected at different depths with the help of a soil auger or a shovel, and then the water content is estimated by observation and hand – feel. Soil is squeezed between the thumb and the index finger (Chapter 2). This method requires a tremendous amount of experience and is highly subject to soil type.

b) Plant base monitoring:

- An *indicator plant* (of the crop that is cultivated) is planted into a 50:50 mixture of soil and sand. Drought stress occurs before damage is done to the rest of the crop and in good time, indicates when irrigation has to start.
- *Drought stress* can also be observed by measuring the increase in growth or fruit setting of plants which had received less water than the rest and to compare that with the other. Drought stress can thus be observed at an early stage.
- Plant stem/trunk diameter measurement is used to measure the fluctuation in stem diameter, which indicates water use and plant growth.
- Sap flow measurement gives an indication of the availability of soil moisture as well as the plant water use. It also shows the tendency and velocity of sap flow in the tree stem. It is used in specialized conditions and with research.
- Canopy measurement: An infrared thermometer is used to measure the leaf coverage of a crop. The leaf temperature is then compared with the temperature of the atmosphere. Considering that transpiration causes cooling, a decrease in this cooling effect will indicate a water shortage in the root zone.

9 Criteria to consider when selecting an appropriate irrigation scheduling tool[7)]

When a farmer is in the market for a scheduling tool, it is important that the capabilities of the specific scheduling tool match with the requirements of the user. The following characteristics of irrigation scheduling tools are considered when selecting a tool[7)]:

- *Ease of use:* What level of technology is the potential user comfortable with? Ease of use is a very important characteristic taken into account by potential users. This is largely related to the relative easiness of use and the skills, knowledge, effort and support required operating and interpreting data from the monitoring system.

- *Cost:* How much money is the potential user willing to spend? Cost is most probably the most important factor when considering what tool to use on the farm. With the current rapid increasing of electricity tariffs and water costs, the cost of not using a scheduling tool will likely be more important. The cost of a specific irrigation scheduling tool will depend on the sophistication and accuracy required.

- *Accuracy:* The accuracy of measurement will dictate the choice of a specific tool. In the first place the calibration of a sensor is of great importance. It is important to identify if site or logger specific calibration of a sensor is required, and determine if the means to perform this calibration is readily available. Secondly, it is important to identify how sensitive the specific sensor performance to correct and incorrect installation procedures are. Capacitance sensors are very sensitive to the way they are installed. Good surface contact between the soil and sensor is absolutely important during installation, but this can be very difficult to achieve with certain sensors. Air gaps can for instance influence the quality of data very negatively.

- *Robustness:* Robustness refers the suitability of the specific tool to the specific situation of the farmer. Aspects such as protection against pest (rodents and ants) must be considered. It becomes especially troublesome when long electric cables are required running from various sensors in different parts of the field to a central transmitter. Waterproof housing of data loggers and connection points is also an important consideration.

- *Time:* How much time can the user of the scheduling tool spend on taking measurements and interpreting data? Very often the irrigator knows the specific irrigation is vital but that he/she does not have time to allocate to data collection and interpretation. Sometimes farmers make use of consultants which is then the best option. For others who can spend time with soil water monitoring, it is a matter of matching tool requirements with the time available to collect and interpret the data.

Activity

Activity 1

Individual activity

1. Explain the concept of scheduling, and describe what it means in practice.

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2 Motivate why irrigation scheduling is an essential part of irrigated farming.

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3 Case study:

The average rainfall for October in the Port Edward area is 86 mm. Bananas are grown in the area and the daily water requirement (ET) for October is 4.6 mm per day.

3.1 Calculate the daily net irrigation requirement (NIR) for the crop.

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3.2 The application efficiency of the micro sprinkler system is 85%, and irrigation is applied on a cycle of 3.5 days. Calculate the gross irrigation requirement (GIR) of the crop.

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4 What is the purpose of monitoring soil moisture?

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5 How can instruments like tensiometers assist you in managing your irrigation applications?

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6 Do an internet search on the weather data for a specific station in your area or alternatively for Pretoria.

Find the following information:

- Monthly average maximum temperatures
- Monthly average minimum temperatures
- Average wind speed and direction (per season if possible)
- Average monthly rainfall figures

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Reference

1 Netafim Hardware Installation Manual, 2008.
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8 Shock CC, 2010. Scheduling with tensiometers. Malheur Agricultural Experiment. Ontario.
9 Waterwise on the farm, 2002. New South Wales, Australia.

My notes............

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Authenticator:

- Mr F Buys

Module 8

Fertigation

Study objective

After completion of this module, the learner should be able to have a basic understanding of:

- What is fertigation
- Reasons for application of chemicals
- Types of fertiliser that can be used for fertigation
- Solubility of products and possible mixtures
- Fertigation methods
- Units and ratios used in fertigation
- Calculation and calibration of fertiliser injections
- Precautionary measures with fertigation
- Herbigation, insectigation, nemigation
- Measures against clogging (chlorination, hydrogen peroxide)
- Flocculation, aeration and sedimentation

Table of contents

Water and nutrients are needed throughout the growing season of any crop and therefore needs to be applied accordingly. Because of the fact that nutrients (fertilizers) are dissolved and transported with water in the soil, it makes sense to incorporate and apply it in the irrigation water. This is known as the concept of fertigation which requires relatively high levels of management skill.

1. What is fertigation[2,4]?

Definition

The term *fertigation* refers to the application of fertilizers (nutrients) through an irrigation system using the water as a transport medium. Fertigation is mainly done through drip irrigation, but both static and mechanized sprinkler systems are also utilized for the purpose.[4)]

*Note: Although fertilizers that are **not** fully water soluble can be carried by irrigation water in suspension, problems can arise with clogging, and therefore only water-soluble fertilizers are used.*

2. Reasons for application of chemicals through irrigation systems [4,2)]

- Economising on expenses of equipment such as fertilizer distributors and spraying machines.
- Economising on labour and energy expenses.
- Compaction of soil by tractors is prevented.
- More effective. It is often difficult to move certain machines through certain crops

  or fertilizer, in solid form, can be detrimental to leaves of plants.
- It is advantageous to apply small amounts of fertilizer more often. Very little fertilizer is wasted as a result of leaching during heavy rain.
- Easy to make adjustments to fertilizer programme

***Note**: Because phosphate (P) and lime (Ca and Mg Carbonates) move through the soil with difficulty, these elements are distributed by a fertilizer spreader before planting and then ploughed in deeply. It is however possible to apply phosphate through fertigation in a number of mixtures, e.g. MAP or MKP.*

3. Types of fertilizer for fertigation[2,4,5)]

All types of chemical fertilizers (also trace elements) are available in water soluble form (Table 1) and can be used for fertigation in cases where[4)]:

a) Farmers want to attain more efficient fertilizer application;

b) in existing orchards and fields, where the soil is not to be disturbed;

c) the price is competitive, and the higher yield warrants higher prices

d) phosphoric acid is incorporated in a fertilizer program where the water pH is high to counteract the clogging of irrigation pipes.

***Note:** Phosphoric acid corrodes metal and can only be used by micro and drip.*

Table 1. Examples of water soluble fertilisers[4,5,6)]

	Water Soluble Fertilizers															
		Composition: g / kg														
	Product	N	N - as		P	K	Ca	Mg	S	Cl	Fe	Mn	Zn	Cu	B	Mo
			NH4	NO3												
B	BORON															
	Borospray														172	
	Solubor														205	
Ca	CALCIUM															
	Calcium Nitrate	155	9	145			195									
	Calcium Magnesium Nitrate Plus	137	10	128			122	33							2.1	
Cu	COPPER															
	Copper Sulphate								128					250		
K	POTASSIUM															
	Potassium Carbonate					567										
	Potassium Chloride					500				470						
	Potassium Nitrate	130		130		380										
	Solupotasse - Potassium Sulphate					420			185							
	M.K.P (Mono Potassium Phosphate)				227	286										
Mg	MAGNESIUM															
	Magnesium Nitrate Crystals	109		109				95								
	Magnesium Sulphate (Anhydrous)							199	263							
	Magnesium Sulphate							100	130							
Mn	MANGANESE															
	Manganese Sulphate								186			315				
Mo	MOLYBDENUM															
	Sodium Molybdate															395
Zn	ZINC															
	Zinc Sulphate Monohydrate													350		
	Zinc Sulphate Heptahydrate													220		
N	NITROGEN															
	Ammonium Sulphate Crystalline WS	206	206						240							
	Ammonium Nitrate Solution (260g N/l)	210	105	105												
	M.A.P. Mono Ammonium Phosphate	120			262											
	Nitric Acid 58%	124		124												
	N-Sul SP	270	192	80					130							
	N-Sul (14) Liquid fertilizer (N = 180g/lt	145	81	22					69							
	Urea L. B.	460														
P	PHOSPHORUS															
	M.K.P Mono Potassium Phosphate				227	286										
	M.A.P. Mono Ammonium Phosphate	120	120		262											
	Phosphoric Acid 85% (Tech. Grade)				251											
S	SULPHUR															
	Sulphur								900							

*** Table 1 only gives some examples of water soluble fertilizers – many other mixtures are available from suppliers.***

Suppliers also have many of their own mixtures including special products for specific crops. These include foliar feeds, micro nutrient mixtures and soil adjuvants.

4. Fertigation Program [6)]

As mentioned in the introduction plants need nutrients for growth throughout the growing season. Different types and combinations of nutrients are required for each growth stage. This set of growth cycles is called the phenology of the plant, which includes vegetative and root growth, flower, fruit set, growth and maturation. Specialized knowledge is required to compile a fertilizer program, and for optimum uptake and utilisation of nutrients, timing of application is important.

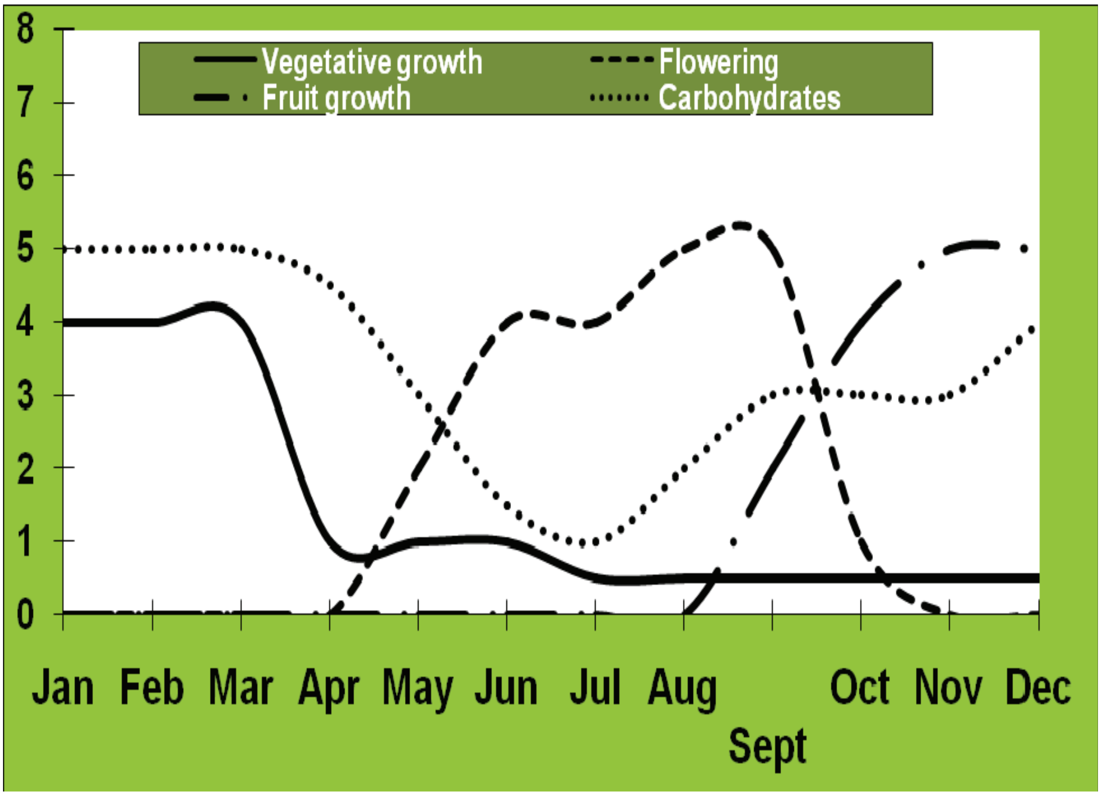

Figure 1. Phenology graph of litchis[6)]

5. Product mixtures and solubility

When mixing fertilizers in a tank, care should be taken that products are compatible, and that the amount of fertilizer mixed is below the maximum level of solubility. This is to prevent chemical reactions and also to ensure that fertilizers are fully dissolved (Table 2)[5,6)].

Table 2. Solubility of different types of fertilizers in various water temperatures.

The solubility (kg/100 L water) of types of fertilizer						
Water Temp °C	**Ammonium Sulphate**	**Potassium Sulphate**	**Urea #**	**Ammonium Nitrate**	**Potassium Nitrate**	**Potassium Chloride**
5	71	3	67	118	13	28
10	73	9	85	158	21	31
20	75	11	105	195	32	34
30	80	13	133	242	46	37

The temperature of the water drops when urea is added

Figure 2. Examples of water soluble fertilizers

The incompatibility of certain formulations causes problems with reactions when fertilizers are mixed together. In practice an A tank and B tank system is used to prevent this problem. More tanks are used in cases where one type of fertilizer (especially liquid fertilizer) is added per tank, and the fertilizer mix is electronically controlled and injected with fertilizer pumps.

Soluble fertilizers not allowed to be mixed

- Calcium nitrate and mixture containing phosphates or sulphates
- Magnesium sulphate and mono / di –ammonium phosphate
- Phosphoric acid and Iron-, zinc-, copper- and magnesium sulphates
- Urea causes precipitation of Calcium carbonates ($CaCO_3$)
- (Urea not commonly used in fertigation programmes)

Table 3. Products mixed using a two or three tank solution system[5,6)]

Tank A	Tank B	Tank C
Calcium nitrate	Ammonium sulphate	* Phosphoric acid
Potassium nitrate	Phosphoric acid	* Nitric acid
Magnesium nitrate	Nitric acid	** Chlorine
Ammonium nitrate	NPK Blends like 3:1:5	
Urea	MAP Mono-ammonium phosphate	
Micro elements	MKP Mono-potassium phosphate	
Potassium chloride	Ammonium nitrate	
	Magnesium sulphate	
	Micro elements with S	

** **Acid** solution for pH control and cleaning system of carbonates.*
***** Chlorine** for control of bacteria and algae in system.*

Figure 3. Tank A and B with various fertiliser mixtures fitted with fertilizer pumps

Definition

Antagonism in soil: There is a negative effect between chlorine (Cl) and nitrate (NO_3) ions. The presence of Cl^- reduces the uptake of nitrate (NO_3).

5.1 Mixing of fertilizer[6, 5)]

Fertilizers are mixed as follows:

a. Manual mixing

The correct amount of fertilizer – according to the fertilizer program – is weighed and added to the tank at least half filled with water. While the fertilizer is added the water is agitated with a clean wooden pole or rigid plastic pipe to dissolve the crystals. While this is done the tank is filled completely.

b. Pump mixing

The preferred method however is to have a **mixing pump** which agitates the water in the tank while fertilizer is added. On the bottom of the cylindrical tank there is a pipe that is connected to the supply pipe of the pump. To rotate the water in the tank, the pipe has a horizontal orifice on either side (at the inside of the tank) from where two jets of water squirt in opposite directions. In the middle of the tank floor, the mixing pipe has a vertical orifice from where a jet of water mixes the fertilizer that accumulates there. This gives a much quicker and effective solution of fertilizer.

c. Air pump mixing

Works exactly like pump mixing, but is forced through the mix with efficient mixing results. The added benefit is that O_2 level in water increases.

6. Timing of fertigation[4,6)]

With stationary systems, the fertilizer can be put into the system during any part of the irrigation period. Therefore:

a) the fertilizer can be placed deep by application at the beginning of irrigation

b) it can be placed shallow by application at the end of irrigation

It is not advisable to let the fertilizer in before all the pipes are filled with water and the system is at operating pressure. The injection of fertilizer into the system must also stop a few minutes before the end of the period, so that the pipes are filled with water only when the system is switched off.

With automated systems, any of the following techniques can be practised to ensure that the correct amount of fertilizer for each block is applied:

a) A **volumetric** valve measures the correct amount of fertilizer (concentrated solution) during the irrigation of each block.

b) Pumping of fertilizer for a certain **time** – an even stream of fertilizer concentrate under pressure into the pipeline. Pump is switched on and off by computer or controller so that each block receives the correct amount.

7. Fertigation methods[4,6,5)]

A. Quantitative fertigation

- The application of a batch of fertilizer as seasonal or growth stage fertilization. This method is not continuous and is used like the conventional fertilization where a batch of fertilizer is applied only a few times per season.
- Usually with quantitative fertigation using a pressure tank, the concentration decreases as the fertilizer finishes.
- The advantage with this method is that a batch of fertilizer is applied fairly quickly, which is especially nice in times of prolonged rainfall.
- Leaching can be a problem and the drastic change in root zone pH and concentration can cause root burn.

B. Proportional fertigation

- This is the application of fertilizers in a certain concentration proportional to the water. This can be a continuous application where the fertilizer concentration remains constant according to set values and adjustments. The concentration is measured through the electrical conductivity (EC) of the water in milli-Siemens per meter (mS/m).
- With this method nutrients are supplied to the plant over a long period, which eliminates leaching, causing fewer changes in the root environment.
- No equipment need to be moved and connected every time, and a stock solution can be prepared to supply fertilizer for a relatively long time.
- Accumulation of salts can be a problem with this method, but can be monitored and leached.
- Computerized control systems can simplify the complex process of multiple applications to different blocks with different mixture requirements.

7.1 Various dosing or fertigation techniques

Many types of fertigation techniques are being used to inject fertilizer into irrigation systems, varying from inexpensive basic methods like mixing the fertilizer in a supply dam, injection by crop sprayer into the irrigation system, to multi injector units which automatically regulates pH and EC (concentration). The term **dosing** is also used to describe the practice of fertigation.

Various dosing or fertigation techniques can be applied to fertigate proportional or quantitative, and equipment can be used in different combinations, e.g. a venturi injector with pump suction inlet or hydraulic injector. To choose an appropriate application method, the following has to be taken into consideration:

a) Is the fertilizer in liquid or solid (soluble) form?

b) At which point of the irrigation system should the fertilizer be let into the system – at the pump house or into the pipe network, and at what pressure?

c) Whether the system is automated

d) At what stage of the irrigation stand time the fertilizer is to be applied.

e) Whether the fertilizer application rate and the concentration needs to be constant.

The following techniques can be applied:

1 Injection through suction of irrigation pump
2 Pressure tank system
3 Electric fertilizer pumps
4 Hydraulic and Venturi type injectors (connected directly or in parallel)
5 Stock solution in storage dam
6 Crop sprayer injection into system
7 Multi system injection controllers.

i. The injection of fertilizer at the suction pipe of a pump.

This simple apparatus can be assembled by the farmer himself and consists of the following:

a) A fertilizer tank of non-corrosive material such as plastic (polypropylene) or glass fibre.

b) Pipes that are connected to the suction and delivery pipe of the pump.

c) An outlet and inlet valve (to regulate or shut off the flow rate).

- **Method of operation**

The inlet valve is opened and the tank half filled with water. The correct amount of fertilizer in crystalline form (calculated according to the number of plants/sprinklers) is placed into the mixing tank while the inlet valve is open and the tank is filled. When the tank is full and all fertilizer is dissolved, the outlet valve is opened and fertilizer solution is sucked from the tank. Valves are adjusted in such a way that the water level in the tank remains constant until all the fertilizer has been applied. Hereafter the outlet valve is closed and clean water is pumped to rinse all the fertilizer from the system. The tank must not run dry or overflow during irrigation (air in the suction pipe will stop the pump).

Notes:

a) This method can only be implemented with systems where a pump serves one stationary type of irrigation system and where all the sprinklers have to deliver the same fertilizer application.

b) This method has the disadvantage that an even supply rate is not possible because the concentration of the fertilizer decreases progressively.

c) When an even concentration of fertilizer is required in the irrigation water, a standard solution (a concentrated solution of, for example 50 kg urea/l00 L water) is prepared in the mixing tank. This concentrate is then let into the irrigation water and the flow rate thereof is controlled by a valve. The concentration in the water is measured electronically by measuring the electric resistance thereof. If the resistance is, e.g., higher than the determined norm, the concentration is too high and then the control valve must decrease the flow rate. This can be done automatically by connecting the sensor to the hydraulic control valve electronically.

ii. Injection of fertilizer through a pressure tank

This method is usually used where different blocks must receive different applications – according to differences in crops or growth stages. Application is done per block and the pressure tank is moved to each irrigation block. The correct amount of fertilizer is placed into the pressure tank (the pressure tank can also be a mixing tank if the fertilizer is in crystalline form). The pressure tank has a lid that closes tightly so that the pressure in the tank becomes the same as that of the irrigation system.

A pressure tank can be inserted anywhere on a supply pipeline and therefore:

a) one pressure tank on a main pipeline can serve a complete system; or

b) where more than one block is irrigated simultaneously and blocks must receive different applications, the pressure tank is moved to each block.

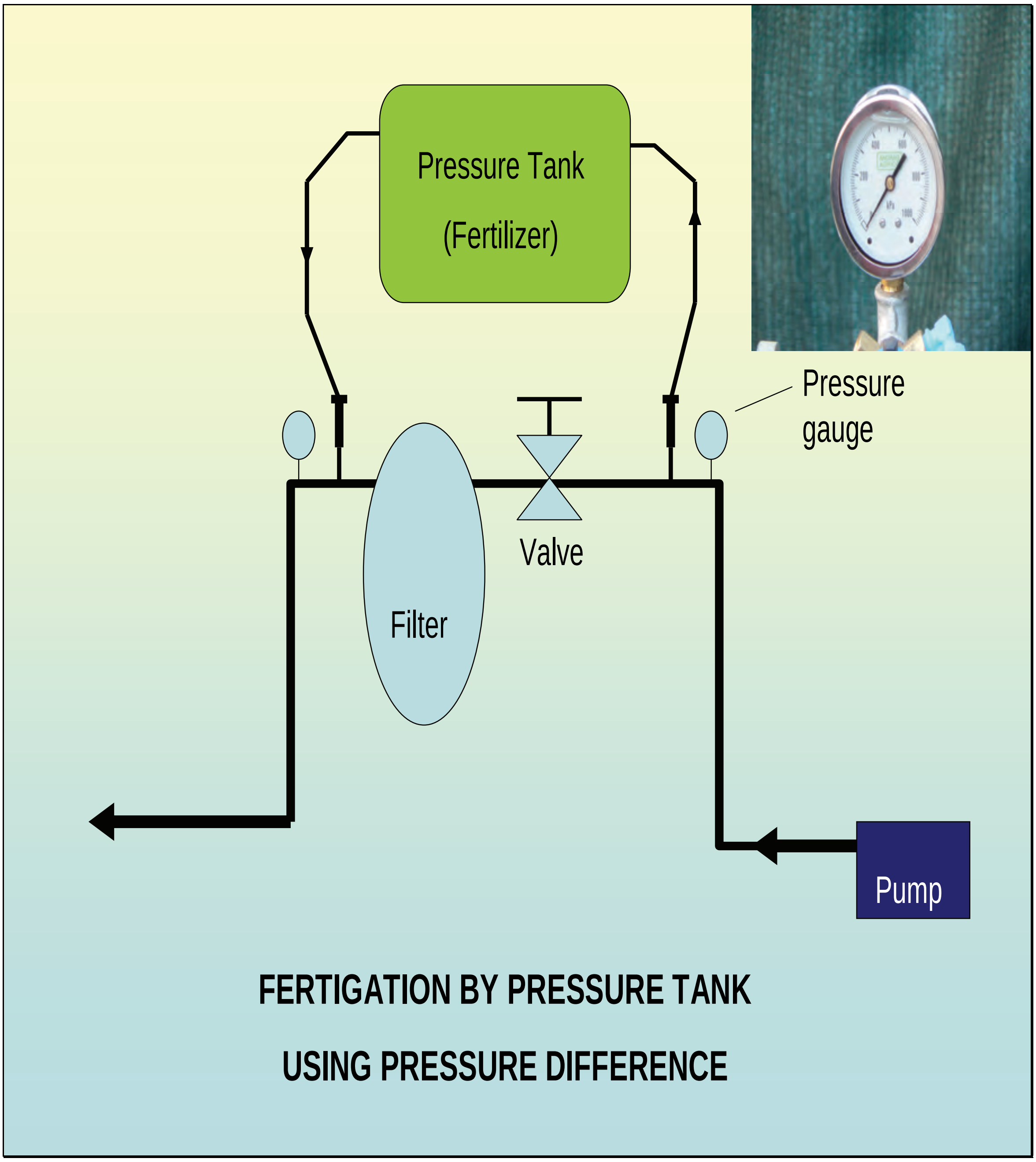

Figure 4. Presentation of the use of a pressure tank

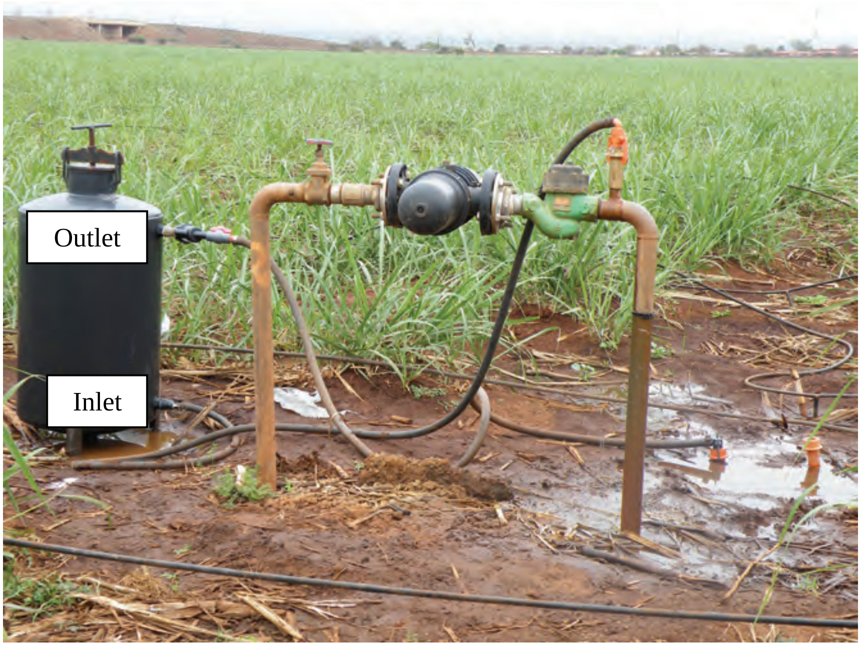

Figure 5. Fertigation with pressure tank

- **Method of operation**

The pressure tank is connected to the pipeline in parallel using two pipes. Fertilizer is mixed in the pressure tank, and the parallel stream of water flowing through the pressure tank gradually supplies the fertilizer to the system. To obtain a flow through the pressure tank an adjustable valve is needed in the pipeline between connections to accomplish a pressure drop.

Note:
1) The connection pipes must have valves for flow regulation.

2) This method has the disadvantage that an even supply rate is not possible seeing that the concentration of the fertilizer decreases progressively.

iii. Injection of fertilizer with a pump

Electrically driven fertilizer and chemical injection pumps are used to pump the fertilizer (mixed to a specific concentration) from the fertilizer tank(s) directly into the supply pipeline of the irrigation system. This is a pump dedicated for pumping fertilizer, and usually is a centrifugal pump that is corrosion resistant and that delivers a higher pressure than in the pipeline. A valve controls the required flow rate. Proportional or quantitative applications can be done with fertilizer pumps.

The flow rate can be kept constant with control valves and can therefore be used with mechanised systems. The method adapts well to automated systems where a computer or controller regulates the required application for each block by switching the pump on and off for certain periods. With an A-tank and B-tank system a pump is usually supplied for each tank to operate independently.

An advantage of the system is that large quantities of fertilizer can be pumped into the system.

iv. Hydraulic and Venturi type injectors (connected directly or in parallel)

These injectors use water flow to inject fertilizer into the system and can be installed directly in line (in small systems) or in parallel. The parallel connection can be done in a number of ways provided there is a pressure difference over the parallel connection.

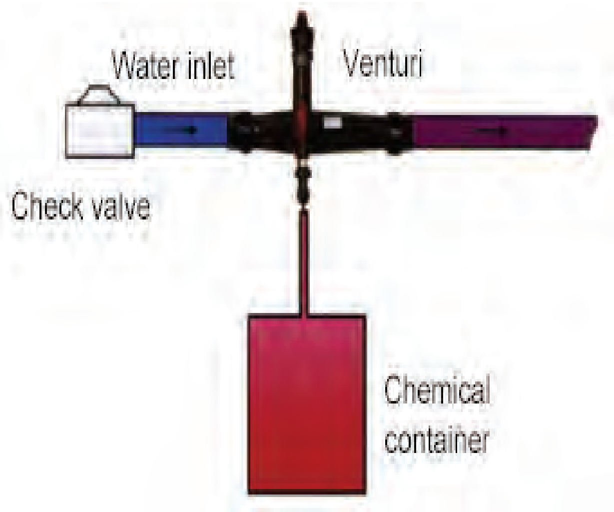

Figure 6. Venturi connected in line

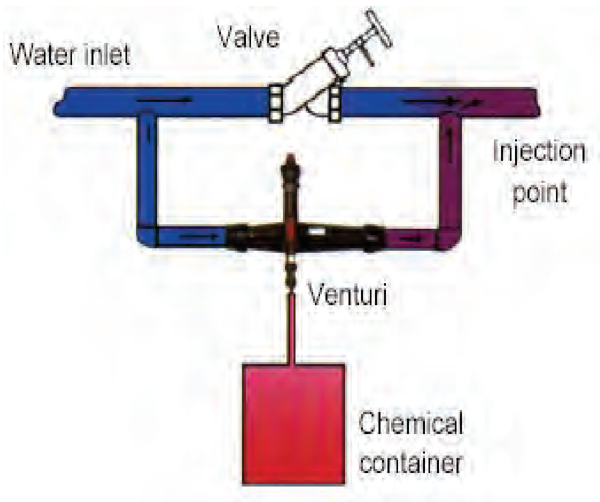

Figure 7. Venturi connected in parallel

Advantages

- no additional electricity is needed and therefore can be used in the fields.
- these injectors are usually very accurate

Disadvantages

- large friction losses occur in parallel connection
- it can only apply small quantities of fertilizer

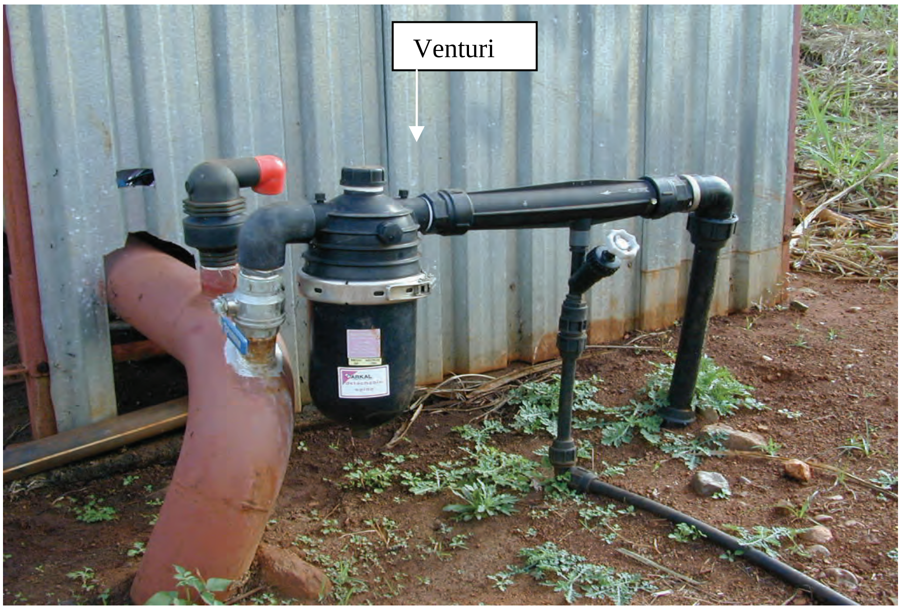

Figure 8. Venturi and filter connected to main line

v. Stock solution in storage dam

This system is usually used in cases where the water source is dedicated to a greenhouse or shade net house where one mono culture crop is grown with a homogenous fertilizer requirement. Plastic lined reservoirs are utilized and the stock solution is mixed in the reservoir either for the growth stage, the duration of the growing season, or for the specific volume of the reservoir. This is a low concentration (low EC) solution measured in mS/m according to the crop requirement. No additional fertilizer tanks or injectors are necessary as the water already contains the required nutrients. Additional fertilizer, acid treatment or chemicals can be added to the irrigation water using most of the other fertigation techniques.

Figure 9. Plastic reservoir covered with shade net for fertigation of vegetables

vi. Crop sprayer injection into system

This is a method used by irrigation farmers where a batch of fertilizer is mixed in the farm crop sprayer and then pumped into the irrigation system at specific blocks. The crop sprayer already exists on the farm and is more efficiently used in this method. The only changes necessary is the provision of injection points at the irrigation valves and the appropriate injector at the sprayer.

Advantages

- no fertigation equipment is needed
- the crop sprayer has its own filters which eliminates the danger of blockages of the irrigation system
- fairly easy to apply a specific mixture to each irrigation block

Note:

- With quantitative fertigation the amount of fertilizer is calculated per hectare, and is applied according to the given fertilizer recommendations.
- With proportional fertigation the injection of fertilizer is calculated according to the system flow rate to have a certain litres of fertilizer solution per m^3 of water.

vii. Multi system injection controllers

These are hi-tech computerised systems able to apply different mixtures at different concentrations to a variety of crops or growth stages. In most cases a system of multiple tanks is used where each tank contains a single type of fertilizer. The multi system injector comprises a number of injectors – usually venturis – each connected to a specific tank.

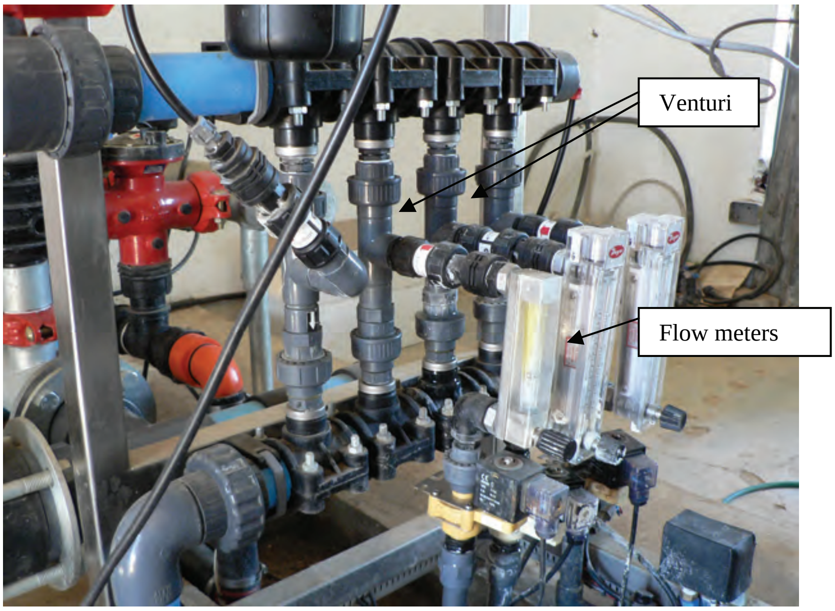

Figure 10. Multi injectors with flow meters

The system computer then regulates the amount of each fertilizer that needs to be pumped into the mixture. This is done according to certain pre determined values, and is regulated by continuous EC and pH measurement to prevent too high concentrations of nutrients.

Figure 11. Greenhouse controller

Figure 12. Controller and injection system

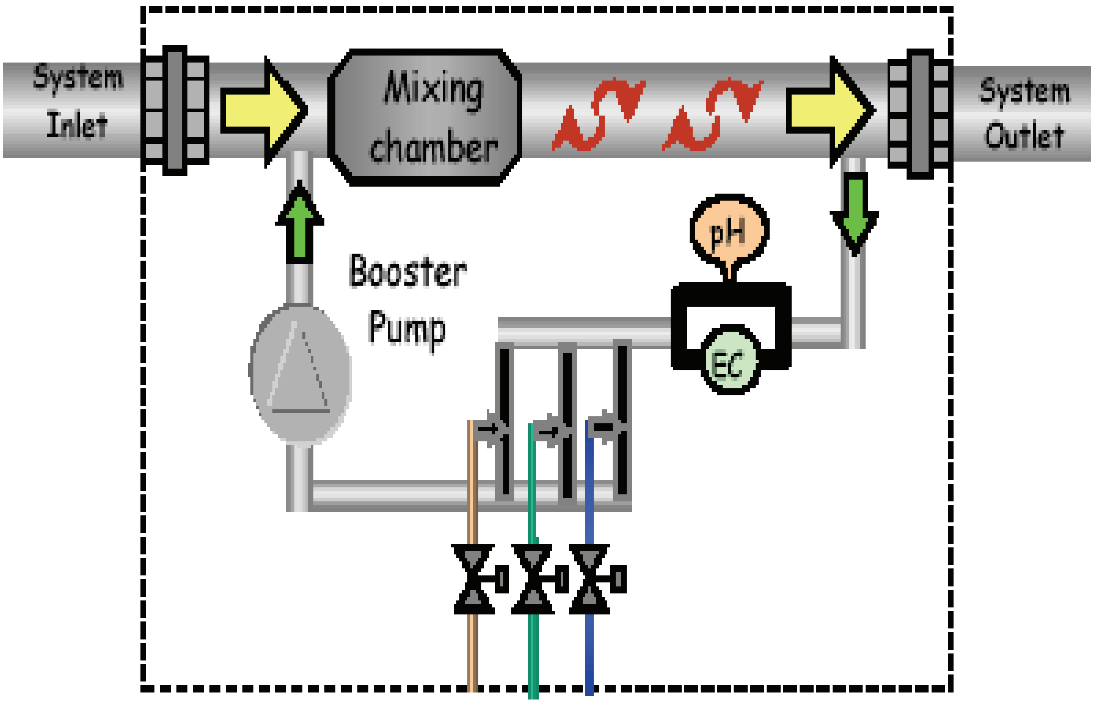

Figure 13. Schematic drawing of controller and injection system

These multi controller systems are mostly used in larger greenhouses and clusters of tunnels or greenhouses. The biggest advantage is that **proportional fertigation is done accurately**

and automatically. The system does however require highly skilled technicians to install, and well trained operators for day to day operation. Although crop management is made easier, it requires careful and accurate management (inputs). Initial costs are also much higher than manual systems.

Figure 14. Fertilizer control room

8. Units and ratios in fertigation

As mentioned earlier the concentration of fertilizer in water is monitored measuring the EC in mS/m. This concentration represents a certain ratio of nutrients to volume of water. In fertigation programs various units are used to describe the ratio or amount of fertilizer that needs to be applied. Table 4 provides conversion figures between different units.

Table 4. Units and Ratios[4)]

%	Ratio	Gram / litre	Kg / m³	PPM **	Mg / litre *
0.2	1:1500	2	2	2000	2000
0.5	1:200	5	5	5000	5000
0.8	1:128	8	8	8000	8000
1.0	1:100	10	10	10 000	10 000
1.6	1:64	16	16	16 000	16 000
2.0	1:50	20	20	20 000	20 000
3.0	1:33	30	30	30 000	30 000
3.3	1:30	33	33	33 000	33 000
4.0	1:25	40	40	40 000	40 000
5.0	1:20	50	50	50 000	50 000
8.33	1:12	83.3	83.3	83 333	83 333
10	1:10	100	100	100 000	100 000

* *mg/L = PPM = mg/kg*

** *PPM = Parts per million*

8.1 Practical conversions

What is parts per million?

- 1 mg in 1 L = 1 ppm
- 1 gram in 1 m³ = 1 ppm
- 1 ml in 1 m³ = 1 ppm

1 gram in 1 Liter = 1000 ppm	1 gram 1 m³ = 1 ppm
800 gram in 1 m³ = 800 ppm	25 gram in 1 m³ = 25 ppm
5 gram in 1 m³ = 5 mg / L	20 kg in 1 m³ = 2%
4% = 40 000 ppm	4% = 40 g / L = 40 kg / m³
220 ppm = 0.22 kg / m³	55 ppm = 0.055 kg/m³ = 55 g / m³
280 ppm = 280 g / m³	1:50 = 20 g / L = 2% = 20000 ppm

8.2 Calculations and Calibration of fertilizer injections

With stationary irrigation systems an accurate application *rate* of the fertilizer is not very important. The *amount* of fertilizer that is put into the tank is calculated by multiplying the prescribed amount of fertilizer per hectare by the area (ha) that has to be irrigated at a time. All of the fertilizer must be used during the course of that irrigation.

With mechanised (moving) systems, it is important that the fertilizer solution must be injected at the *correct and constant rate*. To calculate the flow rate, it is best illustrated by means of an example.

Example 1

The farmer needs to apply 50 kg Urea(46) per hectare to his wheat crop. His centre pivot system has a flow rate (Q_{Sys}) of 210 m³/h and it takes 46.3 hours to apply a gross irrigation of 18 mm on an area of 54 ha.

Total Urea required for 54 ha is thus: 54 ha x 50 kg/ha = 2 700 kg.

The urea is dissolved in water in a 5000 L tank (reservoir) ($V_{Res} = 5\ m^3$).

(See Table 2 solubility of urea = 105kg/100L). [2700 / 5000 x 100 = 54 <105]

This concentrate must be injected into the supply pipeline by a fertilizer pump at an even flow rate of Q_{Fert} so that the 5000 L (5 m³) solution is finished, as soon as irrigation of the 54 ha is completed.

$$\text{Thus } Q_{Fert} = \frac{V_{Res}\ (L)}{T} = \frac{5000\ L}{T\ (h)} = \frac{5000\ L}{46{,}3\ h} = 108\ L/h$$

Fertilizer application rate [Q_{Fert}] = **108 L/h** for 46.3 hours

[Urea contains 46% N, therefore an application of 50 kg x 46% = 23 kg N is applied per hectare.]

Example 2

The requirement of a tomato field is 60 kg N per hectare. It is planned that Ammonium Sulphate (21%N) will be used.

The amount of Amm. Sulph. (21) required is calculated by dividing the required application by the content percentage of the fertilizer type

60 kg / 21% = 285 kg (60 / 0.21 = 285)

The amount of N per plant can also be given and is more accurate. Plants require an application of 8 g N. The plants are spaced 1.5 m between rows and 0.6 m in the row. The number of plants per hectare is then calculated according to the plant spacing:

10 000 m² / 1.25 m / 0.6 m = 13 333 plants per hectare

13 333 plants x 8 g = 106 664 g = 107 kg N per hectare

The amount of Ammonium Sulphate (21) required is calculated:

107 kg / 21% = 509.5 kg Amm. Sulphate (21)

= 21 bags (25 kg) of Ammonium Sulphate (21)

Example 3

A farmer has 5 ha green peppers and applies fertilizer on a weekly basis. His drip irrigation system is divided in 10 blocks, and all fertilizers are applied per block through the drippers. The plants are spaced 0.5 m in the row and 1.2 m between rows. According to the program he has to apply 5 g P per plant. He decides to use MAP as a source, which also contains nitrogen. [12%N, 26%P]

The amount of kilograms MAP that needs to be applied per block is calculated as follows:

5 hectares divided into 10 blocks = 0.5 ha per block.

Number of plants per block = 5000 m^2 / (0.5 x 1.2) = 8333 plants / block

5 g per plant x 8333 plants = 41 665 g/plant

= 41.6 kg P per block

41.6 kg P / 26% = 160 kg MAP to apply 5 g P per plant on 5 ha.

With this application the amount of grams N per plant applied is calculated:

160 k g MAP x 12% = 19.2 kg = 19 200 g N per block

19200 g N / 8333 plants = 2.3 g N per plant

9. Precautionary measures with fertigation[4,6,5)]

9.1 Prevention of damage to equipment and crops

Fertilizer can damage crops as well as equipment and the following precautionary measures must be taken:

a) Because the fertilizer concentration in the irrigation system is usually low, corrosion is not a serious problem but can be limited by:
   (i) using the lowest possible concentration;

   (ii) rinsing the system with clean water after fertilizer application; and

b) Where the fertilizer concentration is high, e.g. in the tank, fertilizer pump, connection pipes and valves, corrosion resistant material such as uPVC, polyethylene or polypropylene should be used. More resistant (but more expensive) metals, such as stainless steel, yellow copper, phosphor bronze, galvanised steel and aluminium can be used. However if aluminium is used with copper alloy, corrosion of the aluminium is quickened. Where corrosion occurs or where steel is used, a protecting epoxy layer can prevent corrosion.

c) A fertilizer concentration of >0,2% can, especially during sunny weather, cause damaging of the leaves, (leaf burn). It is thus advisable to avoid hot days and rather give smaller applications more often.

d) Nitrogen compounds, such as urea, Ammonium Nitrate (NH_4NO_3) and Ammonium Sulphate $(NH_4)_2S0_4$ can possibly precipitate with water that contains a high Ca and Mg content. Soluble fertilizer mixtures can also precipitate with water that has high iron content. This can cause clogging of especially micro jets and drippers. It is thus advisable to inject the fertilizer before the irrigation water has been filtered.

   (The use of phosphoric acid as fertilizer also prevents the clogging and coating of the system.)

e) The compatibility of chemicals must be confirmed.

f) If the danger exists that, during a power failure, concentrated fertilizer ends up on the field or in the water source**,** a safety measure such as a one-way valve and a pressure sustaining valve between the fertilizer tank and the irrigation system, is essential.

9.2 Loss of fertilizer

Fertilizer can be lost as a result of leaching and evaporation (volatilisation). Nitrogen in the form of an ammonia solution is very volatile and is not recommended for fertigation. However, because it is cheap, it is widely used and is applied deep underneath the soil surface with a subsoiler. Ammonium nitrate or urea is usually applied as a top dressing. If the pH of the water is higher than 7.5, the loss of nitrogen, as a result of evaporation, is higher with urea than with an ammonium compound which in turn is higher than with a nitrate compound [urea evaporates > ammonium compound > nitrate compound].

However, with a nitrate compound, the loss of nitrogen because of leaching, is a bigger possibility ($N0_3$ moves through the soil easier and NH_4 evaporates easier).

The following techniques are applied to limit the losses:

a) Due to the fact that evaporation usually occurs from the soil surface, it is advisable to stop applying fertilizer during the last 15 minutes of irrigation. This technique cannot be applied with mechanised systems, but N-loss, as a result of evaporation, is seldom >5%.

b) To limit the loss of fertilizer, as a result of leaching the fertilizer must be placed in the top section of the root zone.

   Depending on the design application and the flow rate of the fertilizer pump, the application can occur by:

   (i) applying clean water for the first 25 minutes;

   (ii) injecting the fertilizer for the next 10 min; and

   (iii applying clean water for the last 15 minutes.

10. Herbigation, insectigation, fungigation and nemigation

The acceptability of pest control through irrigation systems depends on factors such as type of system, soil type and how the pest control program adapts to the irrigation schedule. Especially with mechanised systems, the high application for irrigation purposes is not reconcilable with the low application limit that pesticides demand. Additional sprinkler packages for centre pivots are available for application of chemicals.

10.1 Application techniques

The same application equipment used for fertigation can be used for pest control. Seeing that chemicals used for pest control poses a threat of polluting the water source if the concentrate flows back, strong measures must be applied to prevent this. The following application techniques can be applied:

a) Irrigation equipment such as linear systems, spray boom on a travelling gun and centre pivot systems can be changed to operate as ordinary pest control sprayers **when no irrigation takes place.**

b) With these mechanised systems, the pesticide can also be **applied at a constant rate** with the irrigation water. The irrigation implement must move fast enough to ensure a small enough application.

c) With stationary systems, the pesticide is applied with the irrigation water **at the end of the application.**

Note:

1 Chemigation is efficient with herbicides that have to move through a certain depth of the soil profile, or with systemic chemicals that have to be absorbed by plant roots.

2 Where the chemical has to be placed onto the plant, a too large application can wash it off.

10.2 Precautionary measures with chemigation

Strict safety measures are required where chemicals can cause poisoning of people, animals and plants. Poisoning can be caused by:

a) Pesticide concentrate that, after an application or during an interruption, flows from the tank through the irrigation system to the water source or field as a result of leakage of a defective or open valve (siphoning can aggravate such a leakage);

b) The irrigation system pump stalling for some unknown reason while the injection pump keeps on running;

c) Labourers drinking the water of the irrigation system;

d) Pesticide applied excessively because of incorrect calibration.

The following measures can be taken to prevent poisoning:

a) Calibration must be calculated precisely and applied carefully.

b) Equipment must be checked regularly.

c) A non-return valve will prevent water flowing back to the water source.

d) A vacuum breaker (air inlet valve) between the non-return valve and water source, decreases the danger of a significant amount of contaminated water being sucked through the non-return valve (that possibly does not close 100%) to the water source.

e) A pressure switch on the irrigation system switches the electrical supply to both motors (irrigation system and injection pump) off as soon as the pressure, as a result of a fault, becomes too low.

f) A solenoid valve in the connection pipe (both pipes at a pressure drop system) closes as soon as the electric supply is switched off.

g) Where a diesel engine is used as a power source, the injection pump with a V-belt drive works from the same power source.

h) Strict control and precise supervision is necessary.

Note: Although it does not pose a threat to anybody, it is necessary to ensure that clean water does not leak into the chemical tank as dilution of the mixture influences the calibration.

11. Measures against clogging of irrigation equipment[3,4,6)]

Filters cannot remove all impurities that coat pipe walls and cause clogging of emitters. Colloid (a gelatinous substance in suspension) algae, bacteria and water-soluble salts pass through filters and coat pipe walls. Filters also don't function properly as a result of coatings of algae, ferrous bacteria and precipitates of salts. Plant roots that enter underground dripper lines also create problems.

Certain chemical measures can be applied to:

a) prevent clogging of equipment; and

b) clean clogged equipment.

11.1 Chlorination

I. Timing of chlorination

Slime is formed by iron bacteria if there is 0.3 mg/L iron in the water with a pH between 4.0 and 8.5. Algae are microscopic plants that can pass through a filter. They grow by absorbing nutrients from the water. Algae and slime coat the pipe walls and the flow-path of drippers and if they come loose they can clog the nozzles. Algae slime and plant diseases such as phytophtora can be controlled by chlorination. Accordingly it is recommended that chlorination must be done at least once or twice a year if clogging is not a serious problem. The actual rate can be determined by using a sludge trap. A sludge trap consists of a painted plastic bottle that is connected to a lateral by a micro tube. Inside is a glass plate that can be removed. When the glass plate becomes dull, it is time to chlorinate.

Note:

1 Because some types of algae need sunlight to grow, it is advisable to cover reservoirs with plastic or shade net where possible.

2 Water that contains >0.4 mg/L Fe can, during chlorination, cause the iron to precipitate to such an extent, that clogging of the irrigation equipment can occur. Water must thus be stored for a while to enable the precipitate to settle at the bottom, before using the water.

3 Where the iron content of the water is very high, it can be uneconomical to purify the water for drip irrigation and alternative irrigation methods must be considered.

II. Method of chlorination

One of the following methods can be applied:

a) Calcium hypochlorite granules (65%) are dissolved in water and pumped into the irrigation water for one hour by a fertilizer pump preceding the filter. A DPD chlorine test apparatus (swimming pool test) is used to test the concentration. Six grams of granules per m³ irrigation water produce a concentration of 2 mg/L at the end of the irrigation system.

b) Chlorine gas (100% pure Cl) is injected into the irrigation system. Although the application apparatus is expensive, it can be more economical because the free chlorine that is used is cheaper.

***Note**: Laterals must be rinsed after chlorination.*

a. Calcium Hypo-Chloride (HTH swimming pool chlorine). This is a dry granular product with active concentrations of between 65 and 70%.

Formula 1

Determination of the solution concentration with the use of a fixed injection rate:

$$\text{Concentration HTH solution \%} = \frac{\text{required chlorine (ppm)} \times \text{system flow rate } (m^3/\text{hour})}{\text{Injection rate of pump (l/hr)} \times 10 \text{ (constant)}}$$

Note: maximum concentration of 4% is advised to avoid flocculation.

Formula 2

Determination of the quantity Cl product required for a given container:

$$\text{Kg or Litre of } Cl^- \text{ product} = \frac{\text{concentration of Cl solution (\%)} \times \text{Capacity of container}}{\% \ Cl^- \text{ in Product}}$$

Example

Example

Calcium Hypo-Chloride 67% active.

Require 15 ppm Cl- for injection.

System flow rate is 30 m³/hour.

Delivery of injection pumps is 100 litres per hour.

Capacity of container is 200 litres.

Fill with 150 litre of water.

1. Concentration HTH solution = $\frac{\text{required 15 ppm X 30 m}^3\text{/hour}}{\text{100 litres per hour X 10}}$
= 0.45% concentration

2. Kg of HTH product = $\frac{\text{0.45 \% concentration X 150 litres water}}{\text{67\% Cl- in HTH}}$
= 1.0 kg of HTH

Summary
We must dissolve 1.0 kg HTH in 150 litres of water. This gives us a chlorine solution of 0.45%. If we then inject this 0.45% chlorine solution at a rate of 100 litre per hour, we will get the required 15 ppm chlorine at the injection point, with a system flow of 30 m³/h.

III. Duration of injection

Keep on with the injection for 20 minutes after 0.5 – 3.0 ppm active (measured with a swimming pool test kit that can test for "free available chlorine") chlorine is measured at the last dripper. Measure while dripper is dripping, do not open the end of dripper line. The higher the biological activity in the water, the longer it will take to measure active chlorine at the last dripper.

IV. Point of injection

Do the injection at the block valves. In the case where injection must be done at a central point, the main-line must be cleaned before any block valves are opened, if this is not done, all the dirt from the main-line will move to the drip lines and worsen the existing problem.

V. Flushing of the system

Flush the main and sub-main and then the dripper lines, only one or two lines must be flushed at a time. Flush before and after treatment.

WARNING

1 Chlorine is very dangerous to people and must be handled very carefully by a **responsible person.**

2 When chlorine and fertilizer mix, a violent reaction takes place. Do not fertilise and chlorinate simultaneously.

3 Plants are influenced negatively by a singular application of 50 mg/L or a prolonged application of 15 mg/L (tobacco, especially and also citrus and avocado are sensitive)

4 Chlorinated water must not be sprayed onto the leaves of plants as this can cause leaf-burn.

VI. Dosages of chlorine that can be applied[4)]

a) For algae use, 0.5 up to 1.00 mg/L continuously or 20 mg/L for 20 minutes during each irrigation.

b) For iron-bacteria, use 1 mg/L more than the mg/L present. (This can vary depending on the amount of bacteria present).

c) To precipitate iron, use 0.64 x the Fe content of the water.

d) To precipitate manganese, use 1.3 x Mn content.

11.2 Hydrogen peroxide (H_2O_2)

The aim of this treatment is to solve problems that normal chlorine treatments do not solve. Hydrogen peroxide is more aggressive than chlorine to loosen residues in pipes.

i. Product

Hydrogen peroxide reduces the incidence of Fusarium and Verticillium fungi in soils and growth mediums. It reduces the growth of algae and slime in volcanic rock medium, greenhouse containers as well as irrigation systems. Hydrogen peroxide is used in water at 30 to 50 ppm in vegetables and flowers to reduce the above mentioned. The advantage of using Hydrogen Peroxide is the rapid reaction; it is environmentally friendly and does not cause dangerous residues.

ii. Influence of the pH of irrigation water

Hydrogen peroxide is not sensitive to high pH like chlorine.

iii. Recommendations[4,6)]

Treatment	When *	Injection concentration (ppm) **	Concentration at end of system (ppm)
*** Shock treatment	Annually	200 – 500	100 – 250
Once off treatment	As required	30 – 50	8 – 10
Normal maintenance	Every second week	5 – 10	2 – 3

Notes:

1. * Depending on water quality.

2. Do not apply this treatment continuously.

3. ** Never exceeds concentration of 500 ppm Hydrogen Peroxide.

4. *** Shock treatment not recommended while plants are actively growing in an artificial growing medium.

iv. Corrosion

Hydrogen Peroxide is a corrosive agent for steel, aluminium, cement coating and asbestos cement. In contrast, tanks made of Polyethylene and PVC is not sensitive to Hydrogen Peroxide. It is vital to take these factors into consideration when planning treatment.

v. Hydrogen peroxide is a strong oxidizer

It prevents the accumulation of bacterial slime in pipes and dripper line extensions.

Clean the dripper lines in which organic sedimentation and bacterial slime have accumulated.

- Oxidizes microelements to prevent the development and reproduction of bacteria (iron, manganese and sulphur).
- Improves the efficiency of initial filtering under high organic stress conditions.

- Disinfects sewage and wastewater, irrigation water, drinking water and swimming pool water.
- Prevents and remove odours in the water, impairing biological activity.
- Lowers BOD / COD values by oxidizing the polluting substance, both organic and inorganic.
- Is not effective for the prevention or dissolution of scale sediments, sand and silt.

11.3 Combination treatment[5,4)]

Where normal chemical treatments do not give satisfactory results you could try a combination treatment. Practical experience show good results by doing an acid treatment with a hydrogen peroxide treatment directly after it.

Before treatment | After one treatment | After two treatments

11.4 Calculations

Formula 1

Determination of the solution concentration with the use of a fixed injection rate:

$$\text{Concentration peroxide (\%)} = \frac{\text{Required peroxide (ppm) X system flow rate m}^3\text{/hour)}}{\text{(Injection rate of pump (L/hour) X 10(constant)}}$$

Formula 2

Determination of the quantity H2O2 (litres) needed for a given container:

$$\text{Peroxide needed (L)} = \frac{\text{concentration peroxide solution (\%) X capacity of container (litre)}}{\text{\% Hydrogen peroxide (35 or 50)}}$$

Example

Example

Required 200 ppm hydrogen peroxide for injection.

Use product with 50% concentration.

System delivery is 30 m³/hour.

Delivery of injection pump is 100 litres per hour.

Holding tank is 200 litres.

Fill with 150 litres of water.

Calculation

1. Concentration peroxide solution (%) $= \dfrac{\text{Required 200 ppm X 30 m}^3\text{/hour}}{\text{100 litres per hour * 10}}$

= **6.0 % concentration**

2. Litres peroxide needed = $\dfrac{\text{6.0\% concentration X 150 litres water}}{\text{50 \% H2O2}}$

=**18 litres H_2O_2**

Summary

We must add 18 litres hydrogen peroxide to 150 litres water. This gives us a 6.0% hydrogen peroxide solution.

If we then inject this 6.0% solution at a rate of 100 litres per hour into a system with a flow of 30 m³/hour, we will get the required concentration of 200 ppm hydrogen peroxide at the injection point.

11.5 Step by step practical guidelines for using hydrogen peroxide

- Get the system to working pressure and check all lines.
- Irrigate for one hour with clean water to protect roots.
- Connect the fertilizer injection pump to the block that needs to be treated.
- Turn on the injection pump with clean water and calibrate required rate.

- Do calculations and prepare the solution that must be injected.
- Inject the hydrogen peroxide to required concentration in the water.
- After treatment, flush injection equipment with clean water.
- System can stand for 12 to 36 hours.
- Flush system.

- **Duration of injection**

Keep on with the injection for one hour or time of travel (time it takes for a drop to travel from injection point to last dripper). Use the method that takes the longest. The higher the biological activity in the water, the longer it will take.

Use hydrogen peroxide kit (paper strips) to measure concentration (ppm), if value is higher than the ability of the measuring strip, the sample should be diluted with water.

To calculate results multiply the value received by the dilution factor.

- **Standing time**

Let the system stand for 12 to 36 hours so that the chemicals that have not drained out of the system can work. The lifespan of peroxide is a few days and not as short as chlorine. Flush the system after this time. Flush the main and sub-main and then the dripper lines, only one or two lines must be flushed at a time.

- **Point of injection**

Do the injection at the block valves. In the case where injection is done at a central point, the main-line must first be flushed before any block hydrants are opened, if this is not done, all the dirt from the main-line will move to the dripper lines and increase the existing problem.

SAFETY[5)]

Hydrogen peroxide solutions are very dangerous to man and animals. Follow the manufacturers' instructions with regard to use and handling.

- Avoid eye and skin contact. Wear protective clothes, gloves and glasses.
- Avoid drinking or inhalation of gasses.
- Store separate from other chemicals.
- Always add hydrogen peroxide to water and not vice versa.
- Use clean water, not fertilizer enriched water during hydrogen peroxide treatment.

WARNING
Contact with the Hydrogen Peroxide preparation may cause burns, contact with the eyes may cause blindness, and swallowing may cause death. All operations related to Hydrogen Peroxide preparation (filling the storage tank, etc.) - always use protective goggles, gloves, and shoes and clothes suitable to prevent contact between the substance and exposed skin. Before filling the tank with the substance, verify that it was thoroughly rinsed and clean of fertilizer. Direct contact between Hydrogen Peroxide and some of the fertilizers containing ammonia causes rapid heating and may sometimes cause the tanks to explode. This is a lethal hazard for anyone in the vicinity.

12. Flocculation, aeration and sedimentation[4)]

12.1 Flocculation

Water is murky because solid particles repel each other to stay in suspension for an indefinite period. By adding flocculants such as aluminium sulphate ($Al_2[S0_4]_3$) or slaked lime, the repulsive force of the colloid is removed and a flocculate is formed. The flocculate sinks to the bottom after a few hours and crystal clear water is ready for use. The amount of flocculants needed depends on the dirtiness of the water. Flocculation does not remove soluble salts and iron-bacteria and salts that precipitate remain a problem. Murky water that has passed through a filter is usually no problem with irrigation seeing that any sediment that settles at the bottom and that can cause clogging, can be removed at low cost by rinsing the laterals.

12.2 Aeration and sedimentation

The iron content of water can be reduced by sedimentation. When oxygen comes into contact with the iron solution, it oxidises to insoluble sediment that settles at the bottom of the dam if the water is stored in the dam for some time. This process takes place naturally where air comes into contact with the water surface of a water stream or dam. This process can be speeded up by:

a) allowing water to fall through the air, or by pumping air through the water supply;

b) and applying chlorine at a dosage of 0.64 x iron content.

Notes:

1 The natural sedimentation processes in a sedimentation dam takes place slowly and continuously with the result that the top layer of water contains less iron. It is therefore advisable to withdraw water from the top layer of water in the dam. This can be done by fixing the suction pipe to a float. When there is an abundance of water, the bottom layer of water can be let out to get rid of the iron.

2 Iron bacterium can also be harmful when sprayed onto the leaves of plants.

12.3 Acid treatment

A too high concentration of soluble salts (that cannot be removed by a filter) can, at a pH > 7.5 cause coating of pipes and clogging of emitters. Sedimentation reactions such as the formation of insoluble carbonates and oxides cause clogging and can be identified as follows:

a) Calcium carbonate forms white sediment.

b) Iron oxide forms rust coloured sediment.

c) Manganese oxide forms black sediment. *(Note: Clogging as a result of microbiological activity is also black)*

Adding sulphuric, hydrochloric, nitric or phosphoric acid to the irrigation water can prevent clogging. Enough acid is added to bring the pH down to 2 for a period of 1 hour. The quality of the water will determine how often acid treatment must be applied. However, if the acid causes the soil pH to drop too low, a lime application could be necessary.

Notes:

1 The system must be flushed out after acid treatment.

2 Because phosphoric acid is a fertilizer, it is advantageous to use it in a fertilisation program so that it simultaneously also prevents clogging.

WARNING[5)]

Acid can be added with a fertilizer pump, but the following must be taken note of:

a) A high concentration of acid can corrode metals, cement and can only be used with PVC or polyethylene systems.

b) Phosphoric acid, at a low concentration, can be used with AC or metal pipe systems to lower the pH sufficiently to prevent precipitation.

c) Concentrated acid can safely be added to water, but adding water to concentrated acid causes a violent reaction.

12.4 Pulsating drip irrigation

Pulsating irrigation implies that, instead of a flowing irrigation to be applied continuously, the system is shut off intermittently for determined periods (for example 30 min). It is found that less dripper clogging occurs when this method is used. The reason for this is that:

a) where pressure-compensating emitters are being used, it is because, during shutting off and opening of the water supply, because of the drop in pressure, the flow path is enlarged, causing accumulated dirt to be dislodged.

b) where dripper lines are installed below the soil surface, plant roots could clog the drippers. Where pulsating irrigation is applied, the soil in the immediate vicinity of a dripper is always waterlogged. This, as a result of oxygen deficiency, prevents roots from developing there.

12.5 Measures to remove a coating of sludge, algae or sediments

With drip irrigation, it is better to prevent clogging rather than to clear clogged drippers. This is because there is no way to get a cleaning agent such as chloride or acid into a clogged long flow path dripper. In all treatments mentioned above it can be of great assistance to physically tap the dripper with a piece of poly pipe that will loosen particles stuck in the flow path or drip pipe. This will not damage the dripper but will add to the chemical processes.

Coatings of precipitates, algae and slime (iron bacteria) can be removed from irrigation equipment by chloride, peroxide or acid treatment, but the concentration must be significantly higher than with preventative measures, and the system must be flushed out after such a corrective treatment. Each lateral can be opened at the end to let the dirt out there, or laterals could be joined to a flush pipe and be let out via a flush valve.

Activity

Activity 1

Individual activity

1. Explain why fertigation is an important method used to apply fertiliser and other chemicals in farming practices.

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2. What disadvantages exist in the application of fertilisers through fertigation?

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3. According to your fertiliser programme you need to apply Potassium Sulphate. According to the product solubility, how many kilograms can you mix and dissolve in a 5000 L tank at a water temperature of 20°C?

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4. The fertilizer recommendation for the week on a specific 3 ha block of avocado is as follows:

   75 kg $CaNO_3$ per hectare and 50 kg MAP per hectare.

   a. Indicate why you would (or would not) mix the fertilizers together in a tank.

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5. The spacing of avocado trees is 8 m x 10 m. The MAP contains 12% N and 26% P. Calculate the amount of P that will be applied per tree through the application of 50 kg MAP on the 3 hectares.

   How many kilograms of potassium nitrate (KNO_3) should be applied to the block to apply 30 g of K per tree? [It contains 13% N and 38% K.]

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6. With the above application of KNO_3, how many grams of N is applied per tree?

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My notes............

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Authenticators:

- Mr G Mostert

Module 9

Irrigation benchmarking

Study objective

After completion of this module, the learner should be able to have a basic understanding of:

- Best irrigation practices
- Which irrigation performance indicators to take into consideration with the evaluation of irrigation performance

Table of contents

Irrigation practices as we have seen in these modules discussed as part of Part 4 have the potential to increase the crop yield and the quality of the crop. However, in many areas of South Africa water availability or water quality is a problem and can severely impact on irrigated agriculture. The ability to irrigate however does not automatically guarantee an increase in crop yield and quality, and therefore profitability and long term sustainability of a farm. Inappropriate irrigation management practices may lead to crop stress, impact negatively on the environment through groundwater and surface water contamination, erosion and salinity. This module looks at what to take into consideration that may affect the irrigation performance on the farm, and will help with planning and management of irrigation.

1. What is the best practice?

The measurement of the current performance and the identification of practices to improve the performance are commonly regarded as "best practices". It is not always possible that the

Irrigation system is perfect, but the irrigator with the support of the irrigation extensions should be able to identify areas where an improvement is possible and thus can increase the profitability of the farm.

The specific best practices on an irrigation farm will vary between farms, depending on a wide range of factors (physical, capital and human factors) It is important for the irrigation extensions to help the irrigator to identify his/her current irrigation management performance, and then to set goals to improve the irrigation efficiency on the farm.

2. Irrigation management performance checklist

The following approach with this assessment is that "if you do not measure it-you cannot manage it..." The following checklist can be used by either the irrigation farmer (more commercially oriented farmer) to evaluate his current status of irrigation performance on the farm or it can also be used by the irrigation extensions for the determining irrigation issues which could affect the profitability on the farm.

Step 1: Answer the following questions in relation to the current irrigation practices.

1. Water resources					
Q1: Is there enough water for the cropped area?					
Score 1:Not	2	3	4	5:Aequate	Final score
Q2: Can enough water be delivered to meet the crop peak water requirement?					
Score 1:No	2	3	4	5:Adequate	Final score
Q3: Is a strategy in place to manage periods of limited water availability?					
Score 1:No plan	2	3	4	5:Detail plan	Final score
Q4: Is there a water management plan for the farm available?					
Score 1:No	2	3	4	5:Detail plan	Final score
2. Infrastructure: On farm pumping, storage and distribution system					
Q1: What is the energy costs associated with irrigation?					
Score 1:Not assessed	2	3	4	5:Low cost per ^{m3}	Final score
Q2: How efficient is the on farm storage?					
Score 1:Poor	2	3	4	5:Excellent	Final score

Q3: How efficient is the on farm distribution system?					
Score 1:Poor	2	3	4	5:Excellent	Final score
Q4: What is the current physical condition of the farm pumping (pump house), water storage and distribution system?					
Score 1:Poor	2	3	4	5:Excellent	Final score
3. In field application system					
Q1: Is the irrigation system operating at the design pressure for the specific filed?					
Score 1:Unknown	2	3	4	5:At the design pressure	Final score
Q2 How evenly is the irrigation system applying water to the field?					
Score 1:Poor	2	3	4	5:Excellent	Final score
Q3: Is the rate of water application by the irrigation system to the field measured (known)?					
Score 1:No	2	3	4	5:Yes regularly measured	Final score
Q4: What is the current physical condition of the irrigation system?					
Score 1: Unknown	2	3	4	5:Excellent	Final score
4. Irrigation management on the farm					
Q1: Is record kept and comparisons made of crop yield /volume of water as per irrigation field?					
Score 1: No	2	3	4	5:Yes, routinely	Final score
Q2 Is irrigation scheduling practised on the farm by using a tool to modify irrigation practices?					
Score 1: No	2	3	4	5:Yes, regularly	Final score
Q3: How well is the irrigation interval and volume applied with the crop water requirements and the soil limitations?					
Score 1:Poor	2	3	4	5:Excellent	Final score

Q4 Is irrigation practices modified according to weather conditions?					
Score 1:No	2	3	4	5:Yes always	Final score
Q5: Are there signs of runoff due to irrigation practices?					
Score 1:Yes	2	3	4	5:No	Final score
Q6What is the quality of the irrigation water?					
Score 1: Unknown	2	3	4	5:Excellent	Final score
Q7. Are there signs of erosion associated with the irrigation practices?					
Score 1: Unknown	2	3	4	5:No erosion due to irrigation	Final score
Q8. Are the irrigation practices coordinated with other farming system operations?					
Score 1: no integration	2	3	4	5:Well coordinated integration	Final score

Step 2: Calculate the total score for the farm (Total =100)

Step 3: Use the assessment to identify areas which require action to improve profitability on the farm.

Step 4: Use this record to compare this farm with other farms, and already identify a date for the next review of the irrigation performance.

Activity

Activity 1

Small group activity

Use this checklist to identify the current irrigation management performance of a farm and use the score to plan important strategies that can influence irrigation efficiency on the farm.

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References

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My notes............

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Authenticator:

- Mr F Buys

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