water harvesting and conservation

Volume 2 Part 1: Technical Manual and Farmer Handouts

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WATER RESEARCH COMMISSION
TT 493/11

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Report to the

Water Research Commission

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Introduction to the Manual

This Technical Manual is part of a comprehensive learning package which contains 2 main parts:
– Technical Manual
– Facilitation Manual

Each of these is accompanied by a Facilitation and Assessment Guide for use by the course facilitator.

The purpose of the learning materials package is to equip rural development and agricultural facilitators with the technical knowledge and the facilitation skills to enable them to work with resource-poor farmers in the field of water harvesting and conservation.

The manuals aim to introduce techniques that substantially increase water availability for increased crop production. The manuals do not, however, cover the many agricultural aspects necessary for successful crop growth. It is essential therefore, that the techniques are introduced either to people who already have substantial agricultural skills, or alongside an agricultural skills development process.

The learning package forms a complementary course which is set at NQF level 5, with each module comprising 15 credits. It is expected that the modules will be presented together, thus forming a 30 credit short course (i.e. Technical and Facilitation modules = 30 credits).

The manuals embrace lower-risk agricultural production methods, with a leaning to the use of locally available resources such as manure, mulch, compost, etc. They are to some extent aligned with Low-External-Input and Sustainable Agricultural approaches (LEISA) but because the emphasis is on the water-harvesting and conservation elements and not the crop-production and agronomic elements, many of the methods will apply to the full range of agricultural settings. While the body of work has a primary focus on resource-poor farmers, some methods (such as saaidamme, mulching, dome-water harvesting, etc.) are equally well-suited to larger, more technically intensive, higher risk agricultural enterprises.

In this technical manual, the first four chapters cover foundational information pertaining to water and soils, including: the national water context, catchment dynamics, and soil characteristics. The last three chapters expand on agricultural production systems and present the technical detail of thirteen different WHC methods.

CONTEXTUAL INFORMATION

Some of the information contained in the guide is marked as contextual information. This information, which provides background and is not for assessment purposes, can be identified by the following layout format:

contextual information

The information that is likely to be of interest to students but is not for assessment purposes is presented in grey shading like this.

GLOSSARY

Words in ***bold italics*** are defined in the Glossary at the end of the manual.

Contents

Manxeba Zipho (artist)
"Healthy garden – healthy life."

Chapter 1

Introduction to Water Harvesting and Conservation (WHC)

Contents

Outcomes

At the end of this chapter you should be able to:

- Define the terms *water harvesting* and *water conservation*.
- List the eight principles of water harvesting and conservation.
- Illustrate the process of water harvesting and conservation in diagrammatic form.
- Discuss various ways in which households can benefit from the practice of water harvesting and conservation.

1. Introduction

The practice of ***rainwater harvesting*** for domestic use and crop production supported early civilisations some 3000 years ago. Today, rainwater harvesting remains a highly productive and sustainable practice which is widely used by small producers and commercial farmers alike. What follows are two descriptions of rainwater harvesting and water conservation in practice. The first is the well-known case of Mr Phiri Maseko, a Zimbabwean ***farmer*** whose 3 ha ***farm*** is an excellent example of WHC practiced by a small producer. The second case is Mr Dirk van der Merwe, a commercial farmer from the Northern Cape, whose profitable lucerne and sheep farm is dependent on the practice of WHC.

Phiri Maseko

Poor soil conservation practices and ***deforestation*** in the upland areas of Zimbabwe have led to massive soil ***erosion*** and land degradation. The result is that in a country where 70% of the population relies on agriculture for a living, only 20% of the land can be used for this purpose. Many farms have become unproductive, and those which are marginally productive cannot survive recurring drought. As a result, many farmers have abandoned their farms, while others have been forced into ***subsistence farming***.[1]

Zvishavane District in the Midlands Province of Zimbabwe is a particularly dry area with frequent droughts, and the farmers who live here struggle with fragile soils and erratic rainfall. However, on one farm in this region, a three-hectare rural homestead located in a hilly area outside the small town of Zvishavane, crops grow quickly and bountifully. Here, enough food is produced to support a family of 15 and to raise money for other living expenses. This is the farm of Zepheniah "Phiri" Maseko, a farmer who views natural resources such as soil and water as precious gifts to be respected and protected, and whose innovations in soil and water conservation have drawn international attention and acclaim.

Figure 1.1 A view from the top of the Maseko farm

Zepheniah Phiri Maseko was born in 1927. After he completed his schooling he went to work for the Rhodesian Railways in Bulawayo. In 1964 he was fired from his job for being politically active and was told by the government that he would never work again in any position.[2] At the time Phiri was married with six children, so in 1966 he started farming in order to try and support his family. When Phiri first began he found it very difficult to grow crops successfully, as he had few material resources and there were often periods of drought.

Figure 1.2 Mr Phiri Maseko

He decided to pay close attention to what happened when it did rain, and through careful observation he learned how the water flowed over and into the land. Phiri then began to experiment with ways of capturing the water in the soil so that it could provide nourishment for his crops and trees.

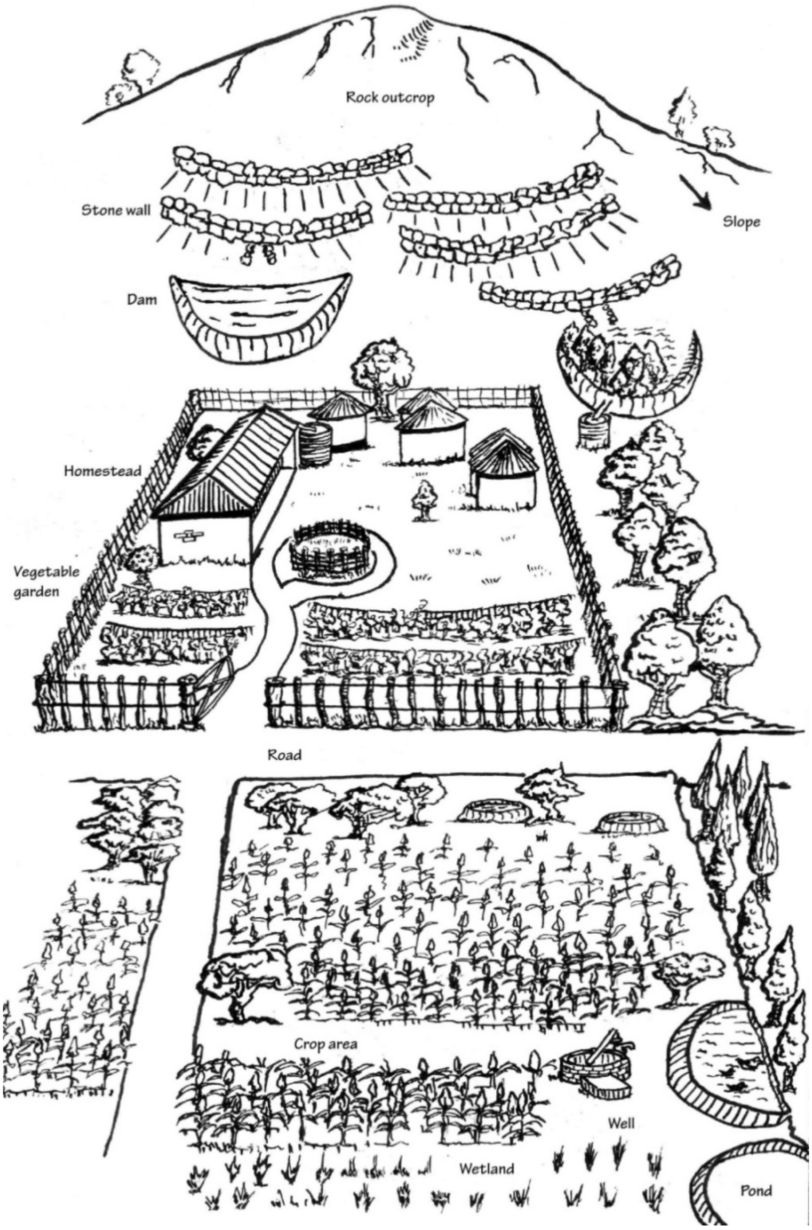


Figure 1.3 The Maseko family homestead

Phiri's plot is situated on the slope of a hill which faces north-northeast, providing good winter sun. At the top of the hill is a large rock outcrop (a granite dome). This rock outcrop posed the first challenge for Phiri. He observed that when heavy rains fell, the rock caused water to run down the hill in channels, taking soil with it and causing severe erosion. Phiri also noticed that although in this situation very little water was able to infiltrate the soil, the soil remained moist for longer in areas just above rocks and plants and in small depressions.

Based on these observations, Phiri decided to try and control the flow of storm water off the rock. He built some low stone walls at random intervals along ***contours*** below the rock outcrop. The walls slow down and spread out the flow of storm water. Patches of indigenous vegetation which grow along the walls also slow the water down and draw it into the soil.

Below the stone walls Phiri then dug two dams, into which the water could be directed. Phiri calls the larger of the dams his “immigration center”. “It is here that I welcome the water to my farm and then direct it to where it will live in the soil,” he says.[3] Water in this dam seeps into the ground over a period of time, replenishing the store of water under the ground. The dam has also become a water gauge for Phiri, who has learned that if it fills up three times in a season, enough rainwater will have seeped into the ground to see his farm through two years of drought.

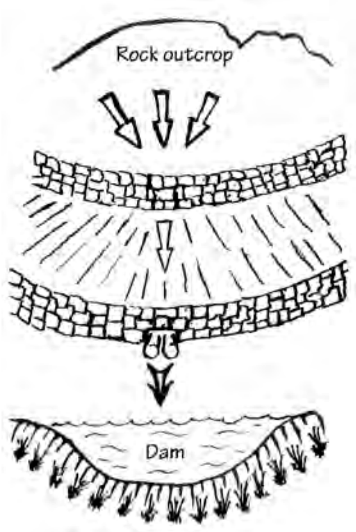


Figure 1.4 Rainwater is directed into dams

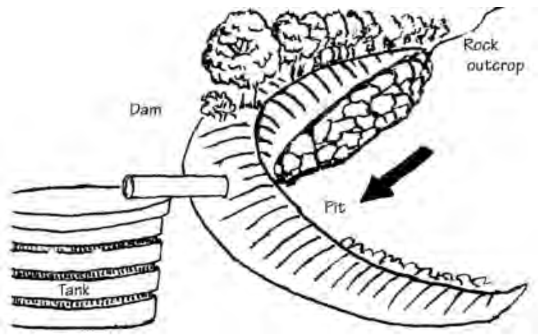


Figure 1.5 Water overflow is directed into a storage tank

Water overflow from the smaller dam is directed by pipe into a storage tank. This water is used to water the homestead garden, where Phiri and his family grow an unusually wide variety of fruit and vegetables such as pumpkins, beans, cabbage, tomatoes, garlic, peas, onions, carrots, chillies, guavas, oranges, naartjies, lemons, paw-paws, peaches and mangos.

Phiri also built a concrete tank next to the main house. When it rains, water runs down the roof and along gutters into the tank, where it is stored for drinking and household use. A granadilla creeper was trained to grow up and over the tank to keep the water cool. All of the water which the family uses for washing (called ***greywater***) is drained into an unsealed underground tank, where it quickly seeps into the ground.

Between the family homestead and the crop area is a dirt road. To control the water ***runoff*** from the road, Phiri dug large pits (4 m long, 2 m wide and 1 m deep) at regular intervals just above the fields and planted ***indigenous*** vegetation around them. When it rains the pits fill with water, which seeps into the soil slowly, feeding the plants and replenishing the water table. The vegetation stabilises the pits and prevents them from collapsing.

Figure 1.6 Pits which store water

The family grows many different crops in their fields, including maize, sorghum, beans, pumpkins, millet, watermelon, nuts, cassava, peas and sweet potatoes. This diversity gives the family food security because if some crops fail, others will survive. Their crop diversity also reduces the likelihood of pest attack and prevents the soil from losing its nutrients.[4] Phiri also built three wells in the cropping area. One of these is carefully protected so that the water can be used for drinking. The other two are used for irrigation and for washing clothes. A network of pipes and canals has also been constructed so that crops can be watered during times of drought.

At the lowest point of the farm lies a natural ***wetland***, an area of land where the soil is saturated with water. Here, Phiri dug two ponds. The larger pond is stocked with fish which are caught for food, while the smaller pond catches water overflow from the larger one. Phiri planted reeds, bananas, kikuyu and elephant grass, and sugarcane around the banks to hold the soil in place. Water from the main pond can also be pumped out and used to water the crops.

As well as observing the ways in which water moves, Phiri also paid close attention to rainfall patterns and has experimented with numerous other water-harvesting methods over the years. Phiri uses the soil as his "catchment tank" so all of his methods are designed to help water sink into the soil as quickly as possible.

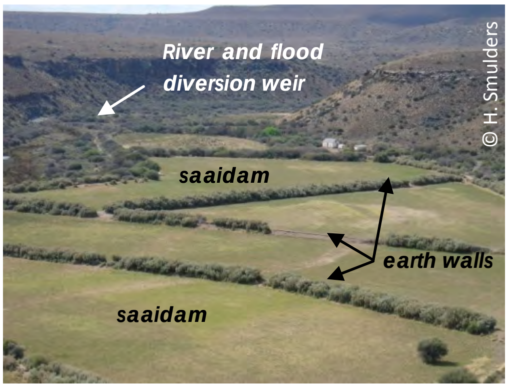
Through observation, inspiration, innovation and dedication, Phiri Maseko changed the landscape not only of his farm, but also of his life. In 1986 he founded the Zvishavane Water Project, a Non-Government Organisation (NGO) which was established to educate people about ***water harvesting*** and conservation and to promote ***sustainable*** farming. Phiri spreads his knowledge and skills freely and tirelessly to anybody who is interested in learning about water harvesting and conservation. Since 1997 more than a thousand people from outside the region have visited the Maseko farm, and "...local visitors are so frequent and numerous that he (Phiri) has ceased to count them."[5] In 2006, Phiri Maseko was presented with the prestigious National Geographic Society/Buffett Award for Leadership in Conservation, to acknowledge his outstanding work and lifetime contribution to further the understanding and practice of conservation in his country.[6]

Figure 1.7 Members of the Phiri homestead standing next to their maize crop

Dirk van der Merwe

In the arid western part of South Africa, small livestock farming is practised and supported by a water harvesting system called a 'saaidam'. 'Saaidam' is an Afrikaans word literally meaning 'planting dam' and is the name of a flood-water harvesting system that is also found in North Africa, the Middle-East and Pakistan. Dirk van der Merwe Jnr. and his family live on Diepdrif Farm in the Northern Cape near the town of Calvinia and his family have practiced this method since the 1920s. Dirk Jnr. is a qualified veterinary surgeon and follows in the farming footsteps of his father (Dirk van der Merwe Snr.) who bred many South African Champion Merinos at Diepdrif Farm over the years.

Their farming business revolves mainly around lucerne production and sheep. The sheep graze on the lucerne fields – which are dependant on the saaidamme for water – and also on the dry surrounding Karoo-veld pastures. The area receives only about 170 mm of rainfall per year, and as a result the veld-grazing is very sparse – so sparse that each sheep needs approximately 40 hectares to sustain itself (40 hectares is roughly the same size as 50 soccer fields). The lucerne production, which is watered using the saaidam water-harvesting system, is a critical part of the van der Merwe's lucerne and sheep farm business.



The saaidam itself is a large flat field which is surrounded on all sides by a low earth wall, similar to a small dam wall about 1 m to 1.5 m high. Once every year or two, a flood comes rushing down the dry riverbed from the mountains about 120 km away. This floodwater is diverted into the saaidamme over a few days of extremely busy activity by everyone on the farm, through a system of large channels and water-gates. The water is held knee-deep in the saaidams for 2 to 3 days and soaks deeply into the soil, after which the excess water is released. The soils in the area are very deep (up to 10 m deep in places), and because lucerne has a very deep tap root it can draw up the moisture as the soil slowly dries out.

The van der Merwe's farm has 600 ha under lucerne in the saaidams and they farm more than 2500 sheep as well as cattle. This example shows that water-harvesting has an important place on different kinds of farms, some small and others large, some producing fresh produce, others animal fodder and meat.

2. Principles of Water Harvesting and Conservation

Principle One: BEGIN WITH LONG AND THOUGHTFUL OBSERVATION

Phiri's water harvesting and conservation (WHC) began when he started observing and paying close attention to what happened when it rained. This action, which for Phiri was the obvious starting point in trying to understand and then change his situation, is also the first principle of water harvesting and conservation.

Principle Two: START AT THE TOP OF YOUR CATCHMENT AND WORK YOUR WAY DOWN

After Phiri had spent time observing how water flows over and into the land, he began to experiment with ways of harvesting the water by capturing it in the soil. Because water flows downhill, Phiri began these experiments at the top of his property where water entered his landscape, and then worked his way down the slope.

Principle Three: START SMALL AND SIMPLE

When Phiri began, he did not have the financial resources to invest in specialized tools or equipment, nor did he have the knowledge to develop a complex, extensive water-harvesting ***system***. However, he did not let this deter him. Instead, he began with something small, manageable, and cost-free: he built – by hand – the low stone walls below the rock outcrop at the top of his farm.

Principle Four: SLOW, SPREAD AND INFILTRATE THE FLOW OF WATER

Phiri built the stone walls in order to try and control the flow of storm water off the rock. His initial observations had made him realize that if he could slow the water down and spread it out, more of it would be able to soak into the ground. Over time Phiri learned that the best place to store water is in the soil, which is why his methods are designed to help water sink into the soil as quickly as possible.

Principle Five: ALWAYS PLAN AN OVERFLOW ROUTE, AND MANAGE THAT OVERFLOW AS A RESOURCE

Phiri did not want any water to go to waste, so he put structures into place to help manage water overflow when it did occur. He did this by directing excess water from the small dam into a storage tank, and by designing his ponds so that the smaller one catches water overflow from the larger one. Every drop of water on the Phiri farm is treated as a valuable resource.

Principle Six: CREATE A LIVING SPONGE

Through observation, Phiri learned that groundcover such as grass, vegetation or ***mulch*** slows down water and draws it into the soil. Phiri set about planting a wide variety of indigenous vegetation around his property and spreading organic mulch over his soil, thereby creating a "living sponge" which maximises the amount of water that infiltrates the soil.

Principle Seven: **DO MORE THAN JUST HARVEST WATER**

Phiri learned about and experimented with different water harvesting methods, and over time he developed an entire farm ***system*** which is efficient and which maximises relationships that are mutually beneficial (for example, the vegetation which grows around the pond helps hold the soil in place).

Principle Eight: **CONTINUALLY REASSESS YOUR SYSTEM**

Phiri learned by trial and error. He changed or altered strategies which did not work, and he built on those which did. His system, which evolved over a long period of time, was developed through continual reassessment. As Phiri said, “Sure, it’s a slow process, but that’s life. Slowly implement these projects, and as you begin to rhyme with nature, soon other lives will start to rhyme with yours.”[7]

While each of these principles is important in its own right, it is essential that all eight are used together so that their effectiveness and value is maximised. You will learn more about the WHC principles as you work through this manual.

3. Defining Water Harvesting and Conservation

The term **rainwater harvesting** refers to collecting, conveying and storing rainwater for various end uses.[8] The following are some more comprehensive definitions:

“Rainwater harvesting refers to the concentration and entrapment of rainwater runoff from a catchment. A catchment is any discrete area draining into a common system and thus can be a roof, a threshing floor or a mountain watershed. Similarly, the means of rainwater storage can range from a bucket to a large dam.”[9]

“Water harvesting can be defined as the process of concentrating rainfall as runoff from a larger catchment area to be used in a smaller target area. This process may occur naturally or artificially. The collected runoff water is either directly applied to an adjacent agricultural field (ie. stored in the soil-rootzone) or stored in some type of on-farm storage facility for domestic use and as supplemental irrigation of crops.”[10]

"Rainwater harvesting is the collection and/or concentra-tion of runoff water for productive purposes. It includes all methods of concentrating, diverting, collecting, storing, utilizing and managing runoff for productive uses. Water can be collected from natural ***drainage*** lines, ground surfaces, roofs for domestic uses, stock and crop watering."[11]

A definition of ***water conservation*** is: "The protection, development, and efficient management of water resources for beneficial purposes."[12]

There are many different ways to conserve water by protecting and managing it efficiently. In situations where water is used for irrigation, conservation involves getting as much water as possible to infiltrate the soil so that the amount of water lost to evaporation or runoff (water which runs over the ground) is minimised. One method of achieving this is to cover the soil with a mulch such as a crop residue, which increases water ***infiltration*** and reduces evaporation.

Other examples of water conservation practices include recycling and re-using water (e.g. using bath water to water vegetables); irrigating crops in sensible ways (e.g. watering less often but more thoroughly, and not watering during the heat of the day); eliminating water leaks (e.g. fixing leaking taps and pipes); and growing indigenous plants which are suited to the local climate and environment.

Based on the above definitions, as well as the practices of people such as Phiri Maseko who harvest and conserve water, we can say that water harvesting and conservation involves:

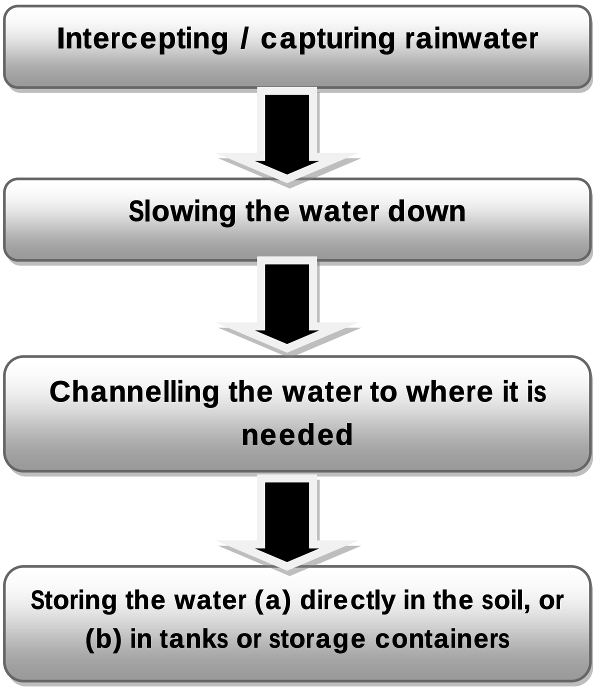


Figure 1.8 The water harvesting and conservation process

Although WHC is an ancient practice, new technologies have enabled us to obtain water from secondary water sources such as rivers and dams, and most of us have shifted away from harvesting and conserving water from its primary source, rain. However, in many rural areas in South Africa water harvesting remains an essential water source for domestic and commercial use.[13] Households which practice water harvesting and conservation can benefit in many different ways. For example:

- WHC can improve food security, income levels and the standard of living of people who live in dry areas.
- WHC helps conserve the soil and reduces soil erosion.
- WHC systems are low-cost, simple to construct, and require little maintenance.
- Women and children benefit as WHC reduces or eliminates the time needed to collect water from secondary sources such as rivers.
- Households can become water-independent, especially through roofwater catchment systems.[14]

activity 1

Group Discussion

1. Read and discuss each definition of water harvesting. Make sure that you understand all of the words used, particularly those which are found in all three definitions.

2. Discuss the definition of water conservation. Brainstorm and list other ways of conserving water (a) inside the home, and (b) outdoors.

3. Discuss the following: Is the concept of WHC new to you? Do you know anybody who practices WHC? How do they do this?

4. What does the word **system** mean? / What is a system? What do you think the term ***farm system*** refers to? How about the terms ***water harvesting and conservation system*** and ***roofwater catchment system***?

Time: 30 minutes

4. Course Overview

Our need for water increases as the world population grows, but many people continue to waste and mismanage this finite resource and our supply is becoming increasingly scarce. In this course you will learn how to design and implement **environmentally *sustainable* water harvesting and conservation systems** on farms.

These water systems are part of the larger productive farming system which aims for sustainability. The goal of sustainable farming is to integrate different farm elements (soil, water, plants, animals, climate and people) into a production system that is appropriate for the environment, the people, and the economic conditions at the farm. Farms become and stay environmentally sustainable when they imitate natural systems. Sustainable farming therefore involves creating a farm landscape which mimics the complexity of a healthy ecosystem.

In this chapter, the **concept and principles of water harvesting and conservation** are introduced and explored. In Chapter 2, we will explore in some detail the **water crisis** that the world currently faces, and we will look at various ways in which this crisis is being addressed at global and national levels.

In order to be environmentally sustainable, a water harvesting and conservation system needs to be integrated into the larger **farm system** of which it forms a part. At the same time, every farm system exists within an **ecosystem**, and the practice of farming changes the composition and functioning of that ecosystem. In Chapter 3 we will examine systems – and in particular, farm systems and ecosystems – in detail, as this will help us understand how and why water harvesting and conservation systems should be incorporated into these greater systems so as to support and augment sustainable farming practices. Two farming approaches which are examined in this chapter and which apply the principles of sustainable farming are the Integrated Systems Approach, and Low-External-Input and Sustainable Agriculture (LEISA). The integrated systems approach, which is about learning to work with natural processes, helps reduce inputs from outside of the farm and contributes positively to the ecosystem dynamic of the farm system, while the LEISA approach to agriculture aims to ensure sufficient food production within the limits of the natural environment.

One of the four major ecosystem process that are at work on any farm is the ***water cycle***. In order to plan and implement appropriate water harvesting and conservation systems, it is important to understand how the water cycle works, and particularly how water moves within a landscape. Chapter 4 provides an overview of the water cycle and examines in detail the movement of water both on and under the ground.

Another important ecosystem component that is essential for the development of sustainable WHC systems is **soil**. Soil is the primary nutrient base for plants, and thus plays an integral role in the process of nutrient cycling. Soil is also the medium for plant growth, and an efficient place to store water. In Chapter 5 we will examine soil and its different properties, and look at the relationship between soil and water and how this relationship impacts on the practice of water harvesting and conservation.

For a water harvesting and conservation system to be successful it is important that the most appropriate WHC methods are selected and that time is spent **planning** the system carefully.

Doing this requires certain skills and technical knowledge, the details of which are presented in Chapter 6.

In Chapter 7 a selection of thirteen WHC **methods** is presented along with illustrated, step-by-step guides for implementation. While most of these methods are used mainly in small gardens, a few have been included which have application on a commercial scale only.

In the second part of this course (WHC Facilitation) you will learn how to share the technical knowledge and skills which you have acquired with small-scale farmers who are interested in integrating WHC into their farm systems.

5. Overview of WHC Methods

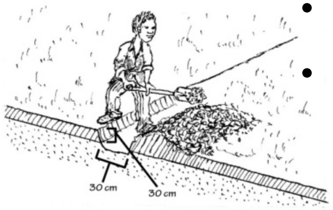
There are many different forms of water harvesting and conservation. The techniques have developed over more than three thousand years, in different countries, climates, soils, and for different crops. As a result, some methods are similar to each other but have different names, along with local variations in technique. Rainwater harvesting as a practice is also necessarily refined for each situation. When appropriate methods are being implemented they will be altered as the site requires, and they will be modified as learning and experience develop.

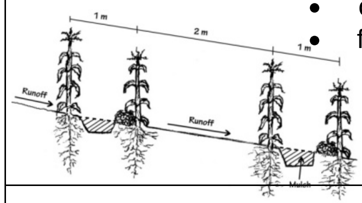
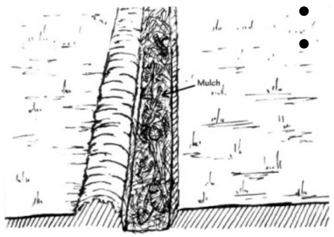
A simple classification of WHC is based on the work of Oweiss and colleagues,[15] who documented North African and other water harvesting systems. Water conservation measures and water storage structures are usually identified separately from water harvesting, although these are used as part of water harvesting systems.

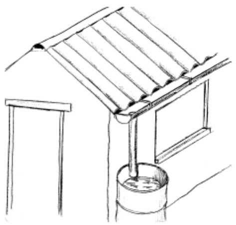
Type	Water flow when raining	Collection area relative to growing area
Micro-catchment	Sheet flow	10 x growing area
Macro-catchment	Channel flow	100 x growing area
Floodwater harvesting	Flood events	Up to 10,000 x growing area

The thirteen methods selected for this manual are summarised in the tables over the page, along with a short description of each one. Many of the methods are complementary and can thus be used together. There are also some important and useful methods which are not included in this guide but are noted at the end of the table. These methods, many of which are commonly known (e.g. small earth dams) may be necessary and suitable for some situations, but their design and construction requires advanced building or engineering input.

The summary table over the page is drawn from publications set out in the Bibliography at the end of the document.

Name Used in Manual	Similar to:	Description	Main purpose or comment	Type of Water Harvesting System
Diversion furrows 	• run-on ditches • run-on RWH • ex-field RWH • feeder channels • diversion trenches	A diversion furrow directs rainwater runoff from gullies, grasslands or hard surfaces (such as paths or roads) to a cropped area or to a storage tank. This increases the water available to the plants.	• Used for field crops and in gardens. • Additional water diverted directly to soils and crops. • Additional water stored in underground tanks for later watering.	Macro-system (collects water from an external catchment and brings it to the field).
Trench beds 	• deep trenching • fertility trenches	Trench beds are 1 m wide and 2 m long. They are dug to 1 m deep then packed with dry grass/leaves, compost, manure and soil.	• Used in food-gardens. • Create highly fertile soils which can absorb and store water. • Provide an immediately usable planting bed even on shallow or poor soils. • Often used with diversion furrows and mulching.	A micro-system when used alone. However, trench beds are usually connected to diversion furrows, which collect water from adjacent areas and direct it to the trenches.
Mulching 	• no other names	Mulching is the practice of spreading organic material like compost, straw, manure, dry leaves, grass clippings or wood chips onto the surface of the soil. It is usually concentrated around the plant.	• Can be used on all crops and orchards, not pastures. • Improves plant growth. • Reduces evaporation from the soil surface. • Improves soil temperature. • Limits weed growth and makes watering easier by protecting the soil.	Water conservation method.

Name Used in Manual	Similar to:	Description	Main purpose or comment	Type of Water Harvesting System
Stone bunds 	• stone lines • stone banks • contour stone bunds	Stone bunds are rows of tightly packed stones built along contour lines.	• Used to improve grazing land. • Slow down, filter and spread out runoff water. • Increase infiltration and reduce soil erosion. • Sediment is slowly captured on the upper sides, forming natural terraces.	Macro-system. The contour ridges collect water from adjacent slopes.
Tied ridges 	• in-field RWH • partitioned furrows[15] • cross-ridges • furrow dikes[16]	Ridges are built along the contour at 3 m spacings. Crops are planted on either side of the ridge. Runoff from the unplanted area is caught in the furrow and infiltrates into the root zone.	• Used in home gardens and on smallholder fields; when mechanised, used on a large commercial scale. • The system has been fine-tuned to South African conditions, and is called "in-field RWH" in local publications.	Micro-system when used without other methods. Can be used with diversion furrows and mulching.
Swales 	• bunds • contour ridges • berm 'n basin • contour ditches	A swale is an earth bank constructed along the contour with a furrow on the up-slope side – this is filled with dry leaves, compost and soil. The top of the earth bank is levelled off to allow planting. The swale intercepts runoff, spreads it out and helps it infiltrate deep into the ground.	• Used in home-gardens and smallholder fields. • Widely used within permaculture systems. • Good groundwater recharge.	Micro-system. Often used with diversion furrows and mulching.

Name Used in Manual	Similar to:	Description	Main purpose or comment	Type of Water Harvesting System
Terraces 	• benches	A terrace is a level strip of soil built along the contour of a slope and supported by an earth or stone bund, or rows of old tyres filled with soil. Terraces create flat planting areas and stabilize slopes which would otherwise be too steep for crop production.	• Used in home gardens and smallholder fields. • Mainly used in steeper-sloping areas for cropping and orchards.	Micro-system used on steeper slopes. Diversion furrows are not used to augment water as there is an erosion risk on steeper slopes. Mulching can be used.
Fertility pit 	• banana circles • circular swale • Katumani pitting	Fertility pits enable runoff water to be captured and conserved in 1 m deep pits that are filled with organic matter such as compost or manure. The organic matter increases the fertility of the soil and minimises the loss of water from evaporation.	• Used in home gardens and smallholder fields. • Often planted with wet-loving bananas and pawpaws • Often used in conjunction with greywater.	Micro-system which lends itself as a soakaway around buildings – to absorb greywater. Katumani pitting is a variation where multiple fertility pits are tightly packed across a field.
Greywater harvesting	• recycling • re-use	Greywater harvesting is the practice of using non-toilet wastewater produced in a household to water the root zone of the soil.	• Greywater includes the water used for bathing, washing, cleaning, cooking and rinsing. • Used in home gardens.	Water conservation method.
Roofwater harvesting 		Collecting water from roofs for household and garden use is widely practiced across South Africa. Tanks and containers of all types – from brick reservoirs to makeshift drums and buckets – are a common sight in urban and rural areas.	• Mainly used for domestic supply. • Surplus can be used in home gardens.	Roofwater harvesting.

Name Used in Manual	Similar to:	Description	Main purpose or comment	Type of Water Harvesting System
Ploegvore 	• pitting • zai • chololo • matengo • ngoro	This water harvesting method involves creating numerous small, well-formed pits or "imprints" in the soil that collect rainwater runoff, seed, sediment and plant litter. This provides a relatively sheltered microclimate in which seed and seedlings can grow.	• Used widely outside of South Africa in more arid areas; pits are made by hand and used for crop production. In South Africa, pitting is more commonly done with specialised ploughs for pasture rehabilitation.	Micro-system. Can be done by hand on a small scale for crops. Pasture rehabilitation requires specialist mechanisation because of the large scale.
Domewater harvesting 	• rock catchment	Dome water harvesting is used to intercept and direct rainwater runoff from impermeable rock domes into a reservoir, or directly to a field where the water is stored in the soil.	• The method provides valuable drinking water in arid areas. • Can be very effective for agricultural use where rock surfaces are located close to agricultural lands.	Macro-system.
Saaidam 	• Wadi floodwater system • flood-spate • Rabta	The saaidam system entails the diversion of floodwater from non-permanent rivers into a series of flat basins which are used for cropping. Each flat field is completely surrounded by a low earth embankment (wall) of between 0.5 and 1.5 metres high. Diverted water from the flooding river is channelled into the fields and completely submerges the land for 1 to 3 days, where it fully saturates the soil.	• Used mainly for lucerne production, but also successful with vegetables. • Deep alluvial soils are well-utilised by deep-rooted lucerne.	Floodwater harvesting.

USEFUL BUT NOT COVERED IN THIS MANUAL	Similar to:	Description	Main purpose or comment	Type of Water Harvesting System
Conservation tillage	• no-tillage • low-tillage • gelesha	Conservation tillage includes any kind of planting, hoeing and ploughing practice that conserves water and soil. The aim is to minimise soil turning, to keep permanent ground cover, to mulch, and to rotate crops.	This is an integrated crop production practice which includes water harvesting, no-tillage or low-tillage and soil conservation practices; the emphasis is on crop selection and on crop rotation.	Water conservation.
Small earth dams	• water ponds • matamo	A (small) earth dam is a 1to 3 m high wall built across a drainage line, stream or river to store water. An earth dam is made of compacted clayey material with a wide base and a narrow crest (at the top of the wall).	Seasonal and permanent water storage for cattle watering and/or domestic use. Small cattle dams on drainage lines are a familiar part of all rural South Africa. Technical competence is usually needed to ensure stability and water-tightness, and experienced input to their design and construction is advisable.	Water storage.
Sand dams	• sub-surface dams	A sand dam is an underground wall across a dry sandy riverbed. The sand fills up to the top of the wall, and water is trapped behind the wall, in the sand. A pump is usually used to get the water out.	Sand dams are more easily built in arid, sandy areas than other dams. The water tends to be a higher quality than other surface water sources because of the filtration effect of the sand. Sand dams recharge groundwater.	Water storage/groundwater recharge.

6. Test Yourself

1. List the eight principles of water harvesting and conservation and explain why each one is important. (16)

2. Provide a definition for each of the following terms: **rainwater harvesting** and **water conservation**. (4)

3. Draw a simple diagram which illustrates the process of water harvesting and conservation. (5)

4. List five benefits of WHC, particularly for rural households. (5)

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Lubabalo Ntsokontsoko (artist)
"Pollution kills the river."

Chapter 2

Water in the World

Contents

Outcomes

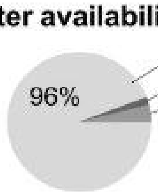
At the end of this chapter you should be able to:

- Discuss the global water crisis with particular reference to the growing world population, water distribution and availability, climate change, virtual water, human activities and pollution.
- Explain how world leaders are attempting to address the global water crisis.
- Interpret and analyse information from climatic maps.
- Discuss South Africa's water sources, with particular reference to rainfall, rivers and dams.
- Name four governmental policies pertaining to homestead agriculture and explain the relevance of each one.
- Explain how Section 21 of the National Water Act (Act No. 36 of 1998) defines the term *water use*.
- Name the various water user groups in South Africa.
- Discuss some of the risks, threats and challenges pertaining to water use in South Africa.

Water in the world and South Africa

Population: *World*: 6.8 billion people *South Africa:* 49 million people

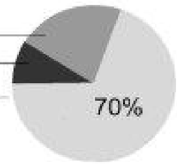
Water availability

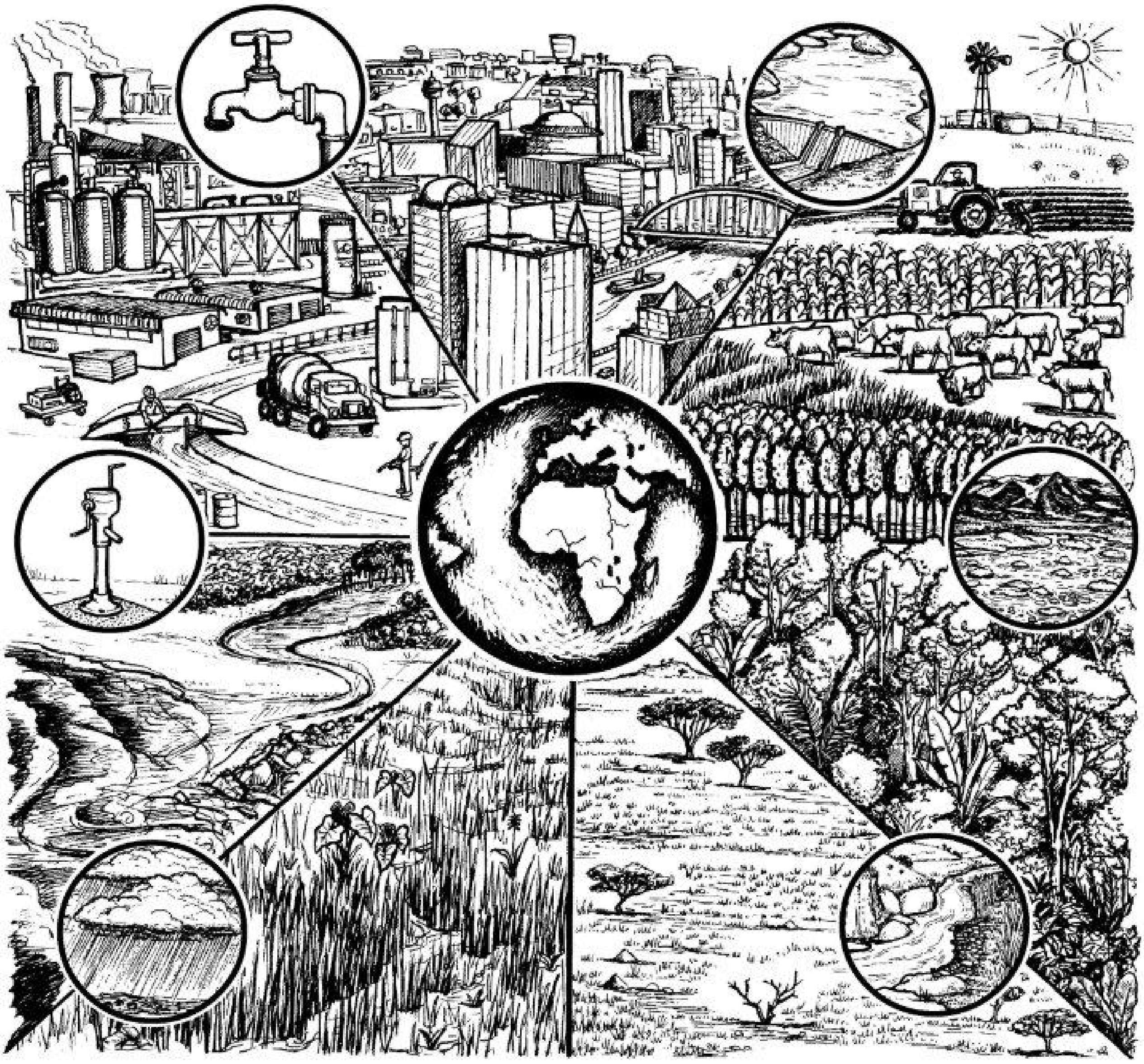


Oceans and saline lakes 96%
Atmosphere 1%
Fresh water 3%:
- 2.4% as ice and snow
- 0.6% as underground water
- 0.003% as drinking water

Water use in the world

Industrial 22%
Household 8%
Agriculture 70%





South Africa

Average rainfall <500 mm a year
65% of SA not suitable for dryland cropping
9% of rainfall reaches rivers

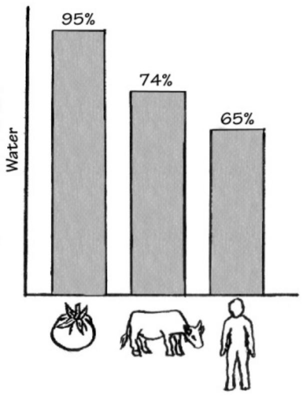
Access to water

5 million people have inadequate water supplies
13.4 million people have no access to basic sanitation

Artwork by Kathy Arbuckle

1. Introduction

Water is the source of life, and as such it is fundamental for our survival and our health. While humans can live for weeks without food, we would die within a few days if we did not have water. Not only do we need water for drinking, we also need it for growing and cooking food, for cleaning, washing, and for sanitation.



The water realm, which is known as the hydrosphere, consists of 1.3 billion cubic kilometres of water. Most of this water is found in the oceans and seas, which cover 60% of the planet's surface. In fact, water is everywhere, even in the most unexpected places. "A potato is 80 percent water, a cow 74 per cent, a bacterium 75 per cent. A tomato, at 95 per cent, is little *but* water. Even humans are 65 per cent water, making us more liquid than solid by a margin of almost two to one."[1]

The earth is a closed system, which means that it rarely loses or gains extra matter, so the total amount of water on earth never changes. The same water that existed on the earth millions of years ago is still present today, and this water keeps going around and around the planet in a process called the *water cycle*, which is powered by solar energy and the earth's gravity. No new water enters the cycle and no water ever leaves the cycle.

Even though we are surrounded by water, this resource is one of the main limiting factors for life on earth. This is because only a very small fraction is *fresh* water, which is what we humans and all other non-marine species depend on for our survival.

activity 2

A drop in the bucket[2]

You will need:

- a 1 ℓ container
- a measuring jug
- three glasses
- an eyedropper
- water

Step 1: Fill the 1 ℓ container with water. This represents the total amount of water on earth (salt and fresh).

Step 2: Pour 30 ml of this water into a glass. This represents all of the *fresh* water on earth – about 3% of the total.

Step 3: Pour 6 ml of the fresh water into a second glass. This represents all of the fresh water on earth which is *not frozen* – about 0.6% of the total. Of this, only about 1.5 ml is surface water; the rest is stored underground in the form of groundwater.

Step 4: Take an eyedropper, remove a single drop of water from the second glass and drop it into the third glass. This represents our clean, fresh water which is available for use (i.e. not polluted, trapped in soil, too far below the ground, etc.) – about 0.003% of the total water on earth.

It is important to note that the fresh water which is available to us, as represented by the single drop, is actually a large volume of water on a global scale (billions of litres).

Time: 30 minutes

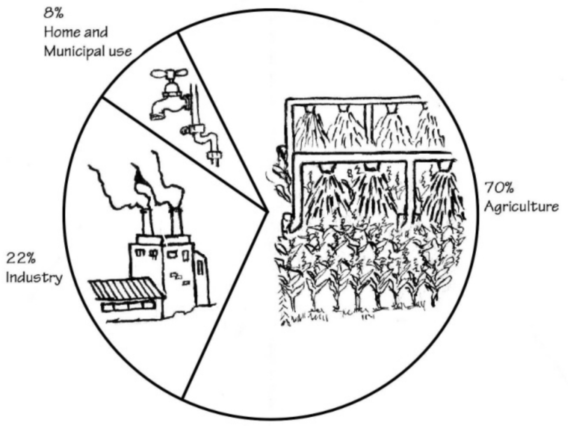
Despite being surrounded by water and having billions of litres of fresh water available to us, humans are facing a serious global freshwater crisis.

2. The Global Water Crisis

One of the main reasons for our water crisis is the *growing world population*. Although there is the same amount of water now as there was in prehistoric times, there are many, many more people on earth, all of whom are completely dependent on water for their survival.

The world population is currently estimated at 6.8 billion people, and it is projected that by 2050 this number will have increased to over 9 billion.[3] The South African population, currently estimated at 49 million[4], is expected to have reached 53.8 million by 2025 and 56.8 million by 2050.[5] The Food and Agriculture Organization (FAO) of the United Nations estimates that between now and 2050, the world's water will have to support an additional 2.7 billion people.

Worldwide, 54% of the available surface freshwater is currently being used, mainly for agriculture (70%), but also for industry (22%) and for home and municipal use (8%). In many areas, this water is being used faster than it can be replaced. It is projected that by 2025, water appropriation will rise to 70%.[6] ***Groundwater*** is one of the major systems being stressed, and water tables in many places are plummeting as water is extracted or pumped out faster than the underground systems can recharge.



As the world population grows and the demand for fresh water increases, problems will intensify. It is estimated that by 2025, forty-eight nations, with a combined population of 2.8 billion, will face freshwater stress or scarcity,[7] and by 2032, more than half the people in the world could be living in severely water-stressed areas.[8] The water crisis is exacerbated by a range of other factors. These include:

2.1 Distribution and availability

The world's freshwater supply is unevenly distributed across the planet. The largest amount is in the Americas, while the smallest amount is in Oceania (Australia, New Zealand and the Pacific islands), although Oceania has the greatest per capita supply due to its small population, while Asia has the smallest per capita supply.

Freshwater resources can also be socially and politically difficult to manage and conserve. Many rivers, lakes and underground ***aquifers*** cross national boundaries and are shared by several countries, each with its own laws and beliefs about water use and ownership.

The availability and supply of water varies considerably even within countries, due, for example, to rainfall patterns. This situation is often further complicated by factors such as droughts, floods, and inappropriate veld and water management.

2.2 Climate change

The world's climate is changing, resulting in an increase in mean (average) surface temperature. Weather and rainfall patterns have become less predictable than before, and there are more droughts and floods than there used to be. As droughts and floods both reduce the ability of soil to hold water, more water is needed to irrigate agricultural and horticultural crops. The Intergovernmental Panel on Climate Change predicts that by 2020, yields from rain-dependent agriculture could be down by 50%.

2.3 Virtual water

"***Virtual water***" is a term used to describe the water that is embedded in the production and trade of food and consumer products[9] – in other words, the water that is used to grow, manufacture and package most of the products we eat, drink, wear and use in our everyday lives. For example, it takes approximately 140 litres of water to grow, produce, package and ship the coffee beans for one cup of coffee; more than 180 litres of water to produce one glass of milk; about 1 000 litres to produce one kilogram of wheat; and about 14 000 litres to produce one kilo of grain-fed beef. It takes more than 2500 litres of water to grow enough cotton to make one cotton T-shirt.[10] As consumer demand for food and for new products increases, so does the amount of water needed to produce such goods.

2.4 Human activities

Canals, dams and levees, which obstruct natural water flow, can change both the quantity and the quality of water downstream (e.g. increased pollution and sediment load),[11] while poor drainage and irrigation practices have resulted in the water-logging and salination of about 10% of the world's irrigated lands.[12]

Increased paving in towns and cities leads to rainwater running off into drains or storm sewers, rather than soaking into the ground and replenishing water tables. In coastal areas, falling water tables may open aquifers to an influx of saltwater, impairing or even ruining them as freshwater sources.

At an individual level we pour all sorts of household chemicals and pollutants down our drains. These substances, which often include hormones, antibiotics and antibacterial compounds, contaminate our fresh water supply and are harmful to many other species, such as plants, frogs, fish and birds.

It is also estimated that about 60% of the water which is extracted for human use is wasted through evaporation, leaks, inefficient appliances and human carelessness, and that some basic changes in behaviours and technologies could reduce this wastage by half.[13]

2.5 Pollution

Every single day, more than 2 million tons of human waste are disposed of in water courses, while in developing countries 70% of industrial wastes are dumped, untreated, into waters where they pollute the usable water supply.[14]

Apart from sewage and industrial waste, other sources of water pollution include fertilizers, pesticides, agricultural run-off, chemicals, poisons and infectious ***pathogens***. Thus, water that is used for drinking and sanitation is often contaminated with micro-organisms that cause water-related diseases such as diarrhoea, typhoid and cholera.

Water scarcity and unsafe drinking water can have devastating consequences, mainly for impoverished people who live in developing countries. Almost 20% of the world's population do not have access to a supply of clean water, while 40% do not have safe sanitation facilities. At present:

- more than 3.5 million people die each year from water-related diseases;
- 43% of these deaths are from diarrhoeal diseases;
- 84% of water-related deaths are children under the age of 14 (and every 15 seconds a child dies from a water-related disease);
- 98% of water-related deaths occur in developing countries;
- at any given time, half of the world's hospital beds are occupied by patients who are suffering from water-related diseases; and
- at any given time, almost half of all people in the developing world are suffering from one or more of the six main diseases associated with water supply and sanitation.[15]

3. Addressing the Global Water Crisis

contextual information

3.1 United Nations Summit of 2000

Of all the major target-setting events of recent years, the United Nations Summit of 2000 remains the most influential. At this summit, Millennium Development Goals were set for 2015. Those most relevant to water are presented in Table 2.1.

Table 2.1 Millennium Development Goals relevant to water[16]

Goal	Targets
Eradicate extreme poverty and hunger	Halve, between 1990 and 2015, the proportion of people whose income is less than $1 a day. Halve, between 1990 and 2015, the proportion of people who suffer from hunger.
Achieve universal primary education	Ensure that, by 2015, children everywhere, boys and girls alike, will be able to complete a full course of primary schooling.
Reduce child mortality	Reduce by two thirds, between 1990 and 2015, the under-five mortality rate.
Improve maternal health	Reduce by three quarters, between 1990 and 2015, the maternal mortality ratio.
Combat HIV/AIDS, malaria and other diseases	Have halted by 2015 and begun to reverse the spread of HIV/AIDS. Have halted by 2015 and begun to reverse the incidence of malaria and other major diseases.
Ensure environmental sustainability	Integrate the principles of sustainable development into country policies and programmes and reverse the loss of environmental resources. Reduce ***biodiversity*** loss, achieving by 2010, a significant reduction in the rate of loss. Halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation. By 2020, to have achieved a significant improvement in the lives of at least 100 million slum dwellers.

All of these goals need to be achieved while protecting the environment from further degradation. According to the United Nations, this requires adequate and equitable access to resources, the most fundamental of which are water and energy.

In September 2008 world leaders met again to assess progress, renew their commitments to achieving the Millennium Development Goals by 2015, and to set out concrete plans and practical steps for action.[17] At present, progress towards some of the targets is on track. For example, 1.6 billion people have gained access to safe drinking water since 1990. However, there are many targets which are unlikely to be met unless additional, strengthened or corrective action is taken urgently. For example, approximately 2.5 billion people – half the population of the developing world – still live without improved sanitation.

3.2 Second World Water Forum

In March 2000, the 2nd World Water Forum took place at The Hague. The Hague Ministerial Declaration adopted the following seven main challenges in its aim to achieve global water security.

Ministerial Declaration of The Hague on Water Security in the 21st Century[18]

Meeting basic needs: to recognise that access to safe and sufficient water and sanitation are basic human needs and are essential to health and well-being, and to empower people, especially women, through a participatory process of water management.

Securing the food supply: to enhance food security, particularly of the poor and vulnerable, through the more efficient mobilisation and use, and the more equitable allocation of water for food production.

Protecting ecosystems: to ensure the integrity of ecosystems through sustainable water resources management.

Sharing water resources: to promote peaceful co-operation and develop synergies between different uses of water at all levels, whenever possible, within and, in the case of boundary and trans-boundary water resources, between states concerned, through sustainable river basin management or other appropriate approaches.

Managing risks: to provide security from floods, droughts, pollution and other water-related hazards.

Valuing water: to manage water in a way that reflects its economic, social, environmental and cultural values for all its uses, and to move towards pricing water services to reflect the cost of their provision. This approach should take account of the need for equity and the basic needs of the poor and the vulnerable.

Governing water wisely: to ensure good governance, so that the involvement of the public and the interests of all stakeholders are included in the management of water resources.

3.3 Fifth World Water Forum

The 5th World Water Forum, which took place in March 2009 in Istanbul, was the world's biggest ever water-related event, with more than 33 000 participants from 192 countries.[19] Declarations from this Forum express an ongoing commitment from Heads of States, Ministers and Heads of Delegations, and Mayors and local/regional elected representatives to urgently address global, national and local water management issues in order to achieve the Millennium Development Goals.

4. Water in South Africa

South Africa is a *water-stressed country*, which means that our demand for water exceeds the amount we have available to us, resulting in an imbalance between our water use and our water resources.[20]

contextual information

4.1 Rainfall, rivers and dams

Much of South Africa is semi-arid and the country has an average rainfall of less than 500 millimetres per year, compared with a world average of 860 millimetres. Nearly 91% of South Africa falls within the United Nations' definition of affected drylands, which are extra-ordinarily dry areas where the rainfall is low and the potential evaporation is high.[22] Sixty-five percent of the country does not receive enough rain for successful ***dryland cropping*** (crop farming which is dependent on rainfall), and the frequent occurrence of drought during critical stages of crop production makes such farming risky.

The maps which follow show South Africa's ***mean annual precipitation*** (the average amount of rain that falls in a year) and rainfall seasonality (the seasons in which rain falls). The eastern parts of South Africa, for example, have an annual rainfall ranging from 600 to 800 mm, concentrated in the midsummer months.

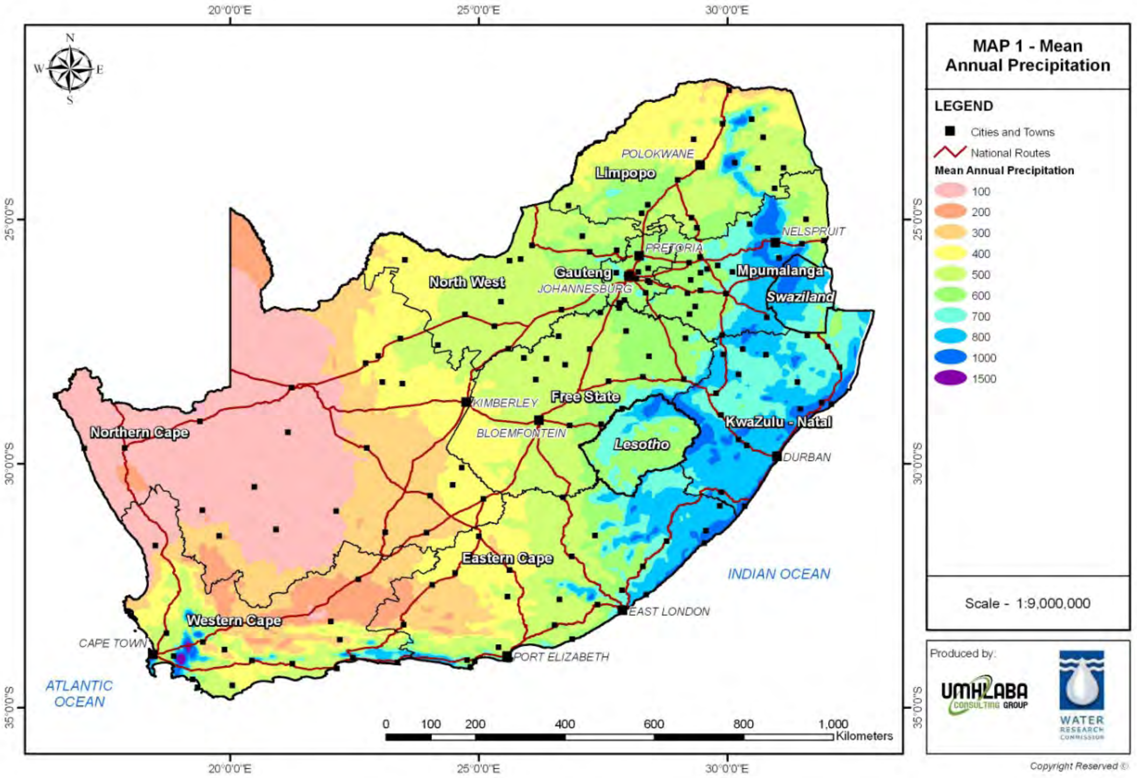


Figure 2.1 Map showing the mean annual precipitation for South Africa

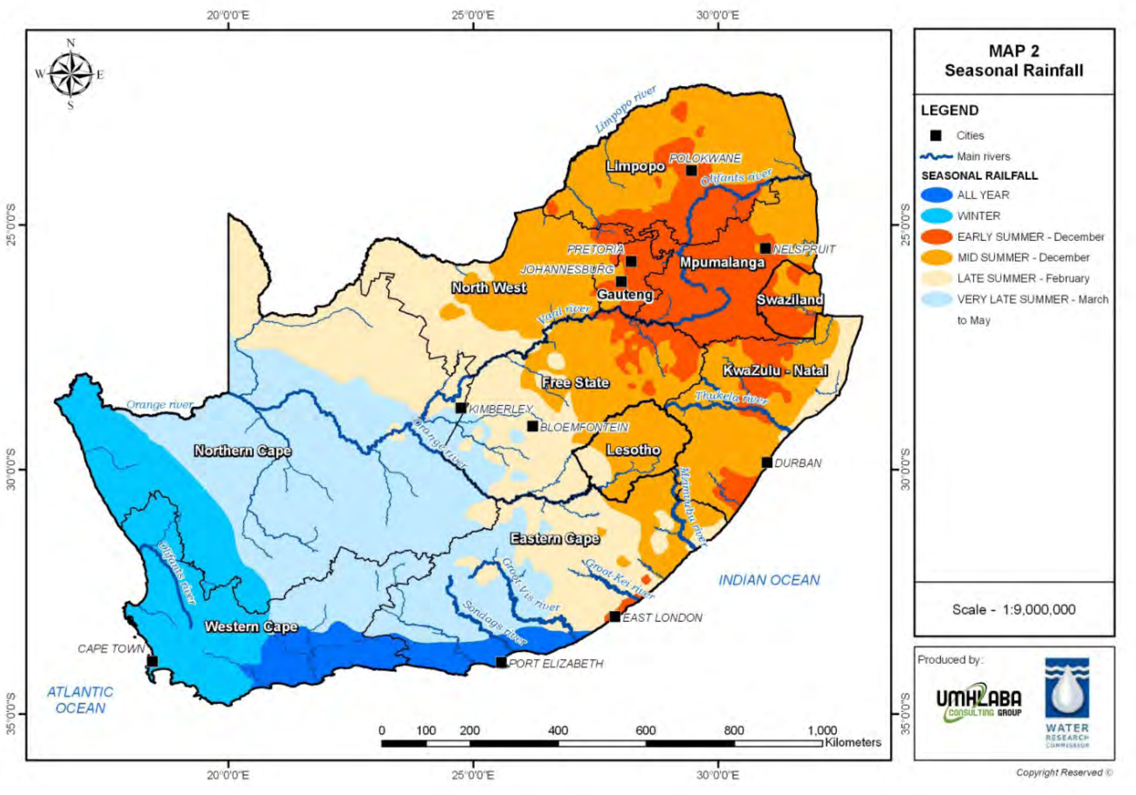


Figure 2.2 Map showing South Africa's rainfall seasonality

activity 3

Map Work

Answer the following by referring to Figures 2.1, 2.2 & 2.3:

1. What is the mean annual rainfall for the area where you grew up?
2. During what season does rain mainly fall in this area?
3. What is the mean annual rainfall in the most northern part of SA?
4. During what season does rain mainly fall along the west coast of SA?

Does the information from the maps match your own experience of rainfall in the area where you grew up, and in other areas where you have lived? Share and discuss your answers with a friend.

Time: 40 minutes

activity 4

Rainfall Information

You have decided to start a vegetable garden at home, and need to find out which plants will grow well in your area. To do this, you need to find out the following information:

1) Your area's average rainfall.
2) Your area's rainfall seasonality (i.e. the months of the year that it rains, and the month/s with the most rain).
3) Your area's average minimum and maximum temperatures (in winter and in summer).

As a class, brainstorm and discuss the different ways in which you could find this information about your area.

Time: 20 minutes

Rivers are the main source of water in South Africa, although on average only 9% of rainfall reaches the rivers. The Orange River Basin is the largest river basin in the country, with almost 600 000 km² of its total catchment area of 1 million km² falling in South Africa.[23] River flow in South Africa is generally variable, and all major rivers have been dammed or modified to meet the demand for water. This has reduced water flow, caused many rivers – such as the Limpopo, Luvhuvhu and Letaba – to become seasonal, and reduced the productive capacity of flood plains such as the Pongola.[24] The map on the following page shows the major rivers of South Africa.

Many large *dams* have been built to regulate the natural variable flow of rivers and to help transfer water between catchments. South Africa has 550 government dams, with a total capacity of 37 000 million m³. Our landscape, however, is not well-suited for dams. Most are shallow, with a large surface area, which results in high levels of evaporation. Also, because the majority of our rivers have a high silt load, our dams become silted and their capacity is decreased. Dams also reduce strong water flow in rivers; this diminishes their scouring ability and leads to the silting of estuaries.[25] Smaller dams such as farm dams also reduce the flow of rivers and streams during the dry season.

4.2 Water management and policy

The Department of Water and Environmental Affairs (DWEA) is the custodian of South Africa's water and forestry resources, and is responsible for formulating and implementing policy governing these two sectors. DWEA also has the overriding responsibility for water and sanitation services provided by local government.[26]

South African water policy is viewed as some of the most progressive in the world. After the first democratic elections were held in 1994, water law was comprehensively reviewed, based on the constitutional principles of efficiency, sustainability and equity. At the 2008 International Water Expo in Zaragoza, Spain, South Africa was still one of only a handful of countries which recognised water as a basic human right and gives effect to this right through its policies and implementation programmes. Table 2.2 shows the policies that are most directly relevant to homestead agriculture.

Table 2.2 Policies relevant to homestead agriculture

Policy	Relevance
Entitlement to water use Section 4.1 and Schedule 1 of the National Water Act (Act 36 of 1998)	A person may use, freely and without the need for licensing, water in or from a water resource (e.g. a river or stream) for various purposes including reasonable domestic use, gardening and animal watering.
The Reserve Sections 16 to 18 of the National Water Act (Act 36 of 1998)	The National Water Act (NWA) formally *reserves* a portion of water (i.e. a specific quantity and quality of water) from all significant water resources. The reserve consists of two parts – a basic human needs (BHN) reserve and an ecological reserve. The basic human needs reserve "provides for the essential needs of individuals served by the water resource in question and includes water for drinking, for food preparation and for personal hygiene."[27] Current policy sets the water for BHN at 25 litres per person per day, but there is strong advocacy to increase this amount, especially to enable economic activity in poor households.
Free basic water	In 2001 the government made a policy decision that municipalities must provide every household with 6 kilolitres (6 000 litres) of water per month, free of charge. This works out at 25 litres per person per day for a family of eight, and 40 litres per person per day for a family of five.
Financial support for resource-poor farmers Sections 61 and 62 of the National Water Act (Act 36 of 1998)	DWA will provide financial support to resource-poor farmers in terms of section 61 of the NWA. This includes a subsidy for household training in intensive home food production and rainwater harvesting, as well as for water storage infrastructure in the homestead yard (e.g. tanks).

4.3 Water managers

South Africa's river systems are currently divided into 19 Water Management Areas (WMAs). Each area is managed by a Catchment Management Agency (CMAs). CMAs were established in order to decentralise water resource management (i.e. to enable water resources to be managed at catchment level), in cooperation with local stakeholders. "The intention is to involve local communities in the decision-making processes, in terms of: meeting basic human needs; promoting equitable access to water and facilitating social and economic development."[28] At a more local level, District and Local Municipalities are Water Service Authorities (WSA) responsible for developing and implementing Water Service Development Plans.

4.4 Water use

Section 21 of the National Water Act (Act No. 36 of 1998) states that *water use* includes:

a) taking water from a water resource;
b) storing water;
c) impeding or diverting the flow of water in a watercourse;
d) engaging in a stream flow reduction activity contemplated in section 36;
e) engaging in a controlled activity identified as such in section 37(1) or declared under section 38(1);
f) discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit;
g) disposing of waste in a manner which may detrimentally impact on a water resource;
h) disposing in any manner of water which contains waste from, or which has been heated in, any industrial or power generation process;
i) altering the bed, banks, course or characteristics of a watercourse;
j) removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people; and
k) using water for recreational purposes.[29]

In instances where there is not enough water for all the users and the water resources are considered stressed, water is allocated through a process of compulsory licensing. Figure 2.5 indicates that licensing and regulatory requirements become more stringent as the risk of a particular water-use activity having a negative impact increases. Harvesting rainwater within a homestead farming system falls under Schedule 1, which means that no registration is required.

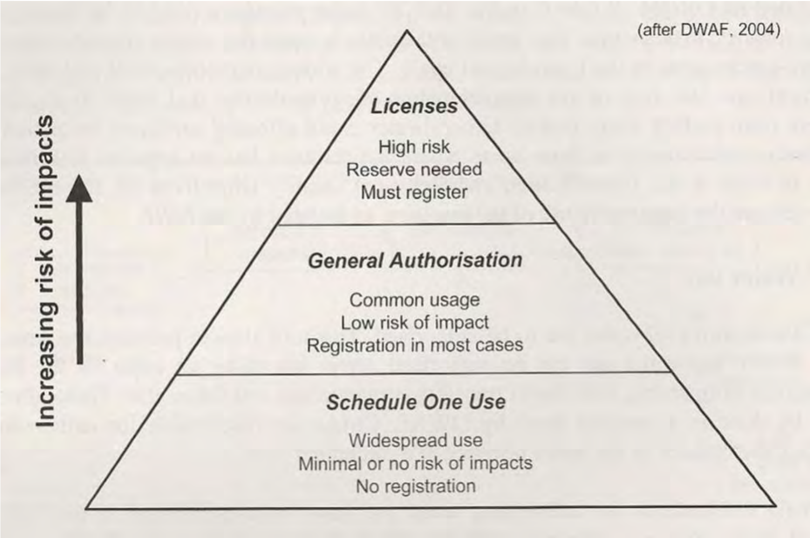


Figure 2.3 Schematic representation of the mechanisms used to regulate water use

4.5 Water users

South Africa has a number of different **water users**, as shown in Table 2.3.

Table 2.3 Current Water Users[30]

Water Users	Current % of allocation	Remarks
Agriculture	62%	As the largest consumer of water, the challenge in this sector is to produce more food with the same or less water, enhancing the productivity of water.
Domestic **- Urban** **- Rural**	27% - 23% - 4%	Population growth will lead to an estimated total of 53 million people by 2025. Growth in urban areas is larger than in rural areas and spatial variances need to be monitored to match future demand.
Industrial	3.5%	Pollution through industry needs to be tightly monitored and control measures put in place and policed.
Afforestation	3.0%	Timber-based products make a significant contribution to the economy. Afforestation is on the increase.
Mining	2.5%	Water usage in the mining industry is a major contributor to water quality problems.
Power generation	2.0%	Eskom has, with some clear directives from DWA, progressed from the highly intensive wet-cooled systems towards the more efficient dry-cooled systems.

It is people who live in rural areas who typically have the least access to a safe water supply. Most of South Africa's non-urban population (11.5 million people) live in deep rural communal land tenure areas, although in the Eastern Cape and Limpopo a significant number of people live in semi-rural areas (303 000 and 515 000 respectively). It is the responsibility of local municipalities to provide services to people who live in rural areas – a task which is difficult when areas are remote.

4.6 Water supply

At present the bulk of our water (77%) is sourced from ***surface water*** sources such as dams and rivers. 14% of our water is from return flows such as sewage and effluent purification, and 9% is sourced from groundwater.

In 2007/2008, local government provided *basic water supply* to 1.27 million people. However, out of our current population of 49.5 million, there are still 2.4 million people who do not have access to a basic level of water supply, and 3.3 million people whose water supply does not meet the basic services standard.

At present, 97.6% of our WSAs are implementing the *Free Basic Water* (FBW) services programme, providing 84% of the South African population with access to free basic water. 73% of the poor population (households earning less than R800/month) are benefiting from this service.

4.7 Water availability: risks, threats and challenges

Climate Change

There is disagreement between scientists about climate change, and there are currently two broad perspectives in the climate change debate.

Perspective 1: In South Africa, a 21-year periodicity in rainfall and stream flow has been statistically verified over a 100-year period. This means that drought and flood cycles happen in 21-year cycles, which is synchronous with sunspot activity. Sunspots are dark or cooler spots on the surface of the sun which affect the modality of rainfall (i.e. how much rain falls, and when) and global temperature. The current warm cycle, for example, should soon end and a cool cycle will begin, leading to a small decrease in global temperature.

Perspective 2: Most scientists agree that the planet is warming and that humans are a major reason why. In the last 200 years, humans have begun to influence the global climate system, mainly by increasing the earth's natural greenhouse effect through our greenhouse gas-emitting power plants, cars, factories, etc. According to NASA, the earth has warmed by about 0.6°C over the past 30 years;[31] an additional increase of between 2.5°C and 10.4°C is expected by 2100, with concentrations of atmospheric carbon dioxide doubling by around 2050. As temperatures rise, about one third of existing land habitats may vanish.[32] This second perspective is held more strongly by the Intergovernmental Panel on Climate Change.

Alden, W.C. Photograph courtesy of the U.S. Geological Survey Department of the Interior

Reardon, B. Photograph courtesy of the U.S. Geological Survey Department of the Interior

Figure 2.4 Shepard Glacier, Glacier National Park (USA). High altitude glaciers appear to be among the first victims of global warming. Of the 150 named glaciers that were in Glacier National Park in 1850, only 26 are still present today. Researchers predict that all of the park's glaciers will have melted by 2030.[33]

Regardless of which perspective one takes, climate change and the resulting increase in mean (average) surface temperature impacts on rainfall patterns and makes weather patterns more volatile. This increases the frequency of droughts and floods, which in turn diminishes the ability of soil to hold water. As a result, more water is needed for the irrigation of agricultural and horticultural crops.

Raw Water Quality

There are various programmes which monitor water quality in South Africa's Water Management Areas. The National Microbial Monitoring Programme monitors the extent of faecal microbial pollution in water resources. This type of pollution is caused by partially or untreated discharges from wastewater treatment works, and from runoff containing human and animal faecal wastes. There are currently 163 high-risk areas in the country which receive untreated faecal discharges and where contaminated water is used for human consumption, irrigation and recreation.

The National Eutrophication Monitoring Programme monitors and assesses the impact of excessive nutrients in our reservoirs. ***Eutrophication*** produces toxic cyanobacterial blooms, which pose a serious health risk to humans, livestock and wildlife. It also produces noxious aquatic weeds. At present, 42% of the monitored dams in South Africa are affected by eutrophication.

The River Health Programme monitors the ecological conditions of our rivers by assessing specific key biological indicators (such as fish, aquatic invertebrate, fauna and riparian vegetation). At present, 638 national River Health Programme sites are being monitored. The current health of our rivers varies across the country, ranging from good natural streams in the upper reaches to deteriorated and poor streams, mainly in highly industrialised areas. In general, the ecological state of our river systems is declining rapidly from their sources to their estuaries, although the upper reaches remain in fairly pristine state.[38]

Natural Resource Management

For many years, too many people have had to rely too heavily on available natural resources such as water, land and trees for their livelihoods. This has led to a systematic decline in and degradation of the natural environment from over-use. A number of wetland environments are under threat, soil erosion is widespread, and degraded land needs to be rehabilitated. These and other water-related issues are especially critical in rural areas, as this is where people are most dependent on natural resources to meet their basic needs.

5. Addressing the Water Crisis in South Africa

At present the government is still working towards achieving full and sustainable access to water and sanitation services for all through its policies and water management strategies.[35] However, about 5 million South Africans remain in need of adequate water supplies and approximately 13.4 million people have no access to basic sanitation infrastructure.[36] According to the Department of Water Affairs and Forestry, "South Africa's available freshwater resources are already almost fully utilised and under stress. At the projected population growth and economic development rates, it is unlikely that the projected demand on water resources in South Africa will be sustainable. Water will increasingly becoming the limiting resource in South Africa, and supply will become a major restriction to the future socio-economic development of the country, in terms of both the amount of water available and the quality of what is available. At present many water resources are polluted by industrial ***effluents***, domestic and commercial sewage, acid mine drainage, agricultural runoff and litter."[37]

Nothing brings out the difference between living in an urban area and living in a rural village more clearly than *the problem of water* – the daily struggle to obtain drinking water, water for bathing, water for cooking, and water for growing food. It is this problem which water harvesting and conservation addresses.

activity 5

Group Discussion

Discuss the following in small groups:

1. Which people/groups of people in South Africa still lack access to adequate water supplies and sanitation? Why is this so?
2. In what ways does a lack of access to water impact on these people/groups of people in their daily lives?
3. To whom could you speak about water-related issues in your area, and how could you go about doing this?

Write down the key points of your discussion and share them with the rest of the class.

Time: 20 minutes

6. Test Yourself

1. One of the main reasons for our water crisis is the growing world population. List and discuss five other reasons for the global water crisis. (15)

2. List the three Constitutional principles on which the review of South African water law was based after the elections of 1994. (3)

3. Name three water-related policies that are relevant to homestead agriculture, and explain the relevance of each one. (9)

4. Based on DWA's licensing and regulatory requirements, rainwater harvesting within a homestead farming system falls under Schedule One Use. Explain what this means. (4)

5. Draw a pie chart which shows South Africa's current water users and the current percentage of water allocated to each user group. (8)

6. List four attitudes towards water which need to change if water is to be managed better, and explain why each attitude change is necessary. (8)

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Sikelelo Holose (artist)
"Use water for food."

Chapter 3

Systems

Contents

Outcomes

At the end of this chapter you should be able to:

- Define the terms *system, ecosystem* and *farm system*.
- List and explain six characteristics of living, open systems.
- Define and discuss the biotic and abiotic components of an ecosystem and give examples of each.
- Explain the difference between a food chain and a food web.
- Name and describe the two main processes of an ecosystem.
- Explain the importance of biodiversity within an ecosystem.
- List and discuss various elements which can disturb an ecosystem.
- Name five different types of farm resources and identify examples of each type within a farm system.
- Explain the term *sustainable farming* and describe two approaches to this type of farming.
- Describe the four major ecosystem processes that are at work on any farm system.
- Analyse a farm system, with specific reference to its inputs, outputs, processes, resources and ecosystem impact.

1. Introduction to Systems

A system is a group of interacting and interdependent elements which together form a complex whole.[1] A human body, for example, is made up of component parts such as cells, tissues and organs, all of which function and interact with each other to form a living person. A car, a computer, a pond, a family, a farm, an organisation, a forest, a city and the earth are all examples of systems.

All living systems – such as human and environmental systems – are *open systems*. These are systems where energy and matter flow freely within the system as well as between the system and its environment. In other words, open systems maintain themselves through constant interaction and exchange with their environment.[2] Any movement of energy or matter into a system is called the system's *input*, and any movement of energy or matter out of the system and into its environment is called the system's *output*.[3] Within the system are *processes* which turn the system's inputs into outputs.

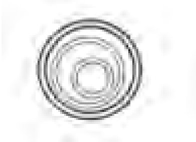
<u>Example</u>: A human body is a physiological system which runs on energy (carbohydrates, fats and proteins). This energy is obtained from food, which comes from outside of the system and is thus an *input* into the system. Inside the body, the *process* of digestion converts the food into simple chemicals which enter the bloodstream and travel to where they are needed.[4] That part of the food which the body does not use is passed out of the body as waste, and is thus an *output.*[5]

2. Ecosystems

An ecosystem, which is a living, open system, can be defined as *"a community of organisms functioning together and interacting with the physical environment (soil, air, water) through (1) a flow of energy and (2) a cycling of materials".*[6]

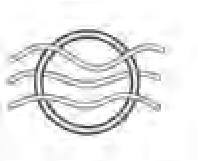
The idea that living organisms interact with every other element in their local environment is central to the concept of an ecosystem. It is also one of the fundamental principles of ***ecology***, which is the scientific study of the relationships between organisms and their environments.[7] The following core principles of ecology can help us to better understand ecosystems. These principles also encapsulate the characteristics of living, open systems.

NETWORKS All members of an ecological community are interconnected in a vast and intricate network of relationships. They derive their essential properties and, in fact, their very existence from these relationships.

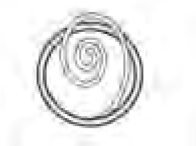


NESTED SYSTEMS Throughout nature we find multi-levelled structures of systems nesting within systems. Each of these forms an integrated whole within a boundary while at the same time being a part of a larger whole.

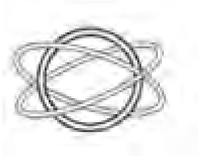
CYCLES The interactions among the members of an ecological community involve the exchange of energy and resources in continual cycles. The cycles in an ecosystem intersect with larger cycles in the bioregion and in the planetary biosphere.



FLOWS All organisms are open systems, which means that they need to feed on a continual flow of energy and resources to stay alive. The constant flow of solar energy sustains life and drives all ecological cycles.



DEVELOPMENT The unfolding of life, manifesting as development and learning at the individual level and as evolution at the species level, involves an interplay of creativity and mutual adaptation in which organisms and environment co-evolve.



DYNAMIC BALANCE All ecological cycles act as feedback loops, so that the ecological community regulates and organizes itself, maintaining a state of dynamic balance characterized by continual fluctuations.[8]

Ecosystems are communities where all of the parts – both living and non-living – exist together and interact with each other. The size of an ecosystem can range from very large (e.g. an ocean or a rainforest) to very small (e.g. a puddle or rock pool). In fact, it is difficult to demarcate the boundary of an ecosystem. Consider the photograph below, in which one can easily see two ecosystems: an aquatic (water) one and a terrestrial (earth) one.

Figure 3.1 An aquatic and a terrestrial ecosystem

Although these ecosystems may appear distinct, they actually interact closely. For example, certain insects feed and are fed upon in both ecosystems, and the trees which form part of the terrestrial ecosystem also utilize dam water for their growth. This highlights the following important aspects of ecosystems:

1. Ecosystem boundaries are difficult to define. In fact, the boundaries of an ecosystem are typically chosen for practical reasons having to do with the goals of a particular ecological study.

2. Adjacent ecosystems interact closely with each other.

3. Adjacent ecosystems are usually interdependent.[9]

contextual information

2.1 Ecosystem components

An ecosystem is made up of an ***abiotic*** (non-living, environmental) component and a ***biotic*** (living) component. These components interact and work together to maintain a balanced system.

The **abiotic component** of an ecosystem includes various chemical and physical factors. Physical factors which have the greatest effect on ecosystems include:

- sunlight and shade;
- temperature;
- precipitation;
- wind;
- latitude and altitude;
- nature of the soil (for terrestrial ecosystems);
- fire (for terrestrial ecosystems);
- water current (for aquatic ecosystems); and
- amount of suspended solid material (for aquatic ecosystems).

Chemical factors include:

- level of water and air in the soil (for terrestrial ecosystems);
- level of plant nutrients dissolved in soil moisture (for terrestrial ecosystems) and in the water (for aquatic ecosystems);
- salinity of the water (for aquatic ecosystems); and
- level of dissolved oxygen (for aquatic ecosystems).[10]

Organisms which make up the **biotic component** of an ecosystem are usually classified as producers and consumers, based on how they get their food and hence the organic nutrients they need to survive.

Producers (or *autotrophs*) are organisms which can manufacture the organic compounds they use as sources of energy and nutrients. Producers are usually plants, which manufacture their food through the process of photosynthesis. Consumers (or *heterotrophs*) get nutrients and energy by feeding directly or indirectly on producers. Consumers can include:

- primary consumers (*herbivores*), which eat plant material;
- secondary consumers (*carnivores*), which eat herbivores;
- tertiary consumers (*carnivores*), which eat other carnivores; and
- decomposers (e.g. fungi and bacteria) and detritivores (e.g. insects, earthworms, spiders, millipedes) – consumer organisms which feed on dead or decaying organic matter which is eventually converted back into inorganic nutrients in the soil.

Living organisms in an ecosystem are connected to each other through *food chains*, which show their eating relationships. The following is an example of a food chain:

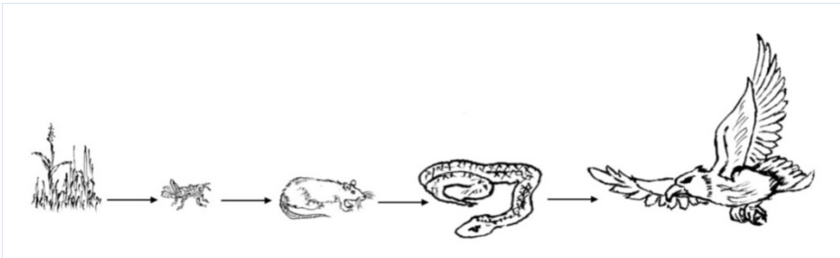


Figure 3.2 A food chain

Every link in the chain is known as a trophic level. In the example above, the grass forms the first trophic level, the grasshopper forms the second level, the rat forms the third level, and so on. Food chains are, however, simplistic representations of what typically happens in nature because they only follow one feeding path. Most consumers feed on multiple species and are in turn fed upon by multiple other species, which means that in reality there are many feeding paths which connect different plants and animals. An ecosystem thus consists of a *set* of food chains which form a complex network of interactions – called a *food web*.

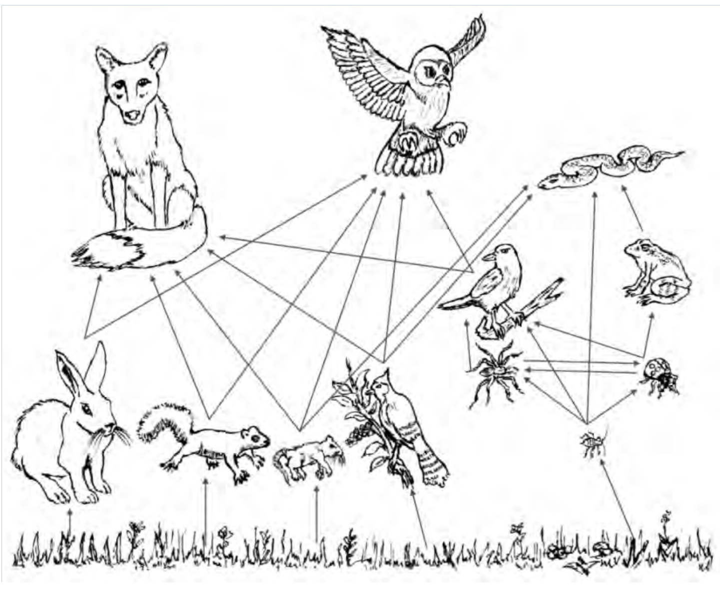


Figure 3.3 A food web

2.2 Ecosystem processes

An ecosystem has two main processes. One involves the flow of energy, and the other involves the cycling of materials (nutrients). An ecosystem uses its food web as the mechanism for these processes.

1. Energy Flow

Energy is constantly flowing from one thing to another. Energy enters most ecosystems from the sun. Green plants capture sunlight using the process of photosynthesis, and use the sunlight to produce energy, in the form of carbohydrates, for plant growth. Plants are food for primary consumers, so herbivores obtain their energy by eating plants. Carnivores in turn obtain energy by eating herbivores. As energy transfers through the trophic levels of the food chain there becomes less and less available at each level because energy is lost through movement, heat, and as solid waste (faeces).

2. Nutrient Cycling

Nutrients are *chemical elements* found in the environment that plants and animals need in order to grow and survive.[11] Nutrients build and repair tissues, provide heat and energy, and regulate body processes.[12]

Elements such as carbon, nitrogen and phosphorus enter living organisms in various ways. Plants obtain elements from their surroundings (i.e. the atmosphere, water and the soil). Animals can also obtain elements directly from their surroundings, but usually obtain them by consuming other organisms.

These elements are transformed biochemically within the bodies of organisms into an organic state, and are later returned to an inorganic state through excretion (waste products) or decomposition. Decomposers such as bacteria play an important role in the decomposition process.

Figure 3.4 illustrates how nutrients move in cycles through the ecosystem.

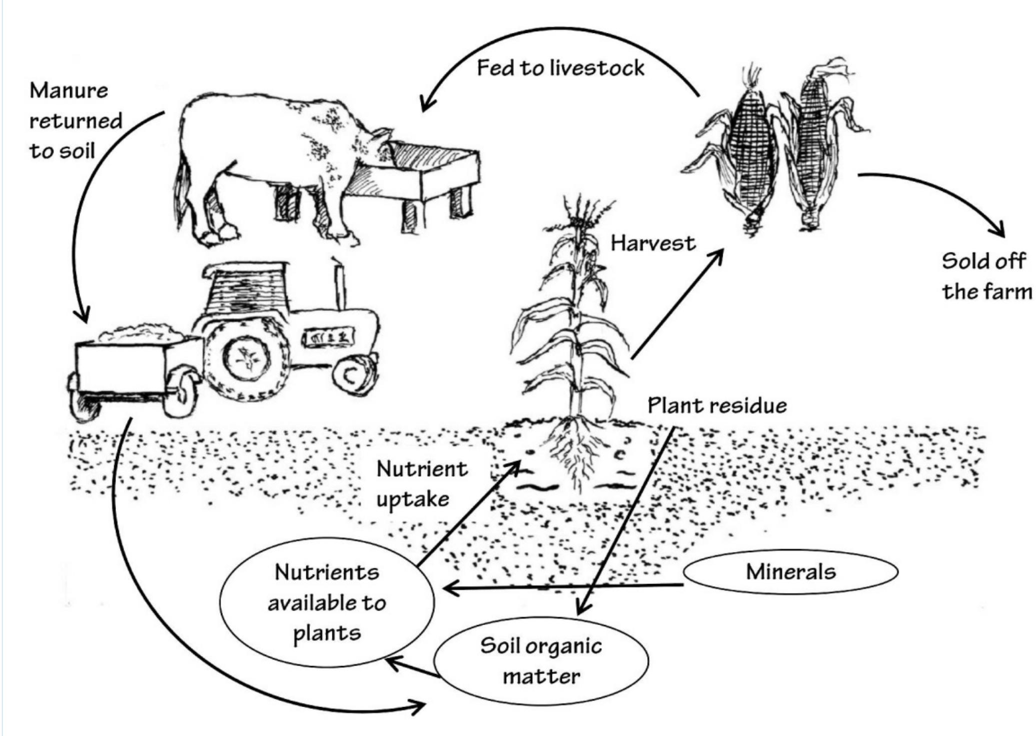


Figure 3.4 A nutrient cycle

A basic nutrient cycle:

1. Plants absorb (or "take up") nutrients in the soil through their roots.
2. The plants are eaten by animals.
3. Animal manure and plant residues are returned to the soil as organic matter.
4. Micro-organisms in the soil (bacteria, fungi and other decomposers) feed on this organic matter, breaking it down into simpler compounds and releasing it into the soil.
5. Plant nutrients and trace elements are also released into the soil when soil minerals dissolve.
6. Plants absorb the nutrients through their roots, and the cycle repeats itself.

A natural farmer works with this nutrient cycle by always trying to increase organic matter and micro-organisms in the soil.

2.3 Disturbed ecosystems

A healthy ecosystem has ***biodiversity*** at all levels of the food chain. The word biodiversity refers to the *variety of life forms within a given biological context*, such as an ecosystem, a biome, or even the entire earth.[13] Biodiversity is usually quantified in terms of number of species, and is used as a measure of the health of a system.

Biodiversity is generated and maintained in natural ecosystems. Each species of vegetation and each creature has a place in the system and performs a number of essential tasks. Plants, animals and insect species interact with and depend on each other for various things, such as food, shelter, oxygen and soil enrichment.[14]

The different species within an ecosystem exist in a delicate balance, both with each other and with the abiotic elements of the system. A disruption to the system can cause it to become imbalanced and may lead to a ripple of further disruptions which can threaten parts or all of the ecosystem.

Ecosystems can be threatened or disturbed by various factors, including:

Pollution
Pollutants which are dumped into the soil, water or air disturb the natural balance of an ecosystem and affect organisms in various ways. Water pollution, for example, can cause fish to suffocate and die, while the dumping of toxic waste threatens many species in an area.

Introduction of exotic (non-native) species
The introduction of exotic species to an ecosystem can endanger a system's biodiversity.

Destruction of habitat
Ecosystems get damaged or destroyed when natural land and sea areas are converted for other uses. The resulting destruction of animal and plant habitat can lead directly to a loss of species and a resulting decrease in biodiversity.[15]

Exploitation of plant and animal species
Many different plant and animal species are used by people for food and as sources of medicine and raw materials for industry. Exploitation of a particular plant or animal can threaten its viability as a species.

Desertification
Desertification is the degradation of land in dry areas, or the transformation of arable or habitable land to desert, resulting primarily from human activities and influenced by climatic factors. The main causes of desertification are overgrazing, woodcutting and water-diversion. Desertification leads to increased wind and water erosion; it also impacts on biodiversity, and causes land to lose its productive capacity.[16]

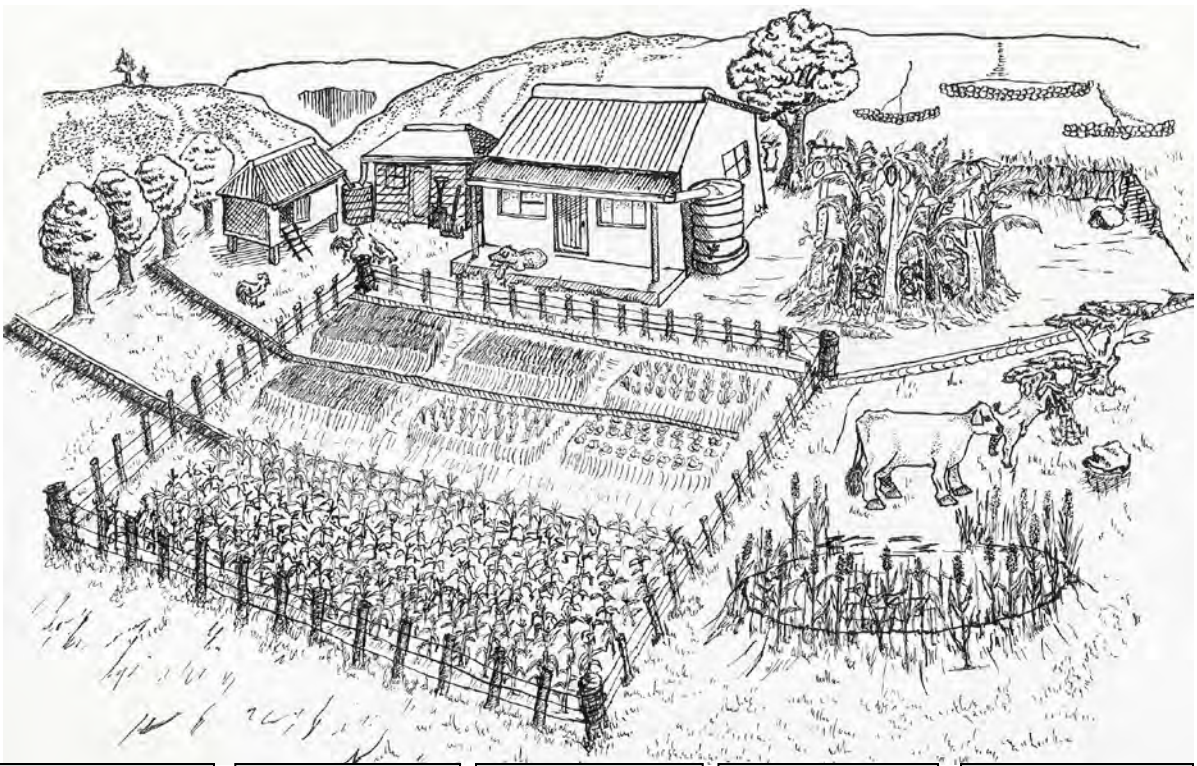
Global warming
The earth is getting hotter and the ice in the Arctic circles is melting. These changes are attributed to the accumulation of greenhouse gases such as carbon dioxide, methane and nitrous oxide, which trap heat in the atmosphere and make the earth warm. The main causes of global warming are industrial pollution, the burning of fossil fuels, and carbon dioxide emissions from road vehicles.

Another activity which disturbs natural ecosystems is ***farming***. While ***farms*** are systems in their own right, every farm exists within an ecosystem, and the practice of farming changes the composition and functioning of that ecosystem.[17]

3. Farm Systems

Every farm is unique, with its own specific characteristics and resources. The household, its resources, and the resource flows and interactions at an individual farm level are together referred to as a ***farm system***.[18]

Farm **resources** include natural and physical resources, as well as human capital, social capital and financial capital:



NATURAL
- Land, soil, water
- Plants, animals
- Access to common resources
- Climate
- Biodiversity

PHYSICAL
- Vehicles
- Roads
- Buildings
- Tools & equipment

FINANCIAL
- Cash
- Savings
- Government support
- Credit unions

HUMAN
- Knowledge
- Skills
- Beliefs
- Good health

SOCIAL
- Community
- Groups and organizations
- Kinship
- Culture & tradition

Regardless of their size, individual farm systems are organized to produce food and to meet other household goals through the management of these available resources.[19] The farming approach that a particular farmer adopts determines the way in which available resources are utilized. The farming approach also determines the degree to which that farm system will impact negatively on its ecosystem. Farming approaches which focus on *sustainability* are the least damaging to local ecosystems and the environment in general.

3.1 Sustainable farming

Sustainability means having the capacity to endure;[20] this is achieved by meeting current needs without compromising future needs. The goal of sustainable farming is to integrate different farm elements (soil, water, plants, animals, climate and people) into a production system that is appropriate for the environment, the people, and the economic conditions at the farm.

Farms become and stay environmentally sustainable when they imitate natural systems. Sustainable farming therefore involves creating a farm landscape which mimics as closely as possible the complexity of a healthy ecosystem.[21]

On any farm there are **four major ecosystem process** that are at work: energy flow, nutrient cycling, the water cycle and ecosystem dynamics. These processes function together as a whole, so a change in one of them affects all of the others. Farm systems which are designed to ensure that these process are functioning properly are sustainable systems in which soil and water is naturally conserved.

Process 1: Energy Flow

Plants capture solar energy (sunlight) using the process of photosynthesis, and use it to grow. Energy flows through the system as animals eat the plants, and as micro-organisms decompose dead plants and animals. At every transfer point in the food chain some energy is lost as heat. Energy is also lost through movement and as solid waste.

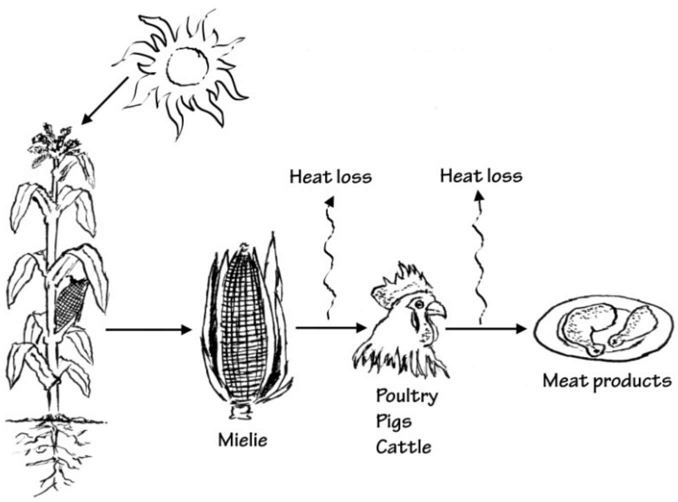


Figure 3.5 Energy flow

The amount of solar energy that is captured by plants determines the amount of energy that will flow through the farm system. Farmers can increase the amount of sunlight that is captured by maximizing the leaf area available for photosynthesis. This can be done by planting *more* vegetation, and by ensuring that there is vegetation all year round. Off-season cover crops, perennial vegetation, and intercropping are some of the tools that farmers can use to capture more solar energy. Farmers can also make sure that the stored solar energy is cycled efficiently through the food chain.[22]

Process 2: Nutrient Cycling

The nutrients needed for plant and animal growth are continuously recycled as they move from the soil through the crops and animals and then back to the soil. In nature, these nutrients are recycled with very little waste and with no need for fertilizer.

When a nutrient cycle is well-functioning, there is no need for the farmer to use fertilizer or to bring in animal feed from outside of the farm. Conditions and practices which inhibit the natural nutrient cycle and thus reduce a farm's sustainability include soil erosion, nutrient leaching, and the depletion of organic matter. Practices which enhance the nutrient cycle include feeding livestock on the farm, managing manure and crop residues carefully, reducing the loss of nutrients through leaching, and preventing soil erosion.[23]

Process 3: The Water Cycle

A water cycle is effective when:

- water enters the soil quickly;
- the soil has the capacity to store large amounts of water; and
- there is no soil erosion.

Sustainable farm systems aim to get as much water as possible into the soil during each rainfall. Rainwater harvesting helps with this process, as do any practices which maintain or increase levels of ground cover and soil organic matter, such as mulching, adding compost or manure to the soil, and growing high-residue crops.

Process 4: Ecosystem Dynamic

The indicator of an effective ecosystem dynamic is a high level of diversity within the system. The term *diversity* refers to the presence of many different plant and animal species, genetic diversity within each species, and a wide-ranging age structure in each population. Spatial diversity is also important for maintaining a healthy ecosystem dynamic. Spatial diversity refers to the vertical location of components in the system (e.g. the number of horizontal levels on a farm, with trees, shrubs, grass and soil each being at a different level), and the horizontal location of components (e.g. the spatial patterns of plants and other organisms).[24] Diversity within a system provides it with greater stability, makes it more resistant to change, and increases its ability to recover from disturbances.[25]

Practices which increase diversity include:

- crop rotation (residues from different crops stimulate soil organism diversity);
- cover cropping (planting non-crop species between cropping cycles, thus providing a habitat for wildlife and beneficial organisms, and increasing the diversity of soil organisms);
- planting hedgerows and buffers (these attract and provide a habitat for beneficial organisms, among other functions such as acting as wind breaks, marking boundaries, and keeping animals out of fields and vegetable gardens); and
- increasing the amount of organic matter in the soil by applying compost and incorporating plant residues into the soil (which stimulates diversity in the soil).[26]

3.2 Approaches to sustainable farming

Two farming approaches which apply the principles of sustainable farming are the Integrated Systems Approach, and Low-External-Input and Sustainable Agriculture (LEISA).

The Integrated Systems Approach

This approach is based on the view that whatever is being grown now was once part of a completely natural process, and grew without any human help. The aim of this approach is to recreate and integrate into the farm the beneficial connections and natural processes that support productivity. The following extract illustrates the integrated systems approach:

> "Picture on one hand an industrial chicken factory, with chickens in cages. Here the chicken is isolated from its natural environment, and virtually all that is needed to sustain it is provided by humans. A huge infrastructure is needed to grow food for the chicken, and to transport the food to the chicken. Because this is a stressful environment for the chicken, it tends to lead to disease so there is also a large pharmaceutical industry to provide medicines and hormones to keep the chicken alive. Every step in the process is energy-intensive, including the disposal of the chicken's waste products and manure, which usually have to be treated as a pollutant. And the end product, an egg in this case, tends to be of questionable quality in the eyes of consumers.
>
> Picture now another scenario: an orchard designed to have chickens run through it to scratch and feed, then return to their roost at night. Here the animals, in more of a natural environment, can feed and mostly medicate themselves from the environment. Their products like manure are used in the system, and rather than being a pollutant, contribute to the productivity of the trees. And the end product, in this case an egg again, may be of higher value in the eyes of consumers."[27]

The integrated systems approach, which is about learning to work with natural processes, helps reduce inputs from outside of the farm and contributes positively to the ecosystem dynamic of the farm system.

Low-External-Input and Sustainable Agriculture (LEISA)

The LEISA approach to agriculture aims to ensure sufficient food production within the limits of the natural environment. LEISA builds on natural biological and ecological processes in order to maintain or enhance ecosystem functions. It combines the knowledge and experiences of traditional agriculture with new scientific understandings of biological and ecological processes, and aims to ensure that agricultural production is environmentally sound, benefitting both rural communities and the environment.

Principles upon which LEISA farm systems are developed include the following:

- "Adapting agriculture to specific local environments by optimising the use of locally available resources and combining different components of the farm system, i.e. plants, animals, soil, water, climate and people, so that they complement and support each other and have the greatest possible synergistic effects;
- Reducing the use of external and non-renewable inputs with the greatest potential to damage the environment or harm the health of farmers and consumers; minimising the use of non-renewable fossil fuels and optimising the use of solar and other renewable forms of energy;
- Increasing the knowledge of farmers and society so as to optimise the management of natural resources."[28]

LEISA uses technologies such as "...soil and water conservation, integrated plant nutrient systems, agroforestry, integrated pest management, intercropping, crop-livestock integration, and microclimate management. The approach aims to secure sustainable increases in agricultural production, while enhancing biodiversity and ensuring the sustainable use of natural resources."[29]

activity 6

Analyse a Farm System

Study the illustration of Thembisa's farm and complete the following in relation to her farm system:

1. What farm resources does Thembisa have available to her? Identify all those which you can see from the illustration, and list them under the following headings: natural, physical, human, social and financial.

2. What other resources might be available to Thembisa, even though they are not shown in the illustration? List each resource under its appropriate heading.

3. Identify and list 5 system inputs, 5 outputs, and 5 processes which take place within the system.

4. Explain in detail how you think this farm system has impacted on its ecosystem.

5. What sub-systems can you identify within this farm system?

6. Do you think that Thembisa's farm system is sustainable? Explain your answer in detail.

Time: 2 hours

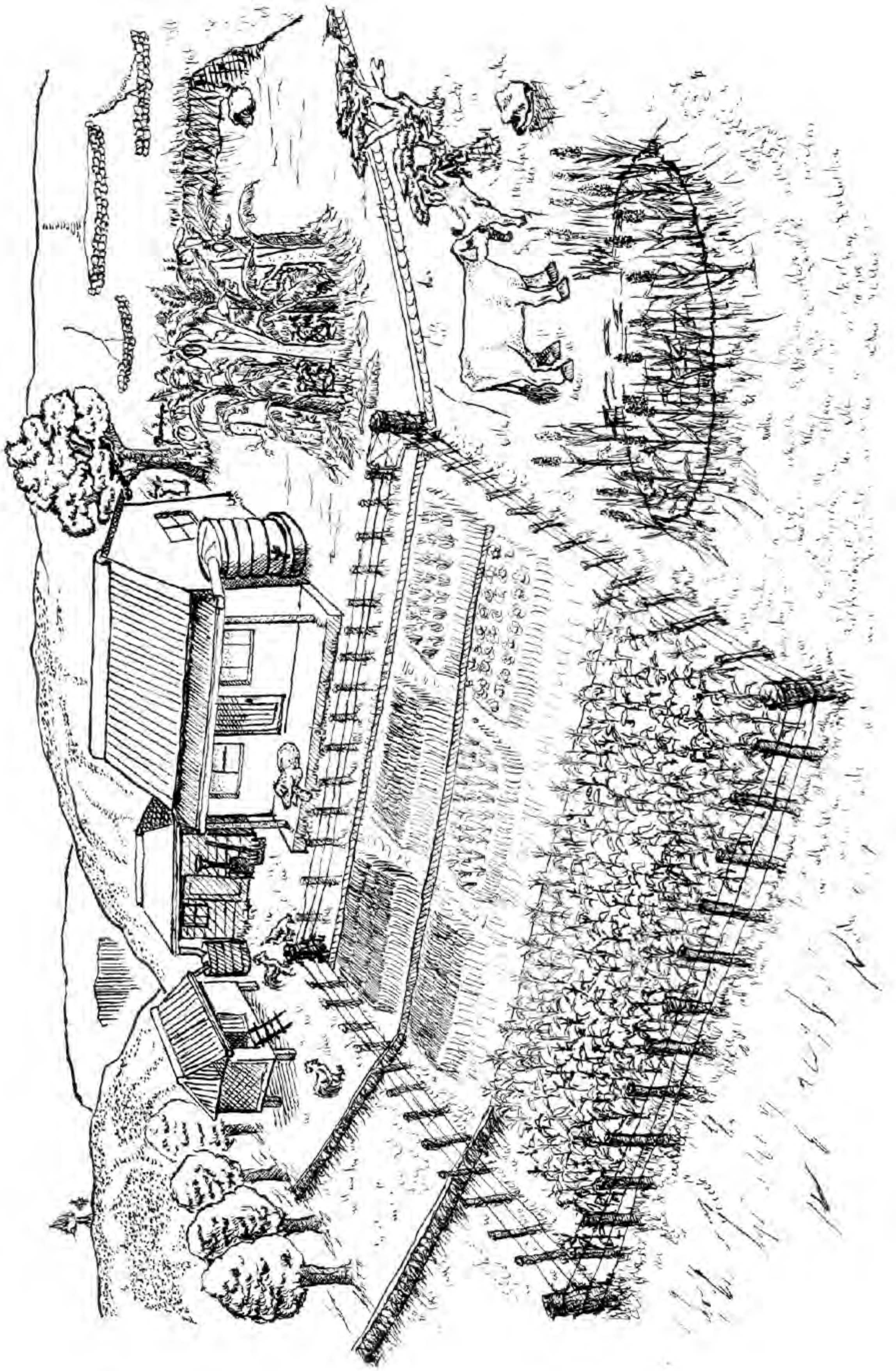


Figure 3.6 Thembisa's farm system

4. Ecotopes

contextual information

An 'ecotope' is a South African concept and can be defined as an area of land on which the natural resources (climate, topography and soil) which influence yield are reasonably homogeneous (i.e. they are nearly the same).[30]

The following are some of the ideas which underpin the concept of an ecotope:

- An ecotope constitutes an agriculturally uniform piece of land in which small differences can be ignored for practical farming purposes.
- The general characteristics of a particular ecotope (i.e. its climate, slope and soil) are sufficiently unique to call for agricultural treatment which is different from other ecotopes.
- The development of solutions to agricultural problems on a particular ecotope will apply wherever that same ecotope occurs.

Several research and development initiatives have used the ecotope as the unit of data collection and analysis when developing agro-technology. This is because it provides a vehicle for the extension of farming technology to farmers wherever subdivision of the landscape into ecotopes, based on climate, soil and slope data, can be achieved. One example is the Ciskeian Ecotope Project, which developed agro-technological recommendations for dryland and irrigated crop production on important ecotopes found in the Ciskei region of the Eastern Cape.[31] Another is the work done in Free State on the development of 'in-field' water harvesting (a form of tied ridges).[32]

The ecotope is not just a useful concept for the development of technology by researchers and for passing this technology on to farmers via extension agents. Ecotopes can also be very useful for farmer-to-farmer research and extension within confined areas, such as villages or settlement clusters. In confined areas, the climate tends to be fairly homogeneous, slope is an easily observable characteristic and soil can be examined using simple methods. Once farm units (field or plots) have been categorised into ecotopes, farmers working on the same ecotope can share their experiences, leading to the local development of "best practices". In research circles, ecotopes are often named using a combination of place names and soil form. Examples are the *Alice Oakleaf ecotope,* for which a considerable database was developed for irrigated crop production,[33] and the *Glen Bonheim ecotope*, which featured prominently in the development of crop production guidelines using 'in-field' water harvesting.[33]

5. Test Yourself

1. Provide definitions for the following terms:

   1.1 System
   1.2 Open system
   1.3 Ecosystem (6)

2. Every ecosystem has a biotic and an abiotic component. Explain in detail the difference between these two components. (8)

3. Explain the difference between a food chain and a food web. (4)

4. Name the two main processes of an ecosystem. (2)

5. Ecosystems can be threatened or disturbed by various things. Name four and explain why each presents a threat to ecosystems. (8)

6. Explain what sustainable farming aims to do, and what doing this involves. (8)

7. Name the four ecosystem processes that are at work on any farm and discuss two of them in detail. (12)

8. Briefly outline two farming approaches which apply the principles of sustainable farming. (8)

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Xoliswa Matangala (artist)
"A long walk up the hill with water."

Chapter 4

Water in the Landscape

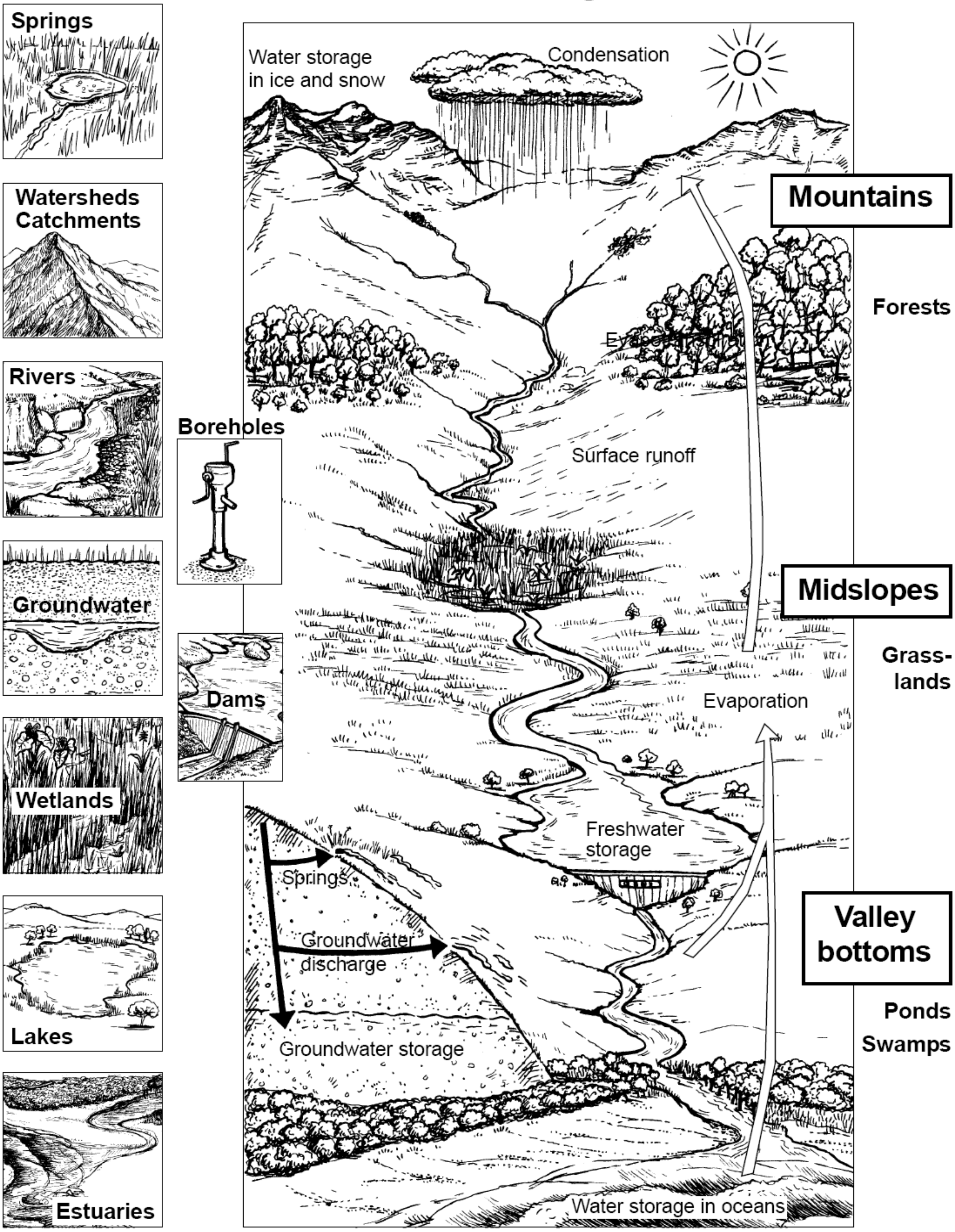
Contents

Outcomes

At the end of this chapter you should be able to:

- Name four different processes which cause water to change its form, and briefly explain each one.
- Explain the process of the water cycle.
- Identify a water catchment and the various water users within the catchment area, and explain how water will move through the catchment area.
- Discuss the importance of wetlands with specific reference to surface water flow, and identify activities which can change the hydrologic conditions of a wetland.
- Define the term *surface water* and explain how surface water gets polluted.
- Explain in detail how water moves through the different groundwater zones.
- Name various human activities which lead to the pollution of groundwater, and explain how and/or why each acitivity causes pollution.

Features in the Landscape
The Water Cycle



Artwork by Kathy Arbuckle

1. How the Water Cycle Works

Water is always on the move and keeps recycling itself in a process known as the ***water cycle***.

Water molecules in the ocean, rivers and lakes get heated up by the sun. This causes them to ***evaporate*** (change from a liquid into a gas) and rise into the atmosphere. The heat of the sun also draws water from plants and the soil (called ***evapotranspiration***), while ice and snow can turn into water vapour through a process known as ***sublimation*** (which is when water changes from a solid directly into a gas).

When the water vapour in the atmosphere cools down it *condenses* into water droplets. These droplets form clouds, which are moved around by air currents. Water droplets collide and join together which makes them large and heavy, and they fall to the ground as ***precipitation*** (rain, snow, sleet or hail).

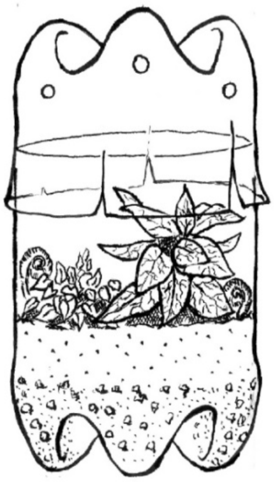
Precipitation falls back into the oceans and onto the land, where it flows as *surface runoff* over the ground down *water catchments*. Some of this runoff flows into rivers, while a portion *infiltrates* the ground and becomes a part of the *groundwater*.

Some groundwater infiltrates deep into the earth and replenishes ***aquifers*** (porous layers of rock which hold water). Other groundwater does not penetrate as deeply. Some seeps back into bodies of water on the surface of the earth – such as lakes and the ocean – as *groundwater discharge*, while other finds openings in the surface of the land and emerges as freshwater ***springs*** or the sources of rivers or streams.

Over time, surface runoff and much of the groundwater flows back into the ocean and other large bodies of water, where the cycle repeats itself.

activity 7

Make your own terrarium



A ***terrarium*** is a small enclosure in which selected living plants are grown. To make your own terrarium, you will need the following:

- a large clear plastic container (e.g. a 2 ℓ coldrink bottle) with a lid or cap
- a marker and scissors
- soil and compost
- pebbles/small stones and sand
- seeds and small plants

To make the terrarium:

1. Draw a line around the bottle about 16 cm from the bottom. (*Tip:* Rest the marker on top of an upside down cup and rotate the 2 ℓ bottle against the tip to make a straight line.)
2. Make a small hole in the plastic and cut along the line with a pair of scissors.
3. Put the stones and sand at the bottom of the bottle (about 5 cm deep).
4. Put the soil and compost on top of the stones (till about 2 fingers from the top).
5. Plant your seeds/small plants. Plant 6-10 seeds to start; as they grow, you can pluck out some of the weaker ones and leave 2 or 3 of the best ones.
6. Water the terrarium. The soil should be moist but not soaked.
7. Put the top onto the base so that the top is on the outside (see picture). If you have trouble fitting it on, cut a small slit into the top so that it will squeeze on more easily.

Once the plants have germinated, make sure they get sunlight but do not leave the terrarium in direct sunlight for the whole day as it will get too hot. Pay attention to the soil also. It should look moist but not soaked or too dry. Beads of water should form on the top inside edge, and these will drip down the sides and continue to water the soil. If the soil is too wet, take the top off and leave the terrarium uncovered for a day or two.

Instructions:

1. Examine your terrarium daily for at least one week. Every day, write down your answers to the following questions: What is happening? What has changed? Why do you think these changes have taken place?
2. Write down any other interesting observations you make during the week.
3. Draw a diagram which illustrates how the terrarium replicates the water cycle.

Time: 4 hours

2. Water Catchments

A ***water catchment*** is an elevated area of land down which water drains to a particular endpoint. Each catchment is separated topographically from adjoining catchments by geographical barriers such as ridges, hills or mountains; these barriers are called ***watersheds***. A ridge along a mountain, for example, creates two catchments, each of which faces a different direction. Elevated catchments drain into lower catchments, so a large catchment will include many smaller catchments at lower ***elevations***.

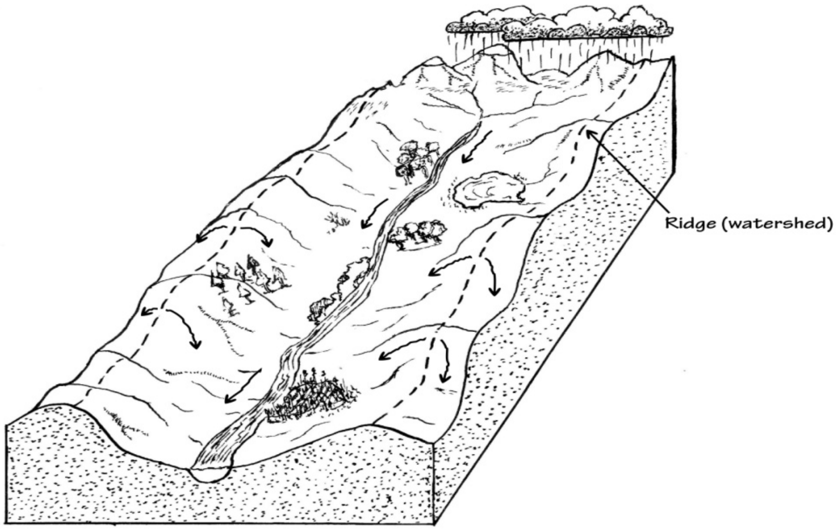


Figure 4.1 A water catchment

No matter where you are, the ground on which you stand forms part of a water catchment. Figure 4.2, for example, shows an urban water catchment. The crosses show the high and low points of the plot, while the arrows indicate the run-off water.

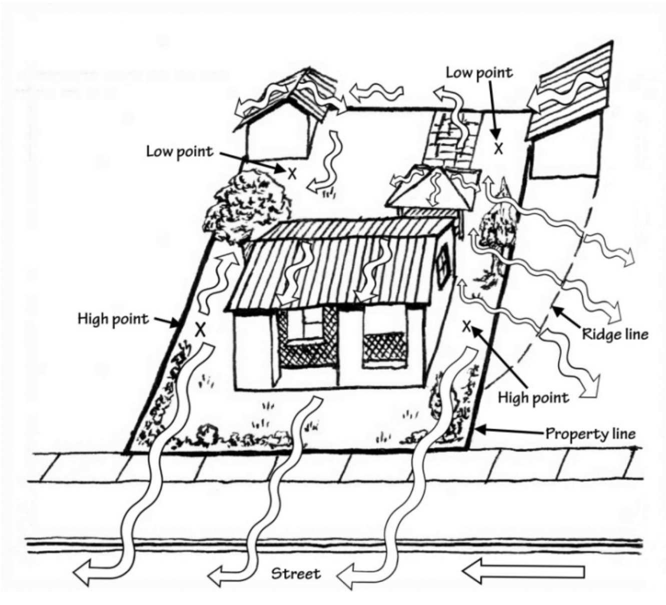


Figure 4.2 An urban water catchment

activity 8

Water Catchments

Carefully examine the piece of land on which you live and complete the following:

1. Identify the high and low points of the land.
2. Note all features on it (buildings and other structures, paving, concrete, trees, flower beds, vegetation, etc.).
3. Draw a plan of the land as close to scale as possible. Include all of its features (see Figure 4.2 for an example).
4. Think about what happens when it rains. Where does the water come from and where does it run to? Is there any place where it accumulates? Use arrows to show how water flows over the land when it rains heavily.
5. Think about the piece of land in relation to the land around it. Are there any features in the surrounding landscape which influence how water flows over your land? Where does the water which flows onto your land come from? Where does it go to when it runs off the land?

Share and discuss your plan with a partner.

Time: 2 hours

All runoff water within a catchment ultimately drains into lower bodies of water (in other words, everything upstream ends up downstream), and most water resources within a catchment area are connected in some way. As the water makes its way down a catchment, its flow and quality is affected by anything happening in the river or on the land over which it flows. Activities in one part of a catchment can affect downstream ecology and water users, and downstream degradation can disrupt ecological processes upstream, or even affect rainfall patterns.

3. Surface Water

Surface water is water that is open to the atmosphere, including springs, streams, wetlands, rivers, dams, lakes and the ocean. Each of these forms a system of interlinked relationships between humans and nature (called a socio-ecological system), and the health of a specific system is dependent on a healthy balance between human and natural activities.

A system becomes polluted when any substance enters into it which harms its natural resources. Overflowing sewage treatment works, faulty or damaged pipelines, and a lack of sanitation facilities all result in human waste ending up in river systems, causing water-related illnesses such as cholera and diarrhoea. Other pollutants of surface water include chemicals such as household detergents, pesticides, herbicides and fertilizers, metals from mines and factories (eg. iron, aluminium, lead, mercury), and chemicals from fuel, brake fluid and exhaust emissions, all of which can enter waste-water systems or wash into rivers when it rains. A summary of the fluid pollution in South Africa is presented in Table 4.1.

4. Wetlands

A wetland is an area of land where the soil is permanently or seasonally saturated with water, which can be salt, fresh or brackish. Swamps, marshes, vleis and bogs are all examples of wetlands.

Wetlands are considered the most biologically diverse of all ecosystems, as they have such an abundant array of plant, animal and bird life.[1] Wetlands are important because they act as natural sponges which trap and slowly release surface water, rain, snowmelt, groundwater and flood waters. Wetland vegetation such as trees and root mats act to slow the speed of flood waters, distributing it more slowly over the ***floodplain*** and thus reducing erosion. Wetlands which are in or downstream of urban areas counteract the greatly increased rate and volume of surface water runoff from pavements and buildings.

There are many human activities which can disturb the conditions of a wetland and cause its degradation. When activities within a wetland area cause the ***hydrologic*** *conditions* of the wetland to change, the chemistry of the soil can be significantly altered and the plant and animal life disturbed. Common activities which change hydrologic conditions include[2]:

- depositing fill material for development;
- draining (for development, farming, mosquito control, etc.);
- dredging and channelling streams (for development, flood control, etc.);
- diking and damming to form ponds and lakes;
- diverting water flow to or from wetlands; and
- creating ***impermeable*** surfaces in the watershed, which increases water and pollutant runoff into wetlands.

Wetlands are able to absorb a limited amount of pollutants from the surface water, but too many pollutants can also damage a wetland. The main pollutants which cause wetland degradation include sediment, fertilizer, human sewage, animal waste, road salts, pesticides, heavy metals and selenium. These pollutants can originate from various sources, such as runoff (from urban areas, agricultural areas and mines), air pollution (from factories, cars, power plants, etc.), and landfills and dumps (which leak toxic substances). Activities which damage wetland vegetation include animal grazing, removing vegetation for peat mining, and introducing alien plants which compete with indigenous vegetation.

5. Groundwater

Groundwater is water which infiltrates into the ground, saturating pores or cracks in the soil and rocks. Groundwater is stored in, and moves slowly through, moderately- to highly-permeable rocks called ***aquifers***. The word 'aquifer' comes from the Latin words *aqua* (water) and *ferre* (to bear or carry) – aquifers literally carry water underground.[3]

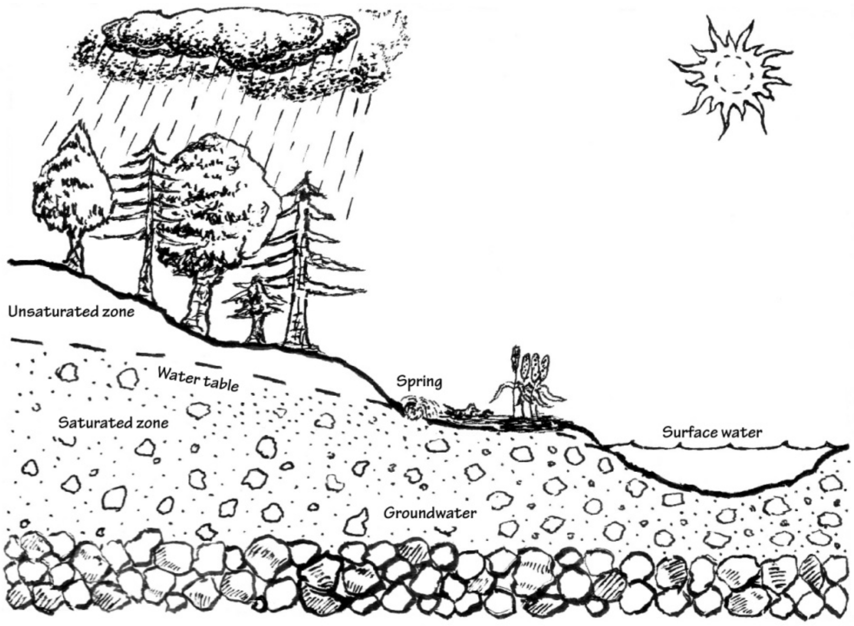


Figure 4.3 Groundwater zones

When it rains (or when snow melts), water seeps into the ground and the force of gravity pulls it down until it reaches a depth where it fills all of the openings in the soil or rock. This is called the *saturated zone* (or *aquifer*). Water which seeps into an aquifer is known as ***recharge***. Recharge occurs in areas where ***permeable*** soil or rock allows the water to be absorbed into the ground easily (called *recharge areas*).

Groundwater leaves the saturated zone at *discharge points*, which typically occur as seepage into wetlands, lakes and streams, or ***springs***. Groundwater usually moves very slowly from recharge areas to discharge points, although it moves faster when it encounters large rock openings or crevices.

Groundwater in a ***confined aquifer*** (an aquifer that is trapped under impermeable rock or soil) may be under pressure, and a well which pierces such an aquifer is known as an *artesian well*. An ***unconfined aquifer*** has the water table as its upper boundary.

The saturated zone ends when the water reaches impermeable rock through which it cannot pass (called the *confining layer*). The top of the saturated zone is called the ***water table***. The water table rises and falls depending on the season and the amount of precipitation that occurs. Between the water table and the surface of the land is the *unsaturated zone*. The water which is in this zone clings to molecules in the rock or sand, replacing water which has evaporated or been used by plants.

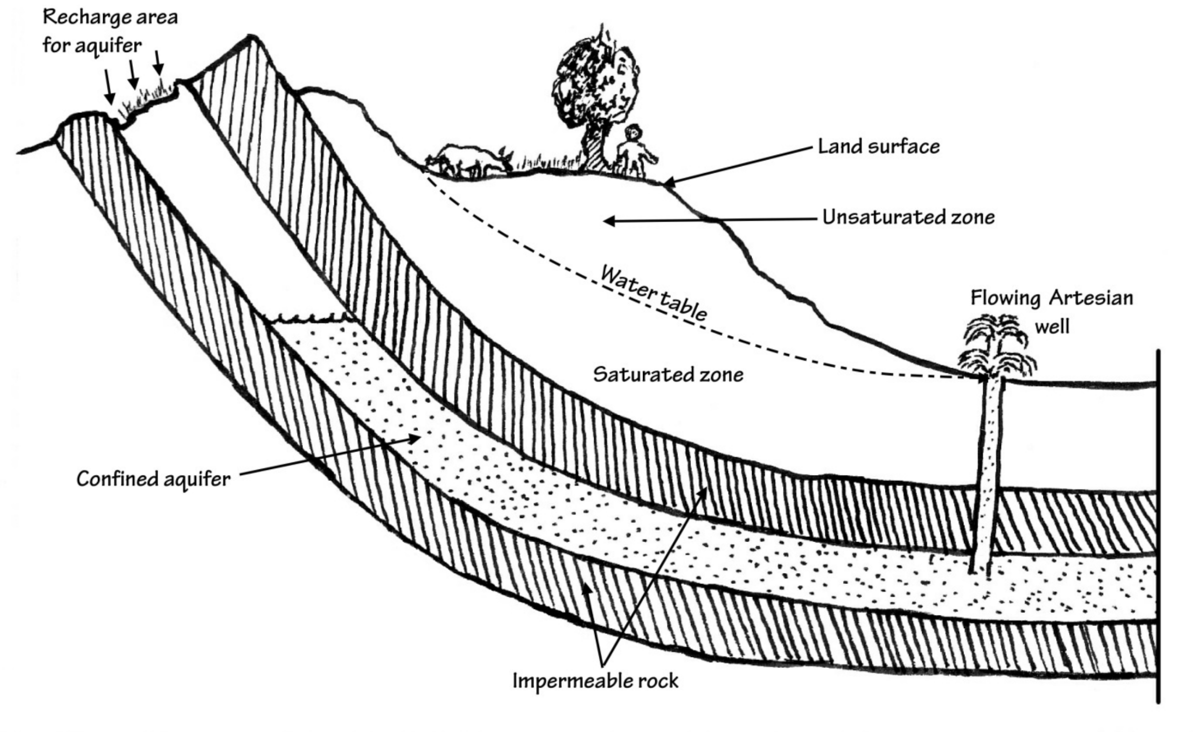
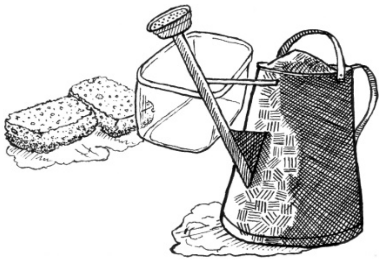


Figure 4.4 Confined aquifer and Artesian well

activity 9

Group Activity

You will need:



- two sponges of the same size
- a clear plastic container
- a watering can or a plastic container with small holes in the bottom
- water

Instructions: Place the sponges in the plastic container, one on top of the other. Pour water onto the top sponge (to simulate rain) and keep pouring slowly until the bottom sponge is full. Take note of what happens and in small groups, discuss what the experiment demonstrates and what each item used represents.

Time: 30 minutes

Groundwater plays a critical role in supplying water to streams and wetlands, but it is vulnerable to both *overuse* and *contamination*. Aquifers can be over-pumped, resulting in an area-wide lowering of the water table. Aquifers which are over-pumped can be permanently damaged, leading to their collapse or to the closure of their water-bearing factures. Over-pumping can also increase the salinity (saltiness) of the water.

There are many ways in which groundwater can become polluted. Seepage from broken sewage pipes and leaking pit latrines enters into the earth and contaminates the groundwater, a situation which is made worse when there is heavy rain or flooding, when the groundwater is close to the land surface, or where the ground is very permeable. Fertilizers and factory waste containing nitrates can seep into the soil or be washed into rivers and streams, and this runoff can cause serious illness in humans.[4] Nitrates also cause the eutrophication of surface water, which means that the water becomes rich in mineral and organic nutrients. This promotes a proliferation of plant life, particularly algae, which feeds on the nitrates and reduces the oxygen content of the water, causing the extinction of other organisms such as fish.[5] Poorly designed water points (places where people get their water from a tap or pump) are often surrounded by stagnant water where mosquitoes breed, animals drink, children play and women sometimes wash clothing. This dirty water seeps back into the groundwater, which in turn becomes contaminated.

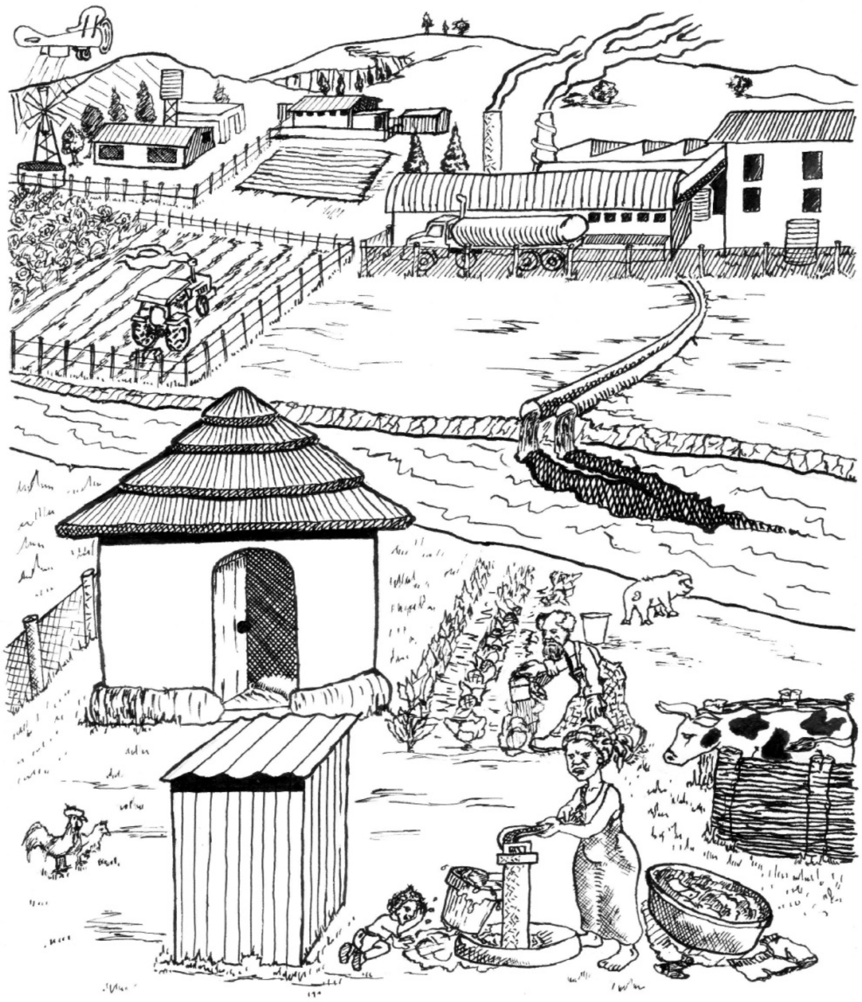


Figure 4.5 Groundwater contamination

Table 4.1 shows different types and sources of water pollutants and the physical effects which each type can have.

Table 4.1 Summary of fluid pollution in South Africa – sources and types of fluid waste[6]

Pollutant	Source	Physical effects
Colourants	Pulp/paper, textiles, abattoirs, steel, dairy, fermentation, tanning.	Aesthetically unacceptable; certain colourants are toxic.
Fixed particles in suspension	Pulp/paper, textiles, abattoirs, tanneries, canneries, breweries, steel industries, distillation kettles, sewage, mining, agriculture, urban.	Blockage in sewerage pipes and equipment, damage to rivers as a result of sedimentation and oxygen depletion. Detrimental to attempts at disinfecting.
Oil and grease	Abattoirs, wool laundries, dairies, steel industries, galvanizing, installations, oil refineries, tanneries, sewage, urban.	Blockage of sewerage pipes and equipment; floating litter on water that adversely affects the transfer of oxygen; anaerobic conditions; stench and flies. Leads to unacceptable taste after chlorinating.
Organic wastes	Pulp/paper, textiles, fermentation, sugar mills, abattoirs, tanneries, canneries, breweries, starch, sewage, agriculture, urban.	Overloads ordinary sewage purification works, leads to decline in oxygen content of rivers. Unacceptable taste after chlorinating and the production of trihalomethanes.
Insecticides and other pesticides	Chemicals, food, textiles and agriculture.	Toxic to bacteria and aquatic life.
Trace metals	Pickling, galvanizing, plating, mining, power generation, urban, vehicle exhaust fumes.	Sewage purification works are crippled. Also a health hazard for people, plants and animals.
Chemical residues	Coking, synthetic collaring, chemicals, plastic, solutions, textile finishes.	Taste and smell; toxic to aquatic life, plants, animals and humans.
Acids (mineral and organic)	Steel staining, chemicals, food, mining, power generation, synthetic fuel, motor vehicles.	Corrosion; release of pollutants from sediments; oxygen depletion; acid rain.
Alkalis	Metal finishes, plating, paper mills.	Toxic to biotic life; release of pollutants from sediments.
Nitrogen and phosphorus	Fertilizer factories, synthetic detergents, sewage, agriculture.	Eutrophication; nitrates may have an influence on health; ammonia may be toxic to fish.
Thermal pollution	Cooling, hypo-limnetic emissions.	Detrimental effect on the ecology.
Detergents	Textiles, metal finishes, sewage.	Formation of foam; possibly toxic.
Pathogens and parasites	Hospitals, abattoirs, sewage, agriculture.	Spreading of diseases.
Salts	Mining, agriculture, sewage, various industries.	Problems with irrigation water; industries and human consumption.
Radio-activity	Hospitals, mining, nuclear installations.	Genetic damage; influence on health.

activity 10

Pollution

Refer to Figure 4.5 and complete the following:

1. Identify the various water users within the catchment.
2. Identify and list possible pollutants of the **surface water**. Discuss the specific impact that each pollutant could have on the environment (people, plants, animals, water cycle, etc.).
3. Identify and list possible pollutants of the **ground water**. Discuss the specific impact that each pollutant could have on the environment (people, plants, animals, water cycle, etc.).
4. List two specific actions that could be taken to control ground or surface water contamination.

Time: 30 minutes

6. Test Yourself

1. Name the three different forms which water can take as it passes through the water cycle. (3)

2. Name four different processes which cause water to change its form, and briefly explain each one. (8)

3. Draw a diagram which illustrates the process of the water cycle. (10)

4. Provide definitions for the following terms:

   4.1 water catchment
   4.2 surface water
   4.3 wetland
   4.4 groundwater
   4.5 aquifer (10)

5. Discuss the importance of wetlands in relation to water flow, and list four human activities which change the hydrologic conditions of a wetland. (10)

6. Name three ways in which groundwater can become polluted. (3)

7. List four specific water pollutants found in South Africa. (8)

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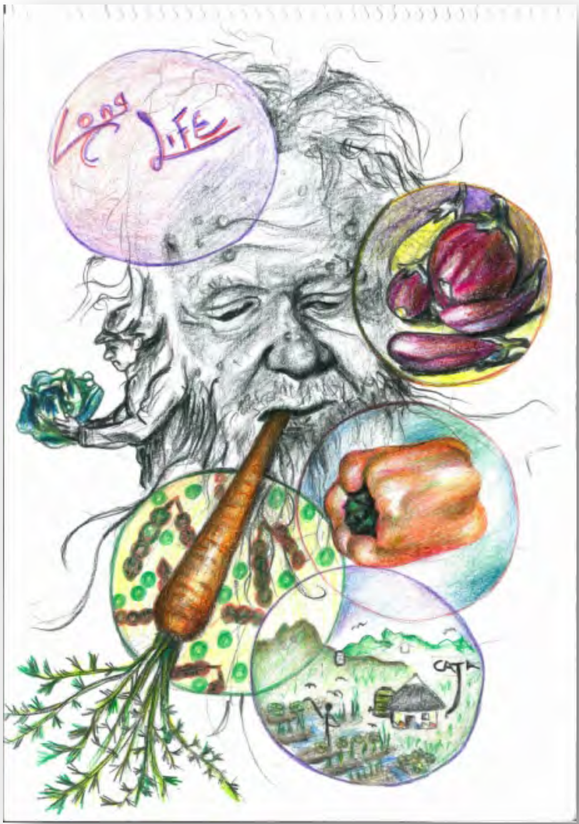


Bonkolo Ntembeko (artist)
"Eat fresh for a long life."

Chapter 5

Soil

Contents

Outcomes

At the end of this chapter you should be able to:

- Explain how soil is formed.
- Describe the role of soil as a medium which absorbs, stores and moves water,
- Identify soil texture using two different methods.
- Explain why and how soil compaction occurs.
- Identify and name different types of soil strucuture.
- Describe various practices which impact on the structure of a soil and explain the impact of each practice.
- Explain the difference between soil depth, rooting depth and effective rooting depth.
- Obtain a soil profile and identify the soil horizons which are revealed.
- Discuss soil fertility and explain the role of nitrogen, phosphorus, potassium and potential Hydrogen ions in soil fertility.
- Discuss the causes and impact of soil erosion in South Africa.
- Identify different types of soil erosion and explain the cause of each type .
- Describe various measures which can be taken to prevent soil erosion.

1. Introduction

Soil, which covers much of the earth's surface, consists of unconsolidated mineral and organic matter (rock, and decayed organic material and living organisms).[1] Air and water are also components of soil.

Most life on earth depends upon the soil for food. Soil serves as a medium for plant growth and is the primary nutrient base for plants, providing them with water and minerals. Humans and animals, in turn, get nutrients from eating the plants. The soil is also home to many organisms such as seeds, spores, insects, worms, snails, mites, millipedes, bacteria, fungi, algae and other micro-organisms.

Soil is a medium which stores and moves water, and thus plays an essential role in the water cycle. When it rains, a large proportion of water falls directly or indirectly onto the soil, where, depending on factors such as the structure and texture of the soil, it:

- infiltrates and is stored in the soil for plant use;
- ***percolates*** down through the soil and recharges groundwater aquifers; and/or
- runs over the soil surface as surface runoff.

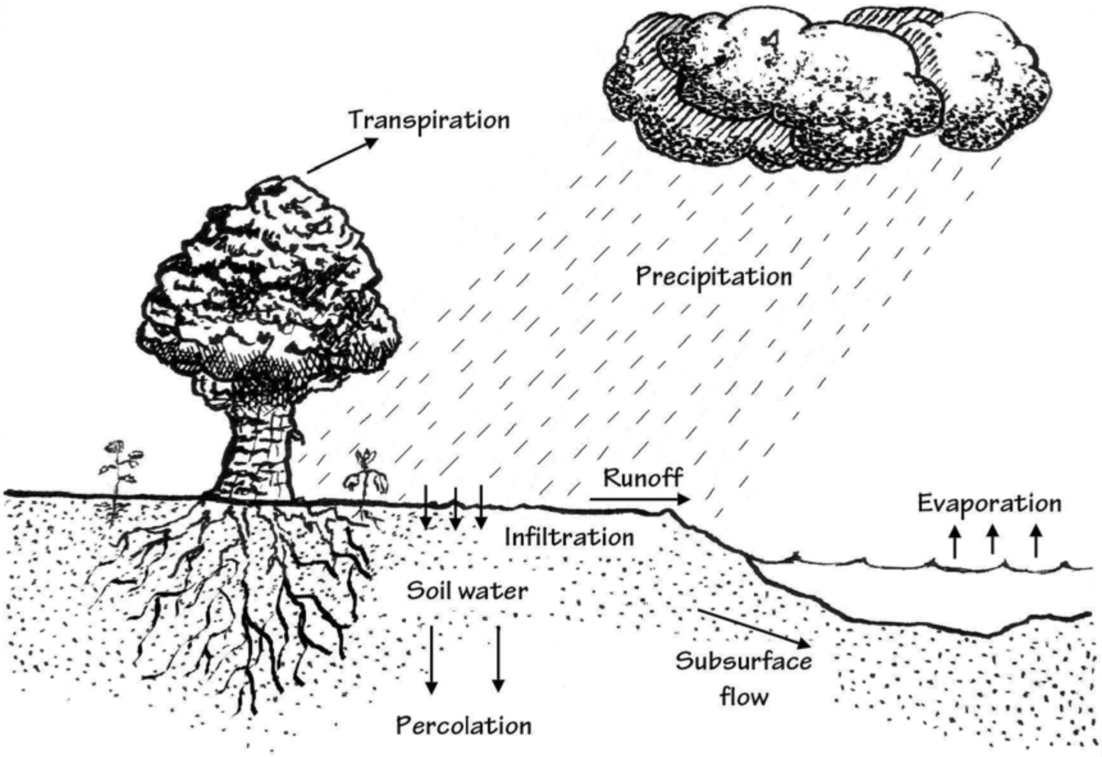


Figure 5.1 Water movement through the soil

2. How Soil is Formed

There are five factors which are involved in soil formation.

2.1 Parent material

Parent material is the material that is formed from the weathering of ***parent rock*** (e.g. ***bedrock***, which is the solid rock that lies underneath loose surface material such as soil, ***sand***, ***clay*** or gravel). This form of weathering takes place through geo-chemical processes, and is both physical and chemical. Physical weathering results in the formation of smaller particles, while chemical weathering results in mineralogical changes to the material, and it is in this new material that soils form. In most cases, the first visible effect of the transformation of a parent material into a soil is the darkening of the surface layer. This is the result of the enrichment of this layer with organic matter which originates from the decay of the tissues of plants and animals that colonised the parent material.

2.2 Climate

Another soil forming factor is climate, the important elements of which are *temperature* and *rainfall*. Temperature has an effect on both physical and chemical weathering, and also on what happens to soil organic matter. Frost accelerates the physical weathering of parent rock. Water that is present in cracks in the rock freezes and swells and the force created by this swelling is strong enough to split rocks apart, breaking it into smaller pieces and creating a parent material for soil formation.

Chemical weathering is accelerated by rising temperatures (which is why chemical weathering is most pronounced in tropical regions, and least pronounced at high latitudes). Water is closely involved in chemical weathering processes, both in the chemical reactions that take place and also in the removal of the weathering products. In humid areas, chemical weathering occurs at a high rate because of the persistent presence of water to bring about chemical reactions and to leach out the weathering products. This is why soils in humid areas tend to be acid, and low in plant nutrients such as calcium, potassium and magnesium. In dry areas, chemical weathering processes occur when the soil gets wet on occasion, but there is no removal of the weathering products, which is why soils in dry areas are rich in calcium, magnesium and potassium. This is not always beneficial, however, because these plant nutrients occur as salts and when the salt content in the soil is too high, many plants that we use as food fail to grow well.

2.3 Organisms

All micro-organisms, plants and animals living in or on the soil affect the way that soil forms. Micro-organisms turn the remains of dead plants and animals into organic matter called ***humus***, which is incorporated into and enriches the soil. The activities of worms, insects and burrowing animals shape and blend the soil.

Humans can also impact on soil formation, for example by removing vegetation cover and thus promoting erosion.

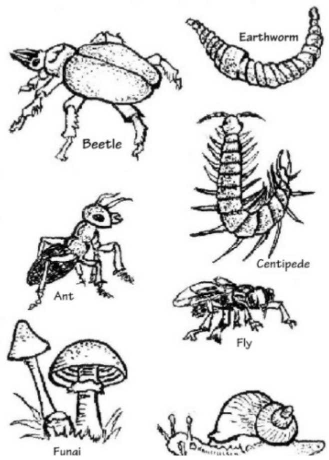


Figure 5.2 Some of the micro-organisms found in soil

2.4 Topography

The location of soil on a landscape will affect how climatic processes impact on it. For example, soil at the bottom of a hill will get more water than soil at the top, and soil which directly faces the sun will be drier than soil which is in the shade. The moisture and temperature of soil and the rate at which the parent material weathers is affected by slope and surface orientation.[2]

2.5 Time

Soil develops over time – often hundreds or thousands of years – as each of the above factors asserts itself, and ***soil profiles*** become increasingly well-developed as time passes.

3. Soil Composition

Soil consists of **solid matter** (mineral particles and organic material), **water** and **air**. Water and air is held in the spaces that exist between the soil particles and organic matter. These spaces, which are called *pores*, enable water, air and nutrients to move around within the soil system.[6] Water infiltrates the soil through the pore spaces when there is precipitation (such as rain) and the pores become filled. As the soil begins to drain or dry, the water in the pores is replaced by air.

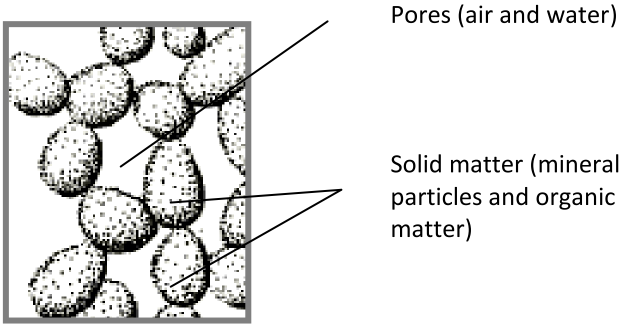


Figure 5.3 Soil composition

4. Soil and Water

Soil is a medium which absorbs, stores and moves water, as illustrated in Figure 5.4.

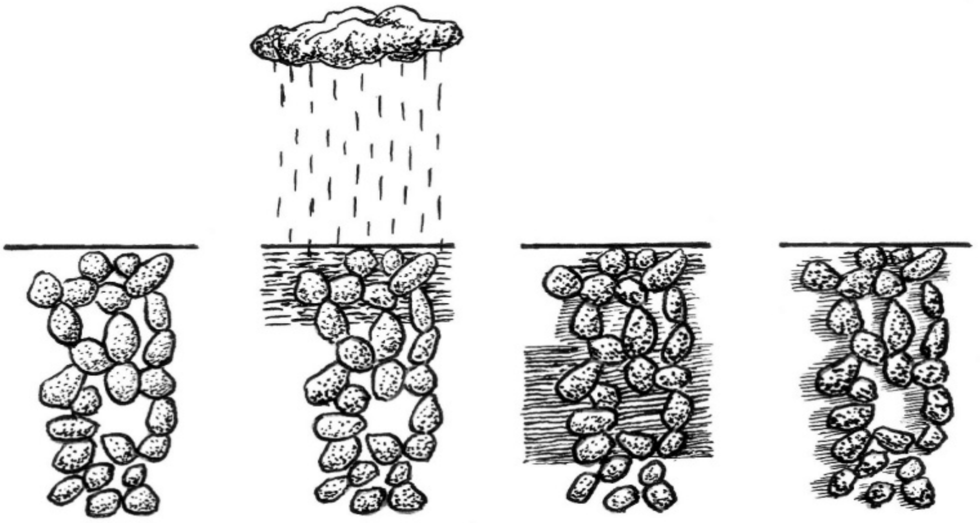


Figure 5.4 Water in the soil

The following terminology is used in relation to the penetration and movement of water through the soil:

Infiltration – the rate at which water enters the soil surface (measured in mm/hour). Infiltration rates can be very low for clayey or compacted soils, and very high for sandy soils.

Drainage – the ability of the soil as a whole to drain excess water. Drainage problems can arise when there is an impermeable layer (e.g. a layer of clay, rock or compacted ***subsoil***) at a shallow depth which prevents water from draining away.

Permeability – the rate at which water (and air) can penetrate or pass through a layer of soil. Some soils are more permeable than others (i.e. water moves through certain types of soil – such as sandy soil – more quickly).

Water Content – water held in the soil.

Water-Holding Capacity – the ability of a soil to hold water, measured as the amount of water held between ***field capacity*** and ***wilting point.*** Water-holding capacity is linked to soil texture: coarse soils such as sand have the lowest water-holding capacity, while medium-textured soils have the highest.

Saturation (or ***saturated soil***) is the soil water content when all of the pores are filled with water. ***Field capacity*** (or *moist soil*) is the soil water content after the soil has been saturated and then allowed to drain freely for 24-48 hours. *Permanent **wilting point*** (or *dry soil*) is the soil water content once plants have extracted all the water they can from the soil.

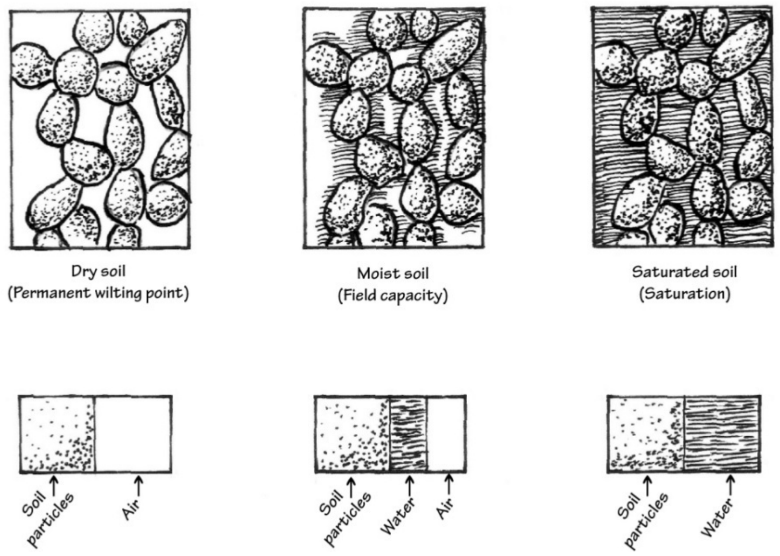
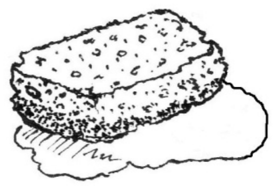


Figure 5.5 Amount of water and air in dry soil, moist soil and saturated soil

activity 11

Soil Experiment A



The way that soil acts is similar to that of a sponge. Take a sponge, place it under water and allow it to soak up as much water as possible. At this point, the sponge is at **saturation** point. Now, support the sponge with both hands and lift it carefully out of the water. When the sponge stops draining, it is at **field capacity**. Finally, squeeze the sponge until no more water comes out. The sponge is now at **permanent wilting point**, and the water which you squeezed out is the **water holding capacity** of the sponge.

Time: 10 minutes

Plants that are growing in the soil link the water that is present in the soil to the atmosphere. This link is referred to as the Soil-Plant-Atmosphere-Continuum (SPAC). The shoots of plants, which consist of the stems and leaves, are exposed to the atmosphere. The leaves of plants contain many small openings, called ***stomata***. During daylight, these stomata open to take up carbon dioxide from the atmosphere. This carbon dioxide is transformed into sugar during a process called photosynthesis. It is this sugar that forms the elementary building block of all the different types of tissues found in plants. When the stomata open, water inside the leaves is exposed to the atmosphere and evaporates. This means that when plants take up carbon dioxide from the atmosphere in order to grow, they lose water to the atmosphere. The water that is lost from the leaves has to be replaced. This is where the roots of the plant play their role. The loss of water from the leaves creates a suction in the leaf cells because the walls of the cells are elastic.

activity 12

Soil Experiment B

To visualise the suction exerted by cell walls, take an empty elastic plastic container with a fairly narrow opening, such as an empty dishwashing liquid container, and compress (squeeze) it a bit. Place the opening of the compressed container into water and watch how water is sucked into the container.

Time: 5 minutes

The suction created in the leaves from the loss of water is transmitted through the stems to the roots, causing the roots to suck water from the soil. The result is that water stored in the soil moves into the roots and is transmitted through the stems to the leaves, where it is then lost to the atmosphere through the stomata. As plant roots take up water from the soil, the soil dries out. It becomes increasingly difficult for plant roots to take up the water that remains, so unless the soil water reserve is replenished, a situation will develop where the roots can no longer supply the leaves with enough water to make up for the losses to the atmosphere. When this situation develops, the plant responds by wilting, a sign that the cells in the leaves do not have enough water. The stomata close to prevent the plant from drying out and dying, and when the stomata are closed, carbon dioxide is no longer taken up so plant growth comes to a halt.

Simply put, the optimum growth of plants is dependent on the leaves of the plant being supplied with sufficient water at all times. Whether this actually happens depends on many factors. One important factor is the weather, as a lot more water is lost from the leaves during dry, hot, windy conditions than in cool, humid, windless conditions.

The ability of plants to maintain an adequate supply of water to the leaves, even under extreme conditions, is dependent on the water content of the soil and on the distribution of the root system of the plant. The closer the water content of the soil is to ***field capacity*** (the soil water content after the soil has been saturated and then allowed to drain freely for 24-48 hours), the easier it is for the plants to suck water from the soil. Therefore, keeping the soil water content close to field capacity is a management practice that promotes high plant growth rate.

The root systems of plants also differ considerably. Leafy vegetables, such as Chinese cabbage and Swiss chard, have shallow and sparse root systems and as a result they need frequent watering of the top soil to grow optimally. Field crops such as maize, wheat and sunflowers have deep and dense root systems, which meant that they can extract large amounts of water from a soil profile before they start experiencing water stress.

Whereas the rooting system is a property of plants, the way in which the root system is distributed in the soil depends on the properties of the soil. One important factor is the effective ***rooting depth*** of the soil, which determines the maximum depth to which plant roots can penetrate (see Section 8).

Another factor is ***soil structure*** (see Section 6). Soil structure refers to the arrangement of primary soil particles into larger secondary aggregates. Usually, the presence of structure in soils is considered a positive attribute because soil structure is associated with fairly large pores which roots use to penetrate the soil. Good soil structure refers to the aggregation of primary particles into secondary units that are *water stable*.

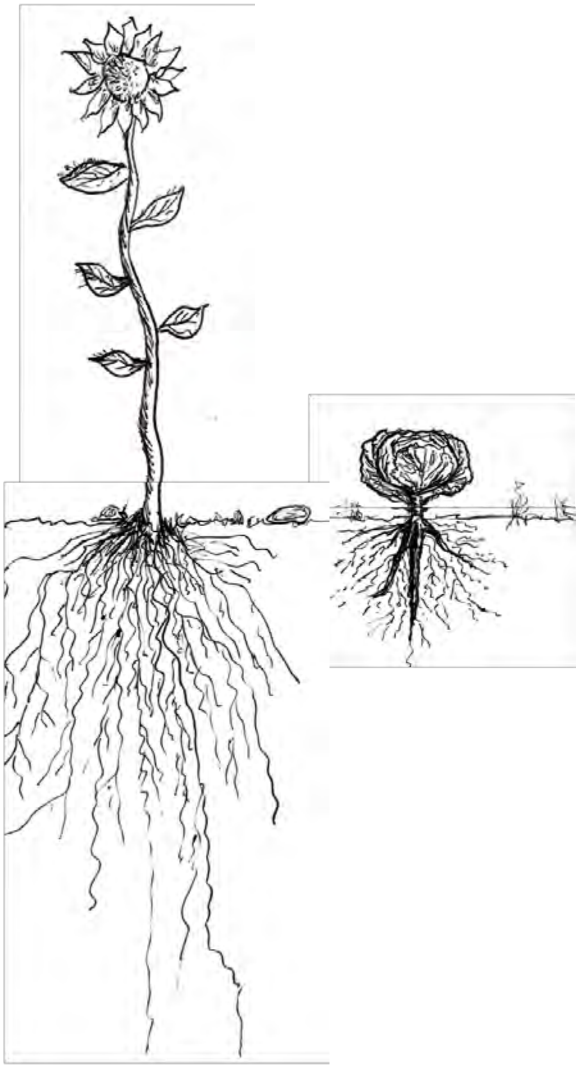


Figure 5.6 Plants with different root systems (sunflower and cabbage)

activity 13

Soil Experiment C

Collect at least three different samples of soil aggregates. Examine each sample carefully and try to identify which class of structure it belongs to (refer to Table 5.3).

One by one, immerse each sample partially in water and see whether it slakes (falls apart). If an aggregate does not slake it can be called water stable, but if it slakes it is not.

Time: 20 minutes

When the structural aggregates of soils are water stable, they will protect the integrity of the pores in the soil during wetting (i.e. the pores will not collapse when the soil gets wet). Remember that roots rely on pores to penetrate the soil, so when the aggregates are not stable, the pores can be destroyed when the soil is watered.

In the ***subsoil***, the presence of strong structure is usually not favourable for plant growth. *Strong structure* refers to the presence of aggregates that are clearly visible, particularly when the soil is dry. In subsoils with strong structure, the aggregates usually occur as medium to large angular blocks or prisms. On close observation, you will see that roots are only found in the fissures between these aggregates, and very few if any penetrate the aggregates themselves. In such cases, soil structure limits root ramification and as a result, water uptake from the soil will occur at a below-optimum rate.

5. Soil Texture

The weathering of large rocks produces smaller rock fragments and eventually soil particles, and it is these particles which make up the mineral component of soil. Soil particles vary in size, shape and chemical composition. To be called a soil particle, the particle should not be larger than 2 mm. Particles found in the soil that are larger than 2 mm are referred to as the coarse earth fraction. When these take up a large proportion of the soil, the soil is called **stony**. Stony soils are difficult to cultivate.

Three categories of particles, called **soil separates** or **particle size classes**, have been established based on particle size:

Sand: 0.05 mm to 2 mm
Silt: 0.002 mm to 0.05 mm
Clay: less than 0.002 mm

***Sand* particles** are the largest and are visible with the naked eye. The particles have sharp edges, so when you rub sand it feels rough. Sand is porous and does not hold many nutrients or water.

***Silt* particles**, which can be seen with a microscope, feel smooth and powdery; when it is wet it feels smooth but not sticky.

***Clay* particles** are the smallest and can only be seen with an electron microscope. It is smooth when dry and sticky when wet. Clay can hold a lot of nutrients and some can also hold a lot of water, but the structure of clay does not allow water and air to move through it easily. All soil consists of a mixture of sand, silt and clay particles.

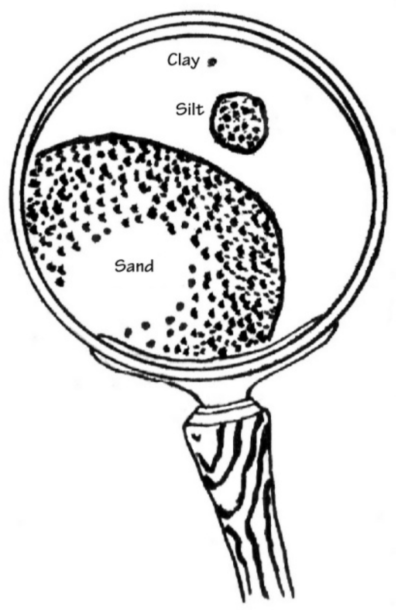


Figure 5.7 Soil texture

The proportion of the different soil separates in a soil is what defines its *texture*.[4]

activity 14

Soil Experiment D

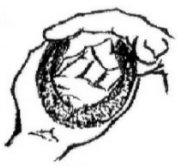
You can estimate how much sand, silt and clay is in a soil by how it feels. Take a handful of soil, wet it and roll it into a ball between your hands. Then roll this ball into a sausage. Refer to the table which follows to identify what type of soil it is. Conduct this experiment with soil from three different places and compare the results.

Very sandy (0-5% clay)
Soil looks very sandy and feels rough. It cannot be rolled into a sausage.

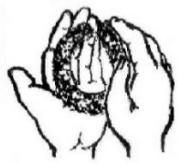
Sandy (5-10% clay)
Soil looks quite sandy and feels rough. It can be rolled into a sausage, but it cannot bend.

Sandy loam (10-15% clay)
Soil looks half sandy and half smooth, and feels rough. It can be rolled into a sausage and can bend a little.

Loam or silt loam (15-35% clay)
Soil looks mostly smooth. It feels a little sandy, quite smooth but not sticky. It can be rolled into a sausage which can bend about half way around.



Clay loam or sandy clay (35-55% clay)
Soil looks mostly smooth. It feels a little sandy, quite smooth and sticky. It can be rolled into a sausage which can bend more than half way around.



Clay (more than 55%)
Soil looks smooth, and feels smooth and sticky. It can be rolled into a sausage which can bend into a circle.

Time: 30 minutes

Another method of identifying the proportion of soil separates in a soil is to conduct a "bottle test". To do this, take a bottle and fill a third of it with soil. Pour water into the bottle until it is almost full, place a lid on and shake it vigorously for a few minutes in order to separate the soil particles. Leave the bottle to settle, and note what happens over the next few hours.

You will see that the substances settle in layers, the heaviest at the bottom and the lightest on top.

Heavy particles such as gravel, pebbles and sand fall quickly to the bottom of the bottle.

The finer elements then accumulate – first the silt, followed by humus and then the fine and very fine clay. These layers vary in colour and consistency.

The layer of water above the settled material remains cloudy for a long time because it contains clay particles which are so small that they stay suspended in the water. Substances which are lighter than water (organic matter like leaves, seeds, spores, and insect and animal waste) float on the surface.

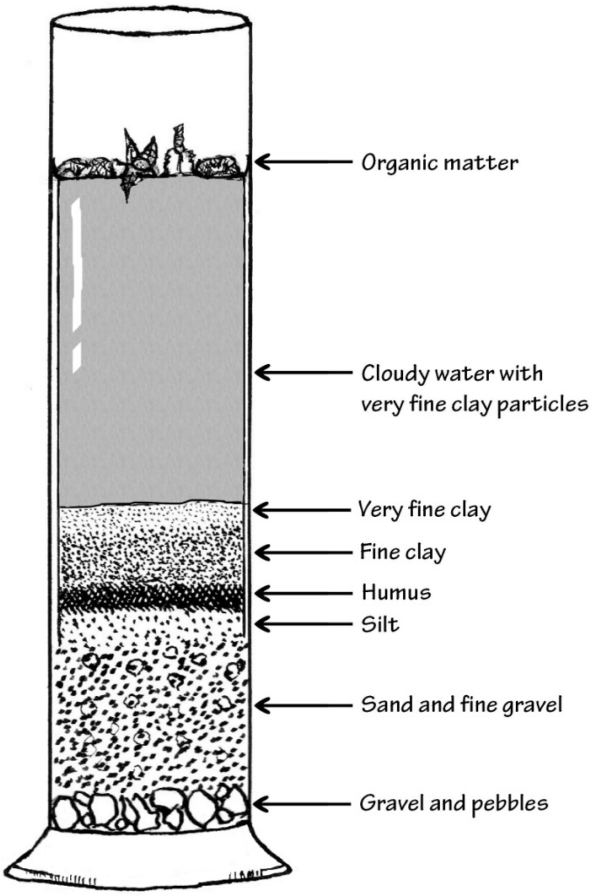


Figure 5.8 Bottle test showing proportion of soil separates

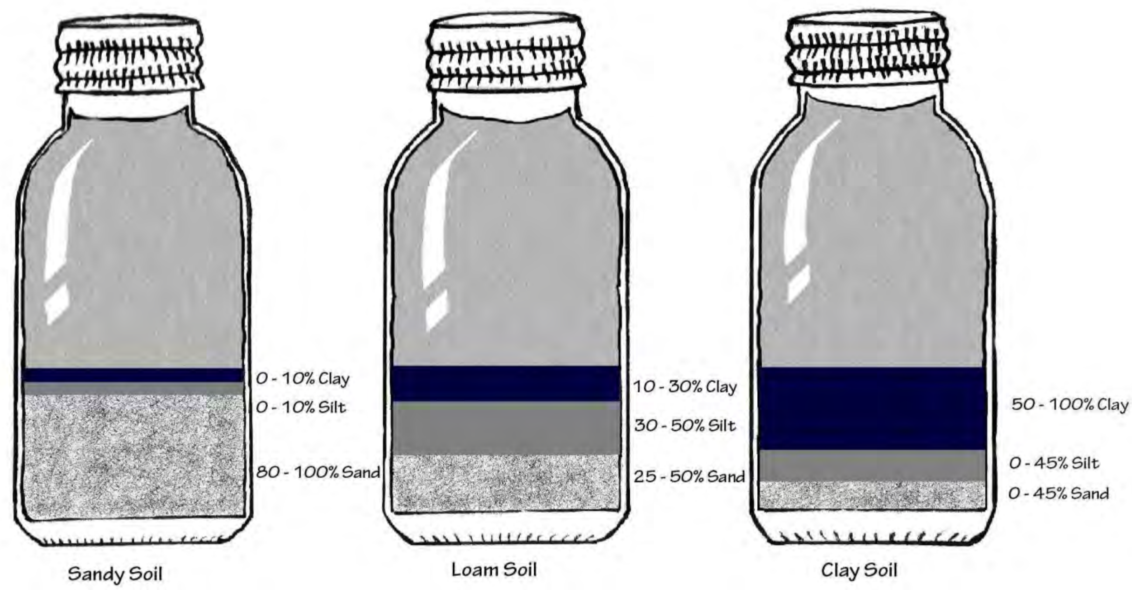


Figure 5.9 Using the bottle test to estimate the proportion of soil separates in a sample

Remember that a soil's water-holding capacity (i.e. its ability to hold water) is linked to its texture: coarse soils such as sand have the lowest water-holding capacity, while fine-textured soils (i.e. clay) have the highest.

Table 5.1 The typical amounts of water available in different soil types

Soil		Available water	
Type	**Texture**	**(mm/m depth)**	**%**
Heavy	Clay	120-200	12-20
	Silty clay	130-190	13-19
	Silt clay loam	130-180	13-18
Medium	Silt loam	130-190	13-19
	Loam	130-180	13-18
	Sandy loam	110-150	11-15
	Loamy sand	60-120	6-12
Light	Sand	50-110	5-11

Eastern cape Irrigation Manual, EC dept of Agriculture, 2004.

The table which follows lists some of the characteristics of sandy soil, loam soil and clay soil.

Table 5.2 Characteristics of sandy soil, loam soil and clay soil

+	SANDY SOIL -
- it is easy to dig and work	- it gets dry quickly
- it warms up quickly in spring	- it does not hold onto soil nutrients
- it is good for root crops	- it does not hold water well
- water and air can get into the soil easily	- it erodes easily
+	**LOAM SOIL -**
- it holds water well	- it can be hard when dry
- roots can penetrate the soil easily	
- it contains organic matter	
+	**CLAY SOIL -**
- it holds water well and for a long time	- it is heavy and hard to work
- it holds fertility well and for a long time	- it is slow to warm up in spring
	- it is sticky when wet
	- it is hard when dry

Another factor which impacts on the water content and water-holding capacity of soil is ***compaction***. Normal, loosely compacted soils are able to absorb and retain water. They also allow the root zone of plants to "breathe", which promotes plant growth.

However, when soil is compacted its macropores get crushed. Water tends to run-off highly compacted soils, which increases erosion. Highly compacted soils also do not allow much air to circulate to the root zone, so these soils typically have little plant growth.

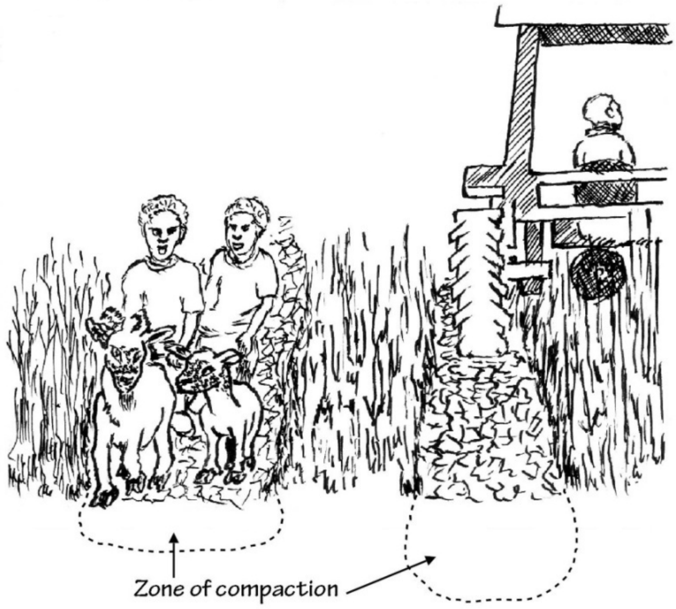


Figure 5.10 Soil compaction

Surface compaction can lead to *soil capping* (or *crusting*), which is when a “cap” or crust forms on the top of the soil. Surface compaction can result from human and animal traffic, surface irrigation systems such as sprinklers, and even big raindrops hitting the soil surface).

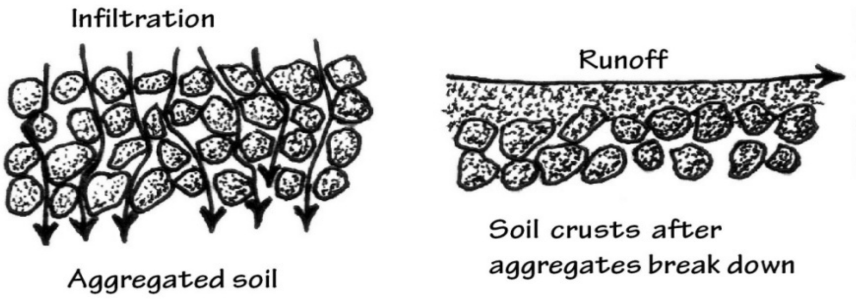


Figure 5.11 Soil capping or crusting

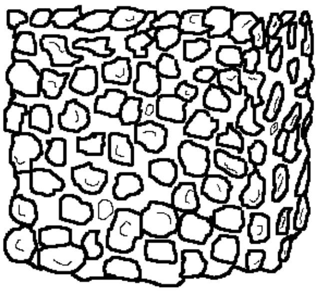
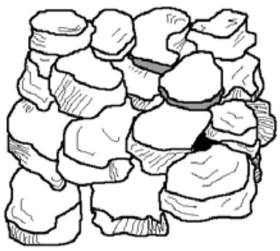
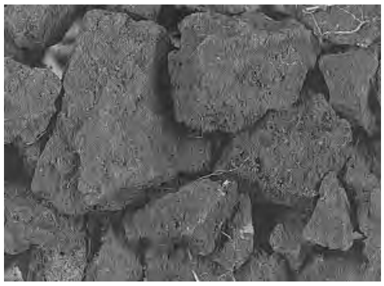
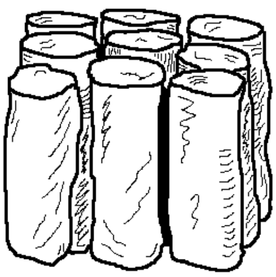
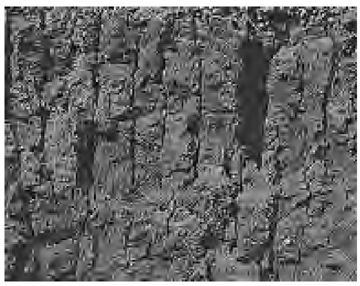
6. Soil Structure

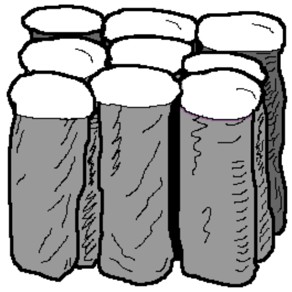
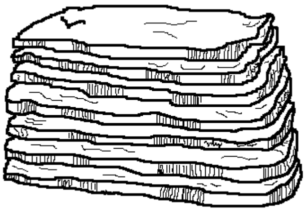
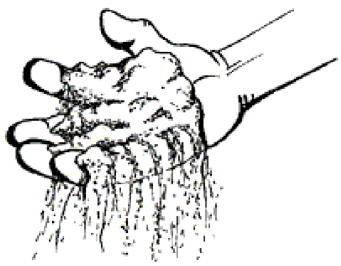
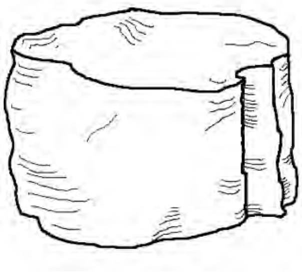
Soil structure describes the grouping or arrangement of primary particles (sand, silt, clay and organic matter) into larger, secondary particles called aggregates or peds. In other words, soil structure is the shape that soil takes, determined by the way in which individual soil particles clump or bind together.

Soil structure affects the movement of water and air in the soil, as well as root penetration and biological activity. For example, a dense structure greatly reduces the amount of air and water that can move freely through the soil, and it is difficult for roots to penetrate such soil.

There are five major classes of soil structure: granular, blocky, prismatic, columnar, platy. There are also soils which lack structure, such as sandy soils, and these are referred to as "structureless".

Table 5.3 Soil structure[5]

Granular: Resembles cookie crumbs and is usually less than 0.5 cm in diameter. Commonly found in surface horizons where roots have been growing.		
Blocky: Irregular blocks that are usually 1.5-5.0 cm in diameter.		
Prismatic: Vertical columns of soil that might be a number of cm long. Usually found in lower horizons.		

Columnar: Vertical columns of soil that have a salt "cap" at the top. Found in soils of arid climates.		
Platy: Thin, flat plates of soil that lie horizontally. Usually found in compacted soil.		
Single Grained: Soil is broken into individual particles that do not stick together. Always has a loose consistency. Commonly found in sandy soils.		
Massive: Soil has no visible structure, is hard to break apart and appears in very large clods.		

Soil structure photographs courtesy of Dr. Elissa Levine, NASA/Goddard Space Flight Center

The structure of the soil is influenced by how it is managed – some practices are harmful, while others are beneficial. Harmful practices break down the structure of the soil, making it a lot harder to work with and for plants to grow well in. Beneficial practices build up the structure as well as the quality of the soil, making it easier to work with and for plants to grow in well.

Some examples of harmful practices:

- Watering too much and too often. *Result:* The soil organisms and plants get choked because they lack air.
- Adding chemical products such as pesticides and fertilizers. *Result:* Causes unnecessary poisoning of the soil.
- Heating of the soil surface through fire or prolonged sunlight. *Result:* The ground dries up and micro-organisms are killed.

Some examples of beneficial practices:

- Controlling soil erosion and rainwater run-off. *Result:* Minimises damage to soil and crops (e.g. valuable ***topsoil*** does not get blown or washed away).
- Allowing fallow intervals (periods where fields/plots are rested and not used for production). *Result:* The soil has time to recover its structure and fertility before planting takes place.
- Cultivating soil-enriching crops – species high in ***biomass*** or green manures. *Result:* Species high in biomass add a lot of organic matter to the environment and soil, while those high in green manures add nutrients such as nitrogen to the soil.
- Incorporating animal manure or compost into the soil. *Result:* Improves the soil structure and increases the soil life; helps create a well-balanced soil that is alive and can support plant growth.

The soil structure benefits when the soil is occupied by the roots of many different plants, because:

- the roots move the soil;
- the roots create a network of living matter which dies and rots to create humus;
- when the roots die they leave tunnels which improve the porosity and drainage; and
- the roots are a living store of plant nutrients.

activity 15

Group Activity

Find an area where foot traffic has worn a bare path. Dig a small, shallow hole in the path, and another one next to the path. Examine the holes and the soil from each hole carefully, and try to identify the soil structure of each. Are there any differences in structure between the soil on the path and the soil next to the path? Discuss as a group and then share your findings with the rest of the class.

Time: 20 minutes

7. Soil Horizons

A vertical section through the soil reveals layers which are called ***horizons***. Not every horizon will appear in every soil – some soils have few or very indistinct horizons, while other have clear, well-defined horizons. The extent to which each horizon has developed depends on various factors, including the time over which the soil has been forming.

O Horizon

This is a surface horizon which consists mainly of accumulated organic matter (such as loose leaves) and humus (the remains of dead plants and animals).

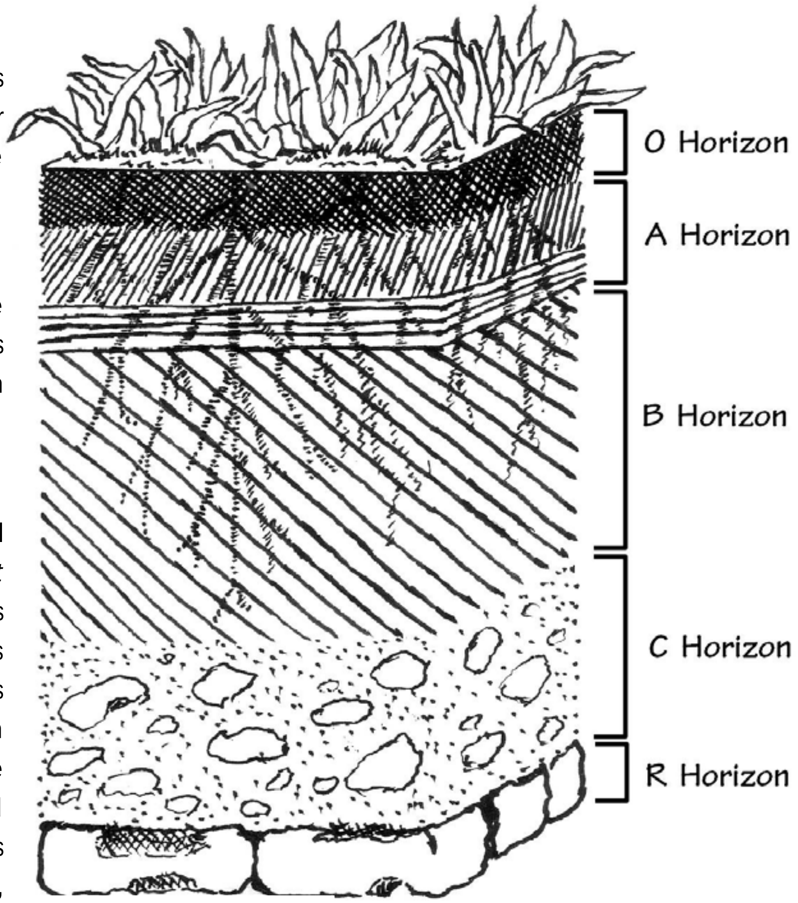


Figure 5.12 Soil Horizons

A Horizon (topsoil)

The A horizon is formed at the surface or just below the O horizon. It consists mainly of mineral particles, mixed with some organic matter.

E Horizon (subsoil)

The E horizon is a subsurface mineral horizon which may (or may not) form *at the base of the A horizon*. The soil in this horizon is bleached white or gray, or is paler than the soil above it. This is because water which passes through the soil carries away agents which give the minerals their colour (e.g. iron and aluminium oxides) and down-washes humus, iron, organic compounds, aluminium and clay particles, leaving behind a concentration of sand and silt particles.[6]

B Horizon (subsoil)

This subsurface horizon is darker than the E horizon, because organic and inorganic materials from above are down-washed into it and accumulate. The B horizon is essentially a mineral horizon, and blocky soil is typically found here.

C Horizon

This horizon consists of unconsolidated parent material (weathered rock fragments) from which the mineral portion of the soil is derived.

R Horizon

The R horizon (sometimes called the D horizon) consists of consolidated bedrock. Strictly speaking, this layer is not a horizon .

8. Soil Depth and Rooting Depth

Soil depth refers to the depth of the solum, which refers to all the horizons present in the soil, irrespective of whether these horizons allow for the penetration of plant roots or not.

The ***effective rooting depth*** of a soil refers to the depth of the horizons in upper part of the profile that can be penetrated by plant roots. In some soils, layers or horizons are present that act as root impeding layers. These can be identified by close inspection of root distribution in the profile. Hard plinthite is an example of a horizon that impedes root growth.

Rooting depth is a characteristic that is dependent on both the soil and the root system of the plant species growing in it. For example, when Swiss chard is grown in a soil with an effective rooting depth of more than 2 m, the shallow root system of this crop will not extend beyond 0.5 m. As a result the rooting depth of Swiss chard in that soil will be 0.5 m. In that same soil, wheat, maize, sunflowers and Lucerne, which are known for their deep rooting systems, will have rooting depths of 2 m or more. It follows that effective rooting depth is the most important attribute of soil depth for purposes of plant growth. Knowledge of effective rooting depth and the depth of root growth of the crop to be grown enables assessment of soil depth for plant production purposes.

Table 5.4 Plant rooting depth

Shallow (less than 600 mm)	Medium (600 mm-1200 mm)	Deep (more than 1200 mm)
Broccoli	Beetroot	Asparagus
Brussels Sprout	Carrot	Artichoke
Cabbage	Cucumber	Lima Bean
Cauliflower	Eggplant	Parsnip
Celery	Green Bean	Pumpkin
Garlic	Green Pea	Squash
Leek	Marrow	Sweet Potato
Lettuce	Pepper	Tomato
Onion	Swiss Chard (Spinach)	
Parsley	Turnip	
Potato		
Radish		
Sweetcorn		

Department of Agriculture (*www.nda.agric.za/publications*)

9. Soil Profile

A ***soil profile*** is a cross-section through the soil which reveals its horizons. A soil profile provides information about the soil, such as its texture, structure, colour and rooting depth. It can also help you determine whether or not the soil is suitable for growing vegetables.

A soil profile is obtained by digging a *soil pit.* A soil pit is a hole in the soil which is at least 1 metre deep, and wide enough to get into so that you can easily observe all of the ***soil horizons*** from the bottom to the top of the pit.

activity 16

Soil Profile

In pairs or small groups, dig a soil pit which is 1 metre deep and wide enough to get into to observe the soil horizons. Complete the following in writing:

1. How deep is the topsoil (the soil in the A horizon)?
2. Is there any root growth in the soil? Describe.
3. Is there an E horizon? How deep is it?
4. Are there any impermeable layers between the topsoil and subsoil (soil in the B horizon and lower)? Describe what they look and feel like.
5. What is the texture of the topsoil? Of the subsoil?
6. Describe the structure of the topsoil and the subsoil.
7. Give an opinion of the ability of the topsoil to support plant growth, and provide reasons for this opinion.
8. Explain what you think will happen to water which lands on this soil. Give reasons for your answer.

Think of a creative way to present your findings to the rest of the class. *(Ideas: take photographs, draw a diagram, collect soil samples, prepare a poster presentation)*

Time: 4 hours

10. Soil Fertility

Soil which is fertile has the following properties:

- It is rich in the *nutrients necessary for basic plant nutrition;* the most important of these are nitrogen (N), phosphorus (P) and potassium (K).
- It contains sufficient *minerals* (also called trace elements) for plant nutrition, such as iron (Fe), sulphur (S), calcium (Ca), silicon (Si), boron (B), zinc (Zn) and copper (Cu).[7]
- It contains *organic matter* which improves the soil structure and soil moisture retention.
- It has a *soil* ***pH*** of between 6.0 and 7.0.
- It is *well-drained.*
- It has a range of *micro-organisms* which support plant growth.
- It usually has a large amount of *topsoil*.

Remember that nutrients move in cycles through the ecosystem (see Chapter 3, Section 2.2).

10.1 Sources of plant nutrients in the soil

Nutrients in the soil come from various sources. These include: the weathering of soil minerals; the decomposition of plant residues and animal remains; the application of manures and composts; nitrogen-fixation by legumes (e.g. beans and peas); and the deposition of nutrient-rich sediment from erosion and flooding.

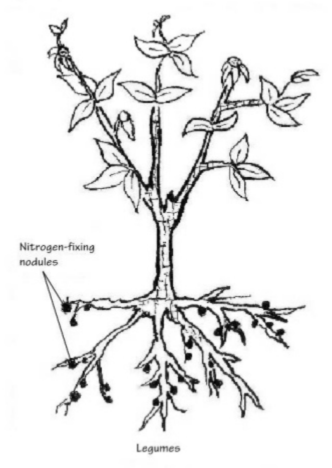
10.2 Losses of plant nutrients from the soil

Mineral nutrients can also be lost from the soil system or can become unavailable for plant uptake. Nutrient losses can result from:

- **runoff** – water moving across the soil carries away dissolved nutrients
- **erosion** – nutrients in or attached to soil particles are removed by wind or water
- ***leaching*** – dissolved nutrients move down through the soil to groundwater
- **gaseous losses** to the atmosphere
- **crop removal** – plants, which have taken up nutrients from the soil, are removed from the field when harvested

The three most important nutrients for soil fertility are nitrogen, phosphorus and potassium. Soil pH (potential Hydrogen ions) is also important for soil fertility.

Nitrogen



Nitrogen controls how plants take their form and how they function inside. Plants which are lacking in nitrogen have thin, spindly stems and stunted growth, and their leaves turn yellowish-green instead of being a strong bright green.

Adding nitrogen to the soil: Nitrogen is found in most manures (cattle, sheep, pig, goat, chicken and rabbit), although there is more nitrogen in chicken and goat manure than other types. Manure must be dried before being used in the garden, otherwise it can be too strong and burn the plants.

Nitrogen is also found in legumes (e.g. beans and peas). These are plants that form nodules or little knots on their roots. The nodules "fix" nitrogen from the air so that the plant can take it up through its roots. When the roots of the plant die, the nitrogen is released into the soil and can be used by surrounding plants.

Phosphorus

Phosphorus is important for plant formation and growth. It helps plants respire (breathe) and it also helps plants use water efficiently. Plants which do not have enough phosphorus have thin, spindly stems that are weak. Their growth is stunted and their older leaves turn a dark bluish-green. Some leaves may also start to show unusual red or pinkish colours, especially around the edges.

Adding phosphorus to the soil: Most of the soils in South Africa are poor in phosphorus. It is difficult to add phosphorus to the soil in an organic way, as most of the sources are somewhat tricky to work with (sources include urine, bone, hair, feathers and blood). Usually these ingredients are added to compost. A good source of phosphorus is bone-meal, which can be bought at agricultural supply stores. Natural rock phosphate can be added directly to the soil, although this is not easily available. One other way to add phosphorus to soil is to place bones in a fire for a few hours. The bones can then be ground into a powder, which can then be spread onto garden beds or a compost heap.

Potassium

Potassium controls the absorption of water into plant pores. It also controls water and chemicals inside plants, and is very important for the process of photosynthesis. Plants lacking in potassium do not have enough energy to grow well; their roots are not well-formed and they have weak stems and stalks. Leaf edges become brown and dry, and fruit does not form properly.

Adding potassium to the soil: Good sources of potassium are chicken manure and fresh wood ash. Ash from coal should never be used as it is very poisonous to the soil and to plants. Another good source of potassium is a plant known as comfrey. This plant has large, hairy leaves and grows in wet, shady places. Comfrey leaves contain a lot of potassium and can be used to mulch vegetable beds and to make liquid feeds/manures for plants.

Soil pH

Soil pH, which is simply a measurement of the acidity or alkalinity of a soil, is important for plant growth. Before a nutrient can be used by plants, it must be dissolved in soil water. If the soil water is too sour (acidic) or too sweet (alkaline), nutrients such as nitrogen, phosphorus and potassium won't dissolve and as a result won't be available to plants (the nutrients are said to be "locked up" because the plants cannot absorb them).[8]

The pH scale[14] ranges from 0 to 14; 7 is neutral, below 7 is acidic, and above 7 is alkaline. Soil pH can be tested in a laboratory, or in the field by using a universal indicator solution or pH paper.

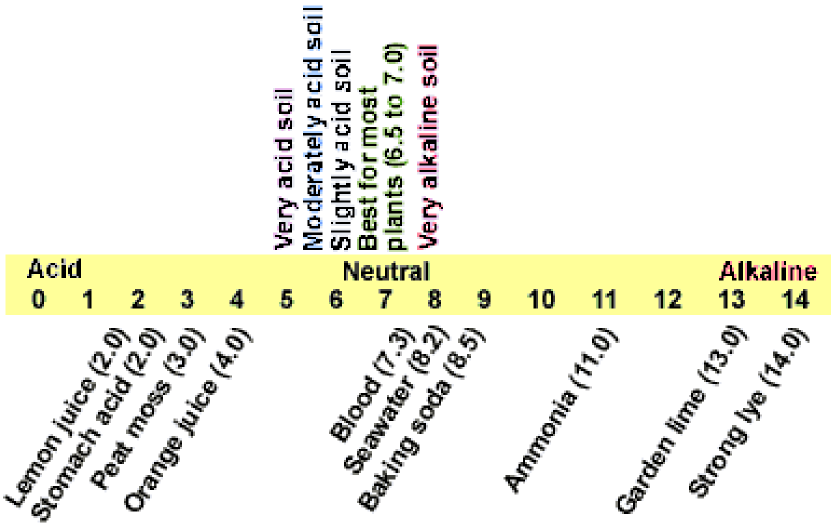


Figure 5.13 The pH scale[9]

In places where it rains a lot, minerals can get washed out of the soil, leaving the soil acidic. The use of chemical fertilizers over a long period of time can also make the soil acidic. Most plants grow best in soil with a pH of 6.0-7.0 (slightly acidic), although some plants prefer soil which is more acidic, while others prefer soil which is more alkaline.

Soil is acidic if plants do not grow even though they have enough compost and water. While it is possible to make the soil less acidic by adding a lot of compost and other organic matter to it over a period of a few years, the only practical and reasonably quick way of dealing with acidity is to add ***lime*** to the soil.

Lime can be bought, and comes in the form of a white powder or grey granules. Usually lime is added 2-3 months before planting as it is slow-acting in the soil. It needs to be dug into the soil, at least as deep as the roots are growing (30-60 cm for vegetables and 60-100 cm for field crops with deep roots, such as maize and sorghum).

Table 5.5 Examples of plant preferences for pH

Very acid (pH 5.0 to 5.8)	Moderately acid (pH 5.5 to 6.8)	Slightly acid (pH 6.0 to 6.8)	Very alkaline (pH 7.0 to 8.0)
Aubergine Blueberry Crabapple Endive Raspberry Rhubarb Shallot Sorrel Spinach beet Sweet potato Watermelon Wild strawberry	Beans Carrots Corn Garlic Parsley Peas Peppers Pumpkin Radish Soybean Squash Sunflowers Tomato Turnip	Asparagus Beet Broccoli Grape Kale Lettuce Mustard Oats Onion Peach Pear Rhubarb Rice Spinach	Acacia Cabbage Cauliflower Celery Cucumber Date palms Geranium Oleander Olive Pomegranate Tamarisk Thyme

activity 17

Conduct a Soil pH Test

In pairs or small groups, conduct a soil pH test on a sample of soil. To do this, use a simple soil pH test kit, which can be obtained from nurseries, garden centres or hardware stores. These tests usually consist of a test tube, some testing solution, a colour chart, and instructions for conducting the test. Follow the instructions carefully and interpret the result using the colour chart provided. Then, complete the following in writing:

1. Did you find the soil pH test kit easy to use? Give reasons for your answer.
2. Do you think that plants will grow well in this soil? Why or why not?
3. List five plants which you could grow in this type of soil (refer to Table 5.5).

Share your test results and answers to the above questions with the rest of the class.

Time: 1 hour

11. Soil Erosion

Soil erosion is the natural process of soil being carried away by wind, water, ice or the force of gravity. While soil erosion is healthy for the ecosystem when it occurs at approximately the same rate that soil is formed, it becomes a problem when human activity – such as overgrazing or unsuitable cultivation practices – causes the soil to be removed faster than it is formed.[10]

Soil erosion is measured as tonnes of soil lost from a hectare in a year. Thus, an area losing 10 tonnes of soil from each hectare is shown as 10 tonnes/ha/yr. Ten tonnes of soil is equivalent to 1 mm of soil spread over a hectare – an amount of soil which would fill more than 150 wheelbarrows. Of course, losing this amount from poor, thin soil is much more of a problem than losing the same amount from deep, fertile soil.

For every tonne of agricultural crop produced in South Africa (e.g. maize, wheat, sugar) an average of 20 tonnes of soil is lost, while annual soil loss in the country is estimated at 300-400 million tonnes. Globally, the loss of productive land through erosion is estimated at 5-7 million ha/year.[11]

Repeated erosion reduces soil fertility by: removing topsoil rich in nutrients and organic matter; reducing the depth of soil available for plant roots and for storing water; and reducing water infiltration into the soil, which increases runoff. It is runoff that carries soil particles away. Erosion has a range of other negative impacts, such as the loss of seeds and seedlings, soil being washed from plant roots, and increased sedimentation in rivers and water courses.

11.1 Main causes of erosion in South Africa

In South Africa, the main causes of soil erosion are wind and water. *Water erosion* begins with rain. As raindrops hit the ground they dislodge individual particles of soil, which can then be washed away over the surface of the ground. Fast and heavy raindrops break apart the soil aggregate, decreasing the soil pore space and reducing infiltration. When rain falls faster than infiltration can take place, runoff occurs. It is runoff which carries soil particles away. We will examine different types of erosion causes by runoff in Section 11.4 of this chapter.

Wind erosion is when wind causes small soil particles to be lifted and moved to another area. This typically occurs in areas which are flat and dry. Water erosion makes the soil more susceptible to wind erosion, because rain dislodges fine soil particles which can easily be picked up by wind.

11.2 Factors influencing erosion

Various factors impact on the amount of soil erosion that takes place in a particular area:

- *The speed of the agent.* The faster the wind or water moves, the more erosion takes place.
- *The frequency of the agent.* Frequent winds and rain increase erosion.
- *The slope of the land.* Water erosion is greater on slopes and hills because the steeper the slope, the faster the runoff.
- *The type of soil.* Soils which contain clay and organic matter are more resistant to erosion than sandy soils, because the soil particles stick together and do not easily wash or blow away. Organic matter also behaves like a sponge and absorbs rainfall.
- *Fire* removes protective vegetation and can seal the surface of the soil, leading to increased runoff and erosion.
- *Compaction* of the soil increases runoff and erosion.

One of the most important factors influencing erosion is *ground cover*. Very high erosion rates are always associated with bare soil, while ground cover in the form of vegetation (grass, plants, shrubs, trees) or other types of cover (e.g. mulch, crop residue, plant debris, stones) protects the soil and decreases or prevents erosion.

11.3 The importance of vegetation

Vegetation helps control the movement of water both in and over the ground.

- Vegetation slows down runoff, allowing more water to soak into the ground.
- Vegetation and plant debris breaks the force of raindrops on the soil.
- Dead vegetation increases the organic content of the soil, increasing its ability to absorb water.
- Plant roots hold the soil in place.
- Plants in wetlands and on river banks slow down water flow, and their roots help bind the soil.

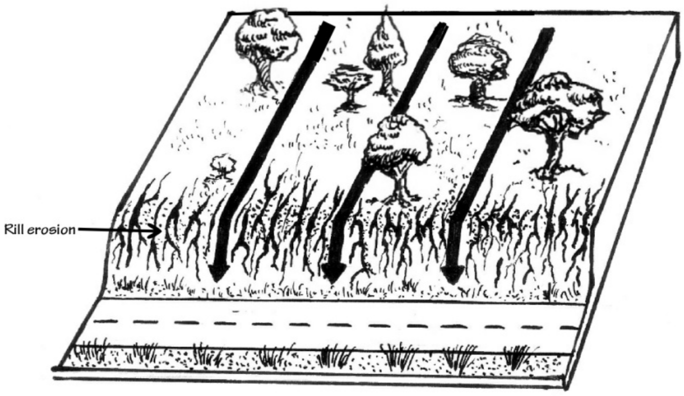
Soil which loses its plants or protective vegetation is vulnerable to erosion because it can be easily swept away by wind or water.

11.4 Types of soil erosion caused by water runoff

Runoff is called ***sheet flow*** when water flows over compacted or waterlogged soil in a "sheet", producing a relatively even distribution of runoff over the land surface which follows the slope of the land downwards. This type of flow can cause ***sheet erosion***.

Figure 5.14 Sheet flow leading to sheet erosion

Small irregularities of the soil's surface causes sheet flow water to collect into and run along small, concentrated flow paths or channels that are a few centimetres deep and wide, called ***rills***. This type of flow can lead to ***rill* erosion**.



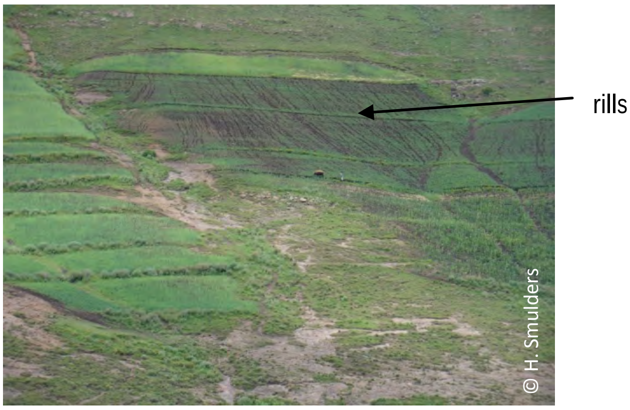


Figure 5.15 Rill erosion[12]

Increased runoff can cause rills to increase in size and eventually become gullies (much larger channels). Cattle paths can also provide starting points for ***gully erosion*** by acting as collection ditches for rainwater flow. Gullies expand when there is above-average rainfall, especially after long dry stretches when vegetation cover has died.

Figure 5.16 Gully erosion

11.5 Preventing soil erosion

There are many measures which can be taken to prevent soil erosion.
Measures include:

- introducing vegetation or other types of ground cover (such as mulch);
- ***contour*** ploughing;
- planting windbreaks;
- leaving grass strips between ploughed land;
- avoiding overgrazing;
- breaking water flow (eg. with logs, stone packs, old tyres); and
- avoiding surface compaction.

Many rainwater harvesting and conservation methods also help prevent soil erosion (see Chapter 7).

12. Test Yourself

1. There are five factors involved in the formation of soil. Name them. (5)

2. Name the two solid components of soil. (2)

3. Explain the importance of soil pores. (3)

4. Name and briefly describe the three soil separates. (6)

5. List three harmful practices which break down the structure of a soil, and explain why each practice is harmful. (6)

6. Explain what a soil profile is and how one can be obtained. (3)

7. Explain the terms *infiltration*, *drainage*, and *permeability*. (3)

8. List four properties of fertile soil. (4)

9. Nutrients in the soil come from different sources. Name three of these sources. (3)

10. Name the three most important nutrients for soil fertility. (3)

11. Complete the following table:

Source	Nutrient/s
comfrey	
sheep manure	
urine	
legumes	
chicken manure	
bone-meal	
wood ash	
bones	

(8)

12. Explain why repeated soil erosion reduces soil fertility. (3)

13. List five factors which impact on the amount of soil erosion that takes place in a particular area. (5)

14. Discuss the role of vegetation in helping to control the movement of water both in and over the ground. (8)

15. Name four measures which can be taken to prevent soil erosion. (4)

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Lubabalo Ntsokonstoko (artist)
"Water harvesting methods."

Chapter 6

WHC Planning

Contents

Outcomes

At the end of this chapter you should be able to:

- Select a site which is suitable for growing vegetables.
- Determine the aspect of a site using two different methods.
- Express the angle of a slope in three different ways.
- Measure the angle of a slope using two different measuring instruments.
- Mark out contour lines using two different devices.
- Construct and calibrate an A-frame.
- Construct a line level.
- Select a range of organic materials which can be used for compost and as mulch.

1. Introduction

A certain amount of planning is important in order to implement a water harvesting and conservation method or system successfully. In addition, many WHC methods such as trench beds, tied ridges and fertility pits require that you select a site which is suitable for growing plants and vegetables. Planning involves developing an in-depth understanding of the site, including its ***topography***, rainfall patterns and soils, so that the most appropriate WHC method/s can be selected and implemented.

In this chapter, information and terminology that is relevant to the planning process is presented in order to help you understand and interpret the technical content of Chapter 7, where a selection of WHC methods is presented and explained in detail.

2. Accessibility and Security

Vegetable gardens need to be tended to frequently (ideally daily), so if you are planning to harvest water for a vegetable garden the site should be located in a place that is close enough to visit regularly.

The site should also be secure from animals (e.g. goats and chickens) as well as from theft, but at the same time it needs to be easily accessible. This includes access with a vehicle, cart or wheelbarrow so that loads of compost, soil or mulch can be brought in without difficulty.

3. Wind, Water and Soil

Wind

The site should be protected as much as possible from wind, which can cause physical damage to the plants, especially to young seedlings. For example, wind can loosen the roots of plants in the soil, and may even damage their root systems.

In addition, cold winds cool the plants and soil and this can delay their growth and maturity, while hot winds increase the rate of water loss from the leaves, causing plants to wilt. Hot winds also dry out the topsoil, reducing the amount of water that is available for plants with shallow roots.

The site can be protected from the wind using fences, artificial windbreaks, hedges, rows of trees, or tall crops (e.g. mielies and sweet corn). Large trees, however, can compete with the garden for moisture and may also cause undesirable shading, especially in winter.

Water

The site for a vegetable garden should ideally be located close to a water supply (e.g. a water tank or a tap), as this will allow for additional irrigation when it is hot and dry, and during times of low rainfall or drought.

Soil

For vegetable gardens, the soil should be as healthy as possible – loamy soil or sandy loam is best as these medium-textured soils contain the most nutrients and have a high water-holding capacity (water and nutrients are both critical growth factors for plants). The soil needs to be deep enough to grow vegetables in (at least 60 cm), and should not be too rocky. Small rocks and stones can be removed from the site by hand.

The type of soil on a specific site can be identified by conducting a sausage test or a bottle test (see Chapter 5). Soil can also be improved by adding compost, manure, organic material, bone-meal and wood ash (again, refer to Chapter 5).

4. Topography

The term *topography* refers to the characteristics of the land in terms of ***aspect***, *slope* and *elevation*. The importance of each of these characteristics for the planning of vegetable gardens and/or WHC methods is explained under each of the headings below.

4.1 Aspect

The direction which a site or slope faces is called its *aspect*, and aspect is important to consider when planning a vegetable garden. Plants need to receive at least 5 hours of *sunlight* a day, so it is important to choose a site where plants will get maximum sunshine all day long. Beds which lie in an east-west direction will get the full benefit of both the morning and the afternoon sun.

The following two methods can be used to determine the aspect of a site:

Method 1

Point with your right hand to where the sun rises (east), and with your left hand to where it sets (west). When standing in this position, you will be facing north, and south will be directly behind you. Once you know where north is, you can determine the direction that the site faces.

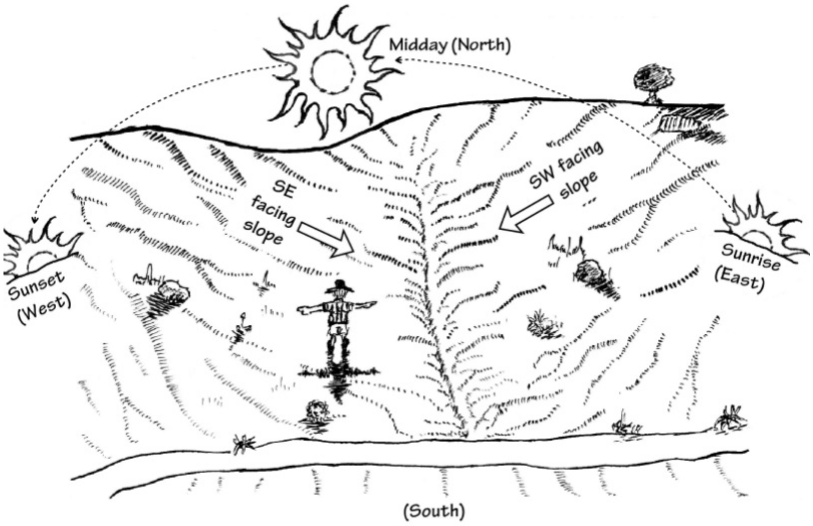


Figure 6.1 How to determine aspect (Method 1)

Method 2

Clear a small space on the ground (about 50-100 cm²). Place a short stick about 15 cm long vertically in the soil. Place another short stick at the exact tip of the shadow that the first stick makes. After about two hours, place a third stick at the exact tip of the shadow of the first stick (the shadow will have moved considerably over 2 hours). Scratch a line in the soil to connect the second and third sticks. This is the "sunline", which is aligned east-west – the second stick gives you your westerly direction, while the third stick gives you east. If you stand and point your right hand towards the east and your left hand towards the west, you will be facing north. For greater accuracy you can intersect the sunline at a 90° angle to give you the north-south line (you can use a protractor to do this).

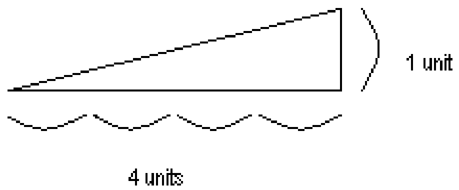
4.2 Slope

The slope of the land is the angle it forms with the plane of the horizon. Slope is important to take into account when planning a vegetable garden as flat sites are are easy to work on and soil erosion and water loss is minimised. Care should be taken, however, on flat sites with clayey soils as waterlogging may become a problem.

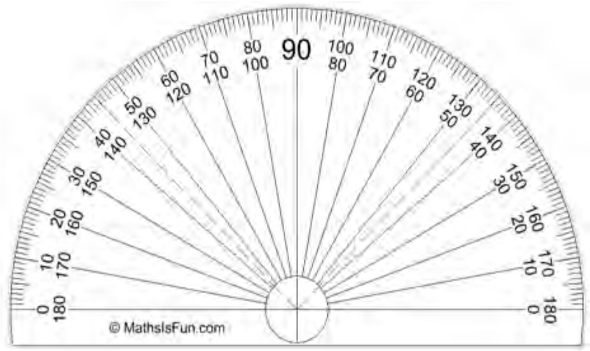
Slope also needs to be taken into account when planning and implementing most WHC methods, mainly to ensure that soil erosion does not occur.

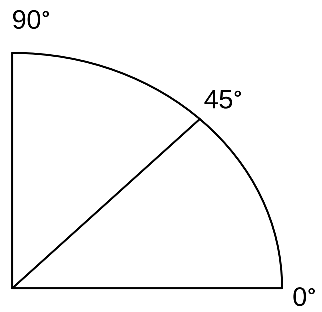
Slope can be expressed in the following three ways:

Proportion – this is the ratio of a slope's horizontal distance to its vertical distance.[1] For example, a 1:4 slope rises a vertical distance of one unit for every four units it extends horizontally.



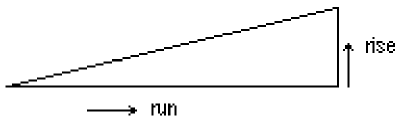
Degrees – this is a measurement used to represent the angle of a slope. Degrees can be measured with a protractor or with survey instruments. Land that is completely flat (horizontal) is 0°, while a vertical cliff is 90°.





Percentage – the percentage of a slope can be calculated using the following formula:

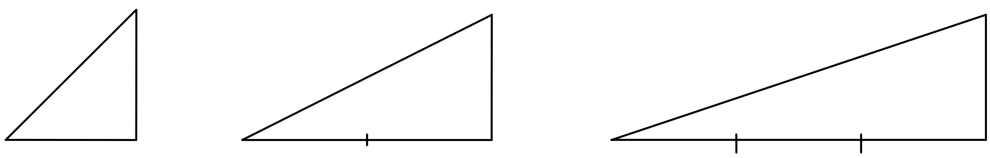
$$\text{Slope (\%)} = \frac{\text{rise}}{\text{run}} \times 100$$



Example: A slope of 1:4, where one unit equals 10 metres, has a rise of ten metres and a run of forty metres. The percentage of the slope (S) can thus be calculated as follows:

$$S(\%) = \frac{10}{40} \times 100 = 25\%$$

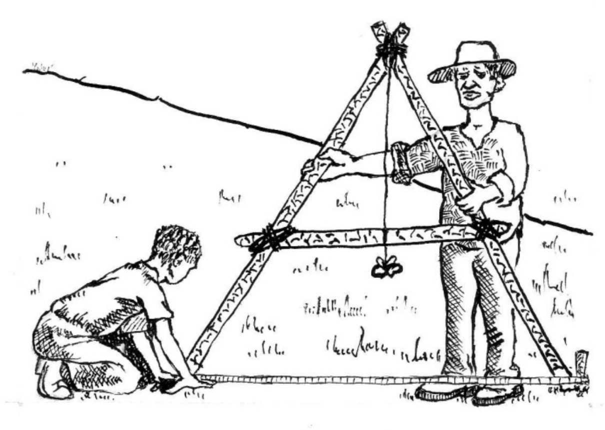
The following slopes are expressed in proportion, degrees and by percentage.[2]



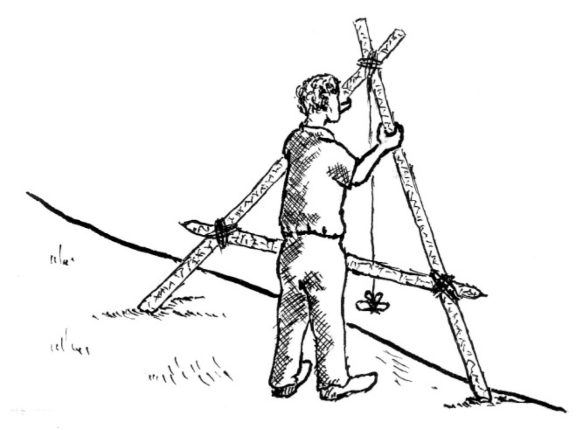
1:1 = 45° = 100% 1:2 = 26° = 50% 1:3 = 18° = 33.3%

Measuring slope using an A-frame

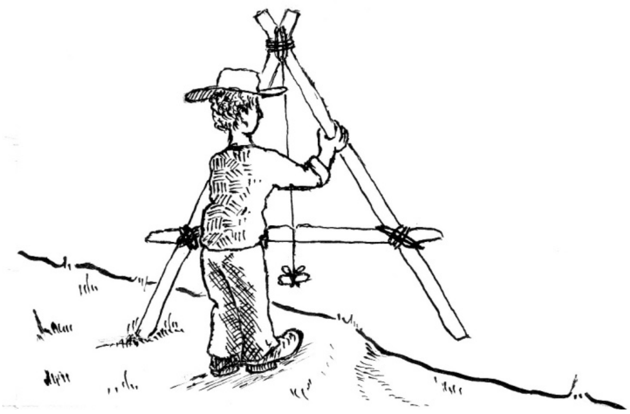
An A-frame is a levelling device which is inexpensive and easy to make by hand (refer to Section 5 for information on A-frames and their construction). The percentage of a slope can be measured with reasonable accuracy using an A-frame. To do this:



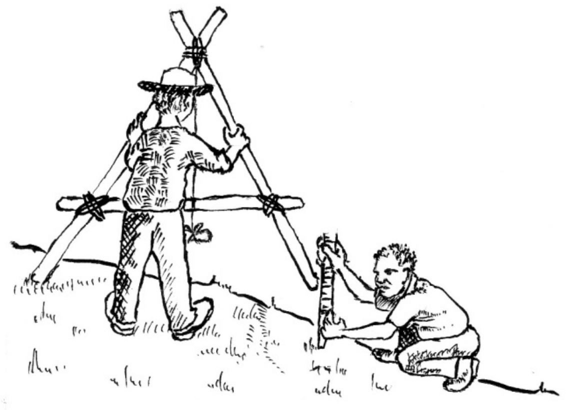
1. Measure the distance between the A-frame legs (the "run").



2. Put the A-frame on the slope, with one leg on the ground and the other going downhill. Make sure that the leg on the ground is placed as flat as possible (i.e. avoid placing it on a clump of soil or protruding stone).



3. Lift up the downhill leg until the string lines up with the level position.



4. Measure the distance between the ground and the base of the downhill leg (the "rise").

5. Use these measurements to calculate the percentage of the slope.

Example:

$$S(\%) = \frac{\text{rise}}{\text{run}} \times 100$$

$$S = \frac{80 \text{ mm}}{2000 \text{ mm}} \times 100$$

$$S = 0.04 \times 100$$

$$S = \mathbf{4\%}$$

6. To make sure that your result is as accurate as possible it is recommended that you repeat this process at least five times, at slightly different places on the slope. Calculate the *average* of these results, and use this as your slope percentage.

Example: You measure the slope five times and obtain the following results:
4%, 3.8%, 4.1%, 4.2% and 3.7%

To calculate the average, add the numbers and divide by 5 (the number of results you are averaging):

4 + 3.8 + 4.1 + 4.5 + 3.7 = 20.1

20.1 ÷ 5 = **4.02**

= **4%**

Measuring slope using a line level

A line level is another levelling device which is also inexpensive and easy to make by hand (refer to Section 6 for information on how to construct a line level). Three people are needed to measure the percentage of a slope using a line level (person A, person B and person C).

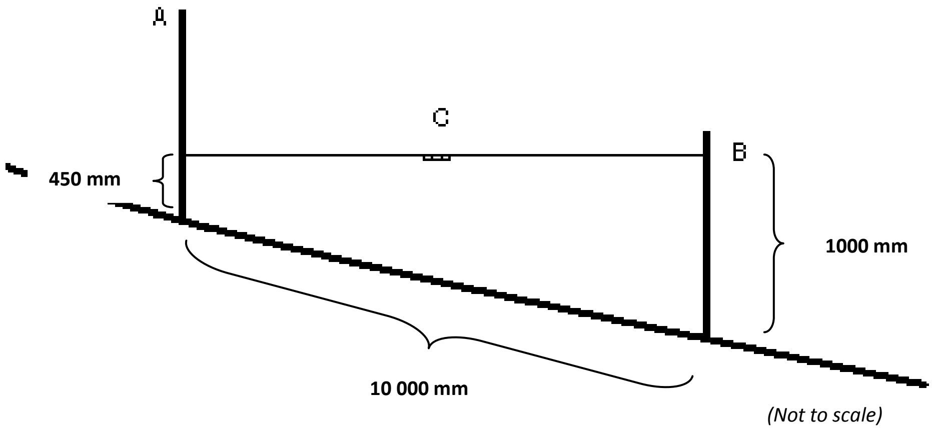


Figure 6.2 Using a line level to measure slope

Figure 6.3 A level reading on a line level

1. Person A stands upslope of person B and adjusts the string down the pole until the line level attached between the poles gives a level reading. This reading is taken by Person C.

2. The percentage of the slope is then calculated using the formula:

$$\text{Slope}(\%) = \frac{\text{rise}}{\text{run}} \times 100\%$$

3. The **run** is the distance between the two poles, which should be 10 000 mm (10 metres).

The **rise** is the difference in height of the string, which is calculated by subtracting the height of the string on pole A (e.g. 450 mm) from the height of the string on pole B (e.g. 1000 mm).

4. Slope(%)

$$= \frac{1000 - 450}{10\,000} \times 100\%$$

$$= \frac{550}{10\,000} \times 100\%$$

$$= 5.5\%$$

5. Note that when measuring slope using a line level it is important that both poles are held vertically and that neither pole is placed in a depression or on top of a minor high spot such as a rock or clump of soil.[3]

4.3 Elevation

Elevation is the height of the land above sea level. Variations in elevation are shown on topographic maps by ***contour lines***, which are imaginary horizontal lines which connect all points in an area that have the same elevation (i.e. are the same height above sea level). WHC methods such as stone bunds and terraces are constructed along the contours of a hillside, so to use these methods one needs to be able to mark out contour lines on a slope. Contour lines are marked out using an A-frame or a line level.

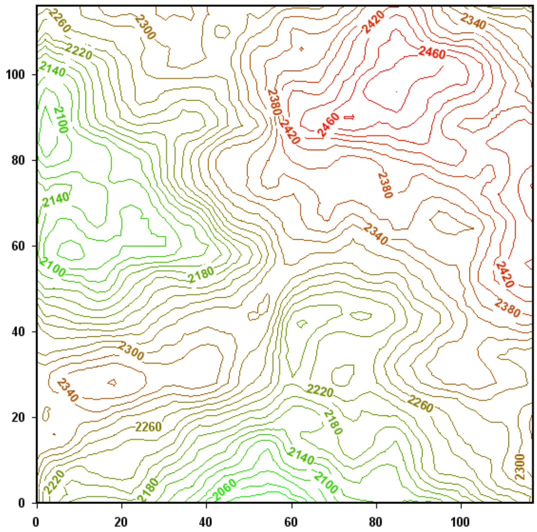
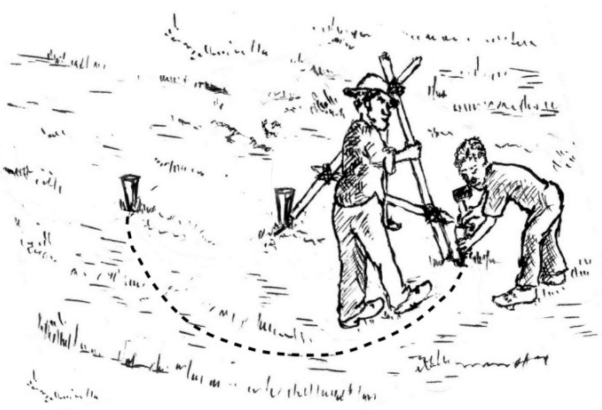


Figure 6.4 A topographic map showing contour lines

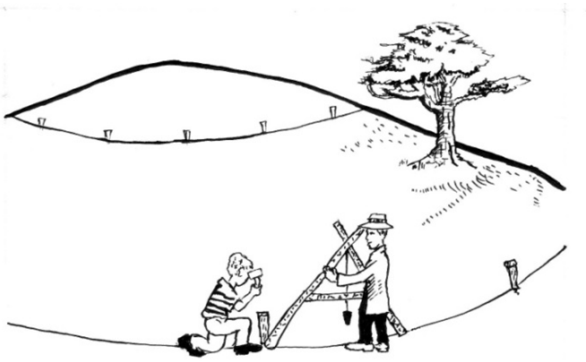
__**To mark out contour lines on a slope using an A-frame**__:[4]

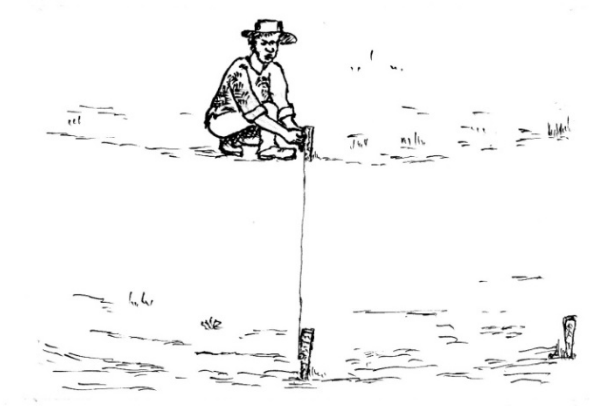
1. Start near the bottom of the slope. Place the A-frame on the ground and mark the position of leg 1 with a marker such as a rock, stick or stake.



2. Use leg 2 as a pivot point and swing leg 1 in an arc along the surface of the field until the string lines up with the *level* position marked on the crossbar of the A-frame. Tilt the top of the A-frame so that the weight hangs freely and the string is not too close or too far away from the crossbar. Once this position is found, mark the position of leg 2 with a stake.

3. Move the A-frame onto this new pivot point and repeat the process across the slope, marking the contour line as you go. Note that contour lines can be smoothed out by aligning the points to follow the general curve.





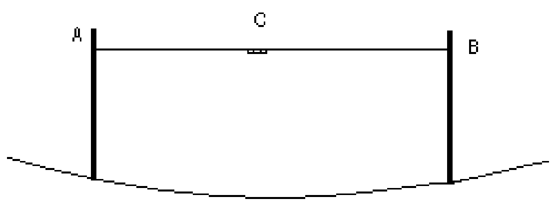
4. Once the contour line has been completed, stand on the line facing the top of the slope and measure out the required distance between contours. [This distance will vary depending on the slope and the method to be implemented. Distance tables for various methods are provided in Chapter 7.]

5. Mark out the next contour line, starting at the position you identified in step 4. Repeat this process until you have marked out all the contour lines required.

Marking out contour lines on a slope using a line level

Three people are needed to mark out contour lines on a slope using a line level (person A, person B and person C).

(Not to scale)



1, Start at the edge of the field. Person A holds their pole in a vertical position and stands still, while person B moves up and/or down the slope until the line level, which is read by person C, gives a level reading. Points A and B are then marked with pegs.

2. Person A then moves to point B, and person B moves further down the field and the process is repeated.

3. Note that when marking out contours using a line level, it is important that both poles are held vertically, and that neither pole is placed in a depression or on top of a minor high spot such as a rock or clump of soil.[5]

5. Constructing an A-Frame[6]

An A-frame is a simple but accurate tool for measuring the percentage of a slope and for constructing contour lines along a slope or hillside.

Figure 6.5 Assembling an A-frame

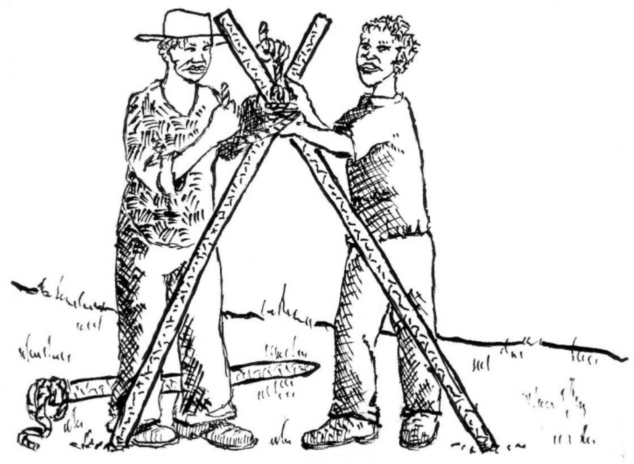
Materials needed:

- 2 x 2 metre long poles
- 1 x 1.2 metre pole
- wire or strong cord to connect the poles (about 2 metres) *or* hammer and nails
- light cord or string (1 metre)
- weight (e.g. a stone or bottle)

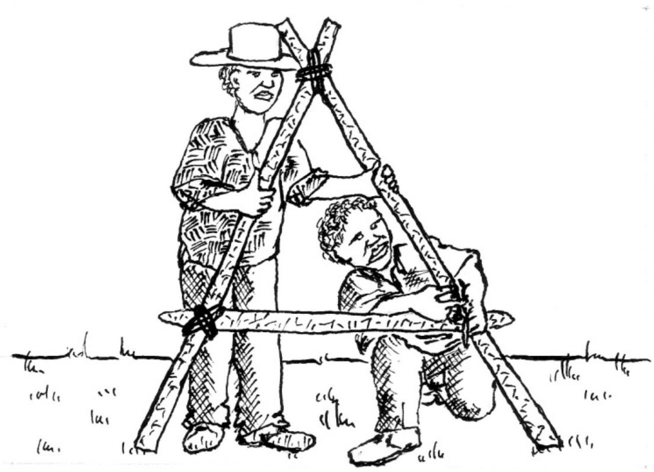
Figure 6.6 Marking contour lines using an A-frame

To assemble the A-frame:

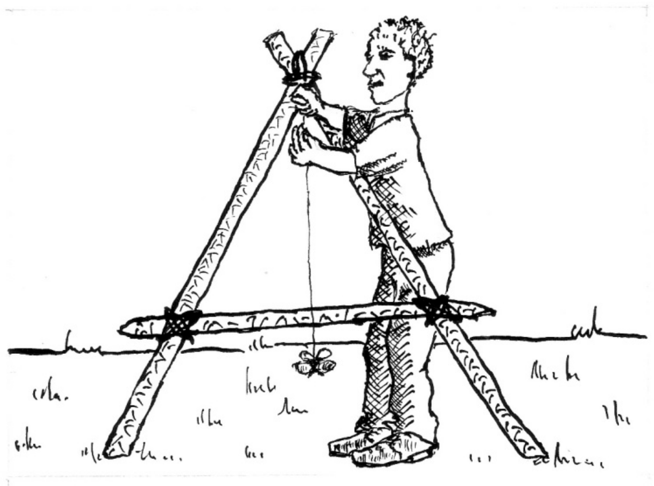
1. Connect the 2 long poles together at one end. Nail them, or use the cord to bind them together tightly. If necessary, make notches at the top of each pole where they connect to prevent them from slipping.



2. Connect the shorter pole securely across the middle of the longer poles to form a figure "A". This is the crossbar.



3. Tie one end of the light cord to the top of the "A" where the two poles are joined. Tie the weight (e.g. a stone) to the other end of the string so that it hangs about 15 cm below the crossbar.



To *calibrate* the A-frame:

1. Put the A-frame on solid ground (it does not have to be completely level).

2. Mark the position of the legs on the ground (A and B).

3. Let the weight settle to a natural position and make a temporary mark where the string passes the crossbar. (Note: the string must be close to the crossbar, but the weight must hang freely.)

4. Rotate the A-frame so that the position of the legs is reversed (i.e. the leg which was on spot A is now on spot B, while the leg which was on spot B is now on spot A).

5. Once again, let the weight settle to a natural position and make a temporary mark where the string passes the crossbar.

Figure 6.7 Calibrating an A-frame

6. Exactly halfway between the two temporary marks is the *level position* of the A-frame. Make a permanent mark on the crossbar to indicate this position.

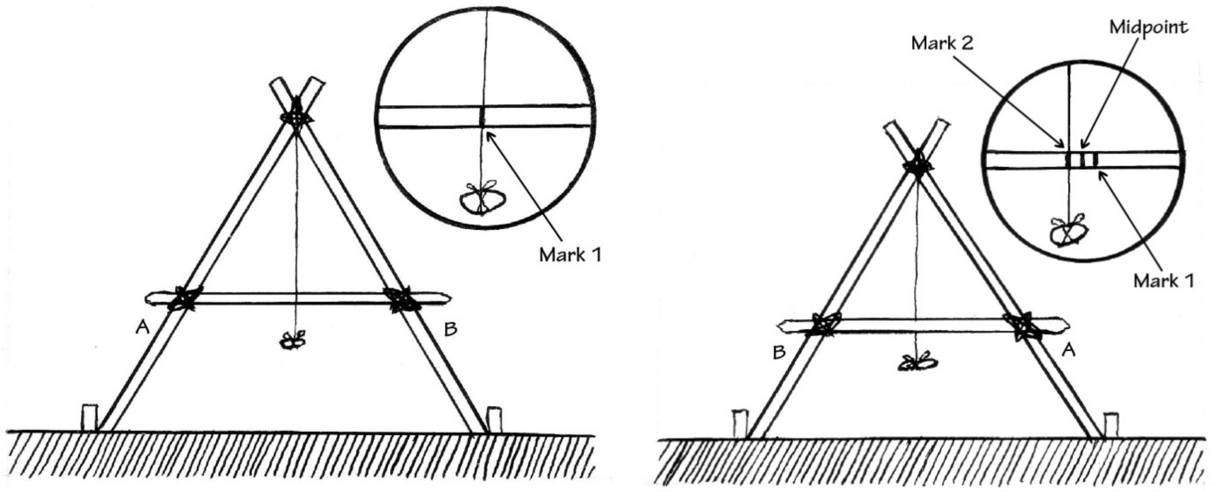


Figure 6.8 How to calibrate an A-frame

activity 18

Working with an A-frame

Follow the instructions provided in this section of the WHC manual to do the following:

1. Construct and calibrate an A-frame.
2. Use a line level (also called a spirit level) to see if the A-frame has been calibrated correctly.
3. Use the A-frame to measure the percentage of three different slopes (any slopes in the area).
4. Use the A-frame to mark out two contour lines on a slope.

Before you begin, list the materials you need and decide how to obtain them.

Time: 4 hours

6. Constructing a Line Level[7]

A line level is a tool which can be used to mark out contours and to measure slope. It is simple to construct and to use, and it is easier to transport than an A-frame. When used correctly, it is very accurate. It does, however, require three people to use it.

Materials needed:

- 2 X long poles which are exactly the same height (1.5 m or 2 m)
- string or fishing line to tie between the poles (about 11 metres)
- a knife (to cut a notch in the poles)
- a line level (used by builders and also called a spirit level)

To assemble the line level:

1. Cut a notch in each pole at exactly the same height (e.g. 1.4 m above ground level).

2. Tie the string to the poles to connect them. **Make sure that the distance between the two poles is exactly 10 metres.**

3. Tie or hang the spirit level from the string **exactly halfway between the two poles**.

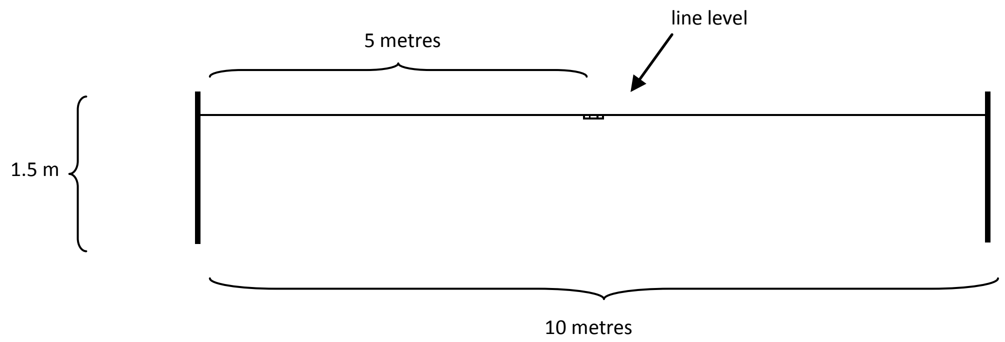


Figure 6.9 Dimensions for constructing a line level

activity 19

Working with a Line Level

Follow the instructions provided in this section of the WHC manual to do the following:

1. Construct a line level.
2. Use the line level to measure the percentage of three different slopes (any slopes in the area).
4. Use the line level to mark out two contour lines on a slope.

Before you begin, list the materials you need and decide how to obtain them.

Time: 4 hours

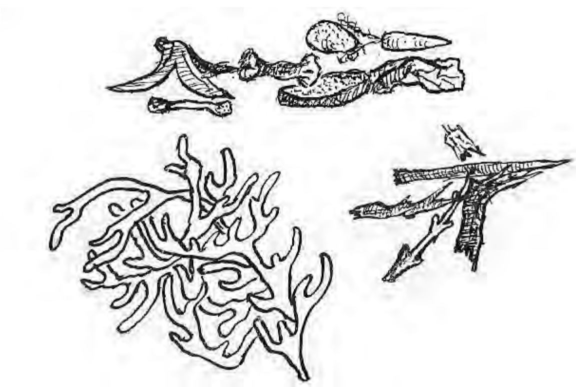
7. Organic Material

Organic material is any dead plant or animal matter in any stage of decomposition.[8] Organic material is used for mulching (see Chapter 7), to fill trench beds and fertility pits, and to make compost.

Common *mulching* materials:

- compost
- animal manure
- tree bark
- wood chips
- straw
- dry grass and leaves
- seaweed
- paper products (e.g. cardboard, egg cartons, newspaper)
- natural fibres (e.g. old cotton clothes, old wool)
- sticks and branches

Common *compost* materials:



- fruit and vegetable scraps
- egg shells
- bones
- feathers
- hair
- paper products (e.g. cardboard, egg cartons, newspaper)
- wood chips
- tree bark
- straw
- ash
- seaweed
- animal manure
- garden waste (branches, sticks, pine cones and needles, leaves, grass cuttings)
- coffee grounds
- mielie cobs and stalks
- weeds
- natural fibres (e.g. old cotton clothes, old wool)

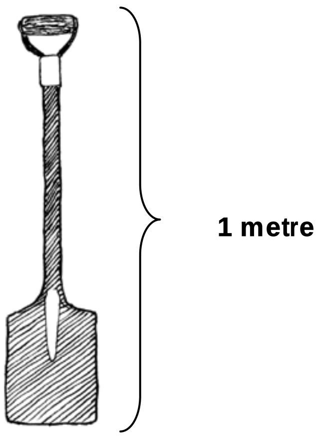
Organic materials for trench beds and fertility pits:

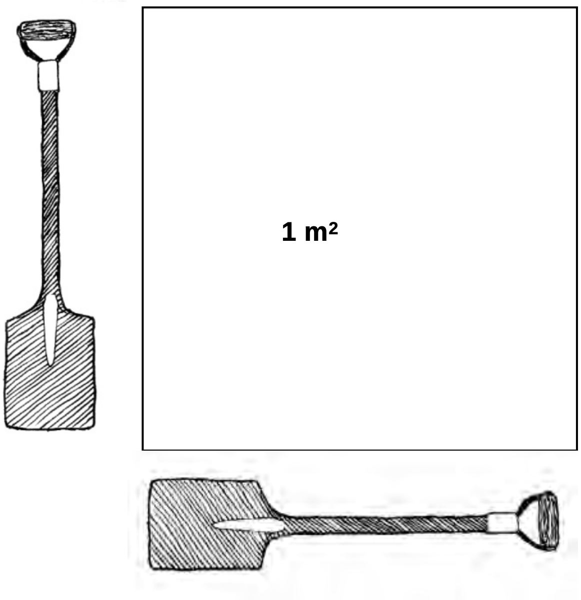
- sticks, branches
- plant residues (mielie cobs and stalks, banana leaves, etc.)
- garden waste (weeds, pine cones and needles, leaves, grass cuttings)
- paper products (egg cartons, cardboard)

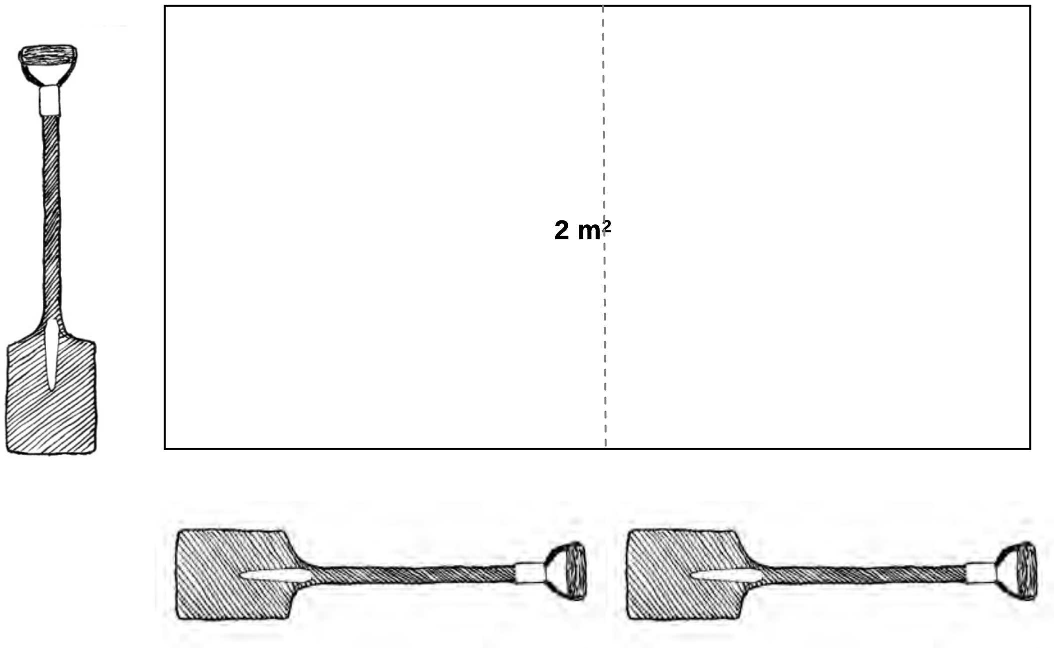
} coarse materials

8. Easy Measurements

A typical garden spade is 1 metre long; the head of a spade is approximately 30 cm long (the length of a ruler).







9. Test Yourself

1. The term *topography* refers to three physio-geographic characteristics of the land. Name and explain each one. (9)

2. The slope of the land is the angle it forms with the plane of the horizon. Explain the three ways in which slope can be expressed. (9)

3. Explain what an A-frame is and what it can be used for. (3)

4. List 8 organic materials commonly used for mulching, and 8 organic materials commonly used to make compost. (8)

5. Discuss six different factors which are important to consider when selecting a site for growing vegetables. (12)

10. References

[1] Lancaster, B. 2008. *Rainwater Harvesting for Drylands and Beyond. Volume 2 Water-Harvesting Earthworks.* Arizone: Rainsource Press.

[2] ibid

[3]Natural Resources Management and Environment Department, FAO. *Water Harvesting: Simple Surveying Techniques.*[Online]. Available from: http://www.fao.org/docrep/U3160E/u3160e0a.htm [Accessed 16 December 2009].

[4]Yarger, L & Lehmkuhl, N. 2006. *A-Frame Level. ECHO Technical Note.* [Online]. Available from: http://www.echonet.org/ [Accessed 10 November 2009].

[5]Natural Resources Management and Environment Department, FAO. *Water Harvesting: Simple Surveying Techniques.*[Online]. Available from: http://www.fao.org/docrep/U3160E/u3160e0a.htm [Accessed 16 December 2009].

[6] Yarger, L & Lehmkuhl, N. 2006. *A-Frame Level. ECHO Technical Note.* [Online]. Available from: http://www.echonet.org/ [Accessed 10 November 2009].

[7]Natural Resources Management and Environment Department, FAO. *Water Harvesting: Simple Surveying Techniques.*[Online]. Available from: http://www.fao.org/docrep/U3160E/u3160e0a.htm [Accessed 16 December 2009].

[8]http://en.wiktionary.org/wiki/organic_matter

Sikelelo Holosi (artist)
"Rainwater harvesting ecosystem."

Chapter 7

WHC Methods

Contents

Outcomes

At the end of this chapter you should be able to:

- Identify thirteen different WHC methods and explain the purpose of each one.
- Design a range of WHC methods for implementation.
- Successfully implement and maintain a range of WHC methods.

1. Introduction

In this chapter, thirteen different rainwater harvesting and conservation methods are presented and explained in detail in order to provide you with enough information to help someone construct a water harvesting system, or to construct one for yourself. Most of the methods can be implemented using the technical information contained in this guide, and with hand tools only. Two of the methods, however (**saaidamme** and **ploegvore**) need some technical engineering input and are thus explained more generally. Should you decide to implement one of these methods you can approach the engineering section of the Department of Agriculture, the Department of Water Affairs, or a technically-oriented NGO for assistance, any of whom should be able to take the design process further based on the descriptions in the guide.

Some of the methods that are described are used mainly in small gardens, while other methods have application on a commercial scale. Often, more than one system will be suitable for the farmer's crop choices and the natural conditions prevailing at a specific site. The decision of which method to use is usually based on the time and resources that are available in the particular situation.

Remember to apply the principles of WHC when designing and implementing a system: begin with observation and experimentation, start at the top of the watershed and work your way down, start small and simple, slow down, spread and infiltrate the flow of water, plan an overflow route and manage that overflow as a resource, create a "living sponge", develop a system which maximises mutually beneficial relationships, and continually reassess the system, making any changes which will improve on it.

Choice of methods included in the guide

There are numerous water harvesting and conservation methods in use around the world. Many of these are similar to each other but go by different names and have slight variations in how they are applied. The focus of this guide is to provide you with a range of practical water harvesting and conservation methods which can be used by resource-poor farmers in South Africa. The 13 methods which have been selected are based on a scoping study of water harvesting in South Africa,[1] a wide-ranging review of international literature, and consideration of the likely farming realities of resource-poor farmers. It is anticipated that at least one of the methods described will find application in any given situation, regardless of where you are in South Africa or what farming system is being employed (gardening, field cropping or grazing). In most cases, three or four methods will have application and you will have to choose which method/s to select.

Presentation of methods

Each method is presented as a "fact sheet". The method is described, followed by a table which outlines where it can be used and the tools and equipment required for implementation. The fact sheet ends with an illustrated step-by-step guide which clearly sets out how the method must be constructed.

2. Diversion Furrows

also called:	used in:	
• feeder channels	gardens	✓
• trenches	fields	✓
• run-on ditches	grazing land	
• ex-field RWH		

A ***diversion furrow*** directs rainwater runoff from gullies, grasslands or hard surfaces (such as paths or roads) to a cropped area or to a storage tank. If a diversion furrow is in an area of heavy foot traffic, it can be filled with a porous material such as gravel so that it does not become a tripping hazard.[2]

Figure 7.1 Diversion furrow leading to a catchpit

Figure 7.2 Diversion furrows leading to trench beds

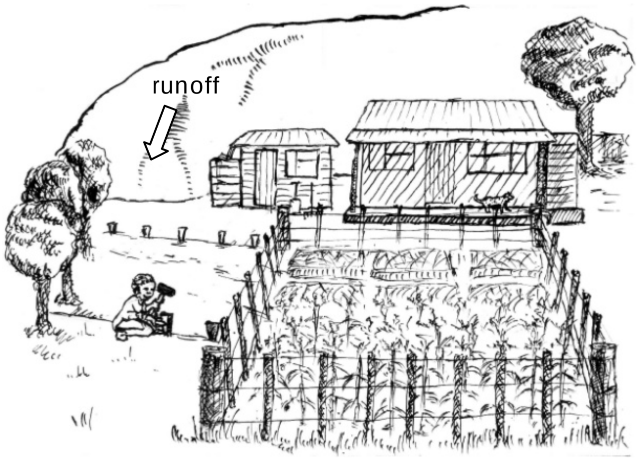
Figure 7.3 Diversion furrow leading to a trench bed

PLANNING

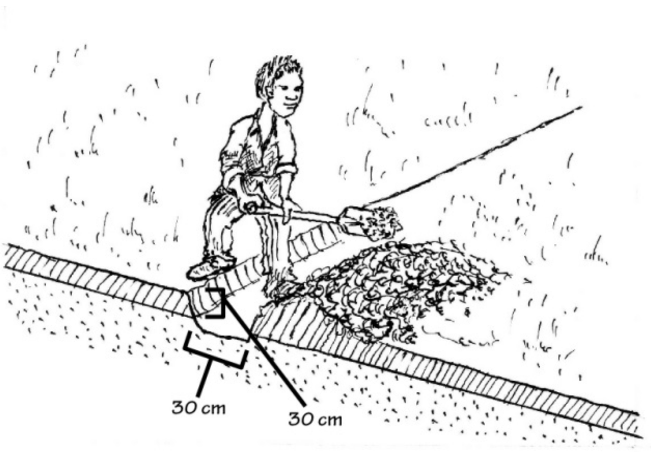
Soil	Slope	Rainfall	Tools & Equipment
Any soil. Where soils are easily erodible or hillside slopes are steep, the diversion furrow should slope gently downwards so as to avoid erosion.	Any slope. On steeper slopes, care must be taken to prevent erosion.	Any rainfall. In higher rainfall areas, measures to prevent erosion may be needed.	spade* pegs and string A-frame **essential*

METHOD

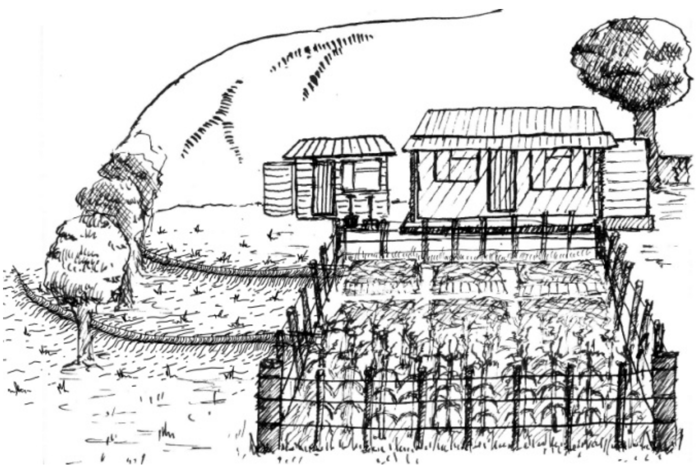
1. Look at the ground when it rains to see where the storm water runs, and decide which of this water you want to divert. Mark out a route for your furrow which will intercept this water and carry it to the garden, field or storage tank.



2. Dig a trench approximately 30 cm wide and 30 cm deep. Place the soil on the downslope side of the trench.



3. Ensure that the furrow leads into the rainwater harvesting method being used in the field or garden. In the case of a tank, the furrow will typically lead into a small catchpit which traps sediment and debris so that it does not enter the tank (see Figure 7.1).



3. Trench Beds

also called:	used in:	
• deep trenching	gardens	✓
• trench bed gardening	fields	
• fertility trenches	grazing land	

Trench beds create highly fertile soils which are soft and loamy and have a very high moisture-holding capacity. Trench beds are often used in combination with feeder channels (diversion furrows), which enable runoff from hard surfaces such as paths and roads to run into the trenches.[3]

Figure 7.4 Trench beds in a vegetable garden

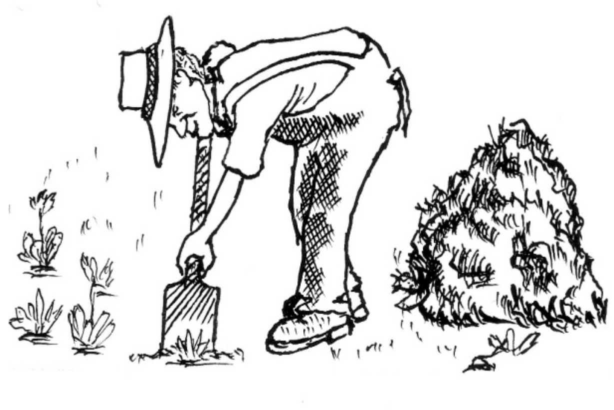
hard surface / roadway

furrows/feeder channels

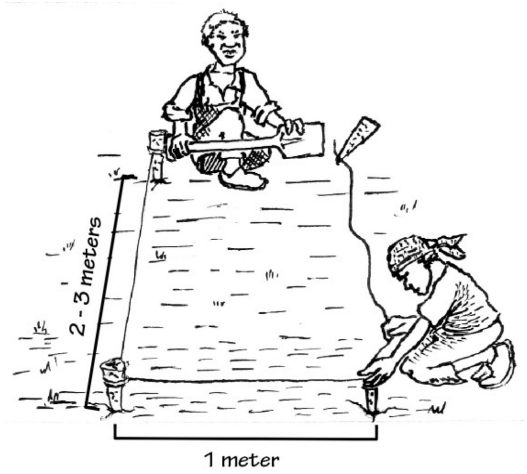
PLANNING

Soil	Slope	Rainfall	Tools & Equipment
Trenches present one of the few options for growing food when you have very shallow, poor or rocky soils. Although trenching will improve any soil, trenches should be placed where the soil is best for growing vegetables.	If the plot is on a slope, the length of the trenches should always be along the contour (i.e. across the slope) to prevent the soil being washed away by rain. Where slopes allow, the length of the trenches should run from east to west.[4]	Suitable for all rainfall areas. In dry areas, additional watering of plants will be required. In high rainfall areas, the use of feeder channels may need to be limited.	spade* fork string sticks organic material* compost wheelbarrow **essential*

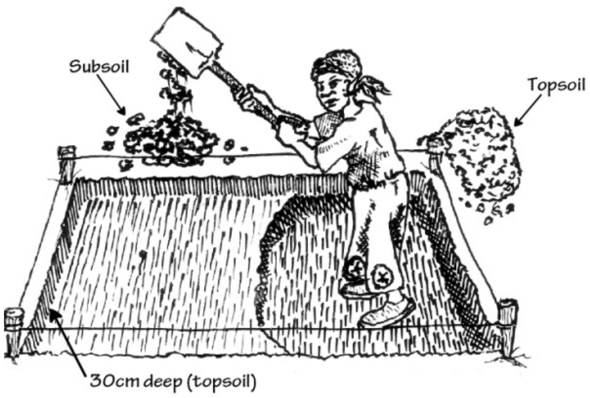
METHOD



1. Choose a place suitable for growing vegetables and clear the ground of any rocks, bushes and grass. Keep this plant material to use for mulching and filling trench beds.



2. Mark out the trench bed using sticks and string. The bed can be any length but should not be more than 1 metre wide so that all gardening can be done from the pathway. A good size for a trench bed is 1 m wide by 2-3 m long.

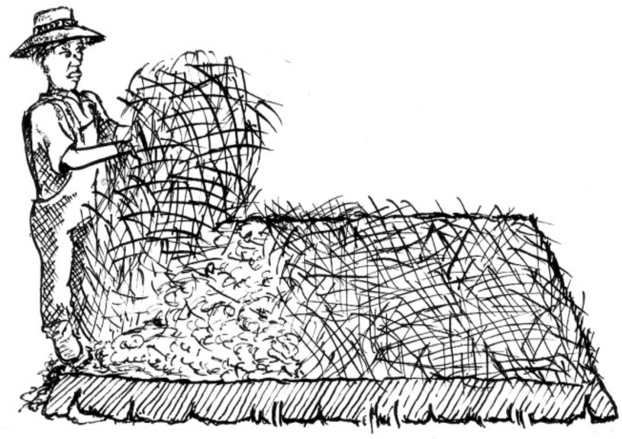


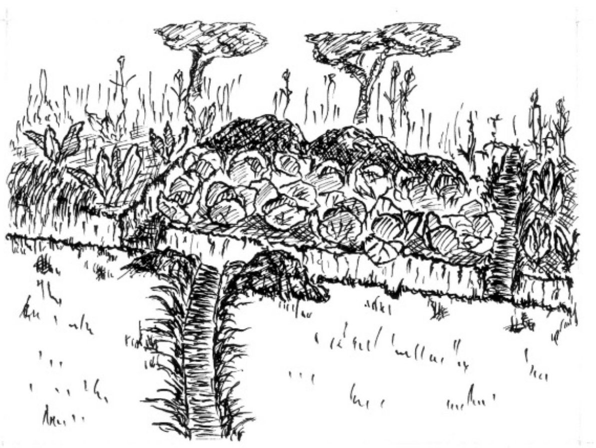
3. Dig out the **topsoil** (about 30 cm deep) and place it on one side of the bed. Then dig out the **subsoil** so that the trench is 1 metre deep and place it on the other side of the bed. Do not mix the topsoil with the subsoil.

4. Use a garden fork to loosen the ground at the bottom of the trench. Put a 20 cm layer of coarse organic material at the bottom and cover it with about 10 cm of subsoil. Use a fork to mix these layers together, and water well.

5. Continue adding layers of organic material (approximately 20 cm)and subsoil (10 cm) until the trench is full. Water each layer well.

6. Place the topsoil on top of the trench. If you have compost or manure, add this to the topsoil and mix it together well (2-3 buckets per trench). Use a rake or flat piece of wood to make the bed flat.





7. Cover the bed with a layer of mulch and leave for a week or two before planting. If you want to plant immediately, add chicken manure to the bed (1 litre of manure per bed) to increase the nitrogen content of the soil.[5]

8. Dig diversion furrows (shallow trenches) from hard surfaces such as paths and roads to the trench beds so that the trenches will receive runoff when it rains.

4. Mulching

also called:	used in:	
• –	gardens	✓
	fields	✓
	grazing land	

Figure 7.5 Mulch placed on a plant bed

Mulching is the practice of spreading plant and other organic material such as compost, straw, manure, dry leaves, dry grass clippings and wood chips onto the surface of the soil[6], usually concentrated around plants.

Mulching conserves water by increasing infiltration and reducing evaporation. Mulch protects the soil from erosion, reduces compaction from the impact of heavy rains, maintains a more even soil temperature, and prevents weed growth.

Figure 7.6 Thatching grass can be used as mulch

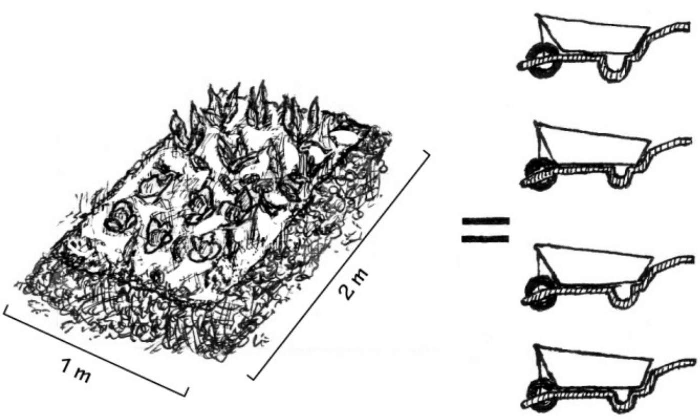
As mulch slowly decomposes it provides organic matter to the soil. This improves root growth, increases water infiltration and improves the water-holding capacity of the soil. The organic matter is also a source of plant nutrients and provides an ideal environment for earthworms and other beneficial organisms.[7] Because significant runoff will wash mulch away, this method is almost always used in combination with other WHC techniques such as trench beds and planting pits.[8]

PLANNING

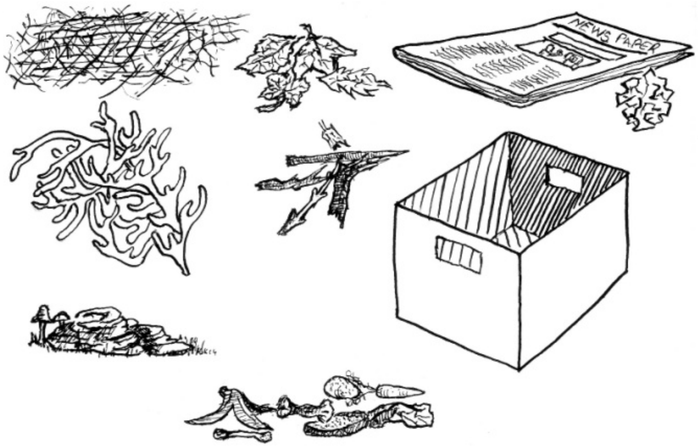
Soil	Slope	Rainfall	Tools & Equipment
Any soil type. On clay soils or soils prone to waterlogging, mulching thickness should be limited to less than 10 cm.[9]	Any slope.	Any rainfall.	organic material* (e.g. dry grass, leaves, compost, straw, manure, egg cartons) fork wheelbarrow *essential*

METHOD

1. Look at the total area you plan to mulch and estimate how much mulch you need (about 2 wheelbarrows of mulch per square metre of garden).



2. Collect the organic materials you plan to use as mulch, and spread it carefully over the soil, around and between plants.



3. When placing the mulch, ensure that it is a few centimetres away from all trunks and stems so that you don't provide a place for insects or diseases to begin attacking the plants.[10]

activity 20

Trench Beds

In small groups (4-6 members), complete the following:

1. Construct a trench bed (1 m x 3 m in size).
2. Cover the trench bed with a layer of mulch.
3. Dig a diversion furrow which leads into the trench bed.
4. Plant a variety of seeds or seedlings in the trench bed.
5. Tend to the trench bed as the plants grow.
6. Compile an activity report, as per your lecturer's instructions.

Completing this activity successfully will involve, amongst other things:

- Selecting a site for the construction of the trench bed and diversion furrow. Groups must have permission to use the site for this purpose. The site must be accessible and the garden area must be secured from animals.
- Compiling a list of all the materials required, deciding how each item will be obtained, and ensuring that the appropriate materials are available when they are needed.
- Developing an appropriate and realistic timeframe for the activity and allocating the time required to complete each step.
- Planning each step in detail and assigning specific tasks to each group member.
- Performing the allocated tasks, working together to ensure that each step is completed successfully and on time.

Your lecturer will provide you with further instructions for this activity and for the group report.

Time: 30 hours

5. Stone Bunds

also called:	used in:	
• stone lines	gardens	✓
• stone banks	fields	✓
• contour stone bunds	grazing land	✓

Stone bunds are used along contour lines to slow down, filter and spread out runoff water, thus increasing infiltration and reducing soil erosion. Over time sediment, which Is captured on the higher side of the bunds, accumulates to form natural terraces.

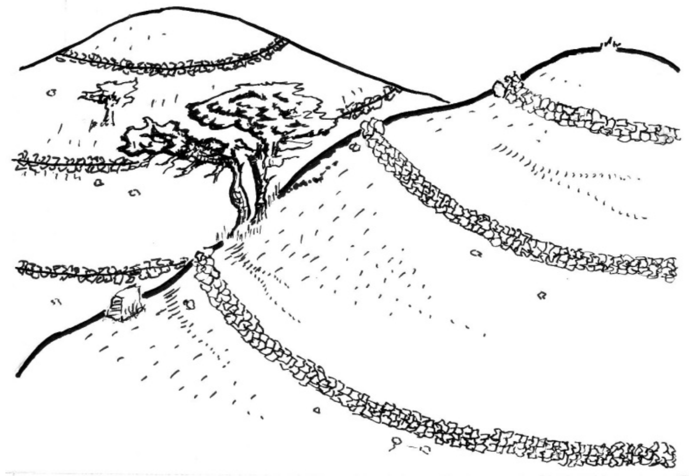


Figure 7.7 Stone bunds on a hillside

Figure 7.8 Natural terraces which have formed from an accumulation of sediment

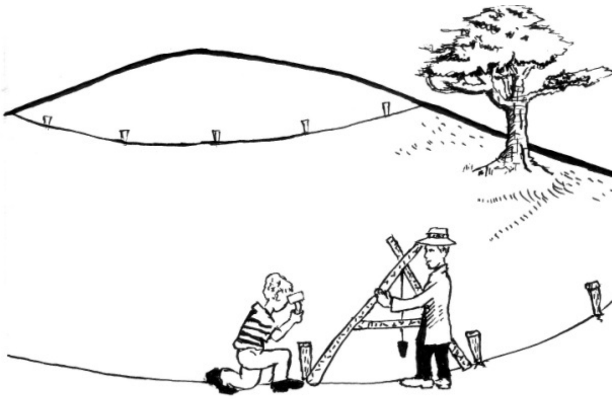
Figure 7.9 Stone bunds being maintained

PLANNING

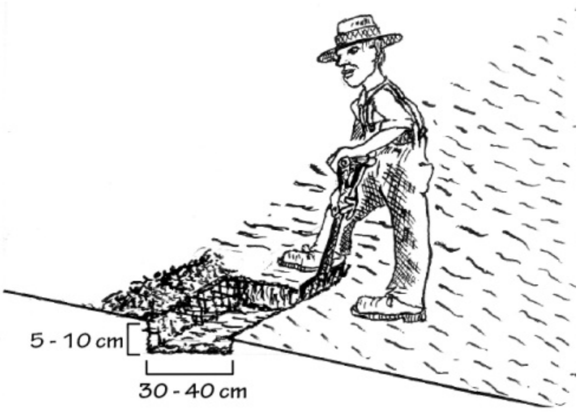
Soil	Slope	Rainfall	Tools & Equipment
Any soil.	0.5 to 3%, preferably below 2%[11]	200-750 mm (arid to semi-arid areas)[12]	stones of various sizes* wheelbarrow* spade A-frame or line level **essential*

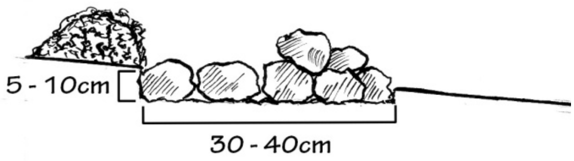
METHOD

Slope	Spacing of bunds[13]
<1%	20 m
1-2%	15 m
2-5%	10 m



1. Calculate the slope of the land to determine how far apart the bunds should be and decide how many bunds you plan to construct.
2. Mark out each contour line using an A-frame or line level. If necessary, make slight adjustments to the position of the pegs so that the lines form a smooth curve.





3. Dig a shallow trench along the contour line (5-10 cm deep, and 30-40 cm wide). Place the excavated soil upslope of the trench.
4. Place large stones along the base of the trench and on the down-slope side to create an "anchor line."[14]

5. Place smaller stones on the up-slope side, and use them to fill any gaps between the larger stones. Leave the excavated soil on the upside of the stone bund.
6. Maintain the bunds by replacing any stones which become dislodged after heavy rainfall.

activity 21

Stone Bunds

Complete the following in groups of 6-10.

1. Construct two stone bunds, each of which is at least 10 metres long.
2. Maintain the bunds for at least two months.
3. Compile an activity report, as per your lecturer's instructions.

Completing this activity successfully will involve, amongst other things:

- Selecting an appropriate site for the construction of the stone bunds. Groups must have permission to use the site for this purpose.
- Compiling a list of the materials required, deciding how each item will be obtained, and ensuring that the materials are available when they are needed.
- Developing an appropriate and realistic timeframe for the activity and allocating the time required to complete it.
- Planning the activity in detail and assigning tasks to each group member.
- Performing the allocated tasks, working together to ensure that the activity is completed successfully and on time.

Your lecturer will provide you with further instructions for this activity and for the group report.

Time: 12 hours

6. Tied Ridges

also called:	used in:	
• in-field RWH • partitioned furrows[15] • cross-ridges • furrow dikes[16]	gardens	✓
	fields	✓
	grazing land	

This method increases the water that is available to plants by collecting rainfall from an unplanted sloping basin and catching it with a furrow and ridge. Planting takes place on either side of the furrow where the water has infiltrated.

Basins are created by digging out shallow furrows along the contour lines of the slope and constructing ridges on the downside of the furrows. These are "tied" together by slightly lower ridges which are constructed at regular intervals along the furrows (these ridges are also called *crossties*). The loss of water through evaporation can also be minimised by placing mulch in the furrows.

Figure 7.10 Mulch placed in furrows to minimise evaporation

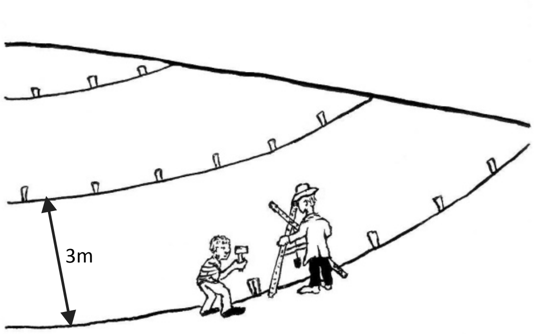
Figure 7.11 Water is captured in furrows

PLANNING

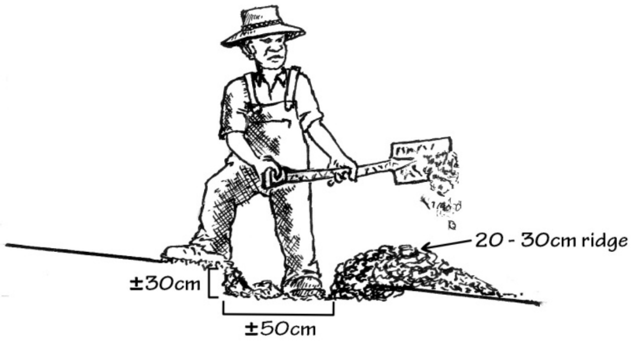
Soil	Slope	Rainfall	Tools & Equipment
Soil depth of 700-1000 mm.[17] Soils should be relatively stable. The best soils are clay or soils with a relatively permeable topsoil over a less permeable subsoil.[18]	Can be up to 7% on non-erodible soils.[19]	Annual rainfall of 400-700 mm.[20]	spade* fork tape measure string, sticks mulch wheelbarrow A-frame or line level **essential*

METHOD

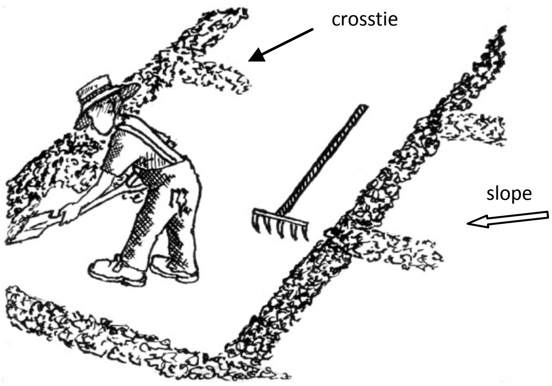
1. Select a site and clear the ground of rocks, bushes, grass and weeds.



2. Mark out the contour lines on the slope, three metres apart.

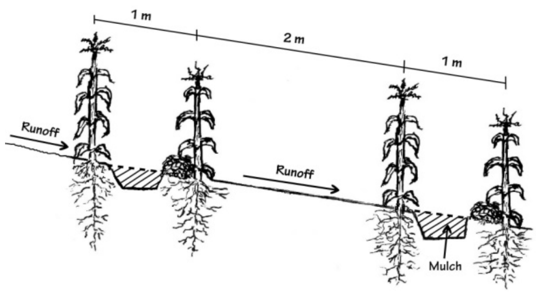


3. Dig out a shallow furrow (about 50 cm wide and 30 cm deep) along each contour and place the soil on the down-slope side of the furrow to create a ridge (about 20-30 cm high).



4. Create crossties (ridges which are 15-20 cm high) every 3 metres. Ties must be lower than the main ridges so that water never flows over the ridges.

5. Use a rake or plank to level out each basin, as this is the water catchment area. Place mulch in the furrows if possible.



6. Plant in two rows , one on either side of the ridge and furrow.

7. Swales

also called:	used in:	
• bunds	gardens	✓
• contour ridges	fields	✓
• berm 'n basin	grazing land	
• contour ditches		

A ***swale*** is an earth bank constructed along the contour with a furrow on the up-slope side. The top of the earth bank is levelled off to allow planting. The swale intercepts runoff, spreads it out and helps it infiltrate deep into the ground. The method as described here is used mainly for crop production and not pastures. Typically, permanent crops (e.g. fruit trees) are planted just below the ridge of the swale, while seasonal crops (e.g. vegetables) are planted between the swales. Over time, seeds and organic matter accumulate on the ridge of the swale, causing vegetation to grow, which stabilizes the ridge. Alternatively, the ridges can be planted with long-living plants such as comfrey, marigolds, nasturtiums or grasses. The ridge of a swale can also double as a raised accessway such as a footpath.

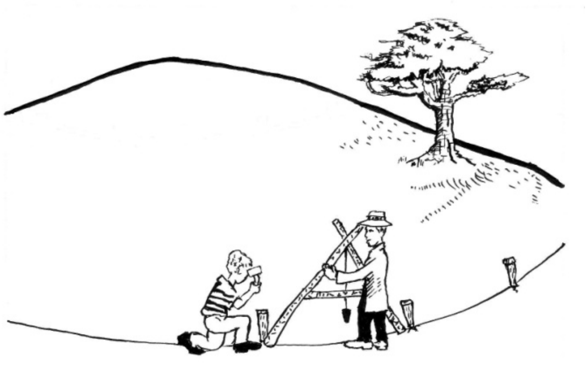
Figure 7.12 Swales prepared for planting

Figure 7.13 Vegetables growing on the swales

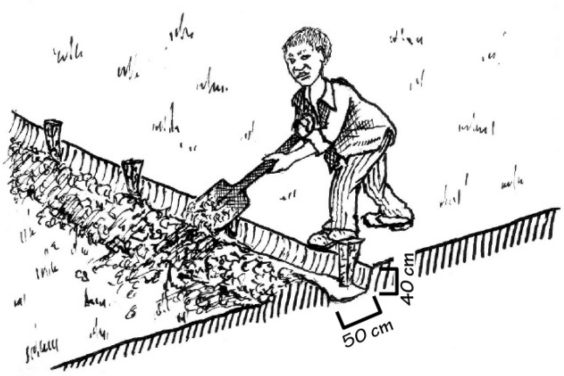
PLANNING

Soil	Slope	Rainfall	Tools & Equipment
Any soil. The sandier the soil, the thicker the swale should be. In clayey soil, swales can be a bit higher and narrower because the clay holds together well.[21]	5-25%[22]	Swales should be used with caution in areas with high rainfall (1200 mm or more) as waterlogging can occur.	spade* A-frame or line level* pegs/stakes **essential*

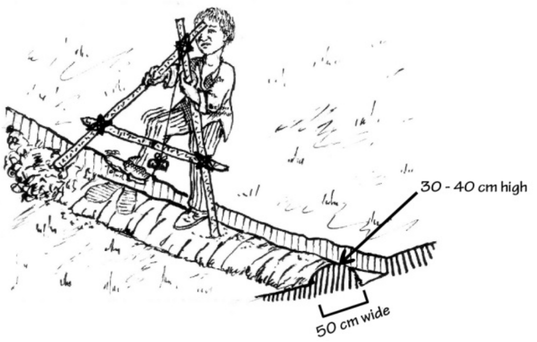
METHOD



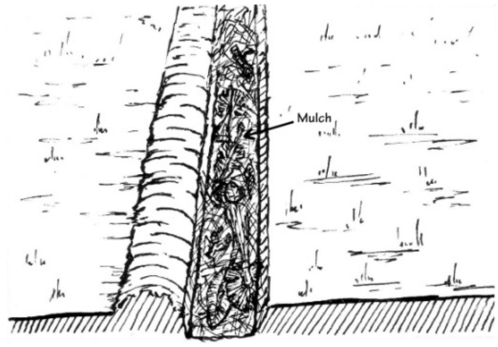
1. Decide where you want to grow your crops and mark out contour lines which are 5 metres apart. If the slope is steeper the lines can be made closer (up to 3 m apart).



2. Dig a shallow furrow along each contour line (30-40 cm deep and 50 cm wide) and place the soil on the down-slope side of the furrow.

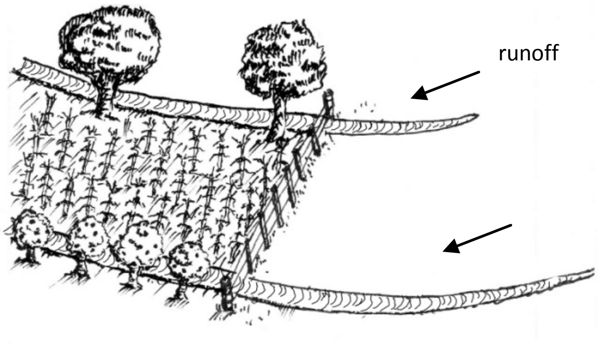


3. Use the soil you have excavated to create a ridge (30-40 cm high and 50 cm wide) on the downslope side of the furrow. Use an A-frame to make the top of the ridge level. Walk along the ridge and stamp on the soil to compact it.



4. Fill the furrow with mulch (place the coarsest mulch at the base).

5. Plant permanent crops (e.g. fruit trees and shrubs) immediately below the ridge of the swale and seasonal crops between the swales. If necessary, dig diversion furrows or extend swales to bring additional surface runoff into the planting area.



activity 22

Tied Ridges and Swales

Complete this activity in small groups (4-6 members).

Select a site which is at least 6 metres long and 6 metres wide and:

1. Construct tied ridges on this site and plant with maize or vegetables.

   OR

   Construct two swales and plant with permanent and seasonal crops.

   NB: Ensure that the soils, slope and rainfall are suitable for tied ridges if you decide on that option.

2. Maintain the tied ridges or swales for one growing season (3-4 months).
3. Compile an activity report, as per your lecturer's instructions.

Completing this activity successfully will involve, amongst other things:

- Selecting an appropriate site. Groups must have permission to use the site, and the site must be secured from livestock.
- Compiling a list of the materials required, deciding how each item will be obtained, and ensuring that the materials are available when they are needed.
- Developing an appropriate and realistic timeframe for the activity and allocating the time required to complete it.
- Planning the activity in detail and assigning tasks to each group member.
- Performing the allocated tasks, working together to ensure that the activity is completed successfully and on time.

Your lecturer will provide you with further instructions for this activity and for the group report.

Time: 18 hours

8. Terraces

also called:	used in:	
• Benches[23]	gardens	✓
	fields	✓
	grazing land	

A ***terrace*** is a level strip of soil built along the contour of a slope and supported by an earth or stone bund, or rows of old tyres. Terraces create flat planting areas and stabilize slopes which would otherwise be too steep for crop production. A series of terraces creates a step-like effect which slows down runoff, increases the infiltration of water into the soil, and helps control soil erosion. Terraces are built on steeper slopes, so there is a high risk of erosion taking place if they are not constructed correctly. To avoid erosion, each terrace must overflow sideways into a drain that is protected with rocks, branches or gabions.

Figure 7.14 A terrace built easily and cost-effectively using old tyres packed with soil.

Figure 7.15 A farmer standing at her stone terrace wall

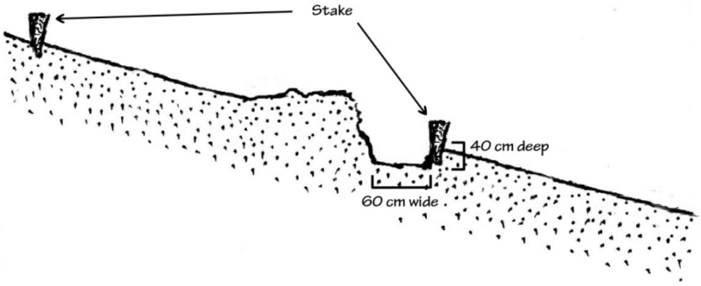
PLANNING

Soil	Slope	Rainfall	Tools & Equipment
Any soils, although there is need for caution in clay soils which are prone to waterlogging, and highly erodible soils.	10-40%[24]	Sufficient rainfall for crop production required.	stones of various sizes (flat or angular stones are preferable)* wheelbarrow* spade* A-frame or line level* stakes/pegs and string* hammer and chisel pick-axe *essential

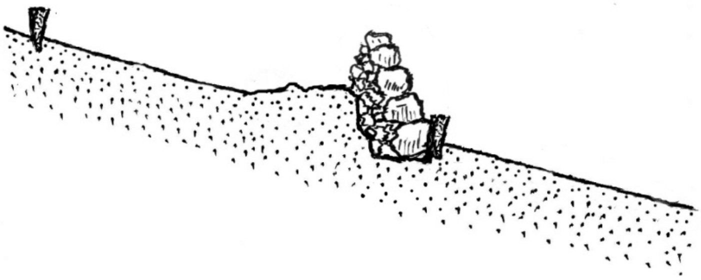
METHOD

1. Calculate the slope to determine the spacing between terraces (see Table 1). Starting at the bottom of the slope, mark out the contour lines for each terrace you plan to build. If necessary, adjust the position of the pegs so that each line forms a smooth curve.

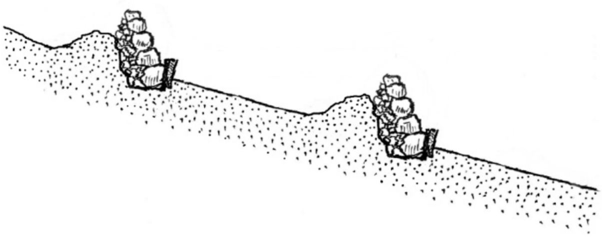
2. Dig a trench about 40 cm deep and 60 cm wide along the first contour line (see Table 1). Place the excavated soil upslope of the trench.



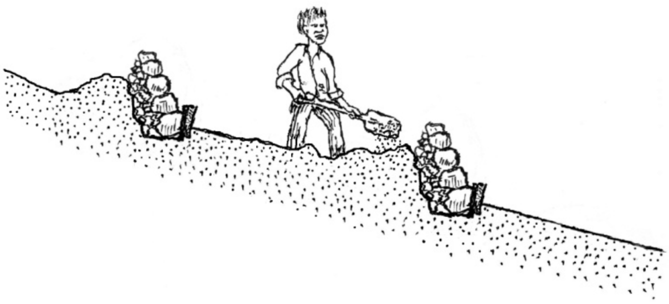
3. Start building the terrace wall by placing large stones along the base of the trench. Place the biggest stones on the down-slope side to create an "anchor line"[25] and place smaller stones on the up-slope side. Use small stones to fill any gaps between the larger stones. Pack the stones so that they lean back *against* the soil to ensure that the wall remains stable.



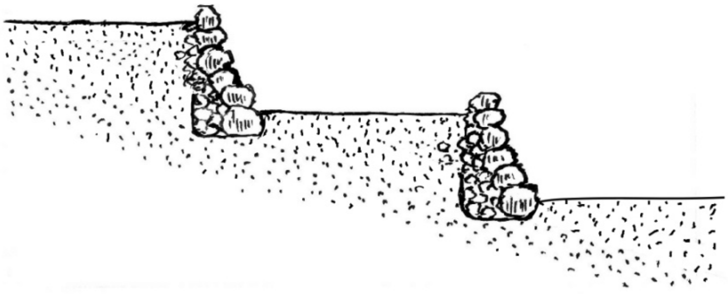
4. Move to the next marked contour line and build the next terrace wall by repeating steps 2 and 3.



5. Level the soil excavated from the terrace foundation up against the back of the *constructed wall*. If you need more soil dig away the upper part of the terrace and spread it across. Make sure you do not dig more than 30cm near to the upper wall, so that you do not undermine the foundation.



6. Use an A-frame and a rake to get the soil level. You will now have two terrace walls and a level terrace of soil between the walls. The final soil surface must be at least 10 cm lower than the terrace wall so that erosion does not take place.

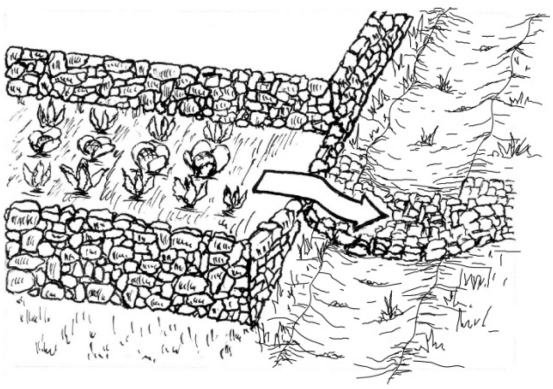


Terrace spacing and dimensions:

Slope		Distance between terraces (metres)	Terrace height above ground level (metres)	Terrace height above bottom of trench (metres)
Percent	Ratio			
10%	1:10	8.0	0.8	1.2
15%	1:6.7	5.3	0.8	1.2
20%	1:5	4.0	0.8	1.2
25%	1:4	3.2	0.8	1.2
30%	1:3.3	2.7	0.8	1.2
35%	1:2.8	2.3	0.8	1.2
40%	1:2.5	2.0	0.8	1.2

EROSION PROTECTION

During high rainfall events, excess water from the terrace must be allowed to overflow at the side of the terrace. Because there is a high risk of erosion at this overflow point, it is necessary to protect the overflow with small rocks and/or grass. The water which overflows will move down a natural drainage line which, due to the steep slopes, may also need erosion protection, for example using rock packs, or brushwood walls, to avoid gullies forming.



9. Fertility Pits

also called:	used in:	
• banana circles	gardens	✓
• circular swale	fields	
	grazing land	

Fertility pits enable runoff water to be captured and conserved in pits that are filled with organic matter such as compost or manure. The organic matter increases the fertility of the soil and minimises the loss of water from evaporation. Plants, particularly those which require a lot of water (such as bananas, paw-paws and tree tomatoes), are grown in or around the pits, where they benefit from the moist and fertile soil.

Figure 7.16 Fertility pit filled with organic material

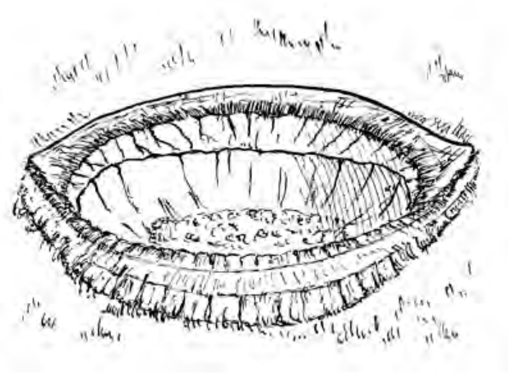
Figure 7.17 A fertility pit being prepared

PLANNING

Soil	Slope	Rainfall	Tools & Equipment
Any soil type (the organic material will improve any soil).	Up to 25%.	Any rainfall.	spade* organic materials (mulch, compost, manure)* trees * (e.g. banana suckers, paw-paw seedlings) plants (e.g. sweet potato, beans, ginger, lemon grass, yams, comfrey) **essential*

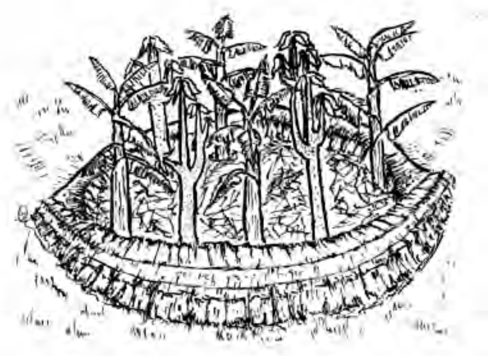
METHOD

1. Decide where the pit should be. Mark out a circle about two metres in diameter and dig down about 1 metre. The pit should be fairly concave (shaped like a bowl). Place the soil you have dug out around the edge of the pit.



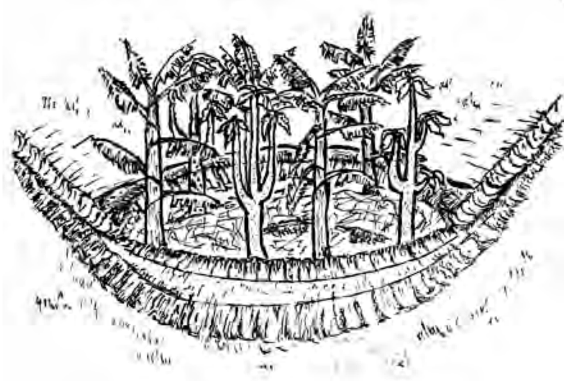
2. Shape the soil around the edge of the pit to form a ridge or mound. If the pit is on a slope you can dig diversion furrows to direct runoff into the pit (see step 5 below).

3. Fill the pit with organic material, placing the most coarse materials at the bottom. You can overfill the pit because the materials will sink over time.



4. Plant trees and plants around the rim of the mound. Space the trees so that they have enough room for growth and place plants between the trees.

5. Use the fertility pit as a compost heap, and construct a diversion furrow to direct any excess runoff into the pit.



activity 23

Fertility Pit

Complete this activity in groups of 8-10.

1. Dig a fertility pit, fill it with organic matter and plant trees (e.g. bananas and paw-paws) and plants around the rim.
2. Dig a diversion furrow to direct excess runoff from the surrounding area into the pit.
3. Collect and add any organic matter to the pit over the time period specificed by your lecturer.
4. Compile an activity report, as per your lecturer's instructions.

Completing this activity successfully will involve, amongst other things:

- Selecting an appropriate site. Groups must have permission to use the site.
- Compiling a list of the materials required, deciding how each item will be obtained, and ensuring that the materials are available when needed.
- Developing an appropriate and realistic timeframe for the activity and allocating the time required to complete it.
- Planning the activity in detail and assigning tasks to each group member.
- Performing the allocated tasks, working together to ensure that the activity is completed successfully and on time.

Your lecturer will provide you with further instructions for this activity and for the group report.

Time: 15 hours

10. Greywater Harvesting

also called:	used in:	
• greywater recycling	gardens	✓
	fields	
	grazing land	

Greywater harvesting is the practice of directing greywater – which is all non-toilet wastewater produced in a household – to the root zone of the soil.[26] Greywater includes the water used for bathing, washing, cleaning, cooking and rinsing. Wastewater from toilets is called ***blackwater***, and this should *always* go into a sewer or septic system.

Greywater does not need extensive chemical treatment before it can be used as irrigation water, because it goes through a natural purification process as it passes through the biologically active region of the soil (i.e. as it percolates through a healthy topsoil).[27] However, greywater should still be treated with an amount of caution because it usually contains grease, detergents, dead skin, food particles and small amounts of faecal matter.[28] For this reason, the best greywater to use is bath/shower water, basin water, and the water used to wash clothes (although water which is used to wash dirty nappies should *never* be recycled because it is likely to contain faecal matter).

Greywater from the kitchen (i.e. the water used for food preparation and dishwashing) is the least desirable water to recycle because the large amount of organic matter that is introduced into the water when food is prepared (e.g. when meat and poultry is rinsed) and when dishes are washed, is a significant source of contamination. The oils and greases which dishwashing water usually contain also have a negative impact on the soil, because they accumulate and this affects the ability of the soil to absorb water, essentially making it water-repellent.[29]

Most soaps and cleaning detergents contain sodium, which can also present a problem when greywater is used over an extended period of time. This is because the sodium builds up in the soil, damaging the soil structure and increasing its alkalinity. Sodium build-up can easily be detected by conducting a pH test.

Figure 7.18 A soil pH test kit

Simple pH test kits are inexpensive and can be bought at most home and garden centres, nurseries and hardware stores. The kit usually consists of a test tube, some testing solution, a colour chart, and a set of instructions for use. The process of testing soil pH typically involves putting a sample of the soil into the tube, adding some test solution, shaking the bottle and leaving the mixture to settle. The solution in the tube then changes colour, and this is compared with the colours on the colour chart from the kit. Matching colours indicate the pH of the soil sample.

A pH of 7.5 or above, indicates that a soil has become loaded with sodium. Any harmful effects caused by sodium can be counteracted or minimised by:

(a) spreading calcium sulfate (agricultural gypsum) over the soil (about 1 kg/30 m^2);

(b) diluting the greywater with fresh water; or

(c) by rotating greywater application with fresh water, as the fresh water will help leach the soil of sodium and excess salts.[30]

Guidelines for Greywater Use

- Use greywater as soon after it is created as possible.
- Collect greywater in buckets and carry it to where it will be used.
- Apply the greywater directly onto the soil, around plants whose edible parts grow above the ground (e.g. tomatoes, beans, mielies, fruit and nut trees). Do not allow greywater to come into direct contact with the edible parts of food crops.
- Add mulch to areas where greywater is used to speed up the natural decomposition of waste residues.
- Alternate between applying greywater and freshwater to the soil, as fresh water will help leach out soil contaminants which may be building up (such as sodium).[31]

Figure 7.19 Collecting greywater in buckets[32]

Figure 7.20 Applying greywater directly onto the soil

Precautions

- Never drink greywater.
- Do not store greywater for more than a day, as micro-organisms will grow and reproduce in it, making it septic.
- Do not use greywater in areas prone to waterlogging.

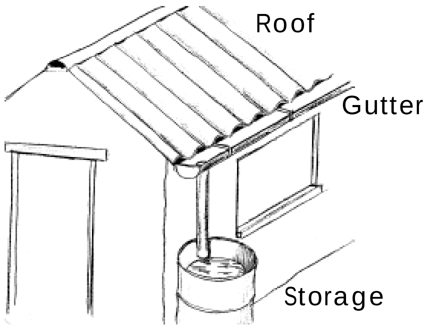
11. Roofwater Harvesting

also called:	used in:	
• No other names	gardens	✓
	fields	
	grazing and degraded land	

Collecting water from roofs for household and garden use is widely practiced across South Africa, and tanks and containers of all types – from large brick reservoirs to makeshift drums and buckets – are a common sight in rural areas. There are, however, many ways of improving both the quality and the quantity of water that can be harvested from the roofs of houses, schools, clinics and outbuildings.

Collecting water from roofs has the following advantages over any other surface:

- Roofs are physically in place and runoff is immediately accessible;
- Water collected from roofs is much cleaner than from ground runoff; and
- Most of the rainwater falling on a roof can be collected, as there is little absorption or infiltration on the roof surface (with thatch being an exception).



There are three main components to roofwater harvesting; the **roof**, the **gutter** and the **storage tank**. What follows is a summary of each of these components and practical suggestions as to how each can best be utilised.

Roofs

Roof type and water quality

Most roofs are suitable for rainwater collection. However, roof water can be contaminated to varying degrees by the roof material itself, by bird and animal faeces, and by leaves and dust. For this reason, a set of basic measures to limit contamination is strongly recommended, regardless of the roof material used (see the end of this section for recommendations).

Safe roofs

Corrugated iron, slate, fibre cement, asbestos cement, tiles and concrete are all sufficiently safe surfaces and provide reasonably clean water. There is no evidence to suggest that asbestos roofs should not be used to harvest drinking water, even though asbestos presents a health hazard during construction due to the potential breathing in of fibres.[33]

Unsafe roof materials

Roofs with metallic or lead paint, or with lead flashing, must not be used because the metals are toxic and can enter the water.[34]

Guttering

Guttering is a potential weak link between the roof and the storage container,[35] so this is an area where losses can be prevented with very little effort. The following types of gutters are widely used in South Africa:

uPVC gutters

These are well-suited to houses which are constructed more formally, where rafters and rooflines provide a straight line for the gutters to be attached. PVC gutters are difficult to attach to informal housing such as huts and shacks, where rafters or beams are often not aligned with each other and where roof structures are often made with rough, untreated poles which are weakened by insect attack, making firm fixture difficult. PVC gutters typically require the installation of a facia, which adds cost to the overall gutter installation. PVC gutters cannot be used on thatch roofs.

Sheet metal gutters[36]

These gutters are made from flat galvanised sheets, or from corrugated sheets which have been flattened with a hammer. Homemade gutters can accommodate the challenges presented by informal or traditional housing, and can be hung from roof sheets which are skew by fixing them to the roof sheets with 3mm fencing wire.

Figure 7.21 Sheet metal gutter fixed to roof sheets with 3mm fencing wire

There is also an innovative and more formalised sheet metal gutter design, whereby the gutter is riveted directly to the upper surface of corrugated iron roof sheets and curves underneath the roof to catch the water.[37] This design has much potential for addressing the challenges of fixing gutters to informal housing, as it circumvents the need for roof timber to be aligned and in good condition. These gutters are more adaptable than PVC guttering as they can be bent or twisted to ensure that sufficient slope is achieved in situations where rooflines do not slope consistently. However, sheet metal gutters cannot easily be used on rondavels or thatched roofs.

U-Round HDPE guttering

This patented system is specifically designed for collecting water from thatched roofs. It is a highly flexible system which is well suited to the widely varying construction situations found in rural buildings. The gutters can bend around corners and can easily accommodate changes in level. The fixings of U-Round gutters need careful attention where rafter spacings exceed 0.5 metres, in which case the gutter can be fixed to the roof sheeting with 3 mm wire to provide additional support.[38]

Figure 7.22 U-Round guttering used in Cata Village, Eastern Cape

Storage Tanks

Many different types of storage tanks can be used. Tanks are typically made of plastic, plastered block, corrugated iron, ferrocement, natural stone or bitumen-geofabric. Recent studies have shown that plastic tanks are approximately half the cost of any other tank type for a typical household application; they are also quicker and easier to install and have fewer quality (leakage) issues. The only disadvantage of plastic tanks is that they have an expected life span of 10 to 15 years, whereas well-constructed ferrocement or plastered block tanks can last for up to 30 years with ongoing minor repairs.[39] Plastic tanks must always be positioned properly, on level and stable bases. Plastic tanks typically come in sizes of 1000 litres, 2000 litres, 5000 litres and 10,000 litres.

Runoff and Storage Calculations

It is important to note that for any roof size there is a maximum amount of water that can be collected. It is common that tanks are installed without any water runoff and storage calculations being done. If the tanks are not sufficient for a household's needs and they overflow significantly during the wet months, additional tanks could be used to store the water which is overflowing. Observation and experience are thus a sensible way of building up storage in a step-by-step manner. As a rule of thumb, you can install 5000 litres of storage for every 40 square metres of roof – but this is a rough approximation and will vary substantially between households and in different parts of the country.

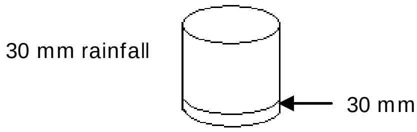
An accurate calculation can be done to arrive at the optimum tank size that is required. This optimum size is related to the monthly rainfall, the size of the roof, and the amount of water to be used each month. The calculations can be done scientifically using publicly available software such as SAPWAT, which can be obtained from the Water Research Commission via their website or by written request. SAPWAT requires computer skills and a level of technical competence to use. There are also more simple methods of estimating water demand, tank size and water runoff from roof areas. These calculations will give acceptably accurate results, and are described next.

Calculating roof runoff volumes

The runoff from a roof is calculated using the rainfall, the plan area of the roof (roof surface area in square metres) and the runoff coefficient.

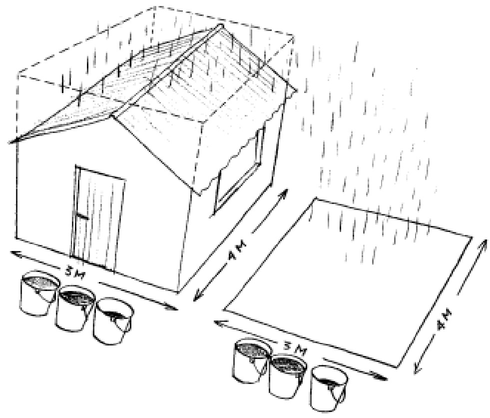
Runoff (litres) = roof surface area (square metres) x rainfall (mm) x runoff coefficient

1. Rainfall



Rainfall is expressed in millimetres, which is the depth of water that has fallen during a rainfall event. For example, during a 30 mm rainfall, 30 mm of water will collect in a container which has a flat bottom and vertical sides.

2. Plan area of the roof



It is important to understand that the roof surface area used in the calculation is the *plan area of the roof*. The reason for this is because the amount of rain that is collected stays the same regardless of whether the roof is flat or pitched.

3. Runoff coefficient

Not all of the rainwater which falls onto a roof will run off into the gutter, as certain amounts will be lost to absorption and evaporation. The amount of water that is lost will differ, depending on the kind of roof system that is in place. Each roof material has a *runoff co-efficient*. This is used to calculate the amount of rainfall that will run off and the amount which will be lost. A runoff co-efficient of 0.9, for example, means that 90% of the rainfall will run off, while 10% will be lost to evaporation and absorption (note that leakage and overflow can lead to further water losses). The higher the runoff co-efficient for the material, the more water can be collected from the roof.

Table 7.1 Runoff coefficients for different roof materials (with effective guttering in place)[40]

Type	**Runoff coefficient**	**Percentage Runoff**
Galvanised iron sheets	0.9	90%
Tiles (glazed)	0.8-0.9	80-90%
Flat cement roof	0.6-0.7	60-70%
Thatch	0.2-0.5	20-50%

Thatch has a wide runoff coefficient range because runoff varies considerably for different types of thatch. Rietgrass, for example, has a higher runoff value than the more widely-available turpentine grass. Other factors which impact on thatch runoff are: the slope of the roof; the age of the thatch; and the sensitivity of all thatch to the type of rainfall that takes place (e.g. a gentle rain of short duration has lower runoff, while thunderstorms have higher runoff).

Example of monthly roof runoff calculation:

A rectangular rural homestead has two houses which feed the *same tank*:

House A: a 'flat' which is 4 m x 6 m, with a corrugated iron roof and gutter system

House B: a rondavel, which is 5 m in diameter, with a corrugated iron roof and gutter system

The January rainfall is **115 mm**.

Step 1: Calculate the total roof surface area

House A roof area (rectangle) = 4 m x 6 m = 24 m^2

House B roof area (circle) = $\frac{\pi \times d^2}{4}$ = $\frac{\pi \times 25}{4}$ = 19.6 m^2

The symbol π is "pi". The value 3.14159 can be used in the calculation.

d = diameter

TOTAL roof surface area = 24 + 19.6 = **43.6 m^2**

Step 2: Calculate the January runoff from the roof

Runoff (litres) = roof surface area (square metres) x rainfall (mm) x runoff coefficient

January runoff from both houses (litres) = 43.6 m^2 x 115 mm x 0.9
= 4512.6 litres
= **4513 litres** (rounded off)

This calculation can be done for each month (January to December) to get an estimate of the total annual roof runoff from both houses into the tank (see Table 2).

Table 7.2 Monthly runoff from 43.6 m^2 of corrugated iron roof

Month	Average Monthly rainfall (mm)	Roof area (m^2)	Runoff coefficient	Runoff volume (litres)	Cumulative volume (litres)
Jan	115	43.6	0.9	4513	4513
Feb	123	43.6	0.9	4827	9340
Mar	109	43.6	0.9	4277	13617
Apr	78	43.6	0.9	3061	16678
May	61	43.6	0.9	2394	19072
Jun	35	43.6	0.9	1373	20445
Jul	30	43.6	0.9	1177	21622
Aug	35	43.6	0.9	1373	22995
Sep	55	43.6	0.9	2158	25153
Oct	60	43.6	0.9	2354	27507
Nov	80	43.6	0.9	3139	30646
Dec	95	43.6	0.9	3728	34374
TOTAL	**876**			**34374**	**34374**

In this example, the total average annual runoff is 34374 litres. It is not necessary to have storage space for this total volume, because every month some water will run into the tank while some will be taken out for domestic and garden use. To calculate the amount of storage space that is actually needed (i.e. the tank size and/or the number of tanks required), one must first calculate the water requirements for both the garden and the household.

Garden Water Requirements

SAPWAT can be used to calculate water requirements for gardens. However, even with this programme there are many assumptions which have to be made about the WHC approaches that are used and how the garden will be planted. These include estimates of garden size, the mix of plants from month to month, water-use efficiencies, and planting densities, none of which are fixed and all of which impact directly on water-use estimates.

The table which follows provides estimates which can be used for approximate tank sizing, given the wide range of garden uncertainties which must be assessed in any single situation.

Table 7.3 Approximate water requirements for vegetable crops where intensive WHC methods are used (litres/month/m²)[41]

Crop water demand	Typical crops	Summer rainfall area demand (litres/month/m²)		Winter rainfall area demand (litres/month/m²)	
		summer	winter	summer	winter
High demand	Spinach, chinese cabbage, rice,	70	98	165	23
Medium demand	Potatoes, mealies, wheat, mixed crops	63	73	135	25
Low demand	Tree crops, beans, cabbage	25	48	65	50

Water requirements for a garden of 50 m² in a summer rainfall area would thus be calculated as follows:

Table 7.4 Garden water requirements across the year for a garden of 50 m²

Month	Season	Crop water demand (see Table 3)	Monthly garden requirement / m²	Monthly WHC garden requirement for 50 m²	Cumulative WHC garden requirement (litres)
Jan	summer	Medium	63	3150	3150
Feb	summer	Medium	63	3150	6300
Mar	summer	Medium	63	3150	9450
Apr	winter	Low	48	2400	11850
May	winter	Low	48	2400	14250
Jun	winter	Low	48	2400	16650
Jul	winter	Low	48	2400	19050
Aug	winter	Low	48	2400	21450
Sep	winter	Low	48	2400	23850
Oct	summer	High	70	3500	27350
Nov	summer	High	70	3500	30850
Dec	summer	High	70	3500	34350
TOTAL					**34350**

Domestic Water Use Estimates

It is common sense that water consumption is linked to availability and quality – the more people have access to, the more they will use, within reasonable limits of supply or cost. Where people must carry water on foot, consumption can be as low as 7 litres / person / day. Where yard connections are available, this can easily increase to 5 times that amount.

When assessing how much water a roof-harvesting system can yield for a household, the particular household situation must be considered. It is recommended that the value of 25 litres per person per day (as set by the DWA) is used in the supply-demand balancing calculation if no other information is available.

Typical *daily* demand for 5 people (litres):	5 x 25 litres = 125 litres / day
Typical *monthly* demand for 5 people (litres):	125 x 30.5 days = 3812.5 litres / month
Typical *annual* demand for 5 people (litres):	12 months x 3812.5 litres = 45750 litres / year

Assessing Annual Supply and Demand

Supply and demand is assessed by looking at the **total supply** versus the **total demand** for the year. In the example we have been using:

- the **<u>supply</u>** is the runoff from the roof, which is 34374 litres/year (average)
- the WHC **<u>garden demand</u>** for crops on a 50 m^2 garden is 34350 litres/year
- the **<u>household demand</u>** for 5 people is 45,750 litres/year

The annual supply and demand is summarised in Table 5, along with the equivalent number of 5000 litre plastic tanks that these volumes would fill (these are the tanks that are widely used in rural areas in South Africa).

Table 7.5 Summary of example – roof runoff and demand

Description	Annual Volume (litres)	Approximate number of 5000 litre plastic tanks per year
Roof water supply (roof area = 43.6 m^2)	34374	Just fewer than 7 tanks (total roof runoff each year)
Garden demand (planted area = 50 m^2)	34350	Just fewer than 7 tanks (total water used in garden each year)
Household demand (5 people)	45750	Just more than 9 tanks (used in household)

In this example, the total annual roofwater supply (of 34374 litres in an average year) is just enough to meet the total yearly needs of the 50 m^2 garden (34350 litres/year), but the roof runoff is not enough to meet the domestic demand.

Calculating Storage Requirements

Because the rain does not fall equally on every day in the year, there is a need for storage to balance the water supply and demand over the wetter and drier months of the year. The storage requirement is calculated for each specific demand situation.

In the example we have been using the roof runoff is not sufficient for domestic use, so the balancing calculation can by simplified by looking only at the roof runoff supply and the garden requirement (which would be the case where people have access to a reliable municipal water supply).

The balancing calculation is done for each month from January to December. The calculation is done on a cumulative basis, which means that the total for each month is added to the previous total. Similarly, each month of demand is added to the next. These can be presented in tables or plotted on a graph.

The storage space that is needed is the largest difference between the two sets of values (i.e. the cumulative roof runoff volume minus the cumulative garden demand.

Month	Cumulative roof runoff volume (litres)	Cumulative garden demand (litres)	Monthly storage required (litres)
Jan	4513	3150	1363
Feb	9339	6300	3039
Mar	13616	9450	4166
Apr	16677	11850	**4827**
May	19071	14250	4821
Jun	20444	16650	3794
Jul	21621	19050	2571
Aug	22995	21450	1545
Sep	25153	23850	1303
Oct	27507	27350	157
Nov	30646	30850	-204
Dec	34374	34350	24

The largest difference is in **April**. The storage needed is 4827 litres, which is approximately equal to one 5000 litre plastic tank.

If the calculation is to be done for both domestic and garden demand (in another situation, for example), then these must be added together to arrive at a total demand. The storage is calculated in the same manner, but using the combined garden and household demand figures.

Uncertainties and Approximations

The calculation for roof runoff is done using average monthly rainfall figures. Using average rainfall data will tend to *overestimate* the tank size that can be supplied by a given roof because low rainfall years are more common than high rainfall years.[42] This means that in most years, there will be less runoff than the average, but in a few years there will be a lot more than the average. In practice this will leave the tanks less than full for most years, although they will overflow every 5 years or so.[43]

The purpose of the approximation (i.e. the use of monthly rainfall figures) is to provide a rough guideline on tank storage linked to roof area. When the widely varying factors related to both gardening demand and to household demand are considered, plus the likely reality that storage will be in easy and cheap plastic tanks (each a size of 5000 litres), then this approximate method still has value. One either has to model the system in full detail (using 50 years of rainfall data and calculating accurate household and garden demand), or accept that the estimate is rough. A more conservative and thus more reliable estimate can be calculated by reducing the average monthly rainfall by 10%, which will narrow the gap between the rough theoretical estimate and the detailed theoretical estimate.

Recommendations for Improved Roofwater Harvesting Systems

Roofs: The roof material must be carefully inspected before installing a rainwater harvesting system for domestic or garden use to ensure that the roof material is one which is safe to use.

Gutters: Three types of gutters are recommended:

- uPVC guttering. This is recommended for roofs on strong, straight structures where facias are in place or can be easily constructed. PVC is approximately 75% the price of other gutters.
- Sheet metal guttering, which is riveted to the top surface of the roof sheeting and is bent down and below the roof sheeting to catch the water. This guttering can be made by any local tinworks, and is the best option for corrugated iron roofs. This guttering is especially useful where roofing timber is either weak or not aligned, or where rooflines are not straight, because the sheet metal can be bent up or down to ensure sufficient slope to the tank.
- U-Round guttering, which is a semi-rigid system designed for use on thatch roofs. U-Round gutters are also particularly useful for connecting any type of gutter to the tank, as the gutter can be twisted to curve down and around corners.

Water losses can be significantly reduced by ensuring that there are no leaks. Gutter slope must be adequate to ensure that water flows into the tank, and gutters must be fixed firmly to the roof sheets or roofing timber.

Storage tanks: The use of plastic tanks is recommended as they are cost-effective, quick and easy to install, and have few problems with leakage. Plastic tanks must always be positioned properly on level and stable bases.

Water quality: The risk of contamination should be minimised from the source (i.e. the roof).

- Bird and animal activity on the roof should be eliminated as far as possible.
- Trees should be trimmed to reduce leaf fall.
- The inlet to the tank should be screened with a fine mesh to minimise organic material or animals getting into the tank.
- The tank should be cleaned each year, at the end of the dry season.
- Outlets (taps or pipes) should be placed 5-15 cm from the tank floor to minimise the outflow of organic material from the tank.
- The tank must have a firmly fixed lid.
- Inlets and outlets must be screened to minimise insect and mosquito activity in the tank.

First flush systems, such as those which catch the initial, dirtier runoff in a separate 20 to 50 litre container (after which the runoff flows into the main tank) are widely recommended, as they will improve water quality significantly. However, first flush systems require substantial maintenance and are rarely observed in practice.[44]

activity 24

Roofwater Harvesting

This activity must be completed individually or in pairs.

Select a building to which you have access, such as a house, a school, a clinic, an outhouse, or an informal dwelling. The roof of the building must be made from one of the following materials: galvanised iron sheets, tiles, cement, or thatch. Examine the roof and the building carefully, and complete the following in writing:

1. Name the material from which the roof is made.
2. Draw a plan area of the roof, and annotate it with the roof dimensions.
3. Use the roof dimensions to calculate the roof surface area. Show all of your calculations.
4. Identify and name the type of gutter which is on the roof (if any). State whether this guttering is the most suitable type to use on the building, and explain why or why not.
5. If there is no gutter on the building, name the guttering which you think would be most suitable to use and explain why.
6. Calculate the total annual roof runoff volume for the building. Show all of your calculations (these can be presented in a table) and present the rainfall data you used. Name the source of this data, and explain how you obtained it.

Your lecturer will provide you with further instructions for this activity and for your written report.

Time: 2 hours

12. Ploegvore

also called:	used in:	
• imprinting • pitting	gardens	
	fields	
	grazing and degraded land	✓

This water-harvesting method involves creating numerous small, well-formed pits or "imprints" in the soil that collect rainwater runoff, seed, sediment and plant litter. This provides a relatively sheltered microclimate in which seed and seedlings can grow.[45] This method is particularly effective for rehabilitating degraded soils and for improving grazing land in arid areas. When used for these purposes, the pits are typically created by machine (a bulldozer or tractor with a specialised imprinter).

Figure 7.23 Degraded land Ploegvore Same land 15 yrs later 'Happloeg' on tractor for pitting

PLANNING

Soil	Slope	Rainfall	Tools & Equipment
Any type of soil, including barren, crusted soils and clay soils with limited infiltration.[46]	Below 2%.[47]	Recommended for relatively low rainfall areas (100-350 mm).	tractor* imprinting implement ("happloeg") or specialised bulldozer* **essential*

In other parts of the world, similar pits – called Zai or Vitengo pits – are constructed by hand for crop production, whereas in South Africa, ploegvore (a local variation where imprints are made with machines) are used to improve grazing or degraded land.[48] Hand-pitting at an extensive scale for grazing improvement in South Africa seems highly unlikely given the labour input; however, hand-pitting for crop production could have local application. In reality there are numerous WHC methods which overlap in terms of agro-climatic and soils suitability and Zai pits for crop production show little advantage over other proven and locally modified methods such as "in-field RWH" (***tied ridges***), trench beds, contour bunds and swales. Pitting is therefore recommended to improve grazing and rehabilitating degraded land, using tractors and a 'happloeg' or a specialised bulldozer. Specialist advice on happloeg design can be obtained from Glen Agricultural College, the University of Potchefstroom or Elsenburg Agricultural College.

13. Dome Water Harvesting

also called:	used in:	
• No other names	gardens	✓
	fields	✓
	grazing land	

Figure 7.24 Dome of 1.2 ha in size, near to fields

Dome water harvesting is used to intercept and direct rainwater runoff from impermeable rock domes directly to a field where water is stored in the soil, or to a reservoir of some sort.

Essentially the dome acts as a large roof, and a low diversion wall around the base of the dome collects and channels water in the same way as a roof-gutter. Domes offer high runoff rates (80% to 90% of the rain runs off) and they are often sizeable, extending more than 1 or 2 ha in size. The high runoff rate and the large surface area results in significant volumes of water that can be collected at relatively low cost.

Figure 7.25 Massive granite dome with large runoff volumes

Figure 7.26 Domewater harvesting feeding field crops

The method provides valuable drinking water in arid areas, and can be very effective for agricultural use where domes are located close to agricultural lands in both arid or wetter climates. Experience shows that cultural beliefs and communal resource-use issues should be directly addressed in relation to dome water harvesting.[49]

PLANNING

Soil	Slope	Rainfall	Tools & Equipment
The hard rock domes are used for water collection, but crop production takes place away from the domes. Soil type in the agricultural lands therefore does not affect the system directly, but should be considered generally in relation to soil-water storage and crop choice.	Any slope is suitable, but construction practicality of the low diversion wall around the base of the dome (i.e. the gutter) becomes difficult when the dome slope is 45 degrees or more.	In low rainfall areas, runoff can be channelled directly to fields or stored in reservoirs. In medium and high rainfall areas, storage is likely to be needed given the high runoff volumes that will result.	spade* A-frame or line level* cement trowel* hammer* crowbar* steel chisel* **essential*

METHOD

On a small scale on rock slabs or domes up to 1000 m^2 in size, this method could be applied by someone with basic house-building or construction knowledge. On larger domes there is a greater need for technical engineering input in relation to the sedimentation tank, channels or pipelines, and water-holding dams or reservoirs.

The sequence of construction is set out below.

1. The slab or dome is typically cleared of all loose rock, soil and vegetation. Large cracks and crevices can be sealed with cement mortar (dagga) to increase yield.

2. A low wall, about 0.4 m high, is built around the base of the dome and channels water to where it will be stored. Walls can be built using a range of materials including brick, natural stone or concrete.

3. Typically, an open sedimentation tank is built to catch sand, gravel and debris before the water overflows into the storage reservoir (or is channelled directly to the planted area if no storage is put in place). Sedimentation tank size can be estimated roughly at 1/20th of the storage volume for small systems, but should be sized by a technical person for larger systems.

4. Storage volumes (size of reservoirs) are calculated from the monthly runoff minus the monthly use. In wet months the runoff will be higher than the use and the storage reservoir will fill up. In dry months the use will be higher than the rainfall runoff and the tanks will be slowly emptied. This inflow-outflow balancing calculation must therefore extend over the whole year to arrive at a suitable tank size and can be done by an engineer or technician. On a very small scale, storage in 5000 litre plastic tanks could be implemented a few tanks at a time, increasing the storage after a year or two by adding additional tanks, based on experience. On a larger scale it will be necessary to get some technical or engineering advice, both on the sizing of the reservoir and on tank or reservoir construction.

14. Saaidamme

also called:	used in:	
• floodwater harvesting • "planting dams"	gardens	
	fields	✓
	grazing land	✓

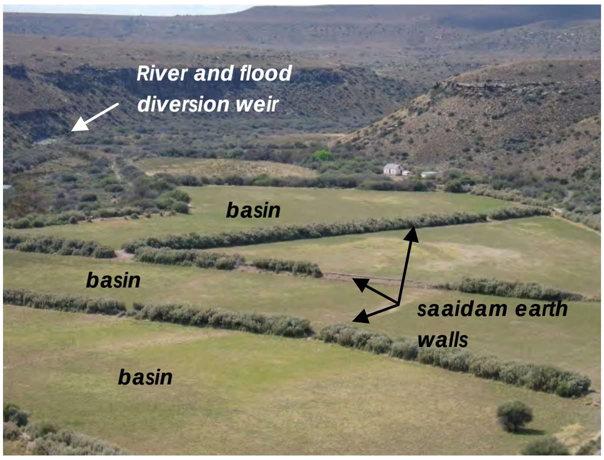
This method entails the diversion of floodwater from non-permanent rivers into a series of flat basins which are used for cropping. Each flat field is completely surrounded by a low earth embankment (wall) of between 0.5 and 1.5 metres high. Diverted water from the flooding river is channelled into the fields and completely submerges the land for 1 to 3 days, where it fully saturates the soil.[50] Water is released from the saturated field to the next field needing water, through small stone spillways or larger steel sluice-gates.

Slopes and field size

The fields vary from a few hundred square metres to 100 ha in size.[51] The steeper the slope, the smaller the fields. (Larger field sizes are found on very flat lands; smaller fields which have some slope require levelling and this demands that topsoil is removed from higher levels to fill the lower levels. Levelling leaves a shallower layer of topsoil on the upper slope. This means that the steeper the slope of the original land, the smaller must be the fields to maintain enough soil depth.)

Implementation support

Saaidamme are used extensively on a commercial scale for lucerne and vegetable production in arid areas in South Africa.[52] This floodwater-harvesting method has potential for small-scale farming of crops and pastures elsewhere in South Africa. The implementation of a saaidam system requires some knowledge of agricultural and irrigation engineering, as well as of South African environmental procedures. Input from the Department of Agriculture or an engineering professional will most likely be needed.



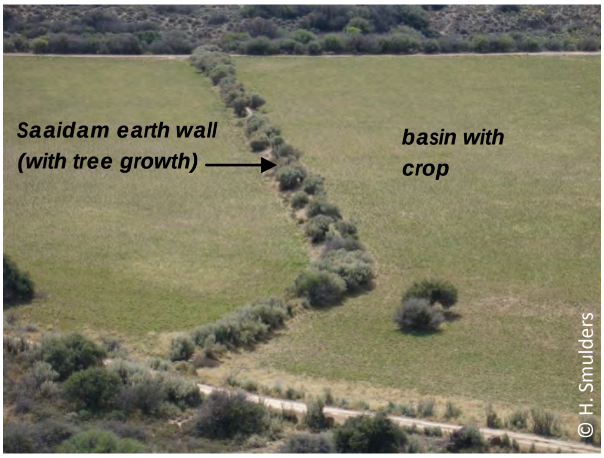


Figure 7.27 Saaidamme at Rooikranshoogte, west of Craddock in the Eastern Cape

Figure 7.28 Ribbon of saaidamme along the Fish River, 80 km east of Calvinia in the Northern Cape (satellite image from Google Earth)

Variations of the saaidam – adding surface water storage

The saaidam is a method of floodwater harvesting where water is stored only in the soil itself (except the 1 to 3 days of holding time in the basins, to saturate the soil to depths of 3m and deeper). The typical saaidam system therefore requires deep soils with high infiltration rates and with good soil-moisture storage properties (ideally, sandy clay loams).

A variation of the saaidam system can be made where ideal soils are not available; this involves diverting floodwater into saaidamme as well as into small surface storage dams. The floodwater held in the small dams can be released into the saaidam later in the season as supplementary irrigation. This combined approach is well suited to smaller fields (a few ha in size) in medium rainfall areas and is essentially a hybrid rainwater harvesting/small irrigation system. Given the low reliability of the water source (infrequent floods), supplementary irrigation methods in this system do not justify major investment in pipes or sprinklers. This combined approach is most practical where low-cost and efficient irrigation such as hand watering or short-furrow irrigation is carried out.

As rainfall increases beyond the medium range (400 to 600 mm), then other RWH methods included in this guide may be more cost effective and productive, and a choice would need to be made.

PLANNING

Soil	Slope	Rainfall	Tools & Equipment
Texture Loams, loamy clays and clay-loams, as these have high water-holding capacity and adequate infiltration rates. Floods are infrequent and clayey soils hold more water, which supports plants for the long dry period between floods. **> 3 m** is needed to absorb large quantities of water from the occasional floods. Often cropped with lucerne (deep rooted, self-seeding and permanent).	Original slope < 2% The final field must be practically flat which means that levelling is inevitable.	Lower rainfall limit is approximately 100 mm per annum, but linked more to flood events, which usually relate to nearby higher-rainfall mountains. Upper rainfall limit of saaidam system (with no storage) is approx-imately 400 mm. Upper limit of saaidam with supplementary storage is not defined by available research. Estimated at 600 mm per annum.	**Small scale (< 10 ha)** tractor* damscoop* dumpy level* Brick/stone work* concrete works **Large scale (> 10 ha)** bulldozer* grader* survey instrument* concrete works* **essential*

15. Test Yourself

1. Explain the purpose of diversion furrows. (3)

2. List six WHC methods which can be implemented in any type of soil. (6)

3. Explain the role of mulch in conserving water, and list four other advantages of using mulch. (6)

4. Briefly outline the process involved in constructing a trench bed. (16)

5. Name the WHC method which leads to the formation of natural terraces. (1)

6. Explain what a terrace is and list four advantages of creating terraces. (6)

7. Explain how tied ridges increase the water that is available to plants. (2)

8. Define the term *swale* and explain why swales should be used with caution in areas with high rainfall. (4)

9. Briefly outline the process involved in creating a fertility pit. (10)

10. Define the term *greywater harvesting*. (2)

11. Explain why greywater does not need extensive chemical treatment before it can be used for irrigation. (2)

12. Explain why greywater from the kitchen is the least desirable water to recycle. (4)

13. List four guidelines and two precautions pertaining to the use of greywater. (6)

14. Name the WHC method which is particularly effective for rehabilitating degraded soils, and explain *why* this method is effective. (4)

15. Explain the difference between harvesting water from rock domes and harvesting water in Saaidamme. (8)

16. Explain the term *runoff coefficient* as used in relation to roofwater harvesting. (2)

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ACRONYMS – TECHNICAL MANUAL

BHN	Basic Human Needs
CCWR	Computerised Centre for Water Research
CMA	Catchment Management Agency
DWAF	Department of Water Affairs and Forestry
DWEA	Department of Water and Environmental Affairs
FBW	Free Basic Water
FET	Further Education and Training
HDPE	High-Density Polyethylene
HEIA	High External Input Agriculture
LEISA	Low External Input and Sustainable Agriculture
NASA	National Aeronautics and Space Administration
NGO	Non-Government Organisation
NQF	National Qualifications Framework
NWA	National Water Act
PVC	Polyvinyl Chloride
SAPWAT	South African Plant Water Requirement Computer Model
SPAC	Soil-Plant-Atmosphere-Continuum
UKZN	University of KwaZulu-Natal
uPVC	unplasticized (rigid) Polyvinyl Chloride
WHC	Water Harvesting and Conservation
WMA	Water Management Areas
WRC	Water Research Commission
WSA	Water Service Authority

GLOSSARY

abiotic	Inorganic or non-living components.
aquifer	Moderately to highly-permeable rock below the surface of the earth through which water can move.
aspect	The direction that a slope faces.
bedrock	The solid rock that lies beneath soil or other loose surface material such as clay or gravel.
biodiversity	A term used to describe the variety of plant and animal species contained within an ecosystem.
biomass	The total mass of biological material contained in a given area of the earth's surface.
biotic	Organic or living components.
blackwater	Wastewater from toilets.
calibrate	Testing and adjusting the accuracy of a measuring instrument.
clay	A soil separate consisting of particles smaller than 0.002 mm in diameter.
compaction	The compression of particles to form a dense mass.
confined aquifer	An aquifer that is trapped under impermeable rock or soil.
contours / contour lines	Imaginary horizontal lines that connect all points in an area which have the same elevation.
deforestation	The removal of trees from a wooded area.
desertification	The spread of desert-like conditions in arid or semi-arid areas, due to human interference and/or climatic change.
diversion furrow	A furrow (trench) which directs rainwater runoff to a cropped area or storage tank.
dome water harvesting	A water harvesting method that intercepts and directs rainwater runoff from impermeable rock domes directly to a field or reservoir.
drainage	The ability of the soil as a whole to drain excess water.
dryland cropping	Crop farming which is dependent on rainfall.
ecology	The scientific study of the relationships between organisms and their environments.
ecosystem	A community of organisms and its physical environment.

effective rooting depth	The depth of the soil horizons in upper part of the profile that can be penetrated by plant roots
effluents	Liquid waste discharged from sewage systems, factories or other industrial plants.
elevation	The height of the land above sea level.
erosion	The natural process of soil being loosened and dissolved or carried away by wind, water, ice or the force of gravity.
eutrophication	The process by which an aquatic ecosystem increases in productivity as a result of increased nutrient input.
evaporate	To change from a liquid into a gas.
evapotranspiration	The combined loss of water by evaporation from the soil and transpiration from plants.
farm	Land used for farming under the control of a farmer, or group of farmers
farmer	Any person who engages in crop and/or animal production in fields or home gardens.
fertility pit	A concave pit approximately 1 meter deep filled with organic matter, in and around which plants are grown.
field capacity	The soil water content after the soil has been saturated and then allowed to drain freely for 24-48 hours.
floodplain	An area of low-lying land adjacent to a stream or river which is covered with water when the river overflows its banks.
greywater	All non-toilet wastewater produced in a household.
groundwater	Water which infiltrates into the ground, saturating pores or cracks in the soil and rocks.
gully / gully erosion	A water-worn channel that is not produced by a permanent stream.
humus	Decomposed organic matter which bears no trace of the anatomical structure from which it originated.
hydrology	The scientific study of the properties, distribution and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.
impermeable	Not allowing liquids or gasses to pass through.
indigenous	Originating in and naturally living, growing or occurring in a specific area or country.
infiltration	The rate at which water enters the soil surface, measured in mm/hour.

leaching	The draining away of soil material from part of the soil profile.
lime	Calcium Oxide (CaO)
mean annual precipitation	The average amount of rain that falls in a year in a specific area.
mulch	A material on the surface of the soil which reduces evaporation, soil crusting and compaction.
mulching	The practice of spreading plant and other organic materials onto the surface of the soil, usually concentrated around plants.
parent material	Material that is formed from the weathering of parent rock.
parent rock	The solid rock that lies underneath loose surface material such as soil, sand, clay or gravel.
pathogens	Disease-causing organisms.
percolate	To filter through a porous substance.
permeability	The rate at which water and air can penetrate or pass through a layer of soil.
permeable	Allowing liquids or gasses to pass through (porous).
pH (potential Hydrogen ions)	A measure of the acidity or alkalinity of a substance.
ploegvore	Small pits that are imprinted or dug into the soil in order to collect rainwater runoff, seed, sediment and plant litter.
precipitation	Moisture that falls on the ground, e.g. rain, snow, sleet and hail.
rainwater harvesting	The concentration and entrapment of rainwater runoff from a catchment.
recharge	Water which seeps into an aquifer.
rill	A small, irregular water course, usually only a few centimeters deep.
rooting depth	The depth of root growth of a specific crop.
runoff	Water that flows off a surface when more rain falls than the surface can absorb.
saaidamme	A water harvesting method that diverts floodwater from non-permanent rivers into a series of flat basins which are used for cropping.
sand	A soil separate consisting of particles between 0.05 and 2 mm in diameter.
saturated soil	When the total pore space of the soil is filled with water.

sheet erosion Erosion caused by sheet flow.

sheet flow When water runoff flows over compacted or waterlogged soil in a "sheet", producing a relatively even distribution of runoff over the land surface which follows the slope of the land downwards.

silt A soil separate consisting of particles between 0.05 and 0.002 mm in diameter.

soil depth The depth of the solum, which refers to all the horizons present in the soil, irrespective of whether these horizons allow for the penetration of plant roots or not.

soil horizons Layers in the soil which have developed through processes which take place within the soil.

soil profile A vertical cross-section through the soil which shows its horizons.

soil structure Soil structure describes the grouping or arrangement of primary particles (sand, silt, clay and organic matter) into larger, secondary particles called aggregates or peds (i.e. the shape that soil takes, determined by the way in which individual soil particles clump or bind together).

spring A source of water that flows out of the ground as a small stream or pool.

stomata Small openings in the leaves of plants which take up carbon dioxide from the atmosphere.

stone bund A low wall of stone which is constructed along a contour line to slow down, filter and spread out runoff water.

sublimation The process in which a substance (such as water) is converted from a solid directly into a gas.

subsistence farming Farming that generates only enough produce to feed the farmer's family.

subsoil The naturally compacted soil found beneath the less compacted topsoil.

surface water Water that is open to the atmosphere (springs, streams, wetlands, rivers, dams, lakes and oceans).

sustainable Having the capacity to endure over time.

swale A furrow with a low ridge on its down-slope side, constructed along the contour of a hillside.

system A group of interacting and interdependent elements which together form a complex whole.

terrace A level strip of soil built along the contour of a slope and supported by an earth or stone bund.

terrarium	A sealed container in which a simulated natural environment is created.
tied ridge	Shallow basins designed to collect runoff and make it available to crops planted on either side of the furrows.
topography	The physio-geographic characteristics of the land in terms of elevation, aspect and slope.
topsoil	The upper layer of the soil (the A-horizon), consisting mainly of mineral particles and organic matter.
transpiration	The evaporation of water from parts of a plant, particularly its leaves.
trench bed	A soil bed created on a trench which is filled with layers of organic matter mixed with subsoil.
unconfined aquifer	An aquifer which has the water table as its upper boundary.
virtual water	The water that is used to grow, manufacture and package food and consumer products.
water catchment	An elevated area of land down which water drains to a particular endpoint.
water conservation	The protection, development, and efficient management of water resources for beneficial purposes.
water content (soil)	The water held in the soil.
water cycle	The movement of water from the atmosphere to and across the earth's surface and back into the atmosphere.
water harvesting	The process of concentrating rainfall as runoff from a larger catchment area to be used in a smaller target area.
water table	The level below which the ground is saturated with water.
water-holding capacity	The ability of a soil to hold water, measured as the amount of water held between field capacity and wilting point.
watershed	Geographical barriers such as ridges, hills or mountains which separate water catchments.
wetland	An area of land where the soil is permanently or seasonally saturated with water.
wilting point	The soil water content once plants have extracted all the water they can from the soil.

BIBLIOGRAPHY AND ADDITIONAL RESOURCES

1. INTERNET RESOURCES

Further information on water harvesting and conservation planning and methods can be accessed on the internet by going to the website links which are shown. The documents that are listed will be found there and can be read online or downloaded for future reference.

Website: http://www.fao.org/docrep/U3160E/u3160e07.htm#5.7%20contour%20stone%20bunds
Document: *Water Harvesting Techniques* (FAO, Natural Resources Management and Environment Department, 1991)

Website: http://dot.tucsonaz.gov/stormwater/downloads/2006WaterHarvesting.pdf
Document: *Water Harvesting Guidance Manual.* (City of Tuscon, 2005)

Website: http://www.fao.org:80/docrep/U3160E/u3160e00.HTM
Document: *Water Harvesting. A Manual for the Design and Construction of Water Harvesting Schemes for Plant Production.* Critchley, W. & Siegert, K. (FAO, 1991)

Website: http://www.fao.org/docrep/U3160E/u3160e0a.htm
Document: *Water Harvesting: Simple Surveying Techniques.*

Website: http://ohioline.osu.edu/hyg-fact/1000/1083.html
Document: *Mulching Landscape Plants.* Ohio State University Extension Fact Sheet. Horticulture and Crop Science (Rose, M.A. & Smith, E.).

Website: http://www.cprl.ars.usda.gov/wmru/pdfs/Jones-Baumhardt-Furrow%20Dikes-Ency%20Water%20Sci.pdf
Document: *Furrow Dikes* (Jones, O.R. & Baumhardt, R.L., 2003)

Website: http://www.oasisdesign.net/greywater/misinfo/index.htm
Document: *Common Grey Water Errors and Preferred Practices* (Ludwig, A. 2009)

The following websites are dedicated to water harvesting and conservation:

Website: http://www.harvesth2o.com/
Website Name: HarvestH$_2$0.com
Website Description: An online rainwater harvesting community.

Website: http://blog.rainwaterrecovery.com/?tag=conservation
Website Name: Rainwater Central

Website Description: Rainwater harvesting and management news and links to resources.

Website: http://worldagroforestry.org/projects/searnet/
Website Name: Searnet. Southern and Eastern Africa Rainwater Network
Website Description: Rainwater harvesting information and resources.

2. BOOKS AND DOCUMENTS

Anschütz, J., Kome, A., Nederlof, M., de Neef, R. & van de Ven, T. 2003. *Water harvesting and soil moisture retention.* Agrodok-series No.13. Agromisa Foundation, Wageningen.

Denison, J. & Wotshela, L. 2008. *Indigenous Water Harvesting and Conservation Practices: Historical Context, Cases and Implications*. Water Research Commission: WRC Report No. TT 392/09, April 2009.

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Oweis, T., Hachum, A. & Kijne, J. 1999. *Water harvesting and supplementary irrigation for improved water use efficiency in dry areas.* SWIM Paper 7. Colombo, Sri Lanka: International Water Management Institute.

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Stimie, C., de Lange, M., Kruger, E., 2009. *Agricultural Water Management for Homestead Farming.* South Africa: Water Research Commission.

Worm, J., van Hattum, T., 2006, *Rainwater Harvesting for Domestic Use,* Agromisa and CTA, Wageningeng, the Netherlands.

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water harvesting and conservation

Farmers Handouts

WATER RESEARCH COMMISSION

UMHLABA CONSULTING GROUP

INTRODUCTION TO THE FARMERS' HANDOUTS

These farmers' handouts are for use by WHC facilitators when working in the field with farmers and gardeners. They aim to present the practical information that resource-poor farmers will need in order to implement water harvesting and conservation techniques. The intention is that the facilitator can photocopy the pages of relevant techniques and leave these with the farmers for their later reference.

Importantly, referencing of information sources has been omitted in these handouts, but is fully included in the main document (Chapter 7 of the Technical Manual).

CONTENTS

DIVERSION FURROWS

Diversion furrow leading to a catchpit

also called:	used in:	
• feeder channels • trenches • run-on ditches • ex-field RWH	gardens	✓
	fields	
	grazing land	

A diversion furrow directs rainwater runoff from gullies, grasslands or hard surfaces (such as paths or roads) to a cropped area or to a storage tank. If a diversion furrow is in an area of heavy foot traffic, it can be filled with a porous material such as gravel so that it does not become a tripping hazard.

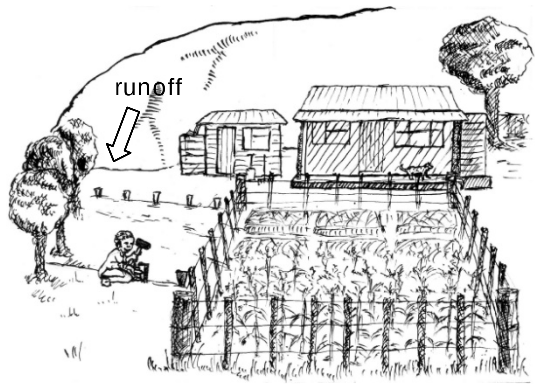
Diversion furrow leading to trench beds

Diversion furrow leading to a trench bed

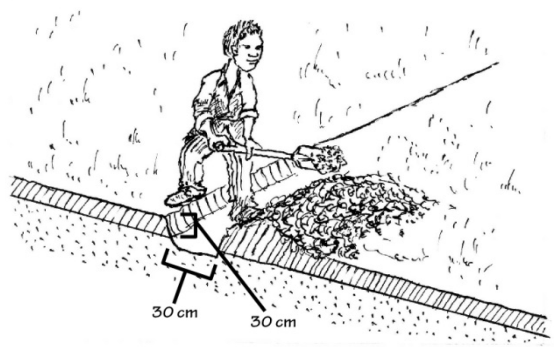
Soil	Slope	Rainfall	Tools & Equipment
Any soil. Where soils erode easily and on steep slopes, the diversion furrow should slope gently downwards to avoid erosion.	Any slope. On steeper slopes, care must be taken to prevent erosion.	Any rainfall. In higher rainfall areas, measures to prevent erosion may be needed.	spade* pegs and string A-frame **essential*

METHOD

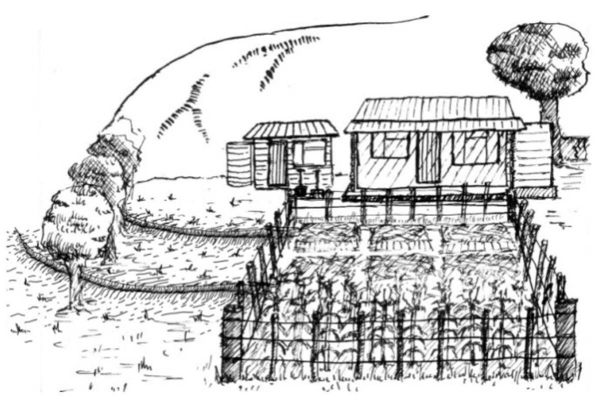
1. Look at the ground when it rains to see where the rain water runs, and decide which of this water you want to divert. Mark out a route for your furrow which will intercept this water and carry it to the garden, field or storage tank.



2. Dig a trench about 30 cm wide and 30 cm deep. Put the soil on the downslope side of the trench.



3. Make sure that the furrow leads into the rainwater harvesting method being used in the field or garden. In the case of a tank, the furrow will typically lead into a small catchpit which traps sediment and debris so that it does not enter the tank.



MULCHING

Mulch placed on a plant bed

also called:	used in:	
• –	gardens	✓
	fields	✓
	grazing land	

Mulching is the practice of spreading plant and other organic material such as compost, straw, manure, dry leaves, dry grass clippings and wood chips onto the surface of the soil, usually concentrated around plants.

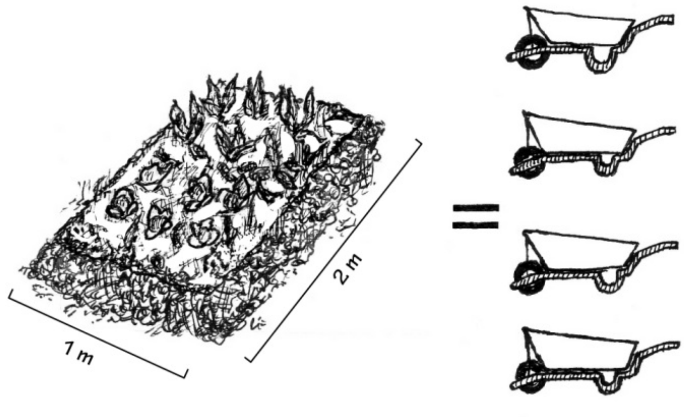
Thatching grass can be used as mulch

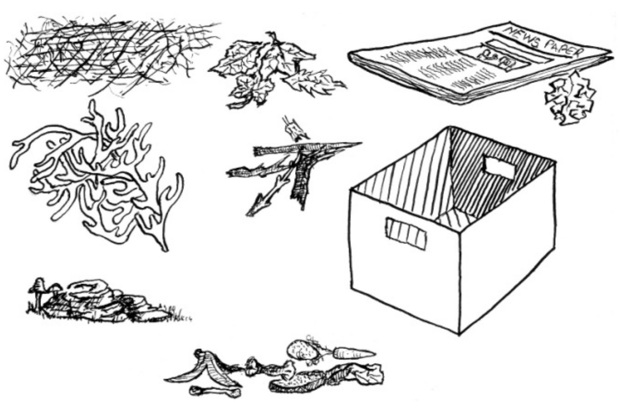
Mulch increases water infiltration and reduces evaporation. It protects the soil from erosion, reduces compaction from heavy rains, prevents weed growth and helps the soil maintain an even temperature. As mulch slowly decomposes it provides organic matter to the soil, which improves root growth and increases the water-holding capacity of the soil. The organic matter is also a source of plant nutrients and provides an ideal environment for earthworms and other beneficial organisms. This method is almost always used in combination with other WHC methods such as trench beds and planting pits.

Soil	Slope	Rainfall	Tools & Equipment
Any soil type. On clay soils or soils prone to waterlogging, mulching thickness should be limited to less than 10 cm.	Any slope.	Any rainfall.	organic material* (e.g. dry grass, leaves, compost, straw, manure, egg cartons) fork wheelbarrow **essential*

METHOD

1. Look at the total area you plan to mulch and estimate how much mulch you need (about 2 wheel-barrows of mulch per square meter of garden).





2. Collect the organic materials you plan to use as mulch, and spread it carefully over the soil, around and between plants.

3. When placing the mulch, ensure that it is a few centimetres away from all trunks and stems so that you don't provide a place for insects or diseases to begin attacking the plants.

FERTILITY PITS

also called:	used in:	
• banana circle • circular swale	gardens	✓
	fields	
	grazing land	

This method enables runoff water to be captured and conserved in pits that are filled with organic matter, such as compost or manure. The organic matter increases the fertility of the soil and minimises the loss of water from evaporation.

Plants, particularly those which require a lot of water (such as bananas and paw-paws), are grown in or around the pits, where they benefit from the moist and fertile soil.

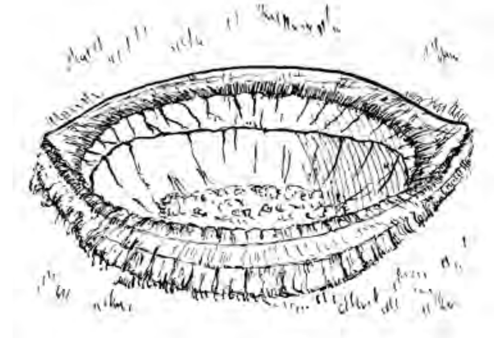
A fertility pit filled with organic material

A fertility pit being prepared

Soil	Slope	Rainfall	Tools & Equipment
Any soil type (the organic material will improve any soil).	Up to 25%.	Any rainfall.	spade* organic materials* (mulch, compost, manure) trees * (e.g. bananas, paw-paws) plants (e.g. sweet potato, beans, ginger, lemon grass, taro, yams, comfrey) **essential*

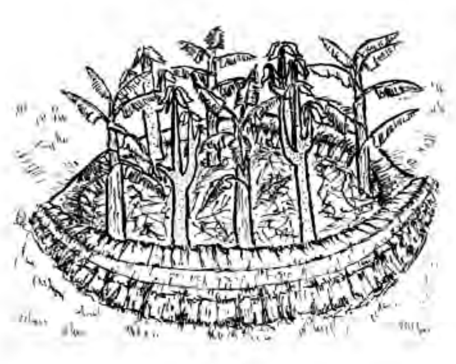
METHOD

1. Decide where the pit should be. Mark out a circle about two metres across and dig down about 1 metre. The pit should be concave (shaped like a bowl). Put the soil you have dug out around the edge of the pit.

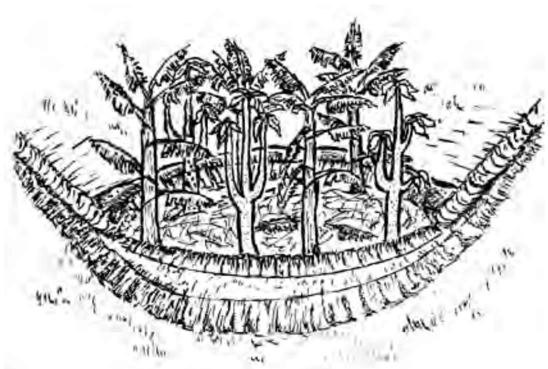


2. Shape the soil around the edge of the pit to form a ridge or mound. If the pit is on a slope you can dig diversion furrows to direct runoff into the pit (see step 5 below).

3. Fill the pit with organic material, placing the most coarse materials at the bottom. You can overfill the pit because the materials will sink over time.



4. Plant trees and plants around the rim of the mound. Space the trees so that they have enough room for growth and place plants between the trees.



5. Use the fertility pit as a compost heap, and construct a diversion furrow to direct any excess runoff into the pit.

SWALES

also called:	used in:	
• bunds • contour ridges • berm 'n basin • contour ditches	gardens	✓
	fields	
	grazing land	

A swale is a furrow with a low ridge on its down-slope side, made along the contour of a slope. The swale catches water runoff, spreads it out and helps it sink into the ground.

Usually permanent crops like fruit trees are planted just below the ridge of the swale, while seasonal crops like vegetables are planted between the swales. Over time, seeds and organic matter accumulate on the ridge of the swale, causing vegetation to grow, which stabilizes the ridge. The ridges can also be planted with long-living plants such as comfrey, marigolds, nasturtiums or grasses.

Swales prepared for planting

Vegetables growing on the swales

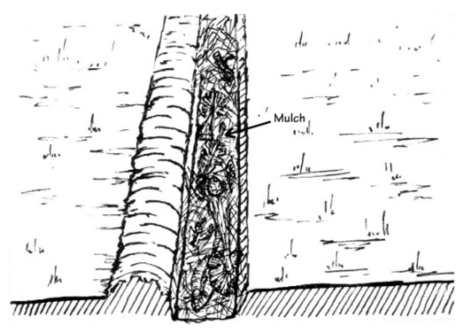
Soil	Slope	Rainfall	Tools & Equipment
Any soil. The sandier the soil, the thicker the swale should be. In clayey soil, swales can be a bit higher and narrower.	5-25%	Swales should be used with caution in areas with high rainfall (1200 mm or more) as waterlogging can occur.	spade* A-frame/line level* pegs/stakes **essential*

METHOD

1. Decide where you want to grow your crops and mark out contour lines at 5 metres apart. If the slope is steeper, the lines can be closer (up to 3 m apart).

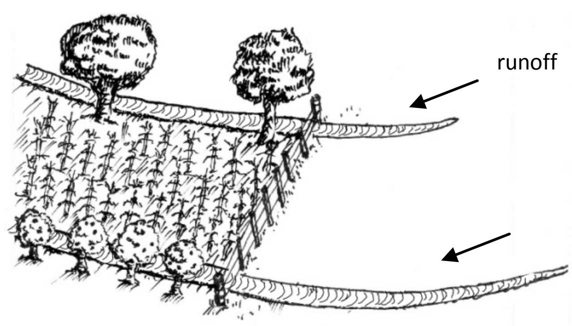
2. Dig a shallow furrow along each contour line (30-40 cm deep and 50 cm wide) and put the soil on the down-slope side of the furrow.

3. Use the soil you have dug out to make a ridge (30-40 cm high and 50 cm wide) on the downslope side of the furrow. Use an A-frame to make the top of the ridge level. Walk along the ridge and stamp on the soil to compact it.



4. Fill the furrow with mulch. Put the coarsest mulch at the bottom.

5. Plant permanent crops (e.g. fruit trees and shrubs) just below the ridge of the swale, and seasonal crops between the swales. If necessary, dig diversion furrows or extend the swales to bring additional water runoff into the planting area.



TRENCH BEDS

Trench beds in a vegetable garden

also called:	used in:	
• deep trenching • trench bed gardening • fertility trenches	gardens	✓
	fields	
	grazing land	

Trench beds create highly fertile soils which are soft and loamy and have a very high moisture-holding capacity. Trench beds are often used in combination with feeder channels (diversion furrows), which enable runoff from hard surfaces such as paths and roads to run into the trenches.

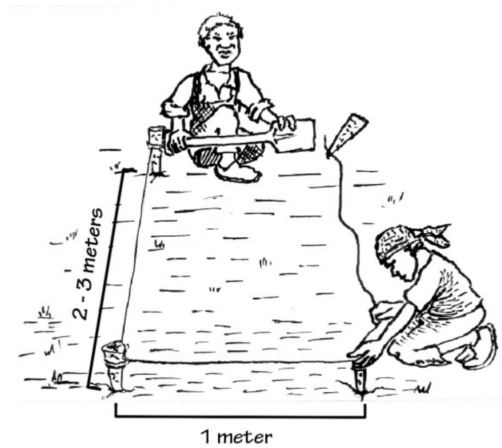
hard surface

furrows/feeder channels

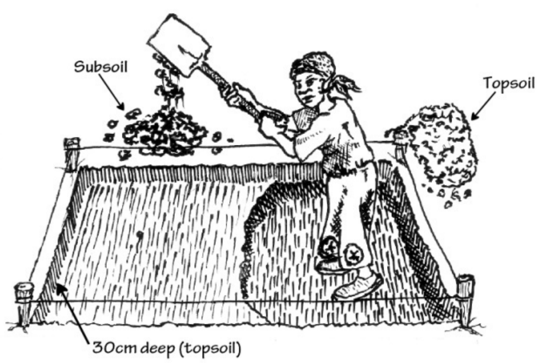
Soil	Slope	Rainfall	Tools & Equipment
Trench beds will improve any soil. Trenches should be placed where the soil is best for growing vegetables.	The length of the trenches should always be along the contour of a slope to stop the soil being washed away by rain. Where slopes allow, the length of the trenches should run from east to west.	Suitable for all rainfall areas. In dry areas, plants will need to be given extra water. In high rainfall areas, the use of feeder channels may need to be limited.	spade* fork string sticks organic material* compost wheelbarrow *essential

METHOD

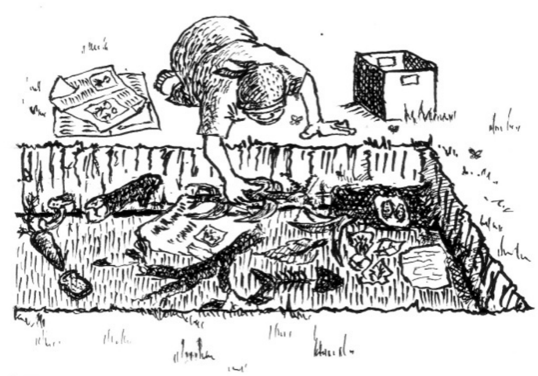
1. Choose a place suitable for growing vegetables and clear the ground of rocks, bushes and grass. Keep this plant material to use for filling and mulching the trench bed.



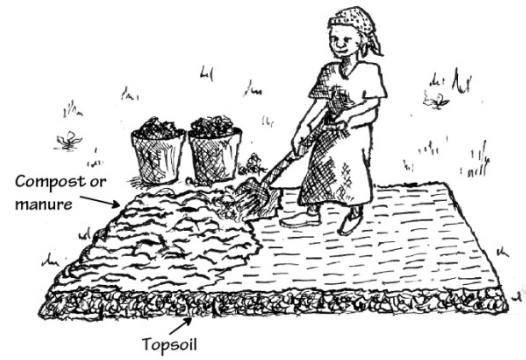
2. Mark out the trench bed using sticks and string. The bed can be any length, but it should not be more than 1 meter wide so that all gardening can be done from the pathway. A good size for a trench bed is 1 m wide by 2-3 m long.



3. Dig out the topsoil (about 30 cm deep) and put it on one side of the bed. Then dig out the subsoil until the trench is 1 meter deep. Put the subsoil on the other side of the bed. *Do not mix the topsoil with the subsoil.*

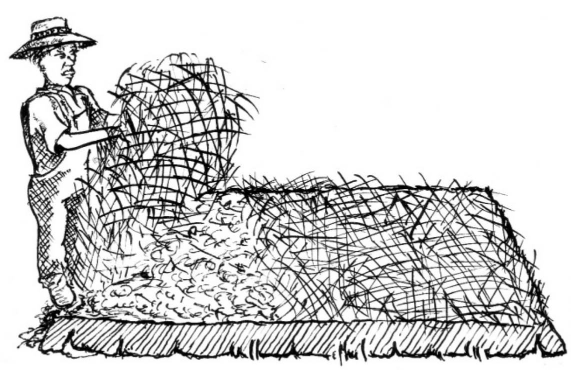


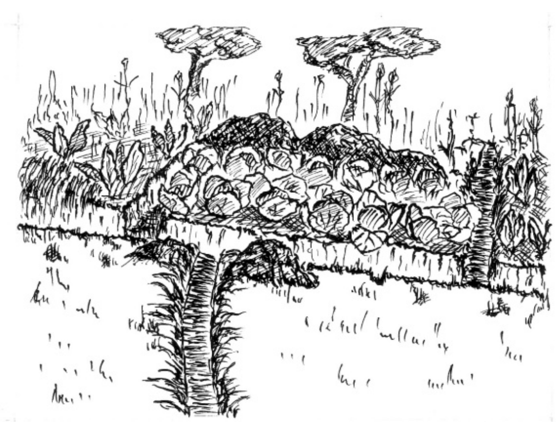
4. Use a garden fork to loosen the ground at the bottom of the trench. Put a 20 cm layer of coarse organic material at the bottom, and cover it with about 10 cm of subsoil. Use the fork to mix these layers together, and water well.



5. Carry on adding layers of organic material (approximately 20 cm)and subsoil (10 cm) until the trench is full. Water each layer well.

6. Put the topsoil on top of the trench. If you have compost or manure, add this to the topsoil and mix it together well (2-3 buckets per trench). Use a rake or flat piece of wood to make the bed flat.





7. Cover the bed with a layer of mulch and leave it for a week or two before planting. If you want to plant straight away, add chicken manure to the bed (1 litre of manure per bed) to increase the nitrogen content of the soil.

8. Dig shallow trenches from hard surfaces (e.g. paths and roads) to the trench bed so that rainwater will run into the trench when it rains.

TIED RIDGES

also called:	used in:	
• infield RWH	gardens	✓
• partitioned furrows	fields	✓
• cross-ridges	grazing land	
• furrow dikes		

Tied ridges increase the water that is available to plants by collecting rainfall from unplanted sloping basins and catching it in furrows and ridges. Planting takes place on either side of the furrows, where the water infiltrates. Basins are made by digging out shallow furrows along the contour lines of the slope and making ridges on the downside of the furrows. These are "tied" together by slightly lower ridges which are made at regular intervals along the furrows. The loss of water through evaporation is minimised by placing mulch in the furrows.

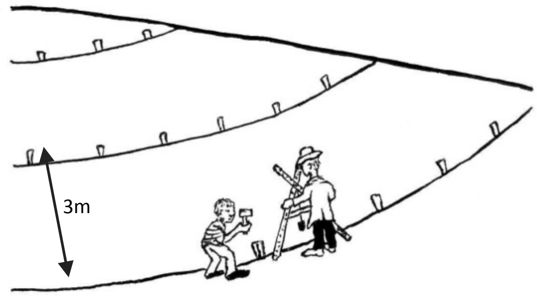
Water is trapped in a furrow

Mulch is put in furrows to minimise evaporation

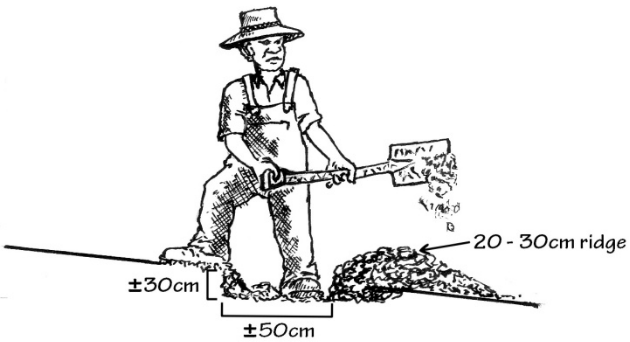
Soil	Slope	Rainfall	Tools & Equipment
Soil depth of 700-1000 mm. Soils should be quite stable. The best soils are clay, or soils with a relatively permeable topsoil over a less permeable subsoil.	Up to 7% on soils which do not erode.	Annual rainfall of 400-700 mm.	spade* fork tape measure string sticks mulch wheelbarrow **essential*

METHOD

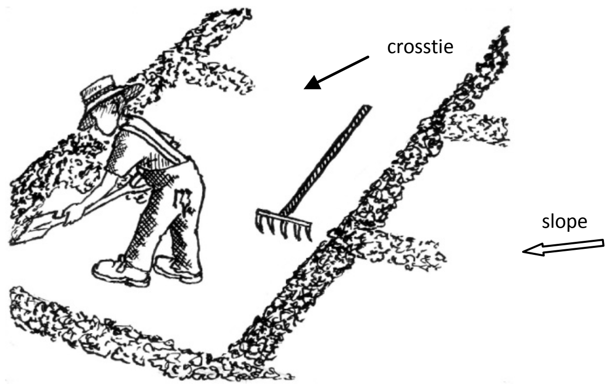
1. Choose a site and clear the ground of rocks, bushes, grass and weeds.



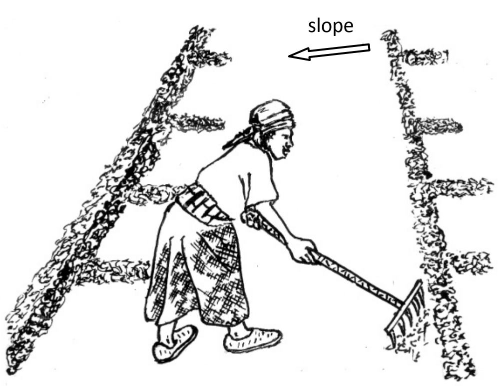
2. Mark out contour lines on the slope, at three meters apart.



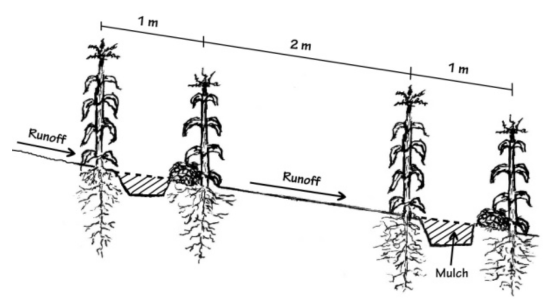
3. Dig a shallow furrow (about 50 cm wide and 30 cm deep) along each contour and put the soil on the down-slope side of the furrow to create a ridge (about 20-30 cm high).



4. Create crossties (ridges which are 15-20 cm high) every 3 meters. Ties must be lower than the main ridges so that water never flows over the ridges.

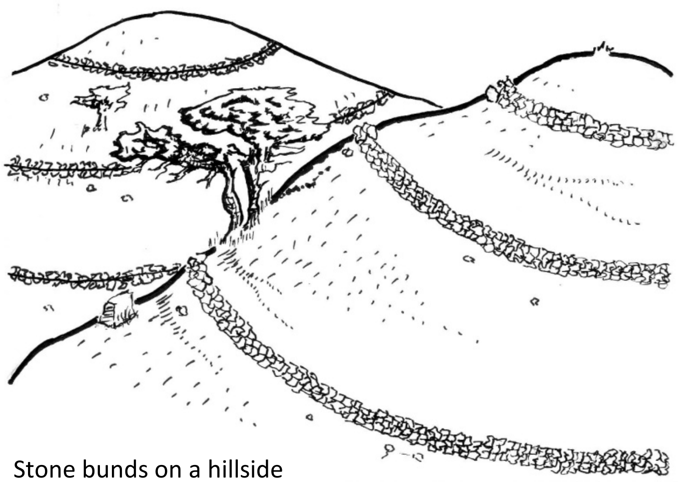


5. Use a rake or plank to level out each basin, as this is the water catchment area. Put mulch in the furrows if possible.



6. Plant in two rows , one on either side of the ridge and furrow.

STONE BUNDS



Stone bunds on a hillside

also called:	used in:	
• stone lines • stone banks • contour stone bunds	gardens	✓
	fields	✓
	grazing land	✓

Stone bunds are used along contour lines to slow down, filter and spread out runoff water, thus increasing infiltration and reducing soil erosion. Over time sediment, which is captured on the higher side of the bunds, accumulates to form natural terraces.

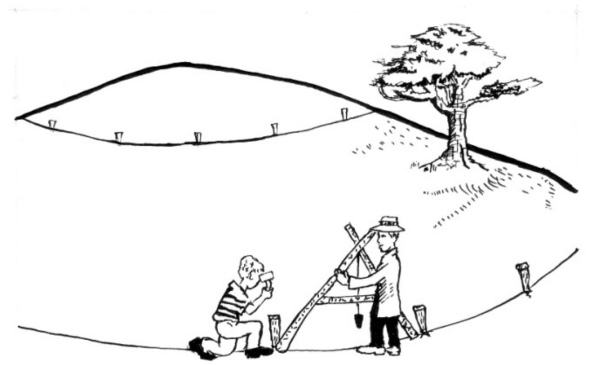
Natural terraces which have formed from an accumulation of sediment

Stone bunds being maintained

Soil	Slope	Rainfall	Tools & Equipment
Any soil.	0.5 to 3%, preferably below 2%	200-750 mm (dry to semi-dry areas)	stones of different sizes* wheelbarrow* spade **essential*

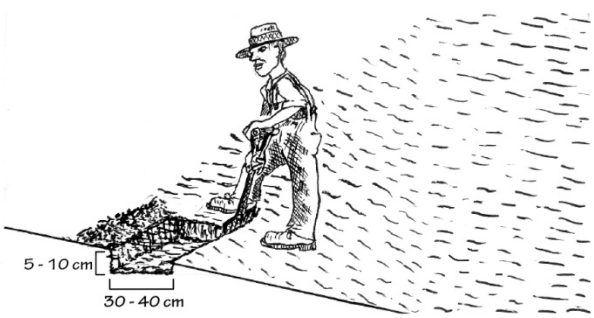
METHOD

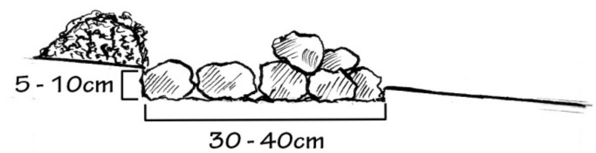
Slope	Spacing of bunds
<1%	20 m
1-2%	15 m
2-5%	10 m



1. Work out the slope to see how far apart the bunds should be and decide how many bunds you want to make.

2. Mark out each contour line using an A-frame or line level. You can adjust the pegs slightly so that the lines form a smooth curve.





3. Dig a shallow trench along the contour line (5-10 cm deep, and 30-40 cm wide). Put the soil upslope of the trench.

4. Put large stones along the bottom of the trench and on the down-slope side to create an "anchor line."

5. Put smaller stones on the up-slope side, and use them to fill any gaps between the larger stones. Leave the excavated soil on the upside of the stone bund.

6. Maintain the bunds by replacing any stones which become dislodged after heavy rainfall.

GREYWATER HARVESTING

also called:	used in:	
• greywater recycling	gardens	✓
	fields	
	grazing land	

Greywater harvesting is the practice of directing greywater to the root zone of the soil. Greywater is all waste water produced in a household ***except*** for toilet water. This includes the water used for bathing, washing, cooking and rinsing. Wastewater from toilets is called blackwater, and this should always go into a sewer or septic system.

Greywater gets purified naturally as it passes through the soil, so it does not need extensive chemical treatment before it can be used for irrigation. However, greywater should still be treated with an amount of caution because it usually contains grease, detergents, dead skin, food particles and small amounts of faecal matter. For this reason, the best greywater to use is bath and shower water, basin water, and the water used to wash clothes. However, water which is used to wash dirty nappies should *never* be recycled because it is likely to contain faecal matter.

Water that is used for preparing food and washing dishes is the least desirable water to recycle, because the organic matter that gets into the water is a significant source of contamination. The oils and greases which get into dishwashing water also have a negative impact on the soil, building up in it and affecting the ability of the soil to absorb water.

Most soaps and cleaning detergents contain **sodium**, which can also present a problem when greywater is used for a long period of time. Sodium builds up in the soil, damaging the soil structure and increasing its alkalinity. Sodium build-up can easily be detected by conducting a pH test.

Collecting greywater in buckets

Simple pH test kits are inexpensive and can be bought at most home and garden centres, nurseries and hardware stores. The kit usually consists of a test tube, some testing solution, a colour chart, and a set of instructions. Testing soil pH usually involves putting a sample of the soil into the tube, adding some test solution, shaking the bottle and leaving the mixture to settle. The solution in the tube will then change colour, and this can be compared with the colours on the colour chart from the kit. Matching colours indicate the pH of the soil sample.

A pH of 7.5 or above, indicates that a soil has become loaded with sodium. Any harmful effects caused by sodium can be counteracted or minimised by:

(a) spreading calcium sulfate (agricultural gypsum) over the soil (about 1 kg/30 m^2); *or*

(b) diluting the greywater with fresh water; *or*

(c) rotating greywater with fresh water, as the fresh water will help leach the soil of sodium and excess salts.

GUIDELINES FOR USING GREYWATER

Applying greywater directly onto the soil

- Use greywater as soon as possible.
- Collect greywater in buckets and carry it to where it will be used.
- Apply the greywater directly onto the soil, around plants whose edible parts grow above the ground (e.g. tomatoes, beans, mielies, fruit trees). Do not allow greywater to come into direct contact with the edible parts of food crops.
- Add mulch to areas where greywater is used to speed up the natural decomposition of waste residues.
- Alternate between applying greywater and freshwater to the soil.

PRECAUTIONS

- Never drink greywater.
- Do not store greywater for more than a day, as micro-organisms will grow and reproduce in it, making it septic.
- Do not use greywater in areas that get waterlogged easily.

TERRACES

Terraces on a hillside

A farmer standing at her terrace wall

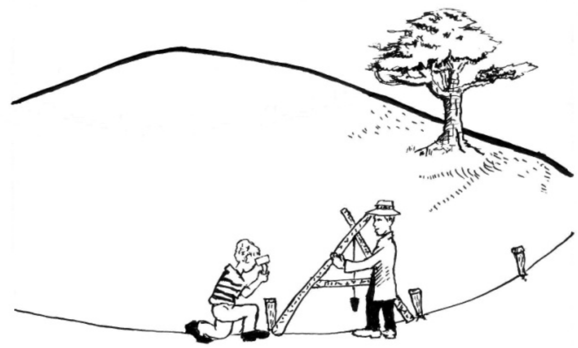
also called:	used in:	
• benches	gardens	✓
	fields	✓
	grazing land	

A terrace is a level strip of soil built along the contour of a slope and supported by an earth or stone bund. Terraces create flat planting areas and stabilize slopes which would otherwise be too steep for crop production. A series of terraces creates a step-like effect which slows down runoff, increases the infiltration of water into the soil, and helps control soil erosion. Terraces are built on steeper slopes, so there is a high risk of erosion taking place if they are not constructed correctly. To avoid erosion, each terrace must overflow sideways into a drain that is protected with rocks, branches or gabions.

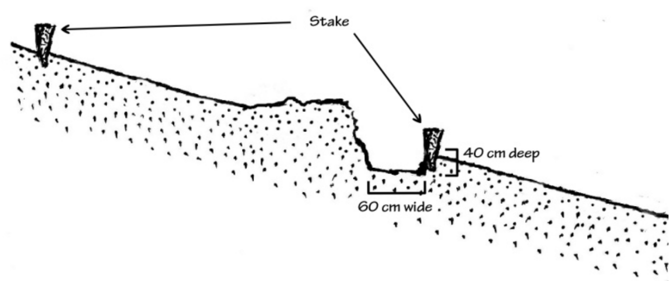
Soil	Slope	Rainfall	Tools & Equipment
Any soil, although there is need for caution in highly erodible soils, and in clay soils (which are prone to water-logging).	10-40%	Enough rainfall to grow crops.	different size stones (flat or angular stones are best)* wheelbarrow* spade* A-frame/line level* stakes/pegs and string* hammer and chisel pick-axe *essential

METHOD

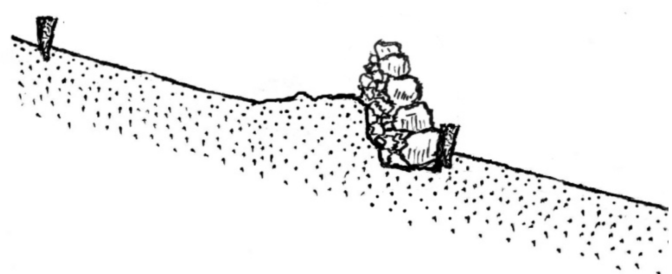
1. Calculate the slope to work out the spacing between terraces (see Table 1). Start at the bottom of the slope. Mark out the contour lines for each terrace you plan to build. If necessary, adjust the position of the pegs so that each line forms a smooth curve.



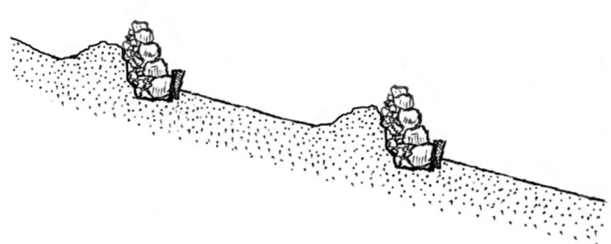
2. Dig a trench about 40 cm deep and 60 cm wide along the first contour line (see Table 1). Place the soil upslope of the trench.



3. Start building the terrace wall by putting large stones at the base of the trench. Put the biggest stones on the down-slope side to create an "anchor line" and put smaller stones on the up-slope side. Use small stones to fill gaps between the large stones. Pack the stones so that they lean back against the soil, so that the wall stays stable.



4. Move to the next contour and build the next terrace wall by repeating steps 2 and 3.



5. Level the soil excavated from the terrace foundation up against the back of the constructed wall. If you need more soil dig away the upper part of the terrace and spread it across. Make sure you don't dig more than 30 cm near to the upper wall, so that you do not undermine the foundation.

6. Use an A-frame and a rake to get the soil level. You will now have two terrace walls and a level terrace of soil between the walls. The final soil surface must be at least 10 cm lower than the terrace wall so that erosion does not take place.

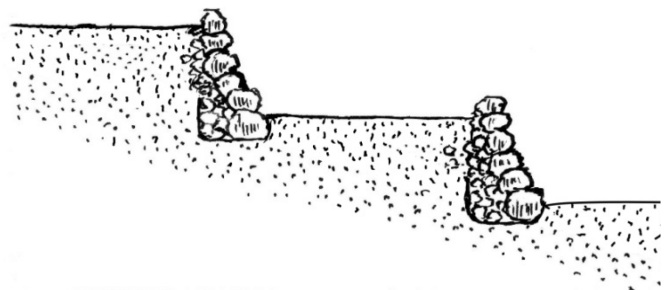
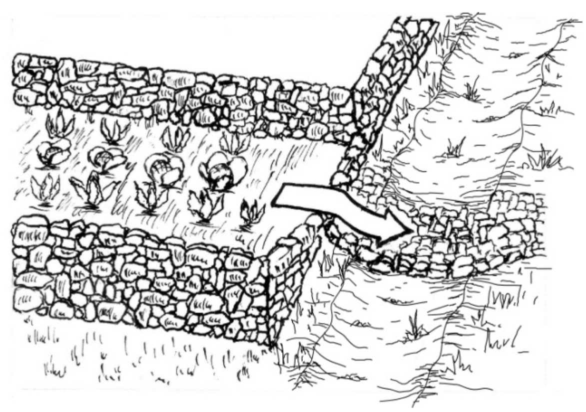


Table 1: Terrace spacing and dimensions

Slope		Distance between terraces (meters)	Terrace height above ground level (meters)	Terrace height above bottom of trench (meters)
Percent	Ratio			
10%	1:10	8.0	0.8	1.2
15%	1:6.7	5.3	0.8	1.2
20%	1:5	4.0	0.8	1.2
25%	1:4	3.2	0.8	1.2
30%	1:3.3	2.7	0.8	1.2
35%	1:2.8	2.3	0.8	1.2
40%	1:2.5	2.0	0.8	1.2

EROSION PROTECTION

During heavy rain, excess water must be able to flow out the side of the terrace. Because there is a high risk of erosion at this overflow point, it is necessary to protect the overflow with small rocks and/or grass. The water which overflows will move down a natural drainage line which, because of the steep slopes, may also need erosion protection (e.g. rock packs or brushwood walls) to avoid gullies forming.



HOW TO MAKE AN A-FRAME

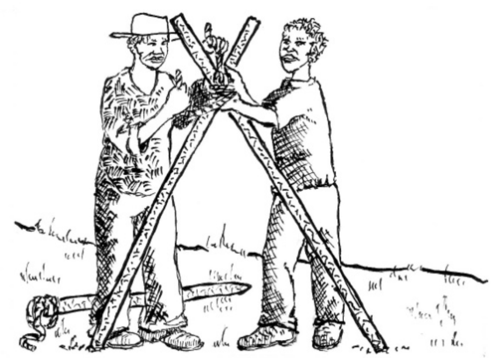
You can use an A-frame to mark out contour lines along a slope or hillside, and to measure the percentage of a slope.

MATERIALS

- 2 x 2 metre long poles
- 1 x 1.2 metre pole
- wire or strong cord (about 2 metres) *or* hammer and nails
- 1 metre of light cord *or* string
- weight (e.g. a stone or bottle)

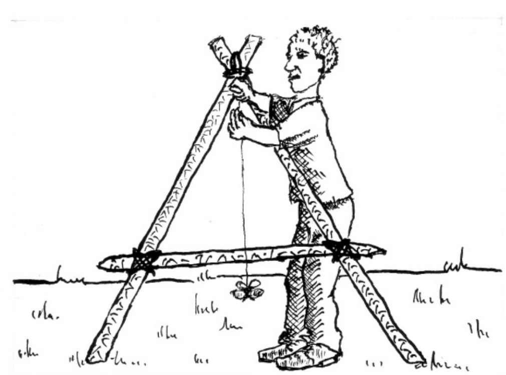
TO MAKE THE A-FRAME:

1. Connect the 2 long poles together at one end. Nail them, or use the cord to tie them together tightly. If necessary, make notches at the top of each pole where they connect to stop them from slipping.



2. Connect the shorter pole securely across the middle of the longer poles to form a figure "A". This is the crossbar.

3. Tie one end of the light cord to the top of the "A" where the two poles are joined. Tie the weight (e.g. a stone) to the other end of the string so that it hangs about 15 cm below the crossbar.



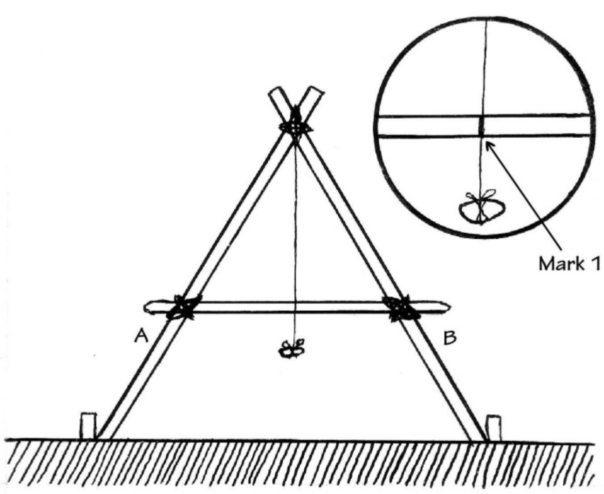
HOW TO CALIBRATE AN A-FRAME

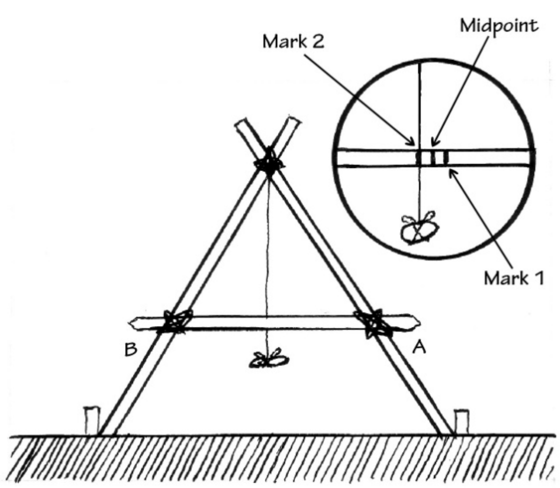
To calibrate an A-frame means to test and adjust its accuracy.

TO CALIBRATE THE A-FRAME:

1. Put the A-frame on solid ground. The ground does not have to be completely level.
2. Mark the position of the legs on the ground (A and B).
3. Let the weight settle to a natural position and make a temporary mark where the string passes the crossbar. *The string must be close to the crossbar, but the weight must hang freely.*
4. Rotate the A-frame so that the position of the legs is reversed (i.e. the leg which was on spot A is now on spot B, and the leg which was on spot B is now on spot A).
5. Once again, let the weight settle to a natural position and make a temporary mark where the string passes the crossbar.
6. Exactly halfway between the two temporary marks is the level position of the A-frame. Make a permanent mark on the crossbar to indicate this position.

Calibrating an A-frame



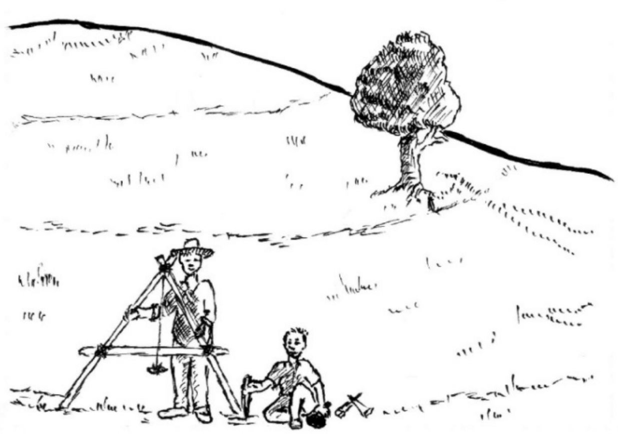


HOW TO MARK CONTOURS WITH AN A-FRAME

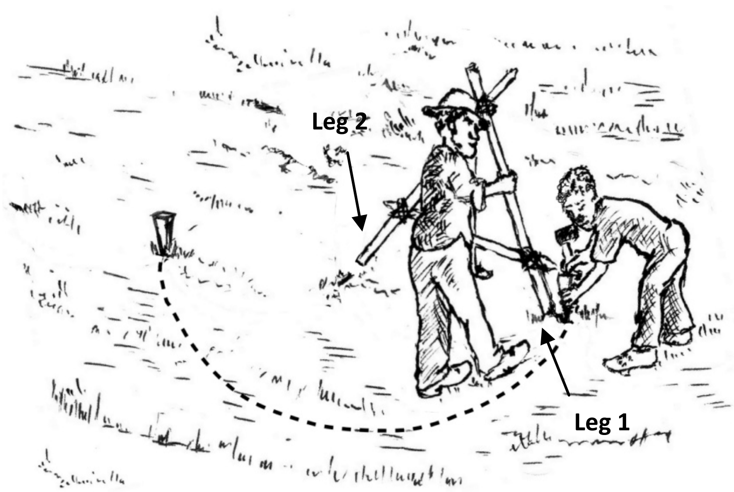
TO MARK OUT CONTOUR LINES:

MATERIALS

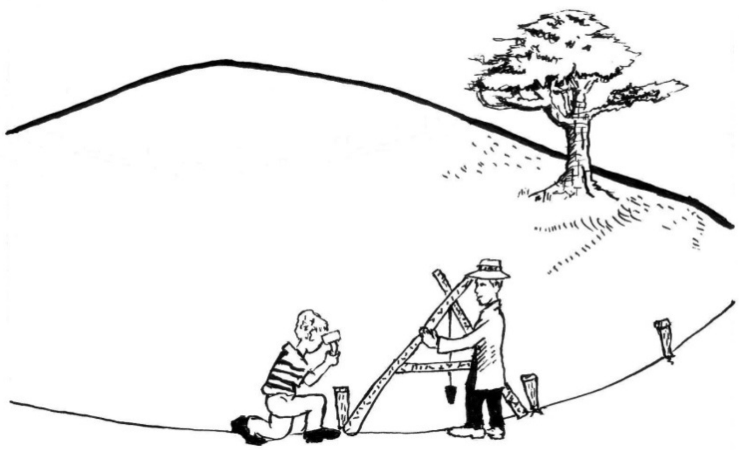
- A-frame
- sticks or rocks
- hammer (if using sticks and the ground is hard)



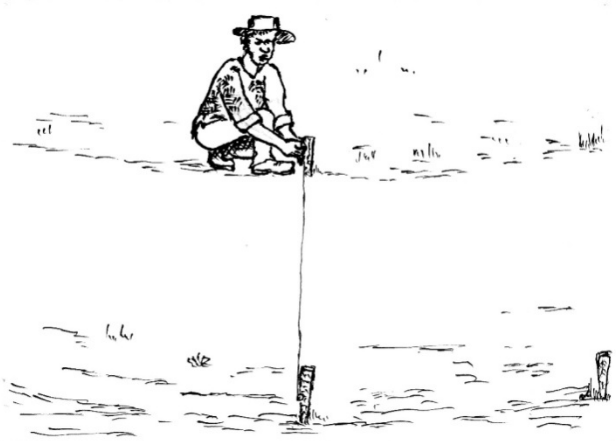
1. Start near the bottom of the slope. Put the A-frame on the ground and mark the position of Leg 1 with a rock or a stick.



2. Keep Leg 2 on the ground and swing Leg 1 in an arc along the surface of the ground until the string is in the level position marked on the crossbar of the A-frame. Tilt the top of the A-frame so that the weight hangs freely and the string is not too close or too far away from the crossbar. Mark the new position of Leg 1 with a stake.



3. Move the A-frame onto this new point and repeat the process across the slope, marking the contour line as you go. The contour line can be smoothed out by lining up the points to follow the general curve.



4. Once the contour line has been completed, stand on the line and face the top of the slope, and measure out the required distance between contours. This distance will depend on the slope and the method you are going to implement.

5. Mark out the next contour line, starting at the position you identified in step 4. Repeat this process until you have marked out all the contour lines you need.

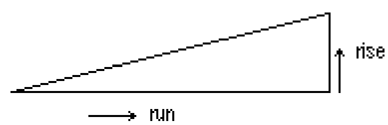
HOW TO MEASURE SLOPE WITH AN A-FRAME

MATERIALS

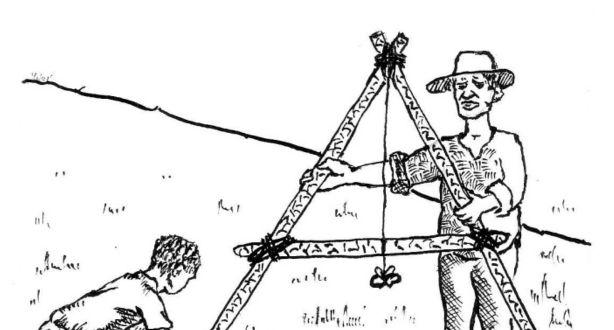
- A-frame
- tape measure
- calculator (optional)

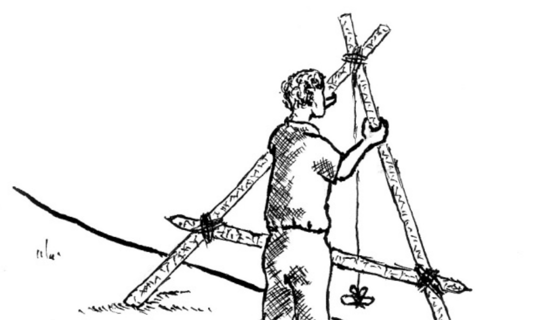
Slope is calculated using the following formula:

$$\text{Slope} = \frac{\text{rise}}{\text{run}} \times 100$$

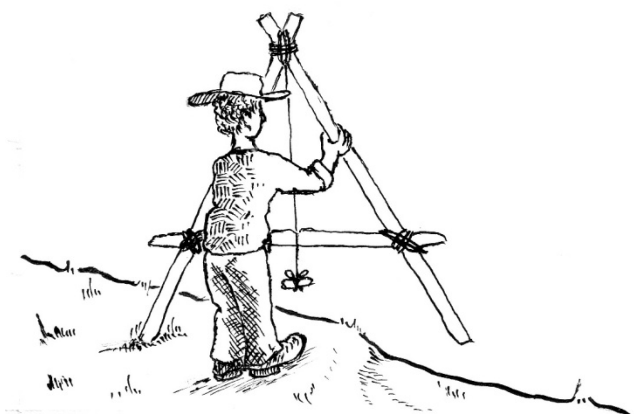


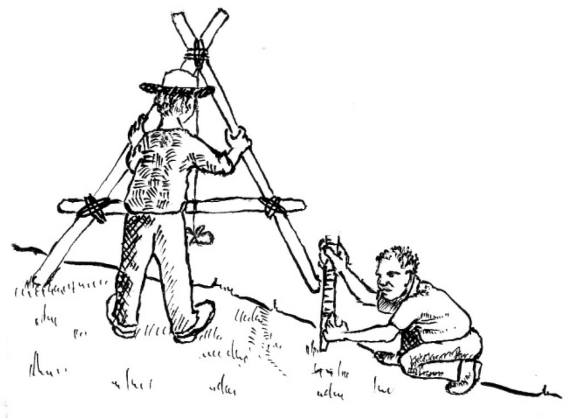
MEASURING SLOPE:





1. Measure the distance between the legs of the A-frame (the ”run”).
2. Put the A-frame on the slope, with one leg on the ground and the other going downhill. Make sure that the leg on the ground is placed as flat as possible (i.e. do not place it on a clump of soil or a stone).





3. Lift up the downhill leg until the string lines up with the level position.

4. Measure the distance between the ground and the base of the downhill leg (the "rise").

5. Use these measurements to calculate the percentage of the slope.

Example:

$$S = \frac{\text{rise}}{\text{run}} \times 100$$

$$S = \frac{80 \text{ mm}}{2000 \text{ mm}} \times 100$$

$$S = 0.04 \times 100$$

$$S = \mathbf{4\%}$$

6. To make sure that your result is as accurate as possible, repeat this process at least five times, at slightly different places on the slope. Calculate the average of these results, and use this as your slope percentage.

Example:

You measure the slope five times and get the following results:
4%, 3.8%, 4.1%, 4.2% and 3.7%

To calculate the average, add the numbers and divide by 5 (the number of results you are averaging):

4 + 3.8 + 4.1 + 4.5 + 3.7 = 20.1

20.1 ÷ 5 **= 4%** (rounded off)

HOW TO MAKE A LINE LEVEL

A line level is a tool which can be used to mark out contours and to measure slope. It is simple to make and use, and when used correctly it is very accurate. Three people are needed to use a line level.

MATERIALS

- 2 x poles of the same height (1.5 m or 2 m)
- 11 metres of string or fishing line
- a knife
- a line level

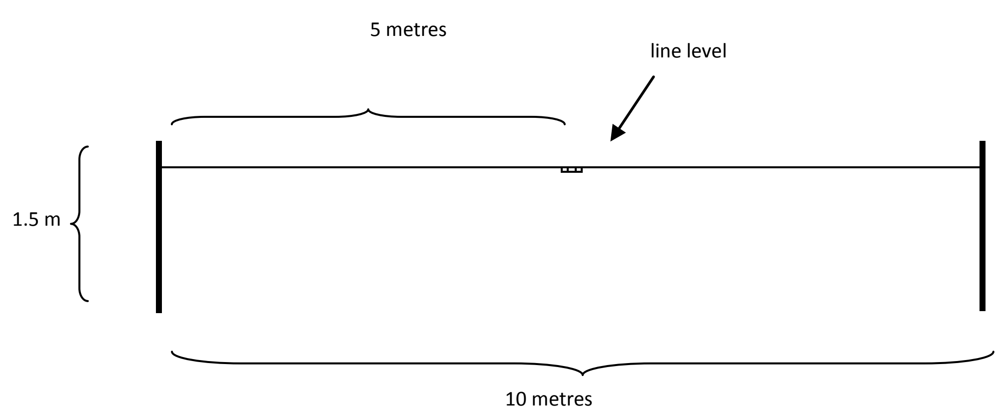
TO MAKE THE LINE-LEVEL:

1. Cut a notch in each pole at exactly the same height (e.g. 1.4 m above ground level).

2. Tie the string to the poles to connect them. Make sure that the distance between the two poles is exactly 10 meters.

3. Tie or hang the spirit level from the string exactly halfway between the two poles.

LINE-LEVEL DIMENSIONS:



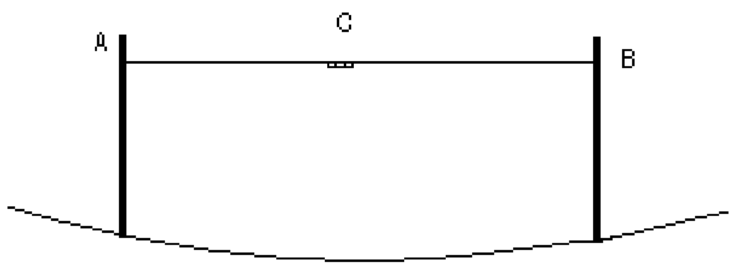
HOW TO MARK CONTOURS WITH A LINE LEVEL

Three people are needed to mark contours with a line level: Person A, Person B and Person C.

MATERIALS

- line level
- sticks or rocks
- hammer (if using sticks and the ground is hard)

TO MARK OUT CONTOUR LINES:



(Not to scale)

1, Start at the edge of the field. Person A must put his/her pole on the ground, hold it straight up and stand still, while Person B must move up or down the slope until the line level gives a level reading. Person C must stand between the poles and read the line level.

2. When the line level gives a level reading, points A and B must be marked with pegs.

3. Person A must then move to point B, and person B must move further down the field. Steps 1 and 2 should then be repeated.

<u>Note</u>: It is important that both poles are held vertically (straight up), and that neither pole is placed in a hole or on top of a minor high spot like a rock or clump of soil.

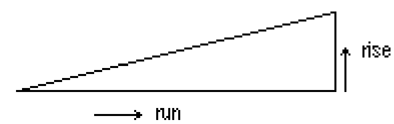
HOW TO MEASURE SLOPE WITH A LINE LEVEL

MATERIALS

- line level
- tape measure
- calculator (optional)

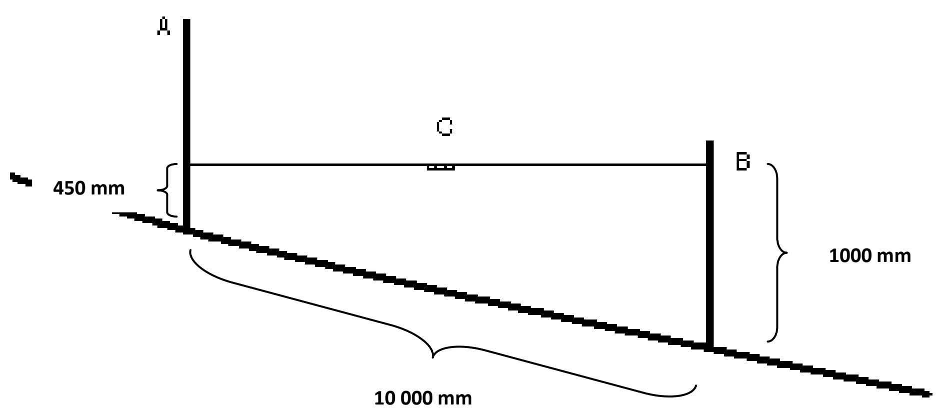
Slope is calculated using the following formula:

$$\text{Slope} = \frac{\text{rise}}{\text{run}} \times 100$$

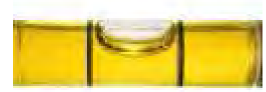


Three people are needed to mark contours with a line level: Person A, Person B and Person C.

MEASURING SLOPE:



1. Person A must stand upslope of person B and adjust the string down the pole until the line level attached between the poles gives a level reading. Person C must read the line level.



A level reading on a line level

2. The percentage of the slope can then calculated using the formula:

$$\text{Slope} = \frac{\text{rise}}{\text{run}} \times 100$$

3. The run is the distance between the two poles, which should be 10 000 mm (10 meters).

   The rise is the difference in height of the string, which is calculated by subtracting the height of the string on pole A (e.g. 450 mm) from the height of the string on pole B (e.g. 1000 mm).

4. $$\text{Slope} = \frac{1000 - 450}{10\ 000} \times 100$$

   $$= \frac{550}{10\ 000} \times 100$$

   $$= 5.5\%$$

> <u>Note</u>: *It is important that both poles are held vertically (straight up), and that neither pole is placed in a hole or on top of a minor high spot like a rock or clump of soil.*

SOIL BOTTLE TEST

This test will help you to estimate the amount of sand, silt and clay that is in a soil sample.

METHOD

1. Take a bottle and fill a third of it with the soil you want to test.
2. Pour water into the bottle until it is almost full.
3. Put a lid on and shake it well for a few minutes.
4. Leave the bottle for an hour so that the soil can settle in the water.

WHAT WILL HAPPEN

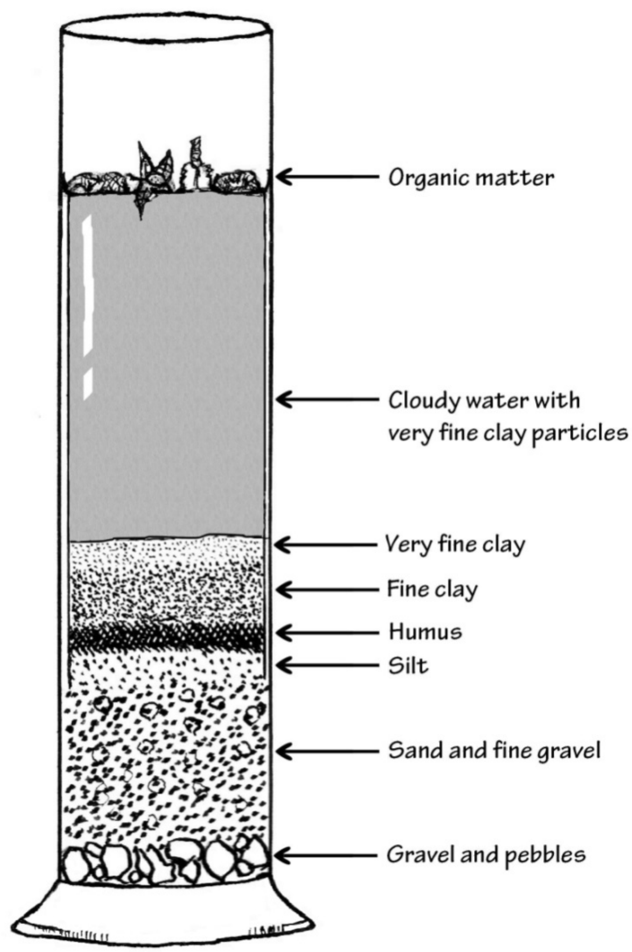
The substances will settle in layers. Each layer will have a different colour and consistency.

Heavy particles (gravel, pebbles and sand) will fall quickly to the bottom of the bottle.

Finer substances will accumulate on top of the heavy particles (silt, humus , and then the fine and very fine clay).

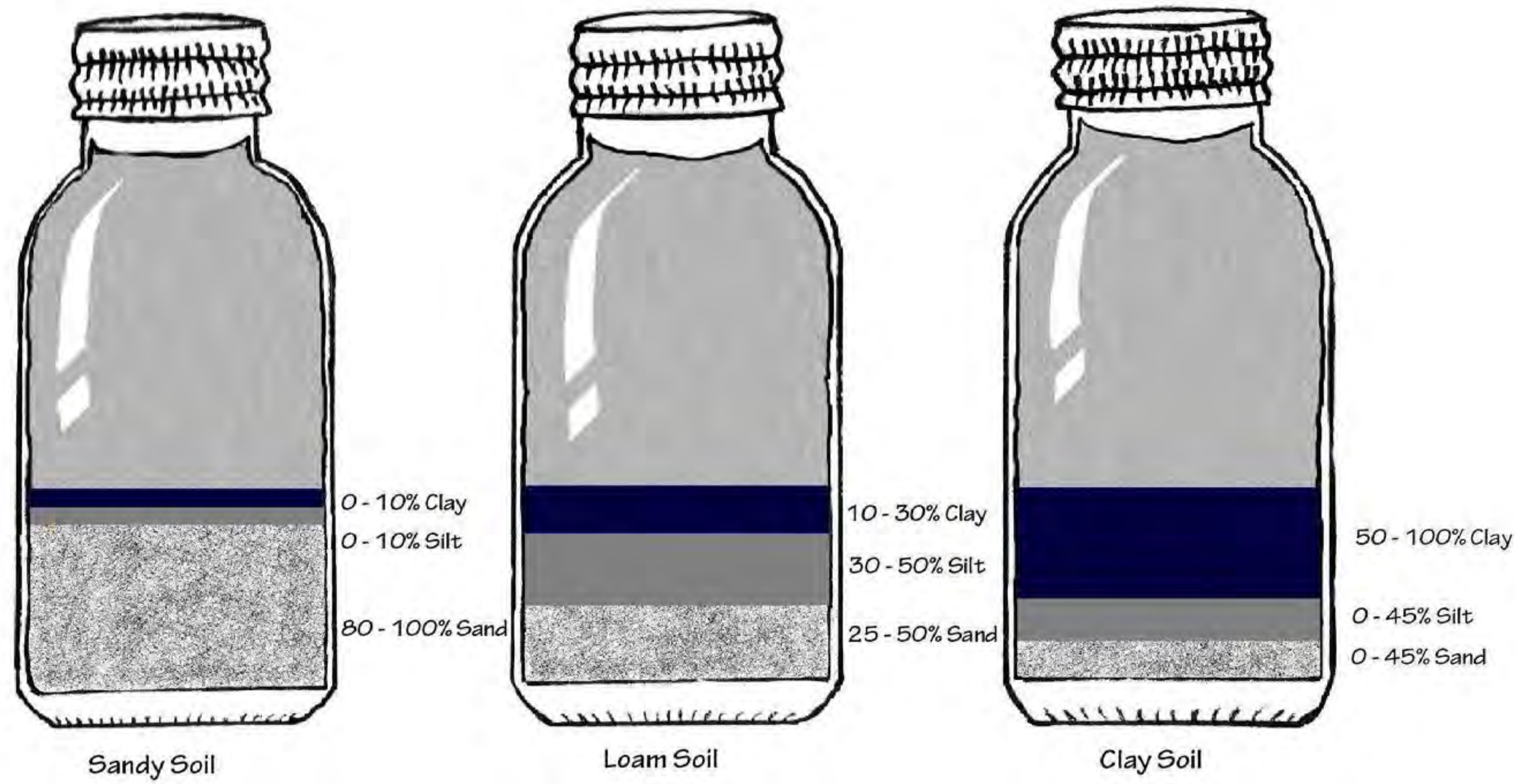
The top layer of the water will stay cloudy for a long time, because it will contain clay particles which are so small that they stay floating in the water.

Substances which are lighter than water (leaves, seeds, spores, insect and animal waste) will float on top.



IDENTIFYING THE SOIL TYPE

Once the soil has settled in the water you can use the diagram on the next page to identify the soil type. You do this by looking at the proportions of clay, silt and sand that are in the bottle.

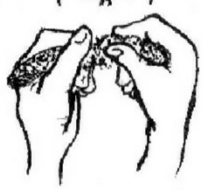
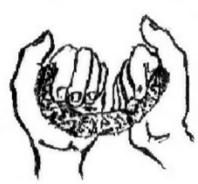
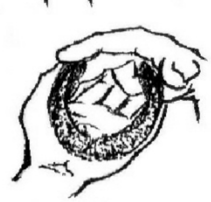

0 - 10% Clay
0 - 10% Silt
80 - 100% Sand
Sandy Soil
10 - 30% Clay
30 - 50% Silt
25 - 50% Sand
Loam Soil
50 - 100% Clay
0 - 45% Silt
0 - 45% Sand
Clay Soil

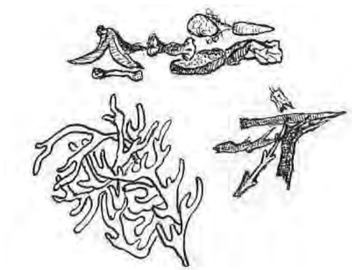
SOIL SAUSAGE TEST

This test will help you to estimate the amount of sand, silt and clay that is in a soil.

METHOD

1. Take a handful of soil, wet it and roll it into a ball between your hands.
2. Try to roll the ball into a sausage.
3. Look at the table below to identify what type of soil it is.

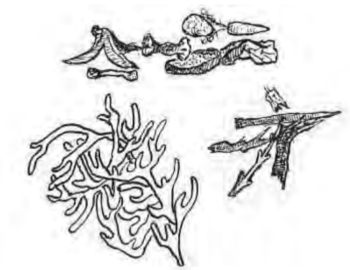
	DESCRIPTION	TYPE OF SOIL
	Soil looks very sandy and feels rough. It cannot be rolled into a sausage.	**Very sandy (0-5% clay)**
	Soil looks quite sandy and feels rough. It can be rolled into a sausage, but it cannot bend.	**Sandy (5-10% clay)**
	Soil looks half sandy and half smooth, and feels rough. It can be rolled into a sausage and can bend a little.	**Sandy loam (10-15% clay)**
	Soil looks mostly smooth. It feels a little sandy, quite smooth but not sticky. It can be rolled into a sausage which can bend about half way around.	**Loam or silt loam (15-35% clay)**
	Soil looks mostly smooth. It feels a little sandy, quite smooth and sticky. It can be rolled into a sausage which can bend more than half way around.	**Clay loam or sandy clay (35-55% clay)**
	Soil looks smooth, and feels smooth and sticky. It can be rolled into a sausage which can bend into a circle.	**Clay (more than 55%)**



ORGANIC MATERIAL

Organic material is any dead plant or animal matter, in any stage of decomposition.

COMPOST	MULCH	TRENCH BEDS & FERTILITY PITS
• fruit and vegetable scraps • egg shells • bones • feathers • hair • wood chips • tree bark • straw • ash • seaweed • coffee grounds • mielie cobs and stalks • weeds • animal manure • paper products (e.g. cardboard, egg cartons, newspaper) • garden waste (e.g. branches, sticks, pine cones and needles, leaves, grass cuttings) • natural fibres (e.g. old cotton clothes & wool)	• compost • animal manure • tree bark • wood chips • straw • dry grass and leaves • seaweed • paper products (cardboard, egg cartons, newspaper, etc.) • natural fibres (old cotton clothes, old wool, etc.) • sticks and branches	Coarse materials: • sticks, branches • plant residues (e.g. mielie cobs and stalks, banana leaves) Other: • garden waste (e.g. weeds, pine cones and needles, leaves, grass cuttings) • paper products (e.g. egg cartons, cardboard, newspaper)



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