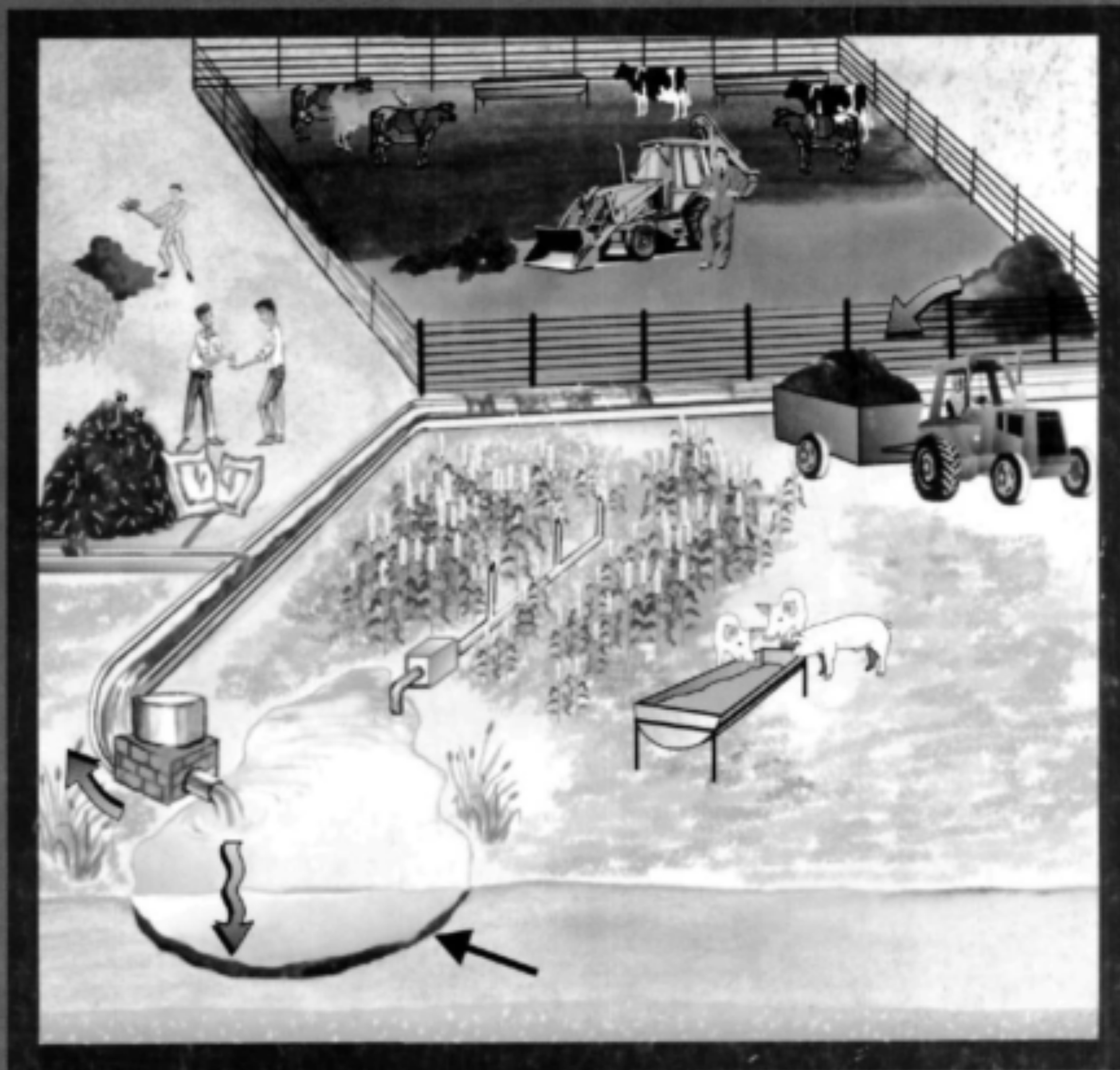
HANDBOOK OF GROUNDWATER QUALITY PROTECTION FOR FARMERS



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HANDBOOK OF GROUNDWATER QUALITY PROTECTION FOR FARMERS

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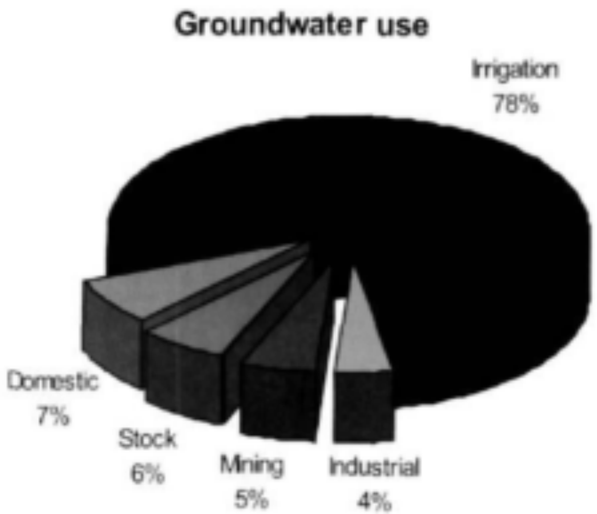
INTRODUCTION

Groundwater is a resource which is vital to much of the agricultural sector. Farmers use an estimated **90%** of groundwater abstracted in South Africa. It is farmers who are therefore most at risk from deterioration of groundwater quality. In many areas groundwater is the only source of water. It is used for irrigation, stock watering and as drinking water.



As well as being the most important consumers of groundwater, farmers are also the custodians of this resource. Groundwater is recharged by water infiltrating through the soil. The activities of farmers can significantly affect the quantity and the quality of this recharge water.

The term **groundwater quality** refers to the water chemistry and micro-organisms living in it. Groundwater naturally contains many dissolved substances like calcium and chloride. Soluble materials that are applied to the land may also be transported into the aquifer and some of these are harmful to health and/or the environment.

This booklet aims to inform farmers about practical measures they can take to minimize the risk of contaminating groundwater. It summarizes research that has been carried out in South Africa and overseas to determine how farming is affecting groundwater quality. A background to groundwater is given at the beginning of this booklet, plus information on **nitrate** which is the most common contaminant from agriculture. Different agricultural activities are discussed in subsequent chapters, with potential risks highlighted. **Good farming practices** appropriate to South African agriculture have been outlined to enable farmers to protect their resource.

Some of the most far-reaching measures to protect groundwater quality are also practical and cost-effective because they reduce long-term losses of fertilizers, water or pesticides. By protecting groundwater quality, farmers keep it fit to drink and to apply to land. The risks of disease to people and livestock, and the risk of fouling surface waters are minimized.

Examples of good farming practices are:

- Efficient irrigation and fertilizer scheduling to match crop requirements and minimize wastage.
- Avoid leaving bare ground and use cover crops, particularly during periods of rainfall.
- Consideration of additional sources of nitrate in the soil, manure and irrigation water when estimating fertilizer requirements.
- Maintenance of an impermeable interface layer in feedlot pads.
- Monitoring groundwater levels and quality regularly to detect any changes.

All farmers can learn more about the impact of their activities from this booklet. Those activities most likely to cause contamination are associated with modern, high intensity farming. Typically these require the use of fertilizers, pesticides and irrigation or produce significant quantities of animal waste.

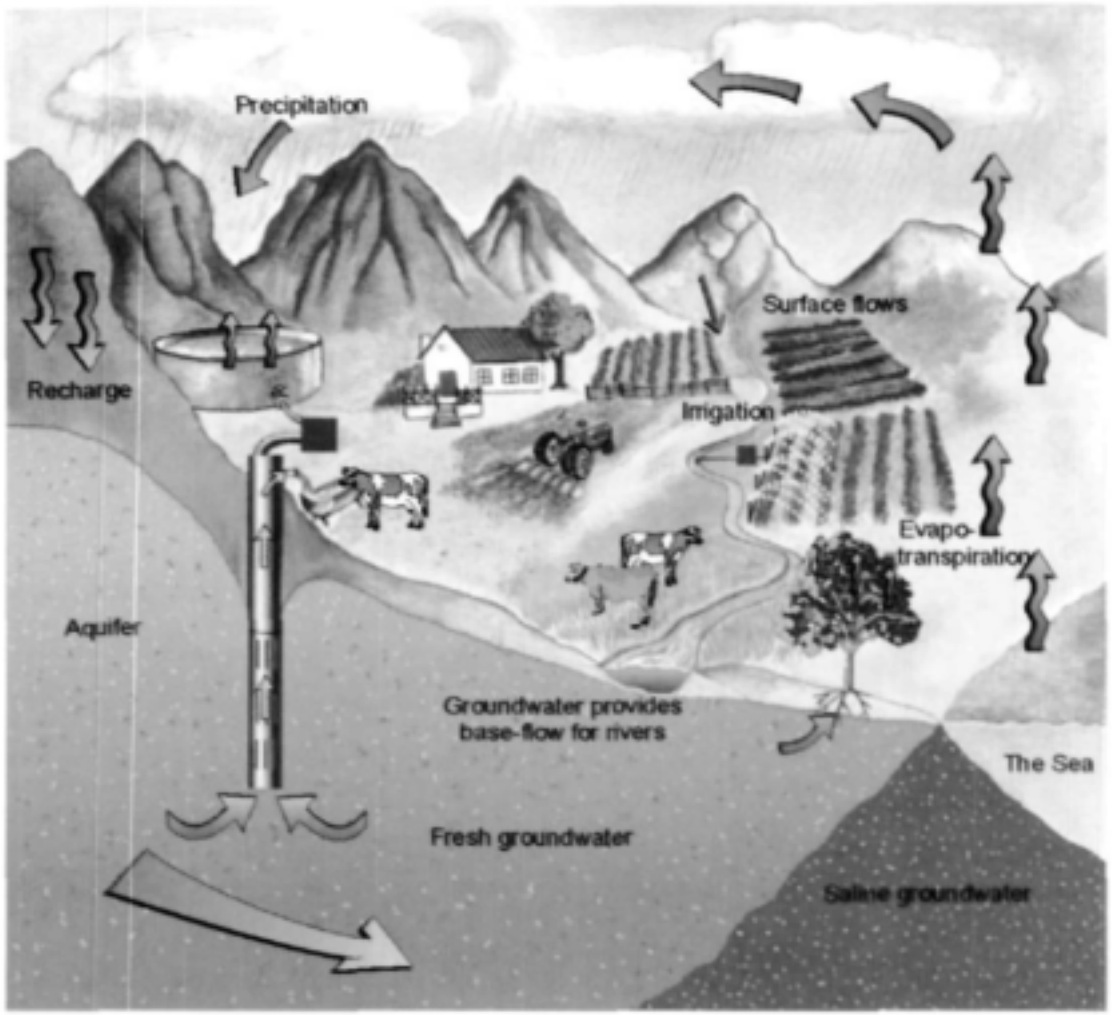
CHAPTER 1: GROUNDWATER

The importance of groundwater

Groundwater provides a vital source of water in many areas of South Africa. It was estimated that approximately 1.8 million m³ of groundwater is abstracted annually in South Africa, 90% by farmers.

Aquifers often provide the only source of water in areas where there is either insufficient surface water or the surface water is not safe to drink. Although access to groundwater requires a well or borehole, it is often the most cost-effective way to supply good quality water to isolated areas such as farms and rural communities.

As well as supplying water to man, groundwater plays an important part in the natural water cycle. Aquifers are **recharged** by water which has filtered through soil and rock. This water is stored and transmitted by aquifers towards areas of **discharge**. Groundwater may discharge into a river, wetland, spring or the sea. All the ecosystems associated with these features are therefore affected by the quality and amount of groundwater that reaches them. Many vegetation types rely directly on groundwater for all or part of the year. So even if groundwater isn't used by people in your area it may still play an important role in the local environment.



The role of groundwater in the water cycle

Groundwater occurs underground in pores and cracks in rock and sediments. **Aquifers** are composed of earth material that is fully saturated with groundwater and is permeable enough to transmit sufficient water to supply a borehole.

Aquifers in South Africa

Over about 90% of the surface of South Africa, groundwater occurs in hard rock. Groundwater in these rocks is contained in fractures and in dolomite and limestone in dissolved openings called fissures. Hard rock aquifers are known as **secondary aquifers** because the groundwater occurs in openings which were formed after the rock was formed. An example is the Table Mountain Group sandstone which underlies much of the Western and Eastern Cape.

Over the remainder of the country groundwater occurs in **primary aquifers**. These comprise porous sediments and groundwater is contained in the spaces between sand grains. Primary aquifers are found in river (alluvial) sediments, in coastal sand deposits, and in the Kalahari deposits.

Where groundwater is found, it may lie one or two metres beneath the ground surface or hundreds of metres underground. The maximum from which it is cost-effective to abstract groundwater, is usually 200 to 300 m. In many aquifers, the level at which water is seen in an unpumped borehole is significantly higher than the level it was encountered (or struck) during drilling. There is therefore a pressure head in the aquifer and this water is said to be **confined**.

Where groundwater is **unconfined** (the strike level is the same as the rest water level) the upper surface of the aquifer is called the **water table**. The material above the aquifer is the **unsaturated zone**.

Groundwater quality

Groundwater quality refers to the water chemistry and micro-organisms living in it. Groundwater naturally contains many dissolved substances like calcium and chloride. The level of total dissolved solids (TDS) in groundwater determines its salinity. Water with a TDS of greater than 450 mg/ℓ tastes salty, but up to 1 000 mg/ℓ it is safe for humans to drink. Livestock can tolerate drinking water with levels up to 3 000 mg/ℓ. Seawater contains 35 000 mg/ℓ TDS.

Guidelines for drinking water quality are given at the back of this booklet. Other guidelines for irrigation and stock water quality are published by DWAF.

All aquifers contain communities of micro-organisms. Microbial contamination occurs when micro-organisms that pose a risk to health are introduced to groundwater, usually from a faecal source. Dysentry, cholera and gastroenteritis are examples of diseases transmitted by bacteria in water. Faecal coliform, particularly *Escherichia coli*, are used to indicate faecal contamination.

Groundwater feeds important wetlands

Groundwater contamination

Groundwater may be **contaminated** with substances which occur as a liquid (e.g. oil), or can be dissolved in water (e.g. nitrate), or are small enough to pass through the pores in soil (e.g. bacteria). These may originate on the surface, as in the case of fertilizers, or underground (sewers, leaking underground storage tanks, etc). Groundwater is said to be **polluted** when the contaminants occur at concentrations which make the water unfit to use. Leaching is the process by which substances are dissolved by infiltrating water and then carried down to groundwater.

Farmers need to be aware of activities on their farms which involve potentially contaminating substances coming into contact with the ground and being leached to the water table by rain or irrigation water. For instance, fertilizers applied to land are soluble and may be leached to the water table if not taken up by the crop. The transfer of diesel from a storage tank to vehicles may also cause contamination if spills occur in an area which has not been sufficiently paved and contained.

Aquifer vulnerability

Some aquifers are very **vulnerable** to contamination whereas others are afforded a good degree of natural protection. A shallow aquifer covered by only a few metres of sandy soil in a regularly irrigated area would be very vulnerable to contamination. Groundwater in a deep aquifer with low permeability clays occurring between the aquifer and the surface is not likely to be contaminated locally. However, that same groundwater may have been contaminated in a recharge area where the aquifer occurs closer to the surface or is overlain by more permeable deposits.

Responsible groundwater management

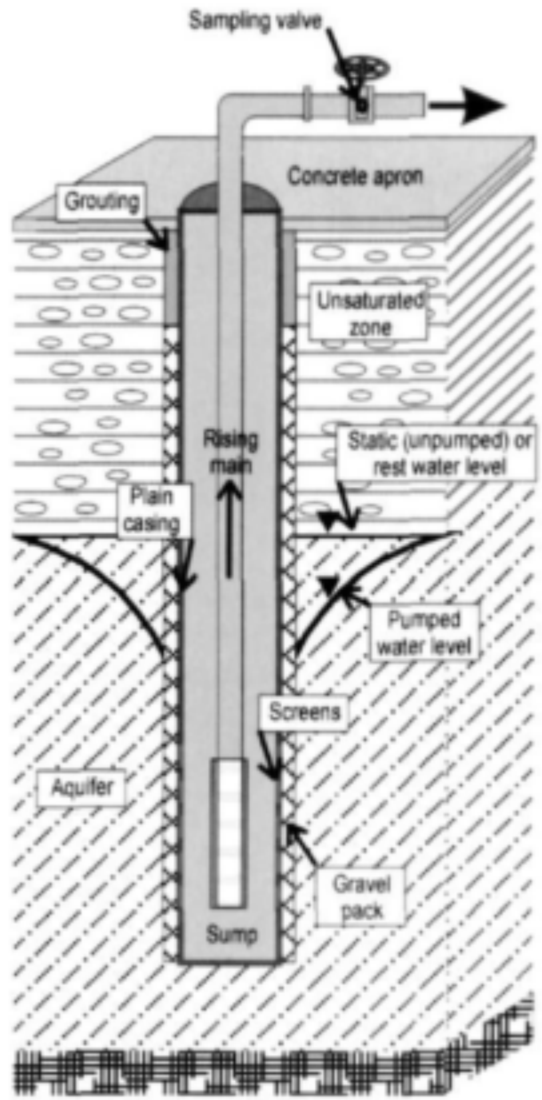
Responsible management of groundwater abstraction and activities in vulnerable areas ensures that groundwater remains a usable resource. If too much groundwater is abstracted or groundwater quality deteriorates as a result of pollution, it will no longer be available as a cost-effective source of water for drinking, stock watering or irrigation. The cost of polluted water treatment is usually higher than the cost of implementing good farming practices. In other words, prevention is not only better but cheaper than cure.

Good farming practices for different agricultural sectors are outlined in this booklet. In addition to those relating to specific agricultural practices, there are some measures that **all farmers with boreholes** should try to implement.

Groundwater which is particularly vulnerable to contamination tends to occur in aquifers with the following characteristics:

- A shallow depth to the water table (e.g. < 5 m).
- Pathways for rapid migration to the water table exist, such as cracks in the soil, fractures in the rock or sink holes.
- The soil and unsaturated zone are highly permeable and relatively inert with low levels of organic matter and clays.
- There is a relatively high rate of recharge by rain or irrigation water.

Diagram of borehole and well-head area



A borehole is a direct pathway to the aquifer and, as such, often acts as a pathway for pollution. Before construction of the borehole is completed, the top few metres of the borehole between the casing and the soil or rock should be grouted. Even boreholes which are not cased for their total depth should be cased for the top few metres. The surface area around the top of the borehole should be cemented over. These measures prevent contaminants from the surface passing down the side of the borehole to the aquifer.

As a general rule the flow of groundwater follows the surface topography. Therefore where possible, **boreholes** should be sited up-slope of potential contamination sources. Boreholes should not be sited within 100 m of a septic tank. A borehole which is closer than 30 m to a septic tank is likely to be polluted. Similarly, watering troughs should be constructed at least 40 m away from the well-head. Animal waste that accumulates around watering troughs may pollute groundwater if it is close to the borehole.

The well-head, or top of the borehole, should be constructed to allow access for a dip meter to measure the rest water level and it should have an outlet valve for obtaining a water sample. Good groundwater management requires information on the level of groundwater and its quality. The **rest water level** of the groundwater should be taken every three months (when the borehole has not been pumped for several hours) and records kept. Water levels vary throughout the annual cycle, but a comparison of levels at the same time of year over several years will indicate whether the amount that is being abstracted is sustainable or whether levels are declining. If levels are falling the aquifer is being over-declining.

A **sample** of groundwater should be analysed every year. An example sampling data sheet is given at the back of this handbook. The most important hydrochemical characteristics to measure are the total dissolved solids (TDS) and nitrate as these are usually the first to increase with agricultural pollution. If the water is being used as drinking water, a microbiological analysis should also be carried out annually for faecal coliforms. Ideally a full analysis for all the drinking water criteria listed at the back of this handbook should be carried out every few years. Guidelines are also available for livestock watering standards.

You may wish to contract the services of a groundwater expert (hydrogeologist or geohydrologist) to help you with a monitoring programme and, more importantly, to interpret the results correctly.

Keeping **records** of groundwater information will help greatly if problems arise. Implementing good farming practices will not only protect your resource, but also help avoid expensive legal disputes between neighbours.

Sampling for a scientific study at the well-head

Eight simple steps should be followed to obtain a worthwhile groundwater sample:

1. Choose your **laboratory** - make sure it is reputable, carries out SABS analyses and preferably takes part in the national accreditation scheme.
2. Confirm with the laboratory the tests you would like to have carried out, **how much sample** they require, whether they will supply you with **sterile sampling bottles** and when they can receive them.
3. The borehole should be **pumped** for at least half an hour to obtain a sample which is representative of water in the aquifer, not water that is standing in the well.
4. The sample should be taken as close to the well-head as possible, preferably **at the well-head** and certainly not from a storage tank where it will mix with standing water.
5. For TDS and nitrate analyses, collect one litre of water in containers that have been **rinsed several times** with the water to be sampled.
6. For microbiological analyses it will be necessary to obtain a **sterilized sample** jar from the laboratory. Do not touch the inside of the container or its lid as this will introduce microbes to the sample.
7. Once the sample(s) have been taken, keep them in a **fridge or cool box** with freezer blocks.
8. Submit the samples to a laboratory within **24 hours if possible.**

Checklist

→ Insist on groundwater protection features in the construction of your boreholes (grouting, sampling and monitoring access, etc.).

→ Monitor rest water levels every three months to check that you are not depleting your resource in the long term.

→ Sample groundwater annually for a basic hydrochemical analysis and a microbiological analysis if it is used as drinking water.

→ Identify areas of your farm with permeable soils and a shallow water table and consider the high risk of groundwater contamination in land-use management.

→ Carry out the farmstead protection measures outlined in Chapter 8.

→ If you:
- farm livestock intensively
- *use commercial fertilizers*
- use manures or sewage sludge
- use pesticides
- irrigate

refer to the relevant chapters for an explanation of the risks and suggestions of good farming practices to protect groundwater quality.

Further information

(See **Useful Addresses**).

➾ Department of Water Affairs and Forestry Geohydrology (Booklet - *Groundwater: Guide-lines for boreholes*) *(South African Water Quality Guidelines)*.

➾ Water Research Commission.
(Report - *Groundwater Sampling*. An abbreviated field guide for sampling methods. 1995. TT 56/92).

➾ Reputable analytical laboratories.

➾ Borehole Water Association.

CHAPTER 2: NITRATES

A recent study of the impact of agriculture on groundwater quality in South Africa showed that nitrate was the most commonly occurring contaminant (*Assessment of the Impact of Agricultural Practices on the Quality of Groundwater Resources in South Africa* - Water Research Commission, 1998). Nitrate pollution is known to result from the application of sewage sludge to land, tilling of the soil (mineralization of organic matter), fertilizer application, and the storage and spreading of animal waste.

Why is nitrate a problem in groundwater?

Nitrate is a cause for concern in drinking water at levels greater than 10 mg/ℓ nitrate-nitrogen (NO_3- N) which is equivalent to approximately 45 mg/ℓ as nitrate. At concentrations greater than this there is an increased risk to infants, of *methaemoglobinaemia*, commonly known as **Blue Baby Syndrome**. The affected babies turn blue because the level of methaemoglobin is increased. This means that the blood cannot carry sufficient oxygen. Mildly affected babies should recover within a week if they stop drinking the contaminated water. Severely affected babies require hospitalization and blood transfusion. If a severely affected baby is not treated, he/she may fall into a coma. The mortality rate among affected infants is reported to be around 10%. High nitrate levels in groundwater are therefore a severe health risk to bottle-fed babies who consume the water.

Livestock has been found to be similarly affected, but at higher nitrate concentrations. Nitrate-nitrogen concentrations in livestock water of 100 to 300 mg/ℓ may cause problems if the feed is high in nitrate. Water with concentrations above 300 mg/ℓ should not be consumed by livestock. Lactating cows are affected at lower levels. Horses are very sensitive to nitrate.

There is suspected to be an increased risk of **stomach and oesophagus cancer** with the consumption of nitrate contaminated water. The risk may be even higher if the water is also contaminated with pesticides. Studies are currently being undertaken to determine the risk.

Groundwater commonly feeds rivers, wetlands and lakes. If the groundwater flowing into these surface water bodies has elevated levels of nitrate **eutrophication** may occur. This has a significant impact on aquatic ecosystems and results in fish kills.

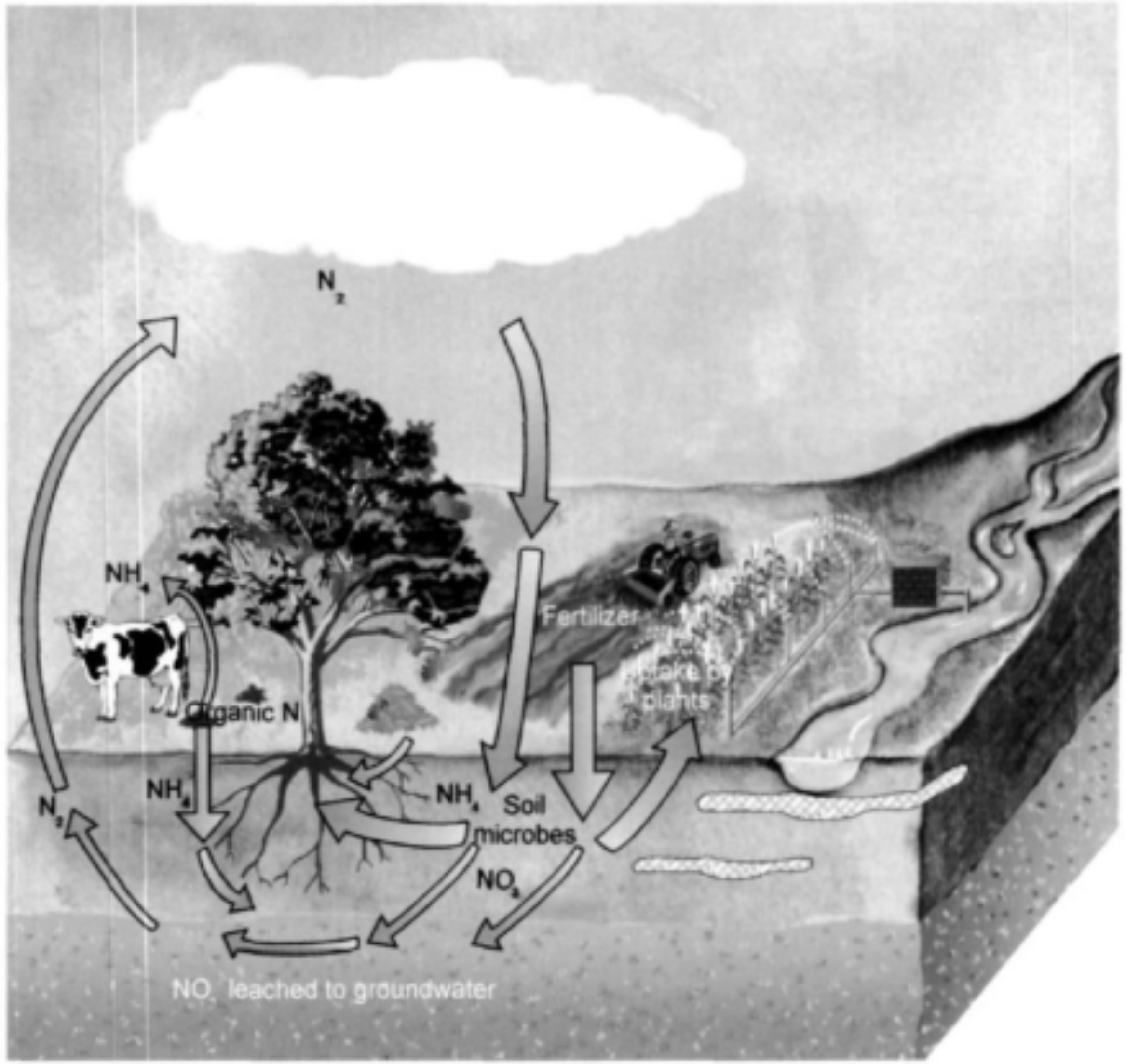
Treatment for nitrate

Nitrate cannot be removed from water simply by boiling or filtering. Special water treatment units involving reverse osmosis, ion exchange, biological denitrification or distillation are required. These usually require skilled maintenance for around half an hour per day to operate effectively. The capital cost for a small-scale unit is about R150 000 (1998).

Nitrate and the nitrogen cycle

Nitrogen is a common element. 80% of the air we breath is nitrogen. Nitrogen is an essential nutrient to all plants and animals. **Legumes** are plants which fix nitrogen directly from the atmosphere into proteins. Legumes and organisms in the soil may fix nitrogen at a natural rate as high as 40 kg of nitrogen per hectare per year. Nitrogenous inorganic **fertilizers** are manufactured from nitrogen in the atmosphere. Nitrogen is also found in **organic matter**, particularly animal waste, and in the environment as **ammonia (NH_3)**, **ammonium (NH_4)** and (more rarely) as **nitrite (NO_2)**.

Nitrate (NO_3) is an oxidized form of nitrogen which is found in soil, water and some of the food we eat. The figure opposite illustrates the nitrogen cycle and the inter-relationships of the different nitrogen compounds.



The nitrogen cycle

Nitrogen found in organic matter, such as manure, degrades in the soil to ammonium. This ammonium and ammonium supplied by inorganic fertilizers may then be nitrified by bacteria in the soil to nitrate. Both ammonium and nitrate are taken up by plants. They are said to be **bioavailable**. Nitrate is easily dissolved in water which is why it is likely to leach to groundwater. Nitrate which is not taken up by plants or **leached** beneath the root zone may undergo denitrification to form **nitrogenous gas** which is released to the atmosphere. Once nitrate has been leached beneath the root zone it is lost to crops and it begins its journey towards the water table. It may be several years, even decades, before the full effect on groundwater quality is seen.

Nitrate is more likely to leach to groundwater under the following conditions:

- High rates of nitrogen loading from fertilizer, manure and organic matter in the soil.
- High soil temperatures which increase the rate of nitrification.
- Well aerated soil also encourages nitrification.
- Low levels of plant uptake due to bare ground, low crop requirements or seasonally variable requirements.
- High levels of precipitation or irrigation.
- Permeable soil and unsaturated zone.
- Shallow water table.

Most of these conditions are determined by the environment but factors such as the rate and timing of nitrogen loading and the level of irrigation are under the control of the farmer and can therefore be managed to minimize the potential impact.

Occurrence of nitrate in groundwater

Nitrate is already a major problem in groundwater in many countries where **intensive agriculture** is practised, such as the Netherlands and the UK. These countries are already implementing costly measures necessary to reduce the rate of contamination and spending millions of Rands on research to reduce nitrate leaching from agricultural land. In **South Africa** high nitrate levels occur naturally in some areas as a result of the local geology and geomorphology, e.g. in the Kalahari and around Prieska. High nitrate levels in other areas result from agricultural activities such as fertilizer application, ploughing and livestock effluent irrigation. If your groundwater is below the 10 mg/ℓ NO_3-N limit, but still contains a few mg/ℓ nitrate-nitrogen, beware: a small addition to the natural level will make the groundwater unfit to drink. If you are fortunate enough to have good quality groundwater it is in your interest to protect it.

Accounting for nitrogen

The nitrogen cycle is complicated in an agricultural setting and it is not possible to determine how much nitrogen is available in all its different forms. However, you can minimize nitrogen losses by making a best estimate of nitrogen **input** and **requirements**. Calibrate this with field observations of crop yields and regular analyses of soil water, irrigation water and groundwater.

Nitrogen balance

Inputs:

- Soil organic matter (typically low in South Africa)
- Inorganic fertilizer
- Manures
- Effluent
- Irrigation water
- Residual nitrogen in soil water

Outputs:

- Crop requirements
- Volatilized to atmosphere
- Leached to groundwater/runoff

Soil water beneath the root zone may be sampled using a lysimeter. Residual levels of up to 5 mg/ℓ nitrate-nitrogen have been recorded in soil water in agricultural areas of South Africa. This obviously contributes significantly to the nitrogen available for crop uptake and reduces fertilizer requirements.

If nitrate occurs in groundwater used for **irrigation** this could contribute significantly to the available nitrogen.

The **timing** of inputs and outputs is also very important and should be considered where possible. Fertilizer should be applied at times of peak crop requirements.

Practical reliable methods for determining the rate of release of available nitrogen from organic matter in **manure** are being researched but are not currently available.

Levels of accuracy in nitrogen accounting

It is possible to know **accurately** the amount of nitrate you are applying per hectare in irrigation water (by analysing the water) and inorganic fertilizers (from the supplier). These sources constitute the bulk of your nitrogen input. You can also make a **good estimate** of the your crop nitrogen requirements from information given by literature and agronomists (the bulk of your output). However, you can only make a very **rough estimate** of the nitrogen supplied from the organic matter in soil and from organic manures. You can make a **reasonable estimate** of nitrate lost from the root zone by analysing soil water (> 50 cm depth) and adjust your application rates accordingly. You will get an indication of long-term losses if nitrate concentrations in the groundwater increase.

Checklist

The most practical approach to accounting for nitrogen and avoiding over-application and leaching losses is to be as informed as possible about the relative inputs and outputs and to monitor the crop, soil water and groundwater for changing concentrations.

- → Research your **crop requirements** (including timing) and the rate of nitrogen up-take by cover crops and pasture (especially important where effluent is being irrigated to pasture).
- → Account for **additional sources** of nitrogen such as manure and effluent.
- → Efficiently **load and schedule inorganic fertilizer** application according to nitrogen uptake.
- → **Schedule irrigation** efficiently to minimize excess water percolating beneath the root zone taking dissolved nitrate with it.
- → **Monitor the crops** for signs of over-application and alter the loading accordingly.
- → If possible, **monitor infiltrating soil water** beneath the root zone for nitrate to give an early indication of leaching.
- → **Monitor groundwater** quality annually for any indication of contamination, but be aware that this may take years to show.

Further information

(See **Useful Addresses**).

- ➾ Agricultural Research Council.
- ➾ Fertilizer Society of South Africa.
- ➾ Water Research Commission (Report 368/1/93: *A Preliminary investigation of the nitrate content of groundwater and limitation of nitrate input).*
- ➾ South African Water Quality Guidelines, DWAF 1996.
  Volume 1: Domestic Use
  Volume II: Agriculture Use.

CHAPTER 3: FERTILIZERS

Modern intensive farming methods depend on the replacement of essential nutrients in the soil by commercially produced fertilizers. The use of inorganic fertilizers world-wide has contributed to the Green Revolution, with dramatic increases in crop yields.

Between 1955 and 1981 the use of inorganic fertilizers in South Africa increased twenty-fold. The level of consumption declined after 1981 as cost increases led to more effective fertilizer application rates and the amount of commercially cultivated land declined. The rate of use in South Africa currently lags behind other areas of the world. In 1996, it was estimated that 2.6 million tons of inorganic fertilizers were used in South Africa. Of those, over 400 000 tons were nitrogenous fertilizers.

Fertilizers and water allow sandy soils to be cultivated

Benefits

Carbon, hydrogen and oxygen are required for plant growth and are usually abundant in the atmosphere, soil and water. **Nitrogen**, **phosphorus** and **potassium** are also essential for plant growth but become depleted in soil which supports intensive crop farming. They are replaced most efficiently by applying commercial fertilizers. Chapter 2 describes the nitrogen cycle and shows the role that fertilizers play.

A major advantage of inorganic fertilizers is that they can be formulated to provide a balanced supply of the major nutrients, readily available to the plants at a time and in quantities best suited to their requirements. This is an advantage over organic fertilizers like farm yard manure which slowly release nutrients and therefore cannot be scheduled accurately.

Inorganic fertilizers are relatively easy to transport and can be stored without risk to the environment.

Hazards

Some of the problems associated with the use of inorganic fertilizers are:

- → **soil acidification**
- → negative **crop effects** associated with over-application (excessive growth, delayed maturity, loss of yield, etc.)
- → addition of **harmful substances** to the soil (e.g. cadmium, arsenic, uranium)
- → **water pollution.**

Other activities associated with commercial cultivation also have environmental risks. Ploughing and leaving bare soil exposed can have an even greater impact that the use of inorganic fertilizers.

Groundwater contamination

The main risk to groundwater quality from the use of fertilizers is **nitrate** contamination. Nitrate is the most soluble nutrient supplied by inorganic fertilizers and therefore the most likely to be leached down to the water table. Chapter 2 describes the problems caused by nitrate contamination of drinking water. If nitrogen is applied to land at a rate which is faster than the crop requires it, maybe at a time when growth is slow, then rain or irrigation water are likely to leach nitrates out of the reach of crops and towards the water table.

Groundwater contamination from fertilizers has been seen in many countries where intensive crop farming is practised. In the **UK,** nitrate sensitive areas (NSAs) were designated and activities controlled to limit the risk of nitrate leaching to groundwater.

Nitrate Time Bomb

In the UK, **fertilizer scheduling** has changed to try and protect groundwater quality. Farmers typically ploughed and fertilized their fields prior to winter. The belief was that the fertilizer would then have time to soak into the soil ready for crop growth after planting in the spring. In fact what happened was that much of the nitrogen applied was lost by leaching by the heavy winter rains to a depth that was beyond the reach of the crop roots. This nitrate has been slowly moving through the soil and unsaturated zone towards the water table and in many cases, where the aquifer is quite deep, the effect on water quality has yet to be seen. It may take years before nitrate levels in groundwater respond - this has been termed The Time Bomb Effect.

Nitrate contaminated groundwater has been sampled in every state in the **USA**. Two types of area particularly affected are areas of widespread grain production, marked by heavy fertilization and row cropping, and areas of irrigation and fertilization of vegetable and speciality crops, particularly shallow rooted vegetable crops on sandy soils.

Nitrate-induced eutrophication has caused extensive algal blooms in coastal waters in the Baltic Sea, with consequent deoxygenation of the water and loss of fishing grounds. The suspected cause of this pollution is the seepage of high nitrate groundwater into the sea from the agricultural areas of **Germany** and **Denmark**.

Here in **South Africa**, the level of fertilizer use is much lower. However, studies have shown that inorganic fertilizers have contributed to high nitrate levels regionally in groundwater in North-West Province and the Free State. Ploughing and the application of farmyard manure have also contributed to elevated nitrate levels.

Case study

Contamination in the Free State

Analysis of groundwater samples from a wheat farming area of the Free State indicated that agricultural activities are pushing nitrate concentrations above the limits for safe drinking water. Samples from groundwater beneath a town in the area contained nitrate at below the limit of 10 mg/ℓ. Nitrate levels in groundwater beneath wheat cultivated areas were double that level. In this area approximately 100 kg/ha.yr of 3:2:0 fertilizer is applied to bare ploughed fields towards the end of the rains in March and April. Wheat is planted one month later. It is thought that nitrate from the fertilizer is leached from the soil towards the water table by infiltrating rainwater during the period between the application of fertilizer and the start of wheat growth. The rates of application in this area are not particularly high, it is the timing of the application that is crucially important. In addition, naturally occurring nitrogen in the soil is thought to be leached following exposure by ploughing.

Nitrate has a high risk of leaching from bare ground during rain

Good farm practices

Nitrate is more likely to infiltrate to groundwater under the following conditions:

- → the water table is shallow and the unsaturated zone is permeable
- → fertilizer is applied at a time when it is not being taken up by the crop
- → fertilizer is applied at a rate which is greater than the crop can use it
- → rain or irrigation water is present to carry the nitrate beneath the root zone and out of reach of crops.

If fertilizers are applied during a rainy period when the ground is bare and there is no uptake by plants it is likely that a significant portion of the nitrogen supplied will be washed beneath the root zone. This means that the crop will not receive the correct amount of nitrogen for optimal growth and there is a high risk of contaminating groundwater with nitrate.

In planning an effective schedule for fertilizer application the farmer needs to know:

→ **When** does the crop require the most nutrients, particularly nitrate? This is usually around early periods of growth following planting and prior to fruiting.

and

→ **How much** fertilizer should be applied at the different times?

Nutrient requirements

Literature available from the sources listed at the end of this chapter gives information on the total nitrate requirements of different crop types as well as other nutrients. Soil testing is carried out by the major fertilizer companies and at Department of Agriculture laboratories for phosphorus, potassium, calcium, sodium and pH. However, nitrogen analyses are not routinely carried out as natural nitrogen in the soil comes from organic matter and South African soils are typically low in organic matter. The amount of nitrogen available from organic fertilizers (manure, etc.) is difficult to determine because it is converted to plant-available forms slowly. It is therefore usually assumed that the total crop requirement for nitrogen will be met by inorganic fertilizers. But remember, if your soil is rich in organic matter or if manures or sludge are being applied then additional nitrogen will be available. Similarly, if nitrogen fixing crops have been grown on the soil then there will be more naturally available nitrogen.

Working out the nitrogen balance for a crop can be a complicated procedure. It is usually carried out over a few years and is based on the practical experience of the farmer. Field observations, such as signs in the crop of excessive growth rates, and measurements of the crop tissue, soil nutrient levels and groundwater chemistry all contribute to getting the balance right. Measurement of nitrate in the root zone soil (as opposed to organic nitrogen) gives an indication of some of the residual nitrogen that will be available (See Chapter 2).

Be particularly aware of over-fertilization risks in high rainfall areas or during rainy periods. Over-irrigation may also lead to greater leaching losses where there is excess nitrogen in the soil. Irrigation should be scheduled to the crop requirements.

Fertilizer application is carefully scheduled to optimise quality

Case study

Good farming practices at grape farms in the Western Cape

Table grapes are grown in the Hex River Valley in the Western Cape. Approximately 200 kg of 1:0:1 fertilizer are applied per hectare each year. The area is typical of many valleys with sediments deposited by the river forming a shallow aquifer beneath the cultivated land. The high permeability of the sediments and the shallow depth to the water table make the groundwater in this area extremely vulnerable to contamination. However, field studies have shown that careful management of fertilization and irrigation have minimized the impact on groundwater quality. Excess water and nutrient supplied to the crop reduce the quality of the yield therefore they are carefully controlled. Fertilizer is applied as granules 3 times a year: when the vines bud (August/September), when the berry bunches appear (December) and after the harvest (April). The scheduling is therefore carefully matched to the crop's requirements and the quantity is determined from the size of the berry bunches and the results of soil analyses which are carried out every 2 to 3 years. The vines are irrigated once a week and again the quantity is carefully determined by measuring soil moisture with tensiometers or neutron probes. This minimizes leaching losses keeping nutrients like nitrate in the root zone.

Action plan

Before fertilizing:

1. Set a realistic crop yield goal.
2. Determine the nutrient requirements of the crop for this yield.
3. Estimate the amount of nutrients, particularly nitrogen, that will be supplied from other sources: residual soil nitrate, soil organic matter, manure, irrigation water (there may be significant nitrate from this source). This may require analyses of soil, manure and water or estimates may be made from observations and literature. Often the help of soil scientists or agronomists will be needed at this stage.
4. Find out how the nitrogen requirements of the crop will change through the growing season.
5. Work out a schedule for fertilizer application.
6. Store fertilizers safely in a covered, contained area on a concrete base.

Fertilization

7. If groundwater is used to apply fertilizer, do not mix the concentrated fertilizer and water within 15 m of the borehole.
8. Do not apply fertilizer within 50 m of a borehole.
9. Avoid applying fertilizer to bare ground for a significant period before planting.
10. Practice multiple fertilizer applications to match the timing of the crop requirements as closely as possible.
11. Practice careful irrigation scheduling to minimize the risk of wasting nutrients by leaching to groundwater.

Long-term activities

12. Minimize the period of bare ground exposure by using cover crops and rescheduling ploughing to before planting rather than after harvesting to reduce losses of nutrients from the soil.

Long-term monitoring

13. Keep a balance sheet of calculated and estimated nutrient inputs and outputs.
14. Check for signs of over-fertilization in the crop (excessive growth, etc.).
15. Monitor soil nutrient levels regularly (every one to three years).
16. Monitor nitrate and total dissolved solids in groundwater regularly, remembering that it may be years before contamination reaches the water table.
17. If irrigating, monitor soil moisture levels to ensure that you are not over-irrigating.

Don't forget...

18. Contamination from fertilizers can also occur during storage or handling. Chapter 8 outlines good practices to minimize contamination risk around the farm yard.

Further information

(See **Useful Addresses**).

- The Fertilizer Society of South Africa.
- Agronomists at the major fertilizer companies (Kynoch, Sasol and Omnia) generally offer assistance in developing responsible application schedules based on crop requirements and soil type.
- Provincial Department of Agriculture. Agricultural Extension Officers.
- Agricultural Research Council (ARC) Institute of Soil, Climate and Water.

CHAPTER 4: INTENSIVE FARMING ACTIVITIES

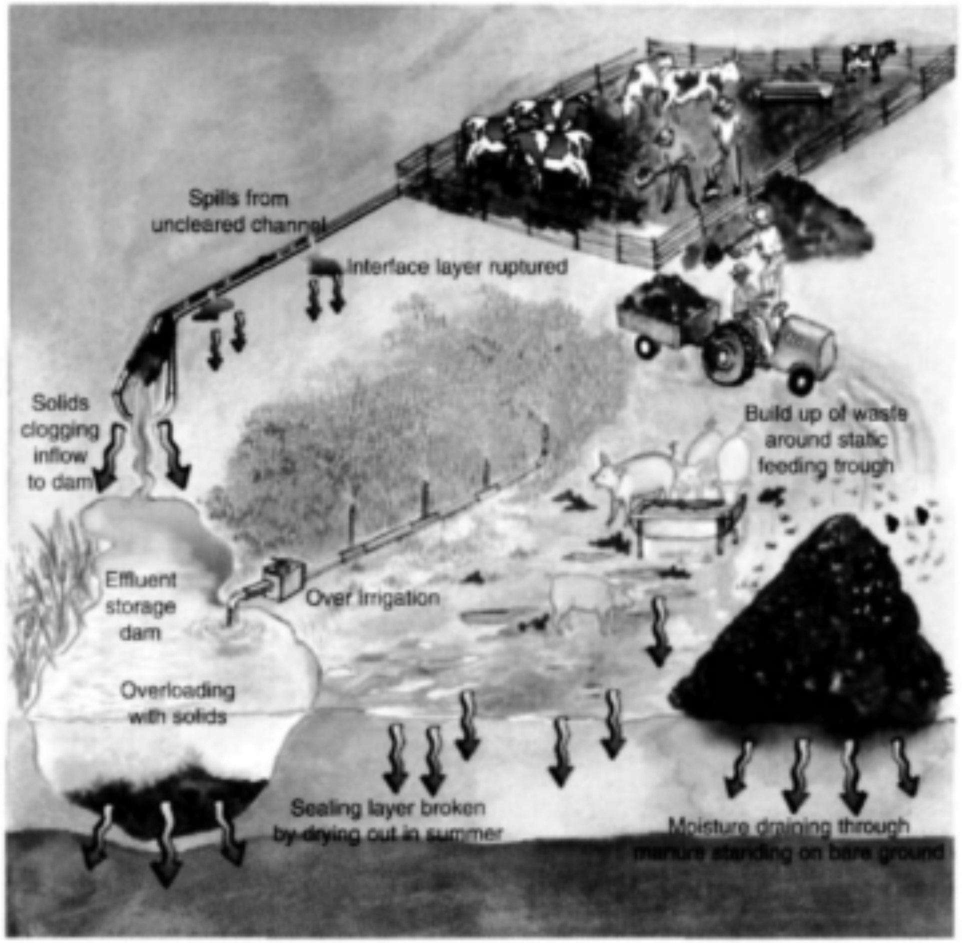
Farmers have become increasingly reliant on intensive agricultural practices in order to reduce costs and increase yields. This is the case in intensive livestock farming where the use of feeding stalls and battery farming, is becoming more widespread worldwide.

Sources of contamination

The main environmental impact of intensive farming enterprises (IFE) is the large volume of animal waste that is produced concentrated in a limited area. IFE waste management is therefore an area of concern. Commonly, livestock waste is disposed of by selling manure as fertilizer or on-site beneficial application to pasture or other cropped land. The main risks to groundwater contamination from IFE are usually as a result of inadequate management of the following practices:

- Storage of liquid and solid waste: unsealed effluent dams and manure heaps on permeable ground.
- Distribution and disposal of liquid and solid waste: particularly where this is carried out without considering crop/pasture nutrient requirements.
- Cleaning stalls and feedlot pads: particular care must be taken to leave the layer of compacted manure (interface layer) intact.
- Inadequate management of run-off water: from stalls, pads, stored manure and silage.
- Abandonment of stalls and pads: shrinkage cracks in drying manure allow contaminated water to flow into the soil.
- Periodic concentration of livestock in pasture: high levels of urine and manure accumulation in areas with limited compaction and frequently no grass, for example around feeding troughs and gates.
- Disposal of sheep dip to limited land areas or soakaways.

Waste management is a problem associated with intensive animal farming



The Conservation of Agricultural Resources Act requires that **effluent** should meet certain water quality standards before disposal to surface water or groundwater. These include the following maximum concentrations:

- → Electrical conductivity of 250 mS/m
- → 10 mg/ℓ free and bound ammonium-nitrogen
- → 1 mg/ℓ soluble orthophosphate
- → 200 mg/ℓ sodium
- → 0.1 mg/ℓ residual chlorine
- → 25 mg/ℓ suspended solids

Types of groundwater contamination

Nitrate is the most widespread groundwater contaminant associated with IFE. Nitrogen contained in urea, ammonium and the organic matter in manure is converted to nitrate under certain conditions in the soil (see Chapter 2). This may then be leached to vulnerable groundwater during periods of rainfall or irrigation. In the **USA** a feedlot workgroup found that nitrate, bacteria and salts from feedlots had contaminated groundwater in 17 states. In **Australia** the single largest source of nitrate in groundwater is that leached from livestock urine on grazed leguminous pastures. The Darling Downs, where many Australian feedlots are situated, overlie a fractured basalt aquifer with nitrate-nitrogen levels of 60 mg/ℓ. Nitrate pollution of groundwater has also been associated with dairies in South Australia.

Animal effluents typically have **TDS** (salinity) levels of 3 000 to 15 000 mg/ℓ. This is much higher than the TDS of fresh groundwaters, therefore an increase in salinity will be seen with contamination. The high levels of nutrients contained in animal wastes lead to an increase in the **biological oxygen demand** (BOD) of the water. This disrupts the balance of aquatic ecosystems. **Micro-organisms** such as viruses, bacteria, protozoa and helminth eggs are present in animal excreta. These microbiological pathogens do not usually represent a major risk to groundwater quality. Most are effectively 'sieved' by the soil and do not survive for the time it takes to transport them to the water table. However, where fractures or cracks exist, or where the soil is very sandy with little clay and organic matter, micro-organisms may reach the water table.

Polluted groundwater was found beneath this manure covered area

Case study

Piggery and dairy waste problems

A study of the groundwater quality at an IFE operation in the Western Cape which included a piggery and a dairy (with approximately 6 000 pigs and 800 cows) highlighted some of the problems which result in contamination. The farm is sited on a shallow aquifer in permeable sediments next to a river. This aquifer is highly vulnerable and is likely to be connected to the river. Any impact on the groundwater quality may therefore affect the quality of the river water. The groundwater was found to be contaminated with nitrates to a maximum measured level of 150 mg/ℓ (NO_3-N). At this level the water is not only unsafe for human consumption but should not be used for livestock watering if the feed is high in nitrates. Increased levels of potassium, biological oxygen demand and salinity were also detected. Sources of contamination at the farm were:

- *Effluent from the pig stalls and dairy irrigated to pasture at unknown rates.*
- *Brick lined channels conveying effluent waste to an effluent dam.*
- *An area in a field next to a feeding trough where cows congregated which was covered in manure and had no grass.*

Good farming practices

Natural processes can be harnessed to help with waste management. For instance, in the case of feedlot pads and effluent lagoons, a layer with very low permeability will naturally form and serve to protect groundwater if it is maintained.

The potential for seepage of nutrients to the groundwater below **effluent lagoons** is reduced by the accumulation of solids and clogging by bacterial cells and fine organic matter. Infiltration may occur from new unlined ponds but with several months accumulation, most become **self-sealing**. A settling basin or **solid separator** is usually required to maintain an efficient life-span for an effluent lagoon. If a large proportion of the solids is not removed the lagoon fills up too fast and effluent has to be removed to prevent overspilling before sufficient breakdown has taken place. Self-sealing may not be established in areas with coarse sands, fractures or fissures. In these areas **artificial pond lining** is required. In anaerobic effluent lagoons any nitrate that forms is usually denitrified. This chemical reduction combined with low permeability at the base of the lagoon mean nitrate leaching rarely occurs. Cases of groundwater contamination from effluent lagoons are associated with the rupture of the sealing layer by seasonal drying out. **Moist conditions** should be maintained at the base of a lagoon at all times. **Avoid scraping out** the lagoon as this will destroy the self-sealing layer.

Feedlot pads receive a high loading of bovine waste but contamination is rarely recorded in well managed pads. *The high density of cattle in the pad compacts* the manure, forming a low permeability, anaerobic layer at the manure-soil interface. Water cannot easily permeate this layer, therefore care should be taken when removing surface manure from pads not to remove the **interface layer**.

Correct siting of feedlot pads and good drainage helps to prevent contamination. Feedlots should not be sited in areas with greater than **750 mm rainfall** per annum. Pads should be sited on a **2 to 5% slope** with feeding and drinking troughs at the upper end. The slope will minimize standing water and **run-off** should be collected in channels and directed to an effluent lagoon. The risk of ground- and surface water contamination is greatest during the first rains of a *wet season. This is known as the first flush effect.* Careful management of this run-off is required to prevent it reaching surface water or areas where it may infiltrate to groundwater.

When a pad is **abandoned** the manure dries and shrinkage cracks form. The permeability of the pad base or interface layer is then increased and the risk of infiltration increases. At this point all manure and the interface layer should be removed.

The literature shows that nitrate leaching to groundwater from areas of **land disposal** of waste and effluent is significant and widespread. Application to land is widely practised as it provides an economic means of disposing of effluent and manure. Other forms of disposal, such as discharge to a surface water body, would require expensive treatment. Disposal to land is a beneficial use option *where fodder crops are grown.*

Problems of contamination occur due to the high levels of contaminants in the waste, high application rates and aerobic conditions in the disposal area which enhance the formation of nitrate and subsequent leaching. The risk of leaching is greatest where high volumes of effluent are applied or irrigation is carried out in addition to waste application. A limit of **250 kg of nitrogen** per hectare per annum in manure applied to land is recommended in Europe. Additional irrigation should be avoided and the nitrogen loading in the effluent or manure should be matched to the requirements of the crop or pasture. Effluent irrigation to land overlying shallow, vulnerable aquifers should be minimized.

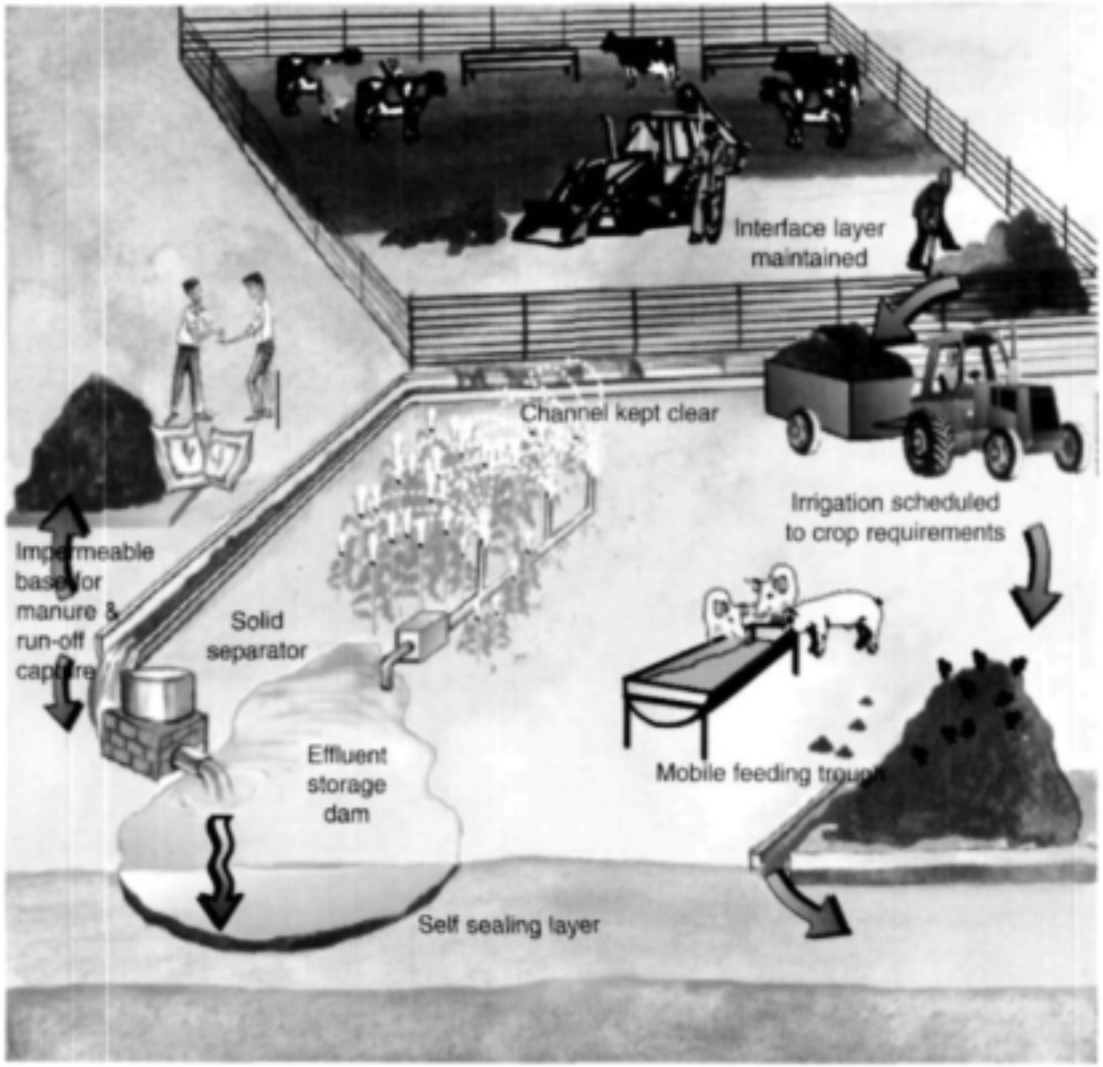
To calculate the amount of piggery waste that may be disposed to land:

Application rate (pigs per hectare) = nitrogen requirement of the crop or pasture (kg/ha.yr) x 0.1

If the waste has undergone some treatment (anaerobic or aerobic) then the nitrogen requirement may be multiplied by 0.15.

General good practice should also include the maintenance of grassed buffer zones several tens of metres wide next to surface water features. No effluent or manure should be applied to these buffers.

Significant leaching of nitrate to groundwater occurs beneath **pastures**. Leaching is mainly associated with urine patches, which release nitrate more quickly than manure. The very irregular distribution of livestock wastes across a paddock results in many small patches where extremely high nitrogen concentrations are a source for leaching. Heavier manure loads are also found where livestock congregate, such as at feeding or water troughs and gates. The impact of this can be minimized by not exceeding the **carrying capacity** of the pasture and using **mobile feeding** and drinking troughs.



Good farming practices at an intensive farming activity

Used **sheep dip** should be disposed of responsibly. It may be disposed to land at a rate less than 5 m^3/ha, but not on fractured bedrock overlying an aquifer occurring at less than 10 m below the surface.

Silage often has a high moisture content. This leachate is frequently highly corrosive and may damage steel and concrete tanks or containment walls. Store silage in corrosion resistant materials and check regularly for corrosion. The storage area should be bunded and leachate fed into secure tanks. Up to 20 ℓ of leachate may be produced by a cubic metre of silage. This leachate should be diluted with an equal volume of water and applied to land at less than 50 m^3/ha. Once again, do not apply to fractured bedrock overlying a shallow aquifer or within 10 m of a river.

Further information

(See **Useful Addresses**).

- South African Feedlot Association.
- Department of Agriculture
  - Agricultural Research Council
  - Directorate of Resource Conservation.
- Water Research Commission - (Report: *Interim Water Quality Guidelines for Livestock Watering).*

CHAPTER 5: SEWAGE SLUDGE

Sewage sludge is a semi-solid waste produced by the treatment of wastewater. It is used in many countries as a soil conditioner and fertilizer. It may be applied as a dried sludge cake or a slurry, spread over an agricultural area and ploughed in.

In South Africa it is estimated that approximately 8% of sludge produced at wastewater treatment works is sold to farmers. A further 20% is applied to agricultural land by the treatment works operators as a means of disposal. In the USA, 42% of sewage sludge is used on agricultural land and in Portugal this figure is even higher at 80%.

Heaps of dried sludge cake will be ploughed in to condition this sandy soil

Benefits

Sewage sludge (also known as biosolids) is primarily used as a **soil conditioner**. The organic matter found in sludge improves the physical properties of the soil, in particular its water retention capacity. This in turn reduces soil erosion and prevents nutrient leaching.

Sludge is also used as a low grade source of **nutrients**. South African sludges typically contain around 3.5% nitrogen and 2.0% phosphorus. The level of potassium (K) in sludge is typically very low at around 0.02% therefore supplementary K sources are usually required. The wastewater treatment operator should be able to provide an analysis of the N:P:K content of their sludge.

Sludge also provides some essential **micronutrients** (zinc, copper, molibdene, iron and manganese) most of which are not common in inorganic fertilizers.

Nitrogen release from sludge

Nitrogen is contained in sludge as ammonia and in organic form. The organic nitrogen must therefore be mineralized (and nitrified) by micro-organisms in the soil before it is **available to crops**. This process happens relatively slowly. The percentage released per year is approximately as follows: 40, 20, 10, 5 and 2.5% for subsequent years, but these figures vary depending on the type of sludge and conditions in the soil. Approximately 20% of the nitrogen contained in dried sludge and 60% in liquid digested sludge is released during the first year. However, dried sludge contains a higher percentage of nitrogen. Whichever type of sludge is used, additional commercial fertilizers are generally required during periods of peak crop nitrogen demand.

Hazards

The quality of sewage sludge varies depending on the health of the population served by the wastewater treatment plant, the type of industries that operate within its catchment and the type of treatments carried out. The main hazards to humans and livestock are the introduction of potentially **toxic** substances and **pathogenic micro-organisms** to the food chain. Pathogens commonly found in sewage sludge include bacteria, protozoa, helminths and viruses. Many potential pathogens are killed during digestion treatment of the sludge. Of those that survive, many remain viable for only a short period of time in the soil system, particularly if applied to the surface.

The application of sewage sludge may present risks to the wider environment when improperly managed. Raw, or untreated, sewage sludge contains **decaying organic matter** which requires oxygen to break down. This creates anaerobic conditions in the root zone which limit plant growth and clog soil pores. To prevent this happening sludge should be **stabilized** prior to land application. This involves breakdown or digestion of organic material in the sludge at the wastewater treatment plant.

If sludge is applied over a long period of time some substances such as **heavy metals** will accumulate in the soil. After several applications these may reach levels which are harmful to animals, crops and people.

Groundwater contamination

Groundwater is vulnerable to contamination by any constituents of sewage sludge that dissolve in water or are small enough to be washed through openings in the soil to the water table.

Nitrate is the most common groundwater contaminant from sludge. Nitrogen is found in sludge as part of organic matter and as ammonia. Once applied to land these forms are broken down to ammonium and nitrate (see Chapter 2). Nitrate is readily soluble and therefore if not used by plants it will be leached through the soil by infiltrating rain or irrigation water.

Case study

Long-term pollution

Severe nitrate contamination of groundwater as a result of sludge application to agricultural land was seen in Gauteng. Liquid sludge has been applied to an area where fodder crops are cultivated for over 15 years. The rate of sludge application was not tied to crop requirements as this was primarily a means of disposing of the sludge. The area overlies a shallow dolomite aquifer which provides irrigation and drinking water to the surrounding agricultural area. Nitrate-nitrogen levels in excess of 40 mg/ℓ were found in groundwater more than 1 km away from the sludge applied area. The highest concentrations close to the area exceeded 200 mg/ℓ. Isotope analyses of the nitrate were carried out to confirm that it had come from the sludge and not from fertilizers used by the farmers or some other source. The contamination was thought to be severe as a result of a long period of high application rates which were not balanced against crop requirements. Dolomitic aquifers are particularly vulnerable because sink holes and fissures provide pathways for rapid migration of contaminants to groundwater.

Case study

Seasonal effects

Nitrate that has accumulated in bare ground during a dry period will be flushed through the soil with the first rains or irrigation. This was seen at a farm in the Western Cape where dried sludge cake was used to condition very sandy soil so that fodder crops could be grown. The natural levels of nitrate-nitrogen in the shallow groundwater were fairly high at around 7 mg/ℓ. After the winter rains these levels temporarily rose to between 10 and 15 mg/ℓ, above the safe limits for human consumption.

The amount of nitrogen lost to leaching is very variable, from insignificant amounts to 60% of nitrogen applied. If sludge is applied to **bare ground** during a rainy period then most nitrate that is formed will be carried below the root zone and through the soil by infiltrating water. The same will happen to nitrate that exceeds the crop requirements on vegetated ground.

In addition to the load of human organic waste matter present in sewage sludge, industrially manufactured **trace organic chemicals** may also occur. The type and concentration of these chemicals depends on the industries served by the wastewater treatment plant. They may include organochlorine pesticides, monocyclic aromatics, chlorobenzenes, and phenols.

Heavy metals and **phosphorus** are not very soluble and tend to accumulate in the soil. **Pathogenic micro-organisms** are usually killed off during treatment of the sludge or when they are exposed to sunlight during application to the field. Those that survive are mainly held in the soil. A few micro-organisms in the form of tough spores may be small enough and survive for long enough to reach the water table and contaminate groundwater.

Good farming practices

Beneficial application of sewage sludge to agricultural land can improve the condition of the soil and increase crop yields. However, farmers need to be aware of the associated risks in order to manage these and protect the natural resources of their farms.

Particular care should be taken with sludge application where any of the following conditions apply:

- → shallow aquifers underlie the fields where sludge will be applied
- → groundwater is used as drinking water for people or livestock on your farm or in the surrounding area
- → the quality of the groundwater is marginal.

Guidelines recommending safe sludge application rates exist in many countries. In South Africa, guidelines are given by the Department of Health. The maximum rate of application recommended is 8 t (dry mass)/ha.yr. The concentrations of potentially contaminating substances such as heavy metals may restrict the application rate to less than this and limit the cumulative loading over a period of several years. From the point of view of metal mobility, sludge should not be applied to soils with a pH of less than 6. The guidelines also recognize that sludge application to agricultural land should not exceed the crop nitrogen requirements to prevent leaching of nitrogen to groundwater. Given the difficulties in accounting for available nitrogen from sludge and any inorganic fertilizers that may be used, they provide only a general guide for crop nitrogen demand.

Guidelines for sludge use (Department of Health)

TYPE	SOURCE AND TREATMENT	STABILITY AND USES
A	Sludge from primary settling tanks, possibly mixed with other sludge types but which has received no treatment other than dewatering.	Unstable with a potentially high fly and odour nuisance and high levels of pathogenic organisms. May be used for composting, landfill and tree plantations with certain restrictions.
B	Waste activated sludge, humus sludge or sludge which has been digested. Generally some dewatering has taken place.	Stable with low fly and odour nuisance and reduced levels of pathogens. May be used as above plus on crops (excluding vegetables), grazing, public gardens and parks, etc. and nurseries with certain restrictions.
C	Sludge to which some specific sterilization treatment has been applied, e.g. composting, pasteurization, lime stabilization.	Stable with insignificant odour and fly nuisance and insignificant levels of pathogens. May be used as above with certain restrictions.
D	Tertiary sludge with low heavy metals content. Similar hygienic quality to Type C and metal contents are below stated limits.	Stable with insignificant odour and fly nuisance and insignificant levels of pathogens. May be used as above with certain restrictions plus on household vegetables and private gardens with certain recommendations.

Sludge is classified into four types by the Department of Health depending on its source, how it is treated and the level of potentially harmful substances it contains. The types are shown in the table below.

Type A sludge should not be applied to a slope of greater than 6% or to land underlain by an aquifer at less than 5 m. The sludge applied area should be further than 500 m from a dwelling and further than 200 m from a river, dam or borehole. Types B, C and D sludge should not be applied to a slope of greater than 4% or to land underlain by an aquifer at less than 2 m. The sludge applied area should be further than 200 m from a dwelling, river, dam or borehole. When considering the depth to the water table, however, remember that very permeable sands or fractured rocks offer less protection to the aquifer than soils with silt or clay.

Checklist

Before applying sludge make sure you obtain relevant information from the sludge producer:

- ➔ moisture content of the sludge,
- ➔ N:P:K and metals content,
- ➔ stability of organic matter,
- ➔ micro-organisms in the sludge.

On your farm be aware of:

- ➔ Depth to water table and soil permeability.
- ➔ Groundwater quality, particularly in terms of nitrates, TDS and micro-organisms.
- ➔ Crop nutrient requirements (amount and timing).
- ➔ Total nitrogen loading (including inorganic fertilizers).
- ➔ General considerations for minimising environmental impact: soil pH, slope, proximity to surface water features and drainage ditches, control access to area by humans and livestock.

Further information

(See **Useful Addresses**).

- ➾ Department of Health.
- ➾ Water Research Commission (Report Number TT 85/97: *Permissible Utilization and Disposal of Sewage Sludge*).

CHAPTER 6: IRRIGATION

Historically, irrigation has played a vital role in agricultural production. Civilisations have risen and fallen with the growth and decline of irrigation systems. In South Africa, irrigation accounts for half of all water consumption and nearly 80% of groundwater consumption.

Approximately 1.3 million hectares are irrigated in South Africa. It is estimated that around 5% of this area is irrigated with groundwater. The Karoo and Gauteng have the largest areas under irrigation using groundwater on approximately 24 000 and 19 000 ha respectively.

78% of groundwater abstracted in South Africa is used for irrigation. Therefore problems that are associated with irrigated areas could affect a large proportion of ground-water consumed. However, it should be noted that groundwater quality may be affected by irrigation whether surface water or groundwater is used.

An example of pivot irrigation

Irrigation with groundwater

AGRICULTURAL REGIONS	IRRIGATION FROM GROUNDWATER (HA)	TOTAL NO OF FARMS USING GROUNDWATER FOR IRRIGATION	FARMS WITH GROUNDWATER AS ONLY WATER RESOURCE (%)	PROBLEMS WITH GROUNDWATER (%)
Highveld	2 620	101	65	85
Karoo	24 184*	755	57	50
KwaZulu-Natal	170	27	11	89
Eastern Cape	2 066	85	62	85
Transvaal	19 785	408	83	94
Free State	8 011	443	86	36
Winter rainfall region	1 205	32	41	21

* Possibly includes some surface water irrigation

Modified after Braune and Coetzer (1992)

Impact of irrigation on groundwater

Although irrigation has enormous benefits, there are also associated disadvantages. The main impacts on groundwater are:

- Increased salinity.
- Declining water levels where groundwater is used to irrigate.
- Rising groundwater levels where surface water is used, sometimes to the point of waterlogging the surface.
- Leaching of other agricultural contaminants such as nitrate from fertilizer and pesticides.

Soil and groundwater **salinization** are the most common problems. Irrigation water always contains some salt. **Evapotranspiration** will consume some of the water but not the salt, thereby concentrating salt in the remaining soil water. This may remain in the soil or infiltrate down to groundwater depending on the relative rates of evaporation and water application. The salinity of the percolating water is typically 3 to 6 times greater than that of the source water. In situations where recycling occurs, and the return flow is used again either from a borehole or after it has flowed into a river, the concentration may increase ten-fold over a period of time. Thus a vicious circle may establish with ever worsening water quality.

The source of salts **leached** to groundwater may not necessarily be the irrigation water. Salts naturally present in soils may be leached to groundwater. This occurs particularly when areas are irrigated for the first time or when deep rip-ploughing methods are used.

Where groundwater is used to irrigate, and the amount abstracted is not sustainable, **water levels** may decline over time. This means that the water has effectively been mined from the aquifer as it is removed at a faster rate than it is replenished. This is particularly common in deeper aquifers which may have received most of their water thousands of years ago when the climate was wetter.

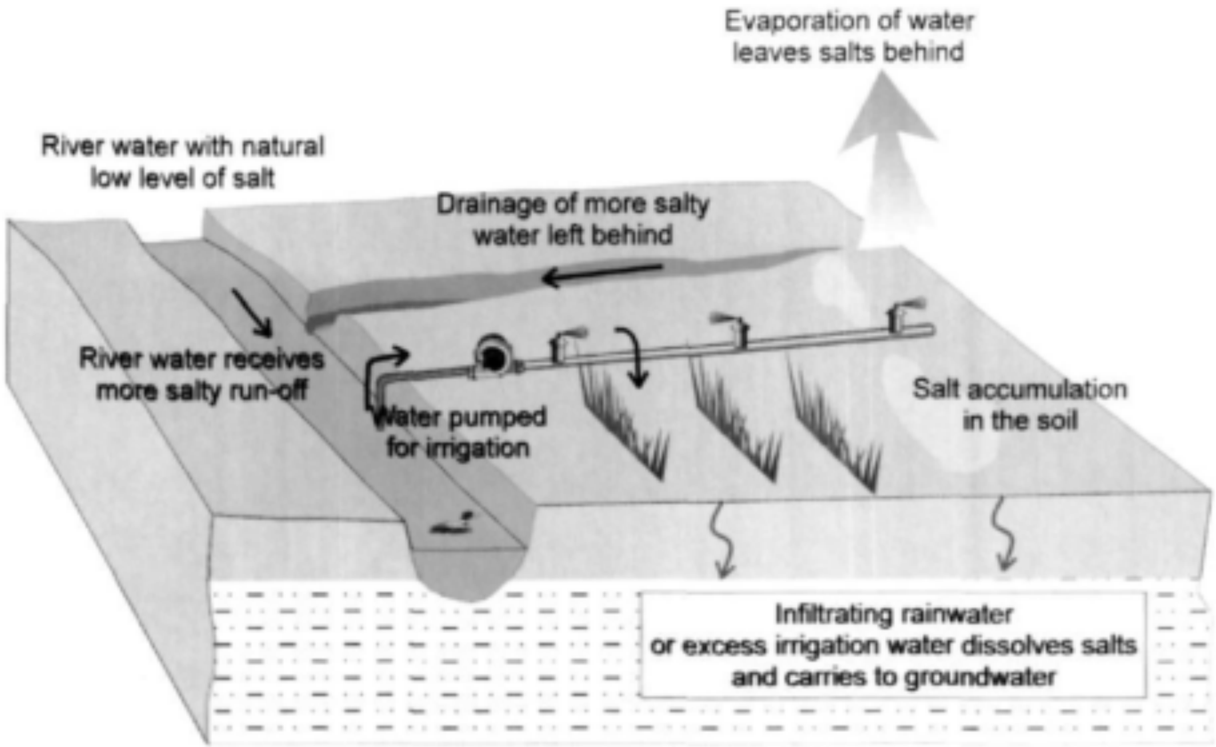


Figure showing irrigation return flow cycle

There is a far higher risk of **contaminating** groundwater in irrigated areas with significant percolation to the water table. Substances that may have otherwise remained on the surface of the soil to be taken up by plants or degrade, are more likely to be washed through to a vulnerable aquifer.

Case study

The Vaalharts Irrigation Scheme

This is the largest irrigation scheme in the country. The main crops include cotton, groundnuts, wheat, lucerne, maize, sunflower, citrus, peas and other vegetables. Vineyards are also irrigated. The climate of the area is semi-arid with an average rainfall of 450 mm per year.

The Vaalharts Government Water Scheme is divided into the West Canal area comprising about 5 000 ha and the North Canal area consisting of about 24 000 ha of irrigated land. The Taung irrigation scheme in North-West Province has an additional 3 570 ha. In the North Canal and the West Canal areas, about 97% of the land available for irrigation is flood-irrigated while about 2.5% is irrigated by overhead sprays and the remaining 0.5% drip-irrigated. Before the start of intensive irrigation, the groundwater table was at about 24 m depth. Over the years, flood irrigation has ***raised the water table*** *to about 1 m below the surface and in some areas has resulted in waterlogging at the surface. To overcome this, a comprehensive system of about 240 subsurface drainage systems was installed in the late 1970s. Computer models of the inputs and outputs at the Vaalharts scheme have been used to try to assess the impact on groundwater quality. It has been estimated that between 17 and 63 million cubic metres (17 and 63 billion litres) of water percolate to groundwater annually. Approximately 28 896 t of* ***dissolved salts*** *are thought to have been carried down to the water table per annum.*

It is estimated that between 65% and 83% of the salt load contained in the irrigation water supplied to the Vaalharts irrigation scheme has been retained in the groundwater store.

Case study

The Great Fish and Sundays River Basin

Fodder crops, maize and citrus orchards are irrigated in this basin. The area is semi-arid to arid with between 350 and 450 mm rainfall per annum. This low rainfall coupled with high evaporation losses mean that only a small percentage of the rainfall recharges groundwater storage. Recharge comes mainly from irrigation and leakage from canals and farm reservoirs. It is estimated that 34% of the volume of irrigation water applied in the Middleton area reaches the groundwater table. During the irrigation season from late August to April, water levels show a substantial rise, while a corresponding decline is observed from May to July when no water is applied to the lands.

The average ***salinity*** *of water in aquifers underlying irrigated land is considerably higher than below non-irrigated lands. The average TDS content of aquifers underlying irrigated lands has been reported at 3 400 mg/ℓ as opposed to 2 000 mg/ℓ for aquifers below non-irrigated veld. Besides the concentrating effect of evapotranspiration, mobilization of salts already present in the soils further increases the salinity of percolating water. Poor soil texture results in salts being precipitated in the soils which may be mobilized during future irrigation.*

Good farming practice

The following practices should help minimize salinization of groundwater.

→ **Efficient irrigation scheduling** closely tied to crop requirements. This will reduce over-irrigation and the volume of water that percolates beneath the root zone. Consider a range of different methods of irrigation and seek advice on which is most efficient and cost-effective for your crop type and climatic conditions. Calibrate existing irrigation schemes by monitoring soil moisture at and below the root zone.

→ Construct canals and dams with **impermeable linings**, such as clay or concrete, to reduce leakage.

→ Where possible, monitor the quality of irrigation water and attempt to use **better quality water** in order to reduce the input of water-borne soluble salts.

→ Carefully chose areas and timing of **new land** development. This is the most vulnerable time for salts from the soil to be washed out.

→ Where fertigation is carried out, install check valves to prevent back siphoning of the fertilizer solution into the borehole.

Where possible try to apply potentially contaminating substances, such as **fertilizers** and **pesticides**, at a time when irrigation is not carried out or is minimal. This will also reduce wastage.

Where you have boreholes, monitor the groundwater level at least every 3 months. Sample regularly for TDS and nitrates to determine if the water quality is being affected. Similarly, monitor the quality of soil water beneath the root zone.

Minimization of groundwater salinization often has to be considered alongside the control of soil salinization. Periodic over-irrigation to flush salts out of the soil is frequently used to reduce soil salinity. Obviously this will increase groundwater salinity if a vulnerable aquifer underlies the land.

Further information

(See **Useful Addresses**).

- Department of Water Affairs and Forestry.
- Department of Agriculture.
- Agricultural Research Council: *Institute of Soil, Climate and Water.*
- Institute of Agricultural Engineers.

CHAPTER 7: PESTICIDES

Pesticides are toxic compounds used to control weeds (herbicides), insects (insecticides), fungi, algae, etc. Their use has increased dramatically since the 1950s, as have the incidences of pesticide pollution. Since the 1980s, however, pesticide concentrations in many areas of the world have declined. Lower rates of application can be used because they are more effective.

Pesticides tend to be highly toxic therefore the maximum allowable concentrations recommended for **drinking water** are very low. South African drinking water guidelines for pesticides are based on the World Health Organization (WHO) guidelines. These state that a maximum level of **2 parts per billion** (ppb), equivalent to 2 microgrammes per litre (μg/ℓ) are allowed in drinking water. In Australia the level is higher at 15 ppb but in the UK it is lower at 0.5 ppb.

Contamination of groundwater

Groundwater has been widely contaminated with pesticides in many countries. Contamination occurs both from the large areas of application and from point sources where pesticides are spilt or disposed of.

In the mid 1980s, a total of 17 different pesticides had been recorded in groundwater in 23 different states in the **USA**. Over 200 wells were closed due to groundwater contamination by pesticides and roughly 6 500 wells were thought to contain pesticide residues arising from normal pesticide usage. This resulted in exposure of around 800 000 people in the USA to pesticides in their drinking water.

Leaching of pesticides to groundwater is dependent on the following factors:

- Rate of application.
- Availability of water (rain or irrigation) to dissolve and transport the pesticides to the water table.
- Solubility of the pesticide. On the whole herbicides tend to be more soluble than insecticides.
- Persistence of the pesticide in the soil. Some pesticides are broken down quite quickly whereas others are more likely to survive for the time it takes to reach the water table. Persistence is dependent on other factors such as soil pH and temperature. Pesticides usually break down more quickly at higher soil temperatures.
- Content of organic matter and clay particles in the soil. These often adsorb pesticides, preventing them from leaching to groundwater.
- Vulnerability of the aquifer to contamination, i.e. shallow groundwater covered by permeable material is more likely to be contaminated.

Groundwater contamination in South Africa

Very few laboratories in South Africa have the capacity to analyse water samples for pesticides. As a result only a limited number of investigations of their occurrence in groundwater have been carried out. However, several studies have shown that they do occur in areas where they are widely applied such as the maize growing areas.

In the early 1990s, a study showed that the herbicide atrazine was present in most rivers and dams in the maize producing areas of South Africa. These included the Olifants, Vals, Vaal, and Renoster rivers. Levels exceeding the WHO limits were detected in December and January just after the pre-emergent herbicide was applied. This river water is used in many areas for irrigation and therefore, where aquifers are recharged, acts as a source of pesticide contamination.

Tests of the **herbicides** methochlor and terbuthylazine have shown that they leach beneath the root zone in a wide variety of South African soils. Important controls on the amount leached were the content of **organic matter** and **silt**. Higher levels of organic matter and silt meant that more of the herbicides were adsorbed in the soil and less leached.

Case study

Vaalharts Irrigation Scheme

Groundwater has been found to be contaminated with atrazine from irrigation water at the Vaalharts Irrigation Scheme in the Northern Cape. The source of the atrazine was irrigation water contaminated to an average level of 0.42 ppb. Contamination of groundwater averaged 0.06 ppb with a maximum of 0.73 ppb. The original source of the atrazine was thought to be the dry land mealie farms upstream. Elevated nitrate levels were also seen in this shallow groundwater, although this was the result of fertilization and not introduced in irrigation water.

Good farm practice

As with many contaminants in groundwater, the negative effects of pesticides are long term and difficult to treat. In Italy for example, atrazine was detected in well water 6 years after its use was banned. Good practice to prevent contamination is therefore vitally important. Careful management is required both in the fields and where pesticides are stored and handled. Pesticides should be **stored safely** in a covered, contained area with a concrete base.

Always follow the recommended pesticide **application limits** on the label and do not add a bit extra "just to be sure". The limit recommended for atrazine is 2.5 kg of active ingredient per hectare per year. Be aware of the effectiveness of the pesticide in your environment and reduce the application rate if possible. During cooler, dry periods it may be possible to attain the same level of control with a lower dose (depending on the pesticide).

If you are **mixing the pesticide** with groundwater make sure this is done at least 15 m from the borehole and remove the hose from the mixing tank before switching off the water supply. This avoids the risk of back-siphoning which may inject pesticides directly into the borehole. Install a **back-flow prevention** device if possible. Remember that spills at the mixing area result in a much higher loading than normal application would. When planning a spraying programme listen to the **weather** report. Some pesticides such as pre-emergent herbicides and soil-applied pesticides benefit from a light rain which washes the pesticide into the upper soil layers. Too much rain, however, washes the pesticide too deep into the soil profile or carries it away with surface run-off. Post-emergent herbicides and plant-applied fungicides and insecticides do not benefit from rain as the pesticide will wash off.

Dispose of pesticide containers responsibly. They should go to a licenced hazardous waste site or returned to the supplier. **Empty pesticide containers should never be used for water**. Once all the pesticide has been used, puncture the bottom of the container to ensure that it will not be used.

Calibrate **spray equipment** to ensure that you do not over-apply. Before spraying check the proper size of the nozzle tip, spray width per nozzle, and flow rate from nozzle.

Similarly, dispose of **excess mixture** and rinse-water responsibly.

At farms where pesticides are regularly used the best practice to minimize the risk of contamination from the handling area is to construct a **pesticide spillage safety trap** (PSST). This makes use of the natural processes of breakdown and pesticide adsorption to clays and organic matter. The PSST should preferably be large enough to accommodate all sizes of pesticide application apparatus used on the farm including air-borne containers if crops are sprayed by plane. If that is not possible, a smaller pit may be constructed to receive all the runoff from the impermeable surface area of the handling area.

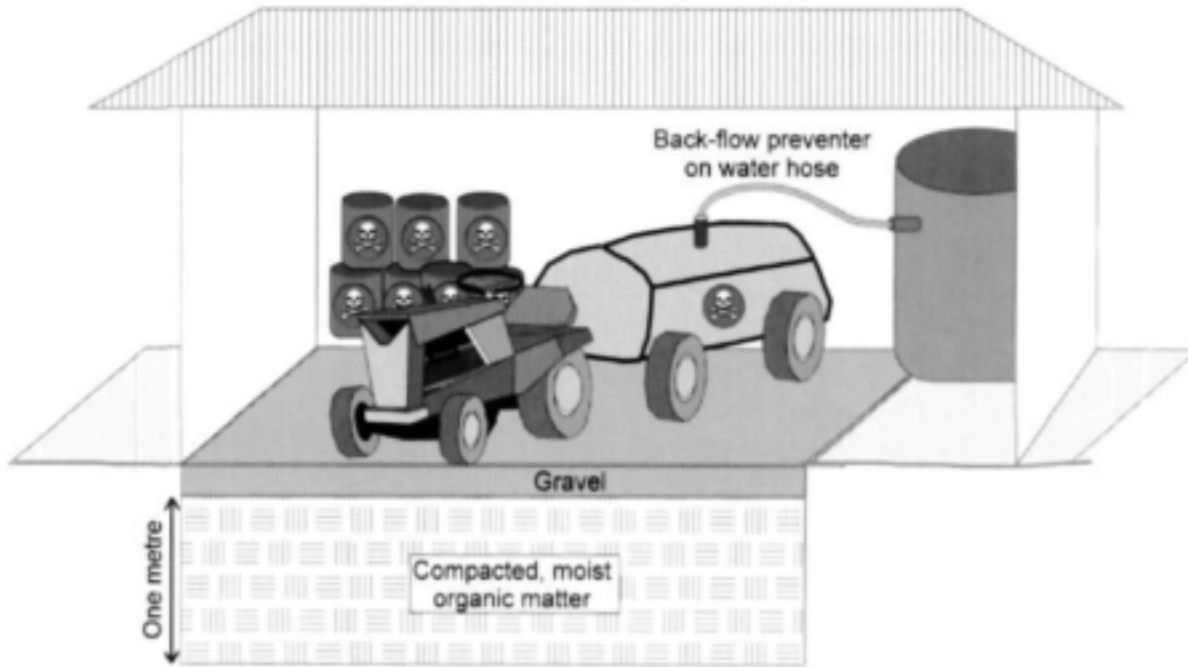


Diagram of a pesticide spillage safety trap (PSST)

PSST - How to build one

To build a Pesticide Spillage Safety Trap, select a site at least 100 m from the nearest borehole and preferably down-gradient of it.

A pit 1 to 1.5 m deep and of adequate surface area must be prepared. Organic matter that is either already well-composted, or has the ability to compost readily is used to fill the pit. The organic matter is compacted well enough so that the weight of a tractor and/or sprayer can be supported. The organic matter is covered with a layer of gravel that forms the working surface on which the tractor/sprayer is parked during filling/cleaning operations.

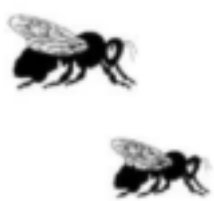
The environment inside the trap system should *ideally be acidic and moist to promote chemical* breakdown and biodegradation of pesticides. In other words do not add lime and periodically it may be necessary to add water. The water content of the organic matter should be checked regularly. The organic matter must not be allowed to dry out completely. Construct a roof, either a lean-to or a carport to prevent excessive flooding.

Over time the surface will subside. The system can be rejuvenated from time to time by addition of organic matter to the system.

Further Information

(See **Useful Addresses**).

- Agricultural and Veterinary Chemical Association of South Africa.
- Agricultural Research Council.
- Pesticide manufacturers, e.g. Novartis (formerly Ciba-Geigy).



Chapter 8: The Farmstead

Many of the activities common to farmsteads can pollute groundwater. Although the farmstead area is small, relative to the rest of the farm, materials and waste are often concentrated here. The borehole supplying drinking water to the farmer's family and workers is also usually in this area, therefore pollution of groundwater here could have a serious health effect.

Common sources of pollution found around the farmstead include septic tanks, stored fertilizer, silage and pesticides, animal waste and fuel tanks. Boreholes themselves may also act as a direct path for pollutants to groundwater if they are insufficiently sealed at the surface or if disused boreholes are left open and rubbish or small animals fall inside. Chapter 1 gives details on how to construct boreholes to reduce the risk of contamination.

Septic systems

Septic systems consist of a holding tank and a soakaway. They are dynamic and living systems and as such are sensitive to misuse. A survey in the USA found that fewer than half of rural septic systems were working properly. Septic systems should be properly designed and not overloaded. They should receive only household wastewater and not other types of liquid waste. **They should be sited at least 100 m down slope from the nearest borehole.**

In a septic system, household wastewater flows into a tank constructed underground. As the water collects in the tank most of the solids settle out to the bottom and are decomposed by microbes to form sludge. Most types of septic tanks require desludging regularly, usually annually. A thick oily scum forms on top of water in the tank, leaving relatively clear water in the middle. If the wastewater has a high level of detergents, antiseptics or solvents, microbes in the sludge may be killed off and biodegradation of the solid matter will slow down. This may result in waste backing up the system. Household wastewater with high levels of these liquids should therefore be disposed of in an alternative, safe way, for example by dilution and application to land at a low rate in an area where it will not run-off to a river.

Partially treated water with a lower level of solids is fed out of the tank to an underground drainage field or soakaway. As water percolates away from the drainage field it is further purified by microorganisms that live in the soil. As long as there is a sufficient distance between the drainage field and the water table (at least 10 m) and pollutants are broken down by microbes or filtered in the soil, the percolating water should be clean by the time it mixes with groundwater.

A borehole (blue pipe) sited dangerously close to a pit latrine

The size of the septic system

In the case of septic systems, size is important! The size of the holding tank in a septic system is dependent on the number of people it should serve. Generally the following formula is used: Size of tank in litres = (180 x number of people) + 2000. The size of the drainage field is calculated by carrying out percolation tests in holes in the soil. Several test holes, 150 mm x 150 mm x 400 mm deep should be dug in the area to be used as a drainage field. Fill each hole with water and leave it over- night. If the water does not drain away overnight the area is not suitable. If the water has drained away, fill each hole with 300 mm of water and time how long in seconds it takes to empty. If it takes longer than 50 minutes the soil is not permeable enough and the area is not suitable. Work out the average time in seconds for all the holes and divide by 300. Take this value and multiply it by the number of people to be served by the system and then by 0.25. This gives you the area (in square metres) necessary for the soakaway.

Storage of fertilizers, pesticides and silage

Fertilizers and pesticides should always be stored in a safe area, with restricted access. This should be under cover, on an impermeable floor (such as uncracked concrete) with a containment wall. Bags of *dry products should be stored on palette and kept* separate from liquids. The storage facility should be located **at least 50 m down slope of the nearest borehole.** Mixing should take place within the contained area so that spills can be easily controlled and will not infiltrate the soil. Make sure that empty pesticide containers and fertilizer bags are disposed of responsibly. They should go to a licensed waste site or be returned to the supplier. Puncture empty pesticide containers so that they cannot be used to hold water.

Moisture from silage is particularly corrosive and may contain potential contaminants. Effective management of silage to minimize the risks to groundwater quality are discussed in Chapter 4.

Fuel storage tanks

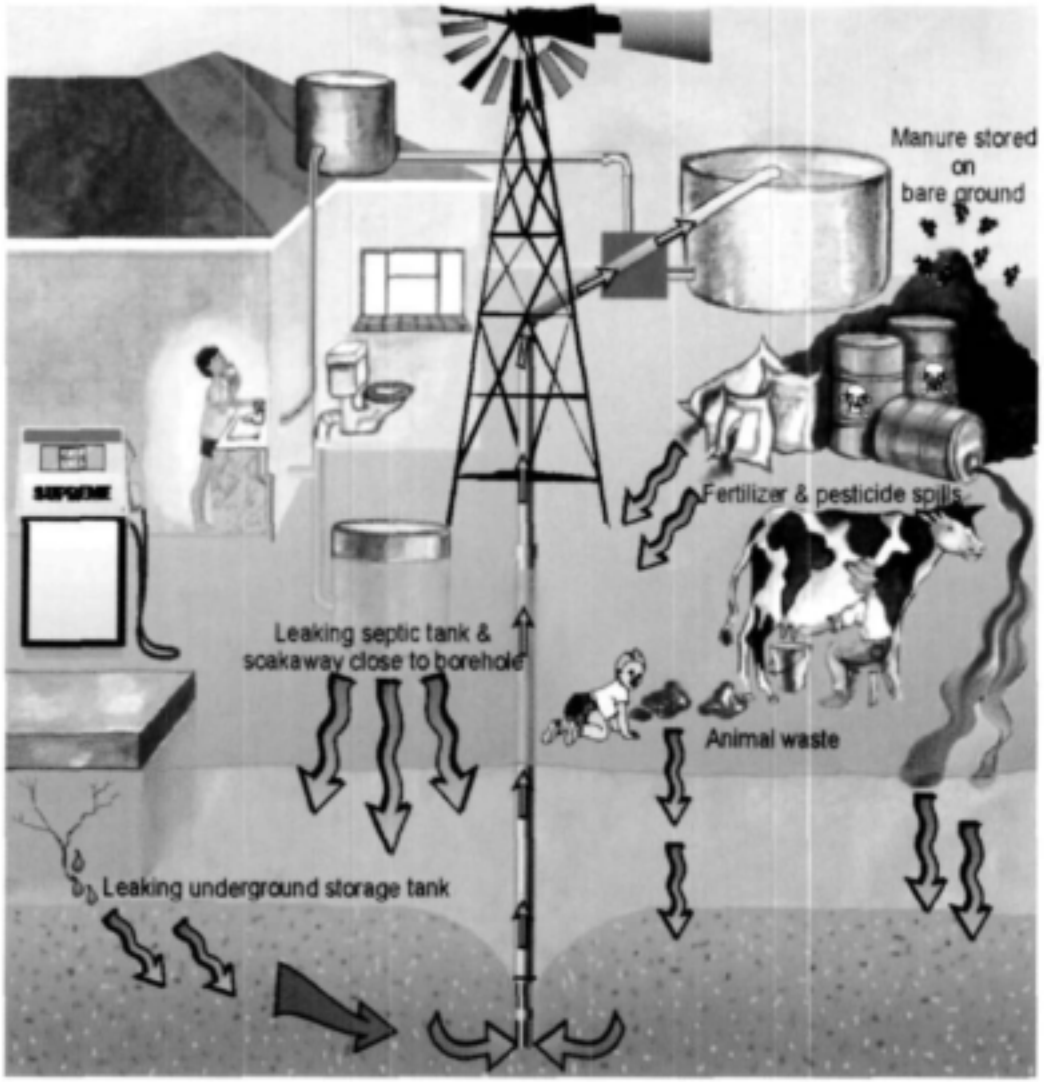
Fuel is frequently stored underground in tanks. Leaks from underground are more likely to go undetected and the source of pollution is closer to the aquifer. Spills on the surface may also infiltrate the soil and contaminate groundwater, however some of the more volatile constituents will evaporate. Petroleum products contain many chemicals which are dangerous to humans and the environment, such as benzene which increases the risk of cancer.

Install tanks in a bund (contained area with impermeable base and walls) or double skin tanks to reduce the risk of leaks infiltrating the soil. If old tanks are in use, keep a careful inventory and investigate the integrity of the tank if the output and input don't balance. Make sure that a responsible person oversees fuel transfer and that they aim to minimize spills. Do not overfill the tank as spills commonly occur as the liquid expands after transfer. If fuel is stored in tanks above ground, ensure that a compacted or concreted containment area is constructed around the tank to retain spills and leaks. If oily water is found in the bund or contained area, a special absorbent blanket may be used to remove the oil. If there is only a little oil in the water, the water should be applied to land at a low rate, where it will naturally degrade.

Animal waste

Chapter 4 deals with the management of animal waste in large volumes. Many of the principles discussed in that chapter should be applied to smaller volumes of animal waste that are produced around the farmstead. A small amount of waste in the wrong place can lead to significant contamination. In one instance, the source of high levels of nitrate in groundwater used for drinking was traced back to the farmer's dogs urinating on the borehole casing!

Manures should be stored on an impermeable pad with controlled run-off. This should be sited **at least 50 m down-slope of the nearest borehole.**



Hazards to groundwater quality at the farmstead

Checklist

Be particularly sure to manage and construct with pollution prevention in mind when:

- → A drinking water supply borehole is located in or close to the farmstead.
- → Groundwater occurs at a shallow depth.
- → The soil in the farmstead area is permeable or the farmstead is located on fractured hard rock.

Important steps towards pollution prevention:

- → Make sure the supply borehole is protected with a concrete apron around the well-head area and grouting surrounds the borehole casing for the first few metres below ground.
- → Construct an effective seal around the top of disused boreholes and never use them to dispose of waste.
- → Do not site septic systems within 100 m of a borehole.
- → Make sure that potentially contaminating areas such as fertilizer and silage storage are at least 50 m down-hill of a supply borehole.
- → Do not mix fertilizers or pesticides near the borehole.
- → Store animal waste, fertilizers and pesticides under cover, on a concrete pad with a containment wall or constructed drainage channels.
- → Be aware of what is happening in septic tank systems and storage tanks underground.
- → Manage septic tanks effectively, ensure they are used by the number of people they were designed for and desludge regularly.

Further information

(See **Useful Addresses**).

- The Water Research Commission - Report 597/2/95 - *Guidelines for the Use of Septic Tank Systems in the Coastal Zone.*

- Department of Water Affairs & Forestry. *A guideline for groundwater protection for the community water supply and sanitation programme.* 1995. ISBN 0-621-16787-8.

USEFUL ADDRESSES

Agricultural and Veterinary Association of South Africa - AVCASA
PO Box 1995
Halfway House
1685
Tel: 011 8052000
Fax: 011 8052222
Internet:http//www.AVCASA.co.za

Agricultural Research Council
Institute of Soil, Water and Climate
PO BOX 8783
Pretoria
0001
Tel: 012 4279800
Fax: 012 3422231
Internet: same as National Dept. of Agriculture

Borehole Water Association
PO Box 1155
Saxonwold
2132
Tel: 011 4470853
Fax: 011 4470851
Email:Boreholewater@mweb.co.za

CSIR
Environmentek Analytical Laboratory
PO Box 395
Pretoria
0001
Tel: 012 841 2620 or 021 888 2400
Fax: 012 841 2590 or 021 888 2682
Internet: http://www.csir.co.za/environmentek/index/html

Department of Water Affairs and Forestry
Directorate of Geohydrology
Private Bag X313
Pretoria
0001
Tel: 012 338 7862
Fax: 012 328 6397
Internet: http://www-dwaf.pwv.gov.za/

Department of Health
Private Bag X828
Pretoria
0001
Tel: 012 312 0000
Fax: 012 325 3209

Directorate Plant and Quality Control
Private Bag X 258
Pretoria
0001
Tel: 012 319 6504
Fax: 012 319 6055/ 3265606
Internet: same as National Dept. of Agriculture

Directorate of Veterinary Services and Livestock Improvement
Private Bag X250
Pretoria
0001
Tel: 012 319 6500
Fax: 012 323 3465
Internet: same as National Dept. of Agriculture

Directorate of Agricultural Engineering
Private Bag X515
Silverton
0127
Tel: 012 842 4279
Fax: 012 804 3048
Internet: same as National Dept. of Agriculture

Directorate of Resource Conservation
Private Bag X120
Pretoria
0001
Tel: 012 319 7547
Fax: 012 329 5938
Internet: same as National Dept. of Agriculture

Fertilizer Society of South Africa
PO BOX 75510
Lynnwood Ridge
0040
Tel: 012 349 1450
Fax: 012 349 1463
E-mail:fssamvsa@cis.co.za

Institute of Agricultural Engineers
Private Bag X519
Silverton
0127
Tel: 012 8424000
Fax: 012 8040753
Internet: http://www.ARC.agric.za

National Department of Agriculture
Private Bag X250
Pretoria
0001
Tel: 012 319 6083/6069
Fax: 012 319 6452/325 3618
Internet: http://www.agric.za

South African Feedlot Association
PO Box 35721
Menlo Park
0102
Tel: 012 3617649
Fax: 012 348 3930
Internet: http://www.SAFeedlot.co.za

South African Agricultural Union
SAAU Building
c/o Schoeman & Andries street
PO BOX 1508
Pretoria
Tel: 012 322 6980
Fax: 012 320 0557
Internet: http://www.agriinfo.co.za

Water Research Commission
PO Box 824
Pretoria
0001
Tel: 012 330 0340
Fax: 012 331 2565
Internet: http://www.wrc.org.za

Glossary of Groundwater Terms

aquifer: permeable earth material such as porous sediments or fractured hard rock, saturated with groundwater. The permeability should be such that it is capable of conducting and yielding usable quantities of groundwater to a borehole(s) and/or springs (a supply rate of 0.1 *l*/s is considered as a usable quantity). Latin: aqua - water and ferre - to carry.

borehole: generic term used for any drilled or hand-dug hole used to abstract or monitor groundwater, irrespective of diameter or construction.

casing: tubular lining installed in some wells to provide structural support for the borehole. Usually made from steel or PVC. *Plain casing* has no holes and prevents anything entering the borehole. *Slotted casing* forms *screens* and allows water to the pump.

confined aquifer: an aquifer which is overlain by a confining layer of low permeability. The groundwater is confined under pressure greater than atmospheric pressure so when the aquifer is penetrated the water level will rise above the top of the aquifer.

contamination: the introduction into the environment of any substance by the action of man.

discharge area: an area in which groundwater is discharged to land surface, to surface water or the atmosphere.

dissolved solids: minerals and organic matter dissolved in water.

evapotranspiration: outflow from a hydrologic system as a combination of evaporation from open bodies of water and soil surfaces, and transpiration from the soil by plants.

gravel pack: loose sand or gravel artificially placed between screens and the borehole wall during construction to stabilize the aquifer (usually in primary aquifers) and provide a zone of high permeability next to the borehole.

hydrogeology: the study of groundwater. Synonymous with geohydrology.

leaching: dissolution and removal of substances in the soil by percolating water.

permeability: refers to the ease with which a fluid can pass through a porous medium. In hydrogeology, permeability is often used synonymously with *hydraulic conductivity*, which specifically refers to the ease with which *water* is transmitted through a porous medium. It is defined as the volume of water discharged from a unit area of an aquifer under unit hydraulic gradient in unit time (expressed as $m^3/m^2/d$ or m/d).

pollution: the introduction into the environment of any substance by the action of man at concentrations which result in significant harmful effects to man and environment.

porosity: the ratio of the voids in a rock to the total volume. Usually expressed as a percentage. Primary porosity is formed at the same time as the rock is formed (e.g. intergranular porosity in a sand). Secondary porosity is formed after the rock (e.g. fractures in hard rock).

primary aquifer: an aquifer in which water moves through the original interstices of the geological formation, e.g. pores between sand grains. This type of porosity is termed primary porosity.

pumptest: a method of measuring the properties of aquifers, specifically transmissivity and storativity in confined and unconfined aquifers.

recharge: process of the addition of water to the groundwater system by natural or artificial processes. Usually given as a percentage of annual precipitation but may also include artificial sources and recharge from rivers, lakes and other aquifers.

rest water level: the static water level in a borehole when not pumped. Usually measured in metres below top of casing.

salinity: see total dissolved solids

screen: casing which is perforated with slots to allow water to flow in to the borehole.

secondary aquifer: an aquifer in which water moves through the secondary interstices, which are a result of post-depositional processes, such as joints and faults.

storativity: the volume of water released from storage in an aquifer per unit surface area per decline in groundwater level.

total dissolved solids: total mass of substances dissolved in water. Usually measured in mg/ℓ. This determines the *salinity* of the water. Water with a TDS of < 1 000 mg/ℓ is *fresh*, water that contains between 1 000 and 10 000 mg/ℓ is termed *brackish*, *saline* water contains between 10 000 and 35 000 mg/ℓ and a brine contains more than 35 000 mg/ℓ.

transmissivity: a property of aquifers measured during pumptests which is a function of the permeability of the aquifer and its thickness (m^2/day).

vulnerability: a relative measure of the susceptibility of a groundwater body to be contaminated; governed by the physical, chemical and biological properties of the soil and rock.

water table: the top of an unconfined aquifer, where the aquifer is fully saturated and the water pressure is equal to atmospheric pressure. Usually measured in metres below ground level or metres below top of casing.

well-head: the top of a borehole and surrounding construction at the ground surface.

GROUNDWATER DATA SHEET

Borehole:	Date:
Location:	Sampled by:
Latitude:	Longitude:

Sketch of location

Sample marked as: ....

Analytical Laboratory: ....

Aquifer type:	Depth of borehole:

Water levels measured from: ....

Rest water level:	Started pumping at:
Pumped water level:	Pumping rate:
Abstraction method:	Time of sampling:
Water temperature:	Air temperature:
TDS:	pH:
Colour:	Odour:
Other (oily sheet etc)	

Analyses to be completed:

EC TDS pH

Ca Mg Na HCO_3/CO_3 SO_4 Cl NO_3 NH_4 TKN

Faecal coliforms Total coliforms *E. coli*

Pesticide Total petroleum hydrocarbons

Other

Attach results of analyses. Specify units, feet or metres, litres per seconds, etc.

GUIDELINES FOR DRINKING WATER

Dept. of National Health & Population Development (1990)

Determinand	Units	Republic of South Africa	
		Maximum limit insignificant risk	Maximum limit for low risk
Physical			
Conductivity	mS/m	300	400
DOC	mg/ℓC	10	20
Dissolved oxygen	% Sat.	30	10
pH	pH unit	5.5 - 9.5	> 4/< 11
Turbidity	NTU	5	10
Microbiological			
Stand. plate count	/ 1 mℓ	1 000	10 000
Total coliform	/100 mℓ	5	100
Faecal coliform	/100 mℓ	1	10
Clostridium perfrigens	/100 mℓ	1	10
Coliphages	/100 mℓ	10	100
Enteric viruses	/10 ℓ	1	10

Table 1 : Proposed criteria for physical and microbiological factors in drinking water

Determinand	Units (mg/ℓ)	Republic of South Africa	
		Maximum limit insignificant risk	Maximum limit for low risk
Macro-elements			
Ammonia	N	2.0	4.0
Calcium	Ca	200	400
Chloride	Cl	600	1 200
Fluoride	F	1.5	3.0
Hardness	$CaCO_3$	650	1 300
Iron	Fe	1.0	2.0
Magnesium	Mg	100	20
Manganese	Mn	1.0	2.0
Nitrates	N	10.0	20.0
Potassium	K	400	800
Sodium	Na	400	800
Sulphates	SO_4	600	1 200

Table 2 : Proposed criteria for macro-elements in drinking water