A CONCISE GUIDE TO

GROUNDWATER QUALITY PROTECTION FOR FARMERS

WATER RESEARCH COMMISSION

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INTRODUCTION

Groundwater is a vital resource to the agricultural sector. Farmers use an estimated 60% 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 infiltration through the soil. The activities of farmers can significantly affect the quantity and quality of this recharge water.

This booklet aims to inform farmers about practical measures they can take to minimise the risk of contaminating groundwater. Some of the most far-reaching measures to protect groundwater quality are also practical and cost-effective because they reduce long-term losses of fertilisers, 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 minimised.

Examples of good farming practices are:

- Efficient irrigation and fertiliser scheduling to match crop requirements and minimise 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 fertiliser requirements
- Maintenance of an impermeable interface layer in feedlot pads
- Monitoring groundwater levels and quality regularly to detect any changes

What is groundwater quality?

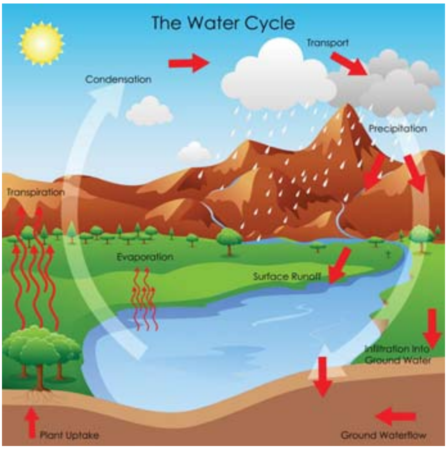
This term refers to the water chemistry and microorganisms living in it. Groundwater naturally contains many dissolved substances such as calcium and chloride. Soluble materials that are applied to the land may also be transported into the aquifer and some of these are harmful to health and/or the environment.

GROUNDWATER

THE IMPORTANCE OF GROUNDWATER

Groundwater provides a vital source of water in many areas of South Africa. It is estimated that South Africa has around 50 billion m^3/year potentially available groundwater. Around 1 770 million m^3/year is being abstracted for use in agriculture, industry and for cities and towns.

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.



Groundwater in the water cycle. 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, wetlands, 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.

AQUIFERS IN SOUTH AFRICA

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.

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 microorganisms 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.

All aquifers contain communities of microorganisms. Microbial contamination occurs when microorganisms that pose a risk to health are introduced to groundwater, usually from a faecal source (like unlined pit toilets or sewage spills from septic tanks). Dysentery, cholera and gastroenteritis are examples of diseases transmitted by bacteria in water. Faecal coliform, particularly ***Escherichia coli***, are used to indicate faecal contamination.

Livestock can tolerate drinking water with TDS (salt) levels up to 3 000 mg/L.

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 fertilisers, 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, fertilisers 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 relatively high rate of recharge by rain or irrigation water

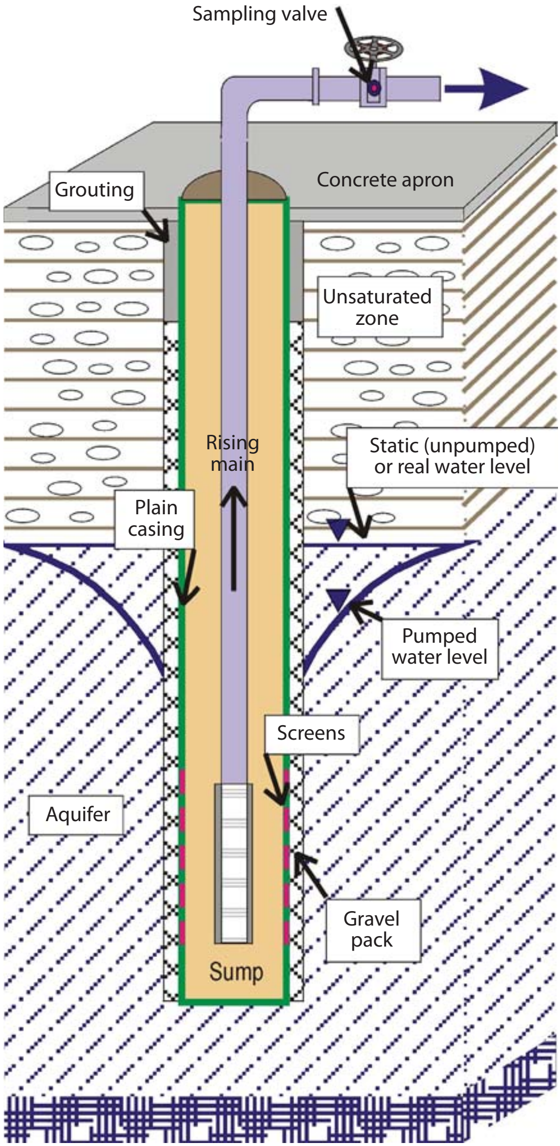


Diagram of borehole and well-head area

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 too 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-abstracted.

A sample of groundwater should be analysed every year. The most important hydrochemical characteristics to measure are the 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 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.

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.

Eight simple steps 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 sterilised sample jar from the laboratory. Do not touch the inside of the container or its lids 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 fertilisers
    - 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.

NITRATES

Nitrate is the most commonly occurring contaminant. Nitrate pollution is known to result from the application of sewage sludge to land, tilling of the soil (mineralisation or organic matter), fertiliser 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 methemoglobinemia, 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 hospitalisation and blood transfusion.

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.

Nitrate cannot be removed from water simply by boiling or filtering.

Special water treatment units involving technologies such as reverse osmosis, ion exchange, biological denitrification or distillation are required.

Horses are extremely sensitive to high levels of nitrate.

NITROGEN AND THE NITROGEN CYCLE

Nitrogen is a common element. Around 80% of the air we breathe 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 fertilisers are manufactured from nitrogen in the atmosphere. Nitrogen is also found in organic matter, particularly animal waste, and in the environment as ammonia, ammonium and (more rarely) as nitrite.

Nitrate is an oxidised form of nitrogen which is found in soil, water and some of the food we eat.

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

- High rates of nitrogen loading from fertiliser, 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

OCCURRENCE OF NITRATE IN GROUNDWATER

Nitrate is already a major problem in groundwater in many countries where intensive agriculture is practiced, 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 results from agricultural activities such as fertiliser application, ploughing and livestock effluent irrigation. If your groundwater is below the 10 mg/L NO_3-N limit, but still contains a few milligrams per litre nitrate-nitrogen, beware: a small addition to the natural level will make the groundwater unfit to drink. If you are fortunate enough to have a good quality groundwater resource 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 minimise 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.

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 fertiliser 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. Fertiliser should be applied at times of peak crop requirements.

Nitrogen balance

Inputs:

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

Outputs:

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

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 fertilisers (from the supplier). These sources constitute the bulk of your nitrogen input. You can also make a good estimate of 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 uptake 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 fertiliser application according to nitrogen uptake
- **Schedule irrigation** efficiently to reduce 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.

FERTILISERS

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

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 fertilisers. The section on nitrates describes the nitrogen cycle and shows the role that fertilisers play.

A major advantage of inorganic fertilisers 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 fertilisers like farm yard manure which slowly release nutrients and therefore cannot be scheduled accurately.

Inorganic fertilisers 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 fertilisers are:

- Soil acidification
- Negative crop effects associated with over-application (excessive growth, delayed maturity, loss of yield)
- 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 fertilisers.

GROUNDWATER CONTAMINATION

The main risk to groundwater quality from the use of fertilisers is nitrate contamination. Nitrate is the most soluble nutrient supplied by inorganic fertilisers and therefore the most likely to be leached down to the water table (see previous section). 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 fertilisers has been seen in many countries where intensive crop farming is practised. In South Africa, the level of fertiliser use is much lower than the global average. However, studies have shown that inorganic fertilisers 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.

GOOD FARM PRACTICES

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

- The water table is shallow and the unsaturated zone is permeable
- Fertiliser is applied at a time when it is not being taken up by the crop
- Fertiliser 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 fertilisers 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 fertiliser 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
- How much fertiliser should be applied at the different times?

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.

Be particularly aware of over-fertilisation 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.

Action plan

Before fertilising:

- Set a realistic crop yield goal.
- Determine the nutrient requirements of the crop for this yield.
- 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.
- Find out how the nitrogen requirements of the crop will change through the growing season.
- Work out a schedule for fertiliser application.
- Store fertilisers safely in a covered, contained area on a concrete base.

Fertilisation

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

Long-term activities

- Minimise 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.
- Keep a balance sheet of calculated and estimated nutrient inputs and outputs.
- Check for signs of over-fertilisation in the crop (excessive growth, etc.)

- Monitor soil nutrient levels regularly (every one to three years)
- Monitor nitrate and total dissolved solids in groundwater regularly, remembering that it may be years before contamination reaches the water table.
- If irrigating, monitor soil moisture levels to ensure that you are not over-irrigating.

Don't forget

- Contamination from fertilisers can also occur during storage or handling.

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 fertiliser 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 runoff 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.

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 section on nitrate). This may then be leached to vulnerable groundwater during periods of rainfall or irrigation.

Animal effluents typically have TDS (salinity) levels of 3 000 to 15 000 mg/L. This is much higher than the TDS of fresh groundwater, 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.

Microorganisms 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, microorganisms may reach the water table.

Microorganisms such as viruses, bacteria, protozoa and helminth eggs are present in animal excreta.

Piggery and dairy waste problems – a case study

A study of the groundwater at a IFE farm which housed around 6 000 pics and 800 cows, in the Western Cape, highlighted some of the problems which results 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. At this level the water is not only unsafe for human consumption but should not be used for livestock watering. 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; and 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 example, 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 lifespan 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 associate 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 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 a year. Pads should be sited on a 2 to 5% slope with feeding and drinking troughs at the upper end. The slope will reduce standing water and runoff 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 runoff 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.

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 year 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 minimised.

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 laoads are also found where livestock congregate, such as at feeding or water troughs and gates. The impact of this can be minimised by not exceeding the carrying capacity of the pasture and using mobile feeding and drinking troughs.

Used sheep dip should be disposed of responsible. 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 many damage steel and concrete tanks or containment walls. Store silage in corrosion resistant material 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.

IRRIGATION

Historically, irrigation has played a vital role in agricultural production. In South Africa, irrigation accounts for more than half of 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. Groundwater quality may be affected by irrigation whether surface water or groundwater is used.

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

SALINISATION

Soil and groundwater salinisation 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 cycle 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

A closeup of salinisation of soil.

Typical waterlogged soil.

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.

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 top of the surface of the soil to be taken up by plants or degrade, are more likely to be washed through to a vulnerable aquifer.

The case of the Vaalharts Irrigation Scheme

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

The Vaalharts Irrigation 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. Before the start of intensive irrigation, the groundwater table was at about 24 m depth. Over the years, irrigation has raised the water table to about a metre 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. It is estimated that between 65% and 83% of the salt load contained in the irrigation water supplied to the irrigation scheme has been retained in the groundwater store.

GOOD FARMING PRACTICES

The following practices should help minimise salinisation 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 the 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 waterborne soluble salts.
- Carefully choose 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 fertiliser solution into the borehole.
- Where possible, apply potentially contaminating substances, such as fertilisers 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.
- Minimisation of groundwater salinisation often has to be considered alongside the control of soil salinisation. 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.

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.

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 Organisation (WHO) guidelines. These state that a maximum level of 2 parts per billion, equivalent to 2 micrograms per litre are allowed in drinking water.

CONTAMINATION OF GROUNDWATER

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

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 can absorb 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 of 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.

GOOD FARM PRACTICE

As with many contaminants in groundwater, the negative effects of pesticides are long term and difficult to treat. 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 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 pesticides into the upper soil layers. Too much rain, however, washes the pesticide too deep into the soil profile or carries it away with surface runoff. 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 minimise the risk of contamination from the handling area is to construct a pesticide spillage safety trap. This makes use of the natural processes of breakdown and pesticide adsorption to clays and organic matter. The trap should preferably be large enough to accommodate all sizes of pesticide application apparatus used on the farm, including airborne 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.

How to build a pesticide spillage safety trap

1. To build a pesticide spillage safety trap, select a site at least 100 m from the nearest borehole and preferably down-gradient of it.
2. Prepare a pit 1 to 1,5 m deep of adequate surface area.
3. Fill the pit with organic matter that is either already well-composted, or has the ability to compost readily.
4. Compact the organic matter well enough so that the weight of a tractor and / or sprayer can be supported.
5. Cover the organic matter with a layer of gravel. This will form a working surface on which the tractor or sprayer is parked during filling and / or cleaning operations.
6. Construct a roof, either a lean-to or a carport to prevent excessive flooding.

The environment inside the trap system should ideally be acidic and moist to promote chemical breakdown and biodegradation of pesticides. In other words, do no add lime and periodically, it may be necessary to add water. The water content of the organic matter must not be allowed to dry out completely.

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

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 are 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 fertiliser, 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.

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. 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 the 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 runoff to a river.

A typical septic tank and soak pit.

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.

STORAGE OF FERTILISERS, PESTICIDES AND SILAGE

Fertilisers and pesticides should always be stored in a safe area, with restricted access. This should be under cover, on an impermeable flood (such as uncracked concrete) with a containment wall. Bags of dry products should be stored on pallets 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 fertiliser bags are disposed of responsibly. They should go to a licenced 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.

Empty pesticide containers should be punctured so that they cannot be reused.

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 tans 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 minimise 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 concrete 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.

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.

FURTHER READING

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ABBREVIATIONS AND GLOSSARY

Aquifer	Permeable earth material such as porous sediments or fractured hard rock, saturated with groundwater
Borehole	Generic term used for any drilled or hand-dug hole used to abstract or monitor groundwater
Casing	Tubular lining installed in some wells to provide structural support for the borehole. Usually made from steel or PVC
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
DWS	Department of Water and Sanitation
Evapotranspiration	Outflow from a hydrologic system as a combination of evaporation from open bodies of water and soil surface, and transpiration from the soil by plants
Gravel pack	Loose sand or gravel artificially placed between screens and the borehole wall during construction to stabilise the aquifer and provide a zone of high permeability next to the borehole
IFE	Intensive farming enterprises
Leaching	Dissolution and removal of substances in the soil by percolating water
mg/L	Milligrams per litre
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.
Pollution	The introduction into the environment of any substance by the action of man at concentrations which result in significant harmful effects on man and environment
Porosity	The ratio of the voids in a rock to the total volume. Usually expressed as a percentage
Primary aquifer	An aquifer in which water moves through the original interstices of the geological formation; e.g. pores between sand grains
TDS	Total dissolved solids

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