CHAPTER 6

Impacts on Waste Planning and Management

CHAPTER 6: IMPACTS ON WASTE PLANNING AND MANAGEMENT

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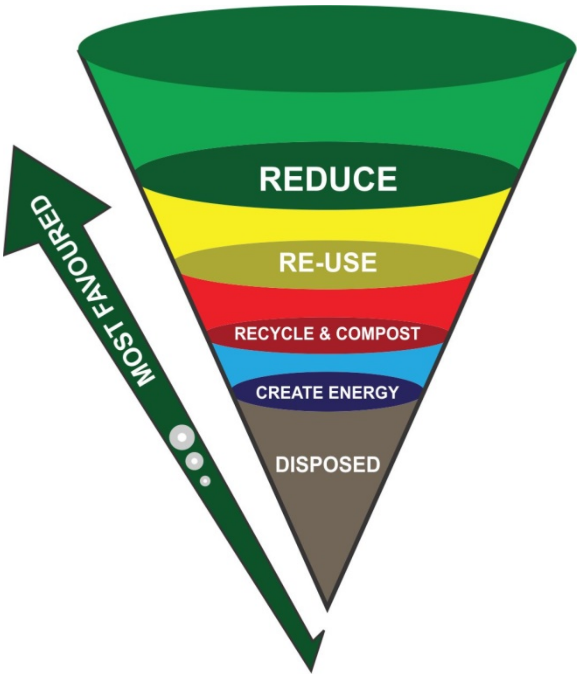
It is reported that "***problems related to mining waste, may be rated as second only to global warming and stratospheric ozone depletion in terms of ecological risk***" (European Environmental Bureau (EEB), 2000). The potential impacts of waste from shale gas development (SGD) is therefore of particular concern in the study area where supporting infrastructure is limited.

Municipal solid waste landfill sites in the study area do not meet the design requirements as outlined in the national norm and standards for disposal of waste to landfill. It is unlikely that the municipalities in the study area will be able to afford the required upgrades in the near future. There is also lack of available capacity, in terms of infrastructure, access control and skills to deal with different types and additional volumes of waste in the study area including hazardous waste disposal facilities licensed to accept Type 1, 2 or 3 hazardous waste.

An imminent amendment to the Waste Act, 2008 may result in SGD waste being classified as general waste in which case municipal waste disposal sites are at risk of receiving waste from SGD in future. Municipal landfills in the study are not designed or equipped to receive waste of this nature and staff do not have the skills or experience to manage this waste responsibly.

Available waste water infrastructure in the study area is under pressure and requires urgent intervention. The technologies and capacity at these already stressed facilities are not sufficient or appropriate to treat waste water from SGD.



Waste must be managed in an integrated way in-line with the waste management hierarchy and the principles for integrated waste management in South Africa. The emphasis here is to minimise waste arisings, promote the use of non-hazardous chemicals, re-use and recycling and minimise the impact of waste on water, the environment and communities.

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6.1 Introduction and scope

The European Environmental Bureau (EEB) stated that "*problems related to mining waste, may be rated as second only to global warming and stratospheric ozone depletion in terms of ecological risk*" (EEB, 2000). The release to the environment of mining waste can therefore result in profound, generally irreversible destruction of ecosystems. The management of waste is an integral part of responsible shale gas development (SGD) but can be especially challenging in areas where supporting infrastructure or regulatory frameworks are not well developed (International Association of Oil and Gas Producers (OGP), 2009). The potential impacts of waste from SGD is therefore of particular concern in the study area where supporting infrastructure is limited.

Principles for Integrated Waste Management in South Africa (Department of Environmental Affairs and Tourism (DEAT), 2000)

- Sustainable Development
- Access to Information
- Precautionary
- Duty of Care
- Preventative
- Polluter Pays
- Best Practicable Environmental Option (BPEO)
- Cooperative Governance
- Integrated Environmental Management
- Environmental Justice
- Participatory
- Equitable access to environmental resources

Waste is defined in South African law in both the National Water Act (NWA), 1998 and in the National Environmental Management: Waste Act, (NEMWA) 2008. The two definitions differ in that the NWA defines waste based on its potential to pollute the water resource (Republic of South Africa (RSA), 1998) while the NEMWA defines waste as any substance, material or object that is unwanted, rejected, abandoned, discarded or disposed of, or that is intended or required to be disposed of, irrespective of whether or not such substance material or object can be re-used, recycled or recovered (RSA, 2008 as amended). When considering waste in the context of this study, both definitions will apply.

Waste must be managed in accordance with the waste management hierarchy and the principles for integrated waste management in South Africa. The emphasis here is to minimise waste arisings, promote re-use and recycling, and minimise the impact of waste on water, the environment and communities. All waste must be separated at source in line with the requirements of the NEMWA to maximise opportunities for re-use and recycling, and treatment efficiencies.

The onshore production of gas includes various phases in which hazardous, non-hazardous waste and waste water can be generated. Typical waste streams would include construction and demolition waste, drill cuttings and drilling muds, and flowback (Amec, 2013). Much of the waste generated by hydraulic fracturing ("fracking") will be Type 1 hazardous waste in terms of Section 7(3) of the National Norms and Standards for the Assessment of Waste for Landfill Disposal, 2013 (RSA, 2013a):

> *"If a particular chemical substance in a waste is not listed with corresponding LCT and TCT limits in Section 6 of these Norms and Standards, and the waste has been classified as hazardous in terms of regulation 4(2) of the Regulations based on the health or environmental hazard characteristics of the particular element or chemical substance, the following applies*
> *(a) the waste is considered to be Type 1 Waste;"*

Inappropriate treatment and management of these wastes and spills of fracking fluids has the potential to threaten human health and safety and impact negatively on water resources and the environment (Kiboub, 2011; OGP, 2009). Fracking uses a large number of chemicals including some known hazardous substances (e.g. the foaming agent 2-butoxyethanol) (see Table A.1 in Burns et al., 2016 Digital Addenda), and brings many potentially dangerous compounds to the surface, such as hydrocarbons, brine, and other naturally occurring geological components (e.g. arsenic, radionuclides) (Council of Canadian Academies, 2014; Zhang et al., 2016). This scientific assessment will therefore assess all waste and waste water streams generated as a result of SGD, and the potential risks associated with the various waste and waste water management options. It will also propose mitigation measures to protect human health and the environment against the effects caused by spills and the collection, transport, treatment, storage and disposal of waste and waste water.

6.1.1 What is meant by this topic?

Fracking and the production of natural gas from wells yield wastes that must be managed responsibly to avoid potential harm to the environment and human health. The waste waters generated are known as "flowback" and "produced water" and both may contain potentially harmful pollutants including salts, organic hydrocarbons (oils and grease), inorganic and organic additives and naturally occurring radioactive materials (NORM) (also see Hobbs et al. (2016) for a description of the groundwater quality). Contaminated

Key definitions and abbreviations

"*Flowback*" refers to fracking fluid injected into a gas well that returns to the surface when drilling pressure is released.

"*Produced water*" refers to all waste water emerging from the well after production begins, much of which is salty water contained within the shale formation.

Source: Hammer and Van Briesen, 2012

run-off also needs to be contained and treated as waste water. The solid wastes produced are mostly drill cuttings (mud) or sludges from waste water treatment. Impacts of spills during off-site transport of waste water or waste may result from accidents, inadequate management or training, and illicit dumping. Domestic solid waste associated with worker deployment to the area and opportunistic migrants looking for employment and other economic opportunities are also considered.

Issues not covered in this chapter are non-water related impacts of waste water management (with limited exceptions). Such impacts include air emissions from trucks used to haul waste water and waste (refer to Winkler et al., 2016), noise (Wade et al., 2016) and traffic impacts from those trucks (Van Huyssteen et al., 2016), soil contamination and land disturbance impact from the construction of waste water management facilities (refer to Hobbs et al., 2016 and Holness et al., 2016).

Assumptions: Operators/prospectors must fully disclose the composition of the fracking fluid additives, consistent with the provisions of the Regulations for Petroleum Exploration and Production, 2015, as this will determine the treatment options required to ensure correct treatment and proper management of this waste stream. The waste stream has been predefined as hazardous waste in Schedule 3 of the Waste Amendment Act, 2014 (RSA, 2014).

6.1.2 Overview of international experience

Disposal of drilling and fracking wastes, as well as spills of fracking fluids and waste, poses a number of potential environmental and health risks. Surface spills of fracking fluid may pose a greater contamination risk than fracking itself (see also Section 6.5) (Grout and Grimshaw, 2012). Released materials include fuels, drilling mud and cuttings, and chemicals (particularly for fracking). Fracking chemicals in concentrated form (before mixing) at the surface present a more significant risk above ground than as a result of injection in the deep subsurface (Grout and Grimshaw, 2012). Leaks and spills associated with SGD may occur at the drill pad or during transport of chemicals and waste materials. Sources at the wellsite include the drill rig and other operating equipment, storage tanks, impoundments or pits, and leaks or blowouts at the wellhead. The primary risk of uncontrolled releases is generally to surface water and groundwater resources (Grout and Grimshaw, 2012).

Many of the waste streams generated by fracking are the same as or similar to those of conventional oil and gas production (Grout and Grimshaw, 2012). The flowback and produced water generated by SGD may pose a serious risk to the surrounding environment and public health because this waste water usually contains many toxic chemicals and high levels of total dissolved solids (TDS) (Zhang et al., 2016). The composition of waste waters changes over the lifetime of the well with produced water increasing in salinity in the latter stages of SGD (Koppelman et al., 2012). The management of these wastes may be the greatest challenge of shale gas regulation by the responsible authorities (Grout and Grimshaw, 2012). The United States Environmental Protection Agency (US EPA) reported groundwater contamination in Pavillion, Wyoming as a direct result of improper operational practices associated with fracking waste management (DiGiulio et al., 2011). "*Detection of high concentrations of benzene, xylenes, gasoline range organics, diesel range organics, and total purgeable hydrocarbons in groundwater samples from shallow monitoring wells near pits indicates that pits are a source of shallow groundwater contamination in the area of investigation. Pits were used for disposal of drilling cuttings, flowback, and produced water*" (DiGiulio et al., 2011:33).

According to Grout and Grimshaw (2012) US regulations for waste storage primarily address temporary pits and tanks for drilling fluid and cuttings and flowback and produced water. These regulations typically include requirements for pit liners, freeboard (excess volumetric capacity), and closure, all of which have the objective of preventing soil and water contamination. Some states in the US are adopting provisions which require that drilling and fracking waste must be stored in tanks rather than pits before disposal to reduce the potential impacts on the environment (Grout and Grimshaw, 2012). Open storage ponds are not allowed in the UK (Koppelman et al., 2012) or in South Africa (RSA, 2015a).

According to Hammer and Van Briesen (2012) there are five basic management options for contaminated waste water from SGD as illustrated in Figure 6.1. These are:

1) Minimisation of produced water generation;
2) Recycling and re-use within operations;
3) Treatment;
4) Disposal; and
5) Beneficial re-use outside the operations.

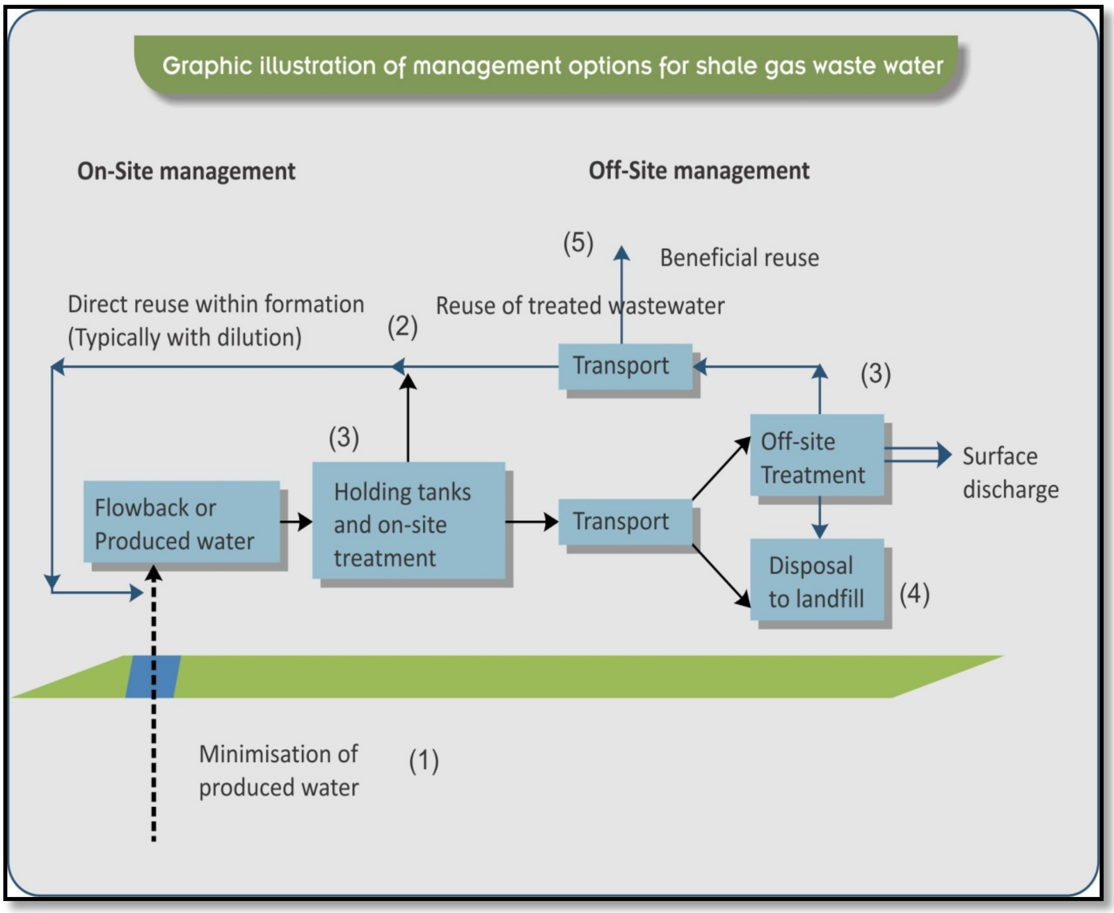


Figure 6.1: Management options for shale gas waste water.

6.1.2.1 <u>Minimisation, re-use and recycling of flowback and produced water</u>

Minimising the volume of produced water that is generated to the surface is a way to simplify water management options and costs. To achieve produced water minimisation, processes are modified, technologies adapted or products are substituted so that less water is generated (Veil, 2015).

Challenges to re-use may include removing constituents that could affect well performance (salts, suspended solids, microorganisms and scale forming chemicals) and adjusting the stimulation chemistry with chemical additives that work in saltier waters (Hammer and Van Briesen, 2012).

Produced water minimisation technologies are summarised in Table 6.1 below (Veil, 2015).

Table 6.1: Produced water minimisation technologies (Veil, 2015).

Approach	Technology	Pros	Cons
Reduce the volume of water entering the wells.	Mechanical blocking devices (e.g. packers, plugs, good cement jobs).	These should be used in new construction. They can be added later on to fix some problems.	May not be easy to fix pre-existing problems.
	Water shut-off chemicals (e.g. polymer gels).	Can be very effective in selected instances, primarily in sandstone and limestone formations.	Need the right type of formation in order to achieve cost-effective results.
Reduce the volume of water managed at the surface by remote separation.	Dual completion wells (downhole water sink).	Can be very effective in selected instances.	Limited prior use. Makes wells more complex.
	Downhole oil/water separation.	May be a good future technology.	Earlier trials were inconsistent and the technology went out of favour. New designs and good candidate wells are needed to bring back this technology.

The opportunity for re-use and recycling is greater during the flowback period than during the production phase. Produced water generated during the lifetime of the well can be collected and repurposed for operations at other wells, but this requires transport to new wellpads which may be costlier than transport to disposal or treatment locations. Logistics and economics therefore control the re-use opportunity (Hammer and Van Briesen, 2012). Reinjection for enhanced recovery is a fairly common practice in the US and elsewhere (Veil, 2015). In general, increased emphasis is being placed on requirements for waste water reduction through re-use and recycling of fracking fluids (Grout and Grimshaw, 2012). Desalination technologies are being developed to control salinity and support re-use of waste waters (Koppelman et al., 2012). Examples of water re-use and recycle management options and some of the specific uses are shown in Table 6.2 below (Veil, 2015).

Table 6.2: Examples of water re-use and recycle management options and some of the specific uses (Veil, 2015).

Management Option	Specific Use	Pros	Cons
Reinjection for enhanced recovery	Water flood; stream flood	Common use of produced water for onshore conventional formations. Usually has low cost	Need to ensure chemical compatibility with receiving formation.
Injection for future water use	Aquifer storage and recovery	Can augment public water supplies	Need to ensure that water meets drinking water standards before injecting it into a shallow aquifer. May encounter public opposition. Oil and gas companies may not choose this option due to fear of future liability.

Management Option	Specific Use	Pros	Cons
Injection for hydrological purposes	Subsidence control	Can help solve a local problem (e.g. Wilmington Oil Field, Long Beach, CA)	Need to ensure chemical compatibility with receiving formation.
Agricultural use	Irrigation; subsurface drip irrigation	Can be a great benefit to arid areas	May need to treat the water before applying it to the soil or add soil supplements. May need to choose salt-tolerant plant species.
	Livestock and wildlife watering	Can provide a source of water for animals	Need to ensure that water is clean enough to avoid illness or other impacts to animals.
	Managed/ constructed wetlands	Provides a "natural" form of treatment. Creates a good habitat for wildlife.	Large space requirements. Needs extensive oversight and management. Typically limited to water with low to moderate salinity.
Industrial use	Oil and gas industry applications (e.g. drilling fluids, fracking fluids)	Can substitute for fresh water supplies in making new drilling or stimulation fluids	May need treatment in order to meet operational specifications
	Power plants (cooling water)	May be able to supplement cooling water sources	Will require treatment. The large volumes needed result in collection and transportation costs.
	Other (e.g. vehicle wash, fire-fighting, dust control on gravel roads; road de-icing)	Can be a good supplemental water supply in arid areas	Will need storage facilities and possibly treatment. Concerns about water quality impacts from runoff after application or inappropriate application.
Treat to drinking water quality	Use for drinking water and other domestic uses	Can help supply water to communities in arid areas	Cost to treat may be high. Need good quality control. May encounter public opposition and face concern over liability. It may be more cost-effective and energy-conserving to treat other water sources like saline groundwater rather than treating produced water.

Pre-treatment could take place onsite, but this is currently very expensive (Koppelman et al., 2012). Off-site re-use of untreated produced water is rare due to the high concentration of salts and the scaling potential (Hammer and Van Briesen, 2012).

6.1.2.2 Treatment

Prior to disposing of or re-using water from fracking operations, different treatment processes and technologies may be required (Veil, 2015). The quality requirement for the final disposition of the water will determine the type and extent of treatment required. For example, if water is discharged, the parameter of greatest concern can be related to either the organic content or the salt content to meet the resource quality objectives. Treatment technologies designed to remove salts and other inorganic compounds from produced water are listed in Table 6.3 below (Veil, 2015).

Table 6.3: Treatment technologies designed to remove salts and other inorganic compounds from produced water (after Veil, 2015).

Technology	Subcategory	Pros	Cons
pH adjustment, flocculation, and clarification	N/A	This is a common pre-treatment step to remove metals. The cost is modest.	This process removes metals but does not treat chlorides or TDS. The process generates sludge that requires disposal.
Membrane processes	Microfiltration, ultrafiltration, and nanofiltration	They are good pre-treatment steps for more advanced processes like Reverse osmosis (RO). They operate at lower pressure and lower cost than RO. Ultrafiltration followed by RO can process high chemical oxygen demand (COD).	These levels of filtration cannot remove most salinity. Potential for membrane fouling. Sensitivity to fluctuating water quality.
	Reverse osmosis (RO)	RO can remove salinity (up to about 40,000 mg/L TDS).	Requires pre-treatment and regular membrane cleaning. Not suitable for high-salinity water. Potential for membrane fouling. Sensitivity to fluctuating water quality. Generates concentrated brine stream that requires separate disposal. Moderate to high energy usage and cost.
	Other (e.g. electrodialysis, forward osmosis)	May offer future treatment opportunities.	Have not been used extensively in full-scale oil field treatment systems yet. Potential for membrane fouling. Sensitivity to fluctuating water quality.
Thermal Treatment	Distillation	Can process high-salinity waters like flowback. Generate very clean water (can be re-used).	High energy usage and cost. Generates concentrated brine stream that requires separate disposal. Potential for scaling. May require remineralisation before release or beneficial re-use.
	Evaporation/ Crystallisation	Can treat to a zero liquid discharge standard. Solar evaporation in ponds could be relatively cheap.	High energy usage and cost if not solar evaporation. Limited usage in oil field applications. Potential for scaling. Challenges in disposing of salt residue.

Technology	Subcategory	Pros	Cons
Ion exchange	N/A	Successfully treats low to medium salinity water (e.g. Powder River Basin).	Large acid usage. Resins can foul. Challenges in disposing of rinse water and spent media (resin). Also ineffective on high salinity produced waters.
Capacitive deionisation	N/A	Low energy cost.	Limited to treating low salinity waters. Limited usage in oil field applications.

Treatment technologies designed to remove oil and grease and other organics from produced water are listed in Table 6.4 below (Veil, 2015).

Table 6.4: Treatment technologies designed to remove oil and grease and other organics from produced water (Veil, 2015).

Technology	Subcategory	Pros	Cons
Physical separation	Advanced separators (e.g. inclined plate, corrugated plate)	Provide enhanced oil capture compared to basic oil/water separators.	Work well for free oil, but not as effective on dispersed and soluble oil. Performance can be improved by adding flocculants.
	Hydrocyclone	No moving parts results in good reliability. Separates free oil very well.	Does not work well on dispersed and soluble oil.
	Filtration	Different types of filter media and filter operations provide a good range of oil and grease removal.	Requires regular back-flushing. Does not treat most soluble oil.
	Centrifuge	Provides good separation of free and dispersed oil.	More expensive than other technologies in this group.
Coalescence	N/A	Collects small oil droplets and forms larger droplets that can be more easily removed by the other technologies.	Limited value for dispersed or soluble oil.
Flotation	Dissolved air flotation, induced gas flotation	Removes free and dispersed oil.	Does not remove soluble oil.
Combined physical and extraction processes	Compact separators and other units	Can treat to very low oil and grease levels.	Not used currently in US because its low level of oil and grease is not needed to meet US regulatory standards.
Solvent extraction	Macro-porous polymer extraction	Can treat to very low oil and grease levels.	Not used currently in US because its low level of oil and grease is not needed to meet US regulatory standards. Probably is very costly.
Adsorption	Organoclay, activated carbon, zeolites, specialised polymers, swelling glass	Does a good job at removing oil and grease. Used primarily for	Most types of media cannot be re-used or regenerated – results in large volume of

Technology	Subcategory	Pros	Cons
		polishing.	solid waste.
Oxidation	Advanced processes using combinations of ozonation, cavitation, and electrochemical decomposition	Creates nearly sterile brine	Has high energy input. Limited use to date.

Veil (2015) reports that new produced water technologies and products are being introduced to the marketplace each month; the technologies listed in the above tables are major technology categories that were in use in 2014.

Treatment is the most complex management option and can be done on- or off-site and in conjunction with recycling, re-use, discharge and disposal. On-site treatment is designed for re-use only and will incorporate the minimum treatment technology required for re-use without compromising the chemistry of the fracking water makeup (Hammer and Van Briesen, 2012). Desalination is possible, but is rarely necessary to produce water suitable for re-use in fracking operations (Hammer and Van Briesen, 2012).

Biofouling of membranes by organic material has historically been responsible for the largest number of failures in reverse osmosis desalination processes. Thus, effective pre-treatment of oilfield-produced brines is necessary to prevent biofouling and scaling of reverse osmosis membranes (Lee et al., 2002). Treatment is predominantly done off-site and therefore requires transport of the waste water (Hammer and Van Briesen, 2012). Off-site options and decisions are more complex and will require initial analysis of the water to determine its fate. Regardless of its ultimate fate, preliminary treatment is likely to be required (Hammer and Van Briesen, 2012).

The main contaminants to be removed during treatment are: 1) salts, including metals; 2) organic hydrocarbons (sometimes referred to as oil and grease); 3) inorganic and organic additives; and 4) naturally occurring radio-active materials (NORM). The treatment technology to employ can only be determined through complete chemical analysis of the water. Significant concern has been raised regarding the nature of the additives, with 29 identified as of particular concern for human health and 13 identified as probable or known human carcinogens (Hammer and Van Briesen, 2012).

Among the most notable are naphthalene, benzene and polyacrylamide. Polyacrylamide itself is not carcinogenic, but the acrylamide monomer is. There is some concern that during manufacture the polyacrylamide retains small amounts of the monomer. A list of the chemicals of concern present in fracking fluids is provided in Table 1 in the Digital Addendum 6A. In the US, there are calls for operators to disclose fully the composition of the fracking fluid additives and it is already a requirement in the United Kingdom (UK) (DiGiulio et al, 2011; Koppelman et al., 2012) and included in South African regulations (RSA, 2015a).

Shale gas operators in the US are known to have sent waste water to publicly owned treatment works for treatment (Hammer and Van Briesen, 2012), but this practice has become controversial and has been banned in some states, while other states require pre-treatment before discharge into publicly owned treatment works (Grout and Grimshaw, 2012). In July 2011, 15 US treatment facilities were exempted from compliance with the regulations, meaning that they were allowed to discharge treated waste water with concentrations exceeding the TDS and chlorides limits. Nine of these facilities were publicly owned waste water treatment plants. An alternative is treatment of produced water at dedicated brine or industrial waste water facilities (Hammer and Van Briesen, 2012). The US EPA has indicated that waste water treatment standards will be developed for shale gas waste water (Grout and Grimshaw, 2012).

Treated water may be discharged, shipped back to the well site for re-use or diverted for beneficial re-use or resource extraction, depending on the final quality (Hammer and Van Briesen, 2012).

6.1.2.3 Disposal

Direct disposal above ground or to soils in the near surface environment, on- or off-site was routine in the early part of the 20th century, and the use of on-site unlined ponds and nearby off-site land applications were common disposal practices (Hammer and van Briesel, 2012). These practices are no longer used due to salt contamination in soils and aquifers. Produced water in the US is often disposed via underground injection into disposal wells (Hammer and Van Briesen, 2012; Shaffer et al., 2013). A small fraction of produced water is reportedly discharged to surface water, managed by evaporation ponds, or beneficially re-used outside the industry (Shaffer et al., 2013). Some states are re-evaluating the practice of on-site land disposal of waste (Grout and Grimshaw, 2012). Field evaluations on a subset of impoundments and pits used for waste and waste water storage in the Marcellus Shale development, found several construction and maintenance deficiencies related to the containment systems and transport pipelines (Ziemkiewicz et al., 2014).

In some shale gas areas, operators manage waste at a centralised waste disposal facility that accepts waste from multiple well sites (Koppelman et al., 2012; Grout and Grimshaw, 2012). These facilities may be subject to general state requirements such as best management practices to protect human health and the environment or to specific requirements such as an operating plan, water well monitoring and stormwater diversion (Grout and Grimshaw, 2012). Water disposal methods (Veil, 2015) are listed in Table 6.5 below.

Table 6.5: Water disposal methods (Veil, 2015).

Technology	Pros	Cons
Discharge*	Very common for offshore facilities. Offers moderate cost and acceptable environmental impact, where permitted.	Not approved for most onshore wells. Where allowed, requires treatment unless the water is high quality, such as some coalbed methane (CBM) effluent. Different treatment requirements for discharges into different types of water bodies.
Underground injection** (other than for enhanced recovery)	Very common onshore practice. Tends to have low cost. EPA and state agencies recognise this as a safe, widely used, proven, and effective method for disposing of produced water.	Requires presence of an underground formation with suitable porosity, permeability, and storage capacity. May require treatment to ensure that injectate does not plug formation. A small subset of disposal wells has been linked to felt earthquake activity – this is an active area of research. Transportation costs can be significant.
Evaporation***	In arid climates, takes advantage of natural conditions of humidity, sun, and wind.	Not practicable in humid climates. May create air quality and salt deposition problems.
Offsite Commercial disposal	Companies providing services to oil and gas community by accepting and disposing water for a fee. Removes water treatment burden from the operator.	Requires infrastructure (disposal facilities and transportation network to move water to disposal site). Can be costly.

Note:
* Discharge of untreated waste water is prohibited in South Africa in terms of Section 124 (5) of Regulation 466 (RSA, 2015a).
** Disposal to underground is prohibited in South Africa in terms of Section 124 (4) of Regulation 466 (RSA, 2015a).
*** Disposal of liquid waste to land is being phased out in South Africa and will be prohibited from 23 August 2019 (RSA, 2013b).

6.1.2.4 Beneficial re-use

The beneficial re-use of oil and gas brines has a long history in the US. For low-TDS water beneficial re-use options include livestock watering, aquaculture and hydroponic vegetable culture, irrigation of crops, washing of equipment and fire control. None of these opportunities exist for waste water from highly saline formations like the Marcellus Shale. The unique mixture of chemicals in treated fracking waste water has not yet been studied with respect to its uptake into crops (Shariq, 2013). However, according to Shariq (2013) arsenic, one of the known toxic inorganic constituents in the waste water, has been shown to bio-accumulate throughout rice plants, and organic hydrocarbons have also been identified in wheat plants grown in contaminated soil.

6.2 Special features of the Karoo in relation to waste

There are currently no specialised hazardous waste disposal or treatment facilities in the Karoo. The spatial distribution of waste water treatment and solid waste disposal facilities in the study area is illustrated in the map (Figure 6.2) below. Eden District Municipality is in the process of building a Class B regional waste disposal site with a hazardous waste cell that will be able to accept Type 2 hazardous waste from 2017. The hazardous waste generated by fracking is likely to be Type 1 hazardous waste (Section 7(3) of Regulation 635) which will not be allowed at the new Eden regional waste disposal facility. All Type 1 hazardous waste generated in the study area will therefore have to be transported to a suitably designed and authorised hazardous waste disposal site in Gauteng, Port Elizabeth or Cape Town. Although the PetroSA landfill in Mossel Bay is also licensed to accept Type 1 hazardous waste, it is not a commercial facility and therefore would require the consent of the permit holder and the relevant authorities (possibly including an Environmental Impact Assessment (EIA) as this would be a change in scope of the original licence issued) to be used for disposal of waste from fracking activities. Construction of a new on-site or centralised disposal facility could be considered for large scale development and production (Scenario 3 (Big Gas)) subject to a full EIA and approval of a disposal site licence under the Waste Act (Act 56 of 2008).

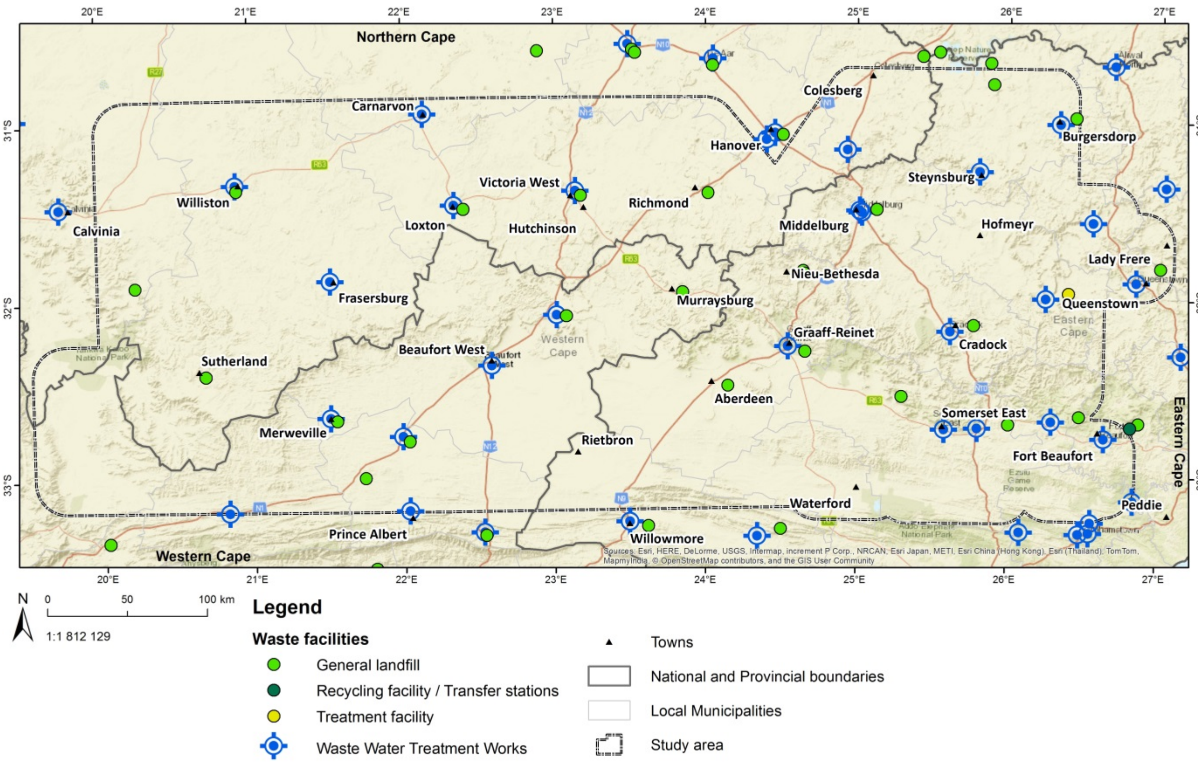


Figure 6.2: Map of the study area showing waste facilities for general landfills and Waste Water Treatment Works.

Facilities for the disposal of domestic solid waste, generated by workers deployed to the study area and opportunistic migrants, are limited to small and communal disposal sites (Table 2 in Digital Addendum 6A). As at 2007, only twelve sites were estimated to have 15 years or more airspace remaining (DEAT, 2007), the other sites are likely to be filled up by now. Additional waste generated for all SGD scenarios will put pressure on these already constrained waste disposal facilities. All landfills in the study area require upgrades to meet the requirements of the National Norms and Standards for Disposal of Waste to Landfill. Recycling initiatives in the Karoo are limited due to relative low volumes and large transport distances to markets for recyclables.

Waste water infrastructure in the study area is limited to municipal owned treatment works (see Table 3 in Digital Addendum 6A). The majority of these facilities are placed under regulatory surveillance or require immediate interventions (Department of Water and Sanitation (DWS), 2014). The 'risk' associated with municipal waste water treatment facilities relates to design capacity (including the hydraulic loading into the receiving water body), operational flow (exceeding, on or below capacity), and number of non-compliance trends in terms of effluent quality (discharged into the receiving environment) and compliance or non-compliance in terms of technical skills (DWS, 2014). Waste water generated by SGD (Scenario 1(Exploration Only) and 2 (Small Gas)) will therefore have to be treated on-site or transported (trucked or piped) to suitable facilities further afield. The volumes during the Exploration Only scenario will likely be best addressed though on-site (possibly mobile or packaged) treatment facilities as it will be too small to justify pipelines. Transportation by road to off-site facilities further afield will be the other alternative. During the Small and Big Gas scenarios the ideal would be to have local modular waste water treatment facilities to minimise fluid transport movement and distances in line with Section 117(a) of the Petroleum Exploration and Production Regulations (RSA, 2015a). Refer to Digital Addendum 6B for examples of packaged, mobile and modular on-site treatment technologies for flowback and produced water from SGD[1].

There are currently no licensed NORM waste facilities in the study area; therefore NORM waste will have to be transported to suitably licensed off site facilities outside of the study area. The proposed uranium mining in the study area will also produce NORM waste and is likely to establish slimes dams for disposal of NORM waste. The establishment of such facilities will be subject to regulatory control by the National Nuclear Regulator.

[1] The authors do not promote this specific technology but merely refer to it as examples of what is commercially available internationally.

6.3 Relevant legislation, regulation and practice

Applicable legislation to SGD in South Africa has been promulgated by the Department of Mineral Resources (DMR), Department of Water and Sanitation and the Department of Environmental Affairs (DEA). The DMR is responsible for the sustainable development of South Africa's mineral and petroleum resources within the framework of national environmental policy, norms and standards while promoting economic and social development (RSA, 2002). The DEA is the lead agent for the protection of the environment (RSA, 1998a) and waste management (RSA, 2008) while the DWS is the public trustee of the nation's water sources (RSA, 1998).

6.3.1 Mineral and Petroleum Resources Development Act, 2002 (Act 28 of 2002)

The objective of the Mineral Resources and Petroleum Development Act, 2002 (MRPDA) (Act 28 of 2002) is amongst other to "*give effect to Section 24 of the Constitution by ensuring that the nation's mineral and petroleum resources are developed in an orderly and ecologically sustainable manner while promoting justifiable social and economic development*" (RSA, 2002).

Section 41 of the MPRDA states that applicants for prospecting rights, mining rights or mining permits must make financial provisions for the rehabilitation or management of negative environmental impacts.

Regulation 466 for Petroleum Exploration and Production (RSA, 2015a) requires, amongst other, the following measures to prevent environmental contamination from SGD:

Section 91	Suitably designed impermeable site underlay systems and site drainage arrangements.
Section 109	Drilling fluids must be declared through material safety data sheets.
Section 112(8)	(g) Proppants must be tagged with radioactive isotopes so that proppant can be analysed to locate where different stages of the proppant went and to locate fractures at depth.
Section 112(8)	(h) Chemical tracers must be added to improve the understanding of fracture fluid loss and flowback.
Section 113	Fracking fluid disclosure including prohibition of substances listed in schedule 1 (refer to Table A1, Burns et al., 2016 Digital Addenda).
Section 115	Fracturing fluids management through a risk management plan.
Section 116	Management of flowback and produced fluids through an approved waste management plan.

Section 117	An approved fluid transportation plan, planning to minimise fluid transport movements and distances.
Section 118	Fluid storage: at the well site and centralised storage for potential re-use prior to disposal, fracking additives, fracking fluids, flowback and produced water must be stored in above-ground tanks with lined bund walls.
Section 123(3)	Re-use of fracking fluids and produced water from operation on site or from neighbouring operations must be considered to reduce competition with freshwater uses.
Section 124(1)	Waste must be disposed of in accordance with applicable legislation.
Section 124(2)	Waste containing radioactive materials must be managed in accordance with National Radioactive Waste Disposal Institute Act, 2008 (Act 53 of 2008).
Section 124(3)	Liquid waste must be disposed of at an approved waste treatment facility in accordance with relevant legislation and disposal of liquid waste at domestic waste water treatment facilities must only take place after prior consultation with the department responsible for water affairs.
Section 124(4)	Disposal to underground, including the use of re-injection disposal wells, is prohibited.
Section 124(5)	Discharge of fracking fluids, fracking flowback, and produced water into surface water course is prohibited.
Section 124(6)	Annular disposal of drill cuttings or fluids is prohibited.
Section 124(7)	Drill cuttings and waste mud must be temporarily stored in above-ground tanks.
Section 124(8)	Solid waste generated during operations must be categorised and disposed of accordingly at a licensed landfill site or treatment facility.
Section 125	A waste management plan must be prepared and approved as part of the application for Environmental Authorisation.

6.3.2 National Environmental Management Act, 1998 (Act 107 of 1998)

This act sets out the fundamental principles that apply to environmental decision making. The core environmental principle is the promotion of ecologically sustainable development. Principles referring to waste and pollution include:

- That pollution and degradation of the environment are avoided or where they cannot be altogether avoided, are minimised and remedied.
- That waste is avoided, or where it cannot be altogether avoided, minimised and re-used or recycled where possible and otherwise disposed of in a responsible manner.
- Decisions must be taken in an open and transparent manner, and access to information must be provided in accordance with the law.

- The cost of remedying pollution, environmental degradation and consequent adverse health effects and of preventing, controlling or minimising further pollution, environmental damage or adverse health effects must be paid for by those responsible for harming the environment.

NEMA Section 30 and 30A establish the framework for dealing with emergency situations and will apply directly to such occurrences in the SGD context.

Waste management activities that have, or are likely to have, a detrimental effect on the environment as listed in Regulation 921 of 29 November 2013 (RSA, 2013c) are subject to the EIA Regulations made under Section 24(5) of NEMA as part of a waste management licence application under the NEMWA.

Relevant regulations under NEMA:

- Environmental Impact Assessment Regulations (Regulation 982 of 4 December 2014);
- Regulations pertaining to the financial provisions for prospecting, exploration, mining or production operations (Regulation 1147 of 29 November 2015).

6.3.3 National Environmental Management: Waste Act, 2008 (Act 56 of 2008)

South Africa has an integrated pollution and waste management policy that is driven by a vision of environmentally sustainable economic development by amongst other, preventing and minimising, controlling and remediating pollution and waste to protect the environment from degradation (DEAT, 2000). Waste management in South Africa is informed by the waste management hierarchy which outlines waste management options covering the lifecycle of waste, in descending order of priority: waste avoidance (prevention and minimisation), re-use and recycling, recovery, waste treatment and disposal as last resort (DEA, 2012).

Waste legislation in South Africa is emerging and constantly changing. The NEMWA is the first law in South Africa dedicated to waste and a number of new strategies and regulations under this act are currently under development.

Waste management activities that may require a licence in terms of NEMWA are listed in Regulation 921 of 29 November 2013 (RSA, 2013c) and Regulation 633 of 24 July 2015 (RSA, 2015b). These activities include:

- Storage of general waste in lagoons and storage of hazardous waste in lagoons excluding storage of effluent, waste water or sewage;
- Recycling or recovery of waste;

- Treatment of waste;
- Disposal of waste;
- Construction, expansion or decommissioning of facilities and associated structures and infrastructure; and
- Establishment or reclamation of a residue stockpile or residue deposit resulting from activities which require a prospecting right or mining permit in terms of the MPRDA.

Depending on the size, handling capacity and the type of waste to be managed at the facility, a basic assessment or full EIA set out in the EIA regulations under Section 24(5) of NEMA will be required as part of the licence application process. All hazardous waste management facilities will require a full EIA.

Applicable regulations under NEMWA include:

- Waste Information Regulations (Regulation 625 of 13 Aug 2012) – every person generating more than 20 kg of hazardous waste per day or disposing of any amount of hazardous waste to landfill must register on the South African Waste Information System (SAWIS) and submit actual quantities of waste into the SAWIS.
- Waste Classification and Management Regulations (Regulation 634 of 23 Aug 2013) - All waste generators must ensure that the waste they generate is classified in accordance with South African National Standards (SANS) 10234 and a safety data sheet prepared for each waste stream as prescribed.
- National Norms and Standards for the Assessment of Waste for Landfill Disposal (Regulation 635 of 23 Aug 2013).
- National Norms and Standards for Disposal of Waste to Landfill (Regulation 636 of 23 Aug 2013).
- List of Waste Management Activities that have or are likely to have a detrimental impact on the Environment (GN 921 of 29 Nov 2013).
- National Norms and Standards for Storage of Waste (GN 926 of 29 Nov 2013).
- National Norms and Standards for Remediation of Contaminated Land and Soil (GN 331 of 2 May 2014).
- Regulations regarding the planning and management of residue stockpiles and residue deposits from a prospecting, mining, exploration or production operation (Regulation 632 of 24 July 2015).
- Amendments to the list of waste management activities that have or are likely to have a detrimental effect on the environment (Regulation 633 of 24 July 2015).

SGD is considered a high risk activity that is likely to result in land contamination in all scenarios. The Minister or MEC may identify investigation areas, direct site assessments to be done and issue remediation orders for the remediation of contaminated land (NEMWA, Chapter 4, Part 8) (RSA, 2008 as amended). All costs associated with the assessments and remediation will be for the account of the owner of the land or company responsible for SGD (RSA, 2008) in line with the "polluter-pays-principle". Financial provision for the costs associated with the undertaking of management, rehabilitation and remediation of environmental impacts from prospecting, exploration, mining or production operations through the lifespan of such operations and latent or residual environmental impacts that may become known in the future is regulated under Regulation 1147 in terms of NEMA.

NEMWA and its regulations will not be able to adequately deal with the waste from SGD. Financial provisions as outlined in Regulation 1147 may not be sufficient to cover the costs for remediation of contaminated land from spills during SGD. The regulations focus on financial provisions to implement the rehabilitation and closure plan as well as latent or residual impacts in the future but not for accidental spills. Although norms and standards for waste classification and containment barrier system designs is prescribed, the law is silent on landfill management, operational and groundwater monitoring requirements at facilities receiving waste from SGD. Possible contact between the waste and humans is also not regulated. Site specific waste management licences are required for each waste activity requiring a licence. Multiple storage and treatment facilities will potentially attract the need for multiple licence applications each with a requirement for an EIA at scoping or full assessment level which will add cost and time delays in obtaining authorisations. There is currently not enough capacity at national and provincial government level to evaluate and process the potential flood of waste licence applications that may be experienced from the Small and Big Gas scenarios. Waste classification regulation stipulate that waste must be kept separate for purposes of classification, and must be "*re-classified within 30 days of modification to the process or activity that generated the waste, changes in raw materials or other inputs, or any other variation of relevant factors*" (RSA, 2013). This implies that every change in the composition of the fracking fluid will require a reclassification of the waste before disposal for all three scenarios.

The DEA have indicated their intention to amend schedule 3 of NEMWA which currently pre-classify wastes resulting from exploration, mining, quarrying, and physical and chemical treatment of minerals as hazardous waste. If this pre-classification of waste from SGD changes, then it is possible that the waste may be classified as Type 1, 2 or 3. Most municipal landfill sites in the study area would at best be Class C or D sites and will not be able to receive Type 1, 2, or 3 wastes.

6.3.4 National Water Act, 1998 (Act 36 of 1998)

The National Water Act, 1998 (NWA), provides regulatory and market based instruments to manage the impacts on water quality. These instruments include licensing of water uses (NWA, Section 21), including disposal of waste, which may impact on water resources and waste discharge charges in line with the "polluter pays" principle (DWA, 2009).

Water used in excess of the limits specified in Schedule 1 and General Authorisation notices will require a water use licence. The Minister may however dispense with the requirement for a licence under the NWA (Section 22(3)) by issuing a Record of Decision which is then incorporated in the waste licence issued under NEMWA.

Several water uses can be covered by one integrated water use licence. The integrated water use licence will prescribe conditions for the management, monitoring and reporting relating to the water use. An integrated water and waste management plan is a typical requirement of a water use licence.

National Water Act, 1998,

Section 21 Waste Discharge related water use

- Engaging in a controlled activity (where the controlled activity relates to waste discharge activities).
- Discharging waste or water containing waste into a water resource.
- Disposing of waste in a manner which may detrimentally impact on a water resource.
- Disposing in any manner of water which contains waste from, or which has been heated in, any industrial or power generation process.
- Altering the bed, banks, course or characteristics of a water course (where such activities have impacts on the water quality of the water course).
- Removing, discharging or disposing of water found underground if it is necessary

The Pricing Strategy, as amended (RSA, 2015), provides for six water use categories including fracking (as illustrated in Figure 6.3) to represent the user groups and to allow for clearly targeted charges. Charges will be calculated based on the volume of the waste water discharged from a point source, and on the degree of management activity required for non-point source registered users. Cost allocations will be based on:

- Point source discharge – management effort for point discharges, attracting all waste discharge related costs.
- Waste disposal to facilities/land – management effort for waste disposal to land, attracting all waste discharge related activity costs.
- Irrigation of land with water containing waste – Management effort for irrigated effluent, attracting all waste discharge related activity costs.

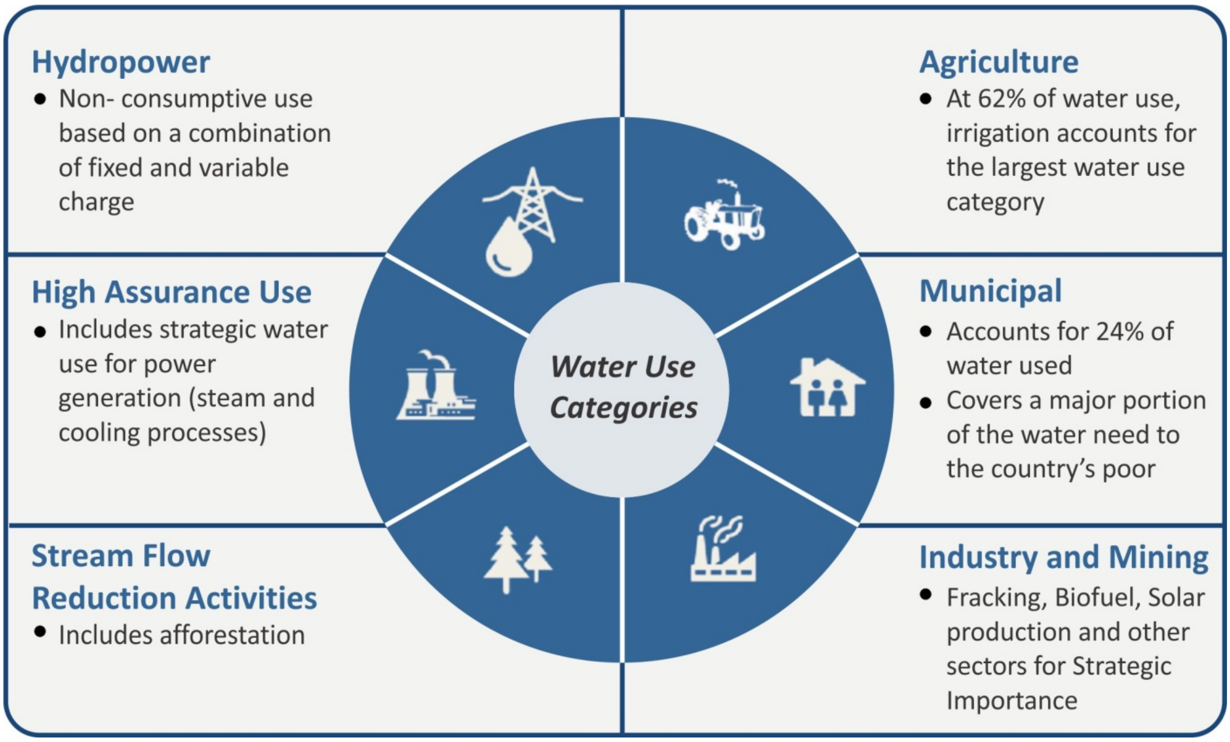


Figure 6.3: Water use categories as defined by the Pricing Strategy (RSA, 2015).

Relevant regulations under NWA:

- Regulations on the use of water for mining and related activities aimed at the protection of water resources (Regulation 77 of 12 February 2010).

6.3.5 National Nuclear Regulator Act, 1999 (Act 47 of 1999)

NORM waste will be regulated under this act. The National Nuclear Regulator (NNR) document RD-004 'Requirements Document on the Management of Radioactive waste associated with waste products from facilities handling NORM (2007)' describes how NORM waste must be managed.

6.3.6 National Road Traffic Act, 1996 (Act 93 of 1996)

Vehicles transporting dangerous goods (including hazardous waste) must adhere to SANS 10228 in terms of identification and classification of goods and display the relevant signage.

In terms of Section 76 of the National Road Traffic Act, 1996 the following standards are deemed to be regulations:

SANS 10228: Identifies and classifies each of the listed dangerous goods and substances and set out information including the United Nations Number, the correct shipping name, hazard class assigned and other information pertinent to the substance.

SANS 10229: Contains information on acceptable packaging for dangerous goods and substances and also include requirements for the testing of packaging and the correct marking and labelling of packages.

SANS 10230: Includes statutory vehicle inspection requirements for all vehicles conveying dangerous goods. This code stipulates the safety aspects of both the vehicle and the goods containment. Minimum inspection requirements by both in-house and outside agencies are listed.

SANS 10231: This code of practice prescribes the operation rules and procedures for transporting Dangerous Goods and Hazardous Materials. It also includes the prescribed responsibilities of the owner/operator of the dangerous goods vehicle. It outlines the information required and who will have to supply information for the safe conveyance of dangerous goods. The requirements for the drafting and formulating of an operational agreement are also specified. This code also requires the owner/operator or vehicle to be registered as dangerous goods carrier. It is also prescribed that the owner operator has available adequate insurance cover for civil liability as well as pollution and environmental rehabilitation cover in the event of an incident.

SANS 10232-1: 2007: This code includes details of new placarding requirements for vehicles transporting dangerous goods and the individual or substance exempt quantities and the compatibility requirements of mixed loads. Part 3 of this code contains information on the Emergency Response Guides to be used in case of an incident or accident.

6.3.7 Disaster Management Act, 2002 (Act 57 of 2002)

This act provides for an integrated and coordinated disaster management policy that focuses on preventing or reducing the risk of disasters (natural or human induced) mitigating the severity of disasters, emergency preparedness, rapid and effective response to disasters and post-disaster recovery.

6.4 Key potential impacts and their mitigation

Waste-generating pathways and handling options, include, *inter alia*, drilling fluids, drilling muds, fracking fluids, lubricating oils and greases, contaminated land (spills on-site), domestic waste, sewage, construction waste etc. The expected volumes of waste generated during the different scenarios for SGD in the Karoo is summarised in Burns et al. (2016). Composition of the waste is important in terms of classification and management of the waste - it is likely that most of the waste will be Type 1 hazardous waste. Disclosure of the fracking fluids in terms of chemical and concentration by mass, as provided for in Section 113 of Regulation 466 (RSA, 2015a) will assist in the accurate classification of the waste. Prohibition of certain chemicals, as listed in Schedule 1 of Regulation 466 (RSA, 2015a) (see Burns et al., 2016, Table A.2 in Digital Addenda), will limit the toxicity of the waste and thereby also the potential risk to the environment and human health.

The NNR regulates the management of low-level radio-active waste. The volume and concentration of NORM waste generation will be dependent on the underlying geology of the SGD area. Options for viable and safe re-use or recycling of NORM waste should be sought before designating NORM residues as waste (NNR, 2015). Treatment processes are often used in combination for effective decontamination of liquid waste streams but result in secondary radioactive waste streams i.e. contaminated filters, spent resins and sludges). Conditioning of NORM residues include immobilisation, stabilisation and packaging to render them suitable for handling, transportation, storage and long-term management. Immobilisation methods include solidification of liquid residues, for example in cement. Stabilisation methods include dewatering and chemical adjustment (NNR, 2015). On-site storage of NORM waste is permissible and final disposal is determined by a safety assessment in the selection of the site and the environmental impacts thereof (NNR, 2015). NORM waste may only be disposed of at a facility authorised by the NNR.

Municipalities will not be able to cope with additional waste loads as a result of SGD (municipal solid waste and waste water) at their facilities (landfill and sewage plants) (refer to Table 2 and 3 of the Digital Addendum 6A) due to limited capacity and technical expertise in municipalities (Municipal Demarcation Board (MDB), 2011, Department of Science and Technology (DST), 2013). Inappropriate academic qualifications and inadequate relevant work experience of municipal staff are issues of concern (Van Baalen, 2014). Similarly, technical knowledge on the specialised waste streams from SGD will need to be developed at national and provincial government level to ensure informed decision making and enforcement of legislation.

The available literature findings suggests that surface spills and leakages from holding ponds, tank battery systems and transport of chemicals and waste materials are important routes of potential ground and surface water contamination from fracking activities (Grout and Grimshaw, 2012; Gross et al., 2013; Ziemkiewicz et al., 2014). Sources of spills at the wellsite include the drill rig and other operating equipment, storage tanks, impoundments or pits, and leaks or blowouts at the wellhead

(Grout and Grimshaw, 2012). Leaks or spills may also occur during transportation (by truck or pipeline) of materials and wastes to and from the wellpad in all three SGD scenarios. The primary risk of uncontrolled releases is generally to surface and groundwater resources (Grout and Grimshaw, 2012). Mitigation measures to prevent pollution from spills include impermeable site underlay (Section 91 Regulation 466) and lined bund walls around storage tanks (Section 118(3) Regulation 466) (RSA, 2015a). Constituents of particular concern include benzene, toluene, ethylbenzene and xylene which, at sufficient doses, have been associated with adverse human health effects (Osborn et al., 2011) and arsenic (Grout and Grimshaw, 2012). These constituents of concerns have all been prohibited from being used as additives in fracking fluids in SGD in South Africa (Schedule 1, Regulation 466) (RSA, 2015a). The prohibition of these chemicals reduces the risk to human health and the environment should SGD proceed in the study area.

Three important characteristics of an incident will determine the severity of its consequences – volume, degree of containment and characteristics of the material (waste water or waste) (Grout and Grimshaw, 2012). It is therefore important to provide secondary containment for areas of fuel and fracking fluid chemicals storage, loading and unloading areas, and other key operational areas (Grout and Grimshaw, 2012) including waste and waste water storage, treatment and disposal sites. Such containment areas are already prescribed in Section 118(3) of Regulation 466 (RSA, 2015a).

6.4.1 On-site storage

Maximising recycling and re-use of flowback and produced water will reduce the amount of chemicals and need for clean water, but may increase the volume of waste and waste water to be stored on-site and may increase the potential impacts. The mitigation measures to implement will include barrier and containment systems such as impermeable site linings, bunding and using non-hazardous chemicals where possible (Koppelman et al., 2012). All these measures are already prescribed in Regulation 466 (RSA, 2015a). Minimising design, construction and maintenance problems associated with: out-slope berm stability, uncontrolled groundwater seepage, geomembrane liner puncture, and tear potential from improper site preparation and maintenance (Ziemkiewicz et al., 2014). In this regard, Regulation 466 already prescribes above-ground storage tanks for all liquids, liquid waste, drill cuttings and waste mud (RSA, 2015a). Secondary containment is a best management practice where the tank sits within a tray-like structure with raised sides or berms such that materials released during a tank rupture would be contained (Hammer and Van Briesen, 2012). Section 118 of Regulation 466 stipulate a containment capacity to hold the volume of the largest container stored on-site plus 10% to allow for precipitation, unless the container is equipped with individual secondary containment (RSA, 2015a).

6.4.2 Liquid Waste Treatment

Liquid waste must be treated at an approved waste treatment facility in accordance with relevant legislation (RSA, 2015a). The designated treatment works must have capacity to accept the load and volume of waste water to be treated and must be duly authorised to receive the waste water from fracking operations. Technologies must be appropriate for the quality of the waste water received and it must be able to produce the required quality after treatment to support re-use, recycling or discharge. Waste water treatment technology choice must be based on the degree and surety of removal of constituents required. Pre-treatment may also be required depending on the treatment technology selected and the objectives to be met (DWAF, 2007).

It is expected that treatment of liquid waste from Exploration Only to Small Gas could potentially be dealt with by modular, on-site treatment facilities which are commercially available (refer to Digital Addendum 6B). Disposal of liquid waste at domestic waste water treatment facilities is not an option given the current status of these facilities (Section 6.2) but in terms of law could be considered after prior consultation with and approval by the department responsible for water affairs (RSA, 2015a). The cost of establishing or upgrading of treatment facilities for treatment of liquid waste from SGD should be for the account of the developer and not that of the municipality.

6.4.3 Off-site management and disposal

The current off-site disposal options for Type 1 hazardous wastes are limited to licensed commercial hazardous waste treatment and disposal facilities in Gauteng, Port Elizabeth and Cape Town and possibly the private PetroSA hazardous waste landfill in Mossel Bay, provided that the relevant authorities and landfill owner approve. Municipal waste water treatment works (WWTW) in the study area do not have the capacity or required technologies to treat the waste water from SGD. It is therefore likely that for the Small and Big Gas scenarios, if on-site treatment is not an option, the waste water will have to be trucked to a suitable off-site facility for treatment. Key potential impacts from off-site management and disposal relates to the transport of the waste and waste water by road or pipelines. Construction and maintenance deficiencies related to transport pipelines, or road accidents if the waste or waste water is transported off site by road need to be mitigated (Ziemkiewicz et al., 2014). Mitigation measures relating to pipelines will include proper design, construction and placement of liquid transfer piping (Ziemkiewicz et al., 2014). It is also imperative that inadequate capacity, treatment technologies and human resources at municipal treatment and disposal facilities be addressed to ensure that additional loads of municipal solid waste and sewage can be handled appropriately.

Whether to have central processing facilities or have those in conjunction with wellpads in the Small and Big Gas scenarios, is a decision that needs to be taken for each specific development, based on minimising the overall negative impact from the development (Det Norske Veritas AS (DNV), 2013). A centralised waste disposal facility for Type 1 hazardous waste may be considered for the Big Gas scenario. Site selection for establishing a disposal facility will involve elimination of areas with associated fatal flaws, identification of candidate sites, based on site selection criteria, ranking of candidate sites and carrying out a feasibility study on the best option (DWAF, 1998a). Site selection criteria include:

- Economic criteria
- Environmental criteria
- Public acceptance criteria

Establishment and authorisation of such a facility will require a full EIA, and meeting the design requirements as outlined in the Norms and Standards for disposal of waste to landfill (Regulation 636 of 23 August 2013).

Processing facilities for solid waste and waste water must be designed and constructed to meet the following criteria (DNV, 2013):

- Design and construction will be in compliance with applicable standards;
- Design and construction will be to achieve effective utility according to anticipated lifetime and future development prospects;
- Processing facilities should as far as reasonably practicable be placed in the terrain in such a way that any impact on vulnerable areas is minimised;
- Shall have area space and load bearing capacity to cater for processing systems and equipment;
- Shall have appropriate spill control measured in place.

6.4.4 Deep well injection

Deep well injection is a common disposal option in the US, but due to the South African geology and legal framework, it is not an option in South Africa. Regulation 466 for Petroleum Exploration and Production (Section 124(4)) prohibits disposal to underground, including the use of re-injection disposal wells (RSA, 2015a).

6.4.5 Surface water discharge

Discharge of fracking fluids, fracking flowback, and produced water into a water source is prohibited in terms of Section 124(5) of Regulation 466 (RSA, 2015a). Treated surplus water not recycled back into the operations (all three SGD scenarios) may be discharged into surface water resources provided that it meets quantity and quality limits stated in the applicable water use licence. There is a risk of pollution of surface and groundwater sources if the water quality does not meet the required discharge standards. Mitigation measures to ensure meeting water quality requirements will include alternative use options for the waste water, treatment to prescribed standards, as specified in General Authorisations or applicable licence, before discharge (this may require some form of pre-treatment as well) and regular maintenance of treatment works. Regular water quality testing of effluent before discharge and regular downstream water quality monitoring will also be required. Development of norms and standards specific for discharge of treated shale gas flowback and produced water in the Karoo may be required to ensure equal and adequate protection of all the water resources and associated ecosystems in the study area.

6.4.6 Land application

Application of produced water to roads for dust control in all scenarios has several potential negative impacts including: surface and groundwater deterioration, soil contamination, toxicity to soil and water biota, toxicity to humans during and after application, air pollution from volatile dust suppressant components, accumulation in soils, changes in hydrologic characteristics of soil, and impacts on native flora and fauna populations (Hammer and Van Briesen, 2012). Areas with shallow groundwater resources may also be at risk of pollution if the quality of the water used in land application does not meet the standards. Mitigation of these negative impacts will be to treat the water to acceptable standards before land application and continued monitoring. Norms and standards for land application of waste water from SGD may be required to ensure adequate protection of the water resource and ecosystems from potential impacts associated with land application of waste water.

6.4.7 Spills

There is a risk of spillages occurring in all three scenarios. The impact of spills of fracking fluids (or waste water) onsite can be mitigated using established best practices such as installing impermeable site linings, bunding and using non-hazardous chemicals where possible (Koppelman et al., 2012). These requirements are already included in Regulation 466 of 3 June 2015. The impacts of spills resulting from transport incidents can be mitigated by prescribing transport routes, limiting the transport distance as far as possible as envisaged by Regulation 466 of 3 June 2015 and having spill response units on stand-by in the study area.

6.4.8 Residuals management

Regardless of the treatment options selected, residuals – the concentrated brines and solids containing the chemicals removed from the produced water, and sludge – will be treated as a waste in all three scenarios. Since chemicals present in the residual wastes are present at higher concentrations than in the original produced waters in all three scenarios, careful management is essential. Solids and sludges generated in treatment plants for produced water should be disposed of in landfills with adequate protection against the formation of subsequent brines in the leachate. The only mitigation measure for this waste will be to dispose of the waste at a duly authorised landfill site, designed and constructed in line with the National Norms and Standards for disposal of waste to landfill and operated in line with the Minimum Requirements for waste disposal by landfill.

6.5 Risk assessment

The risks associated with the impacts discussed in the previous section relates to:

- Exposure of humans and the environment to hazardous waste from SGD including sludge, mud, drill cutting, flowback and produced water and NORM.
- Exposure of humans and the environment to domestic waste i.e. municipal solid waste. Volumes of domestic waste are likely to increase as a result of influx of people into the area if SGD progress to the Small and Big Gas scenarios.
- Additional waste water load at already stressed municipal waste water treatment works as a result of influx of people into the study area.

Assessment of the risks that waste from SGD and associated activities pose to human health and the environment has been based on the methodology and assumptions outlined in Burns et al. (2016). The spatial zone of impact for the identified risks in the study area is based on expert opinion, and delineated as a 1000 m radius around both waste water treatment and waste disposal facilities. It is however acknowledged that impacts from waste water could also extend downstream from the discharge point. It is however assumed that the risk will be decreasing with increasing distance and therefore a 1000 m radius should be sufficient following a conservative, risk-averse approach.

6.5.1 How risk is measured

Assessment of risk associated with waste and potential impacts on human health and the environment must take into account all properties that are related to exposure within the environment (DWAF, 1998), such as:

- Biodegradability

- Persistence
- Bioaccumulation
- Chronic toxicity
- Concentration
- Production volume
- High dispersion
- Leakage to the environment

Risks associated with disposal of waste water sludge relate to sludge stability, disposal site design and location, the constituents in the sludge and their hazardousness, possible groundwater pollution, pollution of surface run-off as well as valuable land surface area taken up by surface disposal (DWAF, 2007).

This risk assessment is at the strategic environmental assessment (SEA) level, and SGD has not commenced in South Africa, therefore no site specific data was available to inform the assessment. Consequently, this assessment based on the expert opinion of the authors. The consequence terms Table 6.6 used in the risk matrix (Table 6.7, Section 6.5.2) are defined as follows:

Table 6.6: Consequence terms for the risk matrix.

Impact	Slight but noticeable	Moderate	Substantial	Severe	Extreme
Exposure to hazardous waste	Low toxicity, short term exposure	Low toxicity, long term exposure	Medium toxicity, short term exposure	Medium toxicity, long term exposure	High toxicity
Exposure to domestic waste	Increase in waste volumes at well managed landfills	Increase in volumes at poorly managed landfills	Increase in volumes at poorly managed landfills and noticeable increase in illegal dumping	Exceeding landfill capacity with substantial amounts of illegal dumping	Indiscriminate dumping, failing waste services, health impacts
Additional waste water load at WWTW	Increased load with spare treatment capacity	Increased load with limited to low capacity	Occasional exceedance of treatment capacity.	Frequent exceedance of treatment capacity	Constant exceedance of treatment capacity

6.5.2 Risk Matrix

Table 6.7: Risk Matrix.

Impact	Scenario	Location	*Without mitigation*			*With mitigation*		
			Consequence	**Likelihood**	**Risk**	**Consequence**	**Likelihood**	**Risk**
Exposure to hazardous waste (Sludge, mud, drill cuttings, flowback and produced water)	Reference Case	Near disposal or spillage site	Moderate	Not likely	Low	Slight but noticeable	Not likely	Very low
	Exploration Only		Substantial	Very likely	Moderate	Moderate	Very likely	Low
	Small Gas		Severe	Very likely	High	Moderate	Very likely	Low
	Big Gas		Severe	Very likely	High	Moderate	Very likely	Low
Exposure to domestic waste	Reference Case	Municipal landfill	Moderate	Likely	Low	Slight but noticeable	Likely	Very low
	Exploration Only		Moderate	Likely	Low	Slight but noticeable	Likely	Very low
	Small Gas		Moderate	Very likely	Low	Slight but noticeable	Very likely	Very low
	Big Gas		Severe	Very likely	High	Moderate	Very likely	Low
Additional sewage load at already stressed WWTW	Reference Case	Municipal WWTW	Substantial	Very likely	Moderate	Moderate	Very likely	Low
	Exploration Only		Substantial	Very likely	Moderate	Moderate	Very likely	Low
	Small Gas		Severe	Very likely	High	Moderate	Very likely	Low
	Big Gas		Severe	Very likely	High	Moderate	Very likely	Low

Risk associated with the transport of the waste and waste water is assessed in Chapter 18 by Van Huyssteen et al. (2016).

6.5.3 Best practice guidelines and monitoring requirements

According to the Council of Canadian Academies (2014) appropriate environmental monitoring approaches for the anticipated level of SGD have not yet been identified. Monitoring programs will have to be adapted to advances in technologies and to the location, scale, and pace of the SGD.

Best practice guidelines of relevance to this study, which are discussed in more detail below, include:

- Best practice guideline No H4: Water Treatment (DWAF, 2007);
- Guidelines for the utilisation and disposal of waste water sludge;
- National Norms and Standards for the Assessment of Waste for Landfill Disposal (Regulation 635 of 23 Aug 2013);
- National Norms and Standards for Disposal of Waste to Landfill (Regulation 636 of 23 Aug 2013);
- National Norms and Standards for Storage of Waste (GN926 of 29 Nov 2013);

- Minimum Requirements for the Monitoring of Water Quality at Waste Management Facilities (DWAF, 1998b).

6.5.3.1 Best Practice Guideline No H4: Water Treatment

These guidelines (DWAF, 2007) outline a water treatment plant evaluation and selection process to assist decision-makers in selecting an appropriate technology for their specific requirements. It describes, in a fair amount of detail, the differences between different treatment technologies including benefits and constraints of each technology option. The guidelines also touch on the characteristics of residue streams and provide some guidance on possible disposal options for the residue streams. Costs associated with the disposal of residues/sludges include disposal costs (based on volume and nature) and transportation cost (transportation distance to disposal site).

6.5.3.2 Guidelines for the Utilisation and Disposal of Waste water Sludge

The development of the sludge guidelines (Herselman and Snyman, 2007) was commissioned by the Water Research Commission (WRC) to encourage the beneficial use of waste water sludge. It is however recognised that beneficial use of waste water sludge is not always feasible. A separate Guideline Volume dealing with each of the management options were therefore developed as follows:

Volume 1: Selection of management options
Volume 2: Requirements for the agricultural use of sludge
Volume 3: Requirements for the on-site and off-site disposal of sludge
Volume 4: Requirements for the beneficial use of sludge
Volume 5: Requirements for thermal sludge management practices and for commercial products containing sludge

The quality and classification of the sludge is the determining factor in selecting the best management option.

6.5.3.3 National Norms and Standards for Assessment of Waste for Landfill Disposal

The assessment of waste for the purpose of disposal to landfill requires a full chemical analysis of the waste and laboratory analysis to determine the total concentrations (TC) and leachable concentrations (LC) of the elements and chemical substances contained in the waste (RSA, 2013a). The TC and LC limits must then be compared to the threshold limits specified in the norms and standards to determine the type of waste. All analyses must be done at accredited laboratories.

6.5.3.4 Norms and Standards for Disposal of Waste to Landfill

The norms and standards for disposal of waste provides for four different classes of landfills based on their containment barrier designs parameters. Waste acceptance criteria for landfill is based on the Type of waste and the class of landfill as outlined in Section 4 of Regulation 636 (RSA, 2013b).

6.5.3.5 National Norms and Standards for Storage of Waste

These standards apply to any person who stores general or hazardous waste in a waste storage facility irrespective of whether a waste management licence is required or not. Waste storage facilities must be registered with the competent authority. Location of hazardous waste storage facilities must be within an industrial demarcated zone or must have a buffer zone of at least 100 m unless there is a prescribed buffer zone by the relevant municipality and must be located in areas accessible to emergency response personnel and equipment (RSA, 2013d).

Liquid waste storage areas must have firm, impermeable, chemical resistant floors and a roof. Liquid waste containers that are not stored under a roof must be coated to prevent direct sunlight and rain from getting into contact with the waste. There are also requirements for liquid storage areas to be surrounded by an interception trench with a sump and a secondary containment system (i.e. bund, drip tray) (RSA, 2013d).

Hazardous waste storage facilities must have impermeable and chemical resistant floors (RSA, 2013d).

These norms and standards also prescribe access control and notices as well as operational requirements. There are also prescribed minimum requirements for above ground waste storage tanks (Section 11) (RSA, 2013d).

6.5.3.6 Minimum Requirements for Monitoring of Water Quality at Waste Management Facilities

Acknowledging the uniqueness of the South African groundwater systems, the Minimum Requirements were developed to ensure coordinated and meaningful water quality monitoring by applying the principle of best available technology, not entailing excessive cost (DWAF, 1998b). It is a minimum requirement that a risk assessment, to determine the risk of water becoming polluted, be performed at all waste sites before the installation of a monitoring system. This serves to ensure that the design of the monitoring system is adequate and the risk assessment methodology to follow is prescribed in the report (DWAF, 1998b).

According to DWAF (1998b) the main purpose of a monitoring system is to:

- Provide reliable data on the quality and chemical composition of the groundwater;
- Detect and quantify the presence and seriousness of any polluting substances in the groundwater at the earliest stage possible;
- Detect possible release or impending release of contaminants from the waste facility;
- Provide a rationale comparison between the predicted and actual flow and solute transport rates; and
- Provide and ongoing and reliable performance record for the design and control systems for effectively controlling pollution.

To achieve the above objectives it may necessary to employ two separate monitoring systems in cases where the generation of hazardous leachate may be a problem. The two monitoring systems are:

- Early warning monitoring systems
- Regional monitoring systems.

A schematic presentation (DWAF, 1998b) of these monitoring systems is shown in Figure 6.4 below.

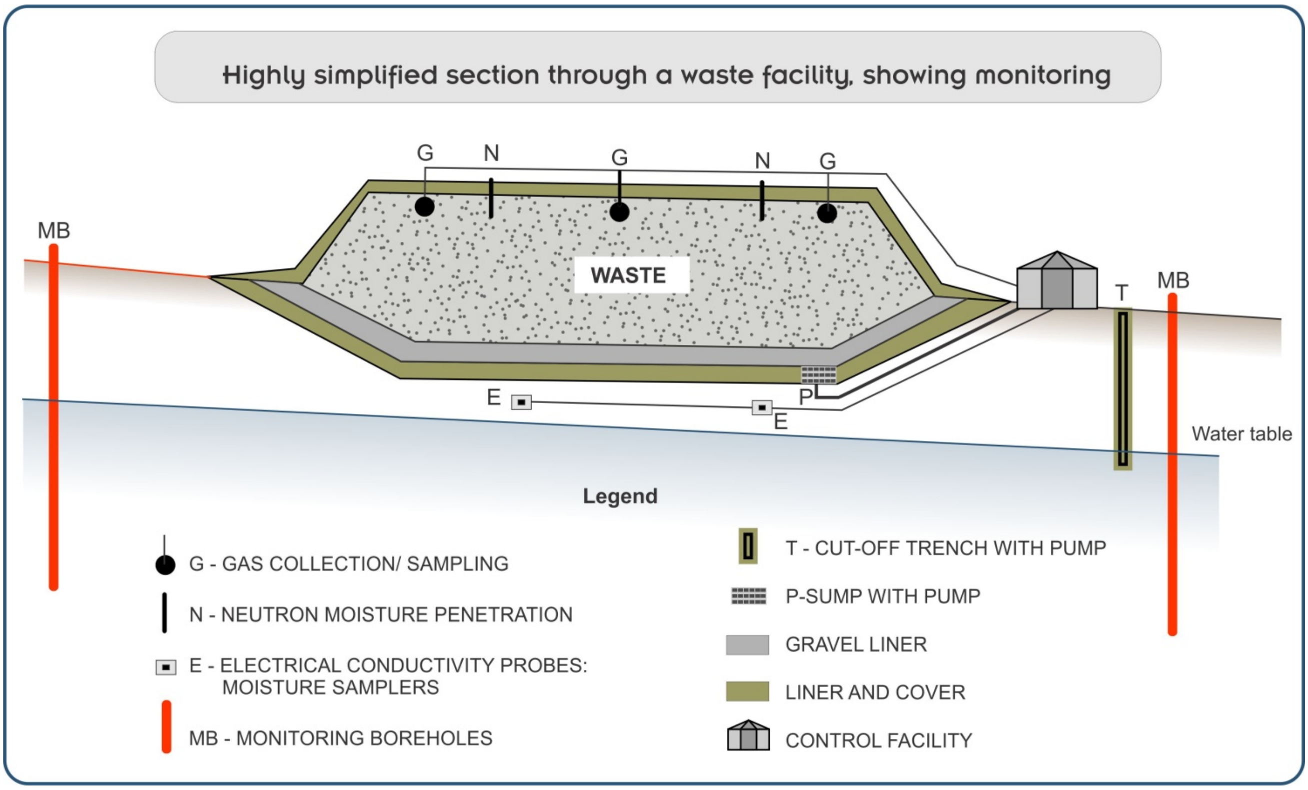


Figure 6.4: A schematic presentation of these monitoring systems (DWAF, 1998b).

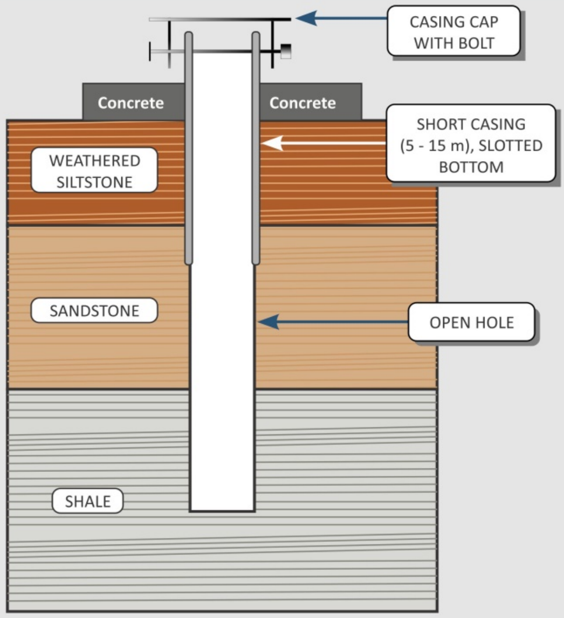
Minimum monitoring requirements at various types of waste management facilities provided does not include above-ground storage facilities as are required for SGD. It does however include monitoring requirements for general and hazardous waste disposal facilities and sewage sludge as indicated in Table 6.8 below.

Table 6.8: Monitoring requirements for general and hazardous waste disposal facilities and sewage sludge.

	At or near surface monitoring								Within waste or unsat. zone						Groundwater monitoring							
Monitoring Requirements → / Waste environment ↓	Rainfall	Evaporation	Run-off (volume, quality)	Water infiltration on waste	Toe seepage from waste	Soil cover on waste	Vegetation on waste or soil	Bioassaying	Pressure vacuum lysimeters	Gas samplers	Electrical conductivity probes	Leachate collectors	Temperature within waste	Special detectors	Special monitoring holes	Other existing holes	Groundwater levels	Groundwater chemistry	Borehole yield	Groundwater usage	Fountain seepage	Water balance
Mines – Reactive environment	d		d																			m
Slimes (Slurry)				m	m	y	y					m			yes	yes	m	6m	yes	y	m	m
Ore discards			d	m	m	y	y					m			yes	yes	m	6m	yes	y	m	m
Rock Discards (opencast)				m	m	y	y								yes	yes	m	6m	yes	y	m	m
Rock discards (other)					m	y	y								yes	yes	y	y	yes	y	y	y
Mine water (impoundment)				m	m										yes	yes	3m	6m	yes	y	m	m
Mine water (discharged)			d					y														w
Mines – Inert environment	d		d												no	yes	y	y	yes	y	y	m
Slimes (slurry)					m										no	yes	y	y	yes	y	y	m
Rock discards					m										no	yes	y	y	yes	y	y	y
Ore discards					m										no	yes	y	y	yes	y	y	y
Mine water (discharged)			d																			d
Coal fired power stations	d		d												yes	yes	3m	6m	yes	y	m	m
Coal stockpiling					m							m			yes	yes	3m	6m	yes	y	m	m
Ash disposal (slurry)					m										yes	yes	3m	6m	yes	y	m	m
Ash disposal (dry)				m			y								yes	yes	3m	6m	yes	y	m	m
Dirty water systems					m										yes	yes	3m	6m	yes	y	m	m
Water discharged			d					y														
General waste																						
Large (>500 t/d)	d		d		m	y	y	y		m		m			yes	yes	3m	6m	yes	y	m	m
Medium (26 – 500 t/d)	d		d		m	y	y			m					yes	yes	y	6m	yes	y	m	m
Small (1 – 25 t/d)					m										yes	yes	y	6m	yes	y	m	
Communal (<1 t/d)					m										no	yes	y	6m	yes	y	m	
Sewage																						
Unlined maturation ponds			d												yes	yes	y	6m	yes	y	m	
Sludge			d																			
Hazardous waste	d	d	d	m	m	m	m	y	m	m		m		m	yes	yes	m	6m	yes	y	m	y
Waste irrigation	d		d	m	m	m	m	y							yes	yes	m	6m	yes	y	m	m
Agriculture (feed lots)	d		d												yes	yes	m	6m	yes	y	y	
Agriculture (diffuse sources)															no	yes	y	y	yes	y		
Septic tanks and pit latrines															no	yes	y	y	yes	y		
Underground storage tanks														m	yes	yes	m	6m	yes	y	m	
Urban development	d		m												no	yes	y	y	yes	y		
Industries	Refer to specific waste above, such as general, hazardous, irrigation, impoundment																					
Radioactive waste	As specified by the CNS in collaboration with the DWA&F																					

Explanation of codes: d = daily monitoring; w = weekly monitoring; m = monthly monitoring; 3/6m = 3/6-monthly monitoring; y = yearly monitoring

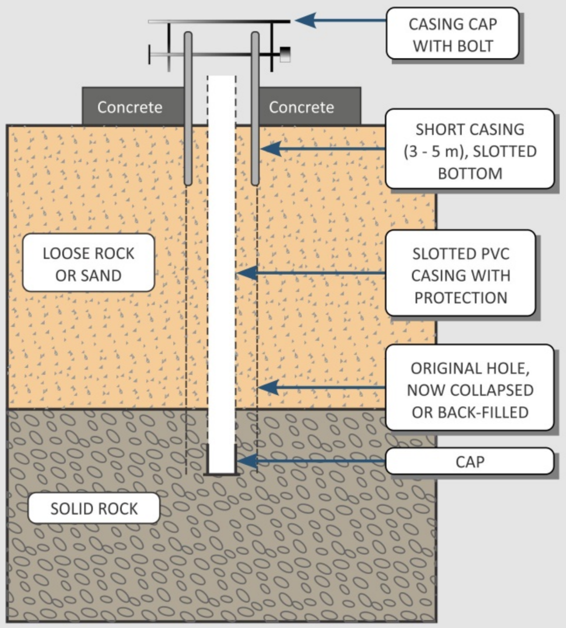
The Minimum Requirements (DWAF, 1998b) also provide guidance on borehole design for groundwater monitoring at landfills as illustrated in Figure 6.5 below.



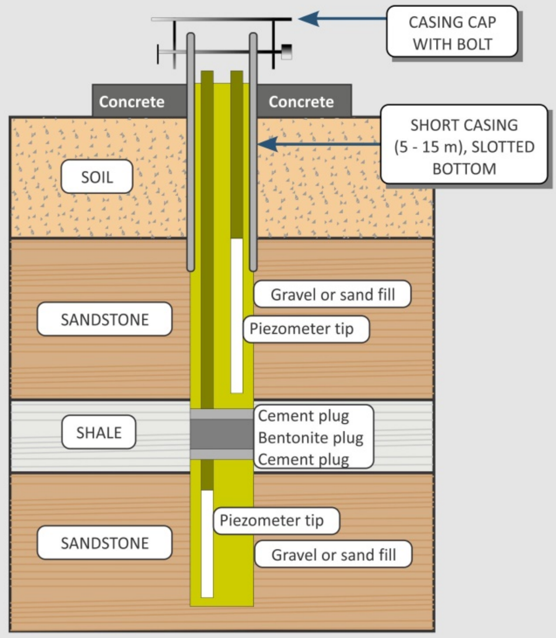
Typical installation required
for monitoring boreholes into solid rock,
average depth 40 metres.

Data required from monitoring boreholes (DWAF, 1998b):

- Geological log.
- Water intersections (depth and quantity.
- Construction information (depth of hole and casing, borehole diameter, method drilled, date drilled).
- Use of water, if not solely for monitoring: Frequency of abstraction; abstraction rate; and whether other water sources are readily available.
- Water quality.



Typical installation for monitoring boreholes
into the loose material such as sand,
gravel, discards or rock spoil at th opencast mines



Typical installation of piezometer
tubes in a monitoring borehole

Figure 6.5: Minimum Requirements (DWAF, 1998b) also provide guidance on borehole design.

6.6 Gaps in knowledge

Suitable sites for waste water treatment and on-site disposal of waste must be identified should SGD go ahead. Detail on the composition of the wastes will be required to inform site selection, design requirements of these facilities as well as the technology choices to consider.

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6.8 Digital Addenda 6A – 6B

SEPARATE DIGITAL DOCUMENT

Addendum 6A: Tabulated detailed information

Addendum 6B: Examples of Commercially available Modular Water Treatment Technologies