Annexure "A"

# Groundwater opinion on the proposed regulations for the exploration and production of onshore oil and gas requiring hydraulic fracturing technology, its related Minimum Information Requirement documents and the guideline for well decommissioning

**By: S Esterhuyse**

**Groundwater opinion on the proposed regulations for the exploration and production of onshore oil and gas requiring hydraulic fracturing technology, its related Minimum Information Requirement documents and the guideline for well decommissioning**

This document provides a technical opinion and detailed comments on the proposed regulations for the exploration and production of onshore oil and gas requiring hydraulic fracturing technology (Notice 6806 of 2025), the minimum information requirements (MIRs) for the exploration and production of onshore oil and gas requiring hydraulic fracturing technology (Notice 6808 of 2025), the MIRs for baseline monitoring for onshore exploration operations (Notice 6811 of 2025) and the onshore well decommissioning guidelines prepared by Petroleum Agency SA (Notice 6818 of 2025).

There was significant improvement and inclusion of suggested revisions to the exploration and production regulations of onshore oil and gas requiring hydraulic fracturing (Notice 2273 of 2022) (RSA 2022a) and the MIRs for permits for the exploration of onshore oil and gas using hydraulic fracturing (Notice 2265 of 2022) (RSA 2022b) that was proposed in 2022. However, some aspects of the newly proposed regulations and MIRs still require improvement.

This submission contains an opinion and detailed comments on both the proposed regulations, the minimum information requirements documents, and the well decommissioning guideline. The opinion begins with an introduction that discusses the potential impacts of unconventional oil and gas (UOG) extraction on water resources, specifically groundwater, and its policy context. It highlights the importance of properly developed regulations to minimise potential negative impacts on water resources. Thereafter, an opinion and detailed comments are provided for the proposed regulations, the 2 MIR documents, and the well decommissioning guidelines. These comments are based on publicly accessible regulations and guidelines from other jurisdictions where oil and gas are being developed, including Australia, Nigeria, Brazil, the US and the UK (API 2013; API 2015; Dodd 2025; Energy glossary 2026; Federal republic of Nigeria 2023; Gawlik and Comero 2022; Huddlestone-Holmes et al. 2022; IADC lexicon 2026; New South Wales government 2023; State of Victoria 2023, United Kingdom 2013; Ward et al. 2020).

The issues that should be addressed in the regulations, MIRs and the well decommissioning guideline are broadly highlighted here.

Under the Regulations (Notice 6806 of 2025):

1. Defining all the terms used in the regulations
2. Ensuring integrated protection of water resources (considering both groundwater and surface water resources)
3. Ensuring that water use for exploration or production is sustainable in the Karoo
4. The extent of the stimulation techniques and resource types covered by the regulations should be revised to include all the possible techniques used to extract unconventional oil and gas resources
5. The regulations should seek alignment with the National Water Act and related fracking regulations
6. Fracturing fluid and fracture fluid containment should be regulated, as migration of the fluids could cause groundwater contamination

Under the MIR for oil and gas production (Notice 6808 of 2025):

1. More detailed project description information is required, specifically in terms of well locations, to ensure proper water resources protection. Well locations must be known to ensure proper aquifer vulnerability assessment, accurate baseline monitoring and timeous response to leakage events or well blowouts (Esterhuyse et al. 2017; Esterhuyse et al. 2022).
2. To protect against groundwater over-abstraction, the environmental impact assessment process for hydrogeology should be improved by incorporating the required climate change impact assessment information (section 5.6) into the groundwater section (section 5.12). This is to determine a climate-adjusted groundwater recharge estimate. Further measures are recommended under the impact assessment, including assessing aquifer sensitivity, long-term abstraction

sustainability, projected water demand from exploration and potential future activities, a comparison of projected water with existing cumulative catchment stress, and determining risk-based abstraction thresholds or adaptive management triggers for groundwater abstraction.

3. Potential transboundary or downstream connectivity risks relevant to project impacts should be identified. The potential oil and gas Karoo target area straddles several major (primary) catchments, which indicates that impacts of various development scenarios on water resource condition may have further-reaching implications for downstream resource users, including natural ecosystems (Hobbs et al. 2016).
4. Additional monitoring and management plans that are not considered under this MIR are needed to minimise the risk of groundwater contamination, including a:
    1) Hydraulic fracturing monitoring plan
    2) Fracturing fluid management plan
    3) Additional plans are required under the 'Water and wastewater management plan', including a
        a. A plan for the safe management of flowback and produced water
        b. A fluids transportation plan
        c. An interim fluid storage plan

Under the baseline monitoring MIR (Notice 6811 of 2025):

To ensure proper water resources protection, additional requirements are needed in terms of the baseline monitoring plans for the following entities:

1. Surface water and aquatic biodiversity
2. Groundwater
3. Seismicity

Under the Well decommissioning guidelines (Notice 6818 of 2025):

To properly protect water resources during and after well decommissioning, the following aspects should be addressed:

1. Defining all the terms used in the well decommissioning guidelines
2. Including long-term monitoring of decommissioned wells, as these wells pose a contamination risk over the long term when their well integrity fails
3. Fugitive emissions monitoring and control during and after well decommissioning is needed to help identify groundwater pollution timeously.
4. Land restoration or remediation obligations during well decommissioning should also be considered in the guideline, as contaminated land pose a pollution risk to groundwater
5. Record keeping of decommissioned wells should be addressed, if records are not properly stored and available for scrutiny, it is not possible to monitor pollution risk
6. Emergency response plans for well blowout or gas releases from decommissioned wells should also be required in these guidelines, as well blowouts pose a contamination risk, and can occur during and after well decommissioning.

## 1. Introduction: Unconventional oil and gas resources in South Africa and the Policy Context

Extracting UOG resources in South Africa's Karoo Basin is one of the options being considered to augment energy supply. UOG may serve as a transition fuel to cleaner energy (IPCC 2021; IRENA 2019). South Africa's pursuit of onshore unconventional gas using hydraulic fracturing, with an emphasis on shale gas resources in the Karoo, has unfolded over more than a decade of public debate, legal challenges, and evolving policy (Esterhuyse 2023). Apart from the Karoo shale gas resources, unconventional oil and gas (UOG) resources in the form of coalbed methane (CBM) are also targeted (DMR 2009).

Shale gas resources occur at a depth of 2 to 6 km in the Karoo main basin as methane that is trapped in shale rock with small pores and low permeability (Nolte et al. 2019; Stroebel et al. 2019). The low permeability of the shale rock necessitates hydraulic fracturing to release the trapped gas. Hydraulic fracturing is the act of pumping hydraulic fracturing fluid under very high pressures into the target formation to increase the permeability of the rock, in order to release the trapped gas. CBM occurs in coal seams between 400 to 600m deep in the Waterberg region in South Africa (DMR 2009). The difference in source rock and depth of these shale gas and CBM means that impacts on water resources during the stimulation and extraction of the gas would also differ (Table 1).

Table 1: Differences in resource types and impacts on water resources (Esterhuyse et al. 2014)

| **Resource type** | **Shale gas resources** | **Coalbed methane** |
|---|---|---|
| **Depth** | 2-5 km (and up to 6km) deep | 400-600m deep |
| **Occurrence of freshwater aquifers** | Does not typically co-occur with shallow freshwater aquifers | May co-occur with shallow freshwater aquifers |
| **Wastewater stream and volume** | Highest volumes of wastewater are in the form of flowback (returned fracking fluids). Produced water volumes are typically less than for CBM | Typically produces very large volumes of saline wastewater in the form of produced water |
| **Stimulation technique** | Typically requires hydraulic fracturing | Typically requires depressurisation via coalseam dewatering, but could require hydraulic fracturing |
| **Water use** | May require large volumes of water as part of fracking fluid makeup | Water use requirements are typically less than for shale gas |

Whereas the shale gas resources could predominantly require hydraulic fracturing to stimulate and release the trapped gas resources, other stimulation techniques, including low pressure hydraulic stimulation, depressurisation and acidification may also be used (Wu 2025; Yan et al. 2020). For the CBM resources, low-pressure hydraulic stimulation coupled with depressurisation via dewatering of the coal seam (Van Averbeke 2017), is already currently used in South African pilot projects (Hidayat 2025; DMR 2009), and it is reasonable to expect that one of the main forms of stimulation for CBM in South Africa would be depressurisation.

For shale gas development in the Karoo, large volumes of water may be required (Esterhuyse et al. 2016; Hobbs et al. 2016). More water would be required to develop shale gas compared to CBM. This water would be needed to do hydraulic fracturing, whereas hydraulic fracturing may not be needed to such a large extent for CBM operations (Esterhuyse et al. 2014). South Africa is, however, water-scarce. Communities in the Karoo Basin, with its very low annual rainfall and limited perennial rivers, depend heavily on groundwater (Esterhuyse et al. 2023). An estimate of water requirements per fracking well is presented in table 2, as sourced from Hobbs et al. 2016. These estimates are based on water use for fracking 4 Texas shale basins. It is important to note that these shale formations are at different depths than those in the Karoo, and the data presented in this table may not therefore be representative of the actual water requirements for fracking of Karoo systems, given that water requirements are a function of depth and other factors.

Table 2: Water requirement estimates for fracking in four Texas shale gas resources, values rounded off to the nearest 100 (Hobbs et al. 2016)

| **Shale gas resource** | **Water requirement per well** | | |
|---|---|---|---|
| | **Low-end estimate** | **Median** | **High-end estimate** |
| Barnett shale | <3 800 | 9800 | >30 300 |
| Haynesville and Bossier Shale | <3 800 | 20800 to 22 700 | >37 900 |
| Eagle Ford Shale | 3 800 | 380022 700 to 24 600 | 49 200 |
| Woodford, Pearsall and Barnett-PB Shale | <3 800 | 2 800 to 3 8000 | < 18 900 |

Hobbs et al. (2016) further determined possible water use for 3 scenarios of shale gas development in the Karoo – exploration only, small gas, and big gas. The estimated water use is presented in Table 3.

Table 3: Summary of estimated water use per drill rig by type of shale gas campaign

| Water use application | | Per drill rig | | Total | |
|---|---|---|---|---|---|
| | Period (years) | Without re-use m3 | With re-use m3 | Without re-use m3 | With re-use m3 |
| Exploration only | 2 | 103 770 | 70 140 | 518 850 | 350 700 |
| | | | | 5 drill rigs | |
| Small gas | 17 | 3 283 500 | 2 237 400 | 9 850 500 | 6 712 400 |
| | | | | 3 drill rigs | |
| Big gas | 21 | 4 104 375 | 2 796 750 | 82 087 500 | 55 935 000 |
| | | | | 20 drill rigs | |

In 2016, more than 35% of the Karoo catchments that were assessed for the SEA for shale gas development, were already over-utilised and presented with extreme groundwater stress (Hobbs et al. 2016). The assessment concluded that additional surface water resources are unlikely to be available for direct utilisation for shale gas development in the Karoo, without impacting on existing user groups including aquatic ecosystems. At the time of the assessment, existing groundwater use was also considered to be an underestimate, because a substantial portion of the resource is either not licensed in terms of the National Water Act 36 of 1998 (NWA) (RSA, 1998) or is considered Schedule 1 use, which does not require licensing.

Using a strict livestock watering versus shale gas production well comparison, just 21 shale gas wells (at 0.2 million $m^3$ per annum each as per Table 3) will consume the coarse estimate (~4.2 million $m^3$ per annum) of Schedule 1 use for livestock watering in the whole study area that was assessed for shale gas development in the Karoo (Hobbs et al. 2016).

Apart from water use, groundwater contamination during UOG extraction is also a concern. The Karoo basin's dolerite dykes and sills, which cover most of the basin, are its main water-provisioning features but can also act as pathways for contaminants that may infiltrate from the surface during fracking operations or migrate from deep to shallow aquifers during UOG extraction. Saline artesian aquifers are postulated to occur in the southern part of the Karoo, where artesian flows have been encountered in deep Soekor wells at depths exceeding 4000m (Hobbs et al. 2016). These aquifers also present a contamination risk. These regional artesian aquifer conditions occur south of the southern limit of the dolerite intrusions, with the Great Escarpment marking the northern limit of this deep artesian flow. Rocks of the Cape Supergroup that underlie the area south of the Great Escarpment are under sufficient hydrostatic and lithostatic pressure to allow deep groundwater from these deep aquifers to reach the surface (Hobbs et al. 2016). The Karoo's groundwater is vital for agriculture and household use, so the specific vulnerabilities of the Karoo aquifers in the shale gas target area are a matter of concern (McGranahan et al. 2019; Finkeldey 2018). When considering CBM production, one concern is the release of large volumes of produced water (Rice and Nuccio 2000), which may be very saline (Mendhe et al. 2015), as indicated by analyses of CBM water samples from the Waterberg (Van Averbeke 2017).

Public concern over the possible water and related seismic and socio-economic implications of shale gas and CBM extraction, includes the following:

- Water scarcity in the Karoo, where fracking requires large volumes of water.
- Fears of groundwater contamination, soil degradation, methane leakage, and surface spills.
- Concerns about regulatory preparedness and limited baseline data.

Due to these concerns, several studies investigated the possible impacts of fracking in the Karoo, including a Strategic Environmental Assessment of Shale Gas Development in the Karoo, where the impact on water resources was flagged as the one severe limiting factor for shale gas development in the Karoo, specifically water availability for fracking (Hobbs et al. 2016). To protect groundwater resources, establishing a baseline of the groundwater quality before fracking was recommended by the SEA (Hobbs). Esterhuyse et al. (2022) identified additional measures to protect groundwater resources during fracking, including:

- Developing UOG extraction regulations to protect groundwater resources in South Africa
- Ensuring the enforcement of these UOG extraction regulations
- Having a central database for storing UOG extraction-related data, which is publicly accessible, and
- Prescribing fines for violators.

Table 4 summarises specific activities that should be regulated to protect groundwater resources during UOG extraction (Esterhuyse et al. 2014; Esterhuyse et al. 2019; Van Averbeke 2017).

Table 4: UOG extraction activities (for both shale gas and CBM resources) that must be regulated to limit adverse effects on groundwater systems in South Africa

| Activity to be regulated | Possible effects |
|---|---|
| A) Groundwater use | Extraction of groundwater for use during fracking operations can cause groundwater drawdown and affect aquifer structural integrity, possibly reducing the aquifer's storage capacity. |
| B) Stimulation techniques:<br>1) Fracking operations<br>2) Depressurisation<br>3) Acidification | 1) Fracking can affect the integrity of an aquifer by changing its geological structure. Upward migration of fracking fluids from the shale reservoir along preferential pathways, which can be natural (faults or fracture zones) or man-made (oil and gas wells), can contaminate the aquifer.<br>2) Depressurisation can cause deformation of the aquifers and change the structure of the geological layers, with migration of produced water to freshwater aquifers<br>3) Acidification can cause migration of acid fluids to freshwater aquifers with related groundwater contamination |
| C) Wastewater and solid waste management | Inadequate solid waste or wastewater management can cause aquifer contamination. A major concern is groundwater contamination from wastewater (consisting of flowback and produced water). Between 0 and 80% of the fracking fluid can return to the surface as flowback and produced water, which may contain heavy metals and radioactive materials, and is also released from the geological formation over the lifetime of the well. Pollution of surface water resources and/or the infiltration of surface contaminants into groundwater resources can occur via accidental spillages of drilling fluid, fracking fluid, flowback, or produced water. During CBM development, significant volumes of saline produced water are returned to the surface during gas production, and must be addressed (Esterhuyse et al. 2014; Van Averbeke 2017) |
| D) Decommissioning of production wells | Inadequate well design or well integrity failure can cause fracking fluid, flowback or produced water to migrate into aquifers during and after well decommissioning |

The proposed regulations (Notice 6086 of 2025), MIRs (Notice 6808 of 2025 and Notice 6811 of 2025), and well decommissioning guideline (Notice 6818 of 2025) aim to minimise the potential negative impacts of UOG development in South Africa.

Whereas several studies in South Africa investigated the effects of shale gas extraction from the Karoo basin on water resources (Esterhuyse et al. 2014; Murray et al. 2015; Miller et al. 2015; Esterhuyse et al. 2016; Hobbs et al. 2016; Harkness et al. 2018; Stroebel et al. 2019; Williams et al. 2020; Williamson and Esterhuyse 2020; Esterhuyse et al. 2022), only a limited number of studies focused on understanding the effects of CBM extraction on South African water resources (Esterhuyse et al. 2104; Van Averbeke 2017).

This lack of focus on CBM stems from the historical, explicit focus of oil and gas companies and the South African government on developing the Karoo shale gas and the associated priority to protect water resources in the Karoo. The lack of focus on CBM is also clear in these regulations, the MIRs, and the proposed well decommissioning guideline, which seem to focus exclusively on regulating possible impacts from the extraction of shale gas resources. This is evident from the fact that CBM is not defined in any of these documents, nor is produced water, which pose a serious risk to water resource quality, specifically during CBM extraction.

The next sections will provide an opinion on these documents and identify areas for improvement. The opinion focuses specifically on groundwater and related surface water and seismicity concerns, which influence the protection of groundwater during UOG extraction.

## 2. Opinion and comments on Notice 6086 of 2025: Proposed regulations for the exploration and production of onshore oil and gas requiring hydraulic fracturing technology

The regulations place strong emphasis on water protection and well integrity controls, tailored to the Karoo's sensitivities. The regulations also support transparency, which builds trust and oversight. However, there are a number of ways that the regulations must be further strengthened, as detailed in the following points of concern listed under General comments and Specific amendments:

1. Defining all the terms used in the regulations
2. The extent of the stimulation techniques and resource types covered by the regulations should be revised to include all the possible techniques used to extract unconventional oil and gas resources
3. The regulations should seek alignment with the National Water Act and related fracking regulations
4. Ensuring that water use for exploration or production is sustainable in the Karoo
5. Ensuring integrated protection of water resources (considering both groundwater and surface water resources)
6. Fracturing fluid and fracture fluid containment should be regulated, as migration of the fluids could cause groundwater contamination

### 2.1 General comments

***Definition of terms***

Several technical terms used in the regulations are not defined. This leaves the regulations open to interpretation and could render the regulations ineffective. See Section 2.2 below for the specific terms that need further defining.

***The extent of stimulation techniques addressed by the regulations***

The regulations address only unconventional oil and gas (UOG) extraction that requires hydraulic fracturing, yet other stimulation techniques can be used to stimulate UOG resources. Stimulation methods such as depressurisation and acidification can also be used during shale gas extraction, and is commonly used during coalbed methane (CBM) production. Several CBM-related terms are not defined in the definitions of the proposed documents, including:

- Coalbed methane (CBM)
- Depressurisation
- Dewatering
- Produced water

Therefore, apart from the fact that additional stimulation methods may be used during shale gas extraction, which these regulations do not consider, it also seems as if the focus of these regulations is on regulating shale gas extraction, while CBM has not been considered. Significant wastewater volumes are expected from the produced water stream associated with coalbed methane production during depressurisation, when compared to shale gas extraction (Esterhuyse et al. 2014).

All the definitions, therefore, pertaining to only hydraulic fracturing (HF) should be revised to also include other stimulation techniques. Considering the observed gap in addressing CBM extraction and regulating its related impacts on water resources, the government must either:

1. Develop additional regulations to address specifically CBM development, or
2. Revise the current regulations, MIRs and well decommissioning guidelines to explicitly include CBM development

***Alignment with the National Water Act***

There should be better alignment with the National Water Act (36 of 1998) (NWA), as the Department of Water Affairs has primary jurisdiction over South Africa's water resources, and their proposed Regulations for the use of water for exploration and production of onshore naturally occurring hydrocarbons that require stimulation, including hydraulic fracturing and underground gasification, to extract, and any activity incidental thereto that may impact detrimentally on the water resource as published in Notice 5582, GG 51642, Nov 2024 (RSA 2024). This is relevant particularly regarding definitions missing from the proposed regulations. These regulations should therefore align with the NWA and use the same water terminology in the first instance and, where possible and necessary, add further detail for clarification. This will avert gaps that may arise should the interpretation of the legislation and the proposed technical regulations become the subject of dispute. Co-operative governance is crucial to comprehensively regulate fracking.

***Water use for exploration or production***

Regulation 4a of the proposed regulations prohibits water abstraction for exploration or production in areas where the rainfall is under 400mm per annum. It should be noted that rainfall is not a reliable indicator of water availability. The Karoo receives between 160 mm rainfall per annum in the west and 4000 mm in the east (Harmse et al. 2020). This rainfall is highly variable, with some years having significant rainfall and some less, and with some regions of the Karoo receiving intense rains in a given rainfall season, and some little rain, indicating large spatio-temporal variability (Dennis and Dennis 2012; Avenant et al. 2016; Botai et al. 2018; Edokpayi et al. 2020). The potential evaporation rates also exceed rainfall in most of the Karoo (Avenant et al. 2016), and rainfall events are frequent, short, and intense, which reduces potential recharge to groundwater (Hohne et al. 2025). Due to rainfall variability, surface water is a scarce resource in the Karoo environment, which is characterised by ephemeral surface water drainages with periodic discharge and an associated low assurance of supply, placing a huge value and reliance on groundwater resources (Hobbs et al. 2016).

Given these facts, groundwater availability is the determining factor for water availability in the Karoo (Hobbs et al. 2016, Esterhuyse et al. 2022). Groundwater sustainable yields should be used as a guideline for water availability in the Karoo. While using rainfall as a proxy for water availability can overestimate sustainable yield in a specific region, it remains a useful tool for limiting water abstraction in the Karoo's dry areas. This tool must, however, be augmented with additional prohibitions specifically tailored to protect the Karoo aquifers from groundwater over-abstraction during fracking operations.

Additional restrictions to protect the Karoo aquifers from over-abstraction, are suggested under ancillary activities (see Table 5), including recommended setbacks around current and future managed aquifer recharge areas, around natural aquifer recharge areas, around artesian boreholes wells and aquifers, and around towns with no current wellfields. Towns that do not currently use groundwater, may in future use groundwater wellfields. This is because groundwater use for domestic water supply will become more prevalent in future as the Karoo is predicted to receive less rainfall due to climate change (Edokpayi et al. 2020).

Regulation 4a further stipulates that abstraction for water should only occur from deep saline aquifers in instances where the rainfall is less than 400mm. In the Karoo saline water is typically found in deeper geological formations, for example the Ecca (Hohne et al. 2020). This saline water could migrate to shallower freshwater aquifers via manmade connections (deep boreholes or the fracking wells) or natural connections (faults, folds, or fracture zones associated with dolerite dykes and sills) (Esterhuyse et al. 2014). Shallow-deep aquifer connections have been observed in the Karoo (Hohne et al.). Pumping could increase the rate of groundwater migration between different aquifer systems if they are connected.

Under the comments on the MIR for baseline monitoring, further recommendations in terms of baseline information that must be gathered for the requirements of the 'groundwater monitoring plan for determining the pre-fracturing groundwater status', are made to protect against shallow aquifer contamination via migration of saline fluids from deep to shallow aquifers.

***Integrated protection of water resources***

These regulations place a large emphasis on groundwater protection. Groundwater should, however, be protected in an integrated manner with surface water to adhere to account for interactions between surface and groundwater, following the principles of integrated water resource management. Surface water protection is not addressed sufficiently in the proposed regulations. The regulations do not define or refer to wetlands or rivers, which form an integral part of the hydrological cycle and are managed in an integrated manner together with surface water in South Africa (DWS 2025). There is no reference to the protection of surface water features, such as wetlands, in the proposed setback distances. The regulations must define wetlands and specify protection zones, and consider relevant setbacks for activities that may impact on watercourses and wetlands (see Table 5).

***Reporting of fracture and fracturing fluid containment measures post testing***

It is essential to contain both fracturing fluid and fractures within the target geological layer after hydraulic fracturing operations, to limit the migration of fracking fluids, flowback and produced water to freshwater aquifers.

Ideally, for fracturing fluid containment, a risk assessment should be conducted and submitted to the regulator under a fracturing fluid management programme. Such a report must describe the control and mitigation measures for primary fracture fluid containment, document the basis for the hydraulic fracturing sealing mechanism and demonstrate that adequate control measures will be implemented.

Fractures should be contained by identifying and monitoring faults and fractures associated with igneous intrusions, that may impact the hydraulic fracturing seal mechanism. These geological features must be researched, assessed and documented to demonstrate that the risk of fracturing fluids migrating via faults and intrusions beyond the designated fracture zones has been mitigated.

## 2.2 Specific amendments

In these proposed amendments, the revised text, which should be considered for inclusion in the revised regulations, are indicated in red.

**Chapter 1: Definitions, purpose and application of these regulations**
**Definitions:**

*Ensure consistent use and spelling of the following terms:*

Flowback. This term is used in the regulations as "*flow back*", "*flow-back*" and "*flowback*". The correct term as used in the oil and gas industry is "flowback". Please revise all the other variations in spelling of this term to "flowback" (IADC Lexicon 2026).

*Revise the following definitions:*

- **"**Applicant" means a person who applies for an exploration right or a production right in terms of the Mineral and Petroleum Resources Development Act, 2002 and which exploration or production requires fracturing technology and a person who applies for an environmental authorisation in terms of the Act, for an exploration, fracturing or production activity intending to or using fracturing technology.

  Note: The specific focus on hydraulic fracturing precludes consideration of other stimulation technologies used to extract UOG resources, such as depressurisation. Consider revising to include other technologies such as depressurisation.

- **"flow back"** means hydraulic fracturing fluid and other fluids that return to the surface after hydraulic fracturing has been completed and prior to the well being placed into production.

  revise to:

  "**flowback"** means hydraulic fracturing fluid that returns to the surface after hydraulic fracturing is completed and prior to the well being placed into production

- **"fracturing"** means an intervention performed on a well to increase production by improving the flow of petroleum from the drainage area into the well bore and includes re-fracturing."

  Revise the definition to be more precise (based on RSA 2021):

  **"hydraulic fracturing"** means an intervention performed on a well to increase production by improving the flow of petroleum from the drainage area into the well bore, in which rock is fractured by a pressurised liquid or gas, which process involves the high-pressure injection of fracturing fluids or gas and proppant into a wellbore to create microfractures or fractures in the deep-rock formations through which natural gas, petroleum and brine will flow more freely, and includes re-fracturing.

  Note: The term 'fracturing' is an imprecise shorthand for 'hydraulic fracturing' and should be revised to the oil and gas industry standard term 'hydraulic fracturing'.

- **"process water"** means all water related to exploration and production, including flow back, and contaminated storm-water;

  Revise the definition to:

  **"process water"** means all water related to exploration and production, including flowback, produced water, and contaminated storm-water;

  Note: Produced water is a significant waste stream that forms part of the wastewater generated during hydraulic fracturing and has been omitted from these regulations. Produced water can be generated in large volumes, even if no hydraulic fracturing occurred, and may be radioactive (Esterhuyse et al. 2014). South Africa would have to plan for this part of the wastewater stream.

  Additionally, the distinction between produced water and flowback is important since there must be differentiation between the different wastewater streams, where flowback is defined as 'wastewater that flows back to the surface following the actual fracking of the well, and is a combination of fracking fluid that returns to the surface during well stimulation, and chemical constituents originating from the shale (Williamson and Esterhuyse 2020)' and produced water is defined as 'Fluids displaced from the geological formation, which can contain substances that are found in the formation, and may include dissolved solids (e.g. salt), gases (e.g. methane, ethane), trace metals, naturally occurring radioactive elements (e.g. radium, uranium), and organic compounds' (Esterhuyse et al. 2014). Produced water is continuously recovered for the remaining life of the well (Williamson and Esterhuyse 2020). The volumes of wastewater generated during the flowback stage are initially high, but then decrease rapidly. Kondash et al. (2016) concluded that as much as 50% of the total wastewater is generated from a fracked UOG well in the first year of operation, in the form of flowback. Smaller volumes of wastewater, in the form of produced water, are generated during the hydrocarbon production phase. However, produced water is usually generated for the remaining lifetime of the well, which is presently projected to be about 30 years (Bai et al. 2013). Considering the difference in chemical makeup and duration of the two different wastewater streams, both the terms 'flowback' and 'produced water' should be defined in the regulations, as they will have different impacts on the groundwater resource, and therefore different regulatory approaches.

*Define the following terms:*

The following terms are used in the regulations, but are not defined. Not defining these terms may lead to an ambiguous interpretation and application of the regulations. Please define these terms. The proposed definitions below have been sourced from the Energy glossary (2026) and the IADC lexicon (2026).

- "Aquifer": "Aquifer" has the meaning assigned to it in section 1(1) of the National Water Act, 1998 (Act No.36 of 1998)
- "Base fluid": "base fluid" means the continuous phase fluid type, including, but not limited to water used in hydraulic fracturing operations
- "Borehole" – Borehole means any borehole drilled for the purpose of providing groundwater for water use.
- "Casing": "casing" means piping positioned in a wellbore and cemented in place to prevent soil or rock from caving and isolates fluids from the surrounding geological formations.
- Conductor casing: means the casing that provides structural support for the well, wellhead and completion equipment, and often provides hole stability for initial drilling operations. This casing string is typically not designed for pressure containment.
- "Competent authority": "competent authority" has the meaning assigned to it in section 1(1) of the National Environmental Management Act.
- "Competent person": "competent person" has the meaning assigned to it in the Mineral and Petroleum Resources Development Regulations
- "Exploration well": "exploration well" means a well drilled for the purpose of obtaining specific geological and geophysical information to prove, define and assess the existence and commerciality of petroleum by conducting any type of pressure tests;
- "Fresh water": "fresh water" means surface and subsurface water in its natural state that - (a) is suitable for human consumption, domestic livestock, irrigation, industrial, municipal and recreational purposes; (b) is capable of supporting aquatic life in line with South African water quality guidelines, and (c) contains less than 1000 mg /l Total Dissolved Solids.
- "Gas": "gas" means natural gas, including casinghead gas, coal bed methane and shale gas.
- "Groundwater": "groundwater" means water found in the subsurface in the saturated zone below the water table.
- "Groundwater monitoring borehole" – Groundwater monitoring borehole means any borehole drilled for the purpose of monitoring groundwater aquifers.
- "Fracturing fluid": "fracturing fluid" means the mixture of the base fluid and the hydraulic fracturing additives used to perform hydraulic fracturing.
- "Hydraulic fracturing string": "hydraulic fracturing string" means a pipe or casing string used for the transport of hydraulic fracturing fluids.
- Horizontal drilling: The intentional deviation of a wellbore from the path it would naturally take, to a horizontal trajectory.
- "independent and competent person" Specify what is meant by 'independent'
- "Intermediate casing": means a casing string run between the surface casing and the production casing or production liner and cemented in place to isolate abnormally geo-pressured strata, lost circulation zones, salt sections, or unstable shale sections.
- Micro-seismicity: seismic activity less than or equal to magnitude 3 using a network of calibrated seismological equipment in order to produce readings on magnitude, depth, location, error and time of each seismic event
- "Micro- seismic monitoring": micro- seismic monitoring" means the monitoring of seismic activity less than or equal to magnitude 3 using a network of calibrated seismological equipment in order to produce readings on magnitude, depth, location, error and time of each seismic event
- "Monitoring well" – Monitoring well means any deep well drilled for the purpose of monitoring the gas well by means of micro-seismicity or other instruments.
- "Oil": "oil" means natural crude oil or petroleum and other hydrocarbons, regardless of gravity, which are produced at the well in liquid form and which are not the result of condensation of gas after it leaves the underground reservoir.

- "Production well": "production well" means a well drilled for the purpose of producing petroleum
- "Proppant": "Proppant" means sand or a natural or man -made material that is used during hydraulic fracturing operations to prop open the artificially created or enhanced fractures.
- "Pollution": "Pollution" has the meaning assigned to in section 1(1) of the National Environmental Management Act.
- "Produced water": "Produced water" means Fluids displaced from the geological formation, which can contain substances that are found in the formation, and may include dissolved solids (e.g. salt), gases (e.g. methane, ethane), trace metals, naturally occurring radioactive elements (e.g. radium, uranium), and organic compounds', but does not include flowback.
- "Seismic monitoring": "Seismic monitoring" means the monitoring of seismic activity using a network of calibrated seismological equipment to produce readings on the magnitude, depth, location, error and time of each seismic event.
- "Surface casing": Casing that is run inside the conductor casing to protect shallow water zones and weaker formations.
- "Water resources": "Water resources" has the meaning assigned to it in section 1(1) of the National Water Act, 1998.
- "Well integrity": Well integrity" means the application of technical, operational and organisational solutions to reduce the risk of uncontrolled release of formation fluids throughout the life cycle of a well.
- "Well site": "Well site" means the surface area, including a well, occupied by equipment or facilities necessary for or incidental to drilling, hydraulic fracturing, production, or plugging a well.

**Chapter 2: Prohibitions and restrictions**

**Prohibited activities**

Under regulation 4, add the following prohibition:

'The abandonment of production wells or decommissioned wells'

Note: The abandonment of an oil and gas well, whether in production or decommissioned, should be prohibited, as the environmental impact and possible negative effects on groundwater systems may be dire (Boettner 2024). As noted in relation to the Decommissioning guidelines below, wells should be transferred from the operator to DMR / PASA / DWA to take custody of these wells to maintain the integrity of the wells.

**Prohibited areas**

Add the setbacks in Table 5 below in the prohibited areas (Esterhuyse et al. 2022, Supplementary Table 2; Hobbs et al. 2016).

Table 5: Additional required setbacks to be added to regulations

| | UOG extraction feature | Recom-mended minimum setback |
|---|---|---|
| **Fracking well** | **250m** setback around geological features from chemicals waste & fuel infrastructure | 250m |
| | **500m** setback from rim of dolerite sill | 500m |
| | **5km** setback around current & future managed aquifer recharge areas | 5km |
| | **1km** setback from centre line of fault / fold axis | 1km |
| | **5km** setback around natural aquifer recharge areas | 5km |
| | **500m** radius around cold springs | 500m |
| | **1km** radius around thermal springs | 1km |
| | No hydraulic fracturing (HF) wells where the wet season groundwater table is at or shallower than **10 meters below ground level** | |
| | **10km** setback from towns with no wellfields | 10km |
| | **5km** radius around seismically active cold / thermal springs | 5km |
| | **1km** setback from centre line of undifferentiated geological feature | 1km |
| | Calculated setback of 1km from a dyke based on dyke length (min **500m**) | 1000m |
| | **10km** setback from existing municipal wellfields | 10km |
| | **5km** setback from cold springs with seismic activity | 5km |
| | **5km** from thermal springs with seismic activity | 5km |
| | **5km** from thermal springs | 5km |
| | **5km** setback from existing water supply boreholes | 5km |
| | **500m** setback radius from centre point of kimberlite diatreme | 500m |
| | **5km** setback from groundwater supply infrastructure | 5km |
| | Not within **500m**, measured horizontally, from the edge of a riparian area or within the 1:100 year floodline of a watercourse. | 500m |
| | No closer than **300m** from the delineated temporary edge of any perched, isolated seasonal pan (i.e. not on a drainage line) | 300m |
| **UOG exploration and production ancillary activities*** | **250m** setback around geological features from chemicals waste & fuel infrastructure | 250m |
| | **5km** setback around current & future managed aquifer recharge areas | 5km |
| | **5km** setback of ancillary activities from artesian boreholes wells and aquifers | 5km |
| | **5km** setback from existing water supply boreholes | 5km |
| | No ancillary fracking water supply abstraction wells where the wet season groundwater table is at or shallower than **10 meters below ground level** | |
| | **5km** radius around seismically active cold / thermal springs | 5km |
| | **5km** setback of ancillary activities from natural aquifer recharge areas | 5km |

Table 5: Additional required setbacks to be added to regulations

| | UOG extraction feature | Recom-mended minimum setback |
|---|---|---|
| | **500m** radius around cold springs | 500m |
| | **1km** radius around thermal springs | 1km |
| **UOG exploration and production ancillary activities*** | No operation under or within the 1:50 year floodline or within 100 m from any watercourse or estuary, whichever is the greatest | 100m |
| | No sanitary convenience, fuel depot, reservoir or other depot for any substance which may cause pollution within the 1:50 year floodline or within 100 m from any watercourse or estuary, whichever is the greatest | 100m |
| | No water use in terms of Section 21 c and 21 i of the NWA allowed within a 500m radius from the boundary of a wetland | 500m |
| | No alteration the bed, banks, course or characteristics of a watercourse within the 1:100 floodline or within the riparian habitat, whichever is the greatest | |

Note: Ancillary activities include drilling stratigraphic wells, water abstraction for fracking operations, and the establishment of roads, wellpads, waste stores and other activities related to UOG extraction operations

**Chapter 4: Standards for the exploration and production of onshore petroleum requiring the use of fracturing technology**
**Well examination**

Revise the wording of Regulation 14 (3):

"The holder must keep a well file, which can be an electronic filing system, which identifies the—
(a) coordinates of the well;
(b) number of the well;
(c) design of the well;
(d) pressure test results; and
(e) the trade name of the fracturing additives used including the monthly amount of additives used per well."

Revise to:

"The holder must keep a well file, which can be an electronic filing system, which identifies the—
a) coordinates of the well;
b) number of the well;
c) design of the well; and
d) pressure test results."
e) the trade name of the fracturing additives used including the monthly amount of additives used per well."
(f) groundwater and aquifer isolation;
(g) fracture containment;
(h) related seismicity risks;
(i) fracturing and flow -back or testing programmes and operations;
and
(j) independent well examination"

Revise the wording of Regulation 15 (1)(c)(iv):

iv. a well examination plan which includes-
(aa) confirmation of groundwater and aquifer isolation;
(bb) measures to address fracture containment;
(cc) measures to manage seismicity risks;
(dd) details of the process water management programme;
(ee) fracturing programme;
(ff) programme for well pressure testing;
(gg) a programme for independent well examination; and
(hh) a programme for final decommissioning and post-decommissioning monitoring

Revise to:

iv. a well examination plan which includes-
(aa) confirmation of groundwater and aquifer isolation;
(bb) measures to address fracture containment
(cc) measures to address fracturing fluid containment;
(dd) measures to manage seismicity risks;
(ee) details of the process water management programme;
(ff) fracturing programme;
(gg) programme for well pressure testing;
(hh) a programme for independent well examination; and
(ii) a programme for final decommissioning and post-decommissioning monitoring

Revise the wording of regulation 16 (1) (e):

(e) submit to the designated agency within 5 days after the testing was undertaken for information, the records and overall summary of the mechanical integrity tests which information must include:
i. type and volumes of water sources for fracturing operations;
ii. volumes and rates of fracturing fluid pumped into the target zone; and
iii. volumes and release of flowback received during and after each fracturing event.

Revise to:

(e) submit to the designated agency within 5 days after the testing was undertaken for information, the records and overall summary of the mechanical integrity tests which information must include:
i. type and volumes of water sources for fracturing operations;
ii. chemical makeup of fracturing fluids
iii. volumes and rates of fracturing fluid pumped into the target zone;
iv. fracture containment measures implemented to contain the fractures within the targeted geological formation
v. primary fracture fluid containment measures to ensure the fracture fluid stays within the target geological zone; and
vi. volumes and release of flowback received during and after each fracturing event.

Revise the wording of Regulation 17 (2):

(2) A post-fracturing well report must include as a minimum-
(a) the location of the well, position in co-ordinates and well number;
(b) the actual fracturing fluid compositions, concentrations and total volumes used;
(c) the actual surface and downhole treating pressure range;
(d) the maximum injection treating pressure;
(e) the actual or calculated fracture geometry;
(f) annuli and offset well pressure monitoring records;
(g) confirmation that wellbore integrity was maintained throughout the operation;
(h) the results of chemical testing of flow-back and process water;
(i) the chemical composition of gases released from wells;
(j) an explanation of operational or design variations to the pre-fracturing design;

(k) data and information concerning any related induced seismic events, in a format as provided
by the designated agency;
(l) steps taken as a result of any identified induced seismic events or activity; and
(m) plans to continue micro-seismic monitoring.

Revise to:

(2) A post-fracturing well report must include as a minimum-
(a) the location of the well, position in co-ordinates and well number;
(b) the actual fracturing fluid compositions, concentrations and total volumes used;
(c) the actual surface and downhole treating pressure range;
(d) the maximum injection treating pressure;
(e) the actual or calculated fracture geometry;
(f) annuli and offset well pressure monitoring records;
(g) Fracture containment measures implemented to contain the fractures within the targeted geological formation
(h) primary fracture fluid containment measures to ensure the fracture fluid stays within the target geological zone
(i) confirmation that wellbore integrity was maintained throughout the operation;
(j) the results of chemical testing of flow-back and process water;
(k) the chemical composition of gases released from wells;
(l) an explanation of operational or design variations to the pre-fracturing design;
(m) data and information concerning any related induced seismic events, in a format as provided
by the designated agency;
(n) steps taken as a result of any identified induced seismic events or activity; and
(o) plans to continue micro-seismic monitoring.

**Chapter 5: Operations and management**

**Disclosure of information**

Regulation 20 requires that various information sources be uploaded onto the website of the holder. If the holder uploads the data to the holder's website, there is no way to verify that all the data has been loaded and is indeed accessible in a form that makes sense to the people who access it.

Rather, require that the data be loaded onto a centralised website run by an independent institution responsible for data storage and public access, to ensure all relevant data is available and in a form that makes it usable.

## 1. <u>Comments on Notice 6808 of 2025 Consultation on the intention to prescribe minimum information requirements for the exploration and production of onshore oil and gas requiring hydraulic fracturing technology</u>

### *3.1 General comments*

More detailed project description information is required, specifically in terms of disclosure of well locations, to ensure proper water resources protection (Esterhuyse et al. 2019, Esterhuyse et al. 2022; Hemingway and Gormally-Sutton 2024). Well locations must be known to identify their proximity to sensitive aquifers, ensure proper aquifer vulnerability assessments (Esterhuyse 2017), ensure accurate and effective baseline monitoring, and to respond to leakage events or well blowouts in time.

To protect against groundwater over-abstraction, the environmental impact assessment process of the hydrogeology should be improved by incorporating the required climate change impact assessment information (section 5.6) in the groundwater section (section 5.12) to determine a climate-adjusted groundwater recharge estimate. Further measures are recommended under the impact assessment, including assessing aquifer sensitivity, long-term abstraction sustainability, projected water demand from exploration and potential future activities, a comparison of projected water with existing cumulative catchment stress, and determining risk-based abstraction thresholds or adaptive management triggers for groundwater abstraction.

Such risk-based threshold levels should be identified for all water supply boreholes that supply water to Karoo towns (Hohne et al. 2025), to protect these boreholes and their wellfields against over-abstraction. These thresholds (or critical levels) would consider the depth of the borehole, any geological structures that intersect the borehole such as fractures that supply water, and long-term water level responses in the borehole, based on monitoring data that was gathered for rainfall and abstraction from the borehole. The borehole thresholds should be translated to regional groundwater thresholds, based on climatic conditions such as long-term droughts or rainfall.

The potential oil and gas Karoo target area straddles several major (primary) catchments, which indicates that impacts of various development scenarios on water resource conditions may have further-reaching implications for downstream resource users, including natural ecosystems (Hobbs et al. 2016). Potential transboundary or downstream connectivity risks relevant to project impacts should therefore be identified.

Additional monitoring and management plans, that are not considered under this MIR are needed to minimise the risk of groundwater contamination, including:

1) Hydraulic fracturing monitoring plan
2) Fracturing fluid management plan
3) Additional plans are required under the 'Water and wastewater management plan', including a
    a. A plan for the safe management of flowback and produced water
    b. A fluids transportation plan
    c. An interim fluid storage plan

### *3.2 Specific comments*

**PART 1 – SCOPING PROCESS**
**2. Chapter 2 – Content of the draft scoping report and final scoping report**
**Section 2.3 Chapter 2 - Project description, location and contact information**

The project description specifies required project-related information, including:

"… the location of the project and the contact details of the EAP who prepared the report:
• The name of the project;
A short description of the project, including the anticipated duration;
• The proposed location of the project,24 including the farm name or names with the relevant

portion number or numbers and the relevant surveyor general's twenty-one-digit codes as well as
the coordinates of the site;
• Details of the property owner/s;
• The relevant major river catchment in which the project is to be undertaken;
• The current land use and adjacent land uses;
• The name and contact details of the applicant. The contact details should include relevant telephone and cell phone numbers, the business street and postal address;
• The experience that the applicant has with undertaking similar projects;
• The name and contact details for the appointed EAP, which must include a business contact as well as a personal cell phone number;
• The company details for the EAP including telephone numbers, and physical and postal address; and
• An annotated location map, the land use context surrounding the proposed project, major roads, towns, major topographical features, the 1;100-year flood lines, railroads, and substations where relevant."

However, there is no requirement to submit site information that includes specific planned well locations. Include these and require that the information be submitted to all relevant departments (DWA, DEA), not only the competent authority.

The well locations should be specified as follows:

- The location(s) of the proposed well(s) within the lease area, shown on the farm(s), showing farms names and the relevant SG data, established by a field survey showing the distances in meters from the proposed well site(s) to the boundary lines of the lease areas, and to the nearest permanent geographic subdivision boundaries (province boundaries, farm boundaries, distance to closest towns).
- The proposed well location(s) should specify the coordinate system, accuracy, as well as method of coordinate determination.
- The following information should also be supplied:
    - The location of water wells in relation to the planned gas well(s) within the precinct, as determined from the hydrocensus
    - The location of all buildings, public roads, railroads, watercourses (perennial and non-perennial streams) and surface water bodies within the precinct where the gas well(s) are planned

## 3. CHAPTER 3 – Plan of Study for Scoping

### Section 3.2 Specialist impact assessments identified

The regulations, the well decommissioning guidelines and the 2 MIR documents require different aspects of monitoring, including baseline monitoring of different aspects that may be impacted by HF (surface water, groundwater, air quality), and monitoring after well decommissioning. However, the process of hydraulic fracturing itself poses the risk of fluid migration which may contaminate freshwater aquifers (Esterhuyse et al. 2016). Monitoring of the hydraulic fracturing process is, therefore, also required. A hydraulic fracturing monitoring plan must, therefore, be required as part of the plans, programmes, well designs, and lists required under section 3.2 'Specialist impact assessments identified'. In addition, a fracturing fluid management plan is required under section 3.2. Each is detailed in turn below.

***Hydraulic fracturing monitoring plan***

A hydraulic fracturing monitoring plan, to be executed during hydraulic fracturing operations, must specify the monitoring, recording, and reporting of HF operations to the regulator. The plan should ideally include information on fracture design, injection parameters, proppant management, real-time monitoring of pressures, flow rates and seismic activity (Bin et al. 2023).

Hydraulic fracturing fluid must be confined to the target zone, by using a ***fracturing fluid management plan (see below)***, and if monitoring indicates that hydraulic fracturing fluid or hydraulic fracturing flowback is migrating outside the target zone, the holder must immediately suspend hydraulic fracturing to prevent fluid migration, and may not resume until the situation is corrected.

***Fracturing fluid management plan***

Fracturing fluid has been identified as a serious risk to human health and the environment, impacting drinking water sources through migration into aquifers or surface leakage and spillages after recovery (Makki et al. 2025; Esterhuyse et al. 2016). Given the risks, a properly designed fracturing fluid risk management plan is required.

A fracturing fluid management plan must be developed for each well to be fractured, and must incorporate the entire lifecycle of fracturing fluids, including:

- Identifying the chemical ingredients and characteristics of each additive,
- Sourcing of chemicals and fluids
- Mixing of chemicals and fluids
- The volume and concentration of hydraulic fracturing additives in the fracturing fluid;
- Assessing the potential environmental and health risks of fracturing fluids and additives in both diluted and concentrated forms; and
- Defining operational practices (injection, flowback) and controls (disposal, recycling) for the identified risk.

The fracturing fluid management plan must maximise the use of environmentally friendly additives while minimising the number and amount of additives.

The requirement for the submission of a **fracturing fluid management plan** to the authorities, should be included under Regulation 9 (c) of the regulations: Submission of applications and implementation of monitoring plans.

The **fracturing fluid management plan** must also be required under section 3.2 (required plans, programmes, well designs and lists during the environmental impact assessment process) of the MIR for the exploration and production of onshore petroleum using fracturing technology.

**PART 2 – ENVIRONMENTAL IMPACT ASSESSMENT PROCESS**
**2.18 Section 5.12 – Hydrogeology study (groundwater)**

Incorporate the climate change impact assessment information (from 2.12 Section 5.6 – Climate change impact assessment) in the groundwater section (2.18 Section 5.12 – Hydrogeology study (groundwater). In the context of the hydrogeology study (2.18.2), a climate-adjusted groundwater recharge estimate should be used.

Also, under the determination of the groundwater setting, include the following:

1. An assessment of aquifer sensitivity, including expected yield, recharge potential, and long-term abstraction sustainability
2. Projected water demand from exploration and potential future activities
3. A comparison of projected water with existing cumulative catchment stress, including considerations linked to Reserve determinations under section 27 of the National Water Act within the MIRs for Baseline Monitoring
4. Determine risk-based abstraction thresholds or adaptive management triggers for groundwater
5. Determine potential transboundary or downstream connectivity risks relevant to project impacts

**Section 2.21 Chapter 6 – Plans, layouts and designs**
**2.21.1 Section 6.1 - Integrated water and waste water management plan**

Additional plans are required under the 'Water and wastewater management plan' of the MIR for the exploration and production of onshore petroleum using fracturing technology. The MIR requires a management plan of 'the waste water which must include recycling and reuse options, treatment options and disposal options, providing detail on the options to be used and providing a copy of the relevant permits or authorisations for the companies to accept the waste'. As part of this water and wastewater management plan as required under the operations MIR, the following sub-plans should be specifically required, to ensure proper protection of groundwater and surface water resources:

1. A plan for the safe management of flowback and produced water
2. A fluids transportation plan
3. An interim fluid storage plan

1) A plan for the safe management of flowback and produced water should include monitoring and reporting to the regulator on:

   - The actual volume of fluids to be recovered during flowback;
   - the water quality balance of additives not recovered;
   - the actual rates, pressures, and temperatures of fluids recovered and produced;
   - the flowback and produced fluids compositional analysis;
   - any identified contamination issues; and
   - any radioactive contaminated fluids.

2) A fluid transportation management plan should describe procedures for preventing and addressing spills and should report to the regulator on fluids transport on a quarterly basis.

3) An interim fluid storage plan should specify where hydraulic fracturing additives, chemicals, oils, and fuels are to be stored before final treatment, and that storage provides sufficient containment capacity.

## 4. Comments on Notice 6811 of 2025 Consultation on the intention to prescribe minimum information requirements for baseline monitoring for onshore exploration operations

The comments on this MIR focus on surface water, aquatic biodiversity, and groundwater.

### *4.1 General comments*

To ensure proper water resources protection, additional requirements are needed in terms of the baseline monitoring plans for the following entities:
1. Surface water and aquatic biodiversity
2. Groundwater
3. Seismicity

### *4.2 Specific comments*

***Typos to be corrected:***

*p. 39: '*aquafer to 'aquifer'.

**Section 3.1 Surface water and aquatic biodiversity**

Add to the requirements of the surface water baseline monitoring plan:

1. **Risk-Based Site Selection:** Site selection should be informed by a **Conceptual Model (CM)** that identifies potential contaminant sources, pathways, and sensitive receptors (Ward et al. 2020)
2. **Distinguishing Impacts:** The baseline should be robust enough to distinguish site-related impacts, such as surface spillages or borehole leakages, from natural processes or existing anthropogenic activity (Ward et al. 2020)
3. **Control and Impact Areas:** The design must incorporate sites representative of potential operational impacts and a comparable number of **non-impacted control sites** remote from the operation (Ward et al. 2020)

Add to the Water quality parameters the following:

1. **Dissolved Gases:** Specifically **dissolved methane (CH4)** and its stable carbon isotopic composition (δ13C) to support further identification of the origin of any detected methane (Ward et al. 2020)

**Section 3.2 Groundwater**

Add to the requirements of the groundwater monitoring plan for determining the pre-fracturing groundwater status:

1. **Conceptual Model (CM) Development:** The baseline groundwater monitoring must be informed by a CM that identifies all potential contaminant sources (e.g., natural methane, deep saline fluids), migration pathways (faults, fractures, borehole annuli), and sensitive receptors (Ward et al. 2020) by developing a 3D geological model and 3D groundwater model incorporating geological structures that describes fluid migration and risks to freshwater aquifers that are present in the lease area. The CM should also consider any potential transboundary or downstream connectivity risks relevant to project impacts.
2. **Shallow and deep aquifers:** Monitoring should target the top groundwater horizon (even if not used for drinking) and all drinking-water aquifers (Gawlik and Comero 2022) In addition, based on the conceptual model development, any deep aquifers in the target area, that are suspected to be in communication with shallow drinking water aquifers, should also be monitored for specific parameters to determine whether any such connection exists. Hobbs et al. (2016) and Esterhuyse et al. (2022) describe the existence of deep aquifers that may be in contact with shallow aquifers, and Hohne et al. (2020) illustrates such a shallow-deep interconnection for a Karoo site. Deep Karoo

aquifers with shallow aquifer interconnections could, when fractured, allow for the migration of fracking fluid, flowback and produced water to freshwater aquifers.

3. **Control and Impact Areas:** Networks must include sites representative of potential operational impacts (API) and a comparable number of **non-impacted control sites** (up-gradient/upstream) to define regional natural variation (Ward et al. 2020)

Add to the Water quality parameters the following:

1. Specifically **dissolved methane (CH4)** and its concentration/origin, CO2, noble gases, and higher hydrocarbons (Lima 2023)

**Section 3.4 Seismicity**

It is important that the seismicity baseline measurements be relevant to groundwater resource protection. It would be ideal that the baseline monitoring of groundwater, surface water and seismicity be done in conjunction, in order to have comparable datasets.

For the groundwater and surface water resources, the MIR requires a duration of at least 24 months of monitoring. This time period is needed especially for groundwater in order to ensure that long term trends are identified. It is, therefore, advised that baseline seismic monitoring also be done for at least 24 months, in order to have long term data. It would be ideal if there could be overlap between the groundwater, surface water and seismic monitoring periods.

The aspects that should be considered under the plan to determine pre-fracturing seismicity, is discussed below.

**Section 3.4.2 Plan for determining the pre-fracturing seismicity**

Important additional points to include in this section, are:

**Duration of monitoring:** Seismicity must be monitored for at least 24 months (Ward , 2020).

Note: While some industry recommendations suggest a minimum of one to six months if regional data is available, a longer period is necessary to capture tectonic activity rates that remain stable over long timeframes (Ward et al. 2020; Braun et al. 2020). This long term monitoring must focus on identifying **hidden or unknown active faults** that may be reactivated by industrial fluid injection (Ward et al. 2020).

**Density of stations:** In cases where there are insufficient seismic stations, additional stations should be added to the plan to allow for the collection of relevant information.

**Spatial coverage**: The monitoring network should cover an area several times larger than the proposed exploitation site, typically extending **at least 10 km** from any future operations (e.g., a 20 km by 20 km grid) (Ward et al. 2020)

**Station Distribution:** Sensors must be distributed uniformly to ensure comparable location accuracy across the region (Ward et al. 2020). To constrain the depth of seismic events and ensure good azimuthal coverage, recording stations should surround the expected source locations (Ward et al. 2020)

**Borehole vs. Surface Sensors:** Installing sensors in **shallow boreholes** (e.g., 20–30 m depth) is highly recommended as it significantly improves signal-to-noise ratios, allowing for the detection of much smaller events compared to surface sensors (Ward et al. 2020)

**Source Parameters:** The baseline must record the **origin time, location (latitude, longitude, depth), and magnitude** for each event (Ward et al. 2020)

**Machine Learning (ML):** Recent advances suggest using machine learning to reveal previously undetected "hidden" earthquakes and faults, which is essential for more reliable forecasts (Ward et al. 2020).

## 5. Comments on Notice 6818 of 2025 Consultation on the intention to prescribe onshore well decommissioning guidelines prepared by Petroleum Agency SA

Effective onshore well decommissioning is not just a technical plugging exercise — it is a **long-term environmental protection, climate mitigation, and governance challenge** that requires integrated legal, technical, financial, and social planning. One of the most important aspects of abandoned wells that have not been properly decommissioned is the potential impact on groundwater resources in South Africa, particularly in areas where surface water is scarce (Hobbs et al. 2016).

Although these guidelines make a good first attempt at providing guidance for well decommissioning, several aspects should be considered in these regulations beyond just the technical decommissioning of the well, including:

1. Defining all the terms used in the well decommissioning guidelines
2. Including long term monitoring of decommissioned wells, as these wells pose a contamination risk over the long term when their well integrity fails
3. Fugitive emissions monitoring and control during and after well decommissioning is needed to help identify groundwater pollution timeously
4. Land restoration or remediation obligations during well decommissioning should also be considered in the guideline, as contaminated land pose a pollution risk to groundwater
5. Record keeping of decommissioned wells should be addressed, if records are not properly stored and available for scrutiny, it is not possible to monitor pollution risk
6. Emergency response plans for well blowout or gas releases from decommissioned wells should also be required in these guidelines, as well blowouts pose a contamination risk, and can occur during and after well decommissioning

### 5.1 General comments

***Definition of terms***

Several technical terms used in the regulations, are not defined. This leaves the regulations open to interpretation and could render them ineffective. See 5.2 Specific comments for more information on definitions.

***Abandonment of wells***

Abandonment of wells (as mentioned in these regulations) should not be an option. Wells should be transferred from the operator to DMR / PASA / DWA to take custody of these wells, in order to maintain integrity of wells. The wells will have to be continuously maintained and monitored. Monitoring frequencies will depend on site sensitivity and the risk of possible well integrity failure. Decommissioned wells may never be abandoned.

***Long-term monitoring of decommissioned wells***

Although all the requirements for well decommissioning are specified and procedures for well decommissioning are prescribed, the guidelines provide no guidance on any long term monitoring of decommissioned wells. Information should be provided on which decommissioned wells should be monitored, for example wells that pose a risk for contaminating water resources, or that are located in specifically sensitive areas. It should also be specified how to decommission the wells to allow for monitoring, and for how long such wells should be monitored.

Well decommissioning requirements are intended to ensure groundwater protection over the long term. Various estimates have been reported for the percentage of well integrity failures, ranging from 1.9 to 3.4%, and the ageing of well components probably increases the risk of failure by 18% with each additional well inspection (Boothroyd et al. 2016).

The risk of leakage over the long term means that a monitoring timeframe of 50 years after well decommissioning may be necessary (Hobbs et al. 2016; Huddlestone-Holmes et al. 2022). This raises the question of who will take the responsibility for performing such a long-term monitoring and carrying the associated costs. Here, water taxes, production taxes, and royalties could prove useful. The regulations should consider this aspect and make provision for the funding required for long-term monitoring, which will have to be done by the state, as the decommissioned wells will be handed over to the state after the developer monitored the wells for an agreed-upon time-period.

Long-term monitoring of methane seepage is also needed, along with monitoring of surface subsidence, seismic activity, and groundwater and surface water quality for parameters that may indicate the migration of contaminants linked to oil and gas production. The duration of monitoring (timelines) should also be addressed.

***Fugitive emissions monitoring and control during and after well decommissioning***

Fugitive emissions should be monitored as part of long-term monitoring of decommissioned wells, as fugitive emissions may indicate well integrity breaches that may lead to groundwater contamination. In terms of fugitive emissions:

- Titleholders must eliminate or reduce emissions from decommissioned wells as far as is reasonably practicable (ALARP) and maintain effective systems for detection (State of Victoria 2023)
- Leak detection and repair (LDAR) Programs: Wellheads must be monitored for leaks through a formal LDAR program (New South Wales Government 2023). An LDAR program is a systematic, proactive process used to identify, measure, and fix fugitive emissions—specifically volatile organic compounds (VOCs), methane, and hazardous air pollutants—from equipment like valves, pumps, and connectors. These programs utilise specialised technology to reduce environmental impact, comply with regulations, and minimise product loss.
- Leaks that are detected should be classified and reported to the regulator. Leak classification could be according to (State of Victoria 2023):
    - Minor Leaks: Unplanned releases yielding methane concentrations between 500 ppm and 5,000 ppm.
    - Significant Leaks: Releases exceeding 5,000 ppm (10% of the Lower Explosive Limit) at the surface, which are treated as well integrity failures and require immediate risk assessment and emergency response
- Remediation: Repairs for identified leaks on decommissioned wells must be completed as soon as reasonably practicable (State of Victoria 2023, New South Wales Government 2023)

***Land restoration / remediation obligations during well decommissioning***

The guideline only focuses on the restoration of the caprock, but does not address land remediation. Land remediation is a critical aspect that should be addressed to minimise groundwater contamination over the long term, to avoid legacy water resource contamination issues.

Some aspects that should be considered during land restoration include:

- Trigger thresholds for remediation: Trigger thresholds should be pre-defined as measurable, or observational limits that, when exceeded, will initiate mandatory land remediation.
- Onshore Restoration: This involves removing contaminated soil, re-contouring the land to its natural shape, replacing topsoil, and replanting native vegetation (Dodd 2025)
- Rehabilitation Criteria: Operators are expected to meet specific set criteria for restoration, such as habitat restoration metrics and biodiversity indicators (Dodd 2025). Rehabilitation criteria should be prescribed

- Site condition: Prescribe the desired site condition after rehabilitation. In Australia, decommissioned well sites must be left in a safe, stable, and sustainable condition, and it must be free of contaminants (State of Victoria 2023; New South Wales 2023)
- Record Keeping: Complete records of the entire decommissioning and surface remediation procedure must be kept and submitted as part of legislative reporting.

***Record keeping of decommissioned wells***

Aspects that should be addressed under record keeping include the following:

- Lifecycle Documentation: Operators should maintain comprehensive records, including engineering design bases, BOP pressure test records, casing tallies, wireline logs, and risk assessments (New South Wales Government 2023). This information could be kept on the operator website.
- Decommissioning Design: The basis of design for decommissioning should include lithology showing oil/gas shows, pore pressure/fracture gradient history, and a history of annulus pressure readings (State of State of Victoria 2023, New South Wales Government 2023).
- Mining and Geological Records: Wells passing through coal seams require accurate plans and sections related to Ordnance Survey datum, full logs of the method of treatment and sealing, and a record of any equipment left in the well (United Kingdom Onshore Operators Group 2013).
- Cementing Reports: Mandatory reports submitted to the Department must include cement pump charts, pressure records, compression strength versus time graphs, and details of centraliser placement (New South Wales Government 2023).
- Chemical and Water Usage: Records must be kept for all chemicals that were used downhole, detailing the name, type, CAS number, and volume of each substance, as well as the source of water used for drilling and stimulation (New South Wales Government 2023, United Kingdom Onshore Operators Group 2013).
- Substance Tracking: The name, type, and quantity of each chemical used during construction, operation, *and decommissioning* must be recorded (State of Victoria 2023).
- Well Integrity Management: A Well Integrity Management System (WIMS) must outline the well integrity records of all decommissioned wells, including up-to-date documentation on well risk levels, operational status, and completion status (State of Victoria 2023).
- Risk Assessment Records: Evaluating the risk of orphan or relinquished wells relies heavily on the availability of complete historical well integrity records, including details on design performance and barrier verification (Federal Republic of Nigeria 2023).
- National Asset Database: The guideline should provide guidance on maintaining a publicly accessible database of all petroleum installations, structures, and pipelines (Federal Republic of Nigeria 2023)
- Retention Period: In Australia, accurate information on well drilling, completion, fracture stimulation, workovers, and decommissioning must be recorded and maintained for at least 5 years following a well's decommissioning, unless otherwise specified by legislation (New South Wales Government 2023). Long-term record-keeping is also recommended for decommissioned wells in South Africa.

***Emergency response plans for well blowout or gas releases from decommissioned wells***

Aspects that should be addressed, include:

- **H2S Emergency Planning:** If Hydrogen Sulphide (H2S) is predicted, emergency response planning must address the safety of landholders and the surrounding community (State of Victoria 2023)
- **Significant Leak Protocol:** A "significant leak" (unplanned wellhead release >10% Lower Explosive Limit) is treated as a well integrity failure, requiring the titleholder to follow the risk assessment and emergency response protocols defined in their safety management system (State of Victoria 2023)

- **Re-entry and Well Control:** If monitoring identifies a surface leak that warrants remediation, the well must be re-entered. This process is complex and requires re-establishing blowout prevention systems and pressure control before the integrity failure can be investigated or repaired (Huddlestone-Holmes et al. 2022)

### 5.2 Specific amendments

The following comments address specific aspects that must be revised in the current comments.

***Typos to be corrected:***

*p. 9: '*abandancey' to 'abundancy'
p. 30: 'DECOMMISSIONG' to 'DECOMMISSIONING'

**Resolution or quality of images and schematics that must be improved:**

p. 25 – Figure C1: Well abandonment summary. Please improve the resolution of this summary since it is illegible.
p. 26 – Figure D1: Isolation of multiple zones – Enlarge the text labels
p. 26 – Figure D2: Reinstatement of the Cap Rock – Improve text resolution
p. 26 – Figure D3: Multiple Barrier Elements – Significantly increase text label size, text is illegible
p. 28 – Figure D7: Annular Cement Requirements - Significantly increase text label size

***Definitions***

To ensure clarity, the well decommissioning guidelines must define the following terms in the Glossary in Appendix A. This is to avoid ambiguity and assist the regulator, holder and scientific community in the correct and consistent interpretation and application of the regulations.

The following terms must be defined:

Annulus
Barrier element
bridge plug
Bullheading
Cap rock
Cement logging
cement plug
chemical wash
Control line
Completion fluid
Control fluid
Cross-flow
FLIR
fundament
Gauge cable
Inflow test
Liner
Liner hanger
Liner lap
Mechanical bridge plug
Over-displacement
pressure differential
section milling (of casing)
Shoe track:
Shoe track valves:
Sidetracking
Slumping
spacer fluid design

Tagging
Tag and weight test
Well control

***Revise the following sentences / wording / terms:***

*p. 21, section 3.7: "*This environmental plug should not considered a competent barrier."

Sentence is incomplete, revise to:

This environmental plug should not be considered a competent barrier."

*p. 37 Annexure D: '*It should be noted that control line and/or instrument cable and/or power cable is not generally advisable across the full length of Barrier Element, as, due to the nature of their design and/or material and method of fastening to the host tubular, they provide a potential leak path either now or in the future.'

This sentence is grammatically flawed, does not make sense, and needs revision. Should it read as follows?

"It should be noted that keeping a control line and/or instrument cable and/or power cable in place during permanent plugging, is not generally advisable across the full length of Barrier Element, as, due to the nature of their design and/or material and method of fastening to the host tubular, they provide a potential leak path either now or in the future.'

p. 18, section 3.4.14: "Decommissioning highly deviated or horizontal wells is in principle similar to that of a standard vertical well."

Sentence is incomplete, revise to:

"Decommissioning of highly deviated or horizontal wells is in principle similar to that of a standard vertical well."

***Under section 3.2 "Zones with flow potential, p. 16:*** *Please explain what '*zones that become charged during the life of the well' means. It is understood by this reviewer to be 'underground rock formations that, over time, fill up with mobile hydrocarbons or pressure due to production-related changes, even if they were not initially designated as the primary, productive pay zone'.

Yours faithfully,

Dr Surina Esterhuyse
Hydrogeologist

**References**

API (American Petroleum Institute). 2013. Deepwater Well Design and Construction (RP 96), First Edition, Global Standards. https://standards.globalspec.com/std/1586765/api-rp-96

API. 2015. Hydraulic Fracturing—Well Integrity and Fracture Containment. https://www.api.org/~/media/files/policy/exploration/100-1_e1.pdf

Avenant M, Watson M, Esterhuyse S, Seaman M. 2016. Potential impact of unconventional gas mining on surface water systems of the Karoo. In: Glazewski and Esterhuyse (Eds). *Hydraulic Fracturing in the Karoo: critical legal and environmental perspectives. Juta, Claremont, South Africa*, 222-243.

Bai B, Goodwin S, Carlson K, 2013 Modeling of frac flowback and produced water volume from Wattenberg oil and gas field. J Pet Sci Eng 108:383–392

Boettner, T. 2024. Repairing the Damage from Hazardous Abandoned Oil and Gas Wells: A Federal Plan to Grow Jobs in the Ohio River Valley and Beyond. In ReImagine Appalachia: Healing the Land and Empowering the People (pp. 175-224). Cham: Springer Nature Switzerland.

Botai, C. M., Botai, J. O., & Adeola, A. M. 2018. Spatial distribution of temporal precipitation contrasts in South Africa. *South African Journal of Science*, *114*(7-8), 70-78.

Boothroyd, I. M., Almond, S., Qassim, S. M., Worrall, F., & Davies, R. J. (2016). Fugitive emissions of methane from abandoned, decommissioned oil and gas wells. Science of the Total Environment, 547, 461–469. https://doi.org/10.1016/j.scitotenv.2015.12.096

Braun, T., Danesi, S., & Morelli, A. (2020). Application of monitoring guidelines to induced seismicity in Italy. Journal of Seismology, 24(5), 1015-1028.

Dennis I, Dennis R. 2012. Climate change vulnerability index for South African aquifers. Water SA 38(3):417–426. https://doi.org/10.4314/wsa.v38i3.7

DMR (Department of Mineral Resources). 2009. THE FUTURE ROLE OF THE WATERBERG COALFIELD IN SOUTH AFRICA'S COAL INDUSTRY. Report R76/2009. https://www.dmre.gov.za/LinkClick.aspx?fileticket=75uia_ngmek%3D&portalid=0

Dodd. 2025. Oil and gas decommissioning regulations in Australia: What companies need to know. https://recyclers.com.au/oil-and-gas-decommissioning-regulations-in-australia/

DWS (Department of Water and Sanitation). 2025. Department of Water and Sanitation strategic plan 2025/26 to 2029/30. https://www.dws.gov.za/documents/Other/Strategic%20Plan/2025/2025-26To2029-30StratPlan_25Mar2025.Rev02_01_final_6.pdf

Edokpayi JN, Makungo R, Mathivha F, Rivers N, Volenzo T, Odiyo JO. 2020. Influence of global climate change on water resources in South Africa: toward an adaptive management approach. In: Singh P, Milshina Y, Tian K, Gusain D, Bassin JP (eds) Water conservation and wastewater treatment in brics nations – technologies, challenges, strategies and policies. Elsevier, Amsterdam, pp 83–115

Energy glossary. 2026. https://glossary.slb.com/

Esterhuyse, S., Avenant, M., Redelinghuys, N., Kijko, A., Glazewski, J., Pitt, L.A., Kemp, M., Smit, A., Sokolic, F., Vos, A.T. and Reynolds, D., Von Maltitz M, Van Tol J, Bragg B, Ouzman S. 2014. Development of an interactive vulnerability map and monitoring framework to assess the potential environmental impact of unconventional oil and gas extraction by means of hydraulic fracturing. Water Research Commission South Africa. WRC Report No. 2149/1/14. https://api.researchrepository.uwa.edu.au/ws/portalfiles/portal/17978795/Full_report_Development_of_an_interactive_vulnerability_map_WRC_Report_No_2149_1_14.pdf

Esterhuyse, S., Avenant, M., Redelinghuys, N., Kijko, A., Glazewski, J., Plit, L., ... & Williamson, R. 2016. A review of biophysical and socio-economic effects of unconventional oil and gas extraction–Implications for South Africa. *Journal of environmental management*, *184*, 419-430.

Esterhuyse, S. 2017. Developing a groundwater vulnerability map for unconventional oil and gas extraction: a case study from South Africa. *Environmental Earth Sciences*, *76*(17), 626.

Esterhuyse, S., Vermeulen, D., & Glazewski, J. 2019. Regulations to protect groundwater resources during unconventional oil and gas extraction using fracking. Wiley Interdisciplinary Reviews: Water, 6(6), e1382.

Esterhuyse, S., D. Vermeulen, and J. Glazewski. 2022 "Developing and enforcing fracking regulations to protect groundwater resources." npj Clean Water 5.1 1-11. https://doi.org/10.1038/s41545-021-00145-y

Esterhuyse, S. 2023. A Historical Timeline of Unconventional Oil and Gas Extraction and Fracking Studies in South Africa: Pointers for Policy Development. Alternation, 30(1).

Federal Republic of Nigeria 2023. Nigeria Upstream Petroleum Decommissioning and Abandonment Regulations, Federal Republic of Nigeria Official Gazette. https://www.nuprc.gov.ng/wp-content/uploads/2023/07/DECOMMISSIONING-REGULATIONS.pdf

Finkeldey, J. 2018. Unconventionally contentious: Frack Free South Africa's challenge to the oil and gas industry. Extr. Ind. Soc. 5, 461–468.

Gawlik B., Comero, S. 2022. Baseline assessment and monitoring of water resources exposed to unconventional hydrocarbon exploration and extraction activities; EUR 27749 EN; Publications Office of the European Union, Luxembourg, 2022, ISBN 78-92-79-55329-5, doi:10.2788/922935

Harkness, J. S., Swana, K., Eymold, W. K., Miller, J., Murray, R., Talma, S., ... & Darrah, T. H. 2018. Pre-drill groundwater geochemistry in the Karoo Basin, South Africa. *Groundwater*, *56*(2), 187-203.

Harmse, C. J., Du Toit, J. C., Swanepoel, A., & Gerber, H. J. 2021. Trend analysis of long-term rainfall data in the Upper Karoo of South Africa. *Transactions of the Royal Society of South Africa*, *76*(1), 1-12.

Hemingway, J. R., & Gormally-Sutton, A. 2024. An analysis of perspectives on groundwater governance arrangements relating to the potential development of unconventional oil and gas in South Africa. *Hydrogeology Journal*, *32*(3), 705-722.

Hidayat M. 2025. Coal Bed Methane: South Africa's Emerging Energy Frontier. https://discoveryalert.com.au/coal-bed-methane-south-africa-energy-2025/

Hobbs, P., Day, E., Rosewarne, P., Esterhuyse, S., Schulze, R., Day, J., … Mosetsho, M. 2016. Water resources. In R. Scholes, P. Lochner, G. Schreiner, L. Snyman-Van der Walt, & M. de Jager (Eds.), Shale gas development in the Central Karoo: A scientific assessment of the opportunities and risks (pp. 97–111). Pretoria: Council for Scientific and Industrial Research. https://doi.org/10.1016/B978-0-12-799954-8.00005-8

Hohne, D., de Lange, F., Esterhuyse, S., & Sherwood Lollar, B. 2019. Case study: methane gas in a groundwater system located in a dolerite ring structure in the Karoo Basin; South Africa. South African Journal of Geology 2019, 122(3), 357-368.

Hohne, D., Esterhuyse, S., & Fourie, F. 2025. Mitigating climate change in South Africa with managed aquifer recharge: five case studies. *Hydrogeology Journal*, 1-25.

Huddlestone-Holmes, Cameron; Arjomand, Elaheh; Kear, James. 2022. GISERA W20 Final Report: Long-term monitoring of decommissioned onshore gas wells . Australia: CSIRO; csiro:EP2022-1246. https://doi.org/10.25919/bx5g-zd28.
IADC lexicon. Drilling lexicon. 2026. https://iadclexicon.org/

IPCC. 2021 Summary for Policymakers: Climate Change 2021 The Physical Science Basis. https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report_smaller.pdf

IRENA. 2019. Global Energy Transformation: A roadmap to 2050. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Apr/IRENA_Global_Energy_Transformation_2019.pdf

Kondash AJ, Albright E, Vengosh A. 2016 Quantity of flowback and produced waters from unconventional oil and gas exploration. Sci Total Environ 574:314–321

Lima GFC. 2023. Environmental baseline for water resources and sediments prior to the unconventional hydrocarbons industry in Brazil. PhD thesis.

Makki, S., Maalouf, E., & Yehya, A. 2025. Review of the environmental and health risks of hydraulic fracturing fluids. Heliyon, 11(1).

McGranahan, D. A., Kirkman, K. P. & McGranahan, D. A. 2019. Local perceptions of hydraulic fracturing ahead of exploratory drilling in eastern South Africa. Environ. Manag. 63, 338–351.

Mendhe, V. A., Mishra, S., Varma, A. K., & Singh, A. P. 2017. Coalbed methane-produced water quality and its management options in Raniganj Basin, West Bengal, India. *Applied Water Science*, *7*(3), 1359-1367. https://doi.org/10.1007/s13201-015-0326-7

Miller, J., Swana, K., Talma, S., Vengosh, A., Tredoux, G., Murray, R., & Butler, M. 2015. O, H, CDIC, Sr, B and 14C isotope fingerprinting of deep groundwaters in the Karoo Basin, South Africa as a precursor to shale gas exploration. *Procedia Earth and Planetary Science*, *13*, 211-214.

Murray, R., Swana, K., Miller, J., Talma, S., Tredoux, G., Vengosh, A., & Darrah, T. 2015. The use of chemistry, isotopes and gases as indicators of deeper circulating groundwater in the Main Karoo Basin. *Water Research Commission, Report to the Water Research Commission*.

New South Wales government. 2023. Code of practice: Construction, operation and decommissioning of petroleum wells (Version 1.1). https://www.resources.nsw.gov.au/sites/default/files/2023-02/code-of-practice-construction-operation-and-decommissioning-of-petroleum-wells.pdf

Nolte, S., Geel, C., Amann-Hildenbrand, A., Krooss, B. M., & Littke, R. 2019. Petrophysical and geochemical characterisation of potential unconventional gas shale reservoirs in the southern Karoo Basin, South Africa. *International Journal of Coal Geology*, *212*, 103249.

Rice CA, Nuccio V. 2000. Water Produced with Coal-Bed Methane. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://pubs.usgs.gov/fs/fs-0156-00/fs-0156-00.pdf

RSA (Republic of South Africa). 1998. National Water Act (Act 36 of 1998) (NWA). Government Gazette No. 19182.

RSA. 2021. Amendments to the environmental impact assessment regulations, listing notice 1, listing notice 2 and listing notice 3 of the environmental impact assessment regulations, 2014 for activities identified in terms of section 24(2) and 24D of the National Environmental Management Act, 1998. GN 517 of 11 June 2021

RSA, 2022a. Proposed regulations pertaining to the exploration and production regulations of onshore oil and gas requiring hydraulic fracturing. GN2273 of 11 July 2022 in Government Gazette 47112. https://www.gov.za/sites/default/files/gcis_document/202207/47112gon2273.pdf

RSA, 2022b. Consultation on the intention to prescribe minimum requirements for the submission of applications for an authorisation, right, permit or license for the onshore exploration of oil and gas intending to utilise hydraulic fracturing. GN2256 of 8 July 2022 in Government Gazette 46688. https://cer.org.za/wp-content/uploads/2022/07/NEMA-Intention-to-prescribe-minimum-conditions-for-onshore-exploration-of-oil-and-gas-intending-to-frack-8-July-2022.pdf

RSA. 2024. Regulations for the use of water for exploration and production of onshore naturally occurring hydrocarbons that require stimulation, including hydraulic fracturing and underground gasification, to extract, and any activity incidental thereto that may impact detrimentally on the water resource. Notice 5582, GG 51642, 22 November 2024

Scholes, R., Lochner, P., Schreiner, G., Snyman-Van der Walt, L. and de Jager, M. (eds.). 2016. Shale Gas Development in the Central Karoo: A Scientific Assessment of the Opportunities and Risks. CSIR/IU/021MH/EXP/2016/003/A, ISBN 978-0-7988-5631-7

State of Victoria (Department of Energy, Environment and Climate Action) 2023. Code of practice for the construction, operation and decommissioning of petroleum wells in Victoria. https://resources.vic.gov.au/legislation-and-regulations/guidelines-and-codes-of-practice/code-of-practice-onshore-petroleum-wells/Code-of-Practice-Petroleum-Wells-Victoria.pdf

Stroebel, D. H., Thiart, C., & de Wit, M. 2019. Towards defining a baseline status of scarce groundwater resources in anticipation of hydraulic fracturing in the Eastern Cape Karoo, South Africa: salinity, aquifer yields and groundwater levels.

United Kingdom Onshore Operators Group. 2013. UK onshore shale gas well guidelines: Exploration and appraisal phase (Issue 1). https://assets.publishing.service.gov.uk/media/5a7a0c7840f0b66eab9995df/UKOOGShaleGasWellGuidelines.pdf

Van Averbeke AN. 2017. Is Waterberg groundwater worth its salt? https://journals.co.za/doi/epdf/10.10520/EJC-773f89616

Ward, R.S., Rivett, M.O. Smedley, P.L. Allen, G. Lewis, A. Purvis, R.M. Jordan, C.J. Taylor-Curran H., Daraktchieva, Z. Baptie, B.J. Horleston, A. Bateson, L. Novellino, A. Lowry D. and Fisher R. E. 2020. Recommendations for Environmental Baseline Monitoring in areas of shale gas development. British geological survey Groundwater directorate. Open report OR/18/043

Williamson, R., & Esterhuyse, S. 2020. Expected wastewater volumes associated with unconventional oil and gas exploitation in South Africa and the management thereof. *Bulletin of Engineering Geology and the Environment*, *79*(2), 711-728.

Wu Y. 2025. CoalbedMethane(CBM)Extraction: Techniques,Challenges,andEnvironmentalConsiderations. https://drpress.org/ojs/index.php/ajst/article/view/30934/30304

Yan, X., Zhang, S., Tang, S., Li, Z., Zhang, Q., Wang, J., & Deng, Z. 2020. Quantitative optimisation of drainage strategy of coalbed methane well based on the dynamic behavior of coal reservoir permeability. *Scientific Reports*, *10*(1), 20306.

Yuan B, Zhao M, Meng S, Zhang W, Zheng H. 2023. Intelligent identification and real-time warning method of diverse complex events in horizontal well fracturing. Petroleum Exploration and Development, 50(6), 1487-1496. https://doi.org/10.1016/S1876-3804(24)60482-9