Development of an interactive vulnerability map and preliminary screening level monitoring protocol to assess the potential environmental impact of unconventional oil and gas extraction by means of hydraulic fracturing.

Report to the
WATER RESEARCH COMMISSION

by

S Esterhuyse, M Watson, N Redelinghuys, M Avenant, A Kijko, J Glazewski, LA Plit, M Kemp, A Smit, AT Vos, F Sokolic, D Reynolds, M von Maltitz, C Bragg, B van Soelen, J van Tol, , S Ouzman

Centre for Environmental Management, University of the Free State

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EXECUTIVE SUMMARY

INTRODUCTION

This report emanates from a project entitled “Development of an interactive vulnerability map and preliminary screening level monitoring protocol to assess the potential environmental impact of unconventional oil and gas extraction by means of hydraulic fracturing”. The study was proposed in light of the applications that were made by various companies for exploration permits with the Petroleum Agency of South Africa (PASA) during 2009-2011. The extent of applications for the extraction of shale gas and coalbed methane spans large areas of South Africa (approximately 32% of the surface area of South Africa at the time of writing the report) and necessitated an investigation into the possible impacts associated with hydraulic fracturing (also known as fracking), as well as identifying vulnerable areas that need protection in terms of unconventional gas extraction.

Hydraulic fracturing has raised some concern worldwide. The Environmental Protection Agency of the United States of America is currently performing an environmental impact study spanning 3 years, on hydraulic fracturing at Federal level, after reports of possible water contamination resulting from unconventional gas operations (USEPA, 2011). Other government commissioned reports include the Bureau d'audiences publiques sur l'environnement or BAPE report in Canada (BAPE, 2011) that noted that it would be appropriate to assess the long-term risk associated with the presence of contaminated water from hydraulic fracturing activities in rock formations and also that a study of the cumulative impacts of the disposal of wastewater from the shale gas industry must be undertaken. The report also stated that a strategic environmental assessment of the cumulative impacts was seen to be "a necessary element of both an informed decision and improved social acceptability". In the United Kingdom (UK) the Tyndall report (Wood et al., 2011) and the Energy and Climate Change Committee, ("the E&CCC enquiry") investigated proposed fracking in the UK. The Tyndall report noted that there is a risk of contamination of groundwater from shale gas extraction and that it is important to recognise that most problems arise due to errors in construction or operation of wells that cannot be eliminated. It also noted that significant amounts of water are required to extract shale gas and this could put severe pressure on water supplies in areas of drilling (which is an issue in water-stressed South Africa). The UK's Energy and Climate Change Committee ("the E&CCC") also recently held an inquiry into the exploration for and exploitation of shale gas (House of Commons, 2011a). Regarding the harmful nature of the chemicals used in fracking, it was noted that there could be some issues related to the mobilisation of chemicals within the shale to surface water and groundwater (House of Commons, 2011a) and that mitigation of the risk to aquifers from hydraulic fracturing relies on companies undertaking the proper measures to protect the environment from pollution (House of Commons, 2011b). The British House of Commons scheduled a second evidence session on the “Impact of Shale Gas on Energy Markets”, to be held on 11 December 2012 (House of Commons, 2012). This public session would focus on what effect the development and expansion of a shale gas industry will have on the UK, how the Government’s Gas Generation Strategy and announcements in the Autumn Statement will influence the development of the UK shale gas industry; and the wider implications of shale gas on the UK’s climate change obligations and investment in renewable energy (House of Commons, 2012).

A report by Havemann et al. (2011) highlights the following concerns with regard to hydraulic fracturing in the Karoo (which also applies to the wider South African context):

- There is insufficient information on the potential health risks to the public as a result of water contamination;

- There is an unacceptable risk of losing globally unique biodiversity, jeopardising ecological integrity and causing loss of irreplaceable resources for which remedy is not feasible;
- There is an unacceptable risk of having an irreversible negative impact on the sense of place of the Karoo and on the lives, health and livelihoods of its communities;
- There is a substantial risk of inequitable distribution of impacts arising from the proposed activity, and of vulnerable rural people having to bear the negative impacts; and
- In the light of significant uncertainties there is a need to take a risk-averse and cautious approach.

The Havemann report (2011) also cautioned the government, stating that:

- Fracking is an unprecedented activity in South Africa;
- A policy vacuum exists in relation to the exploitation of shale gas;
- Project-level environmental impact assessment is an inappropriate mode of environmental management - in this case regional strategic environmental assessment may be more appropriate;
- Authorisation processes are fragmented and limited; and
- There is a serious lack of capacity to monitor and enforce compliance with any conditions of approval.

In view of the above shortcomings in South Africa, the aim of this study was to investigate unconventional oil and gas extraction and hydraulic fracturing by performing a background review; developing an interactive vulnerability map; and developing a provisional screening level monitoring protocol.

This study aimed to contribute knowledge on issues associated with unconventional oil and gas extraction by means of hydraulic fracturing and highlight vulnerable areas for specific entities (e,g, surface water, groundwater, socio-economics) in South Africa. It also proposes a provisional screening level monitoring protocol that can be used as a guideline to monitor unconventional gas extraction activities.

In South Africa, where water demand will exceed water supply in the near future, unsustainable use of water resources will result in increasingly limited water resources for future health and well-being as well as for sustained socio-economic development. Society in general, and specifically the residents in the Karoo where access to water is already limited, needs to be assured of the sustainable use of the water resources for health and well-being by understanding and where possible avoiding the negative social impacts resulting from unconventional gas extraction by means of hydraulic fracturing.

BACKGROUND REVIEW OF UNCONVENTIONAL OIL AND GAS EXTRACTION

The background review is the first step towards understanding the complexities of unconventional oil and gas extraction by means of hydraulic fracturing and should aid government in developing the required regulatory policies and guidelines to effectively manage and monitor unconventional gas extraction and hydraulic fracturing in South Africa in a way that will protect human health and the environment and ensure sustainable use of our very scarce water resources.

Apart from the possible positive impacts of unconventional gas extraction (providing energy and jobs) (Williams, 2011; Chung and Hoffnagle, 2011; Considine et al., 2011), possible negative impacts may also occur in both the biophysical and socio-economic environments. There are multiple and reciprocal linkages between society and the environment, which necessitate research into the possible impacts of unconventional gas extraction on the biophysical and socio-economic spheres, and how these impacts interlink. The possible negative social impacts resulting from unconventional gas extraction need to be well understood and avoided where possible. These possible impacts include competition over water between oil and gas companies and existing lawful water users in the Karoo; securing access to water and sanitation for previously disadvantaged communities in the face of competing demands presented by fracking operations; the potential health risks associated with lack of access to water and adequate sanitation in vulnerable communities; in-migration and higher population density in ecologically sensitive and water scarce areas (Kargbo et al., 2010; Dolesh, 2011; Beemster and Beemster, 2011; Broderick et al., 2011). Even job creation may be contentious as it is not guaranteed that jobs created in the oil and gas sector will offset job losses in other sectors such as the agricultural sector. Therefore, the dynamic and multi-faceted socio-economic and demographic impacts of unconventional gas extraction in communities in these areas where basic resources such as water are already under pressure should be identified and linked with wider developmental and environmental concerns. Negative environmental impacts may also occur, which may include impacts on water resources (in terms of quality and quantity for both surface water and groundwater resources) (ANU, 2012; Broomfield, 2012; Rahm and Riha 2012; Herridge et al., 2012; Lechtenböhmer et al., 2011; IEA, 2012), habitat fragmentation and loss (Jones and Pejchar 2013, Northrup and Wittemyer 2013) as well as air quality impacts (Twine, 2012; Farina, 2011; Tollefson, 2012; Northrup and Wittemyer 2013). By describing the possible impacts, it is hoped that some negative impacts during unconventional gas extraction may be minimised. The identification and description of impacts also aided the development of the interactive vulnerability map.

UNCONVENTIONAL OIL AND GAS VULNERABILITY MAP

The interactive vulnerability map that was developed during this project, focuses on specific aspects, which include surface water, groundwater, vegetation, seismicity and socio-economics, and was developed specifically for South Africa.

The vulnerability map aims to assist decision-makers and other practitioners by providing information on the vulnerability to unconventional gas extraction of the specified mapping themes on a regional scale. The vulnerability map was developed by using experts to help decide on indicators that would indicate vulnerability of a theme to unconventional gas extraction specifically, as well as to classify and weight indicators (where relevant). Regional scale data was used for this map and the map cannot replace local scale maps that may need to be developed to inform decision-makers of local scale conditions of vulnerability to unconventional gas extraction. This map is intended as a reconnaissance tool to inform decision-makers on areas where additional detail field work and assessments may be required as part of Environmental Impact Assessment and licensing conditions.

For the purposes of this report, the vulnerability map includes biophysical and socio-economic entities, of which only selected entities were mapped, including surface water, groundwater, vegetation, seismicity and socio-economics.

Typically vulnerability is a function of exposure, sensitivity and coping (adaptive) capacity (Birkmann, 2006; Lin and Morefield, 2011; O'Brien et al., 2011; Wongbusarakum and Loper, 2011). The greater the exposure or sensitivity, the greater the vulnerability, and the greater the coping capacity, the less vulnerable the system will be. Classically, biophysical systems mostly identify sensitivity indicators (Schauser et al., 2010). Coping capacity indicators are usually identified for the socio-economic sphere and refer to adaptability by humans (O'Brien et al., 2011; Wongbusarakum and Loper, 2011), although coping capacity for the biophysical entities should also be identified. For the interactive vulnerability map in this project, only sensitivity indicators were identified and mapped. Detail information on the mapping approach and limitations are discussed in Section 4 of this report.

A vulnerability indicator, which can be spatially represented as a map, is usually the result of the combination and aggregation of a number of sub-indicators or indicating components (Birkmann, 2006; Kienberger et al., 2009). The normative approach (described in more detail in Section 4 of the report) was followed for the identification of sensitivity indicators. Although this approach requires time and resources and is limited in its application and transferability to other regions (e.g. countries outside South Africa), the integration of expert knowledge provides support for the weighing and aggregation of the indicator components and may increase the acceptability of the results. It is also widely acknowledged that the involvement of stakeholders in the development of indicators is key to identifying relevant vulnerability indicators (Harvey et al., 2011, Nardo et al., 2005).

The vulnerability map should not be viewed as a static entity. More detailed information may become available on themes that are mapped now, and new indicators may later be used for which no accurate spatial data currently exists (an example is heritage sites). There must be the option of possible updates or refinements to the map as a "working document".

Such refinement of and/or additions to the vulnerability map may occur during later stages of follow-up projects. The following disclaimer is valid for the interactive vulnerability map:

Disclaimer:

Every effort was made to select nationally acceptable datasets during the development of these maps and to adhere to strict quality standards. None of the parties involved in creating these maps, guarantee the accuracy of information provided by external sources and the parties accept no responsibility or liability for any consequences arising from the use or misuse of such data.

Neither the Centre for Environmental Management (University of the Free State) nor the University of Pretoria Natural Hazard Centre, Africa nor any other party involved in creating, producing or delivering the map and related reports shall be liable for any direct, incidental, consequential, indirect or punitive damages arising out of the misuse of the information contained in this map and related reports.

UNCONVENTIONAL OIL AND GAS SCREENING LEVEL MONITORING PROTOCOL

Performing monitoring of various entities of the biophysical and socio-economic spheres before exploration, during exploration, during extraction and after extraction is important to assess possible changes in these entities due to the unconventional gas extraction process. Whereas the background review illustrates various possible impacts of concern, active monitoring of certain entities can address some of these concerns and identify possible problems timeously. It is especially important for South Africa to perform baseline monitoring before exploration starts to ensure that we will have reference conditions in order to identify what impact oil and gas extraction activities has on the biophysical and socio-economic environments. Without such a baseline determining impacts would not be possible. Then it is also important that monitoring occur during oil and gas exploration and extraction (to address impacts as they occur in order to minimise and/or mitigate the effects of these impacts) as well as post extraction, since some of the impacts may only be observed long after wells in a certain area have been decommissioned and after the oil and gas companies have moved on to another part of the oil and gas reservoir.

The protocol should be viewed as a provisional screening level monitoring protocol and can be used as a guideline for planning monitoring activities, during the various phases of unconventional gas extraction. The objective of the protocol is to identify the important entities to be monitored during the various phases and discuss means of monitoring for selected entities (surface water, groundwater, seismicity, vegetation and socio-economics). The protocol discusses issues such as why monitoring of certain aspects is required, where monitoring must be performed (site specific or regional), when it must be performed (related to the different phases of unconventional oil and gas extraction), how it must be performed (by discussing aspects such as parameters to be monitored as well as data management) and who the relevant parties are that should do this monitoring (oil and gas companies vs. regulators). The protocol also addresses various legal and governance considerations related to such monitoring, such as the role of international law in South Africa, the interaction of different pieces of legislation related to the monitoring of selected media and areas of concern (surface water, groundwater, vegetation, seismicity and socio-economics), the mandates of different South African departments in performing specific monitoring functions and the feasibility of forming a central independent body to monitor unconventional gas extraction. These aspects relate to questions relating to the execution of the monitoring programmes for the aspects for which monitoring protocols have been discussed.

Although the list of entities discussed in this monitoring protocol is not exhaustive, it could assist government in planning for the monitoring of the entities of most concern.

It is hoped that the background review, interactive vulnerability map and the provisional screening level monitoring protocol can be used by authorities to develop regulations and effectively regulate this activity in order to minimize or mitigate possible impacts that may emanate from this activity. Since unconventional oil and gas extraction advances fairly quickly with new advances in technology, it is recommended that authorities and practitioners update their knowledge regularly.

It will be vital for industry and government to recognise the complexity of the challenges posed by these possible impacts. However, most can be minimised where an effective regulatory system and best monitoring practice are in place and can be remediated where they do occur. If the oil and gas industry is to earn and retain the social licence to operate, it is a matter of some urgency to have a transparent, adaptive and effective regulatory system in place that is implemented and backed by best practice monitoring, in addition to credible and high quality baseline surveys.

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ABBREVIATIONS

ADE:	Aquifer Dependent Ecosystem
AHP:	Analytical Hierarchy Process
AIA:	Archaeological Impact Assessment
Bbl:	Barrel
Bcf:	Billion cubic feet
BTEX:	Benzene, toluene, ethylbenzene, xylene
CBM:	Coalbed methane
CSG:	Coal seam gas
DEA:	Department of Environmental Affairs
DEC:	Default Ecological Category
DMR:	Department of Mineral Resources
DWA:	Department of Water Affairs
EIA:	Environmental Impact Assessment
FEPA:	Freshwater Ecosystem Priority Areas
FRAI:	Fish Response Assessment Index
GAI:	Geomorphology Assessment Index
GIS:	Geographic Information System
GRAII:	Groundwater Resource Assessment II
HAI:	Hydrology Driver Assessment Index
HF:	Hydraulic fracturing
IEA:	International Energy Agency
IHI:	Index of Habitat Integrity Method
IPCC:	International Panel on Climate Change
MIRAI:	Macro-invertebrate Response Assessment Index
NBA:	National Biodiversity Assessment
NEIC:	National Earthquake Information Centre
NORM:	Naturally occurring radioactive material
NPAES:	National Protected Areas Expansion Strategy
NFEPA:	National Freshwater Ecosystem Priority Areas
PASA:	Petroleum Agency of South Africa
PES:	Present Ecological Status
PGA:	Peak Ground Acceleration
psi:	Pounds per square inch
QDS:	Quarter Degree Squares
RHAM:	Rapid Habitat Assessment Method
scf:	Square cubic foot
SAAQIS:	South African Air Quality Information System
SAAO:	South African Astronomical Observatory
SALT:	South African Large Telescope
SANBI:	South African National Biodiversity Institute
SANSN:	South African National Seismological Network
SASS:	South African Scoring System for Macro-invertebrates
SAW:	Simple Additive Weighting
SEA:	Strategic environmental assessment
SKA:	Square Kilometer Array
STB:	Stock Tank Barrel
SQR:	Sub Quaternary Reach

TCF:	Trillion cubic feet
TCP:	Technical cooperation permit
TDS:	Total dissolved solids
VEGRAI:	Vegetation Response Assessment Index
WetFEPA:	Wetland Freshwater Ecosystem Priority Area
WMS:	Water Management System
WPM:	Weighted Product Method
WWF:	World Wildlife Fund

GLOSSARY

Acre:	Unit area (imperial system), equivalent to 0.4 ha or 4047 m^2.
Amplitude:	A measure of change over a single period in a periodic variable
Annual Probability of Exceedance:	The probability that a given level of seismic hazard (typically some measure of ground motions, e.g., seismic magnitude or intensity), or seismic risk (typically economic loss or casualties)
Annulus or Annular Space:	Space between casing and the wellbore, or between the tubing and casing or wellbore, or between two strings of casing.
API gravity:	A specific gravity scale developed by the American Petroleum Institute (API) for measuring the relative density of various petroleum liquids, expressed in degrees.
Area-specific mean seismic activity rate (λ):	Mean rate of seismicity for the whole selection area in the vicinity of the site for which the PSHA is performed.
Attenuation:	The reduction in the amplitude or energy of seismic waves caused by the physical characteristics of the transmitting media or system. It usually includes geometric effects such as the decrease in amplitude of a wave with increasing distance from the source.
Aquifer:	A zone of permeable, water saturated rock material below the surface of the earth capable of storing and producing significant quantities of water.
Aridification:	The process by which a humid region becomes increasingly dry, as by climatic change or human interference with the ecology.
b-value:	A coefficient in the frequency-magnitude relation, $\log N(m)=a-bm$, obtained by Gutenberg and Richter, where m is the seismic event magnitude and $N(m)$ is the number of seismic events with magnitude greater than or equal to m. Estimated b-values for most seismic zones fall between 0.6 and 1.2.
Base fluid:	Any drilling fluid that must act as a mixing agent and carrier fluid during the process of hydraulic fracturing.
Biocides:	Also known as a "bactericide." An additive in the hydraulic fracturing fluid that kills bacteria.
Biodiversity:	The sum of all taxa of animals, plants, fungi, and micro-organisms as well as their communities in a region (After Low and Rebello, 1998, as modified by Mucina and Rutherford, 2006).
Biome:	A broad ecological unit representing major life zones of large natural areas. and defined mainly by vegetation structure, climate as well as major large-scale disturbance factors (such as fire) (Mucina and Rutherford, 2006).

Breaker:	A chemical used to reduce the viscosity of a fluid (break it down) after the thickened fluid has finished the job it was designed for.
Brine:	Water (either displaced from the geological formation or generated from the fracturing fluids used during hydraulic fracturing) which contains elevated levels of dissolved solids.
Blowout:	An uncontrolled flow of gas, oil or water from a well, during drilling when high formation pressure is encountered.
Casing:	Steel pipe placed in a well (borehole).
Catalogue (seismic):	A chronological listing of seismic events. Early catalogues were purely descriptive, i.e., they gave the date of each seismic event and some description of its effects. Modern catalogues are usually quantitative, i.e., seismic events are listed as a set of numerical parameters describing origin time, hypocenter location, magnitude, focal mechanism, moment tensor, etc.
Chemical additive:	A product composed of one or more chemical constituents that are added to a primary carrier fluid to modify its properties in order to form hydraulic fracturing fluid.
Chemical constituent:	A discrete chemical with its own specific name or identity, such as a CAS Number, which is contained within an additive product
Cledoic egg:	An egg that is enclosed by a shell which effectively isolates it from the outside environment and prevents the loss of moisture (i.e. the egg of a land-dwelling animal) - these are eggs with impervious shells as opposed to eggs without hard, impervious shells.
Coal gasification	(Underground) Coal Gasification (UCG) is a method of converting unworked coal - coal still in the ground – into synthetic gas. The "syngas" - a mixture of methane, hydrogen, carbon dioxide and water vapour, is produced from coal, water, air and/or oxygen. During UCG the cavity itself becomes the reactor so that the gasification of coal takes place underground instead of at the surface. UGC does not resort under natural unconventional oil and gas (that occurs naturally in the geological formations in oil or gaseous form) as this gas is produced synthetically from coal.
Coalbed methane:	Natural gas contained in coal beds. Although extraction of coalbed methane was initially undertaken to make mines safer, it is now typically produced from non-mineable coal seams.
Coal seam gas:	Coalbed methane is known as coal seam gas in Australia.
Completion:	The activities and methods of preparing a well for extraction after it has been drilled to the target formation. This principally involves preparing the well to the required specifications; running in extraction tubing and its associated down hole tools, as well as perforating and stimulating the well by the use of hydraulic fracturing, as required.
Compressor:	A facility which increases the pressure of natural gas to move it in pipelines or into storage.
Condensate:	A low-density, high-API gravity liquid hydrocarbon phase that generally occurs in association with natural gas. Its presence as a liquid phase depends on temperature and pressure conditions in the reservoir allowing condensation of liquid from vapour. Condensate is mainly composed of propane, butane, pentane and heavier hydrocarbon fractions. The condensate is not only generated into the reservoir, it is also formed when liquid drops out, or condenses, from a gas stream in pipelines or surface facilities.
Conventional oil and gas:	Conventional oil and gas resources are produced from conventional

	reservoirs.
Conventional reservoir:	For oil gas reserves, conventional hydrocarbons refer to hydrocarbons that are produced from reservoirs that do not require stimulation to produce the gas. These reservoirs typically have permeabilities larger than 1 milliDarcy.
Corrosion inhibitor:	A chemical substance that minimises or prevents corrosion in metal equipment.
Cross-linker:	A compound, typically a metallic salt, mixed with a base-gel fluid, such as a guar-gel system, to create a viscous gel used in some stimulation or pipeline cleaning treatments. The crosslinker reacts with the multiplestrand polymer to couple the molecules, creating a fluid of high viscosity.
Cultural significance:	Aesthetic, architectural, historical, scientific, social, spiritual, linguistic or technological value or significance.
Darcy:	A unit of permeability. A medium with a permeability of 1 Darcy permits a flow of 1 cm^3/s of a fluid with viscosity 1 cP (1 mPa·s) under a pressure gradient of 1 atm/cm acting across an area of 1 cm^2.
Default Ecological Category (DEC):	The DEC represents the sensitivity of a river reach to impacts based on the Present Ecological State (PES) and the highest maximum of the mean of Ecological Importance (EI) and Ecological Sensitivity (ES) rating from the 2011-2013 PESEIS study. The DEC is a very broad indication of the importance of protecting the SQR in a particular desired state.
Depauperate:	Arrested in growth or development; stunted.
Desertification:	The process of desert expansion or formation, which may occur as a direct consequence of climatic change as a result of poor land-use policy, or owning to some complex interaction of these factors.
Directional drilling:	Deviation of the borehole from vertical so that the borehole penetrates a productive formation in a manner parallel to the formation, although not necessarily horizontally.
Disposal well:	A well into which waste fluids can be injected deep underground for safe disposal.
Drilling fluid:	Mud, water, or air pumped down the drill string which acts as a lubricant for the drill bit and is used to carry rock cuttings back up the wellbore. It is also used for pressure control in the wellbore.
Dry gas:	Natural gas that occurs in the absence of condensate or liquid hydrocarbons, or gas that has had condensable hydrocarbons removed. Dry gas typically has a gas-to-oil ratio exceeding 100,000 scf/STB. The production of liquids from gas wells complicates the design and operation of surface process facilities required to handle and export the produced gas.
Economically recoverable reserves:	Technically recoverable petroleum for which the costs of discovery, development, extraction, and transport, including a return to capital, can be recovered at a given market price.
Ecoregion:	WWF defines an ecoregion as a "large unit of land or water containing a geographically distinct assemblage of species, natural communities, and environmental conditions".
Ecosystem:	A complex set of relationships of living organisms functioning as a unit and interacting with their physical environment. The boundaries of what could be called an ecosystem are somewhat arbitrary, depending on the focus of interest or study. Thus the extent of an

	ecosystem may range from very small spatial scales to, ultimately, the entire earth.
Endemic (Region):	A plant or animal species or a vegetation type which is naturally restricted to a particular, defined region.
Environment:	The combination of external physical conditions that affects and influences the growth, development and survival of organisms. This includes all of the biotic and abiotic factors that act on an organism, population, or ecological community and influence its survival and development. Biotic factors include the organisms themselves, their food and their interactions. Abiotic factors include such items as sunlight, soil, air, water, climate and pollution. Organisms respond to changes in their environment by evolutionary adaptations in form and behaviour.
Environmental degradation:	The reduction of the capacity of the environment to meet social and ecological objectives, and needs. Potential effects are varied and may contribute to an increase in vulnerability and the frequency and intensity of natural hazards. Some examples are: land degradation, deforestation, desertification, wild fires, loss of biodiversity, land, water and air pollution, climate change, sea level rise and ozone depletion.
Environmental impact assessment (EIA):	A public process by which the likely effects of a project on the environment are identified, assessed and then taken into account by the consenting authority in the decision-making process. This serves as a tool to facilitate sustainable development.
Exploration right	A right granted to the applicant in terms of section 80 of MPRDA to re-process the existing seismic data, acquisition and processing of new seismic data or any other related activity to define a trap to be tested by drilling, logging and testing, including extended well testing, of a well with the intention of locating a discovery.
Extraction:	Extraction as used in this report refers to all types of unconventional oil and gas extraction, thus to both shale gas (regulated under petroleum resource exploitation (Chapter 6 of the *Mineral and Petroleum Resources Development Act (28 of 2008) (MPRDA)*) as well as coalbed methane (regulated under mining (Chapter 4 of the *MPRDA*)).
Fault:	A fracture or fracture zone in a geological formation along which there has been displacement of the sides relative to each other.
Flare:	The burning of unwanted gas from a well.
Flowback:	Fluid returned to the surface after hydraulic fracturing has occurred, but before the well is placed into production. It typically consists of returned fracturing fluids in the first few days following hydraulic fracturing which are progressively replaced by produced water.
Fold:	A bend in geological rock strata.
Formation:	A rock body distinguishable from other rock bodies and useful for geological mapping or description. Formations may be combined into groups or subdivided into members.
Fracking, fraccing or fracing:	Informal abbreviations for "Hydraulic Fracturing".
Frequency-content:	Describes the distribution of the amplitude of a ground motion among different frequencies
Friction reducer / Friction reducing agent:	A chemical additive which alters the hydraulic fracturing fluid allowing it to be pumped into the target formation at a higher rate and reduced pressure.

Gas in place:	Gas that are determined to occur in shale layers but of which the productive volumes has not been tested by means of hydraulic fracturing.
Gelling agent:	Polymers used to thicken fluid so that it can carry a significant amount of proppants into the formation.
Geographic Information System (GIS):	Analysis that combines relational databases with spatial interpretation and outputs, often in the form of maps. A more elaborate definition is that of computer programs for capturing, storing, checking, integrating, analysing and displaying data about the earth that is spatially referenced. GIS is used in this study for vulnerability mapping and analysis.
Ground motion prediction equation (GMPE):	Equations for predicting the level of ground shaking at any location and includes the associated uncertainty. It is based on magnitude, source-to-site distance, local soil conditions, fault mechanism, etc. GMPEs are efficiently used to estimate ground motions for use in both deterministic and probabilistic seismic hazard analyses. GMPEs are also known as attenuation relationships.
Groundwater:	Water found in the subsurface below the water table. Groundwater is held in the pores of rocks.
Habitat fragmentation:	Habitat fragmentation is usually defined as a landscape-scale process involving both habitat loss and the breaking apart of habitat.
Heritage resource:	Any place or object of cultural significance.
Horizontal drilling:	Deviation of the borehole from vertical so that the borehole penetrates a productive formation with horizontally aligned strata, and runs approximately horizontally.
Hydraulic fracturing:	The act of pumping hydraulic fracturing fluid into a formation to increase its permeability. Hydraulic fracturing has been used in the industry in various forms, for either stimulation of water wells to produce water, or for stimulation of oil and gas wells to produce oil and/or gas. Various technologies can be combined or used separately during hydraulic fracturing. It may involve the use of only water (for water well stimulation) or a combination of any or all of four separate technologies, viz directional drilling, the use of high volumes of fracturing fluids, the use of slickwater additives and the use of multi-well drilling pads. When all four technologies are combined it is more specifically called “High-volume slickwater long-lateral” (HVSLL) stimulation. Hydraulic fracturing as used in the oil and gas industry, commonly includes the usage of 0.5-2% chemical additives (slickwater additives), large volumes of proppant as well as large volumes of fluid. Base fluids that may be used may include water, liquid petroleum gas or other gases such as nitrogen or carbon dioxide. Synonyms for hydraulic fracturing as used in the oil and gas industry include “slickwater fracking” (“slickwater” in short), “high volume hydraulic fracturing” or just “fracking” or “fraccing” in short.
Hydraulic fracturing fluid:	Fluid used to perform hydraulic fracturing; includes the primary carrier fluid, proppant material, and all applicable additives.
Hydrocarbon:	A naturally occurring organic compound comprising hydrogen and carbon. Hydrocarbons can be as simple as methane [CH_4], but many are highly complex molecules, and can occur as gases, liquids or solids. The molecules can have the shape of chains, branching chains, rings or other structures. Petroleum is a complex mixture of hydrocarbons. The most common hydrocarbons are

natural gas, oil and coal.

Land-use Planning: Physical and socio-economic planning that determines the means and assesses the values or limitations of various options in which land is to be utilised, with the corresponding effects on different segments of the population or interests of a community taken into account in resulting decisions. Land-use planning involves studies and mapping, analysis of environmental and hazard data, formulation of alternative land-use decisions and design of a long-range plan for different geographical and administrative scales.

Land-use planning can help to mitigate disasters and reduce risks by discouraging high-density settlements and construction of key installations in hazard-prone areas, control of population density and expansion, and in the siting of service routes for transport, power, water, sewage and other critical facilities.

Land degradation: The reduction or loss in arid, semi-arid and dry sub-humid areas of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, forest and woodlands. Land degradation results from a process or combination of processes, including those arising from human activities and habitation patterns that include: (i) soil erosion caused by wind and/or water, (ii) deterioration of the physical, chemical and biological or economic properties of soil and (iii) long-term loss of natural vegetation.

Livelihood: The means for securing the necessities of life so that individuals, households and communities can sustain a living over time, using a combination of social, economic, cultural and environmental resources.

Living heritage: *The intangible aspects of inherited culture, and may include-*

a) cultural tradition;
b) oral history;
c) performance;
d) ritual;
e) popular memory;
f) skills and techniques;
g) indigenous knowledge systems; and
h) the holistic approach to nature, society and social relationships.

The national estate may include-

a) places, buildings, structures and equipment of cultural significance;
b) places to which oral traditions are attached or which are associated with living heritage;
c) historical settlements and townscapes;
d) landscapes and natural features of cultural significance;
e) geological sites of scientific or cultural importance;
f) archaeological and palaeontological sites;
g) graves and burial grounds, including-
    i) ancestral graves;
    ii) royal graves and graves of traditional leaders;
    iii) graves of victims of conflict;
    iv) graves of individuals designated by the Minister by notice in the Gazette;
    v) historical graves and cemeteries; and
    vi) other human remains which are not covered in terms of the *Human Tissue Act, 198*3 (Act No. 65 of 1983);
h) sites of significance relating to the history of slavery in South

Africa; and

i) movable objects, including-
   i) objects recovered from the soil or waters of South Africa, including archaeological and palaeontological objects and material, meteorites and rare geological specimens;
   ii) objects to which oral traditions are attached or which are associated with living heritage;
   iii) ethnographic art and objects;
   iv) military objects;
   v) objects of decorative or fine art;
   vi) objects of scientific or technological interest; and
   vii) books, records, documents, photographic positives and negatives, graphic, film or video material or sound recordings, excluding those that are public records as defined in section I and
   viii) of the *National Archives of South Africa Act, 1996* (Act No. 43 of 1996).

Magnitude: In seismology, a quantity intended to measure the size of seismic event that is independent of the place of observation. Richter magnitude or local magnitude M_L was originally defined by Richter in 1935 as the logarithm of the maximum amplitude in micrometers of seismic waves in a seismogram written by a standard Wood-Anderson seismograph at a distance of 100 km from the epicenter. Empirical tables were constructed to reduce measurements to the standard distance of 100 km, and the zero of the scale was fixed arbitrarily to fit the smallest seismic event then recorded. The concept was extended later to construct magnitude scales based on other data, resulting in many types of magnitudes, such as body-wave magnitude (m_b), surface-wave magnitude (M_S), and moment magnitude (M_W). In some cases, magnitudes are estimated from seismic intensity data, tsunami data, or duration of coda waves. The word "magnitude" or the symbol M, without a subscript, is sometimes used when the specific type of magnitude is clear from the context, or is not really important.

Maximum Regional Seismic Event Magnitude (m_{max}): Upper limit of magnitude for a given seismogenic zone or entire region. Also, often referred to as the maximum credible earthquake (MCE).

milliDarcy: A unit of permeability, equivalent to one thousandth of a Darcy.

Naturally Occurring Radioactive Materials: Low-level radioactivity that can exist naturally in native materials, like some shales and may be present in drill cuttings and other wastes from a well.

Natural resources: Non-renewable resources such as minerals, fossil fuels and fossil water, and renewable resources, such as non-fossil water supplies, biomass (forest, grazing resources) marine resources, wildlife and biodiversity.

Operator: Any person or organisation in charge of the development of a lease or drilling and operation of a producing well.

Peak Ground Acceleration (PGA): The maximum acceleration amplitude measured (or expected) of an earthquake.

Peneplain: A low-relief plain representing the final stage of fluvial erosion during times of extended tectonic stability.

Perforate: To make holes through the casing to allow the oil or gas to flow into the well or to squeeze cement behind the casing.

Perforation: A hole created in the casing to achieve efficient communication

	between the reservoir and the wellbore.
Permeability:	A measure of the ability of a fluid to move through pores, fractures or other openings in a rock. The unit for measurement is Darcy.
Plateau:	An area of highland, usually consisting of relatively flat terrain.
Play:	Synonym for geological formation.
Polymer:	Chemical compound of unusually high molecular weight composed of numerous repeated, linked molecular units.
Porosity:	Volume of pore space expressed as a per cent of the total bulk volume of the rock.
Primary carrier fluid:	The base fluid, such as water, into which additives are mixed to form the hydraulic fracturing fluid which transports proppant.
Probabilistic Seismic Hazard Analysis (PSHA):	Available information on seismic event sources in a given region is combined with theoretical and empirical relations among seismic event magnitude, distance from the source and local site conditions to evaluate the exceedance probability of a certain ground motion parameter, such as the peak acceleration, at a given site during a prescribed period.
Produced water:	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.
Production right	A right granted to the applicant in terms of section 84 of MPRDA to the applicant to conduct any operation, activity or matter that relates to the exploration, appraisal, development and production of petroleum.
Proppant or propping agent:	A granular substance (sand grains, aluminium pellets, or other material) that is carried in suspension to the target zone by the fracturing fluid. Proppant is used to keep open the micro-scale fractures at depth and can be either sand or ceramic beads. The sand or ceramic beads must have specific physical properties – it must be perfectly spherical, of a specific size and clean from cement such as calcite, otherwise it would not perform optimally in keeping open the fractures in the source rock.
Proved reserves:	The quantity of energy sources estimated with reasonable certainty, from the analysis of geologic and engineering data, to be recoverable from well-established or known reservoirs with the existing equipment and under the existing operating conditions
Reservoir (oil or gas):	A subsurface, porous, permeable or naturally fractured rock body in which oil or gas has accumulated. A gas reservoir consists only of gas plus fresh water that condenses from the flow stream reservoir. In a gas condensate reservoir, the hydrocarbons may exist as a gas, but, when brought to the surface, some of the heavier hydrocarbons condense and become a liquid.
Reservoir pressure:	The pressure within the reservoir rock.
Reservoir rock:	A body of rock that may contain oil or gas in appreciable quantity and that has sufficient porosity and permeability to store and transmit fluids.
Sandstone:	A variously coloured sedimentary rock composed chiefly of sandlike quartz grains cemented by lime, silica or other materials.
Scale inhibitor:	A chemical substance which prevents the accumulation of a mineral deposit (for example, calcium carbonate) that precipitates out of

	water and adheres to the inside of pipes, heaters, and other equipment.
Sedimentary rock:	A rock formed from sediment transported from its source and deposited in water or by precipitation from solution or from secretions of organisms.
Seismic Vulnerability (Hazard):	Any physical phenomena associated with a seismic event (e.g., ground motion, ground failure, liquefaction, and tsunami) and their effects on land use, man-made structure and socioeconomic systems that have the potential to produce a loss. It is also used without regard to a loss to indicate the probable level of ground shaking occurring at a given point within a certain period of time.
Shale:	A fine-grained sedimentary rock composed mostly of consolidated clay, silt or mud. Shale is formed from deposits of mud, silt, clay, and organic matter, usually laid down in calm seas or lakes.
Shale gas:	Natural gas that remains tightly trapped in shale and consists chiefly of methane, but with ethane, propane, butane and other organic compounds mixed in. It forms when black shale has been subjected to heat and pressure over millions of years, usually at depths of 1,500 to 4,500 metres below ground level.
Siltstone:	Rock in which the constituent particles are predominantly silt size.
Slickwater:	Identifies a hydraulic fracturing system in which “friction reducer” has been added to the base fluid.
Species richness:	The number of species present in a particular area.
Specific gravity:	The dimensionless ratio of the weight of a material to that of the same volume of water. Most common minerals have specific gravities between 2 and 7.
Stimulation:	The act of increasing a well’s productivity by artificial means such as hydraulic fracturing or acidizing.
Stock tank barrel:	A measure of the volume of treated oil stored in stock tanks.
Strong ground motion:	Motion of the ground that is of sufficient strength to affect people and their environment.
Sub quaternary reach (SQR):	A SQR changes to the next SQR, when a significant tributary joins it.
Sustainable development:	Generally defined as “Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” Sustainable development is based on socio-cultural development, political stability and decorum, economic growth and ecosystem protection, which all relate to disaster risk reduction. The National Environmental Management Act (No 107 of 1998) defines sustainable development as “the integration of social, economic and environmental factors into planning, implementation and decision-making so as to ensure that development serves present and future generations”.
Target formation:	The reservoir that the driller is trying to reach when drilling the well.
Technical cooperation permit:	A permit issued to applicant in terms of section 77(1) of MPRDA which allows the applicant to do desktop study, acquire seismic data from other sources including the Agency, etc; but does not include any prospecting or exploration activities.
Technically recoverable reserves:	The proportion of assessed in-place oil or gas that may be recoverable using current recovery technology, without regard to cost.

Tight formation:	Formation with a very low permeability (less than 1 milliDarcy).
Tight sands:	A geological formation consisting of a matrix of typically impermeable, non-porous tight sands.
Total dissolved solids (TDS):	All material that passes the standard glass river filter; also called total filterable residue. The term is used to reflect salinity.
Turbidity:	A cloudy condition in water due to suspended silt or organic matter.
Unconventional oil and gas:	Unconventional oil and gas resources are produced from unconventional reservoirs.
Unconventional reservoir:	Reservoirs, which require hydraulic fracturing for the extraction of hydrocarbons occurring in these reservoirs, where the permeability is less than 1 milliDarcy.
Underground injection well:	A steel- and concrete-encased well or borehole into which hazardous waste is deposited by force and under pressure into porous geological formations.
Vegetation type:	A structurally and floristically defined unit of plant communities which share similar climatic, geological, a soil requirements, have similar ecosystem processes, and which have similar management and conservation requirements, as well as potential uses.
Vulnerability:	The conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards.
Wastewater:	A term used to designate collectively returned fracturing fluids and produced water which are sent for disposal or treatment and re-use.
Wellbore:	A borehole of which the hole is drilled by a drill bit. A wellbore may have casing in it or it may be open (uncased); or part of it may be cased, and part of it may be open.
Wellhead:	The equipment installed at the surface of the wellbore. A wellhead includes such equipment as the casing head and tubing head.
Well pad:	A site constructed, prepared, levelled and/or cleared in order to perform the activities and stage the equipment and other infrastructure necessary to drill one or more natural gas exploratory or extraction wells.
WetFEPA:	Wetland FEPAs were identified using ranks that were based on a combination of special features and modeled wetland condition. Special features included expert knowledge on features of conservation importance (e.g. extensive intact peat wetlands, presence of rare plants and animals) as well as available spatial data on the occurrence of threatened frogs and wetland-dependent birds. Wetland condition was modeled using the presence of artificial water bodies as well as by quantifying the amount of natural vegetation in and around the wetland (within 50 m, 100 m and 500 m of the wetland). Based on these factors, wetlands were ranked in terms of their biodiversity importance. Biodiversity targets for wetland ecosystems were met first in high-ranked wetlands, proceeding to lower ranked wetlands only if necessary. Although wetland condition was a factor in selection of wetland FEPAs, wetlands did not have to be in a good condition to be chosen as a FEPA (Nel et al., 2011a).
Wet gas:	Natural gas that contains less methane (typically less than 85% methane) and more heavy hydrocarbons such as ethane and other more complex hydrocarbons. Wet gas may also contain water.
Workover:	Repair operations on a producing well to restore or increase oil

and/or gas production. This may involve repeat hydraulic fracturing to re-stimulate gas flow from the well.

CONVERSION OF UNITS

The oil and gas industry uses the following units and the conversions are represented for the convenience of the readers.

1 Barrel US Oil = 158.99 litres = 42 US gallons
1 Barrel US liquid = 119.24 litres
1 Bar = 0.99 atmospheres
1 Foot = 30.48 cm
1 Cubic feet = 0.02832 m^3
1 Acre = 0.41 hectare
1 Pound/cubic inch = 27.68 g/cm

1 INTRODUCTION

1.1 Rationale of project

This study was proposed in light of applications made by various companies for exploration permits with the Petroleum Agency of South Africa (PASA). The extent of applications for the extraction of shale gas and coalbed methane spans large areas of South Africa (currently approximately 32% of the surface area of South Africa) and necessitated an investigation into the possible impacts associated with hydraulic fracturing, as well as identifying vulnerable areas where hydraulic fracturing can cause irreversible loss of natural resources and may have far-reaching socio-economic impacts.

Hydraulic fracturing has raised some concern worldwide. In the United States of America (USA) the Environmental Protection Agency (USEPA, 2011a; USEPA, 2012a) is performing an environmental impact study spanning 3 years, on hydraulic fracturing at federal level, after reports of possible water contamination resulting from unconventional gas extraction operations. A draft of this report is due to be released in 2014 (USEPA, 2014), and was not available at the time of writing. In Canada the authorities commissioned the "BAPE" report (BAPE, 2011) due to the high percentage of wells drilled by the shale gas industry, which exhibited problems relating to proper sealing in the Quebec province. The report noted that it would be appropriate to assess the long-term risk associated the presence of contaminated water from hydraulic fracturing activities in rock formations and also that a study of the cumulative impacts of the disposal of wastewater from the shale gas industry must be undertaken. The BAPE Commission also pointed out that a high percentage of unexpected natural gas emissions observed from wells pose a risk of explosion, and little is known about the seismic risks associated with the industry. The report also stated that a strategic environmental assessment of the cumulative impacts was seen to be "a necessary element of both an informed decision and improved social acceptability". In the United Kingdom (UK) the Tyndall report (Wood et al., 2011) and the Energy and Climate Change Committee, ("the E&CCC enquiry") investigated proposed fracking in the UK. The Tyndall report noted that there is a risk of contamination of groundwater from shale gas extraction and that it is important to recognise that most problems arise due to errors in construction or operation of wells that cannot be eliminated. It also noted that significant amounts of water are required to extract shale gas and this could put severe pressure on water supplies in areas of drilling (which is an issue in water-stressed South Africa). The UK's Energy and Climate Change Committee (E&CCC) also recently held an inquiry into the exploration for and exploitation of shale gas (House of Commons, 2011a). Regarding the harmful nature of the chemicals used in fracking, it was noted that there could be some issues related to the mobilisation of chemicals within the shale to surface water and groundwater (House of Commons, 2011a) and that mitigation of the risk to aquifers from hydraulic fracturing relies on companies undertaking the proper measures to protect the environment from pollution (House of Commons, 2011b). The British House of Commons scheduled a second evidence session on the “Impact of Shale Gas on Energy Markets”, that was held on 11 December 2012 (House of Commons, 2012). This public session would focus on what effect the development and expansion of a shale gas industry will have on the UK, how the government’s Gas Generation Strategy and announcements in the Autumn Statement will influence the development of the UK shale gas industry; and the wider implications of shale gas on the UK’s climate change obligations and investment in renewable energy (House of Commons, 2012).

A report by Havemann et al. (2011) highlights the following concerns with regards to hydraulic fracturing in the Karoo (which also applies to the wider South African context):

- There is insufficient information on the potential health risks to the public as a result of water contamination.
- There is an unacceptable risk of losing globally unique biodiversity, jeopardising ecological integrity and causing loss of irreplaceable resources for which remedy is not feasible.
- There is an unacceptable risk of having an irreversible negative impact on the sense of place of the Karoo and on the lives, health and livelihoods of its communities.

- There is a substantial risk of inequitable distribution of impacts arising from the proposed activity, and of vulnerable rural people having to bear the negative impacts. In the light of significant uncertainties there is a need to take a risk-averse and cautious approach.

The Havemann report (2011) also cautions the government, stating that:

- Fracking is an unprecedented activity in South Africa.
- A policy vacuum exists in relation to the exploitation of shale gas.
- Project-level environmental impact assessment is an inappropriate mode of environmental management in this case regional strategic environmental assessment may be more appropriate.
- Authorisation processes are fragmented and limited and
- There is a serious lack of capacity to monitor and enforce compliance with any conditions of approval.

In view of the above shortcomings in South Africa, the aim of this study is to investigate hydraulic fracturing by performing a background review; developing an interactive vulnerability map; and developing a provisional screening level monitoring protocol.

This study aims to contribute knowledge on issues associated with unconventional oil and gas extraction by means of hydraulic fracturing and highlight vulnerable areas in South Africa. It also proposes that a provisional screening level monitoring protocol be used as a guideline for monitoring of entities that may be impacted upon by unconventional oil and gas extraction The background review is the first step towards understanding the complexities of unconventional gas extraction by means of hydraulic fracturing and should aid government in developing the required regulatory policies and guidelines to effectively manage and monitor unconventional gas extraction and hydraulic fracturing in South Africa in a way that will protect human health and the environment and ensure sustainable use of our very scarce water resources.

In South Africa, where water demand will exceed water supply in the near future, unsustainable use of water resources will result in increasingly limited water resources for future health and well-being as well as for sustained socio-economic development. Society in general, and specifically the residents in the Karoo where access to water is already limited, needs to be assured of the sustainable use of the water resources for health and well-being. The negative social impacts resulting from fracking need to be well understood and avoided where possible. These possible impacts include competition over water between Shell and other oil companies with existing lawful water users in the Karoo; securing access to water and sanitation for previously disadvantaged communities in the face of competing demands presented by fracking operations; the potential health risks associated with lack of access to water and adequate sanitation in vulnerable communities; and in-migration and higher population density in ecologically sensitive and water scarce areas. Therefore, the dynamic and multi-faceted socio-economic and demographic impacts of unconventional gas extraction in communities in these areas where basic resources such as water are already under pressure should be identified, mapped and linked with wider developmental and environmental concerns.

1.2 Project objectives

This report, “Development of an interactive vulnerability map and preliminary screening level monitoring protocol to assess the potential environmental impact of unconventional oil and gas extraction by means of hydraulic fracturing” has the following objectives:

- Writing a background review;
- Developing an interactive vulnerability map; and
- Developing a screening level monitoring protocol for various entities

The objectives of the “Background review” are to give background details on unconventional oil and gas extraction in South Africa and the rest of the world, describe entities that may be impacted upon by unconventional oil and gas extraction and describe the entities that will be mapped and the methodology to be followed for the vulnerability mapping phase.

The objective of the development of the interactive vulnerability map for unconventional oil and gas extraction is to provide decision-makers at national level and other practitioners with information on the vulnerability to unconventional gas production of the specified themes on a regional scale. The map is intended as a reconnaissance tool to inform decision-makers on areas where additional detail field work and assessments may be required as part of Environmental Impact Assessment (EIA) and licensing conditions.

The objective of the provisional screening level monitoring protocol is to give guidance on the planning of monitoring activities for specific entities (surface water, groundwater, vegetation, seismicity and socio-economics) during the various phases of unconventional gas extraction. The protocol discusses issues such as why monitoring of certain aspects is required, as well as where, when and how monitoring must be performed; and who the relevant parties are that should do this monitoring.

1.3 Team members and disciplines

The core project team members are M. Avenant (Fish), S. Esterhuyse (Geohydrology), J. Glazewski (Legal), M. Kemp (Vegetation), A. Kijko (Seismicity), N. Redelinghuys (Socio-economics), A. Smit (Statistics), F. Sokolic (GIS), M. von Maltitz (Mathematical Statistics), T. Vos (Surface Water Quality) and M. Watson (Aquatic Invertebrates and Surface Water). Student contributors for this report are H. Louw, A. Nell, H. Prinsloo, W. Naude, J. Adendorff, Q. Mkabile, D. Cillie, G. Enke and N. Hütter.

External specialists who contributed to this report are C. Bragg (Ecology and Mammals), J. Glazewski (Marine and Environmental Law), L.A. Plit (Environmental Law and Sustainable Development), D. Reynolds (Amphibians and Reptiles; additional information on mammals), B. van Soelen (Astronomy), J. van Tol (Soil), and S. Ouzman (Archaeology and Heritage Resources). M. Zunckel reviewed the air quality section of the report.

Table 1 lists the study team and their involvement in the project.

Table 1: The study team and their specific fields of expertise involved in the study

Name	Discipline	Institution
Ms Surina Esterhuyse	Project leader, project co-ordinator and groundwater specialist	Centre for Environmental Management (CEM), University of the Free State (UFS)
Ms Marie Watson	Macro-invertebrates	CEM, UFS
Ms Marinda Avenant	Fish	CEM, UFS
Dr Nola Redelinghuys	Sociology	Sociology Department, UFS
Ms Marthie Kemp	Riparian Vegetation	CEM, UFS
Mr Frank Sokolic	GIS	CEM, UFS
Ms Tascha Vos	Limnology	CEM, UFS
Mr Dave Reynolds	Environmental Management	CEM, UFS
Prof Andrzej Kijko	Seismicity	University of Pretoria Natural Hazard Centre, Africa, University of Pretoria
Ms Ansie Smit	Applied statistics in seismicity	University of Pretoria Natural Hazard Centre, Africa, University of Pretoria
Mr Michael von Maltitz	Mathematical statistics	Department of Mathematical Statistics, UFS
Prof Jan Glazewski	Marine and Environmental Law	Institute of Marine and Environmental Law, University of Cape Town (UCT)
Dr Lisa Plit	Environmental Law and Sustainable Development	Institute of Marine and Environmental Law, UCT
Dr Johan van Tol	Soil Science	University of Fort Hare

Name	Discipline	Institution
Mr Brian van Soelen	Physics	Department of Physics, UFS
Mr Sven Ouzman	Archaeology	Iziko South African Museum
Ms Christy Bragg	Zoology; conservation	Endangered Wildlife Trust
Ms Tascha Vos	Water quality and algae	CEM, UFS
Mr Hendrik Louw	Student assistant	CEM, UFS
Mr Arjen Nell	Student assistant	CEM, UFS
Ms Este Prinsloo	Student assistant	CEM, UFS
Ms Willene Naude	Student assistant	CEM, UFS
Ms Joan Adendorff	Student assistant	CEM, UFS
Ms Qawekazi Mkabile	Student assistant	CEM, UFS
Mr Daniel Cillie	Law student (Background: Environmental Law)	UFS
Ms Nora Huetter	Student assistant	Technical University of Dresden
Mr Georg Enke	Student assistant	Technical University of Dresden

1.4 Project limitations and constraints

The observations and findings made in this report are neither totally comprehensive nor exhaustive, but attempt to address most of the important potential issues regarding unconventional oil and gas extraction in South Africa.

Sources that were utilised include government reports, industry reports, journal articles and discussions with specialists from various disciplines. Since the unconventional oil and gas industry is one that advances rapidly in terms of new technologies, it is possible that some of the most recent advances may not be reflected in this report. The scientists aimed to use credible reports containing comprehensive data and information in order to perform as accurate an analysis as possible of the possible impacts associated with unconventional gas extraction and hydraulic fracturing.

Vulnerability mapping will only focus on selected entities that have been identified as the most important from international literature review, and for which regional spatial data on a national scale could be obtained. Various other entities on which unconventional gas extraction may have an impact will be discussed under Chapter 3, but for vulnerability mapping can be included in later iterations of the vulnerability map in follow-up projects.

1.5 Report layout

This report covers a background review of unconventional gas extraction (Chapter 2), focusing specifically on shale gas and coalbed methane. Chapter 3 discusses the possible impacts of unconventional gas extraction for various entities and covers impacts that may occur during the exploration phase, extraction phase and post-extraction phase. The vulnerability mapping of selected entities (surface water, groundwater, vegetation, seismicity and socio-economics) will be discussed in Chapter 4 and the screening level monitoring protocol will be discussed in Chapter 5. The report concludes and makes recommendations on managing unconventional oil and gas extraction in Chapter 6.

2 BACKGROUND REVIEW

Unconventional oil and gas is a resource that occurs in many countries but that has not been developed until the advent of hydraulic fracturing, which has been used recently as a stimulation technique to extract these resources. It has been produced for quite some time now in the USA, Canada and Australia and is set to be produced in a host of other countries outside South Africa, where significant unconventional gas resources may exist. Australia has up to now been focusing mostly on extraction of coalbed methane (Williams et al., 2012) while the United States has thus far been the undisputed leader in unlocking shale gas resources that occur throughout the lower forty-eight states. Canada is emerging as a new and potentially large source of shale oil and gas. Both China and India have historically focused on coalbed methane and are now starting to explore shale gas options. Many countries in Europe also have a great deal of potential to develop shale gas, and they include Austria, Bulgaria, France, Germany, Italy, Poland, Romania, Spain, Sweden and the United Kingdom (Sakmar, 2011).

A background review of unconventional gas extraction, what it is and which resource types constitute unconventional resources is given in Chapter 2. For the purposes of this study hydraulic fracturing is seen as being an operation making use of a water-based mix of chemical agents and proppants (commonly referred to as fracking fluids).

Hydrocarbon resources occur as conventional and unconventional resources. The distinction between conventional and unconventional is made in terms of the geological occurrence of the hydrocarbon resources and the methods that must be used to extract the hydrocarbon resources. Conventional gas resources refer to porous and highly permeable reservoirs with permeabilities larger than 1 milliDarcy (Broomfield and Donovan, 2012).

Conventional hydrocarbons

Conventional hydrocarbons occur in conventional geological formations (usually porous and permeable sandstone and carbonate reservoirs). Geological hydrocarbon formations are created under specific conditions from organic compounds, usually in marine or inland lake environments. Conventional oil and gas originate from thermo-chemical cracking of organic material in sediments (the source rocks). With increasing burial below other rock formations, these formations were heated and the organic material decomposed into oil at a temperature of 60° Celsius and eventually into gas at higher temperatures. The liquids and gases that emerged from source rocks (such as shales) migrated generally upwards into porous and permeable strata, which in turn had to be covered by impermeable rock (the geological seal or cap rock) in order to allow for the accumulation of hydrocarbon. Hydrocarbons that accumulate under these conditions are called conventional hydrocarbons and the relatively high oil/gas content, the position of the resources (relatively close to the surface) and their relatively high permeability make them easy to extract by means of drilled wells.

Unconventional hydrocarbons

Unconventional hydrocarbons occur in unconventional geological formations. These formations are fine-grained, organic-rich sediments, usually in the form of shales or similar rocks. These rocks are both the source and the reservoir for oil and natural gas, unlike for conventional reservoirs. These deposits are called “tight formations” or “continuous-type deposits”. Large hydrocarbon accumulations may exist in the source / reservoir rocks such as shales. These reservoir rocks have a very low porosity and permeability (USEPA, 2011a, Broomfield and Donovan, 2012) and oil and gas that occur in these formations are called tight oil or tight gas. The permeability of these reservoirs may be 10-100 times smaller than in conventional fields, which is why methods such as hydraulic fracturing are applied to extract oil and gas from these resources. Unconventional resources are also usually dispersed over large areas of tens of thousands of square kilometres as opposed to conventional resources which occur over smaller geographic areas (IEA, 2012). Different types of tight rock formations occur in which unconventional oil or gas can be stored. These are discussed in Section 2.1.

2.1 Unconventional hydrocarbon resource types on which hydraulic fracturing may be applied

Unconventional resource types include three broad groups (shale gas and oil, coalbed methane and tight sand formations), which are discussed below.

Shale gas and oil

Oil and gas shales are geological formations of organic-rich shale, a sedimentary rock formed from deposits of mud, silt, clay, and organic matter, in which substantial quantities of natural oil and gas could be present. The shales are continuous deposits typically extending over areas of thousands of square kilometres (Broomfield, 2012). Shales can store hydrocarbons in very small fractures and pore spaces. These pore spaces and fractures exist on nanoscale. These rocks possess very low permeability. The shales usually occur at deeper depths than coalbed methane deposits (typically from 2-5 km depth). Due to these characteristics, high volume hydraulic fracturing or slickwater fracking, which includes multiple wells per well pad and slickwater hydraulic fracturing, must be applied to extract the resources. Other treatments can also be used to stimulate oil and gas extraction, including acidizing to dissolve carbonate materials in the host rock as well as fracturing with gel or gas (Broomfield, 2012).

Coalbed methane

Coalbed methane (CBM) occurs in the pore spaces of coalbeds. Some of the methane is stored within the coal as adsorbed gas, where a film of methane is created on the surface of the pores inside the coal. Open fractures in the coal may also contain free gas or water. In some instances, methane may be present in large volumes in coalbeds which can pose a serious safety hazard for coal-mining operations. Apart from methane, significant volumes of CO2 may also be present in the coal seams (IEA, 2012). There are similarities and differences between coalbed methane and the two other main types of unconventional gas, which are linked to the way in which coalbed methane is extracted, the associated costs and the impact on the environment. The main similarity between coalbed methane and shale oil and gas or tight sand oil and gas deposits, is the low permeability of the oil or gas-bearing reservoir. Virtually all the permeability of a coalbed is due to fractures, in the form of cleats and joints, which usually occur naturally. This means that methane is able to flow through the coalbed within a small part of the seam. As with shale and tight oil and gas deposits, there are major variations in the concentration of oil and/or gas from one area to another within the coal seams. This, together with variations in the thickness of the seam, has a significant impact on potential oil and/or gas production rates. Due to the tightness of coalbed methane formations, similar methods of extraction may be required to extract the oil and gas from these tight formations and usually include hydraulic fracturing.

Tight sand gas and oil

Tight sands are oil or gas-bearing, fine-grained sandstones or carbonates with a low permeability. Almost all tight sand reservoirs require hydraulic fracturing to release oil and gas unless natural fractures are present (USEPA, 2011a).

2.2 Unconventional hydrocarbon resource types occurring in South Africa

The most prominent types of unconventional hydrocarbon that occur in South Africa are shale oil and gas and coalbed methane. A map showing the extent of the different resource types that have been applied for at PASA (as of August 2014) is shown in Figure 1.

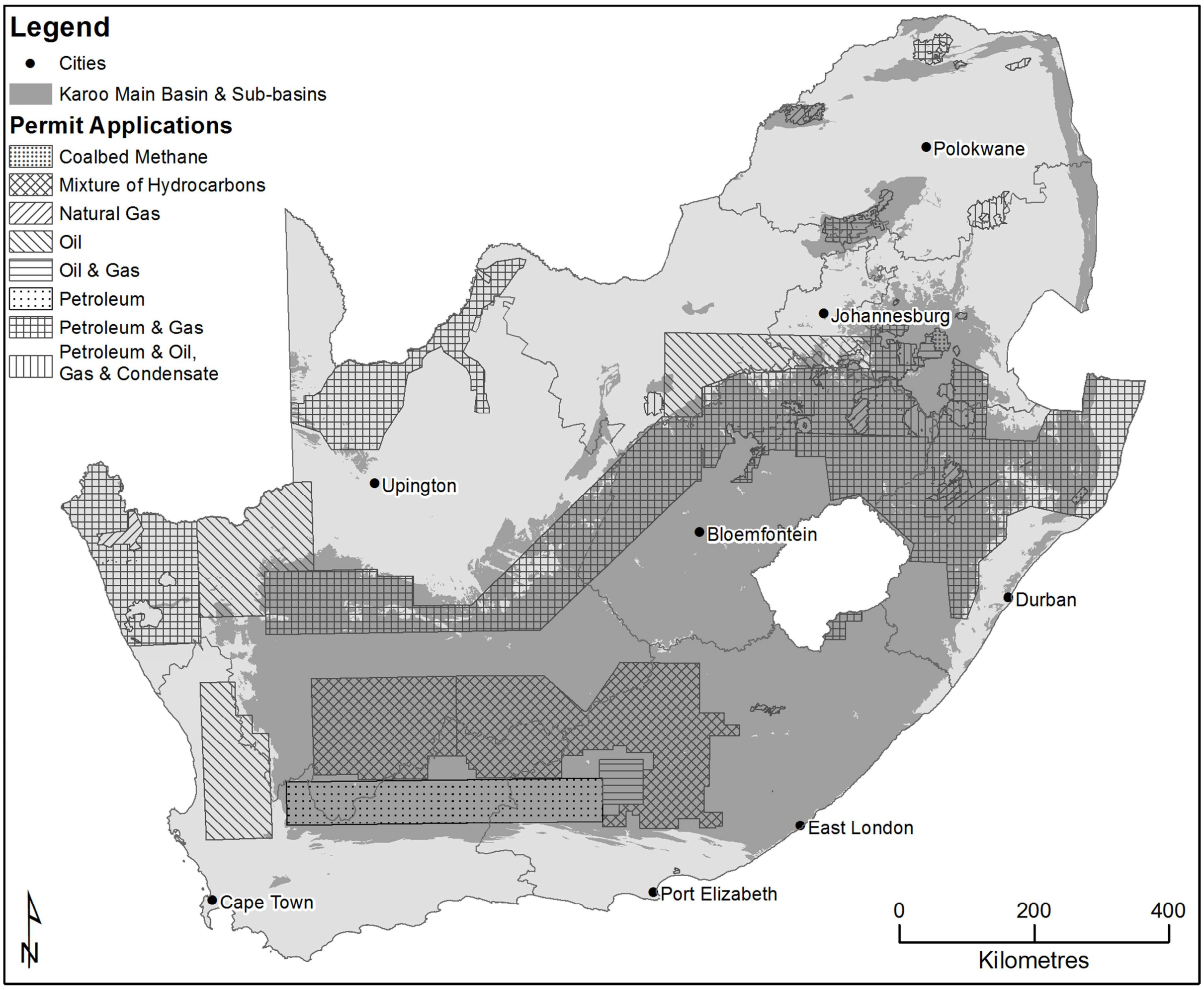

Figure 1: Permit Application Areas (Data sourced from PASA, 2014)

The following sections will discuss shale gas and oil as well as CBM occurrences in South Africa.

Shale gas and oil

Dry gas mostly occurs in the south-western parts of the Karoo basin and as one moves towards the northeaster parts of the Karoo basin, the resource type is assumed to change from dry gas to wet gas and eventually to oil (EIA, 2011) except where younger igneous dolerite intrusions have increased the thermal maturity to generate dry gas (Steyl et al., 2012). Between 2 and 4 km burial depth, oil is produced, between 4 and 5 km, wet gas is produced and between 5 and 6 km, dry gas (including methane) is produced. Deeper burial results in low-grade metamorphism, the termination of hydrocarbon generation and the formation of graphite from the organic material (Steyl et al., 2012). Occurrences of oil may be hosted in sandstones of the Ecca and Beaufort Group in a wide arc across the northern and north-eastern parts of the Great Karoo basin (Raseroka and McLachlan, 2008), while shale gas (methane) may occur in the Lower and Upper Ecca group of the main Karoo basin, as well as minor amounts in the Dwyka formation. Shales in South Africa that contain significant organic carbon are restricted to the Upper Ecca group of the Main Karoo basin, as well as other smaller basins towards the northern parts of the country (Springbok Flats, Ellisras, Tshipise and Tuli) (Steyl et al., 2012). Dry gas may occur specifically in the Whitehill formation of the Lower Ecca group, which has carbon content between 3 and 7% (Steyl et al., 2012). Subordinate volumes of gas may be expected in the Dwyka shales (Steyl et al., 2012) since the Dwyka contains black shales that average only 1.9% organic carbon (Cole and Christie, 1994; Cole and McLachlan, 1994). These thin shales are also interbedded with diamictite and sandstone (Steyl et al., 2012). The Upper Ecca group shales average only 1.2% organic carbon (Cole and McLachlan, 1994). The shales of the Bokkeveld Group have undergone low grade metamorphism and no longer have the capacity for hydrocarbon generation (Rowsell and De Swardt, 1976).

The Energy Information Administration (EIA, 2011) estimates that South Africa has approximately 485 trillion cubic feet (TCF) of gas in place, however recent estimates by the Petroleum Agency of South Africa (DMR, 2012) place these estimates at only 30 TCF. This amount is still more than enough to warrant interest in shale gas. A geological feature that is unique to South Africa is the occurrence of dolerite dykes, sills and ring structures, as well as kimberlite pipes, which occur across the Karoo geological basin. These features heighten the risk of exploration (gas blowouts can occur more frequently as gas pockets could have formed due to dolerite intrusions) and increase the risk of groundwater contamination (due to increased possibility of preferential fluid and contaminant movement along fracture zones) as well as economical risk for gas and oil exploration.

Coalbed methane

South Africa is the sixth largest coal producer in the world and the industry is the second-biggest mining sector after gold. Coal sales contribute 20% toward South Africa's mineral sales, with South Africa currently ranked as the third-largest coal exporter in the world. This means that the potential for Coalbed Methane (CBM) extraction exists and there is a budding market for energy (Rogers, 2010). Recent technical evaluations placed South Africa’s coalbed methane resource estimate at 10 TCF (Reuters, 2012).

Since CBM is still in the exploration phrase, the full extent of the resource in South Africa is still to be defined. Recently, the most advanced CBM exploration project in South Africa took place in Waterberg area, north of Limpopo, which included a five-spot pumping test in the Waterberg (Raseroka and McLachlan, 2008). In 2006 Anglo Coal completed its pilot-phase CBM project, located in the eastern portion of the Waterberg basin. It was reported that the area contains up to one trillion cubic feet of recoverable methane gas (Rogers, 2010). Other exploration companies have drilled 20 exploration wells in the main Karoo basin since the beginning of 2008, to test coal-bed methane potential (Raseroka and McLachlan, 2008).

2.3 Background information on shale oil and gas extraction

This section will give background information on shale oil and gas in terms of the exploration phase, the extraction phase and the post extraction phase. Each phase may have different impacts on different entities, thus it is important to describe the activities associated with each phase separately.

2.3.1 Exploration phase

Shale oil and gas exploration commences in various stages, of which the most notable are *exploration to locate oil and gas reservoirs* and *estimation of the economic extractability of oil and gas in place.* It is important to note that if government will allow exploration up to the phase that profitability of the shale plays are determined, then the environment and water resources could already have been seriously impacted upon. According to the Parliamentary Task Team Report, exploration will only be allowed up to the stage of determining the presence of oil and/or gas, and hydraulic fracturing to determine the economic extractability will not be allowed for the interim (DMR, 2012).

Exploration to locate oil and gas reservoirs

Geological exploration includes geophysical surveys, drilling, as well as laboratory testing. These aspects will be discussed in detail below.

Geophysical surveys

During the exploration phase various geophysical surveys are performed to form a 3D image or model of the subsurface. Surveys such as seismicity, induced polarisation and magneto-tellurics are performed to determine at what depth the target rock (for instance a shale layer) occurs, and what the thickness and orientation of the target layer is.

Geophysical surveys may pose significant environmental challenges in terms of the protection of sensitive ecosystems or habitat for flora and fauna. Seismic surveys are the most common tool used to explore for shale oil and gas. Seismic reflection surveys can be done in 3D or in 2D. Depending on the type of seismic survey, lines that have to be cleared on the land surface can range from one line at every 500 m to one line every 7 km over the area of interest. The lines can vary in width depending on the seismic survey requirements, e.g. whether a thumper truck will be used (road width cleared lines required) or whether explosive charges will be used. Initial 2D seismic surveys can be performed at a lower density. These activities can have a large impact on vegetation and fauna, and can have a large air quality impact in terms of dust generation from the cleared lines (Falcon Oil and Gas, 2011; Kargbo et al., 2010).

Different methods can be used to generate the sound waves needed for seismic surveys. One method is to drill shallow depth boreholes and using explosive charges. Another is to use vibration trucks (thumper trucks). The environmental impacts of using thumper trucks over a specific area for a 3D survey may range from dust generation, compaction of soil in the areas where thumper trucks are used, disturbance of vegetation due to line clearance, enhanced potential for soil erosion due to vegetation clearance and secondary impacts on the movement of small mammals and terrestrial insects due to fragmentation of the land surface with roads and noise pollution.

At this stage no estimate can be made of the percentage of areas that may be affected by 2D or 3D seismic and other land-based geophysical surveys, since potential target areas must first be identified by using areal geophysical surveys such as airborne magnetics, airborne magneto-tellurics etc. (Pers Comm Fourie, 2012).

Drilling

Once the various data sources have been analysed and the locations with the highest likelihood for good oil and gas resources have been identified, drilling locations are identified. Boreholes are drilled at these locations, and during drilling core as well as drilling chips are sampled and sent to laboratories for testing.

Drilling on its own can pose environmental problems in terms of drilling fluid management and spoils management. The soil spoils retrieved from these boreholes may be radioactive and the drilling fluids invariably contain diesel fluids. These impacts are however still more manageable when compared to the fluid and waste management challenges posed by hydraulic fracturing. There is a possibility that shales may produce water that flows to the surface under artesian conditions, in which case such water would have to be treated and disposed of in an environmentally friendly manner (Steyl et al., 2012).

Laboratory testing

Laboratory tests that are conducted on these samples include petrographic microscopy, scanning electron microscopy (SEM), transmission electron microscopy (TEM) and scanning transmission X-ray microscopy (Bernard et al., 2010). Pyrolysis testing (treating shale at high temperatures for extended periods of time to determine the amounts of gas/fluids that can be released from the shale) are also conducted, followed by gas chromatography and mass spectrometry, which are generally conducted on bulk oil and gas shale samples to evaluate their source and reservoir properties (Bernard et al., 2010). In addition mineralogical testing is also performed to determine the clay content, which will affect how the rock will respond to drilling and fracturing.

Testing porosity and permeability on core samples taken from the drilled boreholes, characterizes the reservoir in more detail to appraise the oil and gas in place. Fracturing tests are also performed on the extracted rock samples in order to target the most promising plays.

All these tests just give an indication on the amount of gas / liquid hydrocarbon that are in place (in the shale) but does not give an indication of how much oil and/or gas can be actively produced from these shale layers at depth.

Estimation of the economic extractability of oil and gas in place

In order to determine if shale layers at depth can actually economically produce the oil and/or gas that is in place, in situ hydraulic fracturing tests need to be performed. During this phase in situ hydraulic fracturing tests are performed on the shale layers to determine how the source rock will crack under specific conditions at depth and how much oil and/or gas the wells will be able to produce. In situ tests also make it possible to develop the most appropriate techniques for the specific area in the shale, because every drilling area has its own specific features. Well production tests take place over several weeks, to study the technical behaviour of the wells and their profitability. After performing hydraulic fracturing over a sufficient size of the reservoir and monitoring the well productivity for weeks, an economic feasibility study is written that incorporates the results of production and technical tests. If the results are encouraging, the extraction phase commences (Binnion, 2012; Broomfield, 2012). It is important to note that shale oil and gas requires scalability and repeatability. A lot of money is usually spent on up-front studies to determine rock properties and significant time and money is also spent on determining how to best frack a tight rock formation. In order to make all these activities economically viable, the principle of economies of scale must be applied. This requires an oil and gas extraction operation of large enough scale to recover the high up-front costs spent on initial test wells (Binnion, 2012), which means that oil and gas companies will aim to develop as much of the shale layers that are available and accessible in the Karoo geological basins.

2.3.2 Extraction phase

During the shale oil and gas extraction phase boreholes are established at a density that would optimise oil and gas extraction from the target shale layer. The new technology of drilling multiple horizontal or inclined wells on one well pad has significantly reduced the surface area footprint of shale oil and gas extraction areas. However, well pads can still be at a density of one well pad for each 1–5 km^2.

When planning a shale oil and gas development with several tens to hundreds of wells, a modular facilities approach is recommended by the industry, meaning that a few "building blocks" can be designed and used repeatedly. This well-used USA philosophy demonstrates several benefits, including:

- avoiding continuous rework to design new, customised installations for new extraction activities;
- simplifying procurement of goods and services, enabling significant cost savings; and
- speeding up the permitting process, since stakeholders become familiar with the facilities.

Modularisation can be applied at both plant and field level. At the field level, the "building blocks" are essentially the well cluster facilities (or well pads), the connecting pipelines and the treatment plants. Starting from the experience gained in collaboration with Quicksilver in the Barnett shale, typical field level modularisations are being studied, such as the example shown on the left in Figure 2, which is typically referred to as a "complex" (Guarnone et al., 2012).

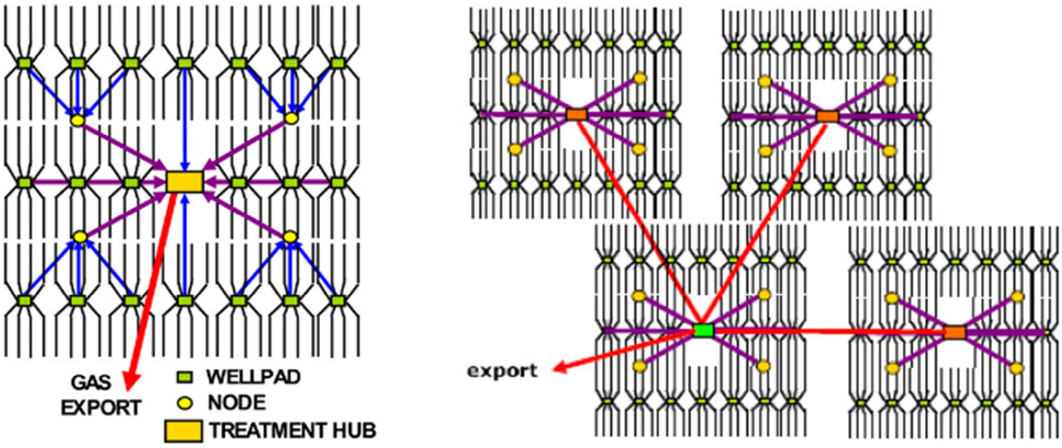

Figure 2: Possible scheme of repeatable "Complex" on the left and "Multi-complex" on the right (Guarnone et al., 2012)

If one takes into account the access roads to these well pads, the surface disturbance may be significant for entities such as vegetation, soil, air quality (in terms of dust generation), and fauna.

A well pad must accommodate the wellheads as well as the gas-liquids separators, one for each well, and the produced water tanks (Guarnone et al., 2012). In the case of presence of condensates in the gas stream, these are separated from the gas and the water streams in the separators and stored in dedicated tanks. One well pad can range in size from 2 to 3 ha (20,000 – 30,000 m^2) (Jacobson, 2012; Broomfield, 2012). The well pad size may be a function of the depth of the targeted resource, as well as the number of multiple wells to be installed, with associated materials requirements. Additional land is also required for pipelines, access roads and associated infrastructure such as compressors (Broomfield, 2012). Produced water is then loaded on trucks and moved to central treatment facilities for re-injection or re-use. All the utilities required by the well pad facilities must be present in the well pad design if not already available in the vicinity (Guarnone et al., 2012).

A typical well pad layout is characterised by a large unused space, with the wellheads in the middle and the production facilities located on a side. This is because the space required by the drilling rig and by the fracturing operations is much larger than that required for the equipment and these operations are leading the execution schedule, and therefore are usually carried out with the production facilities already installed. In addition, free space must be foreseen around the wellheads for possible wells workover operations (Guarnone et al., 2012).

In addition to the above process and utility facilities, a well pad could be provided with lift gas facilities. As water production could be very high, especially in the first months of oil and gas extraction, lift gas is required to increase the oil and gas production or, in some cases, to restart it after a well has been stopped and then flooded with liquids (Guarnone et al., 2012).

Similarly, produced water, after a minimal treatment for solids and sand removal, can be pumped to a central water treatment hub by means of pipelines, in order to minimise truck operations, which are far more expensive and less environmentally friendly than using water pipelines (Guarnone et al., 2012).

Sand management is another important matter: Sand is used as proppant for hydraulic fracturing, but some of it inevitably returns back during oil and gas extraction. Gas separators should be equipped upstream with sand-removal devices and internally with sand cleaning tools, in order to prevent and avoid possible obstructions due to deposits of sand (Guarnone et al., 2012). Sand mining for well construction, surface facilities construction or hydraulic fracturing and clay mining for the production of ceramic beads may pose various environmental problems (Haines, 2012), also in South Africa.

Water management issues are associated with every stage of shale oil and gas development and can impact operator costs, environmental sustainability and public acceptance. Covering the whole water cycle, the first crucial step is water supply (typically fresh water) from public or private sources, which may be subject to restriction in certain areas. With current technologies, each well pad can host up to 35 wells. Since each well requires between 10 and 20 Megalitres of water for the fracking procedure (Broderick et al., 2011; De Wit, 2011; Galusky, 2007; USEPA, 2011a), the water requirements can be quite significant.

Water to be used for fracking is typically stored in above ground ponds with a capacity that varies from 100 000 to 1 000 000 bbls (159 000 to 1 590 000 m^3) or more. Water usage in shale oil and gas industry is represented by drilling and fracturing activities (respectively 10% and 90% of total demand). During a fracking job, about 10 000 bbls (1590 m^3) per stage are required, so a typical well of 6000 ft (1,829m) of horizontal length with 15 stages implies a water volume close to 150 000 bbls (23 850 m^3). Considering that a fracking crew is able to perform 3 stages per day, the water demand is close to 30 000 bbls (5800 m^3) per day, obtained by quickly draining the above mentioned water pond(s). This is the reason why, in many cases, a network to link different ponds is set up in order to create a significant water buffer; this ensures that the required amount of water supply does not exceed the maximum water wells withdrawal capacity (Guarnone et al., 2012).

In the last phase of the water cycle, once a well pad has been drilled and completed, wells are put in production by means of dedicated temporary facilities with robust water and sand separation systems: this operation, often conducted by service companies, is called “flowback phase” and usually lasts approximately 2 - 4 weeks after start-up for a typical well pad. During this period permanent production equipment is installed and put into service as a second separation stage, allowing commercial export of oil and gas. The water rate from each well, during flowback phase, is considerable, since it can be as high as 3 000 bbls (480 m^3) per day in case of a 6 000 ft (1 829m) horizontal drain, but it drops dramatically and after a few weeks reaches values in the order of 1000 - 1500 bbls (160 – 240m^3) per day that can be handled by the sole permanent production equipment. From that moment, water is stored in water tanks and exported from well pads either by trucks or by export pipelines (Guarnone et al., 2012).

Between 0% and 75% of the fracturing fluids that are pumped down a well come back up the well as "flowback" water during the fracturing operation itself (USEPA, 2011a; Broomfield, 2012). This water can be high in various chemicals that pose human health and environmental risks (USEPA, 2011a; USHR; 2011; Volz et al., 2011). These chemicals are mixed with base fluids to modify fluid mechanics in order to increase performance of the fracturing fluid and must also act as biocides to inhibit the action of sulphate reducing bacteria and act as corrosion inhibitors (Struchtemeyer et al., 2012, USEPA, 2011a). In addition to this flowback water, "produced" water is also generated over the lifetime of the shale oil and gas well and can contain very high salt loads, naturally occurring radioactive material (NORM) and various heavy metals (Clark and Veil, 2009; USEPA, 2011a).

Produced water originate from the geological formations and may be produced for the lifetime of the well. Produced water can contain NORMs, high salt loads and elevated concentrations of trace elements (Broomfield, 2012). Wastewater (which can be a combination of the flowback and the produced water) disposal poses serious challenges in countries such as the USA and Canada where unconventional oil and gas extraction by means of hydraulic fracturing is being performed (Volz et al., 2011). Wastewater management currently includes various strategies such as underground injection, treatment and discharge, and recycling (GWPC and ALL Consulting, 2009). According to the API (2000), 92% of the 18 bbls of produced water generated in 1995 was managed through injection. Three per cent of the 18 billion bbls of produced water was discharged under National Pollutant Discharge Elimination System (NPDES) permits, where nearly all of this water was generated from coalbed methane operations and 2 % was managed through beneficial reuse. The remaining 3% was disposed of through other methods including evaporation, percolation pits, and publicly owned treatment works (API, 2000).

A study executed by Argonne in 2009 obtained produced water management information for nearly 17.1 billion bbls (81%) of the 20.9 billion bbls of produced water generated in 2007 in the USA. In the USA, 95.2% of the reported produced water volumes were managed through injection in 2007. More than half of the produced water (55.4%, or 8.6 billion bbls) was injected for enhanced recovery in 2007. More than one third (38.9%, or 6.0 billion bbls) of produced water was injected for disposal and surface discharges totalled 4.4% (700 000 000 bbls) of the total reported volume of produced water managed in 2007 (Clark and Veil, 2009).

Large scale wastewater treatment invariably poses challenges such as brine management (Clark and Veil, 2009; USEPA, 2011a). In addition, underground injection of wastewater may lead to seismicity and resultant loss of lives and infrastructure damage, as has been reported for Ohio, Arkansas, Okolahoma and Texas in the USA (NRC, 2012a). It is important to note that in South Africa produced water may also be generated during the exploration phase when it may be naturally generated by the shale layers as well as coalbed methane layers (USEPA, 2011c) and may move towards the surface due to pressure in the areas of the Karoo geological basin that is under artesian conditions. This means that wastewater management issues may not be limited only to the extraction phase.

Shale oil and gas extraction operations require a lot of experimentation to determine the optimal oil and gas extraction strategy, and drilling results from various shale basins are highly variable in terms of oil and gas production from the wells (Binnion, 2012). This means that many drilled wells are required to understand oil and gas production possibilities from a shale play and determine accurate reserve estimates. Large areas of accessible land are required to do this and existing land use patterns may compete with planned shale oil and gas and coalbed methane development (Blohm et al., 2012). The key elements of shale oil and gas extraction include the extensive drilling campaign, the need for hydraulic fracturing (with its implication on the whole water supply/handling cycle) and the realisation of a continuously growing network of geographically scattered production facilities and flowlines, which accompany oil and gas from wellheads to the final customers (Guarnone et al., 2012).

It is important to note that in the South African context, we do not currently possess the required infrastructure to move water volumes required for hydraulic fracturing to the oil and gas well sites, nor do we possess infrastructure to move gas or oil to refinery facilities and to the end user or to move waste (water) to disposal facilities (Twine, 2012). This may pose a significant developmental, socio-economic and environmental risk.

Taking all of this into consideration, it is clear that shale oil and gas development in South Africa will have large scale cumulative and regional scale impacts on the biophysical and socio-economic environments in South Africa.

2.3.3 Post extraction phase

When an oil/gas well or several oil/gas wells are no longer economical to operate, it is taken out of service temporarily or permanently. Well decommissioning usually takes place in accordance with established procedures in the oil and gas industry. Well decommissioning g procedures include the installation of a surface plug to stop surface water seepage into the wellbore. A cement plug is installed at the base of the lowest underground source of drinking water to isolate water resources from potential contamination by hydrocarbons or other substances migrating via the wellbore. A cement plug is also installed at the top of the shale oil and gas formation. After abandonment of certain areas of a gas field that has been mined out, oil and gas companies would typically migrate to the next part of the shale formation where oil and gas has not yet been extracted (Broomfield, 2012). There is a possibility that methane seepage may occur if long term liners break down and this necessitates the long term monitoring of abandoned wells (Broomfield, 2012).

Several environmental impacts and social ills may persist during the post-extraction phase. If oil and gas extraction activities environmentally degrade certain tracts of land, these areas may rehabilitate very slowly or not at all, and result in disrupted ecosystems. Entities that may be particularly influenced by long term contamination after oil and gas extraction include groundwater, soil and vegetation. Groundwater is notoriously difficult to rehabilitate after it has been contaminated and in South Africa this aspect is enhanced due to the fact that our groundwater systems contain a dense network of dolerite dykes, kimberlite pipes and fracture zones. All these aspects make the movement of contaminants underground unpredictable and very difficult to clean up. Most of the underground organic contaminants also stay underground and cannot be removed since the contaminants may adhere to clay particles and other polar surfaces. These contaminants then pose a long term source of contamination. On the social side the workers who worked as truck drivers or other non-skilled labour in a specific area would be out of work after the drilling rigs have moved on to a new area of the shale formation, or if they wanted to keep their jobs, would have to migrate with the operations. Environmental degradation and air pollution in certain areas may also cause long term human health impacts.

2.4 Background information on coalbed methane extraction

Coalification, the geological process that progressively converts plant material to coal, generates large quantities of natural oil and/or gas, which are subsequently stored in the coal seams. The increased pressures from water in the coal seams force the natural gas to adsorb to the coal. Gases in a CBM reservoir can be grouped into productive gases (CH_4,C_2,C_3, etc.) and inert gases (CO_2,N_2,H_2S) (Moore, 2012). The natural gas contained in and removed from the coal seams is commonly called coalbed methane or CBM (USDOE, 2006).

The amount of available methane in coal varies with coal's hardness (the resistance to scratching). Level of hardness is known as "rank." The softest coals (peats and lignites) are associated with high porosity, high water content, and biogenic methane. In higher-rank coals (bituminous), porosity, water, and biogenic methane production decreases, but the heat associated with the higher-rank coals breaks down the more complex organics to produce methane. The highest-rank anthracite coals are associated with low porosity, low water content, and little methane generation. The most sought-after coal formations for CBM development tend to be mid-rank bituminous coals (USEPA, 2010).

Scientific understanding and extraction experience with coalbed methane is still in its development phase (USGS, 2000). Coalbed methane occurs at much shallower levels than shale gas and oil, and may co-occur with freshwater aquifers. Coalbed methane must contend with similar challenges as shale, since hydraulic fracturing is also used in these formations and produced water is also a challenge that must be managed when exploiting these deposits.

2.4.1 Exploration phase

Seismic surveys may be an important and useful tool for exploration of CBM, as is the case with the exploration for shale oil and gas reservoirs. Seismic surveys in the area of interest would typically be a 3D seismic reflection survey (Richardson et al., 2003) and the possible associated land-based impacts will be similar as in the case for shale oil and gas extraction.

2.4.2 Extraction phase

Both horizontal and vertical wells are used to mine coalbed methane. Horizontal wells will usually be used for thinner coal seams of greater depth. Although a depth of 800 to 1,200 m is typical, in some cases coalbed methane is located in shallow formations as little as 100 m below the surface, making it more economical to drill a series of vertical wells, rather than a horizontal well with extended reach along the coal seam (IEA, 2012). For shallow deposits, wells can often be drilled using water-well drilling equipment, rather than rigs designed for conventional hydrocarbon extraction, with much cheaper associated costs (IEA, 2012).

Extraction of CBM requires drilling and extracting the water from the coal seam (water may be extracted under natural pressure or may be pumped out), which reduces the subsurface pressure and allows the release of CBM from the coal (IEA, 2012; USDOE, 2006; Wheaton et al., 2006). CBM extraction often produces large amounts of water. Methane and water are piped from individual wells to a metering facility, where the amount of gas production is recorded. The gas is separated from the water at the surface and is then compressed at a compressor station and injected into a gas-gathering pipeline for onward transportation (De Bruin et al., 2001; IEA, 2012). The produced water is a by-product of the gas extraction process, requiring some form of management (i.e., re-use or disposal). The volumes of fluid used for coal-bed methane fracturing are typically 200 m^3 – 1 500 m^3 per well (Broomfield, 2012).

Well construction for CBM well drilling operations usually follows one of two basic types: open hole or cased. In open-hole completions, the well is drilled but no lining material is installed, so any gas can seep out all along the well length into the wellbore for extraction to the surface. In cased well completions, a lining is installed throughout all or most of the wellbore. These casings need to be perforated or slotted to allow gas to enter the wellbore for removal of gas to the surface. Open-hole completions, which are less expensive than perforated or slotted completions, may be used more often in CBM extraction than in conventional oil and gas extraction, which use open-hole completion only under certain limited circumstances (NaturalGas.org, 2004). In countries such as Australia and the UK, well construction for CBM wells are submitted to stringent standards and specifications (Williams et al., 2012).

As in the case of shale oil and gas, the rate of gas production of coalbed methane is often significantly lower than that achieved in conventional oil and gas reservoirs and it also tends to reach a peak quickly as water is extracted, before entering a period of decline as the well pressure drops further (IEA, 2012). A CBM well's typical lifespan is between 5 and 15 years, with maximum methane production often achieved after one to six months of water removal (Horsley and Witten Inc., 2001). Usually the low natural permeability of the coal seam means that gas can flow into the well from only a small segment of the coal seam – a characteristic shared with shale and tight oil and gas. A relatively large number of wells are consequently required over the area of the coalbed, especially if wells are drilled vertically (IEA, 2012).

CBM wells go through the following development stages:

- An early stage, in which large volumes of groundwater are pumped from the seam to reduce the underground pressure and encourage the natural gas to release from the coal seam (this stage includes on the spot pilot testing to gather detailed information of gas-bearing coal seams) (Williams et al., 2012);
- A stable stage, in which the amount of natural gas produced from the well increases as the amount of groundwater pumped from the coal seam decreases; and
- A late stage, in which the amount of oil, gas and water produced, declines (De Bruin et al., 2001).

Produced water characteristics

The USEPA (2010) evaluated the quality and quantity of produced water generated from CBM extraction using preliminary data from responses to detailed survey questionnaires and other sources. Water within the coal seam usually must be removed before and during CBM extraction. The quantity and quality of this produced water varies from basin to basin, and even within the basin itself. The quality of produced water depends, in part, on the hardness of the coal found within the formation. The quantity of produced water depends on type of coal and the overall gas production history of the basin.

The USEPA (2010) estimated that, in 2008, more than 47 billion gallons of produced water were pumped out of coal seams and approximately 22 billion gallons of that produced water (or about 45 per cent) were discharged to surface waters.

CBM produced water is generally characterised by elevated levels of salinity, sodicity, and trace elements (e.g., barium and iron) (ALL, 2003). Trace pollutants that may be present in produced water include potassium, sulphate, bicarbonate, fluoride, ammonia, arsenic, and radionuclides. The characteristics of the produced water depend on the geography and location (e.g. naturally occurring elements in the formations). All of these parameters can cause adverse environmental impacts and also affect the potential for beneficial use of produced water (USEPA, 2010).

The USEPA (2010) estimates that average TDS concentrations vary widely, from approximately 1,100 mg/L TDS to 86,000 mg/L. The USEPA (2010) estimates that approximately 500 million pounds of TDS from CBM extraction operations were discharged to surface waters in the USA in 2008. These waters may also be highly alkaline (Williams et al., 2012)

Produced water management

Produced water management would be an important regulatory aspect, should South Africa proceed with CBM extraction. In the USA, CBM produced water from individual wells is often gathered via a pipeline system to transport the water to a centralised storage system and then to either a treatment system or the final disposal location. Determining the amounts of water to be extracted from CBM operations is often hard to calculate, and may vary significantly. CBM wells in the Sydney basin, Australia, produces relatively small volumes of water while CBM wells in the Surat basin in Australia routinely produce up to 20 000 L/day (Williams et al., 2012).

The final destination of CBM produced water may include the following:

- Discharge – either direct discharge to surface water or indirect discharge to a treatment plant;
- Zero discharge (with no beneficial use) – zero discharge might include evaporation/infiltration, underground injection, or land application with no crop production; and

- Zero discharge (with beneficial use) – beneficial use might include land application, wildlife watering, or other miscellaneous beneficial uses, often after water has been treated.

Treatment often involves desalination and strong brines and contaminated residual material may result from treatment, which also poses disposal problems. The amounts of salt to be managed can be very large. As an example, a well discharging 20 000 L/day of saline water with a 5 000 mg salt/L will yield approximately 100 kg of salt a day (Williams et al., 2012).

Scale of operations

CBM wells are rarely operated as single units responsible for their own production costs, because operators realise economies of scale in operating several wells together as an economic unit. Given that CBM extraction requires numerous wells distributed over the coalbed, operators tend to include a large number of wells in each economic production unit, or project. According to USEPA's screener survey, a total of about 56,000 CBM wells, organised into approximately 750 projects, produced gas and/or water in 2008 (USEPA, 2010). The large scale of operations may have an impact on land surface in terms of habitat fragmentation.

Summary of environmental impacts

Some of the documented surface water impacts focus on changes to fish species and amphibian population diversity due to CBM produced water discharges (Confluence consulting, 2004a and 2004b; Davis et al., 2006; Davis, 2008) The remaining documented impacts focus on problems with the salinity of CBM produced water and its impact on aquatic vegetation and macro-invertebrate communities (USEPA, 2010).

Non-surface water environmental concerns discussed in the literature are divided into three broad categories in this report: (1) environmental impacts caused by the land application (e.g., irrigation or dust control) of CBM produced water, (2) environmental impacts that resulted from impounded CBM produced water (e.g., impoundment control technologies, livestock watering impoundments, and constructed wetlands) and (3) subsidence at land surface.

Land applications

The land application of CBM produced water for activities such as irrigation and dust control can cause pollutants in CBM produced water to infiltrate into local groundwater systems. Pollutants that can infiltrate into groundwater include heavy metals, salts, ions, and organic material often present in CBM produced water (ALL, 2006; Fisher, 2001), which can contaminate drinking water supplies (Veil et al., 2004).

Elevated SAR and salinity in CBM produced water applied to land can alter the soil structure of fine-textured soils by causing swelling and dispersion, which decreases pore size and reduces water infiltration rates (ALL, 2002; ALL, 2003; USGS, 2006). Reduced soil porosity increases runoff of rain and irrigation waters, which can decrease the ability of soils to support plant life (Arthur, 2001; USGS, 2006) and can lead to accelerated erosion. CBM produced waters with elevated salinity can also decrease air and water permeability in soil. Fine, clayey soils are particularly prone to impacts from the saline and high SAR content of CBM produced water discharges (ALL, 2002; USGS, 2006).

In nonsensitive soils, the increased salinity of CBM discharges can be toxic to plants and decrease crop yield (Regele and Stark, 2000; Veil et al., 2004). If soil water is too saline, plants must exert more energy to extract waters from soils, decreasing productivity (ALL, 2003), which can cause plant communities to shift to more salt-tolerant species, decreasing diversity and altering the ecosystem (Arthur et al., 2001). In one paper, Stanford and Hauer (2003) observed areas in Montana where land irrigated with CBM produced water contained very little or no vegetation. In areas with abundant rainfall, salts from CBM produced water can leach from the soil; however, in more arid regions (e.g., Montana), salts can accumulate with each application of CBM water (Veil et al., 2004) and render the soil unfit to support vegetation.

Ramirez (2005) reported that infiltration of CBM produced water in land application scenarios can rapidly contaminate groundwater by leaching salts and trace elements from the ground in addition to the water's original elevated salt and trace element concentrations.

Impoundment control

Surface impoundment impacts include groundwater impacts due to infiltration, the concentration or bioaccumulation of pollutants (e.g., salts, heavy metals) due to evaporation, and the potential creation of new aquatic habitats resulting in the introduction or proliferation of species in the area (e.g., West Nile Virus vector mosquitoes). In addition to the initial contamination, evaporation from impoundments can further concentrate pollutants in CBM produced water, decreasing the quality of water released to the environment through infiltration or discharge (ALL, 2002). If connected to surface water bodies, impoundment discharges can also degrade water quality in receiving waters (ALL, 2003; Roulson, 2007).

Subsidence at land surface

Subsidence in relation to CBM extraction could be expected when groundwater aquifers are dewatered, and is generally observed worldwide in cases of groundwater overexploitation. Land subsidence over large areas can affect surface water systems, ecosystems and land-uses in the areas of subsidence (NWC, 2011). Subsidence has been observed in Australia in the Surat basin, where underground water pressure heads have been reduced by as much as 100 m in some areas, resulting in subsidence of a few meters being observed in these locations at surface (Williams et al., 2012).

2.4.3 Post extraction phase

Depending on the wastewater management method selected, some environmental impacts may persist after mine closure. In Australia the disposal of brines, residual solids and slurries from water treatment processes is still an active area of work that has not yet been resolved (Williams et al., 2012).

Evaporation ponds were commonly used in the pioneering days of CBM extraction in Australia, but are no longer permitted in most parts of Australia. Existing evaporation and brine ponds represent a legacy that need to be addressed. Options that have been considered in Australia are the disposal of brine at sea, or transporting it to a waste facility (landfill). These operations would require a large fleet of tankers operating 24 hours a day and was ruled out on environmental and economic grounds. Some Australian companies consider precipitation with resulting salts being sold for industrial purposes, and injection of brines into suitable geological formations. In order to try and manage these regional impacts of brine, the Queensland government has requested operating CBM companies to come up with a salt plan by 2013 (Williams et al., 2012). The Queensland Department of Environment and Heritage Protection developed a Coal Seam Gas Water Management Policy (DEHP, 2012) which states the following priority management options for salt and brine associated with CBM wastewater:

- Priority 1 - Brine or salt residues are to be treated to create useable products wherever feasible.
- Priority 2 - After assessing the feasibility of treating the brine or solid salt residues to create useable and saleable products, disposing of the brine and salt residues in accordance with strict standards that protect the environment.

This policy states that disposal of brine and salt must only be considered after a feasibility assessment has determined that that there are no reasonable options to minimise the volume of waste for disposal. According to the policy there are a range of options for the disposal of salt, including injecting the brine underground or disposing it to a regulated waste facility. These plans are however not aduate to address salt and brine problems associated with CBM extraction (Williams pers comm, 2014). South Africa would do well to heed this lesson and have an economically viable and environmentally acceptable wastewater management strategy in place before allowing large regional scale gas extraction operations, of either CBM or shale oil and gas.

2.5 Background information on hydraulic fracturing

Hydraulic fracturing involves drilling wells to the depth of the source rock (for instance a shale layer) where temperatures can be on average 140° Celcius (Halliburton, 2008). Different sections of the well in the extraction zone are isolated and a mixture of water, fluids (slickwater) and proppant (sand or ceramic beads that keep open the fractures) are pumped down the wellbore through the perforations in the wellbore and into the source rock (Kargbo et al., 2010). The hydraulic pressure used to deliver the fluid into the target formation may range from 10 000-15 000 psi or 69-103 MPa (Broomfield, 2012; Carolyn and Debrick, 2012; Halliburton, 2008) which produces fissures in the reservoir and can crack shale up to 1 000 m or more in all directions from the wellbore. This liberates trapped oil and gas, which can flow into the wellbore and up to the surface. Altough hydraulic fracturing has typically been used in the shale gas industry, this technique has now migrated to the shale oil and tight oil industry as well (Ratner and Tiemann, 2014).

The fluids that are used to perform hydraulic fracturing, including the volumes of water required to perform hydraulic fracturing; are controversial. The amount of water needed in the hydraulic fracturing process depends on the type of formation (coalbed, shale, or tight sands) and the fracturing operations e.g., well depth and length, fracturing fluid properties, and fracture job design (USEPA, 2011a). Volumes of water used for shale gas can range from 10 – 20 megalitres per single gas well (Broderick et al., 2011; De Wit, 2011, Galusky, 2007; USEPA, 2011a). Water use is driven by the type of development where unconventional oil extraction is less water intensive than unconventional gas extraction; and also by the direction of drilling where horizontal drilling is much more water intensive than vertical drilling (Freyman, 2014). Other factors include the local geology and type of fluid system used for hydraulic fracturing (whether it is water, acid or gas) (Freyman, 2014). Water requirements for CBM hydraulic fracturing is typically less due to the shallower depth from which CBM is mined versus shale oil and gas (IEA, 2012; USEPA, 2011a). The fracture fluids usually consist of 98-99% water and proppant (usually sand or ceramic beads) and 1-2% chemical additives (Broomfield and Donovan, 2012). The proppant usually forms 15% of the fracking fluid and approximately 12% of the water can be recycled (Broomfield, 2012). Between 0 and 75% of the fracturing fluids that are pumped down a well comes back up the well as flowback water (USEPA, 2011a). This water is usually high in various chemicals that pose serious human health and environmental risks (USEPA, 2011a; USHR; 2011; Volz et al., 2011). These chemicals are mixed with base fluids to modify fluid mechanics in order to increase performance of the fracturing fluid and must also act as biocides to inhibit the action of sulphate reducing bacteria and act as corrosion inhibitors (Struchtemeyer et al., 2012, USEPA, 2011a). In addition to flowback water, produced water is produced for the lifetime of the shale oil or gas well and can contain very high salt loads, naturally occurring radioactive material (NORM) and various heavy metals.

The characterisation of wastewater is crucial to define for the proper treatment/handling of the water, but such characterisation is difficult due to several reasons. Firstly, a big statistical variance is associated to water quality when looking at different wells even in close proximity, reflecting complex interactions between fracturing fluids and shale rocks. Secondly, oil and gas companies have only recently increased the transparency on fracturing water chemical additives and intellectual properties on their fracturing fluids. Full disclosure on the exact composition of the various substances blended in the fracturing fluids is still not obtained (Guarnone et al., 2012; Sakmar, 2011).

Wastewater disposal poses serious challenges in countries such as the USA, Australia and Canada where unconventional oil and gas extraction by means of hydraulic fracturing is being performed (Volz et al., 2011; Williams et al., 2012). Shale oil and gas extraction wastewater consists of flowback water as well as produced water. Flowback water consists of water that was used during hydraulic fracturing (the slickwater) that returns to the surface. Volumes of flowback water recovered may range between 0 and 75% of volumes pumped into the formations (Broomfield, 2012). Wells experience a flowback period of several weeks in the case of shale formations, and in the case of CBM flowback may last for significantly longer (USEPA, 2011a). The initial flow rate at which the flowback exits the well can be relatively high (more than 100 000 gallons per day) for the first few days, in the case of shale oil and gas wells. This flow diminishes rapidly with time, ultimately dropping to the normal rate of produced water flow rate from a natural oil or gas well (e.g., 50 gallons per day) (Chesapeake Energy, 2010; Hayes, 2009b).

Produced water is the water produced naturally by the formation and is usually produced for the lifetime of a well. The volume of produced water from oil and gas wells does not remain constant over time. The water-to-oil ratio increases over the life of a conventional oil or gas well. For most unconventional wells, water makes up a small percentage of produced fluids when the well is new. The percentage of water production from wells increases over time while the percentage of product declines. For crude oil wells nearing the end of their productive lives, water can comprise as much as 98% of the material brought to the surface (USDOE, 2004). CBM wells, in contrast, produce a large volume of water early in their lives, and the water volume declines over time (USDOE, 2004). The physical and chemical properties of the produced water vary considerably depending on the geographic location of the field, the geologic formation from where the water was produced, and the type of hydrocarbon product being produced (Clark and Veil, 2009).

Contaminants associated with waste water (which includes flowback water and produced water) can include:

Oil and grease

A study of produced water in the western USA found the oil and grease content to range from 40 mg/L to 2 000 mg/L (Benko and Drewes, 2008). Oil is an important discharge contaminant for shale oil and gas operations, because it can create potentially toxic effects near the discharge point (USDOE, 2004). Dispersed oil consists of small droplets suspended in the aqueous phase. Precipitated droplets are often 4-6 microns in size, and current treatment systems typically cannot remove droplets smaller than 10 microns, the small droplets can interfere with water processing operations (Bansal and Caudle, 1999). Oil and grease is not as much of a concern for CBM produced water as it is for water produced from shale oil and gas exploitation (Clark and Veil, 2009).

Dissolved or soluble organic compounds

Hydrocarbons that occur naturally in produced water include organic acids, polycyclic aromatic hydrocarbons (PAHs), phenols, and volatiles. These hydrocarbons are likely contributors to produced water toxicity, and their toxicities are additive, so that although individually the toxicities may be insignificant, when combined, aquatic toxicity can occur (Glickman 1998).

Treatment chemicals

Treatment chemicals are used during hydraulic fracturing and may include biocides, emulsion breakers and corrosion inhibitors. Some of these chemicals may be lethal at concentrations as low as 0.1 parts per million (Glickman, 1998). Treatment chemicals are usually associated with the flowback water component of the unconventional oil and gas waste water. The USHR (2011) identified the following chemicals and compounds, amongst others, that were most often used as frack water additives by oil and gas companies during 2005-2009 in the USA:

- Methanol
- Isopropanol
- Ethylene glycol monobutyl ether (2-butoxyethanol)
- Ethylene glycol (1,2-ethanediol)
- Hydro-treated light petroleum distillates
- Sodium hydroxide
- 2-butoxyethanol (2-BE)
- Acetic acid
- Guar gum
- Heavy aromatic petroleum naphtha
- Hexamethylenetetramine
- Naphthalene
- Benzene, Toluene, Ethylene, Xylene (BTEX)
- Hydrogen chloride (hydrochloric acid)

Produced solids

Produced solids may include sand, silt, carbonates, clay and proppant. Quantities of solids can range from insignificant to a solids slurry, which can effectively shut down wells or wastewater treatment operations (USDOE, 2004).

Scales

Scales can form when ions in supersaturated produced water react to form precipitates when pressures and temperatures are decreased during extraction. Common scales include calcium carbonate, calcium sulphate, barium sulphate, strontium sulphate, and iron sulphate. They can clog flow lines, form oily sludges that must be removed, and form emulsions that are difficult to break (USDOE, 2004).

Bacteria

Bacteria can clog equipment and pipelines. They can also form difficult-to-break emulsions and hydrogen sulphide, which can be corrosive (USDOE, 2004).

Metals

The concentration of metals in produced water depends on the oil or gas field, particularly with respect to the age and geology of the formation from which the oil and gas are produced (Utvik 2003). Metals typically found in produced waters from shale oil and gas operations include zinc, lead, manganese, iron, boron and barium, bromide, calcium, chloride, iron, magnesium, sodium, strontium and bicarbonate (USDOE, 2004, USEPA, 2011a), as well as arsenic and mercury (USEPA, 2011a). Concentrations of calcium and strontium may be as high as thousands of milligrams per liter (Vidic, 2010). Iron, manganese and boron are typical metals of concern for CBM produced water (Clark and Veil, 2009).

pH

Reduced pH can disturb the oil/water separation process and can impact receiving waters when discharged. Many chemicals used in scale removal are acidic and will lower the pH of water flowback water (USEPA, 2011a). The pH associated with shale formations may range from 5-8 (USEPA, 2011a), while CBM formations may have a very high pH (Williams et al., 2012).

Sulphates

Sulphate concentration controls the solubility of several other elements in solution, particularly barium and calcium (Utvik, 2003). Sulphates are usually a component of chemicals in the frack fluid (USEPA, 2011a) but may also occur naturally in the geological formations, and may consequently occur in large quantities in the flowback water (Boyer et al., 2011).

Naturally occurring radioactive materials (NORM)
NORM originates in geological formations and can be brought to the surface with produced water. The most abundant NORM compounds in produced water are radium 226 and radium 228, which are derived from the radioactive decay of uranium and thorium associated with certain rocks and clays in the hydrocarbon reservoir (Utvik, 2003), however, thorium and uranium may also be present in formation water (USEPA, 2011a). As the water approaches the surface, temperature changes cause radioactive elements to precipitate. The resulting scales and sludges may accumulate in water separation systems (USDOE, 2004).

Salinity
Salt content of produced water is a serious constituent of concern for onshore operations. According to Cline (1998), most produced waters are more saline than seawater. Benko and Drewes (2008) found the TDS concentration of produced water in the western USA to vary between 1 000 mg/L and 400 000 mg/L. In general, analyses of flowback from various reports show that concentrations of TDS can range from 5 000 mg/L (Horn, 2009) to more than 100 000 mg/L (Hayes, 2009a), and may even reach 200 000 mg/L (Gaudlip and Paugh, 2008; Keister, 2009; Vidic, 2010). These high values can be reached in a matter of two weeks (USEPA, 2011a) since the start of drilling operations.

Gases
Natural gas (e.g., methane, ethane), carbon dioxide, hydrogen sulphide, nitrogen and helium may occur naturally in geological formations and may be present in produced water from shale or CBM formations (USEPA, 2011a, Zoback et al., 2010). Although most of these gases may not be toxic, they still represent an explosion risk in cases where they may accumulate near built-up structures (DEP, 2009).

Wastewater management for shale oil and gas wastewaters in the USA currently includes various strategies such as underground injection, treatment and discharge and recycling (GWPC and ALL Consulting, 2009). Large scale wastewater treatment invariably poses challenges such as brine management (USEPA, 2011a; Williams et al., 2012).

Underground injection through disposal wells is the preferred disposal method in the USA: in this way, only a basic filtration and suspended solids settlement is foreseen in order to protect injection equipment, wellbore and formation from solids erosion/entrapment. Public concerns about the amount of water used for shale oil and gas operations, coupled with the lack of adequate large scale disposal capacity, have caused some operators to explore treating and/or reusing the produced water. Produced water may be treated for discharge to surface waters or it may be treated and re-used in subsequent fracture operations. If one looks at the overall water treatment process, it could be divided into two main sections (Guarnone et al., 2012): The first, called “pre-treatment”, comprises all the processes necessary in order to reduce TSS and heavy metals. This can be achieved by means of different technologies such as hydrocyclone separation, electrocoagulation, flocculation, resins adsorption and softening that when properly combined, allow reaching the desired output in terms of water specifications. The second step, “core-treatment”, is used to reduce TDS and chlorides, which can be performed by following two different methods depending on the specific water features. For inlet TDS value close or lower than 30 000 - 40 000 ppm, physical separation seems to be the most technically and economically feasible option, with proven technologies such as ultra-filtration, nano-filtration and reverse osmosis: these ensure the achievement of treatment targets with relatively low costs, CAPEX and OPEX typically being in the range 1.5-3 US$/bbl in Northern America contexts. For higher inlet TDS value, instead, thermal technologies (namely mechanical evaporators and crystallizers) are candidates to provide higher efficiencies and recovery factors (more than double compared to a physical process, e.g. reverse osmosis) but they imply final costs internally estimated to be as high as 3-6 US$/bbl for the full water treatment cycle in northern America contexts (Guarnone et al., 2012).

3 ENTITIES ON WHICH UNCONVENTIONAL OIL AND GAS EXTRACTION AND HYDRAULIC FRACTURING MAY HAVE AN IMPACT

Impacts on entities will be discussed under biophysical entities and socio-economic entities. The biophysical entities cover surface water, groundwater, seismicity, vegetation, soil, air quality, aquatic invertebrates, terrestrial insects, mammals, fish and amphibians and reptiles. The socio-economic entities will include economic well-being, agriculture and food security, health, social well-being and living conditions, demographic impacts and astronomy. The activities which may pose some of the largest risks for South Africa, may be the sourcing of water to be used in large scale hydraulic fracturing operations, the impact that regional scale unconventional oil and gas extraction may pose in terms of biodiversity fragmentation and competition with existing land uses, and the as yet unaddressed problem of how wastewater from oil and gas extraction operations and brines resulting from wastewater treatment should be managed.

3.1 Biophysical entities

Section 3.1.1 will discuss impacts from unconventional oil and gas production on biophysical entities.

3.1.1 Surface water

The areas where unconventional gas extraction by means of hydraulic fracturing may occur in South Africa, are illustrated in

Figure 1 and the area where most of the permit applications have been applied for, includes the Karoo Basin. The Orange River Basin is the Karoo region’s main drainage system and many of the tributaries in this basin are either seasonal or temporary (do not flow continuously). The region also contains a large number of pans (mostly endorheic) (Noble and Hemens, 1978), the largest of which, the Grootvloer-Verneukpan complex, plays an important role during migrations of biota, enabling them to have access to breeding grounds in the upper reaches of the Sak River. When summer rainfall is high, the pan system also provides a link between the Orange and Sak River systems, which may enable an interchange of indigenous fish and other aquatic organisms (Lloyd, 1999). The pans also fulfil an important role in the migration of waterbirds as the pans are used by these birds for drinking as well as feeding (zooplankton etc.) along their migration route. Many of these pans are temporary and have a fauna which is adapted to harsh conditions. Eggs lie dormant in the dry mud of these pans for centuries and when the pans are inundated the eggs hatch and an abundant zooplankton fauna emerges which then serves as food for waterbirds etc. (Allan et al., 1995). When these pans are disturbed or removed, the distance between them can become a barrier to the dispersal of zooplankton eggs. Isolation of these pans would lead to genetic isolation as well, and an eventual loss of species (Frankham, 1995).

Surface water ecosystems are complex and an impact on any component of the ecosystem would impact on the rest as well. When surface water is impacted on, either by added sediment, pollutants, increase or decrease in pH and TDS, abstraction or addition of extra flow (water) etc., this has an impact on the biota living in that system. The primary producers (algae, zooplankton etc.) are the building blocks upon which the rest of the biota relies and if the structure or composition of the primary producers is altered then all the biota living in that system would be impacted on; from macro-invertebrates that feed on the algae and zooplankton to fish.

Surface water quality is one of the entities on which oil and gas extraction might have a large impact. Not all the impacts on surface water are direct, many of the impacts are indirect, i.e., polluted groundwater that leach through springs to surface water (Herridge et al., 2012); after rain the pollutants in soil wash into surface water with runoff (Herridge et al., 2012), air pollutants are dissolved in rainwater and also end up in the surface water (Herridge et al., 2012). A list of potential contaminants identified include: diesel (BTEX – benzene, toluene, ethylbenzene, xylenes), ethylene glycol, methanol, naphthalene, carcinogens (benzene, ethylene oxide, formaldehyde, sulphuric acid), radioactive materials (strontium, uranium, radon) and heavy metals (lead, mercury, cadmium, chromium, barium, arsenic) (Herridge et al., 2012). The different chemical makeup of the various featuring fluids will have different impacts on surface water (Cantafio and Slingerland, 2012).

The water produced during the fracturing process is a major water quality hazard as it is highly saline, corrosive and could contain radioactive elements such as thorium, uranium, radium. It also contains pyrite, and heavy metals such as arsenic and mercury (Blake and Hartnady, 2011).

3.1.1.1 Impacts

Impacts on surface water would cover positive, negative and uncertain impacts and will be discussed in terms of the following periods of oil and gas extraction: During oil and gas exploration, during oil and gas extraction and post oil and gas extraction. Oil and gas extraction would include all the relevant tight oil and gas resources on which hydraulic fracturing may be applied to extract the oil and gas, which in South Africa are shale oil and gas deposits and coalbed methane deposits.

Aspects such as stream frequency, stream permanency, stream flow intermittency, river condition and the condition of wetlands are all important aspects that would have an influence on the extent of the impact on surface water features in the area of concern.

Approximately 3.5 million gallons of fresh water are required per well in the Barnett Shale (Ewing, 2008) and an estimated 24 megalitres per well in South Africa (DMR, 2012) and the source of this water for use in hydraulic fracturing is not yet known in South Africa.

General impacts if water is abstracted from either groundwater or surface water are:

- Inadequate downstream water availability for human uses;
- Loss in connectivity in rivers;
- Loss of permanent pools due to depletion of springs – aquifers which leads to additional loss of connectivity and possible change in water temperature;
- Lower/less flood events;
- Less scouring and less substrate ordering;
- Increase in sedimentation;
- Less refreshing of pools;
- Removal of refugia;
- Change in water quality;
- Change in algal growth patterns;
- Change in vegetation/habitat; and
- Loss of biotope/habitat.

Withdrawals of large quantities of water from surface water resources (e.g., streams) may have significant impacts on the hydrology and hydrodynamics of these resources. Such withdrawals from streams can alter the flow regime by changing their flow depth, velocity, and temperature (Zorn et al., 2008). Additionally, removal of significant volumes of water may reduce the dilution effect and increase the concentration of contaminants in surface water resources (Pennsylvania State University, 2010). Furthermore, it is important to recognise that groundwater and surface water are hydraulically connected (Parsons, 2004; Winter et al., 1998); any changes in the quantity and quality of the surface water will affect groundwater and vice versa. For example, if untreated wastewater (e.g., from spills from well pads) is released into streams during transportation or planned releases from wastewater treatment plants, the streams may become unsuitable habitats for fish or other aquatic organisms that cannot tolerate high salt concentrations or the presence of other contaminants. This has occurred in Pennsylvania, where a fish kill was linked to a spill of hydraulic fracturing fluid that contaminated a stream (Lustgarten and ProPublica, 2009). Stormwater runoff from the drilling site may be another water issue of concern. Water produced during the dewatering of coalbed wells is generally discharged into dams and other surface water drainages such as perennial, ephemeral and intermittent streams (USEPA, 2004c). A waste hauling company in Pennsylvania had criminal charges filed against it in March 2012 for illegally dumping millions of gallons of produced water into streams and mine shafts and on properties across southwestern Pennsylvania (Pennsylvania Attorney General, 2012). Truck accidents also occur, given the large volume of truck traffic associated with hydraulic fracturing, and this could also lead to chemical or wastewater spills. In December 2011, a truck accident occurred in Mifflin Township, Pennsylvania; and fracking wastewater was spilt into a nearby creek (Reppert, 2011). Due to a lack of or outdated legislation toxic and radioactive chemicals often are discharged into rivers (Penningrath, 2011).

Road construction and stream crossings could cause erosion, sediment transport and increase in salinity, which impacts the receiving rivers (Rahm and Riha, 2012). No details are available at present on where the sand, for use as proppant, is to be obtained for the fracturing process. The possible removal of sand (if the type is suitable) from riverbeds in the Karoo for use as proppant could impact on the alluvial aquifers present in some of these rivers. The removal and processing of sand for use as proppant is also particularly water-intensive (Freyman, 2014). Table 2 discusses the impacts on surface water.

Table 2: Possible impacts on surface water

	Positive impacts	**Uncertain positive impacts**	**Uncertain negative impacts**	**Negative impacts**
During exploration	None were found.	None were found.	• Drilling fluids (diesel etc.) leaching into surface water via groundwater or via overland flow from surface spillages. [18] • Possible removal of sand from rivers for use as proppant.[19]	• Drilling fluids leaching into surface water via groundwater or via overland flow from surface spillages. [18] • Possible increase in sediment load in rivers due to increased erosion from seismic exploration.
During extraction	None were found.	None were found.	• Not all chemicals used in fracturing fluids are known, therefore unknown chemical impacts is an uncertainty. • Possible removal of sand from rivers for use as proppant.[19]	• Water needed for hydraulic fracturing will impact on the hydrology of the resources.[9] • Various sources of pollutants occur throughout this stage.[4, 17, 20, 21] • Destruction of pans results in genetic isolation of invertebrates.[23]
After extraction	• Cleaner burning fossil fuel.[20] • Risk of surface water contaminati on lowers.		• Not all chemicals used in fracturing fluids are known, therefore unknown chemical impacts is an uncertainty.	• Various sources of pollutants occur throughout this stage.[4, 17, 19, 20, 22]

References	20: Scott et al., 2011.		18: Lechtenböhmer et al., 2011; 19: Freyman, 2014	4: Herridge et al., 2012; 9: Zorn et al., 2008; 17: Rahm and Riha 2012; 20: Lyons, 2012; 21: Scott et al., 2011; 2: Jackson et al., 2011; 23: Frankham, 1995

3.1.1.2 Availability of data to map this aspect

Various databases relating to surface water are available as part of the Atlas of Freshwater Ecosystem Priority Areas in South Africa (Nel et al., 2011b). These databases include:

- Percentage natural wetland;
- River condition;
- River Freshwater Ecosystem Priority areas;

These databases are a collection of data collected as part of a National project and include knowledge from most of the freshwater specialists in South Africa. An updated Present Ecological State (PES) database is also available with information on various aspects of surface water in South Africa (DWA, 2013a).

3.1.2 Groundwater

Various impacts on groundwater by shale oil and gas and CBM extraction activities have been reported (Broderick et al., 2011; Broomfield, 2012; IEA, 2012; USEPA, 2011a, USEPA, 2011b; USEPA, 2011c; Freyman, 2014). Most of the reported impacts from the literature screening were negative or uncertain. Very few positive aspects could be identified.

In terms of groundwater impacts, it is also very important to recognise that groundwater and surface water form an integrated resource and that interactions between the two different water resources occur (Parsons, 2004). This means that impacts on surface water, may eventually impact upon groundwater, and vice versa.

3.1.2.1 Impacts

Impacts on groundwater would cover positive, negative and uncertain impacts and will be discussed in terms of the following periods of oil and gas extraction: During oil and gas exploration, during oil and gas extraction and post oil and gas extraction. Uncertainties will also be highlighted. Oil and gas extraction would include all the relevant tight oil and gas resources on which hydraulic fracturing may be applied to extract the oil and gas, which in South Africa mostly include shale oil and gas deposits and coalbed methane deposits.

During exploration

Positive impacts during gas exploration in shale gas formations would include the fact that the extent of deeper groundwater resources and the associated geology could be characterized in more detail, in areas where exploration would be performed. At this stage geologists and geohydrologists alike have knowledge of the geology and aquifers up to a depth of 300m deep (Steyl et al., 2012; DMR, 2012; De Wit, 2011).

Although it would be positive to learn more about the deeper geology and possible fossil water aquifers in the case of shale gas resources, various unknowns also pose a risk in terms of unintended contamination of freshwater aquifers. Negative impacts include, amongst others:

- Formation water from the deep shales and deeper fossil water aquifers can contaminate shallow freshwater aquifers under artesian basin conditions where deeper water could migrate towards the surface. In some parts of the Karoo basin artesian conditions exist (Steyl et al., 2012, Woodford and Chevallier, 2002). This formation water or "produced water" is generated by the shale formation during exploration and extraction and can contain very high salt loads, naturally occurring radioactive material (NORM) and various heavy metals (USEPA, 2011a; Clark and Veil, 2009). This means that wastewater management issues may not be limited only to the extraction phase.

- During the exploration phase where economic oil or gas productivity must be determined, hydraulic fracturing would be used to determine the economic viability of extracting gas at a large scale (Kargbo et al., 2010; Broomfield, 2012; EIA, 2012) and it is possible that flowback water and produced water may contaminate shallow freshwater aquifers either via leaking boreholes, via fluid migration or via recharge in the case where surface water-groundwater interaction occurs.
- Shales pose various problems during drilling, e.g swelling of shales and resultant shale instability with associated borehole problems such as hole collapse, stuck equipment, poor hole cleaning, plastic flow, fracturing, lost circulation and poor well control (Manohar, 1999; Khan et al., 2011; Cabot, 2010; Khodja et al., 2010). A complicating factor that distinguishes shale from other rock types is its sensitivity to certain drilling constituents, especially water. Shale stability is affected by shale properties (mineralogy, porosity) and by effects when drilling fluid makes contact with the shale (wettability, density, salinity, ionic concentration), changes in pressure states (in situ stress vs the altered stress state when a well is drilled into the shale) (Manohar, 1999). When the altered stresses exceed the strength of the shale, the shale becomes unstable. Factors that influence the effective stress are wellbore pressure, shale pore pressure as well as hole trajectory and angle. These problems may already be encountered during the exploration phase. It is also important to understand the time-dependent mechanical properties of shale rocks in order to predict the long-term reservoir behavior over production time scales. Failing to address the time-dependent response of these reservoir rocks could, for instance, lead to a significant under-estimation of subsidence or permeability reduction of the reservoir. Time-dependent deformational properties of gas shales may be related to the in-situ stress heterogeneity observed in gas shale reservoirs (Sone and Zoback, 2011). Shale stability may influence well stability and may lead to migration of fracking fluids, flowback and produced water.
- In terms of coalbed methane formations, exploration in these formations may cause unintended contamination of freshwater aquifers, since coalbed methane formations and groundwater aquifers may co-occur.

<u>During extraction:</u>

- Shale instability is still an issue during the unconventional oil and gas extraction phase.
- Sourcing water for shale gas extraction operations could very likely pose constraints. If fresh groundwater is used for sourcing the water to be used during hydraulic fracturing, this may impact on groundwater levels in certain aquifers. If deeper fossil water is used, this may contaminate the shallower freshwater aquifers during possible fluid migration. Extracting water from any aquifers in the target gas extraction region may change the structure of the geology and cause subsidence, induced aquifer connectivity, groundwater migration or disappearance, source rock fluid migration and possible seismic activity (ANU, 2012; Myers, 2012; Warner et al., 2012).
- Sourcing water from freshwater aquifers in the region of oil and gas operations may impact on the livelihood of commercial and small-scale farmers in the region as well as towns which are solely dependent on groundwater, and may cause competition between water needed for human consumption, water required for continued ecosystem functioning and water required for oil and gas operations (Havemann et al., 2011). Abstracting water from freshwater aquifers may also cause subsurface disturbance with associated subsidence, fluid migration and triggered seismicity (ANU, 2012).

- Sourcing water from deeper saline aquifers in the region may cause subsurface disturbance with associated subsidence, fluid migration and triggered seismicity, especially if the aquifers occur under artesian conditions (associated with confined aquifers). Fluid migration from fossil water aquifers may reach freshwater aquifers and cause irreversible loss of freshwater resources (Warner et al., 2012). Leakage of saline water past the borehole annulus in cases of poor borehole construction may also cause contamination of freshwater aquifers with saline water (USEPA, 2011a; Broomfield, 2012).

In terms of coalbed methane the following concerns are valid:

- Water requirements for coalbed methane is typically less than for shale gas operations, but coalbed methane operations can produce very large quantities of saline water (USEPA, 2011c). These volumes of saline water need to be managed, treated and disposed of in a way that will not be harmful to the environment. Usually it is treated and used for land application, but if it is not treated properly, it may lead to salinification of soils, which may in turn pollute groundwater (USEPA, 2011c). Wastewater management would be a serious challenge in the case of large scale coalbed methane extraction in South Africa.
- Extraction of large volumes of saline water from the coal formations may lead to deformation of the geology, with subsequent subsidence. Thus it may be required that water be pumped back into these formations to avoid subsidence (ANU, 2012). Large scale abstraction of water from coalbed seams may also impact on spring flows due to base flow decreases, in cases where surface water groundwater interaction occur (ANU, 2012).
- In cases where the permeability of the coalbed methane formations are too low, hydraulic fracturing or other treatments may be required (USEPA, 2011a; USEPA, 2011c), and this can also lead to groundwater contamination if fluid migration occurs between the shallow coalbed methane layers and the co-occurring freshwater aquifers.
- Exploration and extraction in coalbed methane formations may also cause unintended contamination of freshwater aquifers, since coalbed methane formations and groundwater aquifers may co-occur.
- During shale gas extraction and coalbed methane extraction, wastewater (which can be a combination of the flowback and the produced water) disposal poses serious challenges in countries such as the United States and Canada where unconventional oil and gas extraction by means of hydraulic fracturing is being performed (Volz et al., 2011). Wastewater management currently includes various strategies such as underground injection, treatment and discharge, and recycling (GWPC and ALL Consulting, 2009). Large scale wastewater treatment invariably poses challenges such as brine management (USEPA, 2011a; Clark and Veil, 2009). In addition, underground injection of wastewater may lead to seismicity and resultant loss of lives and infrastructure damage, as has been reported for Ohio, Arkansas, Okolahoma and Texas in the USA (NRC, 2012a). It is important to note that in South Africa produced water may also be generated during the exploration phase where it may be naturally generated by the shale layers as well as coalbed methane layers (USEPA, 2011c) and may move towards the surface due to pressure in the artesian aquifers.
- Surface activities associated with shale gas extraction and coalbed methane may also impact on groundwater quality via natural recharge mechanisms. In addition, groundwater surface water interaction does occur in South African water courses and scientists are still grappling with the complexity of trying to determine ways to describe and model these interactions (Seaman et al., 2010). In drier parts of the country or during drier months, this interaction may be more prevalent and river systems and their associated ecology may depend more on groundwater contributions than otherwise (Le Maitre and Colvin, 2008; Rossouw et al., 2005). Due to this interaction there is the very real risk of cross-contamination between surface water systems and groundwater systems, which means that groundwater can be contaminated from surface water pathways and not only from deeper formations.

Post oil and gas extraction:

Although furher structural damage to aquifers and the geological formations may be limited, some negative impacts are associated with the post oil and gas extraction phase. These include:

- If groundwater aquifers have been contaminated by organics either from hydraulic fracturing fluid or from water produced from the shale formations, there is the very likely possibility that the freshwater aquifers could not be rehabilitated again, both from an economic and physical perspective. Certain organic contaminants act as long term contamination agents that absorb to soil particles and can effectively not be removed from aquifer systems (NRC, 2012b, GAO, 2010), due to the fact that sorption processes are spatially heterogeneous, nonlinear, and potentially limited by solute diffusion to sorbent material located within the interior of soil particles. Nonlinear and/or rate-limited desorption can potentially contribute to plume persistence over decades. The NRC (2012b) states that restoration of groundwater contaminated by anthropogenic releases remains a significant technical and institutional challenge and that at least 126,000 sites across the USA, contamination occurs at such levels that closure for these sites could not be obtained. This estimate is a gross underestimate according to the NRC (2012b). Estimates on clean-up costs are in the region of $110-127 billion, which is also likely to be a gross underestimate. Certain organic components are also very toxic to biologic life even if it occurs at parts per billion levels in groundwater (Mayer and Hassanizadeh, 2005).
- The abandonment of producing wells or the poor sealing of wells after well decommissioning, may lead to long term groundwater contamination legacy issues (ANU, 2012, Broomfield, 2012, NRC, 2012b). According to ANU (2012) there are more than 100,000 orphan gas wells and gas production sites in the United States, of which the integrity continually deteriorate across freshwater aquifers. The DEP (2009) stated that stray natural gas migration is associated with these abandoned wells, which may adversely affect water supplies or accumulate within or adjacent to buildings. Bishop (2011) puts the estimate of orphan or abandoned wells in the USA at 1.2 million, of which approximately 200,000 are leaking. This represents a failure rate of 16.7%, but estimates are that almost all wells would eventually leak (over for instance a 50 year period) due to mechanical failure of well casing (Bishop, 2011). Mechanical failure is attributed to concrete shrinkage with associated casing fissuring and is the most severe at the maximum well depth, where casings are exposed to high temperature (sometimes acidic) brines (Dusseault et al., 2000). Other casing deformation mechanisms also exist, such as localised horizontal shear at weak lithologogicla interfaces with overburden, localized horizontal shear at the top of production and injection intervals and casing buckling within the oil and gas producing interval, located mainly at the perforation zones (Dusseault et al., 2001).

Uncertainties

Various uncertainties are also associated with unconventional oil and gas exploration and extraction. In terms of the physical operations on site (drilling, borehole construction etc.) and the physical properties of geological formations:

- Poor well design or construction can lead to subsurface groundwater contamination arising from aquifer penetration by the well, and migration of fluids into the well and/or aquifers or of combustible natural gas to water supplies (Broomfield, 2012, Kargbo et al., 2010, USEPA, 2011a).
- Contamination that can arise during drilling as a result of a failure to maintain storm water controls, ineffective site management, inadequate surface and subsurface containment, poor casing construction, well blowout or component failure (ANU, 2012).

- Cuttings produced from wells also need to be properly handled to avoid for instance the risk of radioactive contamination (Broomfield, 2012).
- The potential wearing effects of repeated fracturing on well construction components such as casings and cement are not sufficiently understood and more research is needed (USEPA, 2011a, Broomfield, 2012, ANU, 2012).
- Control of the size or lengths of fracture zones during hydraulic fracturing may be problematic (Kargbo et al., 2012; USEPA, 2011a)
- Well bore trajectory control and placement of the casing with depth may pose challenges (Kargbo et al., 2010)
- Temperatures of between 35-140℃ (Broomfield, 2012) may be experienced at depth in shale formations and high formation fluid pressures may be experienced which may increase the impact of saturated brines and acid gases on drilling at greater depths (Kargbo et al., 2010)
- The effect of increased temperature on cement setting behaviour, poor mud displacement and lost circulation with depth may lead to poor well cementing (Kargbo et al., 2010)
- There is a risk of hitting permeable gas reservoirs at all levels which may lead to shallow gas blowouts and underground blowouts (Kargbo et al., 2010; Broomfield, 2012) If engineering controls are insufficient, the risk of accidental release or blowouts increases with multiple shale gas wells (Broomfield, 2012).
- The occurrence of various dolerite dykes, sills and kimberlite pipes with associated fracture zones as well as faults, may cause unintended aquifer connectivity and fluid migration (Steyl *et al*., 2012, Myers, 2012).

Uncertain impacts related to treatment and disposal of flowback and produced water from shale gas and oil extraction operations include:

- Wastewater treatment may pose challenges because of brines that may be generated during the treatment of water (ANU, 2012). South Africa currently has no wastewater treatment strategy in place.
- If wastewater is re-injected into deeper porous geological formations, it may cause geological and aquifer deformation with the associated possibility of triggered seismicity (Lechtenböhmer et al., 2011, Zoback, *et al.,* 2010; NRC, 2012a) and possible fluid migration (USEPA, 2011a; Broomfield, 2012).

Regulatory uncertainties which may put groundwater at risk include:

- The current lack of fracking-specific legislation or regulations may lead to poor regulatory control (Havemann *et al.,* 2011; Havemann, 2011)
- Human Resource capacity issues in the Department of Water Affairs may hamper monitoring efforts (Havemann et al., 2011)
- A wastewater treatment strategy specifically aimed at unconventional gas extraction does not exist and would be required to ensure long term protection of water resources.

Uncertain post oil and gas extraction impacts include:

- Groundwater contamination may only become evident a long time after the contamination event occurred, and this is mainly due to the fact that groundwater moves very slowly over time due to low permeability in subsurface formations (NRC, 2012b) and may also be attributed to ineffective subsurface investigations, difficulties in characterising the nature and extent of problems in highly heterogeneous subsurface environments and the fact that restoration could not be achieved in complex geological settings with current technologies (NRC, 2012b).
- The extent of possible long-term contamination in freshwater aquifers could not be predicted at this stage.

Impacts are summarised in Table 3.

Table 3: Possible impacts of unconventional oil and gas extraction for groundwater

	Positive impacts	Uncertain positive impacts	Uncertain negative impacts	Negative impacts
During exploration	Develop a better understanding of the deep geology and geohydrology in the case of shale oil and gas extraction.[1, 2, 3.]	None that could be identified.	• It is not possible to identify at this stage which aquifers may be at risk for contamination since deeper geology and structures are unknown.[2, 3] • Artesian basin conditions [3, 31] in the Karoo geological basin may cause upward migration of formation water	• Shales pose various problems during drilling, e.g swelling of shales and resultant shale instability with associated borehole problems such as hole collapse, stuck equipment, poor hole cleaning, plastic flow, fracturing, lost circulation and poor well control. [24, 25, 26, 27] Large quantities of saline water produced by CBM extraction.[16] • Higher possibility of aquifer contamination is posed by CBM extraction since aquifers and coalbed formations may co-occur.[3, 16] • Possible cases of groundwater contamination if hydraulic fracturing is allowed [8, 5, 11] during the exploration phase, both for CBM and shale oil and gas formations.
References	1: De Wit, 2011; 2: DMR, 2012; 3: Steyl et al., 2012		2: DMR, 2012; 3: Steyl et al., 2012	3: Steyl et al., 2012; 5: Broomfield, 2012; 8: USEPA, 2011a; 11: ANU, 2012; 16: USEPA, 2011c; 24: Manohar, 1999; 25: Khan et al., 2011; 26: Cabot, 2010; 27: Khodja et al., 2010; 31: Woodford and Chevallier, 2002

Table 3: Possible impacts for groundwater continued

	Positive impacts	Uncertain positive impacts	Uncertain negative impacts	Negative impacts
During extraction	None that could be identified.	• The use of safer chemicals is possible, e.g. gasses or plant based oils.[4, 5] • Green chemicals can be developed to use for fracking.[4, 6]	**Shale oil and gas:** • Various impacts on aquifers for different water sourcing options • Various impacts on aquifers for different water sourcing options.[5, 7, 8, 9, 10, 11, 28, 29] • Various physical uncertainties during drilling and extraction of shale oil and gas may impact on aquifers in different ways.[4, 5, 8, 11, 28, 29] • Various wastewater treatment and disposal uncertainties put aquifers at risk.[5, 6, 8, 11, 12, 13, 14] • Various regulatory uncertainties that may put groundwater resources at risk [7,15] **Coalbed methane:** • Wastewater management and treatment poses serious challenges. [16] • Regulatory [1,2] and physical challenges also relate to CBM. [4,5,8,11.]	**Shale oil and gas:** • Sourcing of water for local aquifers may induce aquifer connectivity, [28, 29] change groundwater levels, cause contamination and may cause seismic activity.[13,14] • Shales pose various problems during drilling, e.g swelling of shales and resultant shale instability with associated borehole problems such as hole collapse, stuck equipment, poor hole cleaning, plastic flow, fracturing, lost circulation and poor well control.[24, 25, 26 ,27] Visco-elastic deformation of shales can lead to subsidence and drilling induced borehole failure.[30] • Surface activities contaminate aquifers via surface water-groundwater interaction.[11, 18, 32] • Wastewater poses serious challenges if not managed properly.[5, 8, 19] • Artesian basin conditions and numerous dykes, kimberlite pipes, fracture zones [3] may facilitate fluid migration from shales to surface. • Poor well integrity may cause leakage of gas or fluids and groundwater contamination, also for CBM.[3, 5, 6, 8, 22, 23] **Coalbed methane:** • Challenges with wastewater management due to saline water extraction from CBM.[16] • Extraction of water from CBM → geology and aquifer deformation, subsidence, baseflow decreases and reduced springflow.[11, 16] • Fluid migration from CBM to aquifers due to induced aquifer connectivity.[8, 11, 16] • Contamination of aquifers by hydraulic fracturing fluids, saline water from CBM.[5, 11, 16.]
References	1: De Wit, 2011; 2: DMR, 2012; 3: Steyl et al., 2012	4: Kargbo et al., 2010, 5: Broomfield, 2012; 6: IEA, 2012	2: DMR, 2012; 3: Steyl et al., 2012; 4: Kargbo et al, 2010; 5: Broomfield, 2012; 6: IEA, 2012; 7: Havemann et al., 2011; 8: USEPA, 2011a; 9: Broderick et al., 2011; 10: Galusky, 2007; 11: ANU, 2012; 12: Lechtenböhmer et al., 2011; 13: Zoback et al., 2010; 14: NRC, 2012b; 15: Havemann, 2011; 16: USEPA, 2011c; 28: Myers, 2012; 29: Warner et al., 2012	3: Steyl et al., 2012; 5: Broomfield, 2012; 8: USEPA, 2011a; 11: ANU, 2012; 13: Zoback et al., 2010;14: NRC, 2012b; 16: USEPA, 2011c; 17: GAO, 2010; 18: Seaman et al., 2010 ;19: Volz et al., 2011, 20: Dusseault et al., 2000, 21: Dusseault et al., 2001, 22: Bishop, 2011; 23: DEP, 2009; 24: Manohar, 1999; 25: Khan et al., 2011; 26: Cabot, 2010; 27: Khodja et al., 2011; 28: Myers, 2012; 29: Warner et al., 2012; 30: Sone and Zoback, 2011; 32: Parsons, 2004

Table 3: Possible impacts for groundwater continued.

	Positive impacts	Uncertain positive impacts	Uncertain negative impacts	Negative impacts
After extraction	• Pollution risk in the area where extract-ion ceases, may lower.	None that could be identified.	• Aquifer pollution from deep shale layers may only surface years after a pollution incident. • The extent of possible long-term contamination in freshwater aquifers could not be predicted at this stage.	• South Africa not able to rehabilitate contaminated aquifers in complex geology (physically and economically).[17] • Well abandonment and long term monitoring may be problematic.[5, 11] • Oil and gas well casing failure and leakage may pose long-term legacy issues and lead to inevitable groundwater contamination.[11, 20, 21, 22]
All References	1: De Wit, 2011; 2: DMR, 2012; 3: Steyl et al., 2012	4: Kargbo et al., 2010, 5: Broomfield, 2012; 6: IEA, 2012	2: DMR, 2012; 3: Steyl et al., 2012; 4: Kargbo et al., 2010; 5: Broomfield, 2012; 6: IEA, 2012; 7: Havemann et al., 2011; 8: USEPA, 2011a; 9: Broderick et al., 2011; 10: Galusky, 2007; 11: ANU, 2012; 12: Lechtenböhmer et al., 2011; 13: Zoback et al., 2010 14: NRC, 2012b; 15: Havemann, 2011; 16: USEPA, 2011c; 28: Myers, 2012; 29: Warner et al., 2012	3: Steyl et al., 2012; 5: Broomfield, 2012; 8: USEPA, 2011a; 11: ANU, 2012; 13: Zoback et al., 2010;14: NRC, 2012b; 16: USEPA, 2011c; 17: GAO, 2010; 18: Seaman et al., 2010 ;19: Volz et al., 2011, 20: Dusseault et al., 2000, 21: Dusseault et al., 2001, 22: Bishop, 2011; 23: DEP, 2009; 24: Manohar, 1999; 25: Khan et al., 2011; 26: Cabot, 2010; 27: Khodja et al., 2011; 28: Myers, 2012; 29: Warner et al., 2012; 30: Sone and Zoback, 2011; 31: Woodford and Chevallier, 2002; 32: Parsons, 2004

3.1.2.2 Availability of data to map this aspect

Various databases and shapefiles containing information on groundwater occurrence, quality and vulnerability do exist and could be used during the vulnerability mapping exercise to develop the groundwater vulnerability map. This information will also be used to generate the final vulnerability map which will include the other mapped biophysical entities well as the socio-economic map.

3.1.3 Seismicity

Section 3.1.3.1 will discuss the impacts related to seismicity and Section 3.1.3.2 the availability of datasets.

3.1.3.1 Impacts

Already in the 1920s it became clear that pumping fluids into or out of the earth can cause strong seismic events (NRC, 2012a). Some of the seismic events can be strong enough to cause damage. In seismological literature, these events are known as man-made or induced earthquakes.

The most memorable and well documented example of an induced seismic-related event due to fluid injection is the induced seismicity that occurred in the Denver, Colorado; area in the 1960s. An injection liquid of waste disposal at the Rocky Mountain Arsenal into impermeable crystalline basement rock caused several seismic events with moment magnitudes within a range of 5.0 to 5.5. The largest event caused damage estimated in 1967 of US $500,000 (Healy et al., 1968; Nicholson and Wesson, 1990).

More recent examples of induced seismicity caused by pumping fluids into or out of the rock include seismic events in Basel, Switzerland, as well as in Arkansas, Ohio, and Oklahoma, Texas in the USA (Frohlich et al., 2011; Horton and Ausbrooks, 2010 and 2011, Horton, 2012).

In 2001, seismic activity was observed along the Colorado–New Mexico border, the place where drillers were injecting water to extract methane from coal beds. In central and southern Oklahoma, seismicity increased in 2009 by a factor of 20 over the rate of the previous half-century even when the November's magnitude 5.6 and its aftershocks are excluded from the calculation (Ake et al., 2005; Holland and Gibson, 2011).

In 2011, during extensive fluid injection in vicinity of the town of Guy, Arkansas, a moment magnitude 4.0 event struck about a kilometre northeast of the two fracking wells (Kerr, 2012). Ten days later, a magnitude 3.9 event took place, ca. 2 km further to the northeast toward Guy. Then, two months later, two events of moment magnitude 4.1 and 4.7 took place to the southwest of the deeper well, toward town Greenbrier.

In March 2011, the Ohio Department of Natural Resources announced that it had evidence "strongly indicating" that wastewater injection — at least part of it used for fracking purposes — had triggered several magnitude 2.0 to 4.0 seismic events in the town of Youngstown.

It is not always is clear what is the cause of this strong induced seismicity (Zoback et al., 2010). Dr. Mark Zoback of Stanford University in Palo Alto, California; points out that there are already 144,000 wastewater injection wells in the country, but very few are generating seismic events. Injection of fluid in rocks causes an increase of the pore pressure and also modifies the state of the stress (NRC, 1990; Hsieh and Bredehoeft, 1996). The stress change is associated with a volume expansion of the rock due to the increase of the pore pressure. However, the pore pressure perturbation dominates over the stress variation and when considering the consequence of fluid injection with regard to the induced seismicity, the stress perturbations can often be ignored.

In assessing the potential for induced seismicity, two basic questions arise: (1) what is the magnitude of the pore pressure change and (2) what is the extent of the volume of rock where the pore pressure is modified in any significant manner. Current understanding is that the magnitude of the induced pore pressure increase and the extent of the region of pore pressure change depend on the rate of fluid injection, total volume injected, the fluid viscosity and as well as hydraulic properties of the rock, its intrinsic permeability and its storage coefficient (e.g. Shapiro and Dinske, 2009).

Can we control the occurrence of strong seismic events induced by fluid injection? According to Dr. Zoback, one has to "look before you leap". He believes that the seismic tomography techniques should be employed to locate buried faults capable of generating strong seismic events, up to magnitude 6.0 (Zoback and Townend, 2001; Zoback et al., 2010).

In addition, at the beginning of the injection, the surrounding area should be monitored by a network of seismometers. The monitoring and data analysis should be done in real time. It will allow researchers to produce an image of the subsurface and to identify the potential area of location for strong seismic events. Such "hot spots" must be avoided during fracking. Table 4 shows a summary of the impacts.

Table 4: Possible impacts on seismicity

	Positive impacts	Uncertain positive impacts	Uncertain negative impacts	Negative impacts
During exploration	Not known	Not known	Level of seismicity will increase. However the extent of this increase is uncertain.	Possibility to observe or induce and/or trigger a strong seismic event.
During extraction	Not known	Not known	Level of seismicity will increase. However the extent of this increase is uncertain.	Possibility to observe or induce and/or trigger a strong seismic event.
After extraction	Not known	Not known	Level of seismicity will increase. However the extent of this increase is uncertain.	Possibility to observe or induce and/or trigger a strong seismic event.

3.1.3.2 Availability of data to map this aspect

Relevant databases relating to the current known seismicity of the area will be used in the mapping of the seismic hazard and risk. However, this information will not be enough to create a vulnerability map of the increased level of seismic activity due to fracking.

Seismicity Database References include:

- South African National Seismological Network (SANSN) by the Council for Geoscience, South Africa.
- International Seismological Centre, On-line Bulletin, http://www.isc.ac.uk, Internatl. Seis. Cent., Thatcham, United Kingdom, 2010.
- Harvard CMT Project and Global CMT Project (www.globalcmt.org)
- National Earthquake Information Center (NEIC), USA Geological Survey Earthquake Database (http://earthquake.usgs.gov/)

3.1.4 Vegetation

Mining in general has a direct impact on vegetation cover and unconventional oil and gas extraction will be no exception. Although unconventional oil and gas extraction will be taking place only on a small, localised scale (2-3 ha per well pad), the temporal and spatial impact can be significant (Slonecker et al., 2012). Impacts associated with unconventional oil and gas extraction will occur against the backdrop of global warming, desertification, land use changes from natural to agriculture, industrial and urban use. These added pressures will ultimately lead to the loss of biodiversity and consequently the decrease in resilience of the ecosystem on which we depend.

Depending on the extent and duration of unconventional oil and gas mining, a change in species composition, cover and recruitment can be expected. Since mining sites will be located in specific vegetation types, each with its own characteristics and landscape features, only generalised statements about impacts on vegetation will be made in this report. Given the number of uncertainties pertaining to the intensity and extent on which unconventional oil and gas mining will take place, it is not possible to deduce the exact impacts that this type of mining will have on the vegetation of South Africa. Reliable information from the mining companies on the expected density of well pads in an area will be critical in determining the impact on the ecosystem in which the well pads will occur. Ideally this information should be available before exploration starts, to be able to focus base line monitoring in the area proposed for development.

Although South Africa has the richest temperate flora in the world (Germishuizen and Meyer, 2003), many species are already under serious threat. According to the South African National Biodiversity Institute (SANBI, 2012), a quarter of vascular plant species are considered *threatened* or classified as "*of conservation concern*". When overlaying the map in (

Figure 1) indicating the current location of the unconventional oil and gas mining applications that was submitted to PASA, with the Vegetation map of South Africa (Mucina and Rutherford, 2005), 10 biomes may be impacted upon, currently covering 225 different vegetation types.

With global warming, aridification is almost certain and the two biomes that will be under severe treat are the Succulent Karoo Biome and the Nama Karoo Biome. The Succulent Karoo Biome which has the highest diversity of succulents in the world (Rutherford et al., 2006) and is regarded as the only biodiversity hotspot occurring entirely in an arid region (Mittermeier et al., 1999). It is of the utmost importance that this biome be protected at all cost. Both the Succulent Karoo Biome and the Nama Karoo Biome are likely to be converted to the Desert biome (Driver et al., 2012). It is therefore important that conservation areas be expanded and habitat fragmentation limited, especially in these two biomes, since it is expected that the boundaries of these biomes are likely to shift and current protected areas might not be sufficient anymore. Rutherford et al. (2000) rightly argued for the prevention of further habitat fragmentation to combat the significant changes that are likely to occur. Should this not be taken seriously it will be a case of "*missed opportunities for a better future"* (Rutherford et al., 2000).

More research is also needed to determine the climatic thresholds of species which will enable government to make better decisions on future land-use (such as unconventional oil and gas mining) and the expansion of protected areas. In light of the fact that the above suggested research has not been performed and are likely to be long-term projects, it is therefore essential to conserve as much habitat as possible.

A direct impact of unconventional oil and gas mining is the clearing of vegetation resulting in short, medium and long term consequences, again, depending on where in South Africa the mining is taking place. The more arid, (with less rainfall, both in volume and occurrence), the more difficult rehabilitation will be (Milton and Dean, 2012). To illustrate the scale on which vegetation clearing could take place, reference is made to Broomfield (2012) who has listed the surface area of a well pad as 3 ha. In a report by the International Energy Agency (IEA, 2012), an example was used of Johnson County, Texas, USA, where the well site density was determined from satellite imagery and indicated that 37 well sites occurred in a 20 km^2 area. The average density of well pads (assuming that all the sites are evenly distributed) was almost 2 well sites per km^2. These well pads need to be connected by roads and pipelines, contributing to habitat fragmentation.

Habitat fragmentation poses an extensive and significant threat, not only to biodiversity, but also to ecosystem functioning. It was found that habitat fragmentation happened on an extensive scale in the State of Pennsylvania, USA (Drohan et al., 2012, Slonecker et al., 2012). Until June 2011 at least 644–1072 ha of agricultural land (45–62% of well pads) and 536–894 ha of forest land (38–54% of well pads) were converted and at least 649 km of new roads and pipelines were built. Besides contributing to significant habitat fragmentation, it is also an indicator of an increased level of stress on food production, and food security (Millar and Roots, 2014).

When discussing habitat fragmentation it is very important to emphasise the effect of patch dynamics on an ecosystem. The more fragmented the vegetation in an area gets, the larger the edge-effect. The construction of access roads, pipelines and drilling sites will also have an impact on the soil. In a study done by Watts in 1998, it was found that when soil gets compacted by vehicles, the rate of infiltration of rain will decrease and overland flow (surface runoff) will increase, contributing to more soil erosion and less nutrient infiltration. These tracks also get used by more wildlife and livestock and the erosion rate increases (Milton, 2012). Enlarged, more prominent tracks lead to further habitat fragmentation. Williams et al. (2012) also argued that further loss in connectivity in the landscape due to an increase in habitat fragmentation might have a significant negative effect on ecosystem functioning.

An increase in access roads will also add to the possibility of the spread of alien invasive species and new plant diseases. Building material and machinery that is moved from one site to the next, the use of sand mined from elsewhere, are all pathways with which alien invasive species spread (Milton, 2012). Alien invasive species pose a serious threat to South African ecosystems that are currently moderately intact. An example is the Mesquite (*Prosopis spp.)*, which already poses a significant threat to the community structure of indigenous vegetation in a large part of the Northern Cape Province (Milton, 2012). It is projected that the *intactness score* for different biomes in South Africa could decrease considerably. In the most arid, western side of the country, the Succulent and Nama Karoo biomes are under the highest threat (Van Wilgen et al., 2008). An increase in roads, by inference increase access to previously remote areas. This could in turn increase the occurrence of illegal trade in succulents e.g. *Haworthia* (Lovegrove, 1993) as well as uncontrolled wild fires.

Plants may die off due to spills, including waste water, chemicals, or flow back water. In an empirical study done by Adams (2011) showed that vegetation such as shrubs, have died within a few days after an experimental spill took place, while trees started to show signs of distress (leaf fall) within 7 to 10 days after the spill took place. Although it was argued by Adams (2011) that such a localized spill is unlikely to occur, there is no doubt that vegetation die-off will occur with detrimental effects and with very little likelihood of being rehabilitated. It was also found by Mandre and Pärn (2005) that conifers in northeast Estonia showed signs of retarded growth of needles, shoots and radial growth due to air pollution emitted from the oil shale industry.

Although it is not clear if the type of sand that occurs in South Africa is appropriate for hydraulic fracturing, this impact will be discussed as a secondary impact associated with unconventional oil and gas extraction. Sand in South Africa is usually mined from river beds, although sand mining may not only be limited to river beds. This activity in itself is highly destructive and the ecological consequences are very broad (Personal observations, Mokolo River, April 2012). By extracting sand from a river bed, a change in geomorphology will occur, which will alter the water course in the river and change the capacity of the river bed for water storage and to sustain longitudinal connectivity in base flow. This in turn could have an effect on the velocity of the water, e.g. increasing the energy of the flow that could erode the river banks, decreasing their stability, and consequently the reduction or loss of riparian vegetation. The use of chemicals during the washing and processing of sand also threaten surface and groundwater should a spill occur (Pearson, 2013).

A significant risk associated with the monitoring of the impacts of any development, is the lack of baseline data to establish the change from the baseline situation. This is however not only a South African phenomenon, but also problematic in other countries like the USA (Broomfield, 2012).

More worrisome is the lack of Strategic Assessments on the cumulative impacts that the different activities discussed above, will have on the plant diversity of South Africa. Since the unconventional oil and gas extraction applications have been listed for the majority of the land surface of South Africa, the impacts are also expected to be widespread, crossing Provincial boundaries. It is unclear how the current limited human capacity in Provincial Departments will cope with these unprecedented activities. It is assumed that each oil and gas company will have individual EIA's for each site, sometimes in different provinces, which will result in "death by a 1000 cuts" of the ecosystem, which will not be able to provide the environmental goods and services that humanity depends on anymore (Pers comm. J. Williams, November 2012).

In a study on the successes and failures of rehabilitation that was done by Johnstone and Kokelj, (2008) in the Arctic Tundra in Canada, the vegetation cover on sumps was acceptable after 30 years, post mining, but the vegetation structure was still not comparable with the surrounding vegetation.

Re-vegetated sites showed better results in terms of cover, but species composition was still not the same after 30 years. This was due to topographical differences due to construction of the sumps. As discussed by Milton (2012), when species are lost, it will have a cascading effect on the ecosystem. This is particularly evident when keystone species are lost.

In the next section, a brief overview will be given on the impact of the different unconventional oil and gas extraction activities during the different phases of mining.

3.1.4.1 Impacts

Impacts on vegetation would cover positive, negative and uncertain impacts and will be discussed in terms of the following periods of oil and gas extraction: During oil and gas exploration, during oil and gas extraction and post oil and gas extraction. Table 5 shows a summary of the impacts.

Table 5: Possible impacts on vegetation

Phase	Positive impacts	Uncertain positive impacts	Uncertain negative impacts	Negative impacts
During exploration	None indicated in the literature.	• Possible new species due to vegetation clearance for drilling site and road con-struction.	• Alien invasive species encroachment due to vegetation clearance for drilling site and road construction. • Woody vegetation removal for food and fibre. • Possible occurrence of increased incidence of wild fires. • Surface spills of hazardous material [2] due to surface spills of hazardous material.	• Loss of biodiversity due to vegetation clearance for drilling site and road construction. • Habitat fragmentation due to vegetation clearance for drilling site and road construction. • Soil compaction – increased erosion and decrease rate of infiltration due to drilling site construction and fracking as well as seismic lines.
During extraction			• Alien invasive species encroachment [9] due to vegetation clearance for drill site, road and pipeline infrastructure. • Air pollution [8] due to increased truck traffic. • Surface spills of hazardous material [2] due to temporary storage and trucking of hazardous material (e.g. flowback water).	• Loss of Biodiversity [5, 7] due to vegetation clearance for drill site, road and pipeline infra-structure. • Habitat fragmentation due to vegetation clearance for drill site, road and pipeline infrastructure. • Soil compaction [6] due to increased truck traffic. • Dust pollution due to increased truck traffic. • Woody vegetation removal Increased use of fire by on-site workers for cooking etc. – increase of use of woody species in the vicinity of the drilling site. • Occurrence of increased wild fires Increased use of fire by on-site workers for cooking etc. – increase of use of woody species in the vicinity of the drilling site.
After extraction	None that could be identified in the literature.		• Migration of polluted ground- and/or surface water pollution to the rooting zone – vegetation die-back.[4] • Will surface rehabilitation be successful?	• Continuing habitat fragmentation [3, 9] due to poor upkeep of existing infrastructure, roads or alien invasive control. • Continuing loss of plant biodiversity due to a continued loss of ecosystem services and possible alien invasive species.[1,5] • Continued trade of e.g. succulents due to access roads.[5]
References			2: Adams, 2011; 8: Mandre and Pärn, 2005; 4: Steyl et al., 2012; 9: Van Wilgen et al., 2008; 10: Johnstone and Kokelj, 2008	1: Northrup and Wittemyer, 2013; 3: O'Connor and Kuyler, 2006; 5: Lovegrove, 1993; 6: Watts, 1998; 7: Milton, 2012;9: Van Wilgen et al., 2008

3.1.4.2 Availability of data to map this aspect

Various databases exist, such as:

- The vegetation types and their conservation status (extracted from the updated South African National Vegetation Map (Mucina and Rutherford 2006)).
- Information on plant and animal species recorded for the relevant Quarter Degree Squares (QDS) (extracted from the SABIF/SIBIS database hosted by SANBI).
- Threatened Ecosystem data (extracted from the National List of Threatened Ecosystems 2010).
- Protected areas expansion areas (extracted from the National Protected Areas Expansion Strategy 2008 (NPAES)).
- Critical Biodiversity Areas maps and fine scale conservation plans where available (usually at a district, municipality or provincial level)

3.1.5 Soil

Shale oil and gas and CBM extraction might have a large impact on soil. Soil may serve as a pathway for contaminants that may contaminate surface water, groundwater as well as vegetation.

The exploratory technique used will largely determine the impact on the soil. With non-invasive methods such as the vibroseis technique compaction is presumably kept to a minimum. The minbuggies spent less than 4 seconds on a vibrating point and a single vibrating point is only used once (ESG, 2011). Soil compaction can however occur instantly with limited correlation between the duration and frequency of external impact. Compaction will lead to reduced soil porosity (increased bulk density) and consequently reduced storage capacity and root penetration and water infiltration. Reduced infilration will lead to more overland flow and consequently a higher sensitivity to erosion (Brady and Weil, 2008). With the vibroseis technique the groundcover is normally left *in situ* and the stabilizing ground covers and the vegetative root stock are therefore left intact (ESG, 2011). Invasive methods such as dynamite based seismic will lead to large scale disturbance of the soil surface. Employing the correct exploration technique can however reduce the negative impacts on soils.

Large scale excavation of surface and subsoil is necessary in order to level well pads (often more than 1 ha). The removal of natural vegetation to build well pads and will result in alternating natural water flow paths. Building of roads and stream-crossing may result in erosion and sediment loss on erosion sensitive soils (Beemster and Beemster, 2011). Roads will also cause compaction of soil and increase the area of bare soil due to the removal of vegetation. This will result in reduced porosity and increased sensitivity to erosion due to less infiltration and surface stabilizing material (Watts, 1998).

Fracking carries the risk of leakages from polluted tailing ponds, wastewater and well blowouts and may cause severe soil pollution. In Germany leakage from a wastewater pipe at a tight gas field (Sohlingen) caused benzene and mercury contamination requiring the replacement of agricultural soil where the fluids leaked into the ground (Lechtenböhmer et al., 2011). In New Mexico increased methane concentrations in the shallow root zone resulted in dying vegetation, according to land owners. Examination of soil-gas-methane levels adjacent to 352 gas well casings revealed that gas-well annuli, which are the interspace between casing and wall of drilled hole, were frequently the conduit for movement of methane to surface soils (EPA, 2004). In Pavillion, Wyoming high contents of diesel range organics, gasoline range organics and total purgeable hydrocarbons were measured in soils close to old storage pits for drilling wastes (EPA, 2011b). More examples and case studies of how soils were contaminated by well failure and surface spills can be found *inter alia* in EPA (2011a) and AEA (2012). According to Zoback et al. (2010) the manner in which wastes are temporary stored and transported is crucial. In many cases contaminant rich fluids are stored in unlined evaporation pits resulting in seepage into the subsoil. Even if the fluids do not directly seep into the soil, large rain events might cause pits to overflow, resulting in large areas contaminated by runoff water.

In the case of coalbed methane extraction, additional water supplies are seldom required during production and the water extracted during the dewatering process can be used for irrigation purposes, especially in arid and semi-arid areas (IEA, 2012). Produced water have been successfully used in a number of cases to increase the productivity of the soil through irrigation, resulting in more vegetative growth (less erosion) and higher soil organic matter contents (DOE, 2004). If drilling wastes are applied correctly land spreading of treated wastes does not impact soils negatively but might even benefit sandy soils by increasing water and fertilizer retention capacity. More research on this regard are however required (Taranaki Regional Council, 2011).

Although produced water during coalbed methane extraction might impact the soils positively, negative impacts are reported frequently. Depending on the geology of the deposit produced water can be sodic and salty, containing high concentrations of calcium, magnesium and sodium (IEA, 2012). Studies on the use of CBM produced water suggested that the precipitation of calcium carbonate might decrease infiltration rates thereby decreasing infiltration rates and increase overland flow and erosion. Elevated Sodium Adsorption Ratios (SAR) and Exchangeable Sodium Percentages (ESP) have also been recorded, resulting in dispersion of soil structure, reduction of soil porosity, and consequently reduce infiltrability and conductivity leading to surface erosion and increased sensitivity to drought stress. High Electrical Conductivity (EC) values recorded in soils irrigated of CBM water will further increase the osmotic potential and can significantly influence crops and natural vegetation's capability to absorb water (EPA, 2010; IEA, 2011).

3.1.5.1 Impacts

Impacts on soil would cover positive, negative and uncertain impacts and will be discussed in terms of the following periods of oil and gas extraction: during oil and gas exploration, during oil and gas extraction and post oil and gas extraction. Oil and gas extraction would include all the relevant tight oil and gas resources on which hydraulic fracturing may be applied to extract the oil and gas, which in South Africa are shale oil and gas deposits and CBM deposits. Table 6 shows the possible impacts.

Table 6: Possible impacts on soil

	Positive impacts	Uncertain positive impacts	Uncertain negative impacts	Negative impacts
During exploration			• Soil compaction due to seismic surveys that may use thumper trucks (vibroseis may be used, but alter-natively explosive charges could also be used which would lower the impact of soil compaction).	• Enhanced soil erosion to due removal of vegetation for seismic surveys.
During extraction	• Use of high quality (CBM) produced water for irrigation might improve productivit y of soils.[1, 2]	None that could be identified.	• Chemical, biological and physical properties of soils might be altered during fracturing possibly changing the mobility of natural occurring substances and altering natural hydrological cycle.[3, 4, 5]	• Soil contamination due to possible surface spillages of contaminants.6 • Enhanced soil erosion due to vegetation removal for well pad establishment.[7, 8] • Use of low quality (salty and sodic) produced water will result in decreased physical potential through disruption of porosity and increased osmotic potential.[9, 10]
After ex-traction				• Long term impact of soil pollution due to ineffective remediation.
References	1: IEA, 2012; 2: USDOE, 2004		3: USEPA, 2011a; 4: USEPA, 2011b; 5: Broomfield, 2012	6: Zoback et al., 2010; 7: Beemster and Beemster, 2011; 8: Watts, 1998; 9: IEA, 2012; 10: USEPA, 2010

3.1.5.2 Availability of data to map this aspect

The Land Type survey of soil distribution patterns on a scale of 1:250 000 is available for the whole of South Africa (Land Type Survey Staff, 1972-2006). This survey presents areas with similar climates, geologies, geomorphology and consequently soil distribution patterns.

3.1.6 Air quality

Air quality is one of the entities on which oil and gas mining might have an impact. Section 3.1.6.1 discusses the impacts while Section 3.1.6.2 discusses the availability of data to map this aspect.

3.1.6.1 Impacts

Impacts on air quality would cover positive, negative and uncertain impacts and will be discussed in terms of the following periods of oil and gas mining: During oil and gas exploration, during oil and gas extraction and post oil and gas extraction. Oil and gas extraction would include all the relevant tight oil and gas resources on which hydraulic fracturing may be applied to extract the oil and gas, which in South Africa are shale oil and gas deposits and CBM deposits. Table 7 shows a summary of the impacts.

Table 7: Possible impacts on air quality

	Positive impacts	Uncertain positive impacts	Uncertain negative impacts	Negative impacts
During exploration	None that could be identified.	None that could be identified.	• Dust release due to vegetation clearance for seismic surveys may be high.[3] Emissions due to removal of carbon stocks.[4]	• Toxic gasses released due to venting.[6, 8] Emissions (diesel) released by thumper trucks, equipment and construction activity.[6, 8, 9, 10]
During extraction	• Cleaner burning fuel than coal. [1, 2]	• Newer technologies may decrease the amount of methane lost to the atmosphere during oil and gas extraction.[2]	• Compared against other power generation technologies (e.g. nuclear with zero emissions) methane emissions may be so high as to negate the gains in terms of the cleaner burning capability of the oil and gas.[1, 2, 5, 6, 7] • Uncontrolled flaring due to inadequate legislation [12] and poor infrastructure.[13, 14, 15]	• High methane emissions that contribute to greenhouse gas emissions.[2, 4, 5, 6, 8, 9, 10] • Secondary impacts of methane releases are health impacts (cancer etc.).[8, 11] • Gas migration and built-up near structures may pose explosion risk.[16]
After extraction	None that could be identified.	• Air quality emissions in the region of previous oil and gas extraction lowers.	None that could be identified.	• Pollution still emitted at waste disposal sites, compressors, condensate tanks and in flow back.[4, 8, 9, 10] • Gas migration and built-up near structures due to poor well sealing may pose explosion risk.[16]
References	1: DB Climate Change Advisors, 2011; 2: Tollefson, 2012	2: Tollefson, 2012	1: DB Climate Change Advisors, 2011; 2: Tollefson, 2012; 3: Environmental Protection Authority, 1996; 4: Forster and Perks, 2012; 5: Wuebbles and Hayhoe, 2002; 6: Howarth. et al., 2011; 7: Sovacool. 2008; 12: Farina, 2011; 13: Twine, 2012; 14: DMR, 2012; 15: IEA, 2012	2: Tollefson, 2012; 4: Forster and Perks, 2012; 5: Wuebbles and Hayhoe, 2002; 6: Howarth et al., 2011; 8: Global Community Monitor, 2011; 9: Broderick et al., 2011. 10: Klausmann et al., 2011;11: Research and Policy Centre, 2012; 16: DEP, 2009

3.1.6.2 Availability of data to map this aspect

A central database with air quality is maintained by the South African Weather Service, the South African Air Quality Information System (SAAQIS). Data from government departments, as well as various mines and industries is stored on the SAAQIS (see www.saaqis.org.za). The monitoring stations are usually widely distributed (Pers comm Zunckel, 2012) and data may be made available by request to the individual data holders. This situation makes it very difficult to obtain representative data for mapping purposes.

3.1.7 Aquatic invertebrates

The potential areas identified for hydraulic fracturing in South Africa include a section of the subtropical coastal peneplain (low relief plain) including the Limpopo River basin, the summer rainfall region of the elevated plateau and large sections of the arid west limnological region identified by Allanson et al. (1990). The limnological regions, which will be discussed next, can be seen in Figure 3.

Region 1: The subtropical peneplain region includes the rivers in Northern Kwazulu Natal and Eastern and Northern Limpopo. The region has extensive floodplains and has many shallow wetlands, floodplain pans and freshwater lakes. The aquatic fauna of this region is “Pan Ethiopian”, having palaeartic and oriental affinities, with tropical warm stenothermal (fauna sensitive to change in temperature) species (Harrison, 1978). The region is characterised by invertebrates such as the mayfly families, which are sensitive to temperature and water quality (pale burrowers, brushlegged mayflies and prongills) as well as stoneflies, caddisflies, blackflies and midges. The freshwater shrimp (tolerant of salinity) also occurs in this region (Davies et al., 1993).

Region 2: The summer rainfall region of the elevated plateau and south eastern coastal plains includes the larger part of the Highveld and the Bushveld plains of the Limpopo Plains. The region is characterised by rivers, endorheic pans and “vleis”. Both temporary and permanent waterbodies are found. Many of the rivers have already been impacted on by dams. Water quality in the rivers of the summer rainfall region is mostly alkaline with a high level of turbidity. The aquatic fauna is Pan Ethiopian (Sub-Saharan). Some of the invertebrates present in the Highveld area are freshwater shrimps, stoneflies, mayflies, dragonflies and damselflies, caddisflies, blackflies, midges and several bugs and beetle families (Davies et al., 1993).

Region 5: The Arid Karoo. The Orange River basin drains most of this region. The Sundays and Great Fish River basins are also included in this region. Most of surface water is temporary and many pans (mostly endorheic) are present (Noble and Hemens 1978). The aquatic invertebrates of the Orange River downstream of the Vaal River confluence are mostly resilient from the Pan Ethiopian element, which is widespread, hardy and temperature tolerant (eurythermal) (Davies et al., 1993). The aquatic fauna in this region consists mostly of water mites, bugs, beetles, mayflies, dragonflies, damselflies and resident fauna, such as the midges and earthworms that have the ability to survive when the waterbodies dry out. Although these fauna are hardy and resilient they each have a specific part to play in the functioning of the freshwater ecosystem ensuring the provisioning of ecosystem services such as clean water.

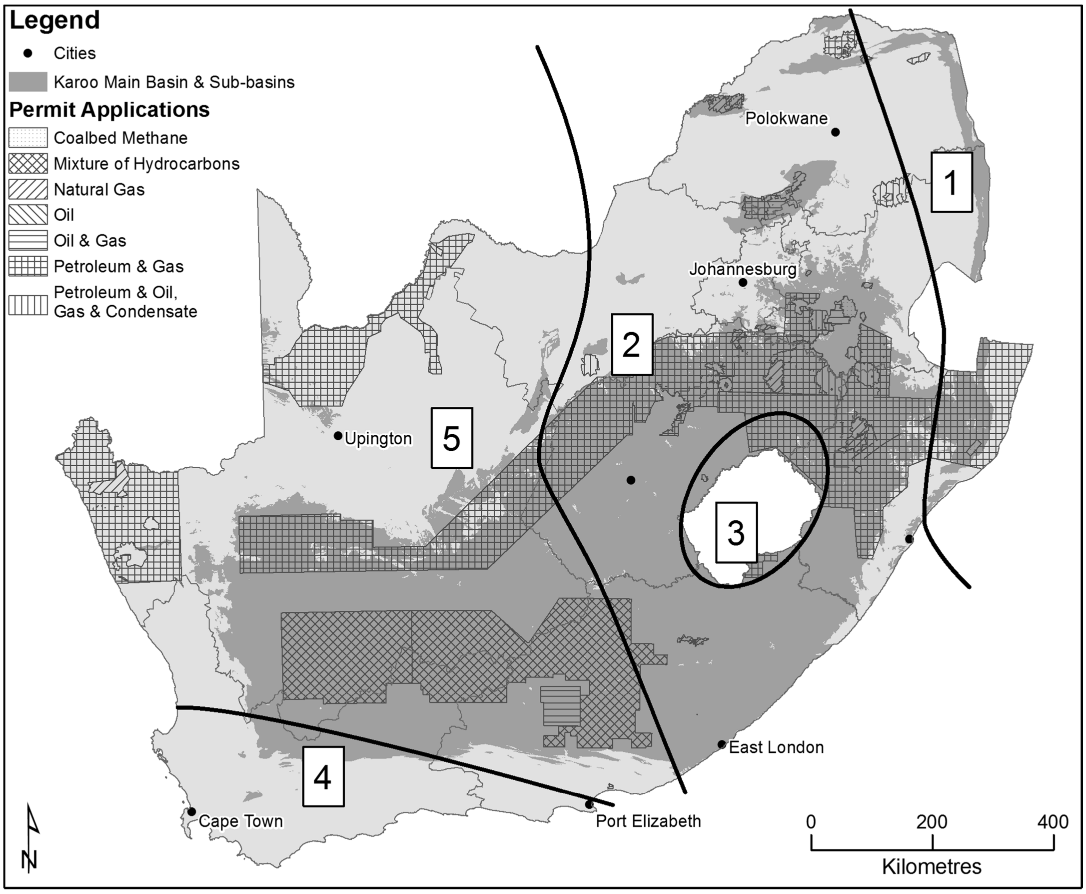

Figure 3: Limnological regions of southern Africa proposed by Allanson et al. (1990) overlain on proposed hydraulic fracturing areas.

For this background review only the arid west region will be discussed in terms of impacts on aquatic invertebrates. Data on aquatic invertebrates in this region is sparse especially for the smaller temporary tributaries where very little research has been done. Many studies have been completed on the Orange River and some on a few of its tributaries. A new species of stonefly (sensitive species which are mostly restricted to cool, well oxygenated unpolluted mountain streams) (Marsh and Desmet 2008) has been found in Kamiesberg Upland area. Although this does not fall in the area where hydraulic fracturing could occur it illustrates the fact that several new species of aquatic invertebrates could be present in the arid western region.

3.1.7.1 Impacts

Impacts on aquatic insects would cover positive, negative and uncertain impacts and will be discussed in terms of the following periods of oil and gas extraction: During oil and gas exploration, during oil and gas extraction and post oil and gas extraction.

Oil and gas extraction would include all the relevant tight oil and gas resources on which hydraulic fracturing may be applied to extract the oil and gas, which in South Africa are shale oil and gas deposits and CBM deposits. Table 8 shows the possible impacts on aquatic invertebrates.

Table 8: Possible impacts on aquatic invertebrates

	Positive impacts	Uncertain positive impacts	Uncertain negative impacts	Negative impacts
During exploration	None that could be identified.	None that could be identified.	• Impact of vibration generated during seismic exploration on invertebrates.[7] • Impact of removal of sand on biota in alluvial aquifer/hyporheios.[33]	• Increase of sediment in rivers would increase turbidity and limit habitat and food available to invertebrates.[1, 2, 3, 4] • Diesel pollution reduces abundance and diversity of freshwater invertebrates.[5, 6]
During extraction	None that could be identified.	None that could be identified.	• Impact of removal of sand on biota in alluvial aquifer/hyporheios.[33]	**Shale oil and gas extraction** • Abstraction of water from surface water would lead to decrease in connectivity which would result in decrease in abundance, diversity of invertebrates, and increase in pest species. [8, 9, 10] • Change in land use would lead to rivers and pans becoming isolated resulting in genetic isolation, reduction in number of refugia, disruption of migrating routes of birds, amphibians, invertebrates and other biota.[11, 13] • Increase in sediment in rivers.[3] • Pollution of surface water by chemicals etc. in fracking fluid influence invertebrates.[6, 14. 15, 16, 17, 18] • Mercury impacts on larval stages of invertebrates.[19] • Uranium pollution affect valve closure of bivalves and result in impact on reproduction as well as mortality of certain invertebrates.[20, 21] • Invertebrates are sensitive to strontium pollution.[22, 23, 24, 25] • Pyrite reduces pH which can be toxic to invertebrates.[26] • Pollution by metals and trace elements.[27] • Toxins such as 4,4-Dimethyl-oxazolidine and 2,2-Dibromo-3-nitrilopropionamide are toxic to certain invertebrates.[3, 28] High levels of TDS in produced and flowback water would impact on surface water if released and impact on invertebrates.[29]
References			7. McCauly et al., 2000; 33. Boulton et al., 1998.	1. DWAF, 1996; 2. Chutter, 1969; 3. Bishop, 2011; 4. Vaughn, 2005; 5. Lytle and Peckarsky, 2001; 6. Wood et al., 2011; 8. Broomfield, 2012; 9. Grubert and Kitasei, 2010; 10. DMR, 2012; 11. Palmer, 1996; 13. Mead et al., 2011; 14. Peterson et al., 2002; 15. Sumi, 2010; 16. CIEH, 2012; 17. Herridge et al. 2012; 18. Ramirez, 2005; 19. Boening, 2000; 20. Pickett et al., 1993; 21. Canadian Council of Ministers of the Environment, 2011; 22. Sample and Irving 2011; 23. USDOE, 2002; 24. NCRP, 1991; 25. IAEA, 1976; 26. Dallas and Day, 1993; 27. Davis et al., 2006; 28. Thompson and Forbis, 1979; 29. Pennsylvania Department of Environmental Protection, 2009

Table 10 continued: Possible impacts on aquatic invertebrates

	Positive impacts	Uncertain positive impacts	Uncertain negative impacts	Negative impacts
During extraction				**Coalbed methane extraction** • Release of coalbed methane discharge in rivers increases pH and result in increase in level of un-ionised ammonia which is toxic to invertebrates.[30, 31] • A decrease in the macro-invertebrate abundance after produced water from CBM was released into the surface water.[32, 33]
After extraction	None were identified.	None were identified.	• Contamination due to possible groundwater contamination as they are interconnected.[34]	None were identified.
References			34: Graham and Butts, 2005	30. Patz et al., 2004; 31. Malan and Day, 2002; 32. Vickers, 1990; 33. O'Neil et al., 1993

3.1.7.2 Availability of data to map this aspect

No specific database can be used for mapping aquatic invertebrates as the databases available are incomplete and do not have data available for all the tertiary catchments identified as potential areas for unconventional oil and oil and gas extraction. Freshwater Ecosystem Priority Areas in South Africa (Nel et al., 2011b) could be used as a surrogate for freshwater invertebrate condition. A pristine or unmodified river or wetland would imply a healthy invertebrate community.

These databases include:

- Percentage natural wetland – ranging from 100% natural (pristine) to 50% natural (modified).
- River condition – ranging from unmodified (pristine) to critically modified.
- River Freshwater Ecosystem Priority areas – ranging from areas where biodiversity targets are met (pristine) to modified (biodiversity targets not met).

These databases are a collection of data collected as part of a national project and include knowledge from most of the freshwater specialists in South Africa. Data from the updated PESEIS database (DWA, 2013a) can also be used as a surrogate for invertebrate vulnerability mapping.

3.1.8 Terrestrial insects

Insects form a large part of living species. They have immense species richness and represent major functional groups such as herbivores, pollinators, parisitoids and predators (Strong et al. 1984). The diversity of insect life forms makes insect communities an important part of terrestrial ecosystems (Strong et al. 1984). Invertebrates are the most dominant animals in the Karoo, and very diverse, and evidence suggests that more than half of the species in some insect groups are endemic (Dean and Milton, 1999). Unconventional oil and gas extraction may have a large impact on terrestrial insects.

3.1.8.1 Impacts

Impacts on terrestrial insects would cover positive, negative and uncertain impacts and will be discussed in terms of the following periods of oil and gas extraction: During oil and gas exploration, during oil and gas extraction and post oil and gas extraction.

Oil and gas mining would include all the relevant tight oil and gas resources on which hydraulic fracturing may be applied to extract the oil and gas, which in South Africa are shale oil and gas deposits and coalbed methane deposits. Table 9 shows a summary of the impacts.

Table 9: Possible impacts on terrestrial insects

	Positive impacts	Uncertain positive impacts	Uncertain negative impacts	Negative impacts
During exploration	None that could be identified.	None that could be identified.	• Clearing and resource depletion of vegetation can decrease generalist and opportunistic species population and diversity.[5]	• The transportation infrastructure will cause habitat fracturing and plant resource depletion. This will affect plant–pollinator and predator-prey interactions.[7]
During extraction	None that could be identified.	None that could be identified.	• Greater fragmentation and resource depletion of vegetation can decrease generalist and opportunistic species population and diversity.[1,8]	• More land clearing and transportation infrastructure will cause habitat fracturing and plant resource depletion. This will affect trophic levels, plant – pollinator and predator-prey interactions.[7,8]
After extraction	None that could be identified.	None that could be identified.	None that could be identified.	None that could be identified.
References			1. Aizen and Feinsinger, 2002; 5. Gibb and Hochuli, 2002; 8. Strong et.al., 1984	7. Steffan-Dewenter and Tscharntke, 2002; 8. Strong et al., 1984

3.1.8.2 Availability of data to map this aspect

There are no known electronic databases that exist for insects in southern Africa. The South African National Collection of insects at the Agricultural Research Council is one of the most comprehensive collections of Southern African terrestrial insects, and electronic databases are still being developed. The book, Field Guide to Insects of South Africa by Picker et al., (2004), is a comprehensive guide to African insects of over 1 200 species. This book is not a complete insect database and should be used with caution.

3.1.9 Mammals

Small and large mammals are one of the entities on which oil and gas extraction might have a large impact. The areas where oil and gas mining applications have been submitted (nationally) contain the full suite of South African small and large mammal species. Environmental impacts are described for the whole Karoo Geological Basin area generally and for the Karoo biome in more detail due to the large proportion covered by the proposed activities and the high proportion of threatened and endemic small mammals that occur in these areas. The Karoo biome boasts a diversity of elephant shrews (sengi), including the recently-discovered (in 2008) Karoo rock elephant-shrew (*Elephantulus pilicaudus*, Smit et al. 2008), known from only five localities near Calvinia and Loxton. Vervet monkeys and chacma baboons are present in the Karoo. Lagomorphs, including the Cape hare, Scrub hare, and Smith's Red Rock Rabbit are present, as well as the Critically Endangered Riverine Rabibit, *Bunolagus monticularis*, which is endemic to the Karoo and is highly threatened by existing habitat loss and fragmentation due to anthropogenic causes (IUCN, 2012a). The antbear or aardvark (*Orycteropus afer*) and porcupine (*Hystrix africaeaustralis*) play an important role in the ecosystem for their role in natural disturbance and habitat creation (pits, diggings and burrows) (Dean and Milton 1991, Bragg et al. 2005), As many small mammals (as well as reptiles and invertebrates) rely on burrows and crevices in the substrate to escape extreme cold and heat (Lovegrove 1993), the role of habitat modifiers, such as aardvark, probably play a key part in supporting small mammal diversity. Some Karoo small mammals are threatened and rare, such as Visagie's Golden Mole (*Chrysochloris visagiei*) which is also a Critically Endangered species, with very little information on its habitat or presence in the Nama-Karoo (Skinner and Chimimba 2005). Further afield from the Nama-Karoo but within shale gas application areas, species such as the white-tailed mouse (*Mystromys ablicaudatus*) are endangered. Aardwolf, pangolin and shrews occur marginally in the Karoo biome along the more mesic habitats on the edges of the Karoo (Dean and Milton 1999).

The greater areas where unconventional oil and gas extraction is likely to occur (should applications and other processes be approved), include most of South Africa's large mammals, as mentioned earlier, and include domestic animals, livestock and wildlife. As the main Karoo basin and the sub basins in the north and north-east of the country are potential targets for unconventional oil and gas extraction, this means that the ranges of almost all the indigenous wildlife species will be affected to a greater or lesser extent. Vulnerable large mammals include black rhinoceros *Diceros bicornis minor*, blue duiker, bontebok, Cape mountain zebra, cheetah, lion, pangolin, roan and sable antelope, samango monkey and suni. The African elephant and the hippopotamus are also listed as vulnerable globally although they are considered as lower risk regionally. Endangered species include wild dogs, Hartmann's mountain zebra, tsessebe and the black rhinoceros (arid ecotype) *Diceros bicornis bicornis* (Critically Endangered) (IUCN, 2012a). The Red Data Book of the Mammals of South Africa (Friedman and Daly, 2004), lists 249 species/subspecies of terrestrial mammals; of which 14% are endemic to South Africa; whilst in the list of threatened species 10 are listed as Critically Endangered (of which 70% are endemics), 18 species as Endangered (37.5% being endemics), and 25 species as Vulnerable (with 16% as endemic). This does not include new species / subspecies added since 2004.

The occurrence of the terrestrial endemics in South Africa is not spatially even, and there is a biased density of occurrence in the southern and western Cape spreading through the eastern Cape and KwaZulu-Natal (especially the coastal forest areas) and up along the Mpumalanga escarpment and with isolated distribution patches on the Gauteng and Limpopo highveld areas. The highest densities of endemicity are in the arid west of the country and the majority of the species listed are small, burrowing mammals (including, the golden moles, Cape mole rat and the riverine rabbit).

It is important to note that, historically, many of the areas under application (especially in the more sparsely populated, arid western part of the Karoo geological basin) have been very poorly sampled and thus for many groups of animals, currently mapped distributions and point localities will not adequately reflect the full complement of animal diversity that is likely to occur at any site. Consequently, the potential impacts of shale oil and gas extraction on small and large mammals has been assessed using the available (and in some cases, limited) existing knowledge in conjunction with a habitat- and ecosystem function-based approach (Noss, 1990), this is likely to have a moderating influence on the resulting assessment as given here.

3.1.9.1 Impacts

Impacts on small and large mammals would cover positive, negative and uncertain impacts and will be discussed in terms of the following periods of oil and gas extraction: During oil and gas exploration, during oil and gas extraction and post oil and gas extraction.

Oil and gas extraction would include all the relevant tight oil and gas resources on which hydraulic fracturing may be applied to extract the oil and gas, which in South Africa are primarily shale oil and gas and CBM deposits.

The extent of the impacts on small and large mammals will be determined by the scale of the oil and gas development. Furthermore, impacts on mammals are likely to vary depending on the habitat requirements, size and behaviour of the species concerned. Due to uncertainty around the intensity and extent on which unconventional oil and gas extraction will take place, it is not possible to deduce exact impacts that this type of activity will have on the fauna of South Africa. Reliable information from the oil and gas companies on the expected density and locations of well pads will be critical in determining the impact on fauna in the area. Ideally this information should be available before exploration starts, to be able to focus baseline faunal monitoring of an area.

The most likely and most harmful impacts would be caused by the large amount of roads, pipelines and well pads required for the development of commercial oil and gas extraction (Slonecker et al. 2012), which could result in habitat fragmentation of small mammal populations in particular, and could facilitate increased levels of predation. Fragmentation is the subdivision of contiguous areas of habitat by extensive linear developments, such as roads and pipelines, into smaller and increasingly dispersed fragments (see Seiler 2001 for a review). As fragmentation increases, individual fragments may become too small and too isolated from each other to support viable populations of those species that depend on that particular habitat (Fahrig and Merriam, 1994). Fragmentation therefore reduces the amount of habitat available to wildlife in the landscape and thereby diminishes population sizes and the number of species that can live in the affected landscape (Fahrig and Merriam, 1994; Seiler 2001). It is however very difficult to predict the extent of this impact as there are no previous studies of unconventional oil and gas extraction impacts on mammals. Although the roads are likely to fragment the landscape, this would have different levels of impact for different species – for example, the more mobile, larger species would be able to traverse roads and cleared areas more easily than slower moving, smaller, shy or subterranean fauna, which are likely to experience greater difficulty. However, although larger mammals are more mobile the possibility exists that reductions in habitat availability and the fragmentation of remaining habitat could negatively impact such factors as home range size, foraging behaviour, territoriality and territory size; all of which are functions of population density which is in turn influenced by suitable habitat availability. The full implications of these impacts would require further study as they are compounded by localised intra- and interspecific habitat requirements, restrictions and limitations (Carette et al., 2005; Litvaitis et al., 1994).

The direct impacts of roads and vehicular traffic on mammals include collisions between wildlife and vehicles; and increased predation risk while traversing roads. The potential for collisions with mammals is proportional to traffic volume and speed. Hence, roads that are infrequently used by vehicles travelling at relatively low speed will generate significantly less impact than roads used by large volumes of high speed traffic. Thus there is likely to be high potential negative impacts of mortality caused by collisions during the construction and operational phases of unconventional oil and gas development when large volumes of heavy vehicles are likely to be using the roads (Ewen et al., 2012), and a relatively low impact during the exploration and post extraction phases when traffic volumes are likely to be lower.

Since the risk of predation for many small mammal species is higher in open areas, such as cleared areas or roads, this could result in increased predation levels on many species. Predators such as crows are adept at taking advantage of open areas such as roads (Dean et al., 2006) and will quickly learn to utilise the roads and other infrastructure developments to search for exposed prey items. Table 10 shows a summary of the impacts on mammals.

Table 10: Possible impacts on mammals

	Positive impacts	Uncertain positive impacts	Uncertain negative impacts	Negative impacts
During exploration	None known.	EIAs must be conducted, leading to new local data on mammal species. Habituation to exploratory activities.[24, 41]	• Potential biodiversity loss, species loss and species isolation. Disruption of ecosystem services.	• Clearing of vegetation, dust, disturbance and noise pollution degrades habitat.[25] • Roads fragment habitat Alien invasives degrade habitat.[8,25,26] • Animals might migrate away from area.[30] • Vulnerable species and keystone spp might be particularly affected.[13]
During extraction	• Few known, but roads associated with extraction might provide predation opportunities and corridors for some species.[14, 16]	• Increase in pest animals, such as vervet monkeys, associated with waste of human settlements.[22]	• Potential species loss, genetic diversity loss [15] and ecological disturbance. Disruption of ecosystem services. Increase in human-wildlife conflict.[41] • Noise pollution might impact predation success. Unknown impacts from changes to water table and riverine vegetation on which fauna rely. Unknown impacts of sedimentation on water resources and flooding regimes on fauna. Impacts of fauna of an increased risk of fire.	• Reproductive, neurological, gastrointestinal, dermatological, urological, respiratory problems and death in livestock.[2, 15] • Loss of habitat for fauna through clearing and fragmentation.[9, 23, 30, 31, 39, 41] • Reduced landscape connectivity for fauna, leading to habitat degradation [19, 35, 38, 41] and reduced populations • Noise and light pollution[11] impacting predator-prey dynamics.[1, 4, 20] • Direct faunal impacts through poaching, road mortality, toxic chemical spills or air pollution.[37, 40] • Rare species would be disproportionately impacted by road effects,[31] Increase in dust could exacerbate tooth enamel wear, decrease forage palatability, result in mineral imbalances.[26, 37] • Erosion could result in ecosystem disruptions, particularly of aquatic systems. Increased alien invasives could lead to disruptions in animal populations.[6, 26]
References	14: Forman and Alexander, 1998; 16: Getz et al., 1978	22: MacDonald, 1992; 24: McLellan and Shackleton, 1989; 41: YFWMB, 2002	15: Forrest, 2011; 41: YFWMB, 2002	1: Apfelbach et al., 2005; 2: Bamberger and Oswald, 2012; 4: Brown et al., 1988; 6: Dean and Milton, 1999; 8: JBR Consultants, 2008; 11: Ewen et al., 2012; 15: Forrest, 2011; 9: Dyer, 2000; 13: Fay, 2011; 19: James and Stuart-Smith, 2000; 20: Kotler et al., 1991; 23: McEnroe and Sapa, 2011; 25: Milton and Dean, 1998; 26: Milton and Dean, 2012; 30: Sawyer et al., 2006; 31: Seiler, 2001; 35: Smith and Cameron, 1985; 37: TEEIC, 2012; 38: Van Dyke and Klein, 1996; 39: Verboom and Van Apeldoorn, 1990; 40: Wolf, 2009; 41: YFWMB, 2002

Table 10: Possible impacts on mammals continued

	Positive impacts	Uncertain positive impacts	Uncertain negative impacts	Negative impacts
After extraction	• Rehabilitation programme is necessary by law which would enhance ecological capital and encourage return of some fauna.	• Rehabilitation is often not enforced or monitored and takes many years for ecosystem function to return.[26] • Some fauna such as predators would benefit from altered prey behaviour.[41]	• Behavioural changes and population and species changes in fauna after oil and gas extraction impacts will disrupt ecosystem dynamics with unknown conse-quences.[15]	• Rehabilitation takes years, is very costly and often does not incorporate elements necessary for faunal return to the area.[26, 38]
All references	14: Forman and Alexander, 1998; 16: Getz et al., 1978	22: MacDonald, 1992; 26: Milton and Dean, 2012; 41: YFWMB, 2002	15: Forrest, 2011; 41: YFWMB, 2002	1: Apfelbach et al., 2005; 2: Bamberger and Oswald, 2012; 4: Brown et al., 1988; 6: Dean and Milton, 1999; 11: Ewen et al., 2012; 15: Forrest, 2011; 9: Dyer, 2000; 19: James and Stuart-Smith, 2000; 20: Kotler, et al., 1991; 23: McEnroe and Sapa,. 2011; 26: Milton and Dean, 2012; 30: Sawyer et al., 2006; 31: Seiler, 2001; 35: Smith and Cameron, 1985; 37: TEEIC, 2012; 38: Van Dyke and Klein, 1996; 39: Verboom and van Apeldoorn, 1990; 40: Wolf, 2009; 41: YFWMB, 2002

3.1.9.2 Availability of data to map this aspect

A central database with impacts on large mammals might be created if data are obtained, since no impacts on large mammals in South Africa have been recorded yet, a database is unavailable.

- Limited information on animal species recorded for the relevant Quarter Degree Squares (QDS) (extractable from the SABIF/SIBIS database hosted by SANBI).
- Citizen Science databases such as the Mammal Map database run by ADU at UCT and the iSpot database run by SANBI
- Mammal disribution data held by the University of Pretoria
- Data from NGOs, such as the Endangered Wildlife Trust, on endangered animal sightings

3.1.10 Fish

The development of shale oil and gas and CBM resources holds serious risks for freshwater ecosystems (Bishop, 2011; Energy Institute, 2012; Sonik, 2012). Freshwater fish communities are, therefore, one of the ecosystem components put at risk by the development of the oil and gas sector in South Africa. Even though information on the potential impacts of oil and gas extraction and hydraulic fracturing on South African fish species is largely lacking at present, international literature indicates that the development of the oil and gas sector poses serious risks for the integrity of freshwater fish communities (e.g. Committee on Management and Effects of Coalbed Methane Development and Produced Water in the Western United States, Committee on Earth Resources and National Research Council, 2010; Davis et al., 2006; Davis, 2008; Johnson, 2007; Lechtenböhmer et al., 2011; Skaar et al., 2004; Sonik, 2012).

In order to develop a better understanding of how hydraulic fracturing could impact fish assemblages in central South Africa, background information on the nature of inland river systems and fish species occurring in the affected basins are provided.

South Africa has a depauperate fish fauna compared to the rest of the African continent. It hosts only 10% (214 species) of the African fish fauna despite covering 16% of the continent's land area (Skelton, 2001). Species richness and diversity further decrease from north to south with the Zambezi, Limpopo, Orange, Olifants and Berg Rivers hosting 134, 44, 16, 10 and 4 indigenous fish species respectively (Skelton, 2001). This decline in species richness is largely due to a decrease in tropical fish species component – the Orange River forms the southern boundary for the majority of tropical species.

The southern African freshwater fish fauna comprises two distinct bio-geographical fish assemblages, a tropical or Zambezian fauna (178 species) and a temperate Southern fauna (36 species) (Skelton, 2001). The Southern temperate fauna, which is dominated by cyprinid species and entirely endemic to southern Africa, can be divided into two sub-groups: the Cape fauna with 15 species and the Karoo fauna with 21 species (Skelton, 2001). Species of the Cape fauna are restricted to the rivers of the Cape Fold Mountains, the Amatolas and the Drakensberg. Unfortunately, the majority of these fish species are listed as endangered by the IUCN – six of them as "critically endangered" (Skelton, 2001). The Karoo fauna is mainly associated with the Orange River and its tributaries and include yellowfishes, labeos, barbs and rock catfishes.

The Orange River and its tributaries drain the central plateau of South Africa. The largest part of the area earmarked for unconventional oil and gas exploration in South Africa (see Figure 1) falls within this river basin. Other catchments that might be impacted/affected are the source areas and upper reaches of several rivers disemboguing along the south, and south east coasts, notably the Gouritz, Gamtoos, Sundays, Great Fish, Kei, Mzimkulu, Mkomazi and Tugela Rivers, the Molopo River in the Kalahari (also part of the Orange River system) and isolated areas in the Limpopo River basin. This discussion will, however, focus on the Karoo fish fauna as this is the dominant fauna associated with the Orange River system and its tributaries.

The waters of the Orange River system are a hostile environment for most aquatic species associated with it. Rainfall is variable and unpredictable over most of the catchment (Bowmaker et al., 1978; Davies et al., 2006) and results in highly unreliable stream flow (Poff et al., 2006). Most of the tributaries regularly experience an interruption in surface flow, leaving fish captive in isolated pools until surface water is reconnected during the next rainy season. The system is event-driven and is regularly subjected to disturbances such as floods and droughts (Allanson et al., 1990). Water in the river is further heavily silt-laden, especially during the rainy season, and generally devoid of submerged macrophytes (Allanson et al., 1990). Fish food and cover are relatively scarce.

The Karoo fish fauna is, therefore, dominated by hardy, generalist species. These fish have evolved life history strategies that allow them to survive in this hostile environment (extreme conditions). Many of these riverine species are bottom feeders or predators (Bowmaker et al., 1978; Gaigher et al., 1980) that can benefit from the natural seasonal changes in environmental factors such as flow, temperature and turbidity (Tómasson and Allanson, 1983). Opportunism plays an important role in the seasonal or episodic colonisation of lentic habitats by riverine fish species (Allanson et al., 1990). The fact that these species are perceived as "tough" and resilient does, however, not imply that they are immune to anthropogenic changes. Fishes in non-perennial rivers have, for example, limited habitat to survive in, making them very vulnerable to local extinctions if these habitats are threatened.

Healthy river ecosystems generally have the ability to withstand and recover from most disturbances imposed by natural environmental processes, and to some extent, those induced by humans (Loeb, 1994; Simon, 1999, Schmidt et al., 2002). This ability depends on both the inherent sensitivity of the ecosystem and the nature of the disturbance (defined by its frequency, magnitude and duration) (Simon, 1999). However, as anthropogenic activities degrade catchments, aquatic communities become modified to some degree (Siligato and Böhmer, 2002). Fish communities are known to reflect conditions in the catchment, since they are sensitive to changes in a wide array of environmental factors (Karr, 1981). The structure of fish assemblages are known to change when their habitats are modified through perturbations such as alterations to the flow regime, habitat degradation and water quality changes (Scott and Hall, 1997; Matthews, 1998; Davis et al., 2006). Fish typically need four types of habitat: habit to feed in (rearing); to take shelter from e.g. predators, high flows or periods of droughts (resting); to breed successfully (spawning); and to allow movement from one river section to another (passage) (based on Hall, 1989; see Table 11 for an explanation of the different habitat types). Alterations to the physical or the chemical (water quality) attributes of the required habitats will influence the carrying capacity of fish populations and cause changes in the composition and structure of fish communities in a river section (Karr et al., 1986).

Table 11: Fish habitats needed in a seasonal river system (based on the categories of Hall, 1989)

Fish habitat	Dry season	Onset of wet season	Wet season (Rain, flow and floods)	Onset of dry season (rainy season/floods)
Rearing (Areas in which fish feed.)	Pools	Accessibility to new feeding areas	Rapids/riffles for some species. Shallow nursery areas for young.	
Resting (Refuge areas in a river e.g. deep pools, woody debris and macrophyte beds.)	Deep pools		Deep pools for larger fish, shallow areas for young. Availability of fish cover. Refuge from floods.	
Spawning (Habitat requirements for successful spawning e.g. certain depths, substrates and velocities, plus conditions necessary to cue reproduction or migration.)		Cues for spawning e.g. floods, water temperature	Cues for spawning e.g. floods, water temperature.	
Passage (Conditions that allow or prevent fish movement from one river section to another.)	N/A due to river comprising series of isolated pools.	Accessibility to spawning areas e.g. gravel and vegetation. Restocking of river after dry period.	Necessary during breeding season, as well as extending feeding grounds and exchange of genetic material.	Migration to refuge pools before loss of surface water connectivity.

3.1.10.1 Impacts

In the following section, the possible impacts of oil and gas extraction on freshwater fish communities are discussed. After a general discussion, reference would be made to positive, negative and uncertain impacts that could occur during the various phases of oil and gas extraction, namely: During oil and gas exploration, during oil and gas extraction and post oil and gas extraction. Detailed information on the various impacts is presented in Table 12. Oil and gas extraction would include all the relevant tight oil and gas resources on which hydraulic fracturing may be applied to extract the oil and gas, which in South Africa are shale oil and gas deposits and CBM deposits.

The methods for the extraction of shale oil and gas, tight oil and gas and CBM are fairly similar (Lechtenböhmer et al., 2011). They do, however, differ with regards to the amount of effort it requires to extract the oil and gas and the risks involved for the environment. According to Lechtenböhmer et al. (2011), it becomes increasingly more difficult from conventional oil and gas (contained in permeable structures) to shale oil and gas (impermeable structures). For the purpose of this fish section, the impacts of extracting CBM and shale oil and gas will be discussed together.

Tight oil and gas exploration and extraction could lead to complex and cross-cutting environmental problems (Sonik, 2012). The scale and complexity of the problems, generally, depend on the hydraulic fracturing method used, the composition of the fracturing liquid, the depth and the construction of the wells and the area of surface land affected (Sonik, 2012). The key risks and impacts for surface water resources (fish habitat) associated with shale oil and gas and CBM processes and development are (Energy Institute, 2012; Lechtenböhmer et al., 2011; Rahm, 2011; Wood et al., 2011):

- The contamination of ground and surface water sources due to spills and blow outs, leaking fracturing fluid, contaminated flow-back water, and waste water discharge;
- Abstraction of large volumes of water from surface and/or groundwater sources;
- The storage, transport and treatment of wastewater;
- Discharge of saline water; and
- Land and landscape impacts from well development.

Riha and Rahm (2010) make a useful distinction between environmental impacts (with regards to surface water) arising from deterministic and probalistic activities or events. Deterministic activities, e.g. water abstraction and waste water production, are part of the oil and gas extraction process and certain to occur. These activities can, therefore, be expected, planned for and closely regulated (Riha and Rahm, 2010). Probalistic activities, on the contrary, are unintended actions such as leaks and spills that do occur from time to time. These events can be anticipated, but their occurrence and consequences are highly uncertain over time and space (Riha and Rahm, 2010).

The environmental impacts associated with the exploration for oil and gas resources and the actual extraction of the oil and gas resources is very similar. An important difference is, however, the intensity and scale of the operations which are much more severe for the extraction phase (Lechtenböhmer et al., 2011). The biggest environmental impacts are, therefore, expected during the extraction phase. These impacts of are unfortunately not limited to the oil and gas exploration and extraction phases, but remain to be a real threat for surface water integrity over the long-term (Bishop, 2011).

Table 12 shows a summary of the possible impacts oil and gas extraction could have on fish communities.

Table 12: Possible impacts on fish

Phase	Specific activities	Impacts: Positive impacts	Uncertain positive impacts	Uncertain negative impacts	Negative impacts
During exploration	Vegetation disturbance and removal for surveys, roads and well pads; soil compaction; soil erosion	None	None	• Loss of riparian vegetation could result in less cover and shade available to fish.	• Increased sediment delivery to river, may smother critical fish habitats e.g. spawning habitat essential for breeding.[1] • Increased turbidity leads to reduced visibility for predaceous fishes and lower productivity in river. • Increased frequency of flash floods due to increased overland flow to rivers, resulting in increased disturbance to aquatic biota. • Fragmentation of aquatic habitat due to road crossings may disrupt fish feeding and breeding migrations. • Loss of surface water connectivity which may disrupt drift of food sources (e.g. invertebrates). • Loss of fish diversity due to combined effect of increased sedimentation, turbidity and habitat fragmentation.[1]
During exploration	Abstraction of water from pools and rivers for hydraulic fracturing	None.	None.	• Uncertain at this stage where water will be sourced from. • Uncertainty around the volume of water needed or to be extracted.	• Reduction of stream flow in perennial rivers. • Loss of aquatic habitat availability and quality e.g. less deep habitat available for mature fishes. • Dropping water levels in pools, e.g. shallower habitats serving as important refuge habitat for fish larvae and fry are especially vulnerable. This could expose young to predatory fishes before critical lengths are reached. • Loss of critical passage habitat e.g. riffles and runs that connect pools. This may lead to the loss of mobility, reduced availability of food, habitat fragmentation and isolation of fish assemblages etc. • Loss of critical refuge habitat during dry periods. • Deterioration of water quality in isolated pools when surface water connection is broken due to water abstraction. Water quality continues to deteriorate as water is lost by evaporation.[1] • Heat death of fishes in isolated pools.[2] • Increased exposure to contaminants during periods of low stream discharge or isolation.[1] • Reduction in fish fitness and health due to increased predation, intra- and interspecific competition and crowding in isolated pools.
References					1: Davis et al., 2006; 2: Mundahl, 1990

Table 12: Possible impacts on fish continued

Phase	Specific activities	Positive impacts	Uncertain positive impacts	Uncertain negative impacts	Negative impacts
		Impacts			
During extraction	Abstraction of water from groundwater sources for hydraulic fracturing	None.	None.	• Uncertain at this stage where water will be sourced from. • Uncertainty around the volume of water needed or to be extracted.	• Loss of crucial refuge habitat during dry periods due to the loss of groundwater connections between groundwater and pools. • Deterioration of water quality, especially in pools, due to reduced input from groundwater and water loss due to evaporation. • Loss of water input from springs/groundwater could result in the loss of crucial refuge habitat during dry periods. • Loss of hyporheic flow due to the loss of groundwater input. The hyporheic zone is important for maintaining refuge areas, also for macro-invertebrates which is an important food source for fish in ephemeral systems.[1]
	Contamination of surface waters due to spillage of, or poor management of, drilling fluids and spoils.	None	None		• Reduced habitat quality due to lower water quality e.g. increased conductivity, lower pH, lower dissolved oxygen and higher turbidity.[1, 3, 4] • Reduced habitat quality due to exposure to toxic substances (acute and chronic effects).[1] • Reduced fish fitness and health due to exposure to toxic substances e.g. gill lesions, kidney damage, disruption of hormonal and endocrine functioning.[1, 5, 6] • Reduced fish breeding success due to i.e. sexual deformities, hormonal imbalances, lower hatch rates and survival of larvae.[6] • Reduction in food availability e.g. loss of algae and macro-invertebrates due to toxification by biocides and other substances. • Reduced visibility due to higher turbidity could reduce feeding success for visual predators.[1] • Bioaccumulation of toxic substances in fish tissue, which could have an effect on the whole food web. • Fish kills.[4, 7] • Changes in natural water quality could give competitive edge to introduced species over indigenous species.[1]
References					1: Davis et al., 2006; 4: Bishop, 2011; 5: Davis, 2008; 6: Lloyd-Smith and Senjen, 2011; 7: Bamberger and Oswald, 2012

Table 12: Possible impacts on fish continued

Phase	Specific activities	Positive impacts	Uncertain positive impacts	Uncertain negative impacts	Negative impacts
During extraction	Construction of infrastructure e.g. well pads, roads; pipelines	None	None	• Greater access to areas that were previously "protected" by their relative isolation.	• Fragmentation of aquatic habitat due to construction of culverts and roads in the catchment. Acts as barriers that inhibit fish migration.[1] • Impaired breeding for some species due to inability to migrate upstream to spawn. • Loss of gene flow due to fragmented populations. • Reduced recolonisation of dewatered sites due to barriers.[1] • Reduced fish diversity due to fragmentation.[1]
	Degradation of roads and bridges due to excessive truck traffic causing accelerated erosion and road dust	None	None	• The volume of sediment to be delivered to the river still uncertain as it depends largely on slope and the state of the catchment. • The severity of the impact on fish species may vary between river systems. Impacts expected to be more severe in clear water streams e.g. Western Cape, KwaZulu-Natal and Mpumalanga.	• Decrease in habitat quality due to increased sediment delivery to river, e.g. cause smothering of critical fish habitats. • Reduction in fish habitat availability due to the filling of pools with sediment. • Decrease in fish condition due to impaired feeding: Reduced visibility due to higher turbidity could impede feeding of visual predators. The vulnerability of many macro-invertebrate species to sedimentation could diminish this food source for fish. • Lower productivity in river due to reduced light penetration could inhibit algal growth, an important food source for some fish species. • The accumulated effect of these impacts on the food web. • Reduced fish fitness due to gills being clogged and brazed by increased levels of suspended sediment. • Lower fish recruitment due to spawning habitat being covered with sediment and eggs smothered by sediment.
References					1: Davis et al., 2006

Table 12: Possible impacts on fish continued

Phase	Specific activities	Impacts: Positive impacts	Uncertain positive impacts	Uncertain negative impacts	Negative impacts
During extraction	Abstraction from rivers, pools and dams for hydraulic fracturing	None	None	• Uncertain at this stage where water will be sourced from. • Uncertainty around the volume of water needed or to be extracted.	• Loss of aquatic habitat, due to a reduction in the depth, volume and frequency of pools.[1] • Lowering of water levels in pools – shallower habitats that serve as important refuge habitat for fish larvae and fry are especially vulnerable. Could expose young to predatory fishes before critical lengths protecting them from predation are reached. • Loss of critical passage habitat e.g. riffles and runs that connect pools. Lead to loss of mobility, reduced availability of food, fragmentation and isolation of fish assemblages etc. • Loss of critical refuge habitat during dry periods. • Deterioration of water quality in isolated pools when surface water inflow is lost due to upstream water abstraction. Water quality continues to deteriorate as water is lost by evaporation.[1,8] • Heat death of fishes in isolated pools.[1] • Exposure to contaminants more severe during periods of low stream discharge or isolation.[1] • Reduction in fish fitness and health due to increased predation, intra- and interspecific competition and crowdedness in isolated pool.
	Abstraction of water from groundwater sources	None	None	• Loss of crucial refuge habitat during dry periods due to a loss of groundwater connection between groundwater and pools. Uncertain which pools are connected to groundwater. • Uncertain at this stage where water will be sourced from; • Uncertainty about the volume of water needed or to be extracted.	• Loss of water input from springs/groundwater could result in the loss of crucial refuge habitat during dry periods. • Loss of hyporheic flow due to loss of input from groundwater. Hyporheic zone important for maintaining refuge areas and providing habitat to macro-invertebrates which are an important food source for fish in ephemeral systems.[1] • Deterioration of water quality in isolated pools due to water being lost by evaporation.
References					1: Davis et al., 2006; 8: NRC, 2010

Table 12: Possible impacts on fish continued.

Phase	Specific activities	Impacts: Positive impacts	Uncertain positive impacts	Uncertain negative impacts	Negative impacts
During extraction	Contamination of surface waters due to spillage of, or poor management of, drilling fluids and spoils	None	None	• The accumulative (synergistic) effects of different combinations of chemicals on fishes and other aquatic biota. • Uncertainty about the water chemistry of produced water as this could vary according to the potential effect of local soil, geology and water quality.[5, 9]	• Reduced habitat quality due to lower water quality e.g. increased conductivity, lower pH, lower dissolved oxygen and higher turbidity.[1, 3, 4] • Reduced habitat quality due to increased exposure to toxic substances (acute and chronic effects).[1] • Reduced fitness and health of fishes due to exposure to toxic substances e.g. gill lesions, kidney damage, disruption of hormonal and endocrine functioning.[1, 5, 6]; • Reduced fish breeding success as a result of sexual deformities, hormonal imbalances, lower hatch rates and survival of larvae.[6] • Reduction in food availability such as the loss of algae and macro-invertebrates due to toxification by biocides and other substances; • Reduced visibility due to higher turbidity could reduce feeding success for visual predators.[1] • Accumulation of toxic substances in fish tissue, and the effect this may have on the rest of the food web. • Fish kills.[4, 7] • Changes in the natural water quality could give a competitive edge to introduced species over indigenous species.[1]
	Contamination of surface water via groundwater	None	None	• Uncertainty regarding the impact of radioactive substances on fishes. • Uncertain about the impact of water contaminated with methane could have on fish communities.	
References				5: Davis, 2008; 9: Patz et al., 2004	1: Davis et al., 2006; 3: Rahm, 2011; 4: Bishop, 2011; 4: Bishop, 2011; 5: Davis, 2008; 6: Lloyd-Smith and Senjen, 2011; 7: Bamberger and Oswald, 2012

Table 12: Possible impacts on fish continued

Phase	Specific activities	Impacts: Positive impacts	Uncertain positive impacts	Uncertain negative impacts	Negative impacts
During extraction	Discharge of large quantities of product water into streams and pools (CBM)	None	• Extra water could relieve pressure on existing surface water resources by augmenting streamflow if disposed water is of good quality e.g. irrigation, stock drinking, wildlife drinking, aquaculture etc. [1, 8] • Could provide capacity the for dilution of polluted or saline water if disposed water is of good quality. • Could increase available aquatic habitat to fish species if disposed water is of good quality.	• Alteration of natural flow regime could influence natural life cycles of indigenous fish species adapted to natural conditions e.g. disrupts cues for breeding. • Water chemistry of product water is highly variable and depends on underlying geology.[1, 4] Product water quality uncertain. • Water chemistry can change as product water mixes with the receiving surface water; chemical composition could change from day to day.[1, 8] • The effect of metals and trace elements present in product water on fish uncertain. Elevated levels of metals in fish tissue have been found in the Powder River[1]; • Much uncertainty regarding the full impact of CBM product water on fish due to the lack of field studies.[1]	• Changes to the natural flow regime, e.g. surface flow during periods of natural intermittence, timing of flow events.[5, 8] • Changes to the natural physico-chemical signature of stream or pool e.g. temperature, pH, NH3 etc. [1, 4, 8, 10, 11, 12] • Increased fish stress due to low DO levels associated with product water.[1] • Chronic exposure to low levels of NH_3 possibly reducing production and growth, increasing susceptibility to disease. Chronic effects generally increase with higher temperatures.[11] • Degradation of physical habitat. Discharges of additional water into the river may cause river bank erosion, the degradation of stream beds and riparian vegetation communities.[1, 8] • Higher salinity produced water could increase natural salinity in receiving streams[1]; • Soil salt accumulation in arid and semi-arid regions if saline water are disposed onto soils, possibly causing decreased water infiltration and increased runoff and erosion,[10] possibly impacting fish habitat quantity and quality negatively. • Elevated salinity possibly causing increased oxygen consumption and overall metabolic rates in certain species.[1] • Disappearance of fish species sensitive to higher levels of conductivity.[5, 13] • Elevated conductivity levels could reduce hatch rates and survival of fish larvae, impairing recruitment of certain fish species.[4, 14] • Major ions (Cl, HCO3, Na etc.) could be toxic for fish in combination with elevated TDS.[8] • Elevated conductivity could reduce the vitality and fitness of fish populations and cause kidney damage[4].
References				1: Davis et al., 2006; 4: Bishop, 2011; 8: NRC, 2010	1: Davis et al., 2006; 4: Bishop, 2011; 5: Davis, 2008; 8: NRC, 2010; 10: McBeth et al., 2003; 11: Johnson, 2007, 12: Kempema et al., 2011; 13: Lind, 2004.

Table 12: Possible impacts on fish continued

Phase	Specific activities	Impacts			
		Positive impacts	Uncertain positive impacts	Uncertain negative impacts	Negative impacts
During extraction	Discharge of large quantities of product water into streams and pools (CBM)				• Increased conductivity could act as a chemical barrier to the distribution of more sensitive species. • A reduction in the quality of rearing habitats due to the higher concentration of dissolved solids.[13] • Increased habitat homogeneity and loss of natural variability from system due to more constant surface flow and temperatures (due to added water).[1] • Disruption of fish behaviour due to changes in natural environmental cues.[1] • Changes in water quantity and quality could give competitive edge to introduced species over indigenous species[1] causing changes in species composition and structure of fish communities.[1]
After extraction	Contamination of surface waters via oil and gas well	None	None	• The impact specific chemicals could have on individual endemic species or the community as a whole.	• Reduced habitat quality due to exposure to toxic substances. • Reduced fitness and health of fishes. • Fish kills.[4, 7] • Reduction in the availability of food sources e.g. invertebrates. • Bioaccumulation of toxic substances in fish tissue – effect on food web.
References		1: Davis et al., 2006; 2: Mundahl, 1990; 3: Rahm, 2011; 4: Bishop, 2011; 5: Davis, 2008; 6: Lloyd-Smith and Senjen, 2011; 7: Bamberger and Oswald, 2012; 8: NRC, 2010; 9: Patz et al., 2004; 10: McBeth et al., 2003; 11: Johnson, 2007; 12: Kempema et al., 2011; 13: Lind, 2004; 14: Skaar et al., 2004			

There is much uncertainty about the impacts hydraulic fracturing may have on surface water systems in southern Africa, especially in the long term. The lesson we can learn from international literature, is that the contamination of ground and surface waters due to leakages, accidents, poor enforcement of environmental regulations and laws and neglect, will occur in future. If South Africa decided to proceed with oil and gas extraction, it is of the utmost importance to allocate resources to appropriate research. Freshwater fishes, together with other aquatic biota, are important indicators of catchment and instream condition and conducting field-based research, including baseline monitoring, should be a matter of urgency.

3.1.10.2 Availability of data to map this aspect

The data needed to determine the status of the fish indicator for the identified tertiary catchments would be taken from the databases prepared for the establishment of the National Freshwater Ecosystem Priority Areas (NFEPAs). The following spatial input databases would be used:

- Sub-quaternary catchments (ArcHydro);
- River network (1:500 000 rivers GIS layer, DWA); and

- River ecosystem types (as coarse filter for biodiversity – e.g. Level 1 ecoregion, slope categories.

3.1.11 Amphibians and reptiles

Background and context

Amphibians and reptiles are some of the taxa for which unconventional oil and gas extraction by means of hydraulic fracturing will have certain potential impacts. The scale of these impacts could increase exponentially with relatively small increases in the scale of oil and gas operations, or in the particular siting of the operations, especially where relatively small populations of rare and/or endemic species are concerned.

The amphibians differ radically, both morphologically and physiologically, from other terrestrial vertebrates. They lack cleidoic eggs (eggs with a protective shell) and impermeable skins, and are recognised as having followed a separate evolutionary trajectory from the Amniota: the reptiles, birds and mammals (Stanley et al., 2009). There are currently nearly 6 000 recognised, extant species of amphibians globally, contained within three orders: Anura (frogs); Caudata or alternatively Urodela (salamanders and newts) and Gymnophiona or Apoda (caecilians) included within the group Lissamphibia ("smooth amphibians"). The larger class Amphibia also incorporates the extinct tetrapods, recognised as having transitioned from fish to all terrestrial vertebrates (Stanley et al., 2009. and Du Preez and Carruthers, 2009). Of these three orders, which occur globally, only the Anura (frogs) occurs in southern Africa where they are represented by 13 families, including 33 genera and 157 species (Du Preez and Carruthers, 2009). Given the foregoing this section discusses the frogs as the only extant representatives of the Amphibia in South Africa.

Southern Africa has an extraordinarily diverse and rich reptile fauna, comparable to other parts of Africa of similar size, and greater than the entire USA; it is a largely unappreciated and undervalued part of southern Africa's natural heritage (Alexander and Marais, 2007). The class Reptilia consists of four orders: Rhynchocephalia (tuataras); Squamata (snakes and lizards); Crocodylia (crocodiles) and Testudines (tortoises, terrapins and turtles). All of these orders, with the exception of the Rhychocephalia have representative species in southern Africa (Alexander and Marias, 2007 and ADU, 2012a) The Reptile Atlas of southern Africa website, ReptileMAP (ADU, 2012c) lists 469 species (468 extant and 1 extinct), within 110 genera and 21 families as occurring in South Africa.

Table 13 and Table 14 summarise the occurrence and status of the amphibians and the reptiles in South Africa as gleaned from the various, available, up-to date sources (ADU, 2012b; Alexander and Marais, 2007; Du Preez and Carruthers, 2009; Minter et.al., 2004). It can be noted that there is a high degree on endemicity in both of the primary taxa, and a significant percentage of the species listed as occurring are either unlisted, unevaluated or data deficient in terms of their threat listings so that in all probability there will be a higher number of threatened species following a more intense and detailed study of these species. Currently close to 10% and 25% of the extant reptile and amphibian species respectively, are shown to be under some level of threat.

Table 13: Summary data of the occurrence and status of the amphibians and reptiles in South Africa in relation to degree of endemicity

Taxa	South African Extant Species	Families	Genera	Atlas Region Endemic	Du Preez and Carruthers (Geographic Endemicity)	Taxa Percentage Endemicity
Amphibians	125	12	31	70	70 + 1 (near endemic)	55.20%
Reptiles	469	21	110	182	N/A	38.81

Table 14: Summary data of the occurrence and status of the Amphibians and Reptiles in South Africa in relation to threat status in terms of the red data listings

Taxa	Red Data Listing Categories								
	NL	NEv	DD	LR/LC	LR/NTh	Vul	EN	CR/EN	EX
Amphibians	5	1	6	29	8	9	8	6	0
Reptiles	3	147	2	5	18	13	4	3	1

Key to the Red Data listing category codes	
NL	Not listed
NEv	Not evaluated
DD	Data defecient
LR/LC	Lower risk: Least concern
LR/NTh	Lower risk: Near threatened
Vul	Vulnerable
EN	Endangered
NL	Not listed
NEv	Not evaluated

Many of the endemic and red data listed species have distribution ranges which correspond either entirely or partially with the Karoo main basin and the sub-basins, including the isolated outcroppings in the Limpopo, Mpumalanga, KwaZulu-Natal provinces and the south-western Cape. Many of these outcroppings are synonymous with isolated mountain ranges which are the "island" habitats of isolated populations of amphibian and reptile species which are either endemic or Red Data listed, or both.

Also included in the list of reptiles are the five species of marine turtles which occur off the South African coast, which inclusion may appear strange at first glance, but as the majority of the equipment and material requirements for the hydraulic fracturing operations will, in all likelihood, be shipped into South Africa from abroad via the main ports of Cape Town, Port Elizabeth, East London and Durban there is also the possibility of impacts to these species. The Karoo formations also run up to the coastline in a large portion of the Eastern Cape, and limited sections of the KwaZulu-Natal coast above the high tide mark and run beyond into the off-shore areas as well, which could also pose a future, increased risk of impacts to these species and their local habitats.

Distribution patterns

In the southern African sub-region the species richness of the reptiles is generally highest in the north-eastern extremes and decreases to the south and west. There are however, localised peaks in species richness: such as lizards in the southwestern Cape. Many of the reptile species in KwaZulu-Natal and Mpumalanga are endemic to these areas and have small, patchy distribution ranges, giving rise to scattered local peaks of species richness in these parts. For both the reptiles and the frogs there are a number of species for which data are deficient or the threat status has not been listed or evaluated, and therefore further research is necessary to fully ascertain the risk posed by the potential impacts from oil and gas operations, and other causes.

According to Alexander and Marais (2007) centres of distribution (where individuals of the species are most abundant) of the different species of reptiles are clustered into two main areas over southern Africa: the south-western Cape and the lowlands of the north-eastern parts of the region (in the case of South Africa this would include the lowlands of Limpopo, Mpumalanga and northern KwaZulu-Natal provinces). These two assemblages of species are considered to have adapted to temperate and tropical environmental conditions respectively. The same authors also refer to a third assemblage of relatively few, arid-adapted species, found in the dry west (including large tracts of the Northern Cape and sections of the Karoo biomes in the Western and Eastern Cape and the southern Free State). The distribution of the species in these three assemblages appears to be limited by climatic factors. However many species of lizard and several species of snake appear to be restricted to certain soil or rock types, and the resultant ranges of these species may be small. A high proportion of these "substrate limited" species are either fossorial (burrowers) or rupicolous (rock-living).

In the case of the frogs (as the only representatives of the amphibia) the distribution is uneven in southern Africa in terms of both species diversity and population numbers. The three main determinants of distribution patterns are climate, centres of origin and range restriction (Du Preez and Carruthers, 2009).

Climate

Despite having developed some remarkable adaptations to cope with changing environmental conditions, all amphibians remain physiologically dependant on moisture (water and ion exchange/budgets) and temperature (thermal balance and thermal energy budgets) (Du Preez and Carruthers, 2009 and Hillman et al., 2009). Thus, according to Du Preez and Carruthers (2009), a larger number of species will be found in areas that are wet and warm. Therefore, the number of species found at any specific locality increases as one moves from the arid west to the better-watered east of the sub-continent.

Centres of origin

Similar to the species assemblages referred to for the reptiles, most of the southern African frog species also fall into two broad categories. Du Preez and Carruthers (2009) state that the first of these categories comprises species with evolutionary origins centered in the southern provinces or high altitude areas of the interior, whilst the second comprises species with tropical origins distributed in the northeast. This can be explained through the fact that during past periods of climatic warming, the distribution of tropical species expanded southwards, while those that already inhabited the south retreated (Du Preez and Carruthers, 2009), while during periods of climate cooling the process was reversed. At the interface between these two faunal groups, some populations became isolated and evolved into independent allopatric species. There is an increase in species diversity northwards along the coast from the Western Cape towards northern KwaZulu-Natal, and an inversed increase in endemicity southwards. In general, the interior of the region (in the case of South Africa, the Northern Cape, Northwest and Free State provinces) has a lower level of species diversity and endemicity.

Range restriction

Several of the southern African frog species have distribution ranges of less than 20 000 km^2, and are confined to isolated topographical areas. Most of these species are found on or below the Cape and KwaZulu-Natal escarpments where mountain ranges and deeply incised river valleys offer a variety of different habitats with barriers to movement between them (Du Preez and Carruthers, 2009).

Amphibians as indicators of biodiversity and ecosystem health

Some of the major environmental hazards that are known to be causal factors in the declines of amphibian populations (both globally and locally) are listed below. Du Preez and Carruthers (2009), and Collins and Crump (2009) present similar lists compiled from the work and observations of numerous other cited authors in the field of amphibian research.

- Habitat destruction or modification (land use change)
- Introduction of alien or exotic (non-indigenous) species
- Global climate change
- Depletion of stratospheric ozone
- Emerging infectious diseases
- Environmental contaminants (pollution by a variety elements and compounds)
- Exploitation for the food and pet trades (over-exploitation)
- Predation (intensified)
- Parasites

Amphibians generally, and frogs in particular; in the case of the South African situation; can be used as important and useful bio-indicators of environmental health (Collins and Crump, 2009; and Du Preez and Carruthers, 2009); Hillman et al. (2009) also expand on this issue in relation to the physiology of the amphibians. Amphibians make use bio-indicators as they are widely distributed across South Africa and their habits make them visually and audibly conspicuous. In addition the terrestrial activities of certain species will in turn expose them to the ambient environment where their permeable skin readily absorbs water and any solvents that it may contain. The tadpoles or larval stages of many species are benthic or bottom feeders in their home water bodies. Here they are susceptible to the ingestion of various compounds and heavy metals. Adult frogs may also take in contaminated soil, plant or invertebrate material depending on their foraging strategies. Exposure to foreign hormones or endocrine disruptors can significantly change the hormone-driven process of metamorphosis and the normal, healthy development of tadpoles.

Distribution patterns of reptiles

Alexander and Marais (2007) state that, because the reptiles are ectothermic, their activity patterns are also governed to a large extent by the prevailing environmental conditions. This makes the activity patterns highly predictable. Reptiles become less active in winter, but southern African species do not generally become completely dormant, even during the coldest months. Each species of reptile exhibits a particular daily activity pattern. Many species of lizards (the agamas, chameleons, monitors, lacertids, cordylids, plated lizards and skinks) are strictly diurnal (Alexander and Marais, 2007; Reilly et al., 2007), as are the tortoises; whilst most geckos are nocturnal. Although many species of snakes are either diurnal or nocturnal, many are crepuscular (active for a period just after sunset and, possibly, again just before sunrise). Some other species, such as the Southern African Python (*Python natalensis*), forage during the night in summer, but are active only during the day in winter. Yet other species such as the Nile Crocodile (*Crocodylus niloticus*) may be active during the day and night year-round, in part due to the ameliorating effects of being able to move freely between the terrestrial and aquatic environments.

Diurnal reptiles usually emerge from their retreats when the ambient temperatures are within the range most conducive to activity. During the coldest months, this is usually around midday, when the sun's rays are warmest. However, the temperatures at midday are often too high in summer, and reptiles that emerge earlier in the morning must return to their retreats to avoid overheating. They may emerge again later as the afternoon cools down. Therefore, many of the diurnal reptiles shift between a unimodal (single peak) activity pattern during winter and a bimodal (twin peak) pattern in summer (Alexander and Marais, 2007; Reilly et al., 2007).

The reptiles have adapted to a wide variety of habitats. Certain specialised species, such as the Spotted Rock Snakes (*Lamprophis guttatus*) and the Flat Lizards (*Platysaurus*), are found only in very particular habitats (in this case, exfoliating rock outcrops), while other species may occur in a range of habitat types. Certain lizards, such as Turner's Tubercled Gecko (*Chondrodactylus turneri*) spend periods of inactivity in one habitat (rock crevices) but may forage in another (on the ground surface). The habitat generalists tend to have wider distribution ranges than the habitat specialists (Alexander and Marais, 2007; Reilly et.al., 2007).

The majority of southern African reptiles, all species of tortoise, the majority of snakes and many lizards are best categorised as terrestrial as they spend most of their time on the ground surface. Many of the southern African lizard and snake species are fossorial (live underground). For these burrowers the substrate type is important and many species avoid substrates that regularly become waterlogged or are too hard due to high clay content. These suitable substrate types (such as aeolian sands) often occur in isolated patches resulting in fragmented distributions for the species that are dependent on them. Similarly, the strictly rupicolous species may be limited to specific rock outcrops, and may occur only in restricted areas simply because they have been unable to disperse to other suitable sites (Alexander and Marais, 2007).

The same authors make the further observations that there are relatively few truly aquatic reptiles in southern Africa, the most notable being the Nile Crocodile (*Crocodylus niloticus*) which is limited to permanent water in the northern and eastern parts of the sub-region. In South Africa this means the low-lying portions of northern and eastern Limpopo, northern and eastern Mpumalanga and north-eastern KwaZulu-Natal. Many species of freshwater terrapins are also dependent on permanent bodies of water; however, the Marsh Terrapin (*Pelumadusa subrufa*) is capable of burrowing into the mud bottoms of drying water bodies to aestivate until conditions become more favourable. This adaptability to changing conditions allows for a much wider distribution of the Marsh Terrapin than the other species of freshwater terrapins. There are also several species of snake, including the Water snakes (*Lycodonomorphus*) and the Marsh snakes (*Natriciteres*) which are also aquatic specialists that are restricted in occurrence to the close proximity of permanent water.

3.1.11.1 Impacts

The impacts on amphibians and reptiles are listed under the characterisation of positive, negative and uncertain impacts and are discussed in terms of the following phases of the oil and gas extraction process: During oil and gas exploration, during oil and gas extraction and post oil and gas extraction. The impacts are identified based on personal observation and experience with conventional oil and gas extraction operations in Tanzania and Mozambique (Reynolds, pers. observation) and adapted according to the observations on Impacts during three phases of mining from a presentation made at the Second Karoo Development Conference, held in Beaufort West during October 2012 (Milton, 2012).

The term oil and gas extraction is used in this section in the context that would include all the relevant tight oil and gas resources on which hydraulic fracturing may be applied to extract the oil and gas; which in South Africa are shale oil and gas deposits and CBM deposits. Table 15 shows a summary of the impacts.

Table 15: Possible impacts for amphibians and reptiles

	Positive Impacts	Uncertain positive impacts	Uncertain negative impacts	Negative impacts
During exploration	No definite positive impacts	• Possible new distribution data record collection. [1]	• Reduction in water quality in remaining water resources.[2, 3] • Reduction in habitat (soil, and vegetation) quality from dust, tailings dumping and "slash" disposal.[1, 2,3] • Reduction in air quality.[2] • Soil contamination /pollution.[2, 4]	• Increases in pressure on water resources.[2] • Reduction in groundwater recharge.[2] • Habitat reduction and fragmentation.[1, 2] • Roadkill of of affected species. • Trampling disturbance to non-target areas.[1, 2] • Increased rainfall run-off and channelling, leading to increased soil erosion. [2] • Disturbance and possible destruction of reptiles and amphibians (especially fossurial species). • Localised ground temperature increases due to clearing. • Vegetation composition change.[2]
During extraction	No definite positive impacts	None that could be identified	• Ground and possible surface water contamination due to borehole casing failure.	• Reduction of available water resources [2, 3, 5] • Soil and water contamination by toxic heavy metals (and other minerals and compounds.[2, 4] • Bioaccumulation of contaminants in the natural trophic pyramid.[7] • Introduction of saline water into fresh water resources. • Wildlife exposure to contaminated water (especially in impoundments in arid areas).[1, 2] • Wildlife entrapment in impoundments, excavations and other infrastructural developments.[1] • Air, soil and water contamination, loss of quality. • Habitat reduction and fragmentation. • Roadkill of affected species.
References	2: Milton, 2012	1: Reynolds, 2012 (Pers Obs)	1: Reynolds, 2012 (Pers Obs); 2: Milton, 2012; 3: Dean and Milton, 2011; 4: Rademeyer, 2008.	1: Reynolds, 2012 (Pers Obs); 2: Milton, 2012; 3: Dean and Milton, 2011; 4: Rademeyer, 2008; 5: Van Tonder and De Lange 2012; 6: Tiemann and Vann 2012; 7: USEPA, 2012b

Table 15: Possible impacts for amphibians and reptiles continued

	Positive Impacts	Uncertain positive impacts	Uncertain negative impacts	Negative impacts
After extraction	• Re-establishment and rehabilitation of disturbed habitat areas in accordance with the EMPs.[2]	None that could be identified	• Failure to comply with the terms and conditions of EMPs	• Abandonment of sub-surface infrastructure to long-term weathering and decay.[5, 6]
All References	2: Milton, 2012	1: Reynolds, 2012 (Pers Obs)	1: Reynolds, 2012 (Pers Obs); 2: Milton, 2012; 3:Dean and Milton 2011; 4: Rademeyer, 2008	1: Reynolds, 2012 (Pers Obs); 2: Milton, 2012; 3:Dean and Milton 2011; 4: Rademeyer, B: 2008; 5: Van Tonder and De Lange 2012; 6: Tiemann and Vann 2012; 7: USEPA, 2012b

3.1.11.2 Availability of data to map this aspect

Data bases exist for the reptiles and the amphibians (frogs) of South Africa with linked distribution map data recognised by SANBI, in the Virtual Museum, managed by the Animal Demography Unit, Department of Zoology, University of Cape Town (ADU, 2012a).

3.2 Socio-economic entities

Socio-economics is a field of study that profiles the social well-being and economic development of communities. Where environmental issues are concerned, it is important that linkages be drawn between socio-economic development (i.e. unconventional oil and gas extraction), the impacts thereof on the natural environment and how these two aspects in turn affect human populations. The issue of unconventional oil and gas extraction definitely will benefit from a better understanding of the linkages between the social environment and the natural environment.

Before defining what is meant specifically with socio-economic entities and how these entities are interlinked with the issue of unconventional oil and gas extraction, it is vital that the relationship between social and environmental factors be understood first. Currently there is a growing realisation among social and natural scientists alike that social and environmental systems are inextricably linked. Therefore, what happens in one system will without a doubt affect the other system as well. This relationship is encapsulated in the PED-nexus framework that postulates multiple and reciprocal linkages between population (size, growth rate, age composition, density etc.), environment (ecosystems; rivers; air; land; biodiversity etc.) and development (industry, mining, economic growth etc.) See Figure 4.

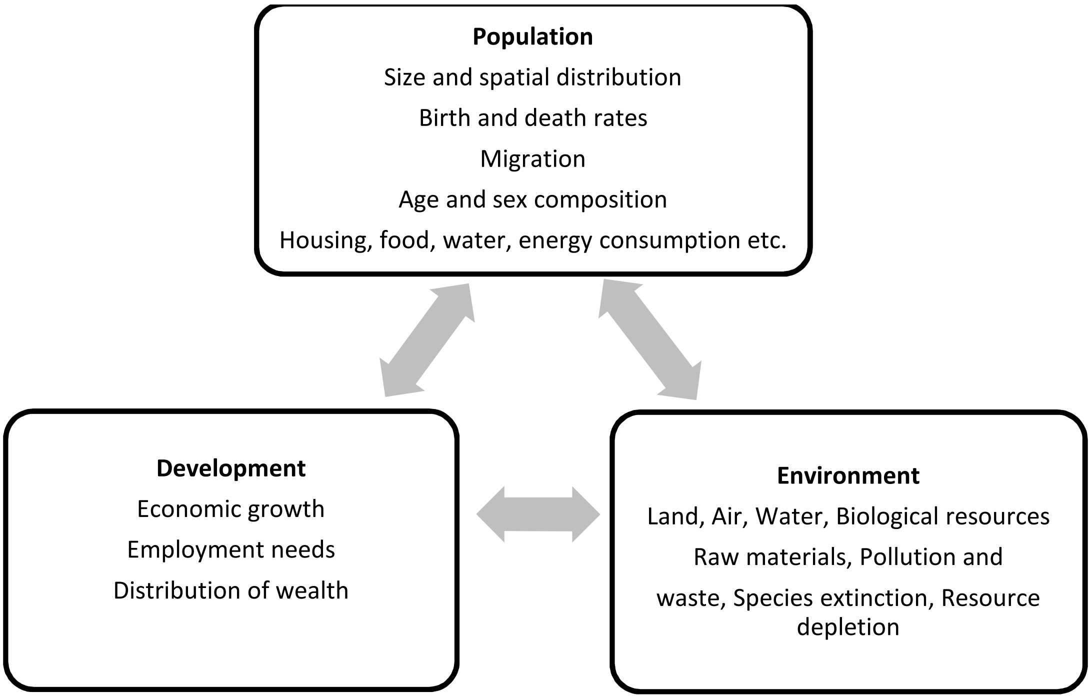

Figure 4: The PED Nexus (Source: Pelser and Redelinghuys, 2008)

These three components do not operate in isolation, but through the dynamic interaction between these three elements, the cumulative interaction of the three elements determine human impact on the natural environment, and also determine the impact of environmental changes on the social environment. This nexus further forms the basis for the international and national policy frameworks that address the multiple, complex and dynamic linkages between society and environment (Pelser and Redelinghuys, 2008). The value of the PED-nexus framework lies in its applicability to analyse and describe any environment-society interactions, from large-scale issues such as transboundary river governance, to the more localised analyses of the interaction between communities and unconventional oil and gas extraction developments.

In order to determine the social well-being of a population in this regard, both population and development aspects therefore need to be addressed.

3.2.1 Economic well-being

Section 3.2.1.1 will discuss the impacts of the different unconventional oil and gas extraction phases on economic well-being.

3.2.1.1 Impacts

During the oil and gas exploration and extraction phases, most of the positive impacts of unconventional oil and gas pertain to increased economic and infrastructure development. Since unconventional oil and gas wells are mostly located in regions where there is limited economic development, the employment opportunities generated through this development could boost local economies and create job opportunities in these less economically developed areas. According to Beemster and Beemster (2011), potential economic benefits include more jobs and a secure supply of oil and gas and revenue, but this has to be weighed against the negative impacts of this type of activity. There is evidence that unemployment decreases slightly as oil and gas extraction starts taking place. In Clearfield, Pennsylvania, for example, unemployment dropped by 1.1% in three months as a result of unconventional oil and gas drilling (Coburn et al., 2011). Unconventional oil and gas extraction can therefore be regarded as a potential employment generator (Chung and Hoffnagle, 2011).

During both the oil and gas exploration and the initial phases of oil and gas extraction there is generally an increase in temporary jobs. Based on figures derived from the Marcellus shale play, an average of 11 temporary jobs was created per well pad during the construction and development phase (Beemster and Beemster, 2011). During exploration, fewer wells may be drilled than during the extraction phase. However, the number of workers needed per well for both exploration and initial drilling and development of well pads are the same. Williams (2011) states that during the clearing of the area for putting up the well pad, the preparation of the well-pad for drilling (setting up the drilling rig, drilling, fracking, installing operational equipment etc.) – a process that can take from a few months to years – as new wells are continuously drilled around 100 workers in total are required, but once the well is operational only one worker is needed to maintain the well. However, some optimistic estimates e.g. Considine et al. (2011) estimate the number of jobs for a total shale play to range from the 1000s to even 100 000s over the lifetime of the shale play.

Temporary increases in employment can potentially provide an economic boost for communities through, among others, the spending of wages in the local economy. Since the construction and drilling phase can extend over a period of months to a few years, at least in the short term local communities may benefit from the fact that there are a greater number of economically active people in the communities. Many of the increases in employment in local communities come from the fact that local businesses thrive on the increased economic development in the area (Coburn et al., 2011).

There is also the potential tax benefits derived from extracted oil and gas. Taxes in turn fund infrastructure development and the provision of essential social services such as education, health care, and welfare (Coburn et al., 2011; Considine et al., 2011). Another positive impact of unconventional oil and gas extraction is that it drives property value up, thereby improving the property market in areas where oil and gas extraction is taking place (Coburn et al., 2011).

While there will certainly be an increase in employment, particularly during the exploration and drilling phases of oil and gas extraction, there are also negative impacts. Many of the employment opportunities created are firstly temporary in nature, and secondly, industry specific. Most of the jobs created during exploration, drilling and constructing of well pads are reserved for industry specialists who temporarily migrate to the areas where exploration and drilling takes place. These transient workers have a much less positive long-term impact on the local economy in terms of job creation. The migrant workers leave the site once exploration and drilling is done (within a period of 8 months). Most of the jobs generated for local people during these phases are low paying jobs such as those in concrete delivery, road building, construction and trucking (Beemster and Beemster, 2011).

Once a well is constructed, it only requires three workers permanently and these workers will only be needed for a period of 7-8 years (over the lifetime of the well) (Beemster and Beemster, 2011). Furthermore, while some permanent jobs may be created through unconventional oil and gas extraction, it may take as long as 10 years for the jobs to materialise after the initial decision to explore has been taken (DMR, 2012).

Job increases in fracking come at the price of job losses in tourism and agriculture (Beemster and Beemster, 2011). Job gains in unconventional oil and gas extraction may not be equal to those lost in these two employment sectors.

Impacts of hydraulic fracturing on recreation-based economies are, at the moment, uncertain. However, anecdotal evidence point towards potential negative impacts. Land fragmentation as well as the loss of aesthetically pleasing environments due to the presence of well pads, combined with noise from trucks, and the increased risk of air and water pollution may severely damage tourist potential in pristine landscapes where oil and gas extraction is proposed (Beemster and Beemster, 2011; Dolesh, 2011).

Post oil and gas extraction negative impacts may include the fact that communities experience a severe economic downturn and many businesses that benefited from the oil and gas boom close down, leading to increased poverty and economic hardship (Pelser et al., 2005). The impacts of mine closure on local economies have been studied widely. No uncertain impacts in terms of the socio-economic environment have so far been identified in this study. Table 16 shows a summary of the impacts.

Table 16: Possible impacts on Economic well-being

	Positive impacts	**Uncertain positive impacts**	**Uncertain negative impacts**	**Negative impacts**
During exploration and extraction	• Infrastructure development. • Direct temporary employment opportunities. • Indirect employment opportunities over time. • Multiplier economic impacts.	• Potential tax benefits.	• Decline in tourism potential.	• Limited long-term permanent employment opportunities. • Potential jobs can take 10 years to materialise. • Job losses in the agricultural and tourism sectors not offset by employment in unconventional oil and gas industry.
After extraction	None identified	None identified	None identified	• Severe economic downturns experienced in local communities. • Unemployment rises. • Poverty increases.
References	Beemster and Beemster, 2011; Considine et al., 2011; Chung and Hoffnagle, 2011; Coburn et al., 2011; Williams, 2011.		Beemster and Beemster, 2011; DMR, 2012; Dolesh, 2011; Kargbo et al., 2010; Pelser et al., 2005.	

3.2.1.2 Availability of data to map this aspect

Reliable sources of economic data on district and local municipal level exist that can be used to map entities related to the economic environment. Some possible indicators include: poverty rate, the Gini coefficient, employment rate, average household income and sectoral employment figures; and number of tourists per hectare of land. This data is available from the following sources: Statistics South Africa, Global Insight Southern Africa, Labour Force Surveys, and Household Surveys, among others.

3.2.2 Health

Section 3.2.2.1 will discuss the health impacts of the different phases of unconventional oil and gas extraction.

3.2.2.1 Impacts

During oil and gas exploration and extraction possible p*ositive impacts may include that* access to health care services may improve in under resourced rural communities due to increased economic development (Esteves, 2008; Rolfe et al., 2007). The creation of employment opportunities may also improve the ability of households to buy food, thereby positively impacting on the nutritional status of the populations affected.

The possible negative impacts of unconventional oil and gas extraction are related primarily to the pollution of water resources and air pollution by the chemicals used as fracking fluids. A study by the Tyndall Centre for Climate Change Research on hydraulic fracturing in the UK (2011), found that out of a list of 260 chemicals that are used in hydraulic fracturing, 58 gave rise to concern in terms of their potential negative impacts on human and ecosystem health (Broderick et al., 2011). Among these chemicals, eight were classified as carcinogens, six were classified as mutagenic, five were classified as having impacts on reproductive health, and 17 were classified as being harmful to aquatic organisms.

Chemicals such as fluorocarbons, naphthalene, butanol, formaldehyde, hydrochloric acid, petroleum distillate, and ethylene glycol are commonly added to fracking fluids, all of which are linked to various health issues. Benzene, toluene, ethyl benzene and xylene (BTEX) have been linked to health complaints such as dizziness, confusion, irritation of the eyes, nose and throat, kidney and liver damage, while benzene specifically is linked to the development of leukaemia (Larson et al., 2011).

Some of the short-term effects of exposure to these chemicals include irritation to the eyes, nose throat, headaches, nausea, and allergic reactions. Long-term exposure to chemicals can lead to chronic respiratory disease, lung cancer, heart disease, and damage to organs such as the brain, liver, kidneys and the nervous system (Larson et al., 2011). Marsa (2011) adds that in the Barnett shale, which has been in operation since 2002, residents are complaining of a range of ailments that include nosebleeds, dizziness and nausea in children who attend schools within a mile radius from drill rigs. Adult residents complain about unexplained health problems such as headaches, dizziness, blackouts and muscle contractions.

Some sectors of the population are more vulnerable to the impacts of air pollution, notably, young children, the elderly and those with chronic diseases. For example, air pollution aggravates medical conditions such as asthma and emphysema, while also negatively impacting on the lungs of growing children (Larson, 2011).

Volatile organic chemicals (VOCs), CH_4, and CO_2 from processing plants, and truck emissions have contributed to air quality problems and an increase in ozone (O_3) in areas where fracking is being done i.e. Texas, Wyoming and Colorado (Kargbo et al., 2010). Air pollution in the form of ozone smog can spread to up to 300 km beyond the immediate gas-producing region (Beemster and Beemster, 2011). Some types of sand used in hydraulic fracturing, such as crystalline silica, emits a fine dust that can cause lung cancer and silicosis (Beemster and Beemster, 2011).

Dangerous chemicals such as those listed above also find their way into water resources. These chemicals affect eyes, skin, lung, intestines, liver, brain, and the nervous system. There have been instances where water samples from wells (Pavillion, WY) have contained drilling chemicals (Kargbo et al., 2010). Increased truck traffic poses a danger to small cars and children. The increased traffic increases the risk of motor vehicle accidents (Coburn et al. 2011). In a country like South Africa, with its already high traffic accident rate, increased traffic is quite a serious health concern for small communities.

Another worrying health concern is the spread of HIV driven by increased population movement, socio-economic inequalities, gender imbalances and loss of social cohesion. Population mobility, coupled with gender inequality and the socio-economic vulnerability of rural women increase the risk of HIV. The symbiotic relationship between mining and the spread of HIV is well researched and documented (DSD 2010; Pelser and Redelinghuys, 2006). Mining, which is essentially what unconventional oil and gas extraction is, is identified by Heunis et al. (2012) as one of the key socio-economic factors fuelling the spread of HIV. Added to this, long distance trucking is another key factor in South Africa that drives the spread of HIV. Both these two factors are present in unconventional oil and gas extraction.

Uncertain impacts may include the presence of NORMs in flowback water, which poses some potential health risks to populations. However, although this issue is acknowledged as a possible risk factor as far as the presence of NORMs in wastewater is concerned, there is insufficient data on the levels of NORM concentrations in wastewater (Broderick et al., 2011).

Some other health risks that are associated with unconventional oil and gas extraction pertain to increased risks of disasters and accidents. Well blowouts, the improper transportation, handling and storage of toxic chemicals and waste, as well as the migration of NORMS into air and water resources may in future become more widespread as a result of unconventional oil and gas extraction, with concomitant negative health impacts (Chung and Hoffnagle, 2011). There are also the risks of drilling through abandoned gas and oil wells, or the risk of blowouts caused by faulty cementing of pipes (similar to the blowout that occurred at the Deepwater Horizon drill in the Gulf of Mexico) (Marsa, 2011).

In other cases, methane leaked from gas wells into aquifers with the result that at least in some instances of taps emitting methane gas (Dolesh, 2011). One study by the National Academies of the Sciences by Duke University indicated that drinking water wells that are within a radius of one kilometre from drilling sites have 17 times higher concentrations of methane than those outside of this radius. However, the health impacts of ingesting methane in water are unknown (Coburn et al., 2011). Coburn et al. (2011) point out that many of the health impacts related to fracturing are unknown. No one knows what the long-term impacts of exposure to many of the chemicals in the water and air may be on populations that are exposed to these forms of pollution over an extend period of time. The cumulative health impacts resulting from water and air pollution are also not known at this stage.

Possible positive impacts post oil and gas extraction may be that the short-term health impacts will decline, leading to a better health status in affected communities. Possible *negative impacts may include* the lingering environmental pollution will affect populations well into the future. Exposure to mutagenic chemicals that cause birth defects will impact on families affected by this for extended periods. Lingering impacts of HIV-infections on populations will also be experienced after the areas' oil and gas resources have been depleted (Pelser and Redelinghuys, 2006).

Table 17 shows a summary of the impacts.

Table 17: Possible health impacts

	Positive impacts	**Uncertain positive impacts**	**Uncertain negative impacts**	**Negative impacts**
During exploration and extraction	None identified	• Possible improved access to health care services. • Better nutritional status as a result of increased economic development.	• The impact of NORMs on the health of population.	• Increase in short term health complaints. • Long term impacts on reproductive health. • Risk of cancer increases. • Risk of organ damage increases. • The worsening of chronic conditions, especially in vulnerable populations like children and the elderly. • Higher incidence of motor vehicle accidents.
After extraction	• Decline in the prevalence of short term health impacts.	None identified	None identified	• Lingering ill health. • Birth defects as a result of exposure to mutagenic chemicals. • Decreased access to health care. • Lingering impacts of an increase of HIV.
References	Broderick et al., 2011; Esteves, 2008; Larson et al., 2011; Marsa, 2011; Rolfe et al., 2007.		Beemster and Beemster, 2011; Broderick et al., 2011; Coburn et al., 2011; Kargbo et al., 2010; Chung and Hoffnagle, 2011; Dolesh, 2011; DSD 2010; Heunis et al., 2012; Marsa, 2011; Pelser and Redelinghuys, 2006	

3.2.2.2 Availability of data to map this aspect

Health care impacts are indicated by measuring the incidence of different diseases in a population. However, many of the health issues identified are difficult to categorise and map, for example evidence of throat irritations. Cancer rates, the nature and extent of children born with birth defects as well as the HIV rate are more accurately quantified and mapped. Data on these disease patterns are readily available from the Department of Health, as is data pertaining to the availability of various health services in relation to the size of populations.

3.2.3 Agriculture and food security

Section 3.2.3.1 will discuss agriculture and food security.

3.2.3.1 Impacts

Possible negative impacts during oil and gas exploration and extraction may include that agriculture and the food industry are sectors that employ large numbers of people, while agricultural output creates additional economic benefits in the wider economic sector. Losses in the agricultural sector in terms of jobs may not be countered by increasing jobs in the mining sector (Beemster and Beemster 2011). After the oil and gas reserves have been depleted, farmers on whose land unconventional oil and gas mining took place may be left with land that is no longer usable for agriculture (Beemster and Beemster, 2011).

Some fracking fluids chemicals, such as 2-butoxythanol, are known to cause reproductive problems in animals (Kargbo et al., 2010). Crop production may be affected due to high levels of air pollution, particularly where dust particles settle on crops, thereby hampering the growth and health of crops.

A higher demand for water from the oil and gas industry may also take water away from crop production in water scarce areas, while deteriorating water quality may also affect crop production negatively. This may have widespread impacts on food security (Williams et al., 2012).

Contamination of surface water resources through spills, accidents and seepage of wastewater into water sources can affect the habitat of aquatic species like fish that local communities rely on as wild food sources. Walsh (2011) cites one case where a family in Bradford County, Pennsylvania's wild pond was contaminated by a well pad spill on an adjacent property, leading to all the fish in the pond dying. Rural people also rely directly on the natural environment for fuel wood; they hunt animals for food and collect wild food sources (Pelser and Redelinghuys, 2008). Due to the clearing of land for fracking, people may lose access to some of these food sources.

Possible negative post oil and gas extraction impacts may include that land that has been used for unconventional oil and gas extraction is not be rehabilitated, therefore decreasing the possibility of conversion from oil and oil and gas extraction to agricultural land use post oil and gas extraction (Williams et al., 2012). Table 18 shows a summary of the impacts.

Table 18: Possible impacts on agriculture and food security

	Positive impacts	Uncertain positive impacts	Uncertain negative impacts	Negative impacts
During unconventional hydrocarbon exploration and extraction	None identified		• Long-term impacts of uncon-ventional oil and gas extraction on crop production are uncertain.	• Loss of employment opportunities in the agricultural sector. • Some chemicals used cause reproductive problems in animals. • Crop production affected due to dust pollution, water shortages and deteriorating water quality. • Rural livelihoods affected by impacts of unconventional oil and gas extraction on access to wild food sources.
After extraction	None identified			• Land that is unsuitable for farming after oil and gas is depleted.
References			Beemster and Beemster, 2011; Kargbo et al., 2010; Walsh, 2011; Williams et al., 2012; Pelser and Redelinghuys, 2008	

3.2.3.2 Availability of data to map this aspect

Reliable sources of agricultural-related data on district and local municipal level exist that can be used to map entities related to this sector. Some possible indicators include: proportion of populations dependent on agriculture for employment; contribution of agriculture to GDP, agricultural output per municipality. The direct reliance of local populations on wild food sources and environmental resources are less easily quantifiable, but some scientific data, notably from the Department of Social Development, the Department of Agriculture and Forestry and the Department of Environmental Affairs are available and could provide insight into this aspect of the social environment. Other agricultural data is available from the following sources: Statistics South Africa, Global Insight Southern Africa, and the Department of Agriculture, among others.

3.2.4 Social well-being and living conditions

Section 3.2.4.1 will discuss the impacts of oil and gas extraction on social well-being and living conditions.

3.2.4.1 Impacts

During oil and gas exploration and extraction possible positive impacts include higher levels of socio-economic development will lead to increased access to sanitation, water provision and housing and communities benefit from the development of infrastructure such as roads, health services and more commercial activity. Added economic opportunities may alleviate some of the dire poverty experienced in some rural areas (Rolfe et al., 2007).

Possible negative impacts may include traffic increase during drilling. The completion of the well pads also impacts negatively on human well-being. During this time, heavy traffic uses local roads around the clock (Beemster and Beemster, 2011). Broderick et al. (2011) estimates 7 000-11 000 truck visits are needed for the construction of a single ten well pad in the United Kingdom. With such heavy traffic road infrastructure becomes damaged, and the damage may prevent local populations from getting adequate access to roads. This may impact negatively on the well-being of populations that have to cope with the continuous traffic, increased hazards of road travel and slower traffic movement in the case of emergencies.

During exploration the construction of a ten well pad will require between 8 00 and 2 500 days of noisy activity on the surface A well pad takes around 60 days of 24 hour-continuous drilling to complete, translating into 8-12 months of continuous drilling (Broderick et al., 2011). The increasing noise levels impact on the quality of life of communities.

Wastewater can be transferred to municipal treatment plants, but these plants may be unequipped to undertake the treatment of this water. This may result in the release of poorly treated water into the municipal water system, impacting negatively on the quality of potable water (Dolesh 2011).

Increased property values mean that when house prices and rent increases accordingly, housing may become unaffordable to many people in the community (Coburn et al., 2011). It is commonly experienced that an influx of workers over a short period of time drives up housing prices, making housing unaffordable for locals. Often poorer families that do not own houses have to suffer the consequences of higher rent (Walsh, 2011; Williams, 2011).

Rapid change in community life may be experienced as a result of unconventional oil and gas exploration and extraction (Weigle, 2011). Communities that are confronted with the exploration and extraction of unconventional oil and gas are often found in rural areas where any social changes may have a severe impact on the fabric of community life. It may transform communities, from being stable, functioning social entities to disorganised entities that may be characterised by a range of social ills, including substance misuse and abuse, prostitution, interpersonal violence and family disorganisation (Pelser and Redelinghuys, 2006).

Increased crime may be experienced. Interpersonal violence increases, as does alcohol abuse and illegal drug trafficking (Coburn et al. 2011). Williams (2011) states that the costs associated with police, fire and social welfare tend to increase when fracking starts.

Uncertain impacts, including psychological impacts may be experienced, such as fears associated with the potential risks of fracking i.e. children getting sick, worries about contamination of wells and methane explosions (DEP, 2009). The loss of access to recreational activities such as fishing and stargazing may negatively affect the psychological well-being of communities (Weigle, 2011). A sense of betrayal may be experienced by those who were made promises that did not materialise by oil and gas companies (Walsh, 2011).

Social change can be positive, as it brings new innovation, and a reconstituted social fabric. However, based on existing data with regard to the aftermath of extraction, it is likely that there will be limited positive impacts in terms of community functioning and the social fabric of communities (Pelser et al., 2005).

Possible negative impacts may include that communities commonly experience a sense of fatalism, loss and deprivation after extraction activities cease in a community. Many of the benefits derived from oil and gas extraction in the form of economic prosperity (at least for some sectors of the population), increased access to services and infrastructure and a general sense of socio-economic well-being is lost when oil and gas production activities cease (Pelser et al., 2005). Table 19 shows a summary of the impacts.

Table 19: Possible impacts on social well-being and living conditions

	Positive impacts	Uncertain positive impacts	Uncertain negative impacts	Negative impacts
During exploration and extraction	• Restoration of unused buildings. • Infrastructure development. • Increased access to health and welfare services.	None identified	• Psychological impacts – fears over the risks of extraction, accidents; sense of betrayal experienced if promises by oil and gas companies are not kept. • Sense of loss experienced over loss of recreational activities.	• Nuisances such as increased traffic and noise. • Inability of local municipalities to deal with the challenges i.e. waste water management. • Housing being unaffordable. • Rapid social change. • Increase in social ills i.e. substance abuse, interpersonal violence, family disorganisation. • Higher costs associated with police and emergency services due to increased demand.
After extraction	None identified	None identified	None identified	• Increased traffic, noise and activity. • Sense of fatalism, loss, deprivation and perceived deterioration in socio-economic well-being.
References	Rolfe et al., 2007; Weigle, 2011		Beemster and Beemster, 2011 Broderick et al., 2011; Coburn et al., 2011; Dolesh, 2011; Pelser et al., 2005; Walsh, 2011 Weigle, 2011; Williams, 2011	

3.2.4.2 Availability of data to map this aspect

Socio-economic well-being is gauged by relying on data such as poverty levels, employment, housing provision, access to sanitation and water. This data is widely accessible and can be mapped.

3.2.5 Demographic impacts

Section 3.2.5.1 will discuss the demographic impacts of oil and gas extraction.

3.2.5.1 Impacts

During the oil and gas exploration and extraction phases, population size, density and structure are all affected, but these demographic impacts can either be positive or negative, depending on the social dynamics within particular communities. With the advent of unconventional oil and gas exploration and in the initial extraction phase, smaller rural areas can expect an influx of workers, which increasesthe population density of the area, at least in the short term. In addition, the age structure of these communities may reflect the influx of more people in the economically active age cohorts (between 18 and 45) (Esteves, 2008; Lockie et al., 2009; Weigle, 2011). Areas in which oil and gas exploration and extraction take place may also experience a gender imbalance as migrant workers will more likely be male than female.

During the post oil and gas extraction phase, oil and gas resources have been depleted and areas may experience a reverse of the above demographic trends. As economic opportunities decline, people migrate to other areas where there are economic opportunities, often leading to smaller towns becoming ghost towns where only the aged and young children are left behind, while people in the economically active age cohorts migrate in search of employment (Pelser et al., 2005). Table 20 shows a summary of the impacts.

Table 20: Possible demographic impacts

	Positive impacts	Uncertain positive impacts	Uncertain negative impacts	Negative impacts
During exploration and extraction		• Population increase.	• Population increase.	• Gender imbalance. • Distorted age structure.
After extraction		• Population decline.	• Population decline.	• Distorted age structure.
References	Esteves, 2008; Lockie et al., 2009; Pelser et al., 2005; Weigle, 2011			

3.2.5.2 Availability of data to map this aspect

Demographic data to map population trends are easily obtainable from Statistics South Africa.

3.2.6 Astronomy

South Africa has promoted its potential as a location for astronomical observations. This has led to the construction of a large optical telescope, the Southern African Large telescope (SALT) at the South African Astronomical Observatory (SAAO) site near Sutherland, and the awarding of a large portion of the Square Kilometre Array (SKA) to South Africa. The core site of the SKA will be built near Carnarvon in the Northern Cape. The low population density, limited light pollution and low radio noise are the reasons that these projects have been developed in the Karoo region. The SKA will consist of thousands of dishes and compact arrays. The importance of astronomy is highlighted by the *Astronomy Geographic Advantage Act, 2007*, which serves to protect both radio and optical astronomy. The process of hydraulic fracturing in the Karoo region has the potential to be very detrimental to astronomy in South Africa.

Due to limited information about the extent of the proposed hydraulic fracturing, it is difficult to estimate the direct influence on astronomy. For this reason this section will serve to highlight potential problems that will have to be considered and mitigated to prevent interference with the astronomy sites. It is important to note that the requirements for optical observations (e.g. SALT) are different to those required for radio observations (e.g. SKA), and the two sections will be treated separately.

Optical astronomy

The telescopes located at the SAAO observatory, which include SALT as well as a number of other national and international telescopes, operate in the ultraviolet, optical and near-infrared region of the electromagnetic spectrum. Optical telescopes observe at wavelengths which are influenced by the properties of the earth's atmosphere, since light is scattered as it moves through the atmosphere. This means that optical telescopes must be built in areas where the atmosphere remains very stable, is free of pollutants, dust, water vapour and clouds. Telescopes are also built high above sea level to limit the amount of atmosphere through which the telescope must observe. The other important requirement is that telescopes must be built in dark locations. Artificial lighting produces what is referred to as light pollution. This results from light which is directed up towards the sky. Light pollution interferes with optical observations, limiting the number of observable stars. This effect is easily seen in cities, where stars are not visible. Similarly, lights which are directed towards the telescopes produce stray light which can interfere with observations, or damage equipment.

Radio astronomy

The SKA telescope is a radio telescope array which will operate between the frequency range 0.07-10 GHz. For this reason, it is extremely important that the radio telescopes are placed within extremely radio quiet regions. In lieu of the proposed hydraulic fracturing activities in the Karoo, the Department of Mineral Resources prepared a report on the potential impact of hydraulic fracturing. This included a report on the positional impact on radio astronomy prepared by Dr. A. Tiplady, South Africa SKA (Tiplady, 2012). This report has identified a number of potential sources that can produce radio interference. The potential effects will be discussed below.

3.2.6.1 Impacts

Radio astronomy

Impacts of unconventional oil and gas exploration and extraction on radio astronomy include:

- Radio telecommunication established as part of the oil and gas extraction operations.
- Radio frequency emission arising from industrial and mechanical operations (e.g. arc welders, vehicles, etc.).

The initial analysis contained in Annexure D of the Parliamentary Task Team report (Tiplady, 2012) finds that no hydraulic fracturing can occur within 30 km from a SKA telescope, and suggests that detailed analysis must be undertaken for any operations that will occur within 50 km. It is stressed in Annexure D of the Parliamentary Task Team report that this is a preliminary analysis, and the document calls for more detailed modelling of the possible effects. In the case where the proposed protection radii must be enlarged, the *AGA Act* allows the Minister to prescribe greater distances (within the Northern Cape province), or more stringent requirements if so required (Pers Comm Tiplady, 2012). It is also important to remember that the SKA will not be confined to one single location, but that satellite sites will be spread out over the Karoo, South Africa and Africa. The 30-50 km region applies to each of these sites, requiring that large regions must be keep radio quiet.

Optical astronomy

Impacts of unconventional oil and gas exploration and extraction on optical astronomy include:

- Dust generated during oil and gas extraction activities and related processing and industrial activities.
- Pollutants released during the oil and gas extraction and industrial activities, including smoke associated with gas flaring.
- Flaring is the process whereby additional gases released during oil and gas extraction are not directly vented into the atmosphere but ignited and burnt. While this process is done to burn toxic materials it does produce CO_2 emission and smoke.
- Lighting erected for industry and security. Artificial lighting can produce light pollution which can negatively impact optical observations. Additionally there is lighting associated with additional vehicles which may operate within the region.
- Flaring associated with gas venting. Flaring produces extremely bright flames. Such flaring is visible from satellites and has been measured by NASA Earth Observatory as documented by NOAA's National Geophysical Data Center (e.g. Elvidge et al., 2011). For example, the region around the Niger Delta is brightly lit at night. Any flaring activity in the Karoo region will have to have methods in place to mitigate these effects in order to not influence observations.

A summary of the possible impacts can be seen in Table 21.

Table 21: Possible impacts on astronomy

	Positive impacts	Uncertain positive impacts	Uncertain negative impacts	Negative impacts
During exploration and extraction	None identified	None identified	For Radio astronomy: • Radio telecommunication established as part of the oil and oil and gas extraction operation. • Radio frequency emission arising from industrial and mechanical operations (e.g. arc welders, vehicles, etc.). For Optical astronomy: • Dust generated during oil and gas extraction actives and related processing and industrial activities. • Pollutants released during the oil and gas extraction and industrial activities, including smoke associated with gas flaring. • Lighting erected due to industry and security. Artificial lighting can produce light pollution which can negatively impact optical observations. Additionally there is lighting associated with additional vehicles which may operate within the region. • Flaring associated with gas venting. Flaring produces extremely bright flames. Such flaring is visible from satellites and has been measured by NASA Earth Observatory as documented by NOAA's National Geophysical Data Center.[1] For example, the region around the Niger Delta is brightly lit at night. Any flaring actively in the Karoo region will have to have methods in place to mitigate these effects in order to not influence observations.	None identified
References	1: Elvidge et al., 2011			

3.2.6.2 Availability of data to map this aspect

The CISPR standards can be used to quantify the level of radio interference as discussed in Tiplady (2012). This will depend on the final location of the SKA stations and the extent of the oil and gas extraction activities.

3.2.7 Archaeology and heritage resources

The *National Heritage Resources Act 25 of 1999* provides for the integrated and interactive management and protection of national heritage resources and empowers civil society to nurture their heritage resources so that they may be bequeathed to future generations. Unconventional oil and gas extraction will have many and extensive impacts on archaeology and heritage resources. Section 3.3.1.1 will discuss the importance of archaeology and heritage resources and possible impacts of extraction activities in the Karoo.

3.2.7.1 Impacts

South Africa is home to over 2 million years of human and hominin life. Millions of artefacts, sites, rock art, historic farmhouses, indigenous architecture, graves, oral histories, battlefields, sites of resistance and other human products mark this landscape. These are all “heritage resources”, which are part of the “national estate”. The Karoo is one such heavily marked human landscape, though most archaeological artefacts and sites have not yet been recorded. Any development will have a physical impact on this valuable but fragile heritage. This heritage is protected by the *National Heritage Resources Act 25 of 1999,* and any development must be preceded by an Archaeological Impact Assessment (AIA) and a Heritage Impact Assessment (HIA) by a qualified heritage practitioner. Too often people with little or no competence in Archaeology make pronouncements on the presence and "worth" of heritage resources. It is thus vital that archaeologists accredited with the Association of Southern African Professional Archaeologists are employed to conduct the AIA. All "heritage resources", under *Act 25 of 1999*, have equivalent worth – they tell us different things about human life – so a single stone tool has the same protection and status as an historic building. These heritage resources must be studied in their physical and conceptual context in order to fully understand how they build our knowledge of the past. The Karoo is especially rich in stone tools from all periods (these will look like "natural" stones to most non-archaeologists, which is why a foot survey of all affected areas is non-negotiable); human remains, graves, living sites, factory sites, sacred sites, San rock engravings, Khoekhoe herder finger paintings, Mfecane period refuge sites, corbelled houses, battle sites from ancient times through to frontier wars and the South African War), homesteads of early farmers, multi-ethnic frontier groups and the like, oral histories, landscapes of genocide and clearance. Even after an AIA and foot survey has been conducted there may still be undetected sub-surface archaeology, exposed during development, so a watching brief is essential. Should archaeology be encountered in this way, all work must cease until an archaeologist determines an appropriate course of action. Prior to any impact on an archaeological site or "heritage resource" the appropriate heritage permits needs to be obtained and a suitable repository for the artefacts and documentation identified and their agreement to curate the material must be obtained.

The Karoo, with its often extreme environmental conditions, means that places for human habitation tend to be re-used by people over the ages. This applies also to, for example, contractors' camps where rock shelters, locations near water and so forth being prime locations for siting camps, site offices etc., but which are also very sensitive archaeologically.

It is highly advantageous that developers ask the archaeologist(s) that they employ to conduct the AIA and also provide some basic artefact and site identification sessions for developer staff. This will help lessen the impact on the heritage resources and allow quick notification of experts when heritage resources are encountered. Also, such identification work helps build the knowledge and skills base of workers, and can add value, in a commercial sense, to many developments.

3.2.7.2 Availability of data to map this aspect

A national database containing spatial information of all possible heritage sites does not exist. But the South African Heritage Resources Agency's SAHRIS system (www.sahra.org.za/sahris) is now on-line and has some sites entered.

An AIA and foot survey of archaeological and heritage sites would be required to determine the possible impacts of unconventional oil and gas exploration and extraction on archaeology and heritage resources at each prospective site; as well as all access routes, places for workers' camps and plant, and so forth.

3.2.8 National parks

National parks are one of the entities on which unconventional oil and gas extraction might have a large impact. The *National Environmental Management Act, Protected Areas Act of 2003* provides for protection and conservation of ecologically viable areas representative of South Africa's biological diversity and its natural landscapes and its seascapes. Section 3.2.8.1 will discuss possible impacts of unconventional oil and gas mining on parks in South Africa.

3.2.8.1 Impacts

Impacts on national parks would cover positive, negative and uncertain impacts and will be discussed in terms of the following periods of oil and gas extraction: During oil and gas exploration, during oil and gas extraction and post oil and gas extraction. Oil and gas extraction would include all the relevant tight oil and gas resources on which hydraulic fracturing may be applied to extract the oil and gas, which in South Africa are shale oil and gas deposits and CBM deposits.

Hydraulic fracturing poses a considerable threat to the biodiversity of South African national parks. According to the Millennium Ecosystem Assessment (2005) *Homo sapiens* are the most important contributor to the current mass extinction on earth. In addition, freshwater ecosystems are fragmented at a rate that has never been recorded in geological history. It is therefore important to increase our understanding on impacts of hydraulic fracturing on national parks.

The following national parks lie within the Karoo geological main and sub- basins:

- Mapungubwe National Park (MNP)
- Kruger National Park (KNP)
- Golden Gate Highlands National Park (GGHNP)
- Mokala National Park (MNP)
- Tankwa Karoo National Park (TKNP)
- Karoo National Park (KNP)
- Mountain Zebra National Park (MZNP)
- Addo Elephant National Park (AENP)

The national parks can be seen in Figure 5.

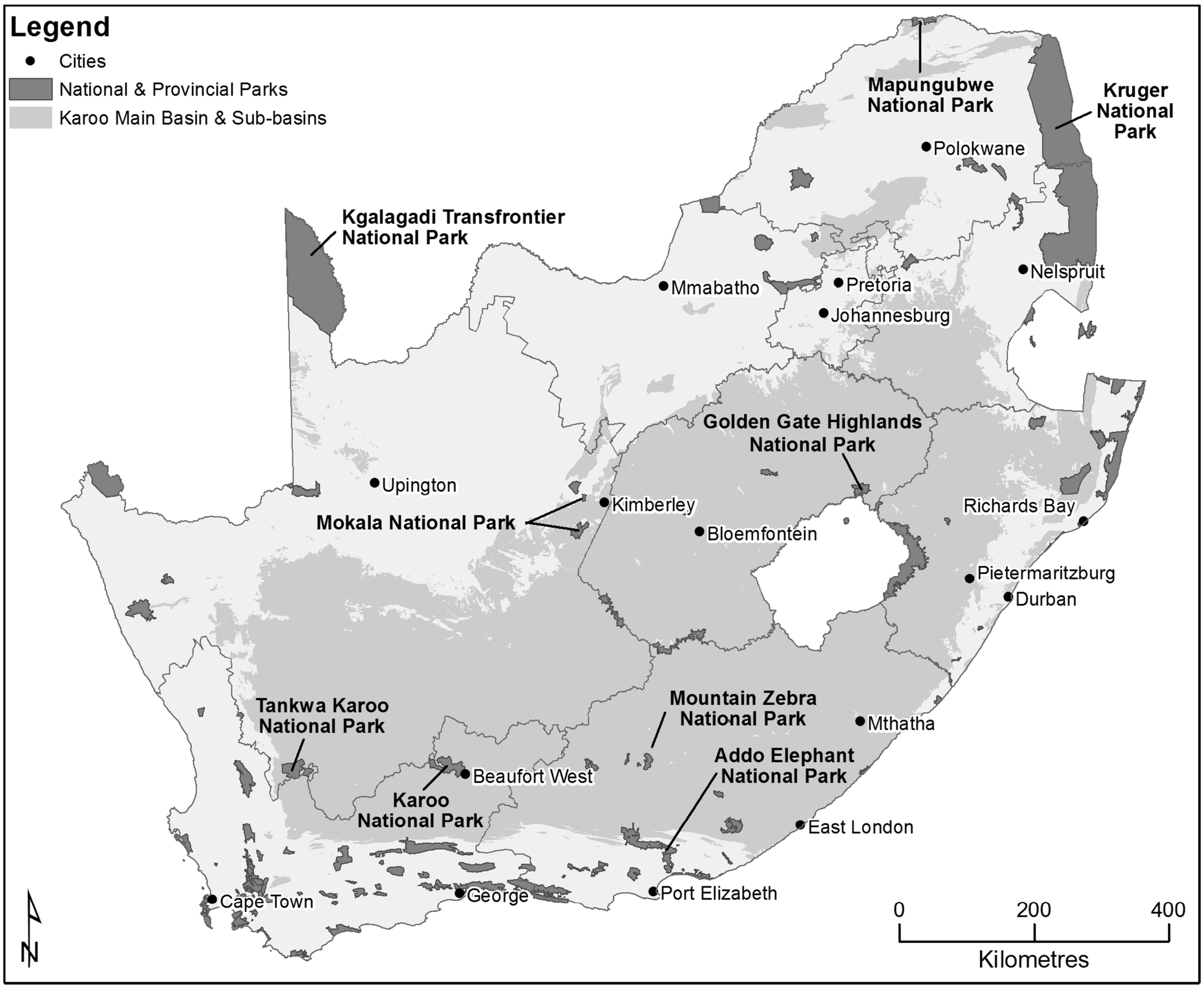

Figure 5: South African national parks that occur in the Karoo Main and Sub-basins.

It is required by the *National Environmental Management Protected Areas Act (*Act 57 of 2003) for every national park to have a management plan. These management plans highlight the main objectives of each of the respective national parks. The primary objectives of each of the national parks above are mainly (AENP, 2008; GGHNP, 2012; KNP, 2008; MNP, 2008; MONP, 2008; TKNP, 2008):

- Biodiversity conservation,
- Conservation of ecological patterns and processes, and
- Heritage conservation and the conservation of cultural landscapes.

The next sections will discuss possible impacts.

During oil and gas exploration

Possible positive impacts may include minor economic spending of mine workers at shops in national parks during the exploration phase.

Possible negative impacts may include the clearance of large vegetation strips for seismic lines (EMROG, 2006) that may lead to habitat fragmentation. Habitat fragmentation is recognised as one of the biggest threats to biodiversity (Bossuyt, 2007; Brook et al., 2003; Valladares et al., 2006; Wiegand et al., 2005), and by implication ecosystem patterns and processes. The reduction in vegetation cover reduces soil quality that in turn increases soil erosion rates (Mills and Fey, 2003). Seismic activity therefore poses a significant threat to biodiversity conservation, which is a primary objective of the affected national parks (AENP, 2008; GGHNP, 2012; KNP, 2008; MNP, 2008; MONP, 2008; TKNP, 2008).

Vegetation clearance (EMROG, 2006) will most likely have an impact on cultural heritage sites. The conservation of cultural heritage is one of the primary objectives of the affected national parks (AENP, 2008; GGHNP, 2012; KNP, 2008; MNP, 2008; MONP, 2008; TKNP, 2008). In addition, the MNP is one of eight World Heritage Sites in South Africa. Seismic lines associated with the disruption of land (EMROG, 2006) may therefore significantly impact the ruins in the MNP as well as the cultural heritage of the other national parks.

The tourism industry of the affected national parks may be impacted by oil and gas exploration within the parks, or within the vicinity of the affected national parks. The increase in noise, dust as well as traffic may deter tourists from visiting the parks. Over the long term this might inhibit development within the tourism industry and in turn impac on employment within the tourism industry (Beemster and Beemster, 2011).

The potential contamination of groundwater with fracking chemicals may also impact the tourism industry, as the tourism sector in national parks largely relies on groundwater as a source of drinking water (Leyland and Witthueser, 2008; Martinelli and Hubert, 1979). The possible contamination of groundwater may also result in large scale mortality of both fauna and flora in national parks.

Exploration for oil and gas may threaten park expansion, especially with reference to the formation of TFCA's (Transfrontier Conservation Areas). The possibility of producing natural oil and gas may make international conservationists ill at ease. This could jeopardise cooperation with international conservation agencies, hence preventing restoring past cross-boundary ecological patterns and processes.

Flaring during the exploration phase may pose a risk to both biodiversity and tourism. Tourists are unlikely to be in favour of light pollution in the night sky, especially in the Karoo, renowned for spectacular star gazing opportunities. Insects will probably be attracted to the artificial light, which will in turn attract predators such as bats and other reptilians. Exposure to flares, together with an increase in human concentration around the well might expose wild animals to a higher mortality rate.

An increase in labourer activities in and around national parks may increase poaching activities. The extinction probability of endangered and targeted species such as the rhinoceros may therefore increase. Seismic activity may also disturb patterns and processes of wildlife. Wildlife may avoid the areas associated with seismic activity, hence concentrating in certain sections of the park. This may influence predator-prey dynamics and may also cause overutilisation of certain sections within the park. Overgrazing may result in a reduction in ecological capacity of the veld, hence altering ecosystem patterns and processes.

During oil and gas extraction

Possible positive impacts may include minor economic spending of hydraulic fracturing mine workers at shops in national parks.

Possible negative impacts may include the development of large infrastructure, i.e. drilling pads, parking areas for trucks, clearance of large open areas to allow trucks to turn around as well as storage facilities for equipment (Lechtenböhmer, 2011). This will increase habitat fragmentation, a leading threat to biodiversity (Bossuyt, 2007; Brook et al., 2003; Valladares et al., 2006; Wiegand et al., 2005;). The increase in habitat fragmentation by means of hydraulic fracturing within and around national parks in South Africa contradicts national parks policy and could jeopardise conservation initiatives in national parks such as park expansion.

Uncertain impacts may include induced seismicity associated with hydraulic fracturing (Shapiro and Dinske, 2009), which may significantly threaten the biodiversity of national parks. Earthquakes are an uncommon phenomenon in South African national parks. Plants and animals most likely evolved in the absence of earthquakes and may be forced into a threshold once exposed to seismic activity. The consequent loss in biodiversity may alter ecosystem patterns and processes and extinction of some species may be inevitable.

An increase in human activity associated with heavy vehicles and machinery may impact animal behaviour, causing animals to concentrate in certain areas within a National Park. This could result in trampling as well as overgrazing that reduces the ecological capacity of the veld. Additionally, an increase in human activity during oil and gas extraction may possibly increase illegal entering and poaching of both fauna and flora within the affected national parks. This could pose a significant threat to endangered species in particular.

The construction of large infrastructure within and around national parks possibly pose a major threat to cultural and heritage conservation, another one of the prime objectives of national parks in South Africa (AENP, 2008; GGHNP, 2012; KNP, 2008; MNP, 2008; MONP, 2008; TKNP, 2008). The MNP is one of eight World Heritage Sites in South Africa and was home to the first strong black empire in southern Africa; it existed between 900 and 1300 years after Christ. Today, the MNP is well-known for Mapungubwe Hill as well a number of ruins. The MNP is therefore an important archaeological site in South Africa, representing the best known Iron Age settlements (Steyn et al., 1999). Hydraulic fracturing may therefore pose a significant threat to the heritage sites of MNP.

The construction of fracking wells in and around national parks most likely pose a considerable threat to the tourism industry of parks. Beemster and Beemster (2011) predict a reduction in tourism after the construction of well pads, which may result in considerable job losses within the industry. The reduction in tourism may be ascribed to an increase in pollution by means of dust as well as a reduction in aesthetic beauty of national parks. This may deter tourists, both local and international, from visiting national parks. According to Coburn et al. (2011) approximately 15 000 000 litres of water is required for each drilling site. The majority of the rivers in South Africa are non-perennial (Seaman et al., 2010). These rivers are exposed to highly variable runoff and rainfall patterns and are easily disturbed (Seaman et al., 2010). The people residing in these areas as well as tourists visiting the national parks require assurance of water as well as water of an acceptable quality. The possible contamination of groundwater resources elsewhere, as documented by DiGiulio et al. (2011), pose a significant threat to tourists, park personnel as well as the fauna and flora of South African national parks. Groundwater and surface water contamination therefore pose a significant threat to the biodiversity and ecological patterns and processes of national parks.

Post oil and gas extraction

A possible positive impact may be the fact that oil and gas companies may be willing to pay for the restoration in a National Park.

Although vegetation and animal movement patterns could be rehabilitated after oil and gas extraction activities, the rehabilitation of cultural heritage sites is highly unlikely. Park management will therefore have failed to conserve the heritage of the park, one of their primary objectives (AENP, 2008; GGHNP, 2012; KNP, 2008; MNP, 2008; MONP, 2008; TKNP, 2008). The rehabilitation of vegetation is a time consuming and expensive process (Snyman, 2003). Mechanical input is critical once vegetation has been destroyed beyond a threshold (Snyman, 2003). Post oil and gas extraction vegetation and land rehabilitation will therefore be a lengthy process that will require numerous resources.

The long term impacts on ecological capacities, migration patterns of animals where national parks have international borders, rehabilitation success as well as the full impact on the tourism industry remain largely uncertain.

Other uncertain impacts include:

- How severe will soil erosion be under post-extraction conditions?
- Will groundwater contamination be detected after oil and gas extraction operations?
- Where will contaminated water be stored?
- Who will be responsible for wildlife losses?
- Will the loss in ecosystems patterns and processes be expressed in monetary terms and will oil and gas companies be held responsible for the changes of these patterns and processes?
- Will oil and gas companies be billed for the loss in aesthetic value of a National Park and will they be held responsible for the loss in sense of place after oil and gas extraction activities?

Table 22 shows a summary of the impacts.

Table 22: Possible impacts on parks

	Positive impacts	Uncertain negative impacts	Negative impacts
During exploration	• Minor economic spending by mine workers.	• Impact of seismic lines on cultural heritage sites, a prime management objective if the affected national parks.[1, 4, 5, 6, 7, 8, 9, 15] • Impacts on the tourism industry.[12] • Contamination of groundwater and the effect on biodiversity and tourism.[11, 14] • Prevention of park expansion. • Effect of flaring on biodiversity. • Increase in poaching activities. • Reduction of ecological capacity.	• Seismic lines that will lead to habitat fragmentation.[1, 4, 5, 6, 7, 13] • Soil erosion and a loss in biodiversity, a prime management objective of national parks.[2, 5, 8, 9, 10, 11, 12, 14]
During extraction	• Minor economic spending by mine workers.	• Induced seismicity and the effects on biodiversity.[3] • Alteration of animal behavioural patterns. • Reduction in ecological capacity of veld. • An increase in illegal activities inside parks. • Impacts on cultural heritage. • Effects on the tourism industry and groundwater systems.[12, 14]	• Habitat fragmentation.[1, 4, 6, 7, 13]
After extraction	• Likelihood of oil and gas companies to pay for rehabilitation.	• Long term impacts on ecological capacities and animal migration patterns. • Rehabilitation success.[2] • Effects on the tourism industry.[12] • Soil erosion.[3] • Groundwater contamination.[14] • Storage of contaminated water.[4] • Who will be accountable for the loss in biodiversity and will these losses be expressed in monetary terms.	• Restoration of vegetation and cultural heritage will not be feasible.[3] • Vegetation and land rehabilitation is time consuming and expensive.[3]
References		1:Steyn et al., 1999; 2: Mills and Fey, 2003; 3: Snyman, 2003; 4: EMROG, 2006; 5: AENP, 2008; 6: KNP, 2008; 7: MNP, 2008; 8: MONP, 2008; 9: TKNP, 2008; 10: Shapiro and Dinske, 2009; 11: Seaman et al., 2010; 12: Beemster and Beemster, 2011; 13: Coburn et al., 2011; 14: DiGiulio, 2011; 15: GGHNP, 2012	1: Brook et al., 2003; 2: Mills and Fey, 2003; 3: Snyman 2003; 4: Wiegand et al., 2005; 5: EMROG, 2006; 6: Valladares et al., 2006; 7: Bossuyt, 2007; 8: AENP, 2008; 9: KNP, 2008; 10: MNP, 2008; 11: MONP, 2008; 12: TKNP, 2008; 13: Lechtenböhmer, 2011; 14: GGHNP, 2012

3.2.8.2 Availability of data to map this aspect

A national database containing spatial information of all possibly impacted national parks does exist. The name of the spatial dataset is Parks and the source is Mucina and Rutherford (2006).

4 VULNERABILITY MAPPING

This section of the report discusses the vulnerability map for unconventional oil and gas extraction that was developed as part of project K5-2149. An interactive stand-alone vulnerability map was developed, which allows the end-user free access to and visualisation of vulnerability within a particular location, through spatial data on vulnerability and sensitivity of selected mapping themes covering surface water, groundwater, seismicity, vegetation and socio-economics.

The approach to vulnerability mapping, the mapping framework, the mapping process and the challenges, limitations and constraints of the vulnerability mapping will be discussed in Section 4.1. Section 4.2 will discuss detail information for each mapping theme, with Section 4.3 summarising the vulnerability mapping exercise.

The vulnerability map aims to provide decision-makers at national level and other practitioners with information on the vulnerability to unconventional oil and gas extraction of the specified themes on a regional scale. The vulnerability map was developed by experts in the respective fields, who decided on indicators that would indicate vulnerability of a theme to unconventional oil and gas extraction specifically. Only regional scale data was used for this regional map and the map cannot replace local scale maps that may need to be developed to inform decision-makers of local scale conditions of vulnerability to unconventional oil and gas extraction. This map is intended as a reconnaissance tool, to inform decision-makers on areas where additional detail field work and assessments may be required as part of EIA process and licensing conditions.

4.1 Mapping approach

Sections 4.1.1 to 4.1.3 discuss the mapping approach followed for the development of the interactive vulnerability map.

4.1.1 Approach to vulnerability mapping

Vulnerability mapping typically has various issues that must be addressed, including mapping approaches, indicator identification, weighing of indicators and aggregation of maps. For the purposes of this report, the vulnerability system will include biophysical and socio-economic themes, of which only selected entities will be mapped.

Typically vulnerability is a function of exposure, sensitivity and coping (adaptive) capacity (Birkmann, 2006; Lin and Morefield, 2011; O'Brien et al., 2011; Wongbusarakum and Loper, 2011). The greater the exposure or sensitivity, the greater the vulnerability, and the greater the coping capacity, the less the vulnerability of the system will be. Classically, biophysical systems mostly identify sensitivity indicators (Schauser et al., 2010). Coping capacity is usually most easily identified for the socio-economic sphere and refers to adaptability by humans (O'Brien et al., 2011; Wongbusarakum and Loper, 2011), although coping capacity for the biophysical entities could also be identified.

A vulnerability indicator, which can be spatially represented as a map, is usually the result of the combination and aggregation of a number of sub-indicators or indicating components (Birkmann, 2006; Kienberger et al., 2009). The approaches for indicator development include the deductive approach (based on theory), the inductive approach (using statistical relations to explain observed impacts through the indicating components) and the normative approach (using expert knowledge based on subjective individual or collective expert opinion).

The normative approach was followed for the identification of indicators in this project. Although this approach requires time and resources and is limited in its application and transferability to other regions (e.g. countries outside South Africa), the integration of expert knowledge provides support for the weighing and aggregation of the indicator components and may increase the acceptability of the results. It is also widely acknowledged that the involvement of stakeholders in the development of indicators is key (Harvey et al., 2011, Nardo et al., 2005). Biases and heuristics can influence expert opinion (Milkman et al., 2009) and the team aimed to minimise these influences and improve expert assessment by means of contextualisation, communication and feedback during the elicitation process. Experts were asked to give input on identification of various sensitivity indicators. Coping capacity indicators were not included in this map due to various challenges related to this concept.

The IPCC definition of vulnerability describes vulnerability in terms of exposure, sensitivity and coping capacity, but most critically does not describe the form of the function which relates these three components and various researchers find it difficult to operationalise these concepts (Patt et al., 2009a, Preston and Stafford-Smith, 2009; Schauser et al., 2010). The most challenging concept is how coping or adaptive capacity is influenced by social, political, economic, technological and other components. Additionally, there is considerable debate in the literature as to what constitutes adaptive capacity and how it might be recognised (Brooks et al., 2005; Preston and Stafford-Smith, 2009; Schauser et al. 2010; Vincent, 2004; Yohe and Tol, 2002). Regarding the assessment of adaptive capacity, the distinction between sensitivity and adaptive capacity can be blurry and are not concepts that are easy to separate (Fay et al., 2010; Schauser et al., 2010). Sensitivity can be the degree to which a system is affected (positively or negatively) in its current form, however, adaptive capacity is dynamic and affects future sensitivity. In practice, the same factors that determine current sensitivity may also determine the extent of adaptive capacity (Fay et al., 2010; Schauser et al., 2010), leading some researchers to question whether adaptive capacity should form part of vulnerability mapping (Birkmann, 2006).

The measurement of coping/adaptive capacity is a relatively new and evolving area of study (Smith et al., 2010); adaptive capacity has traditionally been examined from either an ecological or a social perspective (Gleeson et al., 2011), but efforts are underway to integrate knowledge of adaptive capacity of social and ecological systems (Miller et al., 2010; Smith et al., 2010; Turner, 2010). Recent research projects also plan to assess the nature of adaptive capacity, its utility for decision-making as well as approaches to the application and understanding of adaptive capacity in different disciplines (Smith et al., 2010; Smith, 2012). It is however important to acknowledge that coping capacity can influence vulnerability considerably, and this needs to be investigated in future revisions of this map.

Schauser et al. 2010 report that recognition and classification of indicators into exposure, sensitivity and coping or adaptive capacity is often too complex to yield usable results and thus team members identified various sensitivity indicators for the mapping themes. These were verified by experts and were used in the interactive vulnerability map.

4.1.2 Process for vulnerability mapping

The process followed for vulnerability mapping can be summarised as follows:

- Identification of indicators for vulnerability mapping (to be classified according five classes of vulnerability) as well as indicators that may be flagged on the vulnerability map (not classed);
- Weighting and aggregation of indicators for each aspect that is to be aggregated;

- Identification of areas where mining as well as oil and gas production is prohibited by law (to be flagged on the interactive map); and
- Development of the browser based structure for the interactive vulnerability map.

Each of these steps will be discussed below.

Identification of indicators to be classified for vulnerability mapping as well as indicators to be flagged on the vulnerability map

For the identification of indicators that are to be classified or flagged, the project team decided to use experts as a means of theory building throughout the process of vulnerability mapping. Key informants related to each discipline were identified during the indicator identification phase and the aim was to use them throughout the mapping exercise. It was deemed very important to use experts, in order to ensure proper adherence to policy goals, and also encourage transparency, credibility and pragmatism. The experts who were chosen to partake in the study had to have knowledge about unconventional oil and gas extraction by means of hydraulic fracturing, or had to be involved in research related to it. In some cases not all the participants could comply with this requirement, and this is illustrative of how new this field of research is in South Africa. Experts however still needed to be consulted for the indicator identification phase, and it was hoped that the contextualisation and information given to the experts could assist with identifying relevant indicators.

Based on the “issues/impacts concept” (Harvey et al., 2009; Harvey et al., 2011; Preston and Stafford-Smith, 2009), the team gave experts information on the possible impacts/issues that may emanate from exposure to unconventional oil and gas extraction by means of hydraulic fracturing.

Possible positive and negative impacts during each of the unconventional oil and gas extraction phases (exploration, extraction and post-extraction) for the mapping themes were identified by team members during the execution of the background review, and are based on literature. This information served as a conceptual framework to guide the development of indicators and to help experts understand the links between indicators (Brown, 2009). It was hoped that this information would avoid the selection of a mix of indicators with no clear rationale for their selection. This information could be used by experts to assess the appropriateness of indicators that were proposed for mapping various sensitivity indicators in relation to possible impacts. It was difficult to identify guidelines for the identification or development of vulnerability indicators (Birkmann, 2006; Eriksen and Kelly, 2006).

In the indicator identification questionnaire, experts in each discipline were asked to review the appropriateness of using proposed indicators to indicate vulnerability, and to suggest additional indicators where applicable. As a pragmatic step forward in this specific vulnerability mapping exercise, the team decided to concentrate primarily on sensitivity indicators as related to the exposure to unconventional oil and gas extraction, since variables for these elements are most often and easily investigated and quantified. Schauser et al. (2010) also report that recognition and classification of indicators into exposure, sensitivity and coping/adaptive capacity is often too complex to yield usable results.

Feedback from the first round of questionnaires to experts was used to identify the relevant indicators to be classified, as well as indicators to be flagged.

Weighting and aggregation of indicators to be aggregated

Weights express the contribution and relative importance of the individual indicator component. The elicitation of weights requires a deep understanding of the theoretical vulnerability framework (Hiete and Merz, 2009); however, existing theories and models usually do not provide any arguments about how various components should be weighted when aggregated (Schauser et al., 2010). Most vulnerability assessments use normative arguments using expert opinion or may be purely data-driven or a combination of both. Data-driven approaches are usually based on the structure of the component datasets and little information is provided by theory. Due to the difficulty in judging the importance of single components in such instances, many data-driven approaches apply equal weighting (Schauser et al., 2010). Different AHP (analytical hierarchy process) analyses options, as well as the budget allocation weighing option have been investigated to determine suitable options for weighting of the base maps.

The team used expert opinion to determine weighting by means of the budget allocation method (Nardo et al., 2005). Although the AHP method is usually well received by experts as they find it intuitive (Saaty, 2008), the team decided to use the budget allocation method to ensure consistency between mapping approaches for different entities. The budget allocation method was seen as a more relevant weighting approach specifically for the socio-economic map indicator weighting, where the application of the AHP process for derivation of weights might have been problematic when importance of indicators have to take into account the dimension in which the indicator operates and not necessarily the importance of each individual indicator. It also makes re-weighting of mapping components and disaggregation of indicators easier.

Indicators were to be classified into five classes of vulnerability. This weighting was determined via expert input during a second round of questionnaires to experts. The indicators that were to be flagged did not require weighting and were included as overlays on the base maps in the browser. Flagged indicators were indicators that needed to be included on the map due to important information that the flagged indicators would convey.

For indicator aggregation, various studies recommend that aggregation methods be as simple as possible, in order to ensure transparency and allow disaggregation of indicators (Schauser et al., 2010). Independent indicators were aggregated by means of the simple additive weighting (SAW) method and dependent indicators were aggregated by using the weighted product method (WPM) (Triantaphyllou, 2002). Interaction between different indicators that were to be aggregated for each aspect was investigated by the mathematical statistician, using various statistical methods.

The team decided that the maps for seismicity, groundwater, surface water, vegetation and socio-economics would not be aggregated for the interactive vulnerability map, since the usefulness of such an aggregated map may be limited, because different government departments have mandates to manage different components, e.g. the DWA must protect, manage and monitor groundwater and surface water resources while the DEA is responsible for protection of vegetation and biodiversity.

Based on the above investigations, an exploratory questionnaire was developed for each aspect to be mapped in order to determine possible indicators. For seismicity only one indicator (seismic hazard) has been used and questionnaires have thus not been developed for seismicity. A generalised template of the exploratory questionnaires can be seen in Appendix 1. A follow-up questionnaire (Appendix 2) was developed to classify and weigh the indicators.

Experts were asked to respond on the appropriateness (on a scale from 1 to 10) of possible indicators, and to give reasons for their answers. These answers were used to identify useful indicators that can be used for vulnerability mapping of each aspect. The time dimension that the vulnerability mapping focused on, is the present. During the indicator identification phase, experts were also asked to indicate data availability if they indicated the use of alternative indicators.

Detail information on the appropriateness of using specific indicators for each aspect, as well as the main themes that emerged from reasons that experts gave for the appropriateness of indicators for each aspect, are discussed in section 4.2.

Identification of areas where prospecting and mining or petroleum resource exploration and production is prohibited by law or where entities are protected by law

The team deemed it useful to identify mapped areas where prospecting and mining (in the case of for instance coalbed methane mining) as well as exploration and production (in the case of petroleum production) or certain other activities are prohibited by law, or where certain legislation requires assessment or protection zones to be applied. The only areas that are legally protected by law from mining or petroleum resource production are areas declared under s.48 of the *National Environmental Management: Protected Areas Act* (No. 57 of 2003) (*NEM: Protected Areas Act)* and areas declared under s.49 of the *Mineral Petroleum Resources Development Act* (No. 28 of 2002) (*MPRDA*). Sections 48 and 69(2) of the *MPRDA* are the relevant sections of the Act in relation to the protections granted under s48 of *NEM: Protected Areas Act.*

For all other important biodiversity aspects that may need protection such as NFEPA wetlands, RAMSAR sites and mountain catchment areas there is only a legal requirement for an impact assessment process and as such these areas cannot be identified as areas where no prospecting or other activities may be allowed. Prospecting and mining may be prohibited in certain sensitive areas after going through the impact assessment phase. At this stage these sensitive areas can only be flagged on the map but cannot be blanked out as areas where mining or petroleum resource production is prohibited by law.

Freshwater Ecosystem Priority Areas (FEPA) maps, components of which were used in the surface water mapping theme, have no formal legal status, but several of the processes they inform do. The primary means of securing FEPAs and giving effect to FEPA maps is through the classification of water resources in terms of the *National Water Act* (No. 36 of 1998) (*NWA*). Other legal processes that should be informed by FEPA maps include publication of bioregional plans and listing of threatened ecosystems in terms of the *National Environmental Management Biodiversity Act (No 10 of 2004) (NEMBA)*, the declaration of protected areas in terms of the *National Environmental Management: Protected Areas Act* (No. 57 of 2003), environmental impact assessments in terms of the *National Environmental Management Act* (No. 107 of 1998) (*NEMA)*, and development of Spatial Development Frameworks in terms of the *Local Government Municipal* Systems Act (No. 32 of 2000).

Onshore technical cooperation permits (TCPs) and exploration rights (ERs) for oil and gas extraction (PASA, 2014) are also indicated as an overlay on the interactive vulnerability map.

Spatial data that were indicated as an overlay, as linked to the specific legislation, can be seen in Table 23.

Table 23: Spatial data linked to legislation

Mapped spatial layer	Mapping theme to which spatial layer is applicable	Legislation, guidelines or plans relevant to mapped spatial layer	Implications
Mining and petroleum resource production legally prohibited	All mapping themes	Provisions related to areas declared under s.49 of the *MPRDA,* which are extended under s.69(2)(a) that deals with petroleum exploration and production. Areas where prospecting and mining is declared as prohibited under s.48 of the *NEM:Protected Areas Act* (	Prospecting or mining projects cannot commence in these areas as prospecting and mining is legally prohibited. The provision of the *MPRDA* that limits prospecting and mining in protected areas, is extended in s.69(2)(a) to petroleum resource exploration and production. Although prospecting and mining and petroleum exploration and production are prohibited in protected areas, these activities may be allowed in these areas if both the Minister of Mineral Resources and the Minister of Environmental Affairs approve it. In cases where mining was conducted lawfully in protected areas before s.48 of the *NEM: Protected Areas Act* came into effect, it may be allowed after consultation with both ministers of DMR and DEA, subject to prescribed conditions aimed to reduce environmental impacts.
Onshore technical cooperation permit (TCP) and exploration right (ER) areas		Areas where a TCP has been issued under s.77(1) of the *MPRDA* or where an ER has been issued under section 80 of the *Mineral Petroleum Resources Development Act* (no. 28 of 2002).	A TCP issued to applicant in terms of s.77(1) of *MPRDA* allows the applicant to do desktop study, acquire seismic data from other sources including the Agency, etc.; but does not include any prospecting or exploration activities. An exploration right granted to the applicant in terms of s.80 of *MPRDA* allows the applicant to re-process the existing seismic data, acquisition and process new seismic data or any other related activity to define a trap to be tested by drilling, logging and testing, including extended well testing, of a well with the intention of locating a discovery.
Subterranean groundwater control areas	Groundwater mapping theme	Subterranean groundwater control areas that were declared under the *Water Act* (No. 54 of 1956) and included in regulations of the *NWA*	Subterranean groundwater control areas are areas that still receive protection under the *NWA*) as they are important water supply aquifers for certain towns in South Africa.
Mining and petroleum resource production to be assessed before approval	Socio-economic mapping theme	*Astronomy Geographic Advantage* (*AGA) Act* (No. 21 of 2007)	Assessment in areas as identified in regulations under the *AGA Act*, under development, not promulgated yet.
		Subterranean groundwater control areas that were declared under the *Water Act* (1956) and included in regulations of *the NWA*	Subterranean groundwater control areas are areas that still receive protection under the *National Water Act (*No. 36 of 1998) as they are important water supply aquifers for certain towns in South Africa.
	Vegetation mapping theme	Critical biodiversity areas and associated ecological support areas	Assessment in areas as identified under *NEM:BA*.

Although prospecting and mining as well as petroleum exploration and production is prohibited in the protected areas identified under s.49 of the *MPRDA* (extended under s.69(2)(a) to petroleum resources), this flagged spatial layer has the option to be deactivated in the interactive vulnerability map, since such activities may be allowed in the protected areas, if approved by both the Ministers of Mineral Resources and Environmental Affairs.

Development of the browser based structure for the interactive vulnerability map

The DVD accompanying this report contains the interactive vulnerability map, which is a stand-alone website that runs in a computer's default browser without requiring an internet connection. The website includes an interactive map browser that allows the user to explore the various datasets mentioned in this report. Instructions on running the interactive vulnerability map can be seen in Appendix 3.

The Vulnerability Map website comprises three sections, namely ***Home***, ***Interactive Map*** and ***Documents***. These sections are accessible via the orange menu bar near the top of the screen. The Home section contains an introduction to the website and also provides background on the interactive map browser: the Interactive Map section is the main section of the website where the user can explore and interrogate the spatial datasets referred to in this report. From the Documents section the user can download PDF versions of the report and other documents relevant to the report.

The interactive vulnerability map covers five mapping themes, namely surface water, groundwater, vegetation, seismicity and socio-economics. Only one theme can be selected at a time on the interactive map. When a vulnerability theme is selected, the list of base maps and overlays for that theme are displayed and the map is automatically updated to show the default layers. The user can then select from one or more of these base maps and/or overlays. Note that only one base map can be shown at a time whereas multiple overlays can be displayed at the same time.

The vulnerability map is an interactive live map that can be zoomed, panned and queried. The user can also zoom within the map window, or zoom to a specific feature by using the Zoom to Town, Zoom to Water Management Area or "Zoom to Catchment" option. The Zoom to Catchment option enables the user to zoom to a quaternary catchment.

Base maps are classified according to five classes of vulnerability, indicated on the map by specific colours described in Table 24. Certain datasets are not classified and will be depicted in grey. Towns or cities are depicted by a black dot.

Table 24: Legend items and depiction

Legend items		Depiction in legend
Vulnerability description	Very low vulnerability	Blue
	Low vulnerability	Green
	Medium vulnerability	Yellow
	High vulnerability	Orange
	Very high vulnerability	Red
Uncategorised data		Grey
Town/city		Black dot
Quaternary catchments		Dashed red polygon
Water Management Areas		Dashed green polygon

The interactive map contains the following mapping themes, with the following additional information depicted in overlays, which can be seen in Table 25.

Table 25: Base layers and overlays of interactive vulnerability map

Map theme	Base maps	Overlays
Surface water	• River condition by default ecological category. • Wetland condition based on wetland ranks.	• Prospecting and mining; oil and gas exploration and production legally prohibited (Holness, 2013). • PASA Permit Areas (TCP and ER areas) (PASA, 2014). • Wetland clusters (NFEPA data - Nel et al., 2011b). • Wetland condition based on wetland ranks (NFEPA data - Nel et al., 2011b). • Threatened and near threatened fish species (NFEPA data - Nel et al., 2011b). • Rivers (NFEPA data - Nel et al, 2011b). • Water Management Areas (DWA, 2013b).
Groundwater	• Drastic groundwater vulnerability (groundwater vulnerability based on the DRASTIC approach from the GRAII assessment) (DWA, 2005).	• Prospecting and mining; oil and gas exploration and production legally prohibited (Holness, 2013). • PASA Permit Areas (TCP and ER areas) (PASA, 2014). • Geological structures (1:1 000000 scale geological structures) (CGS, 2013). • Subterranean groundwater control areas (DWA, 2013c). • Rivers (NFEPA, 2011). • Water Management Areas (DWA, 2013b). • Boreholes (information from the National Groundwater Archive (DWA, 2014).
Vegetation	• Aggregated map (ecosystem threat status and ecosystem protection level). • Ecosystem threat status. • Ecosystem protection level.	• Prospecting and mining; oil and gas exploration and production legally prohibited (Holness, 2013). • PASA Permit Areas (TCP and ER areas) (PASA, 2014). • Aquifer dependent ecosystems (Colvin et al., 2007). • Category B Critical biodiversity area bioregional and provincial (Holness, 2013). • Category C Critical biodiversity area bioregional and provincial (Holness, 2013). • Category D Ecological area bioregional and provincial (Holness, 2013). • Category D Ecological support area equivalent (Holness, 2013).
Seismicity	• Seismicity The seismicity base layer is the peak ground acceleration (PGA) that is expected, with a 10% probability, to be exceeded at least once within 50 years. The area hazard parameters, activity rate (λ), the Gutenberg-Richter *b*-value and the area characteristic maximum possible seismic event magnitude (m_{max}), are calculated for an equal size grid of 0.1˚x0.1˚.	• Prospecting and mining; oil and gas exploration and production legally prohibited (Holness, 2013). • PASA permit areas (TCP and ER areas) (PASA, 2014). • Geological structures (1:1 000 000 scale geological structures) (CGS, 2013).
Socio-economics	• Aggregated map (population density, number of children under 5 years of age, % of population dependent on groundwater as a domestic water source, % of population employed by agriculture and % of female headed households). • Population density. • % of children under 5 years of age. • % of population dependent on groundwater as a domestic water source. • % of population employed by agriculture. • % of female headed households.	• Prospecting and mining; oil and gas exploration and production legally prohibited (Holness, 2013). • PASA Permit Areas (TCP and ER areas) (PASA, 2014). • Astronomy assessment Areas (SKA protection zones) (Tiplady, 2013). • Subterranean groundwater control areas (DWA, 2013c).

4.1.3 Challenges and limitations of vulnerability mapping

This section discusses challenges and limitations related to vulnerability mapping.

Challenges

Identification of the relevant indicators for mapping presented challenges. Although various indicators can be used to indicate vulnerability, the team had to select regional scale indicators that had data available throughout the whole of the country. Some experts were of the opnionion that certain local scale indicators should rather be used, but this was not always feasible because local scale indicators did not contain the same level of information throughout the country, or because local scale conditions should be interpreted differently for each site. An example of where use of local scale information would have resulted in a biased vulnerability map, was if local scale provincial biodiversity plans had been used to map vegetation vulnerability. In this case the biodiversity map for the Free State is at a very advanced stage of development whereas the Northern Cape map is only at its initial stages of development. An example of local scale conditions differing between sites relates to the influence of geological structures at a local scale. Challenges are discussed in more detail in Section 4.2 for each aspect.

Limitations

The development of the vulnerability map was approached in a holistic manner due to the uncertainties related to where unconventional oil and gas exploration and extraction would take place and uncertainties in identifying the likelihood of certain impacts occurring in relation to activities associated with unconventional oil and gas extraction. Vulnerability is mapped for the entire country since infrastructure development to capture and transport oil or gas as well as store and/or transport wastewater and waste may influence areas outside the target unconventional oil and gas extraction zones.

Available regional datasets that are nationally acceptable were used during vulnerability mapping, resulting in a map that is applicable on a regional scale. This map should be used as a reconnaissance tool to identify areas of concern on a regional scale and, for local scale assessments, local scale maps should be developed.

This map does not take into account coping capacity, which should be factored into local scale EIAs. The map also does not indicate monitoring indicators (e.g. water provisioning wells and changes in water use), changes in water chemistry or the progression of landscape fragmentation during unconventional oil and gas extraction activities. Such indicators are very relevant during monitoring activities and should also be presented spatially during local scale studies, which should be regularly updated.

Several of the databases had inconsistencies. The researchers corrected these where possible and where they could not be corrected, plotted the data as is to ensure integrity. NFEPA fish indicators is one example where the data in the received shapefile was incorrectly calculated but this data was plotted as is to preserve the integrity of the data. Some databases, such as the biodiversity map, contained information that was submitted by various sources. In some cases attributes in shapefiles were named with abbreviations or contained metadata with abbreviations that were not explained. The researchers retained the original abbreviated attribute names and metadata content for these files so that the datasets would be recognisable to the original contributors of this information (see list of shapefiles in Appendix 3).

4.2 Detailed information for each mapping theme

Section 4.2 discusses the detailed information for each aspect map.

4.2.1 Surface water

This section describes the detail indicator selection process (Section 4.3.1.1), detail on indicator classification and weighting (Section 4.3.1.2) as well as the final vulnerability map for surface water (Section 4.3.1.3).

4.2.1.1 Indicator selection process

Surface water vulnerability to unconventional oil and gas extraction was investigated by the team. Several indicators and data sources were originally identified using a desktop review of available reports. The appropriateness of these indicators and data sources was then tested by sending questionnaires to local surface water experts.

The experts were purposively selected based on their own knowledge of the field. Twenty key informants knowledgeable about surface water were contacted for input in indicator selection. Of these informants, eight completed the questionnaire developed for this purpose and two gave qualitative input without filling in the questionnaire. Ten key informants who were approached indicated from the outset that they were, due to the sensitivity of the unconventional oil and gas issue, or lack of sufficient knowledge about the matter, not prepared to contribute inputs to the study. The profile of all key informants is presented in Table 26.

Table 26: Profile of key informants

Profile	Number of informants approached	Number of key informants contributing inputs
Invertebrate specialists	9	6
Vertebrate specialists	3	2
Water quality specialists	8	2
Total	20	10

Some key informants were reluctant to permit their identities to be revealed. As a result, it was decided to treat all responses anonymously to adhere to ethical research practices (Maree and Van der Westhuizen, 2010).

The component surface water indicators chosen for surface water vulnerability mapping needed to comply with the following criteria:

- Must be indicative of vulnerability to unconventional oil and gas mining by means of hydraulic fracturing (unconventional oil and gas extraction was termed mining in the survey, but the term unconventional oil and gas mining has recently been revised to unconventional oil and gas extraction based on legal definitions);
- Must have data available for the whole of South Africa;
- Must be spatially presentable;
- Must be existing data that are reliable, accessible and available in GIS format; and
- Should already have been verified by local experts where possible.

The following possible indicators (Table 27) were identified based on the dimensions of the biophysical aspects of **surface water** vulnerability. These indicators are all from the NFEPA study (Nel et al., 2011a), which incorporated data and expert knowledge (over 1 000 person years of experience) from numerous specialists throughout South Africa, and was chosen due to the availability of data.

Table 27: Possible surface water vulnerability indicators.

Dimensions of vulnerability	Indicators
River condition	River FEPA and associated sub-quaternary catchment. (Rivers currently in good condition and that contribute to the biodiversity targets for river ecosystems.) This would serve as a surrogate for water quality, invertebrate and fish presence and health in rivers.
Wetland condition	Wetland cluster. (Groups of wetlands in a relatively natural landscape that allows for important ecological processes such as migration of frogs and insects between wetlands.) Wetland ranks. (Include aspects of wetland condition, conservation importance, occurrence of threatened frogs and wetland dependent birds etc.).
Threatened fish	Fish sanctuaries and associated sub-quaternary catchments. (Areas essential for protecting threatened freshwater fish that are indigenous to South Africa).
River connectivity	Flagship free-flowing river. (Undisturbed rivers with no dams from source to confluence.)

The suggested indicators and data sources were sent to eight identified surface water experts to determine the appropriateness for use (see Appendix 1 for a generalised template of the first questionnaire). The experts were asked to rate the appropriateness on a scale from 1 to 10 (“not appropriate at all” to “extremely appropriate”) and to suggest alternative indicators and data sources if needed.

The data received from the first set of questionnaires on indicator selection were analysed and interpreted using descriptive statistics as well as qualitative analysis methods. The results of the basic analysis for the first round of questionnaires can be seen in Table 28.

Table 28: Results of questionnaire sent to local experts to determine the appropriateness of indicators chosen to determine surface water vulnerability to unconventional oil and gas mining (extraction).

Indicator Name	N Valid	N Missing	Mean	Median	Std. Deviation	Min	Max	Main themes supporting indicator and/or data source	Main themes not supporting indicator and/or data source
Appropriateness of the river condition indicator	8	0	7.000	7.5	2.9277	2	10	Good indicator as rivers in A and B condition need to be protected	NFEPA data outdated and needs to be replaced by 2011-2013 PESEIS data
Appropriateness of wetland condition using wetland clusters indicator	8	0	7.375	7.0	2.1998	4	10	Good indicator as it includes important migration routes for biota as well	NFEPA wetland data is flawed
Appropriateness of wetland condition using wetland ranks indicator	7	1	6.286	7.0	3.5456	0	10	Good indicator and includes RAMSAR sites that need to be protected	NFEPA wetland data is flawed
Appropriateness of the threatened and vulnerable fish indicator	8	0	5.375	6.5	3.9978	0	10	Includes data on fish sanctuaries and sensitive and threatened fish species	NFEPA provides a very limited perspective
Appropriateness of the river connectivity indicator	7	1	7.000	7.0	2.3805	3	10	It is crucial to protect the existing free-flowing rivers at a national level	Definition of free-flowing rivers in NFEPA is not realistic and is contentious

Although descriptive statistics are useful in helping to identify indicators, it cannot be used as a sole measure and analysis should lean more heavily on thematic analyses. Thematic analyses revealed a few issues that made the inclusion of certain indicators that did not receive unambiguous support, or the exclusion of indicators that did receive good support, paramount.

For example, experts did indicate that they were not convinced that wetland ranks and wetland clusters should be included as indicators of wetland vulnerability as they were of the opinion that the data used (NFEPA data; Nel et al. 2011) were not accurate enough. No other data source was however recommended and no other regional data source for wetland condition or vulnerability for the whole country is currently available.

The inclusion of river condition using the 2011-2013 PESEIS dataset was recommended and this resulted in other indicators, such as river connectivity and threatened and vulnerable fish species, falling away as they are either partially or completely included in the PESEIS data.

Analyses of key words and themes that emerged during an NVivo software analyses (using QSR Nvivo 10.Ink) can be seen in Figure 6. This analysis did not really indicate any specific indicators that needed to be included, except that general river and wetland indicators were viewed as important by respondents.

Figure 6: Word tag cloud for surface water indicator identification

The following indicators were investigated further for use in the surface water vulnerability map as suggested by the experts consulted in the first round of questionnaires (see Table 29).

Table 29: Surface water indicators investigated for use for surface water vulnerability map

Indicator Name	Indicator 1: River condition (Default Ecological Category - DEC)	Indicator 2: Wetland condition using wetland ranks	Indicator 3: Wetland condition using wetland clusters
Suggested data chosen to represent the indicator	2011-2013 PES data per sub-quaternary reach (SQR),specifically the DEC, which includes the median present ecological status (PES) and highest maximum of the mean for ecological importance (EI) and ecological sensitivity (ES) perSQR	FEPA data on wetland ranks	FEPA data on wetland clusters

Indicator 1: River condition - Default Ecological Category (DEC)
River condition could be included as an indicator. Experts indicated that the NFEPA data used to determine river condition was out of date and that an updated dataset, the PESEIS dataset should be used. The 2011-2013 PESEIS databases, which include water quality, ecological importance and sensitivity and change in flow regime, could be used. The DEC in the PESEIS dataset, is calculated from the median present ecological state (pes) and highest maximum of the mean for ecological importance (EI) and ecological sensitivity (ES). It provides a very broad indication of the importance of protecting the SQR in a particular desired state, which is also an indication of how vulnerable the SQR is to impacts (DWA, 2013a). It does however not address attainability or more detailed considerations (Kleynhans, pers comm.). The DEC is presented as categories A–D where A represents a very good category and D a largely modified category.

Indicator 2: Wetland condition using wetland ranks
Ranking of wetlands was done at the level of a wetland unit (entire wetland system, which could comprise several wetland ecosystem types or wetland conditions) in the NFEPA study (Nel et al., 2011a). Sub-national biodiversity priority data were used to identify important wetlands. RAMSAR sites were also included. Wetlands supporting threatened frog, waterbird, and crane species were identified. Wetlands that formed a group of >3 wetlands within 1 km were also included and expert opinion was also used to identify important wetlands (Nel et al., 2011a). Wetland ranks (1-5) are provided in the NFEPA database and could therefore be used to identify five classes of vulnerability. As the NFEPA data is the only data presently available for the whole of the country it could be included, although experts had doubts about its accuracy.

Indicator 3: Wetland condition using wetland clusters
Wetland clusters are groups of wetlands embedded in a relatively natural landscape. This clustering would enable important processes such as migration of frogs and insects between wetlands. Only non-riverine wetlands (buffered by 500 m) including artificial wetlands (<50% of total wetlands in cluster), were used to identify clusters. Wetlands within 1 km of each other were included. Wetlands clusters identified comprised three or more wetlands and had to have >50% of area under natural land cover (Nel et al., 2011a). Wetland clusters are indicated as present (1) or absent (0) in the NFEPA database. As the NFEPA data is the only data presently available for the whole of the country it could be included, although experts had doubts about its accuracy.

Some wetland cluster data (all groups with >3 wetlands in a 1 km areaare is however also included in the determination of wetland ranks and including it as an indicator in the vulnerability map would therefore be double counting. It was suggested by experts that wetland clusters are extremely important and should therefore be flagged as areas where caution should be excercised if unconventional oil and gas extraction is proposed. The wetland cluster layer will therefore not be included in the surface water vulnerability base map, but be included as an overlay.

Other indicators suggested
The South African Scoring System for Macro-invertebrates (SASS) scores suggested for inclusion in the vulnerability map by some experts could not be used as data were not available at a regional scale for all rivers and tributaries, and SASS family presence data were already included in the DEC calculation. Diatoms could also not be included, as data are only available for flowing rivers, and also not for all rivers in the country. The diatom data suggested for use by experts would also need to be interpreted and this was beyond the scope of the project. A verified database indicating the degree of perenniality of South African rivers is lacking at present, but data on perenniality were (however) included in the PESEIS database.

An expert also suggested the inclusion of mineral signatures of surface water under natural conditions, which would enable a comparative analysis as a subset of general water quality analysis. The possible use of old DWA Water Management System (WMS) records was suggested as data source, but the data would need to be analysed. The suggested indicator (mineral signatures) could however not be used as the project does not allow time for data analysis and has to rely on data that have already been analysed and interpreted by experts.

4.2.1.2 Indicator classification and weighting

After the research team received feedback from the surface water experts (first questionnaire) and the tentative indicators were identified, a second questionnaire was sent to the experts, who assessed the classification of the levels of vulnerability for each indicator, confidence in data to be used and the weighting of the individual indicators in the final surface water vulnerability map. See Appendix 2 for a generalised template of the second questionnaire**.**

The data received from the second questionnaire on the appropriateness of the vulnerability classification for each chosen indicator, the confidence in the data to be used and the weighting of individual indicators in the surface water vulnerability map, were analysed and interpreted using descriptive statistics. The results of the basic analysis for the second round of questionnaires can be seen in **Table 30**. Some of the experts only completed sections of the questionnaire and there are therefore not seven responses for each question asked.

Table 30: Results of questionnaire sent to local experts to determine the appropriateness of the vulnerability classification of indicators, confidence in data used and weight given to each of the components for the surface water vulnerability map

Indicator Name	N			Mean	Median	Std. Deviation	Min	Max	Main themes supporting classification/confidence in data
	Valid	Missing							
Appropriateness of the vulnerability classification of the river condition indicator (scale of 1-10 where 1 = not appropriate at all)	6	1	6.67	7	2.4220	3	10		The uncategorised rivers are not necessarily of very low vulnerability.
Degree of confidence in the DEC data to be used to represent river vulnerability (1=Low, 2=Medium, 3=High)	5	2	2.00	2	0.7071	1	3	The PESEIS database containing the DEC data is the most up-to-date data available in South Africa.	
Appropriateness of vulnerability classification of the Wetland ranks indicator (scale of 1-10 where 1 = not appropriate at all)	5	2	6.60	7	2.0736	4	9	It is important to keep wetlands in as good a condition as possible. The ranking is fairly acceptable for hydrological associated impacts.	Consider a closer alignment between the ratings and the envisaged impacts. PES needs to be taken into account. Also vulnerability in terms of wetland type (hydrogeomorphic) i.e. inwardly draining systems are more vulnerable than exorheic systems.
Degree of confidence in the NFEPA data to be used to represent wetland vulnerability (1=Low, 2=Medium, 3=High)	5	2	1.60	2	0.5477	1	2	Although the degree of confidence is rated as low, it is the only dataset suitable for wetland vulnerability at present.	
Appropriateness of use of wetland cluster as an overlay in the surface water vulnerability map (yes = 1, no =2)	6	1	1.00	1	0.0000	1	1	Important for connectivity - fragmentation of the landscape of the primary threats to biodiversity and its persistence over time.	
Degree of confidence in the NFEPA data to be used to represent wetland clusters (1=Low, 2=Medium, 3=High)	5	2	1.80	2	0.8367	1	3	Although the degree of confidence is rated as low, it is the only dataset suitable for wetland clusters at present.	
Percentage weight assigned to river vulnerability	4	3	52.75	55	13.5492	35	66		Cannot indicate a fixed weighting for rivers and wetlands across the board, and suggest that the weighting should therefore be system specific i.e. at whatever unit one is looking at, e.g. catchment level etc.
Percentage weight assigned to wetland vulnerability	4	3	47.00	45	13.8804	33	65		

As suggested by experts, two indicators, namely, “river condition/vulnerability” using the DEC data from the PESEIS study (DWA, 2013a), and “wetland vulnerability” using NFEPA wetland rank data (Nel et al., 2011a), were used to produce the surface water vulnerability map. Two overlays to flag areas where caution is needed were also used, namely, the presence of wetland clusters and the presence of critically endangered, endangered, vulnerable, near-threatened and data-deficient fish species per sub-quaternary catchment.

Indicator 1: River condition/vulnerability

Using the 2011-2013 PESEIS data was suggested by most experts during the first round of questionnaires. Experts who were involved in the PESEIS study were then consulted and they suggested that river condition/vulnerability should be represented by the DEC data determined in the 2011-2013 PESEIS study (DWA, 2013a).

The suggested method for inclusion of the DEC data from the 2011-2013 PESEIS study was to include a 100 m buffer on each side of the river (development within a 100 m horizontal distance from a river is not recommended according to the regulations on the use of water for mining and related activities aimed at the protection of water resources, which were published in the Government Gazette in June 1999). Each SQR was colour coded according to the suggested vulnerability classes (see Table 31). *If Section 38(2) of the proposed technical regulations for petroleum exploration and exploitation (Government Gazette, 2013) is approved then a 1 km buffer should be included on each side of the river. This could however not be included in this study as the regulations had not yet been approved when the vulnerability maps were compiled.*

Table 31: Suggested classes of vulnerability for river condition using the DEC from the 2011-2013 PESEIS study

Vulnerability description	Suggested classes
Very low	DEC = Uncategorised
Low	DEC = D
Moderate	DEC = C
High	DEC = B
Very high	DEC = A

Note: Uncategorised includes all SQRs where no DEC could be determined due to the episodic nature of the small tributaries (no data is available for these SQRs; they are mostly reaches where there is no flow for very long periods and they are little more than drainage lines). These uncategorised rivers/tributaries would need additional local scale research, in a future study, to determine their actual vulnerability.

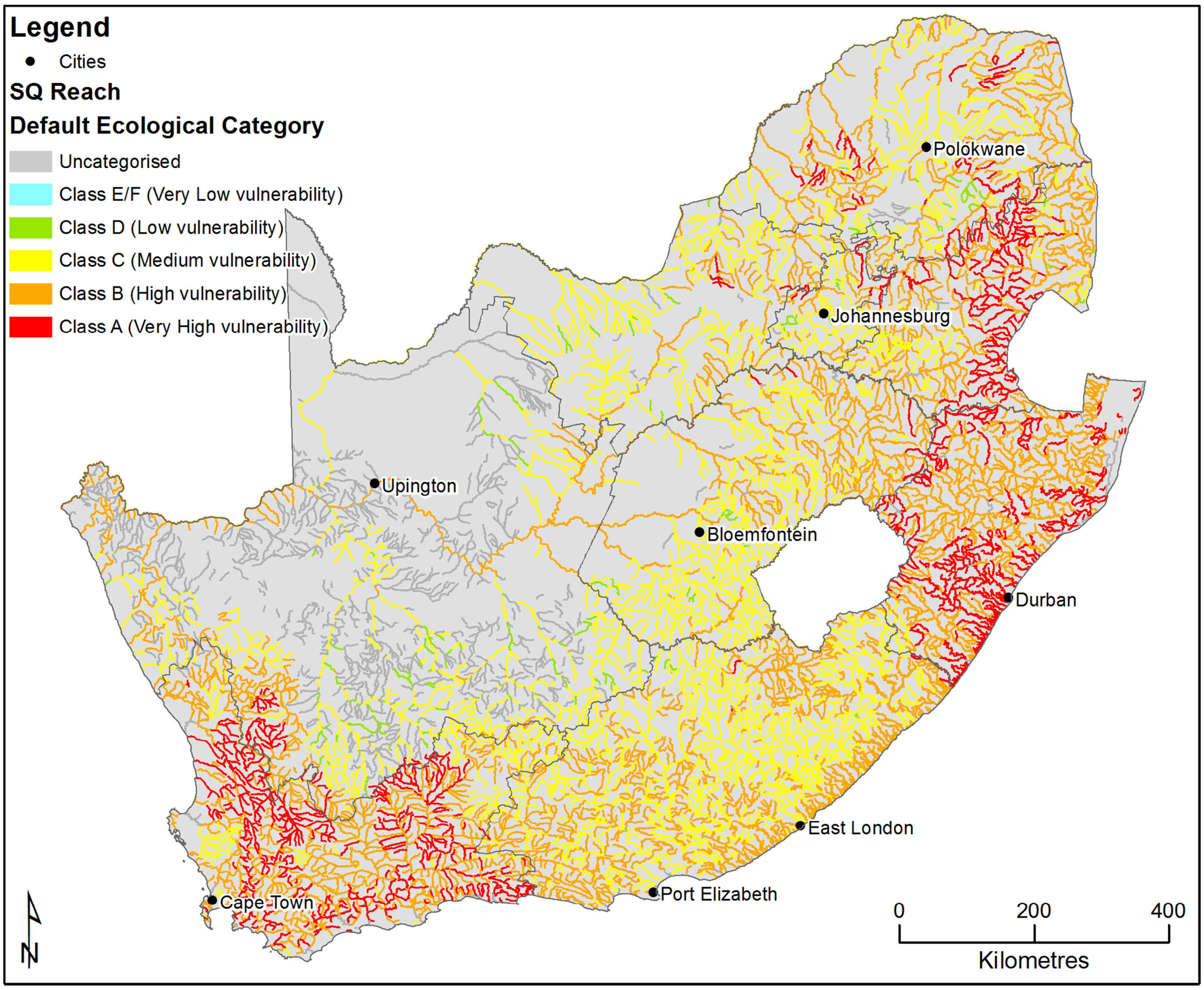

Figure 7: Map indicating surface water vulnerability using DEC data from the 2011-2013 PESEIS data (DWA, 2013a).

Comments by experts

Some of the experts consulted misunderstood the aim of the river condition indicator; they thought that it needed to represent the actual river condition. The aim of the indicator was however to specifically represent the vulnerability of rivers to the impacts of unconventional oil and gas extraction.

The DEC is calculated in the PESEIS model using the PES and the highest mean of either the EI or ES (DWA, 2013a). Due to the way the PESEIS model works, many (most) rivers will have either high/very high EI and/or ES. It may thus be better to use the actual PES, as that is indicative of river condition (as indicated by the heading of this indicator). EI and ES are not actually river condition indicators (although it is obviously dependant on it), instead it is an indication of importance, resilience, etc.

There was also concern that the classes used were not appropriate. The uncategorised class should not be indicated as very low vulnerability because the actual vulnerability of these rivers is not known.

The PES is, as the experts say, an indication of the present river condition but this is not what is needed for a surface water vulnerability map because the present condition of the river does not necessarily indicate how vulnerable it is. For instance, a river in an A/B condition is not necessarily more vulnerable than a river in a D condition and the PES alone can therefore not be included as a vulnerability indicator. The naming of the indicator as river condition was probably incorrect (and led to confusion among experts). The indicator should rather have been named river vulnerability.

The DEC includes the PES as well as the ES and EI, and it therefore takes all of these into consideration. The DEC is an indication of the present river condition as well as its importance and sensitivity to impacts and it could therefore be used to indicate vulnerability. Other experts agreed that the DEC could be used with confidence to indicate surface water vulnerability.

A constraint to using the DEC is that it indicates how vulnerable the river reach is. It is nevertheless possible that the DEC of the particular reach is not attainable as the reach has already been impacted on. The DEC does however indicate how vulnerable even the impacted reaches would be to additional impacts.

The vulnerability classes were adjusted so that uncategorised rivers were left as such (not indicating very low vulnerability) and a fifth class (DEC = E/F category) was included that indicated very low vulnerability.

Indicator 2: Wetland ranks

Ranking of wetlands was done according to the NFEPA study (Nel et al., 2011a) at the level of a wetland unit (entire wetland system and could comprise of several wetland ecosystem types or wetland conditions). Sub-national biodiversity priority data were used to identify important wetlands. RAMSAR sites were also included. Wetlands supporting threatened frog, waterbird, and crane species were identified. Wetlands that formed a group of >3 wetlands within 1 km (wetland cluster) were also included and expert opinion was also used to identify important wetlands (Nel et al., 2011a).

The team (with input from wetland experts) decided to adjust the classes of wetland ranks used in the NFEPA study and the following vulnerability classes were suggested (see Table 32 and Figure 8). Experts indicated that wetlands identified as WetFEPAs should be included with RAMSAR wetlands as being of very high vulnerability/ranking. In the NFEPA study a politically acceptable national biodiversity target for South Africa's freshwater ecosystems was to maintain at least 20% of each major freshwater ecosystem type in a good condition. The identified WetFEPAs therefore only represent the target of 20% of wetland types to be protected and if these WetFEPAs were to be impacted on further, the biodiversity target set in the NFEPA study would not be reached (Nel et al., 2011a).

Table 32: Classes suggested for vulnerability of wetlands according to wetland ranks

Vulnerability description	Suggested classes
Very low	No wetland
Low	Not WetFEPA
Moderate	Presence of frogs and or CWAC (coordinated waterbird counts)
High	Presence of cranes
Very high	Presence of WetFEPA and/or RAMSAR site

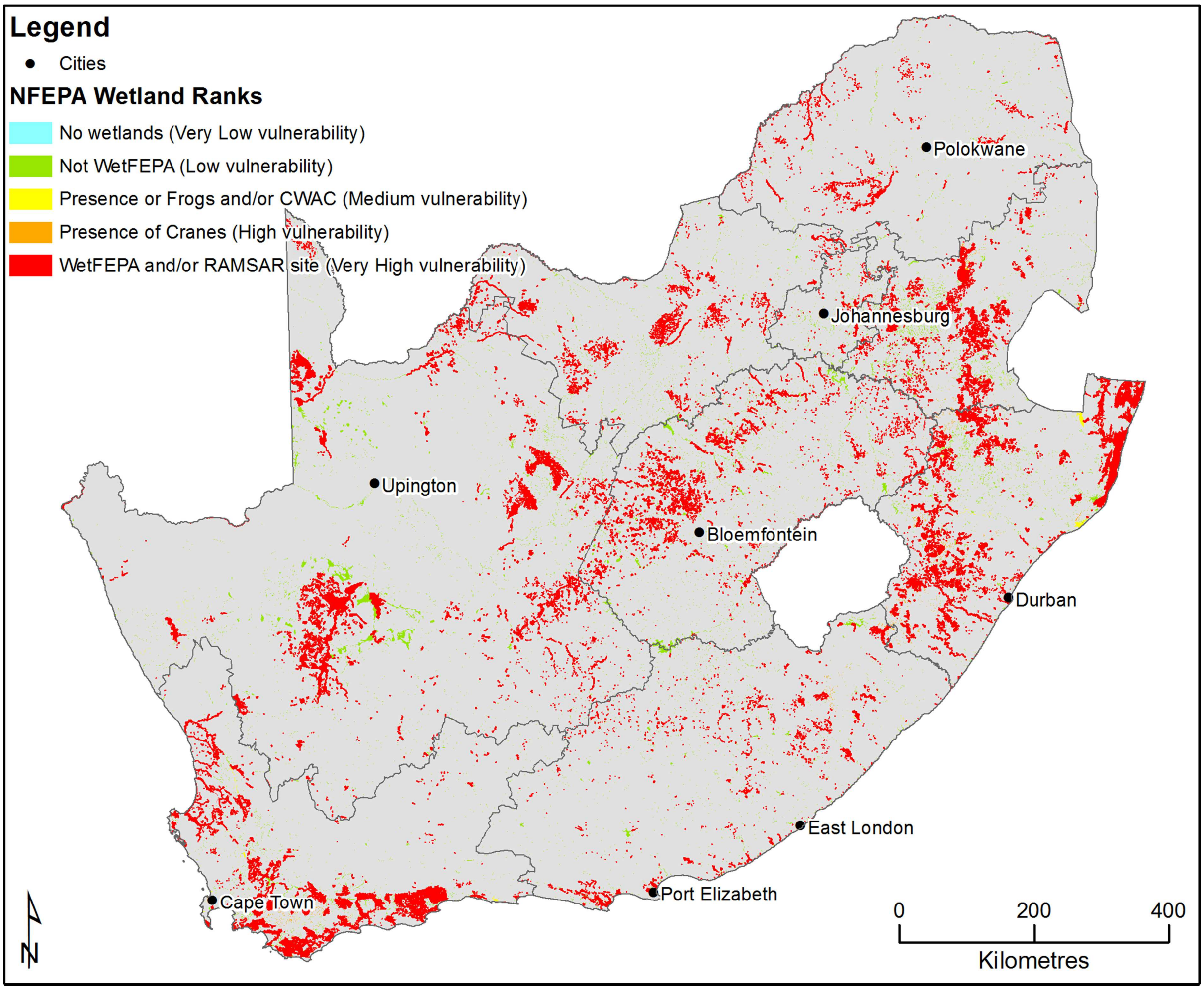

Figure 8: Wetland vulnerability according to five vulnerability classes using wetland rank data from the NFEPA study

Comments from experts

Most experts agreed that the wetland ranks from the NFEPA study (Nel et al., 2011a) should be included in the surface water vulnerability map but all were concerned that the data used were of low confidence. Although the degree of confidence is rated as low, it is the only dataset suitable for this purpose (low confidence is the result of out of date data being used to inform the NFEPA process, specifically the land cover data layer, which is widely known to be problematic). One expert also asked that the PES of wetlands using the NFEPA data be included. Also, vulnerability in terms of wetland type (hydrogeomorphic) i.e. inwardly draining systems, is more vulnerable than exorheic systems and should be included.

Another aspect that needed to be considered is that one aspect of the NFEPA project was to flag the most important wetlands in South Africa using specific criteria. All wetlands are however important, whether they are FEPA wetlands or not. This principle was also used in the "systematic conservation planning" process, where all wetlands that are not included as conservation biodiversity areas are included as ecological support areas.

The experts also suggested that a closer alignment between the ratings, specifically a closer alignment between the ratings and the envisaged impacts, be considered. For example, if the impact is going to be a physical disturbance of the area (noise, movement, etc.), then wetlands with fauna that are sensitive to such disturbances (e.g. cranes) should be rated higher than those without (e.g. only frogs or RAMSAR sites based on uniqueness of wetland but not necessarily supporting sensitive fauna).

Based on expert input, the wetland rank data from the NFEPA study were used to represent wetland vulnerability to unconventional oil and gas extraction impacts. The wetland condition was not available for all wetlands in South Africa, and modelled wetland condition was used in the NFEPA study due to a lack of data (Nel et al., 2011a). The wetland condition (using percentage natural land cover) was used in the determination of the wetlands that could be classed as WetFEPAs in the NFEPA study (Nel et al., 2011a). The modelled wetland condition (equivalent to wetland PES) is therefore already included in the ranking of wetlands and therefore cannot be included in the surface water vulnerability map as an additional layer. The same concern as with river PES, namely, that A/B category wetlands are not necessarily more vulnerable than E/F wetlands, is also an concern here.

Taking wetland type and the envisaged impacts into account and then rating wetland vulnerability according to the type and impact are local scale matters which could not be dealt with in this project. Future studies are therefore needed to provide data so that these aspects can be included in a more detailed vulnerability map.

4.2.1.3 Vulnerability map

River condition/vulnerability (DEC data from the 2011-2013 PESEIS database; DWA, 2013a) has been used as a surface water vulnerability base layer together with wetland condition/vulnerability (using wetland rank data from the NFEPA study; Nel et al., 2011b).

Indicator 1: River condition/vulnerability
The DEC data from the 2011-2013 PESEIS study (DWA, 2013a) were used. The classification used is presented in
Table 33.

Rivers indicated as **Uncategorised** include all SQRs where no DEC could be determined due to the episodic nature of the small tributaries (no data is available for these SQRs and they are mostly reaches where there is no flow for very long periods and they are often little more than drainage lines). These uncategorised rivers/tributaries would need additional local scale research, in a future study, to determine their actual vulnerability. **It must be emphasised that this does not mean that these rivers are not vulnerable, and caution should be taken when unconventional oil and gas extraction is proposed in these areas**.

Table 33: Classes of vulnerability for river condition using the DEC data from the 2011-2013 PESEIS study

Vulnerability description	Suggested classes
Uncategorised	No data available
Very low (value 1)	DEC = E/F
Low (value 2)	DEC = D
Moderate (value 3)	DEC = C
High (value 4)	DEC = B
Very high (value 5)	DEC = A

Indicator 2: Wetland ranks

FEPA wetlands were buffered using a 1 km buffer, as recommended in the Mining and Biodiversity Guidelines (DEA et al., 2013) for use in the vulnerability map. The FEPA wetlands and a buffer of 1 km are considered to be of the highest biodiversity importance. "*This category includes biodiversity priority areas where mining is not legally prohibited, but where there is a very high risk that due to their potential biodiversity significance and importance to ecosystem services (e.g. water flow regulation and water provisioning) that mining projects will be significantly constrained or may not receive necessary authorisations"* (DEA et al., 2013).

The team (with input from wetland experts) decided to adjust the classes of wetland ranks used in the NFEPA study and the following vulnerability classes were used (see Table 34).

Table 34: Classes used for vulnerability of wetlands according to wetland ranks.

Vulnerability description	Suggested classes
Very low (value 1)	No Wetland
Low (value 2)	Not WetFEPA
Moderate (value 3)	Presence of frogs and or CWAC
High (value 4)	Presence of Cranes
Very high (value 5)	Presence of WetFEPA and/or RAMSAR site

Overlays

The possibility of increased sensitivity, indicated by wetland clusters and critically endangered, endangered, near threatened, vulnerable, least concerned and data deficient (where experts believed the species was of importance although data was not available) fish species were flagged as overlying layers on the surface water vulnerability base map. The flagged layers indicate the areas that require caution and more detailed studies are recommended before unconventional oil and gas extraction can be considered.

Wetland clusters could not be represented using five classes of vulnerability and it has also been included partially in the wetland rank data. The team decided however that the wetland cluster map should be used as an additional layer in which the presence of wetland clusters is flagged as areas where caution is recommended if unconventional oil and gas extraction were to be considered.

The PESEIS data (DWA, 2013a) do not include the threatened fish species (as defined by the IUCN, 2012b) per se. The intolerance level of fish species is included but their threatened status is not (Kotze, pers. comm.). It was therefore advisable to include the NFEPA data (Nel et al., 2011a and 2011b) in this instance as it provides an added perspective to the fish intolerance ratings and gives a better idea of the spatial distribution of threatened fish species (Kotze and Kleynhans pers. comm.). *The critically endangered, endangered, near threatened, vulnerable, least concerned and data deficient fish species layer* was not included in the surface water vulnerability map but included as an additional overlay. The aim of identifying these areas is to keep further freshwater species from becoming threatened and to prevent those fish species that are already threatened from becoming extinct.

The raw data from the Fishsanc-All species database from the NFEPA study (Nel et al., 2011a and 2011b) were used. The presence of all critically endangered, endangered, near threatened, vulnerable and least concerned fish species in each sub-quaternary catchment was included. Species identified by the IUCN as data deficient but deemed important by specialists in the NFEPA study were also included.

The fish status of each sub-quatenary was used and two categories were included in the map:

- Status 2: Red - sub-quaternary catchments indicate catchments where critically endangered or endangered species are present and
- Status 1: Pink -sub-quaternary catchments indicate catchments where vulnerable, near threatened, least concern or data deficient species are present.

It must be noted that the raw Fishsanc-All species data obtained from the NFEPA study were used and although discrepancies were identified in the data, the team decided not to alter the data as this would compromise the validity. The team also did not want to discard this overlay, because valuable information is provided in the data. This overlay should therefore be used with caution until an updated version of the data has been made available and the layer has been revised in a follow-up version of the vulnerability map.

An analysis of the NFEPA Fishsanc All Species data revealed some discrepancies, namely: The NOFISHSANC column represents the total number of threatened and near threatened fish species in a sub-quaternary (Nel et al., 2011a and 2011b). In the SQ4HASH (sub-quaternary identifier) column number 566, 734 and 848 have a value of 1 for NOFISHSANC but there are no species present in any of the species columns from SP0072 to SP2051 etc.

4.2.2 Groundwater

This section describes the detail indicator selection process (Section 4.3.2.1), indicator classification and weighting (Section 4.3.2.2) as well as the final vulnerability map for groundwater (Section 4.3.2.3).

4.2.2.1 Indicator selection process

Indicators were selected by using a structured questionnaire that was distributed to groundwater experts (see Appendix 1 for a generalised questionnaire). At the time of performing this survey, unconventional oil and gas extraction was viewed only as a mining activity (which it essentially is), but based on legal definitions in the *MPRDA*, this term was revised by the researchers to unconventional oil and gas extraction. Thirteen key informants who can be viewed as experts (possessing more than 10 years' experience each) in the field of groundwater and one expert with experience in hard rock and structural geology; were contacted for input in the indicator selection process. The years of experience of the experts ranged between 12 and 38 years, with an average of 25 years' experience. Experts were chosen mainly based on their involvement in research or consulting related to unconventional oil and gas mining, and seven of the contributing respondents complied with this requirement. Four respondents had detail knowledge on governance aspects, five respondents possessed in-depth knowledge on geological structures and one respondent had extensive knowledge of GIS. The profile of the key informants can be seen in Table 35.

Table 35: Profile of key informants for groundwater

Profile	Number of key informants approached	Number of key informants contributing inputs
Groundwater specialists in academia	3	2
Groundwater specialist consultants	8	7
Groundwater specialists in government	2	2
Hard rock and structural geologist (consultant)	1	1
Total	14	12

Of these informants, 11 completed the questionnaire developed for this purpose and one gave qualitative input without completing the questionnaire. Five key informants contributed to the questionnaire and gave additional qualitative inputs. Two key informants who were approached indicated from the outset that they are, due to the sensitivity of the unconventional oil and gas issue, or lack of time, not prepared to contribute inputs to the study.

The experts were asked to rate on a scale from 1 to 10 (not appropriate at all to extremely appropriate), the appropriateness of suggested indicators or data sources to indicate sensitivity to unconventional oil and gas mining (extraction). Each of the scale-based questions had a follow-up question in which key informants had to supply reasons for their answers to the scale-based questions.

It was decided to treat all responses anonymously to adhere to ethical research practices (Maree and Van der Westhuizen 2010), due to the fact that some key informants were reluctant to allow their identities to be revealed.

The received data from the first set of questionnaires on indicator selection were analysed and interpreted by using descriptive statistics as well as qualitative analyses methods. The results of the basic analysis for the first round of questionnaires can be seen in Table 36.

Table 36: Results from first set of questionnaires to identify indicators

Indicator / data source	N		Mean	Median	Mode	Std. Deviation	Min	Max	Main themes supporting use of indicator and/or data source	Main themes not supporting use of indicator and/or data source
	Valid	Missing								
Appropriateness of the composite aquifer vulnerability	11	0	5.3636	5.0000	5.00	3.07482	1.00	10.00	Relevant to surface aquifer contamination, which will also be an issue in unconventional oil and gas mining (extraction)	Only relevant to surface aquifer contamination, fracking will take place at much deeper levels
Appropriateness of including dykes as an indicator	11	0	8.0909	9.0000	10.00	2.30020	4.00	10.00	Dykes are appropriate as they may indicate zones of higher transmissivity	Surface outcrop of dykes, although useful, may not provide an indication of morphology at depth
Appropriateness of including kimberlites and diatremes as an indicator	10	1	7.4000	8.0000	10.00	2.67499	4.00	10.00	They affect hydraulic conductivity (k), they are known to penetrate at depth, may represent conduits from depth to surface	May fall outside area of oil and gas unconventional mining (extraction)
Appropriateness of including faults and shear zones as an indicator	11	0	8.9091	9.0000	10.00	1.22103	7.00	10.00	These may be potential preferential pathways, high conductivity zones	None
Appropriateness of including folded strata as an indicator	11	0	7.0000	7.0000	7.00[a]	2.40832	3.00	10.00	Affects k, folds are more related to surface outcrop, potential for up-dip frack fluid migration	This is mainly outside the area of interest (for oil and gas mining [extraction])
Appropriateness of including EC as an indicator	11	0	6.8182	7.0000	10.00	2.82199	1.00	10.00	Useful under normal circumstances, but uncertain in terms of confined aquifers, may be critical to sole source users	Local variations, spatially and in depth may be important. Desalination may become cheaper, salty water may become more economical to use
Appropriateness of "aquifer yield" as an indicator	11	0	6.6364	6.0000	10.00	3.58532	1.00	10.00	Important to protect high yield aquifers, valuable indicator for near surface transmissivity, surrogate for k	Refers only to uppermost aquifers, national mapping can mask local variability (alluvial channels, fracture zones), even low transmissivity zones may be vital sole source aquifers, no less important to protect

Although descriptive statistics are useful for helping to identify indicators, it cannot be used as a sole measure and analyses should include qualitative thematic analyses. Thus, for the groundwater indicator selection, the eventual decision of indicators to be included for mapping was based on a quantitative analysis of scale-based data and a qualitative analysis of expert opinion given on the questionnaire.

Thematic analyses revealed a few concerns with specific indicators that guided the inclusion or exclusion of indicators.

One indicator that did not receive unambiguous support, but that was included as an indicator, was the South African DRASTIC vulnerability map that was developed during the Groundwater Resource Assesment II (GRAII). In terms of the DRASTIC map, experts did not always take into account the importance of surface activities related to unconventional oil and gas extraction that could impact on shallow groundwater via surface water/groundwater interaction. The experts mostly focused very narrowly on the possible deep impact of specifically fracking, while not taking into account possible pollution from leaking waste pits, transport accidents and spillages, amongst others. When considering indicators such as EC and yield, the mode was 10, but responses on the appropriateness of these indicators ranged from 1 to 10, illustrating a large variance. The reasons cited for not including these as indicators of sensitivity to vulnerability (poor quality groundwater and low yielding aquifers are also socio-economically important and thus sensitive, if these are the only sources of water; and the fact that poor quality water can also be treated to potable standards) was more important than the fact that it received good quantitative support for inclusion in the vulnerability map.

An analysis of key words and themes that emerged during NVivo analysis can be seen in Figure 9. Words in larger font denote words that were mentioned more often in the completed responses and illustrate higher importance.

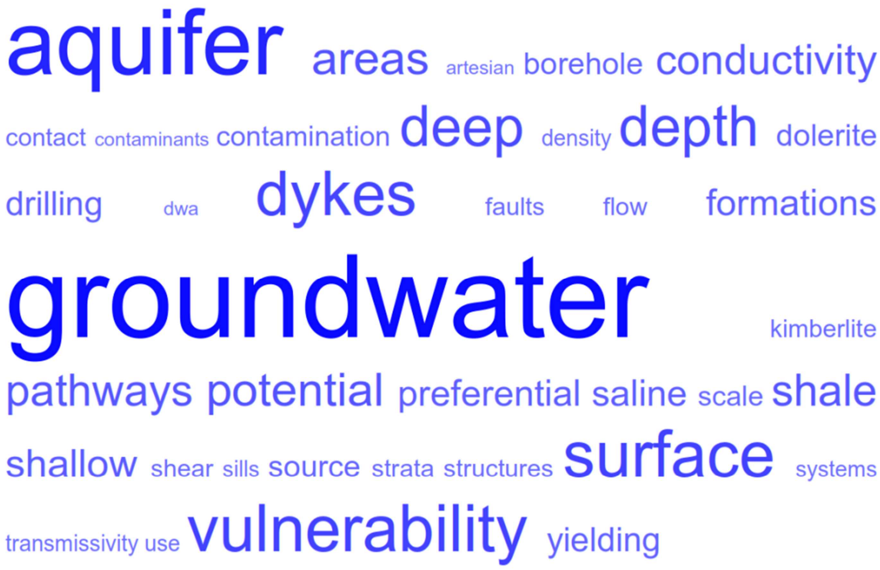

Figure 9: Word tag cloud for groundwater indicator identification

Based on the data received from the first round of questionnaires, the indicators that were included for mapping purposes are regional scale aquifer vulnerability and structures. The GRAII DRASTIC aquifer vulnerability was included as an indicator, because it is relevant to the unconventional oil and gas extraction process where surface activities such as infrastructure development, accidents during transport of fracturing fluids and wastewater, disposal of wastewater and solid waste may impact on shallow aquifers. The DRASTIC vulnerability is also important for cases where surface water-groundwater interaction may cause contamination of groundwater from surface water and vice versa (Broomfield, 2012; Cook et al., 2013; Frogtech, 2013; Lechtenbohmer et al., 2011). Identified geological structures were included because the potential exists that these features may increase hydraulic connectivity between deep strata and more shallow formations (Broomfield, 2012). The geological structures are also important in cases where the geological structures may be intersected and stimulated by fracturing, possibly resulting in fluid migration (Cook et al., 2013; Frogtech, 2013). Structures are also relevant for shallow aquifer contamination from the surface. Setback rules may be applied in the vicinity of these structures to ensure better protection of aquifers. Certain indicators that were suggested by experts in addition to the questionnaire indicators under structures that may indicate increased hydraulic connectivity between deep strata and shallow formations include sills and sill margins, undifferentiated lineaments and thermal springs. These additional indicators were included under structures on the map.

Yield and EC were not included as separate sensitivity indicators because many experts felt that yield and EC do not indicate intrinsic aquifer vulnerability and that poor quality groundwater and low yielding aquifers are also socio-economically important and thus sensitive, if these are the only sources of water. Poor quality water can be treated to potable standards. Instead of using yield and EC as indicators, groundwater use as an indicator of socio-economic importance, were included under the socio-economics map. Yield and EC information as associated with boreholes are however indicated on the interactive vulnerability map in the “Boreholes” map overlay. This information is based on the most recent field measurements from the National Groundwater Archive (DWA, 2014). Experts frequently mentioned boreholes for inclusion on the interactive vulnerability map (during both the first and second round of questionnaires). Information on boreholes that experts wanted on the map, included mapping boreholes with poor borehole construction as well as water production boreholes. Although boreholes are more relevant on a local scale and is a monitoring indicator, the researcher eventually decided to indicate the positions of boreholes that are available on the NGA. The associated borehole information, such as the identifier number, the data owner, coordinates, other numbers, pH, temperature EC, yield, water use, borehole depth, casing information and waterlevel information, where available, is indicated if a user clicks on a specific borehole in the “Boreholes” overlay. The aim of the borehole information overlay layer is to provide additional reconnaissance information for further detail studies. Setback rules may be applied to water production boreholes, but were not performed for this map, due to the fact that information such as the productivity and use of the boreholes may change (some boreholes may cease to yield productive volumes and may be closed while previously unused boreholes with lower yields or poor water quality may subsequently be used as water production boreholes). It is extremely important that updated borehole information should be indicated in local scale studies at the time when an exploration license is sought, and that practioners do not rely solely on borehole information indicated on this map, as the borehole information may be outdated. When plotting water production boreholes, care should be taken to confirm the exact positions of these boreholes. Accurate borehole positions, construction, water use volumes, type of use and closure information would be extremely important during monitoring for unconventional oil and oil and gas extraction and it is a very relevant monitoring indicator.

Certain indicators that were suggested would be relevant for local scale maps, would require extensive time to develop or do not yet have data available to develop the specified indicators. These include:

- The elevation difference between the potential shale oil and gas formation and the bottom of shallow aquifer systems could be mapped and a limiting (threshold) value could be identified. This activity would require assessing geological profiles from mapped areas, which may only be available on local scale, and is viewed as a necessary activity during local scale EIA assessments or studies required as part of licensing conditions.

- Reactivated geological features could be identified from the current structures as neo-tectonically reactivated dolerite dykes, kimberlite fissures and faults may have a higher tendency to create preferential pathways in areas where shale oil and gas exploitation will be shallow (<1 500m formation cover). The identification of these structures would however require an extensive assessment of geological maps, profiles and deep drilling data, and should be addressed in future mapping efforts.
- The presence of potable or economically exploitable deep aquifer systems should be identified and mapped. Identifying such aquifers would require information from exploration drilling results that are not available currently, but should be available in future.

Another possible indicator that received much attention was the identification of zones with artesian basin conditions. Some experts identified certain areas as areas with possible regional scale artesian conditions. These included:

- The Karoo basin at an elevation below 800 to 900 mamsl, between the Great Escarpment and the Cape Fold belt, with postulated recharge areas being the fractured Ecca and Dwyka formations where it crops out next to the Cape Fold belt; and
- The Witwatersrand Supergroup, where it occurs at an elevation <1 500 mamsl directly underneath the Karoo Supergroup, with postulated recharge areas being the upturned Witwatersrand formation where it crops out close to the Vredefort dome at an elevation of 1 450-1 500 mamsl.

Some experts expressed the view that large regional scale artesian basin conditions could possibly not be sufficiently sustained by localised recharge zones and that artesian effects observed in Soekor boreholes may in fact be returned drilling fluids from the core drilling process (Pers comm. Van Wyk, 2013). Most experts however agree that local scale artesian basin conditions do exist and that for these the recharge area is usually situated in close proximity to the localised artesian basin. Such examples include the localized Aranos basin and the Taaiboschgroet graben structure of the Karoo Supergroup (Van Wyk, 2013), and localised areas in the Table Mountain Group Sandstones such as the Uitenhage and Oudshoorn artesian basins (Riemann and Hartnady, 2013; Sun *et al*., 2013). In an effort to address artesian basin condition concerns, it might be worthwhile to identify potential aquifers, aquicludes and aquitards, which can be done more effectively once exploration drilling results become available. Due to the uncertainties with respect to the occurrence and extent of artesian basin conditions, postulated artesian basins will not be included on the map at this stage.

Aquifer dependent ecosystems (Colvin *et al*., 2007) were also listed as important by some respondents. This indicator will be flagged on the vegetation vulnerability map. Groundwater use as an indicator of socio-economic importance will be included on the socio-economic vulnerability map.

4.2.2.2 Indicator classification and weighting

Aquifer vulnerability as updated during the GRAII project (DWA, 2005) is an accepted representation of South Africa's regional groundwater vulnerability, and was used as a base layer to indicate regional groundwater vulnerability to unconventional oil and gas extraction. Various surface activities that form part of the unconventional oil and gas extraction process can contribute to shallow aquifer contamination and vulnerable shallow aquifer areas should thus be protected.

Aquifer vulnerability classes were suggested and tested via expert input via a second structured questionnaire. It was classed into Low (<90), moderate (90-140) and high (>140) classes by the

GRAII project. The low and high classes are further subdivided into very low and very high classes (see

Table 37) in order to derive five classes.

Table 37: Drastic aquifer vulnerability classes

Vulnerability Description	Suggested classes
Very low	<50
Low	50-90
Moderate	90-140
High	140-160
Very high	> 160

A map of these classifications can be seen in Figure 10.

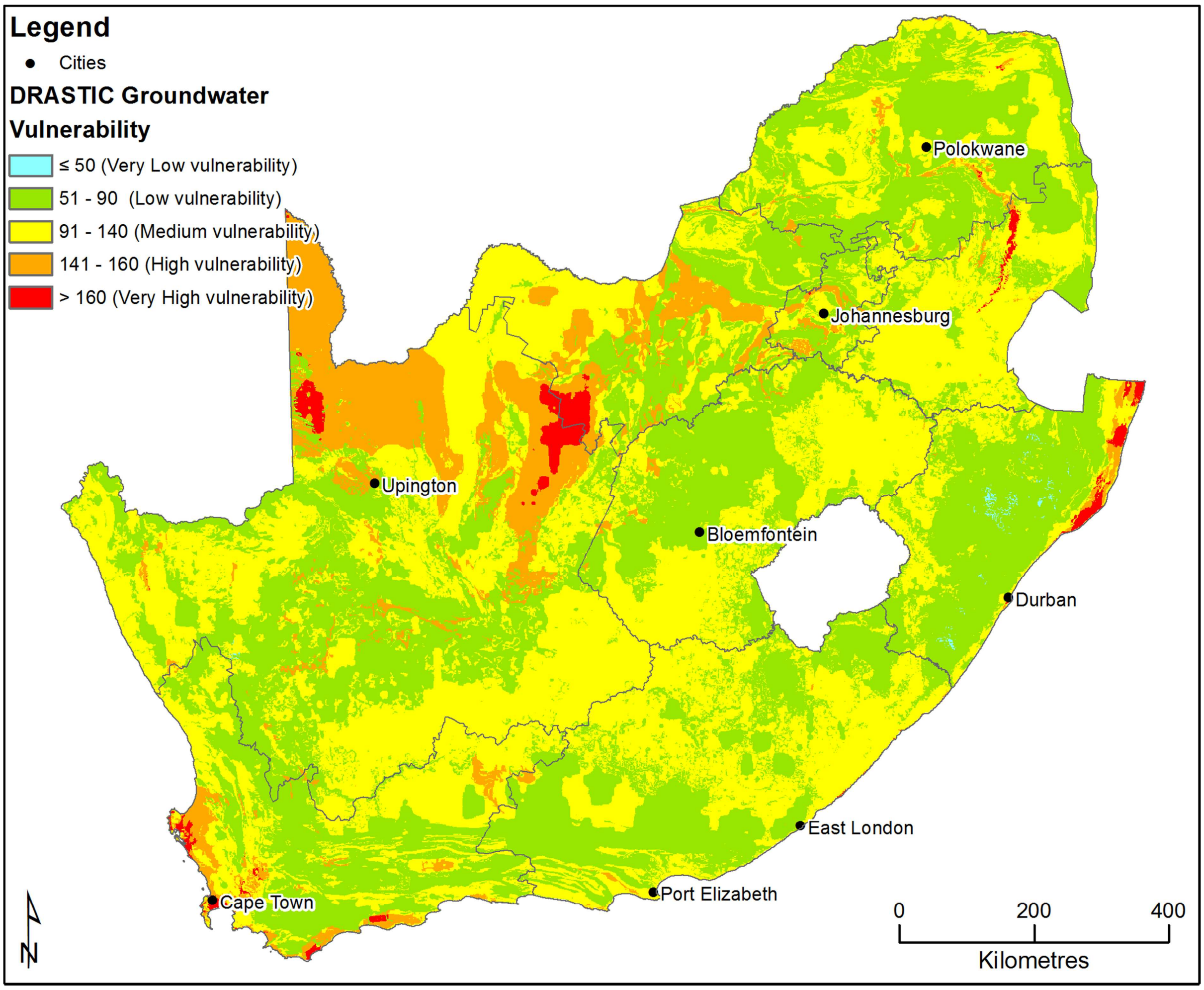

Figure 10: GRAII Drastic aquifer vulnerability base layer

Sixty per cent of the respondents supported the aquifer vulnerability classification fully (more than 7 on the scale of appropriateness). Of those who did not support it fully (5 on the scale of appropriateness), reasons that were supplied were not related to the classification, but were related to the use of the indicator. It was stated that the aquifer vulnerability map is relevant to impacts that may develop on the land surface (which are quite applicable to shale oil and gas and CBM extraction processes). One expert expressed the opinion that there must be a separate set of vulnerability descriptions for impacts generated at the source of shale oil and gas (deep seated shale horizons) and the methodologies that are applied to develop shale oil and gas (HF and borehole construction works). This respondent did not make any comments on CBM extraction, which occurs on a much shallower level and in close association with shallow aquifers.

Structures such as dykes, kimberlites and diatremes, faults, shear zones and fold axes were all flagged to be displayed as an overlay on top of the vulnerability base layer as areas where more caution should be exercised. The flagging of these structures is a first attempt to address the vulnerability aspects of impacts generated in depth at the source (as highlighted above by the one respondent). Buffer zones were assigned and can operate as “setback rules” or to identify zones where a more cautious approach should be followed. The buffer zones used in the interactive map were identified after expert input. A map of these structures, with buffer zones, can be seen in Figure 11.

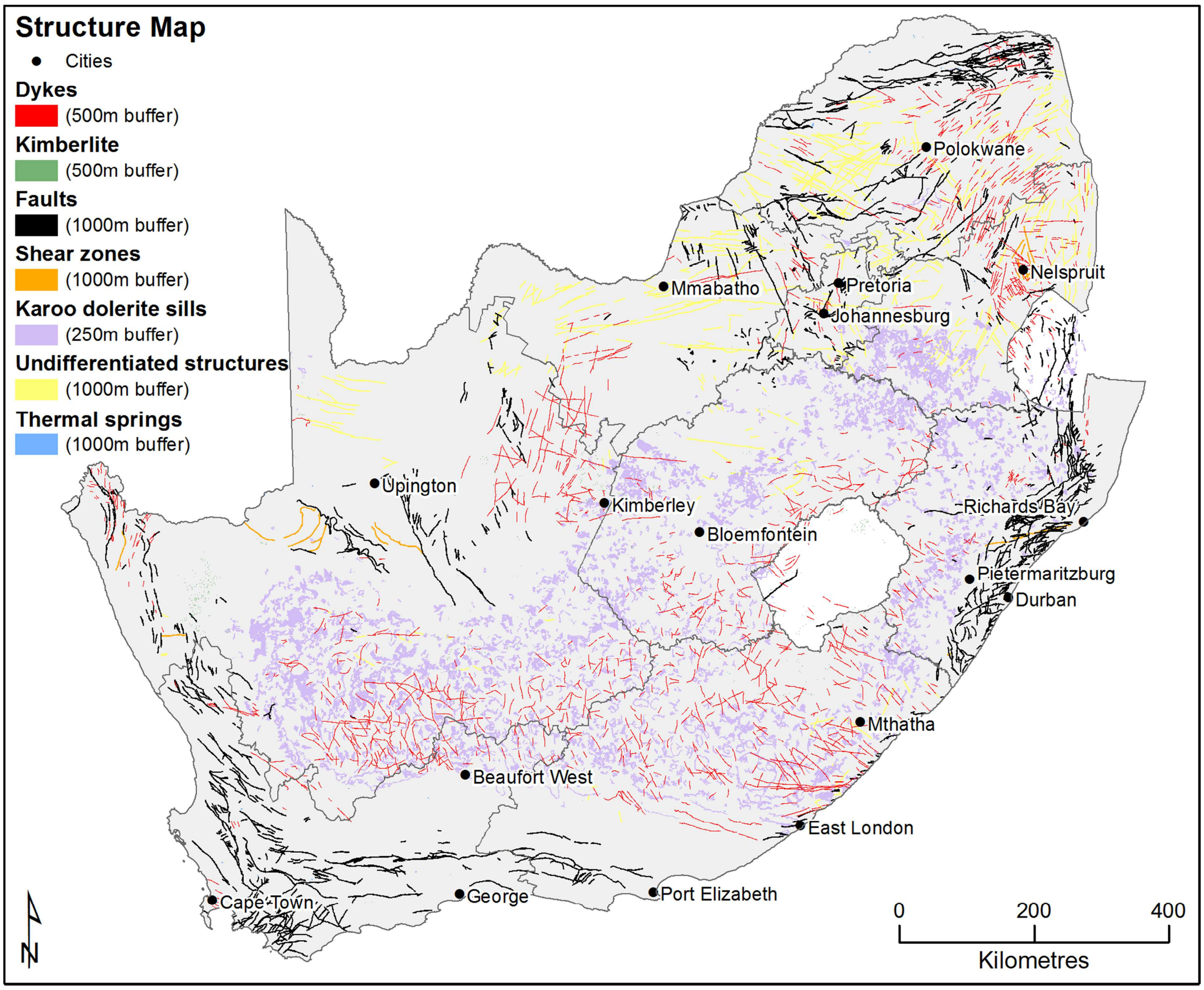

Figure 11: Map indicating structures

A buffer zone was applied to these structures due to the uncertainty of the morphology of these structures at depth. These buffer zones are based in part on mapping work done for the Karoo Groundwater Atlas (Rosewarne et al., 2013). The buffer zones indicate zones within which more care should be taken during unconventional oil and gas exploration and mining (now termed extraction). The following buffer zones were applied, after the buffer zones were tested for appropriateness via expert input, see Table 38. Eighty per cent of respondents supported the buffer zones as identified by the researcher; however some of these buffer zones have been adjusted based on input and comments from certain experts.

Table 38: Buffer zones for geological structures

Indicator	Buffer zone used in Figure 5	Reasons for using these buffer zones
Dykes	500 m from centre line of structure	250 m buffer zones were suggested by Rosewarne et al. (2013), however one expert suggested 500 m to cater for the possibility of reactivated dykes (where a series of several deep fractures may run along the dyke). Another expert stated that if a 250m buffer zone is applied, it should be applied from the rim of the structure and not from the centre line. CGS data on dykes is however only available as lineaments and thus a 500 m buffer zone will be applied.
Kimberlites and diatremes	500 m radius from centre point of structure	100 m consideration zones were suggested (Rosewarne et al., 2013), however kimberlites have complex associated emplacement models (Field and Scott-Smith, 1999; Skinner, 2009) and the surface and underground morphology of these structures may be quite large and varied (Field and Scott-Smith, 1999; Woodford and Chevallier, 2002), with surface outcrop morphology varying from 1ha to >15 ha (Skinner, 2009). The researcher suggested a 250m buffer zone from the centre point of the structure; however one expert stated that the possibility of radial structures running from these features may still exist 250 m from the feature and suggested a 500 m buffer. Another expert stated that buffers should be applied from the rim of the structure and not from the centre point – a 500 m buffer zone is thus deemed more appropriate.
Faults, shear zones and fold axis	1000 m from centre line of structure	250 m buffer were suggested by Rosewarne et al. (2013), however one expert stated that unless these features are mapped in detail, a buffer of 250 m is too narrow. Fold axes must be treated separately as their fold axis limp angles should be considered which may push the distance to several kilometers. A buffer of 1000 m is thus applied based on the buffer suggestion by this expert.
Dolerite sills	250 m from rim of surface outcrops	Morphology of sill surface outcrops may not be representative of underground morphology (Rosewarne et al., 2013). The researcher suggested the applying the precautionary principle with a buffer zone of 250 m from the rim of these structures. One expert stated that a differentiated approach should be used here, since transgressing sills are complex and a dislodged contact may reach all along the contact zones, which might stretch for kilometers. Bedding plane sills may offer a high security to percolating fluids/gasses from the shale gas source. A buffer of 250 m is used here in lieu of more detailed data and to adhere to the precautionary principle.
Undifferentiated structures	1000 m from centre line of structure	Due to unknown structure type and morphology, the researcher in the questionnaire suggested applying the precautionary principle with a 250m buffer zone. One expert stated that depending on the geometry, shale oil and gas exploration and extraction should be limited near these features. Unless detailed geophysical investigations have been conducted, the buffer should be 1000 m. Concerns have again been raised by one expert regarding applying buffer zones from the rims of these structures, thus a 1000 m buffer zone may be more appropriate.
Thermal springs	1000 m radius from coordinate position	1000 m consideration zones are suggested in Rosewarne et al. (2013). Thermal springs are associated closely with deeper geological structures (Kent, 1969), usually with faults and folds (Olivier et al., 2011) and thermogenic methane associated with some thermal springs indicate definite deep connections (Talma and Esterhuyse, 2013). The researcher suggested a 500 m radius as a 1000 m may be too stringent, but one expert stated that springs get their water from recycling shallow water sources and indications are that this geothermal water may come from 1000 mbgl. A 1000 m radius buffer zone is thus suggested by the experts and will be applied.

Dolerite lithologies in the DRASTIC GRAII classification scheme were not reclassified to increase their importance relative to the classification of the other lithologies. While 81% of respondents view dolerite dykes (and sills) as areas with increased hydraulic conductivity due to the associated fracture zones that develop in the country rock and dyke during dyke emplacement and due to contact metamorphism associated with the dolerite intrusions, some respondents also contend that dyke contact zones may no longer act as preferential pathways below the zone of erosional depressurisation. On a local scale the influence of dolerite dykes acting as barriers or conduits to flow may depend on dolerite petrography, level of weathering and the fracturing density of specific dykes (Holland, 2012; Leyland et al., 2008; Woodford and Chevalier, 2002) and also on the lithology in which it occurs, e.g. when comparing dolerite dyke occurrences in karstic environments to dolerite dyke occurrences in Karoo sediments (Holland, 2012; Leyland et al., 2008). Reclassification of the DRASTIC classes should only be attempted on a local mapping scale, preferably after detailed field investigations have been performed.

4.2.2.3 Vulnerability map

The GRAII aquifer vulnerability has been used as a base layer while the possible increased sensitivity is indicated by 1 000 000 scale geological structures (CGS, 2013), which was flagged in the "Geological structures" overlay on the aquifer vulnerability base map. This overlay indicates the type of geological structure as well as the applied buffer zone.

Additional overlays on the groundwater mapping theme include the shapefiles on areas where prospecting and mining as well as petroleum exploration and production is legally prohibited (Holness, 2013), subterranean groundwater control areas (DWA, 2013c), borehole information from the National Groundwater Archive (DWA, 2014), rivers (NFEPA, 2011), water management areas (DWA, 2013b) and technical cooperation permit (TCP) and exploration right (ER) areas (PASA, 2014).

These overlays were indicated by experts as useful during reconnaissance and were thus included as overlays.

4.2.3 Vegetation

This section describes the detail indicator selection process (Section 4.3.3.1), detail on the indicators and data sources selected for vulnerability mapping (Section 4.3.3.2) as well as the final vulnerability map for vegetation (Section 4.3.3.3).

4.2.3.1 Indicator selection process

Based on a literature search, discussions with experts, and incorporating comments from the WRC steering committee, two indicators were proposed to indicate vegetation vulnerability for unconventional oil and gas extraction.

To verify the appropriateness of these indicators, a questionnaire was developed and distributed to respondents who were experts in the field of terrestrial ecology. Respondents were not only selected based on their experience pertaining to terrestrial ecology in South Africa, but also on the geographical area where they conducted research or are actively working in. Due to the high plant diversity in South Africa, it is unlikely that all the experts will be familiar with all the vegetation types in South Africa, and for that reason they were purposefully selected to represent the different geographical areas that they have worked in.

Experts were contacted telephonically, before the first questionnaire was distributed via email. The scope of the project was explained to them and only three experts were not willing to partake in the study and the next expert for that particular geographical area was then approached. At the time of performing this survey, unconventional oil and gas extraction was viewed only as a mining activity but based on legal terminology; this term was recently changed to mean unconventional oil and gas extraction. Although some participants were hesitant to partake due to their lack of knowledge about unconventional oil and gas mining, they did agree to partake in the study. Additional information on unconventional oil and gas mining was therefore included in the questionnaire to help experts understand the context of the threat to vegetation.

In both rounds of the questionnaires, the experts were quick to respond and during the first round, all 10 experts responded (100% response rate) with a 90% response rate during the second round. The sum of their years' experience in terrestrial ecology, adds up to 241 years.

In the indicator questionnaire, two indicators were proposed, namely, Ecosystem Threat Status and Ecosystem Protection Level. A very brief background on how these indicators were developed will be discussed to place it in the context of unconventional oil and gas extraction.

Both indicators, Ecosystem Threat Status and Ecosystem Protection Level were adopted from the National Biodiversity Assessment (NBA) 2011 that was published in 2012 (Driver et al., 2012). This assessment involved various experts from government, academia and consultants and took three years to complete. This document also informs the National Biodiversity Strategy and Action Plan (NBSAP), the National Biodiversity Framework (NBF) and the National Protected Area Expansion Strategy (NPAES). It is important to note that these indicators were assessed independently of each other in the NBA 2011. While the Ecosystem Threat Status assessed the proportion of the ecosystem that is in a good condition, the Protection Level assessed the proportion of the ecosystem that is formally protected.

The **Ecosystem Threat Status** indicator can be defined as: "*the degree to which ecosystems are still intact, or alternatively losing vital aspects of their structure, function or composition, on which their ability to provide ecosystems services ultimately depends*." (Driver et al., 2012). The process that was followed to assess the ecosystem's threat status can be divided into four steps and will be briefly explained.

The first step was to determine the spatial boundaries of the ecosystems and the 438 vegetation types, as delineated by Mucina and Rutherford (2006); 26 national forest types that were identified by the Department of Agriculture, Forestry and Fisheries in 2003, and data from systematic biodiversity plans of Gauteng, Mpumalanga and KwaZulu-Natal were used as a basis (Driver et al., 2012). It is important to note that this indicator assesses ecosystems and not individual species, although threatened species is one the criterium that was used to determine the threat status.

Biodiversity targets were then determined for all ecosystem types, as the second step. A biodiversity target can be defined as "*the minimum proportion of each ecosystem type that needs to be kept in a natural or near natural state in the long term in order to maintain viable representative samples of all ecosystems types and the majority of species associated with those ecosystems*." (Driver et al., 2012). Thresholds were subsequently determined based on these biodiversity targets for each criteria, as can be seen in Figure 12. After thresholds and criteria listed in Table 39 had been assigned for each ecosystem, it was classified as one of the following classes: Critically Endangered (CR) Endangered (EN) or Vulnerable (VU) as the final step. Ecosystems that did not fit any of these classes were classified as Least Threatened (LT).

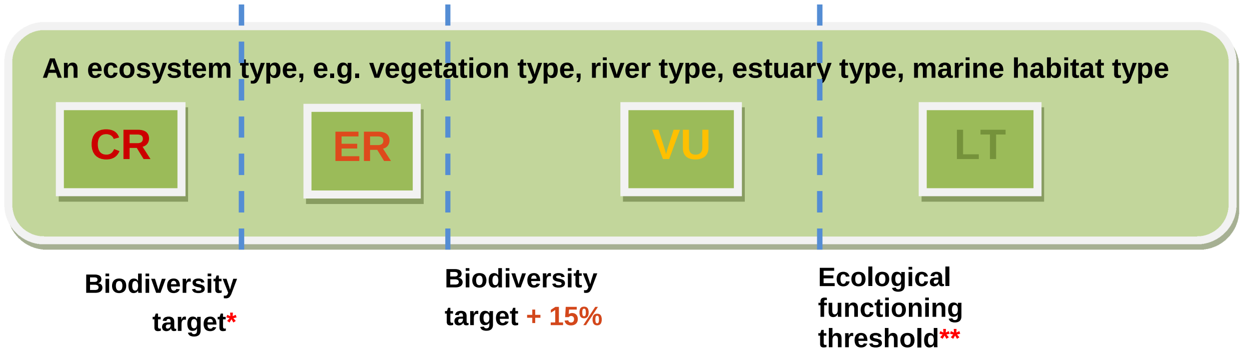

Figure 12: Thresholds used to assess ecosystem threat status. (Redrawn from Driver et al., 2012)

*This is a threshold for representation of biodiversity pattern. Set at 20% if there is insufficient data to determine ecologically differentiated biodiversity targets per ecosystem type.
**This is a persistence threshold. Usually 60%.

Table 39: Criteria used to identify threatened terrestrial ecosystems, with thresholds for CR, EN and VU ecosystems (Taken from Driver et al., 2012)

Criterion	Critically Endangered (CR)	Endangered (EN)	Vulnerable (VU)
A1: Irreversible loss of natural habitat	Remaining natural habitat ≤ biodiversity target	Remaining natural habitat ≤(biodiversity target + 15%)	Remaining natural habitat≤ 60% of original area of ecosystem
A2: Ecosystem degradation and loss of integrity*	≥60% of ecosystem significantly degraded	≥40% of ecosystem significantly degraded	≥20% of ecosystem significantly degraded
B: Rate of loss of natural habitat**			
C: Limited extent and imminent threat*		Ecosystem extent ≤ 3 000 ha, and imminent threat	Ecosystem extent ≤ 6 000 ha, and imminent threat
D1: Threatened plant species associations	≥80 threatened Red Data List plant species	≥60 threatened Red Data List plant species	≥40 threatened Red Data List plant species
D2: Threatened animal species associations**			
E: Fragmentation**			
F: Priority areas for meeting explicit biodiversity targets as defined in a systematic biodiversity plan	Very high irreplaceability and high threat	Very high irreplaceability and medium threat	Very high irreplaceability and low threat

* Owing to data constraints: Criteria A2 and C were applied to forests but not to other vegetation types.
** Owing to data constraints: Criteria B and 02 are dormant at this stage and thresholds have not been set for these criteria. Further testing of Criterion E is needed to determine whether it is a workable criterion for terrestrial ecosystems.

Ecosystem Protection Level was the second indicator, and indicates which ecosystems are adequately protected, or not at all. Four categories were assigned: Well protected, moderately protected, poorly protected and not protected. Protected areas are formally protected by law (*NEM: Protected Areas Act)* or it could be a conservation area, which is not formally protected by law. There are a number of different types of protected areas such as special nature reserves, national parks, nature reserves and protected environments, world heritage sites, mountain catchment areas, and specially protected forest areas. Only areas formally recognised and protected by law have been included in the NBA 2011 assessment.

The ecosystem protection level was determined in the NBA 2011 by calculating the proportion of an ecosystem that was encompass in a protected area, and should that surface area meet the biodiversity target for that ecosystem, it was considered to be well protected. Different ratios would result in different categories of protection.

It is however evident from the comments of the respondents that the protection level is controversial. Some of the national parks or provincial nature reserves were proclaimed decades ago without taking into account threatened or endangered ecosystems (the classification only came about in 2004) and that resulted in areas that are not in good shape, but are protected, while other areas that are vulnerable and in need of protection (e.g. Nama-Karoo) are not protected. It is therefore also important that the National Protected Area Expansion Strategy that was published in 2008 be taken into account when unconventional oil and gas extraction commences. In this Strategy, 42 future areas were identified that are in need of protection. These areas include large, intact, unfragmented areas (Driver et al., 2012). Given the nature of unconventional oil and gas extraction, and the expected high degree of habitat fragmentation, activities within these identified areas should be excercised with caution.

Experts agreed that both these indicators should be used to indicate vulnerability of vegetation to unconventional oil and gas mining (extraction).

Although the rating on the appropriateness of the indicators was fairly consistent (Table 40), it was clear from the comments to the open-ended question, that the experts interpreted the use of the indicators differently. The fact that experts were from government, private industry and academia, could explain the different views experts had regarding the chosen indicators.

Experts were asked to suggest additional or alternative indicators and the suggested indicators are summarized in Table 41. Comments on the appropriateness of each of these indicators and their sources are provided after each source had been investigated by the researcher. A set of rules for selecting indicators were communicated in the questionnaire, e.g the data should be spatially available for all parts of the country.

Table 40: Results from first set of questionnaires to identify indicators

Indicator / data source	N		Mean	Median	Mode	Std. Deviation	Min	Max	Main themes supporting use of indicator and /or data source	Main themes not supporting use of indicator and /or data source
	Valid	Missing								
Appropriateness of Ecosystem Threat Status	10	0	7.60	8.50	10.00	2.95	1.00	10.00	• This indicator could potentially be used as a proxy for vulnerability of vegetation. • No mining (extraction) should take place in any CR, EN or VU ecosystems and buffer zones should be enforced. • In theory, this surrogate is ideal, but the land cover map is not very accurate. • Vegetation is an appropriate way to measure ecosystem status, since it is also a habitat for other organisms. • Although a threatened ecosystem should have a high conservation value, an unthreatened ecosystem that is targeted by oil and gas mining (extraction), could be cause for a higher threat status. • In the Karoo the vegetation is subject to many restricting factors, which makes rehabilitation extremely difficult (unlikely).	• This would not be an appropriate indicator, should this indicator be used to target intact ecosystems. • This indicator is not sensitive enough to detect change over time.
Appropriateness of Ecosystem Protection Level	10	0	5.50	5.50	7.00	3.17	1.00	10.00	• This is definitely an option. • This criterion can only be used if extremely broad no-go buffer zones are applied around protected areas – if exploration is done in the immediate vicinity of the protected area, the vegetation could still be compromised. • There are very few formally protected areas in the Nama-Karoo relative to its size and it is poorly surveyed from a vegetation perspective. • Theoretically a good indicator, but it is only coarse scale classification on the country-wide scale. • Should a particular ecosystem not be protected, oil and gas mining (extraction) should be a cause for a higher level of protection. • Ecosystem protection level is an indication of how well an ecosystem is represented in the current protected area network. Poorly protected not necessarily at risk and a moderate protected area could be under threat. Rather highlight threatened and not protected as important.	• An indicator should be sensitive enough to the pressure being measured, and this indicator is not going to change much, therefore not sensitive enough. • I do not always think this is a good indicator. How much is really enough?

Table 41: Additional or alternative indicators suggested by vegetation experts and data sources

Alternative or additional indicators suggested by experts	Data source of indicator suggested by experts	Researcher comments on the appropriateness of the suggested data sources
Land Degradation Index	http://wiredspace.wits.ac.za/bitstream/handle/10539/2137/Dissertation-031006-final.pdf	No peer-reviewed index exist currently This source was only for the Limpopo Province.
Plant Red Data List (Listed by 3 respondents)	http://redlist.sanbi.org/	Red data species were considered as part of the criteria to determine the ecosystems threat status
Conservation plans (C-plans) for provinces and Critical Biodiversity Area (CBA) plans of districts within the provinces could be consulted (Including comments on biodiversity infrastructure map categories). Listed by two respondents.	Various, depending on when the analysis was completed. Is currently not available in the Free State and half of the Northern Cape.	Could be included in the updated maps. Currently not yet completed for entire country.
Consult latest land cover map (e.g. 2009) and protected area map (e.g. 2010 or later). Listed by two respondents.	BGIS spatial information: SANBI	Already included in both indicators.
Functional aspects of Northern Cape vegetation: 1. Productive patches 2. Low lying areas and the riparian zone	1. High resolution satellite imagery of the areas being subjected to shale oil and gas exploitation will need to be assessed to identify highly productive patches. 2. Hydrological models need to be used to indicate the direction of flow of surface and shallow water on the landscape.	New studies that should be done. Not in the scope of this project.
Ecosystem functioning	Field work and specialists	Not in the scope of this study.
Vegetation map of SA	Vegmap (Rutherford and Mucina, 2006)	Already included in the ecosystem threat status.
Recruitment of seedlings	VEGRAI	Not available for all the rivers in RSA.
The effect on water (availability, quality, pollution)	DWAF	Included in the ground and surface water indicators.

For each indicator, the experts had to briefly explain the reason for their rating on the appropriateness of the indicator. The text answers on these open-ended questions were analysed using NVivo where a larger font size indicates that the word was used more often than a word in a smaller font size. In Figure 13, the following words were the most dominant: *ecosystem, vegetation, protected, status, species, areas, threatened, biodiversity*.

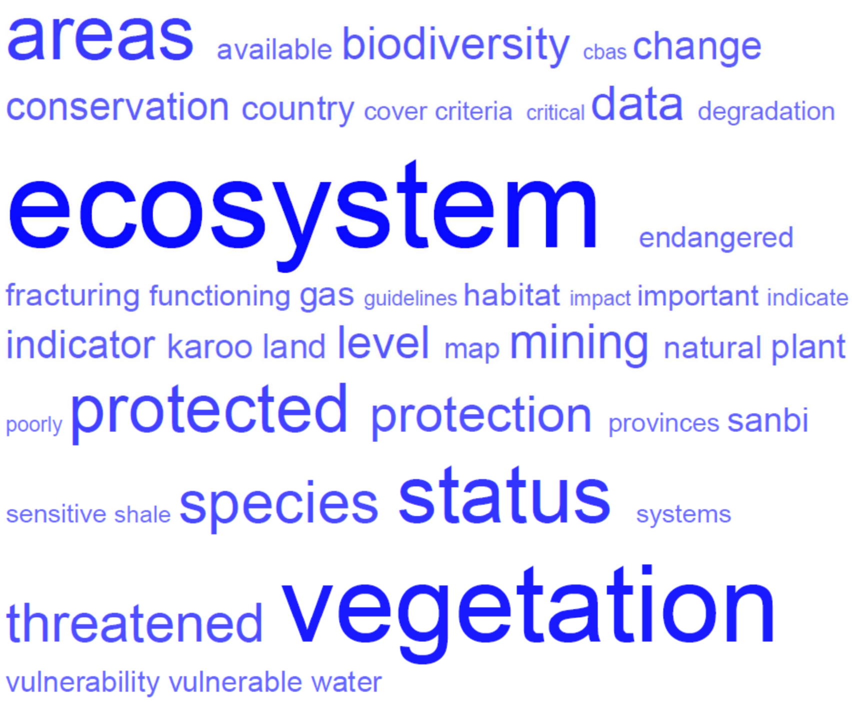

Figure 13: Word tag cloud for vegetation indicator identification

3.1.4.1 Indicator classification and weighting

After confirming the indicators that would be used during the vulnerability mapping for the vegetation component, a questionnaire was developed to determine vulnerability classes and weighting of indicators.

Indicator 1: Ecosystem Threat Status

This indicator was classified into four different vulnerability classes (see Table 42).

Table 42: Ecosystem Threat Status classification

Vulnerability description	Ecosystem Threat Status	Comments from experts
Very low vulnerability	No data exists for this class and this vulnerability class will therefore not be included in the map.	
Low vulnerability	Least threatened	Accepted
Medium vulnerability	*Vulnerable	Accepted, but some experts indicated that the word "Medium" implies that this vulnerability class is not particularly important and that it is sufficient to merely mitigate impacts. It is however not the intention of this indicator.
High vulnerability	Endangered	Accepted
Very high vulnerability	Critically Endangered	Accepted

Some experts were concerned that the meaning of the "Vulnerability" class assigned during the classification of threatened ecosystems in the NBA (2011) could be confused with the "Medium Vulnerability" category assigned for unconventional oil and gas extraction. It is therefore important to note that the data should be used in the context for which it was intended.

The Ecosystem Threat Status and its associated vulnerability classification in relation to unconventional oil and gas extraction classification can be seen in Figure 14.

Some experts were concerned that some areas should have a higher threat classification, than that indicated by the classification on the map (e.g. coastal areas due to development pressure). Although this concern was raised, it should be remembered that this is a regional scale map and it is expected that local studies (EIAs) will be conducted when oil and gas applications are submitted for authorisation.

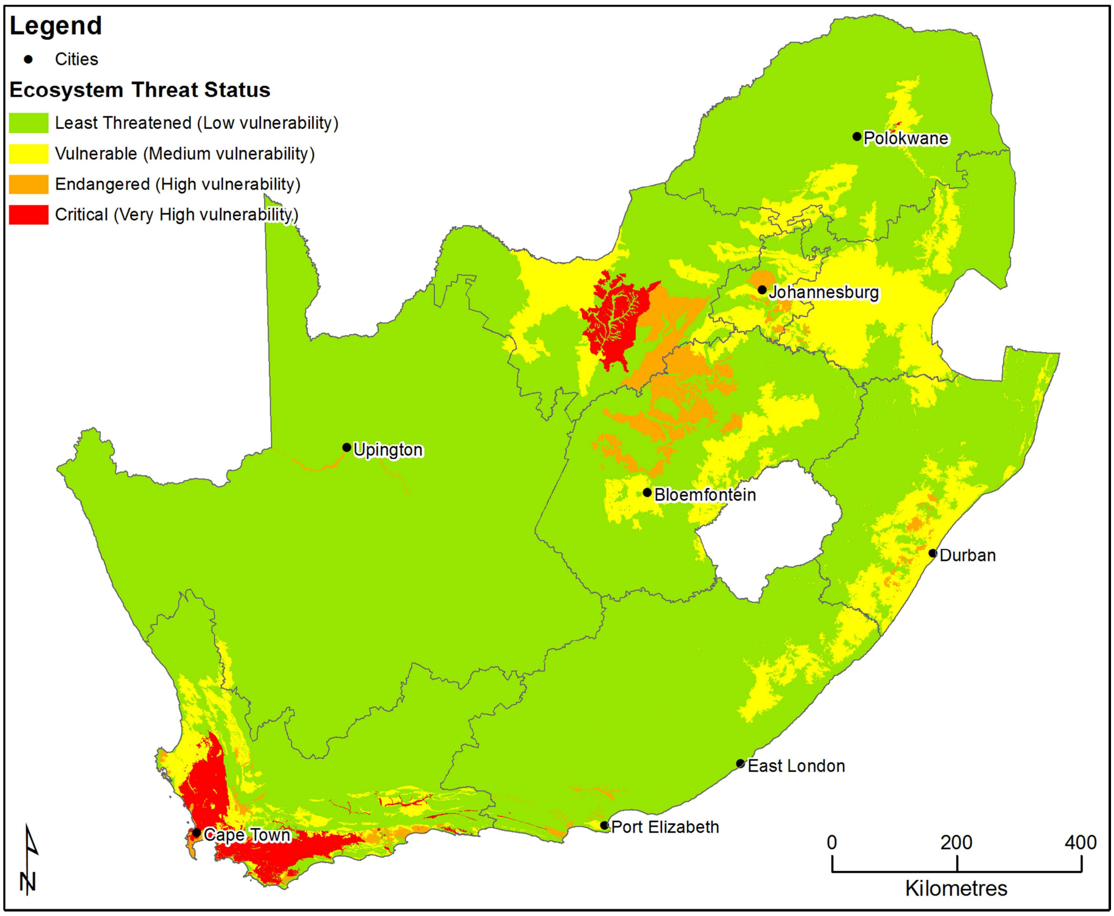

Figure 14: A map indicating the vulnerability rating associated with each Ecosystem Threat Status classification.

Indicator 2: Ecosystem Protection Level

For the Ecosystem Protection Level the following classification was tested in the questionnaire (see Table 43).

Table 43: Ecosystem protection level classification

Vulnerability description	Protection level status	Comments from experts
Very low vulnerability	Unclassified	Rather “Unclassified Vulnerability”
Low vulnerability	Well protected	Accepted
Medium vulnerability	Moderately protected	Accepted
High vulnerability	Poorly protected	Accepted
Very high vulnerability	Not protected	Accepted

An “Unclassified” level was added to cater for the unclassified data that was present in the dataset. These data points in the attribute table (Mucina and Rutherford, 2006), were described as “N/A”, and these included estuaries, lakes, and river mouths. Some data points were not classified and consisted of 11 points on the map indicating “Azonal vegetation: Alluvial vegetation”. The species-area curve that was used to determine the protection status could not be used for aquatic ecosystems. It was suggested by the experts that the “Unclassified” category be classified as “Unclassified vulnerability” rather than “Very low vulnerability”.

One of the experts explained that it is necessary to acknowledge the limitations of the Ecosystem Protection Level map. Although many protected areas that were considered in the Ecosystem Protection Level base map were included in the assessment, they were never proclaimed. Given the complexity of this data set, it is not in the scope of this project to re-analyse the data. The experts were also concerned with the loss of connectivity due the isolated nature of some of the protected areas. The question was raised whether some of the protected areas are indeed still functional.

An important feature that is indicated in this map (Figure 15) is the large area (indicated in red and orange) that is poorly protected or not protected at all, which makes this area very vulnerable to unconventional oil and gas extraction or any other development.

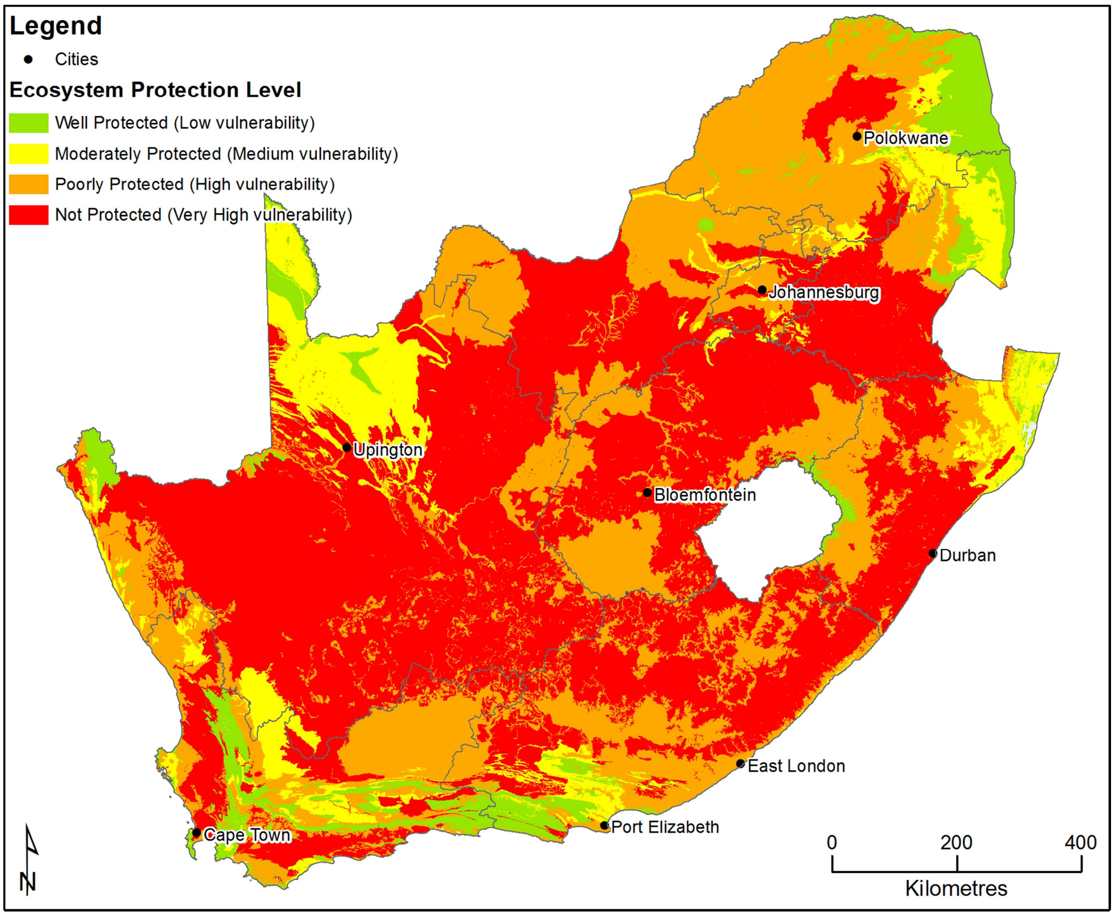

Figure 15: Map indicating the vulnerability rating associated with each ecosystem protection level classification

3.1.4.2 Vulnerability map

Eight of the nine experts assigned a final percentage weighting to the two selected indicators. The mean of the weights for the two indicators were determined, the mean for Ecosystem Threat Status was 48.75% and for Ecosystem Protection Level was 51.25%.

A statistical correspondence analysis was performed on the two indicators, which showed that there is dependence between the two indicators (Table 44). The null hypothesis of independence is rejected (with a p-value <0.0001). This is confirmed by the following statement in the NBA 2011: "*While threat status and protection level co-vary for some ecosystems, this is not always the case*....". These base maps will therefore be aggregated multiplicatively in the interactive vulnerability map.

Table 44: Results of the statistical analysis of the data comprising the two base maps

```
. ca eco_stat protect_stat, plot
```

Correspondence analysis

4 active rows	Number of obs =	1946
4 active columns	Pearson chi2(9) =	153.28
	Prob > chi2 =	0.0000
	Total inertia =	0.0788
	Number of dim. =	2
	Expl. inertia (%) =	99.92

Dimension	singular value	principal inertia	chi2	percent	cumul percent
dim 1	.2707511	.0733062	142.65	93.07	93.07
dim 2	.073447	.0053945	10.50	6.85	99.92
dim 3	.0080574	.0000649	0.13	0.08	100.00
total		.0787655	153.28	100	

Statistics for row and column categories in symmetric normalization

Categories	mass	overall quality	%inert	dimension_1 coord	dimension_1 sqcorr	dimension_1 contrib	dimension_2 coord	dimension_2 sqcorr	dimension_2 contrib
eco_stat									
2	0.758	1.000	0.189	0.268	0.994	0.202	0.040	0.006	0.017
3	0.203	1.000	0.711	-1.009	0.998	0.763	0.085	0.002	0.020
4	0.021	0.976	0.028	0.483	0.599	0.018	-0.736	0.377	0.155
5	0.017	0.998	0.072	-0.519	0.226	0.017	-1.843	0.772	0.808
protect_stat									
2	0.059	1.000	0.130	0.609	0.575	0.080	-1.004	0.424	0.804
3	0.136	0.993	0.077	0.376	0.854	0.071	0.291	0.139	0.157
4	0.372	0.999	0.269	0.457	0.990	0.287	0.083	0.009	0.035
5	0.433	1.000	0.523	-0.593	0.999	0.562	-0.027	0.001	0.004

Overlay maps

It was suggested by the groundwater experts that the Aquifer Dependant Ecosystems (ADEs) map be included in the vegetation vulnerability map. Activities within these areas should be excercised with caution. The Aquifer Dependant Ecosystems are indicated in red (Figure 16).

Aquifer Dependant Ecosystems is defined by Colvin et al. (2007) as “ecosystems which depend on groundwater in, or discharging from, an aquifer.” They further note that these ecosystems are “distinctive because of the connection to the aquifer and would be fundamentally altered in terms of their structure and functions if groundwater was no longer available.” Given the large amounts of water needed during unconventional oil and gas extraction, these areas will be very vulnerable to a change in water availability. Riparian ecosystems, riverine aquatic ecosystems, wetlands, and estuarine and coastal ecosystems are just some of the ecosystems that were identified to be dependent on aquifers. This map is included as an overlay on the interactive vulnerability map.

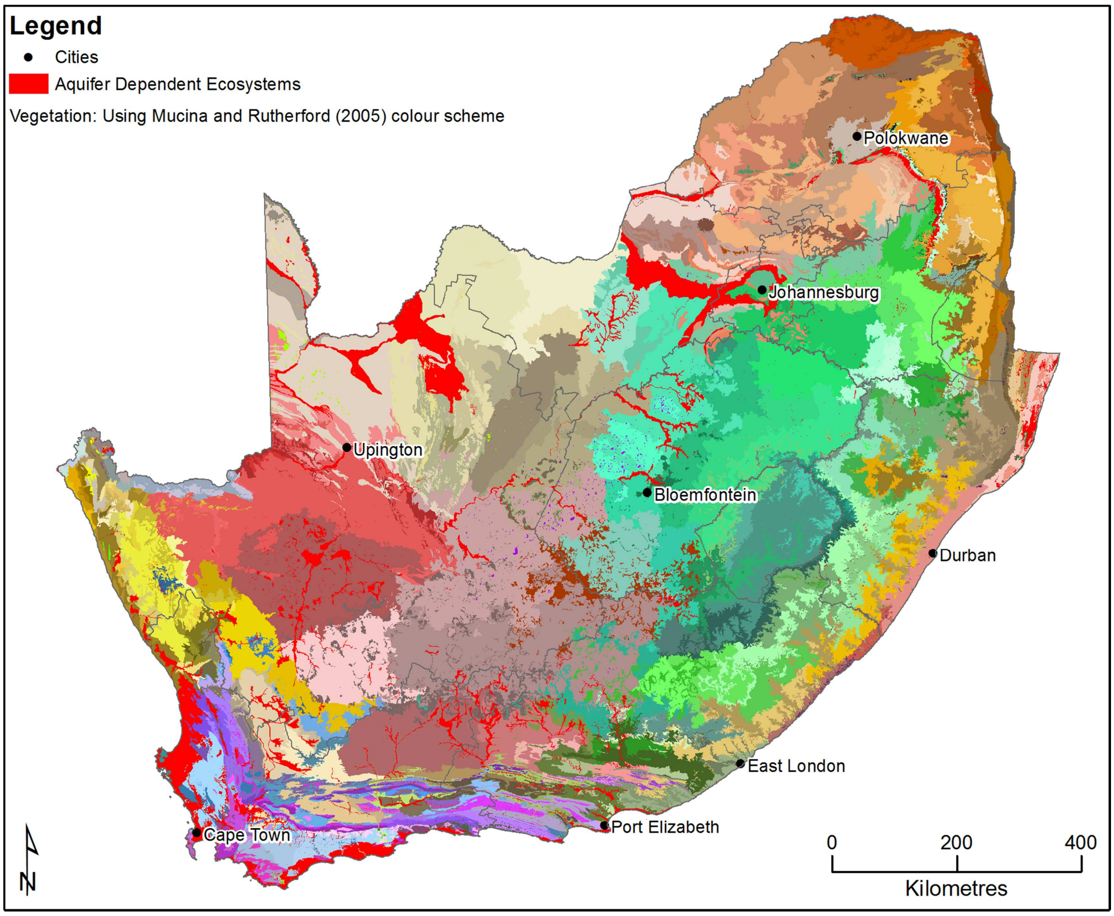

Figure 16: Aquifer Dependent Ecosystems (2007) overlain on the vegetation types from Mucina and Rutherford (2005)

Components of the Ecological Infrastructure map (also known as the Biodiversity Priority Areas map) that was developed as part of the NBA 2011 are also included on the interactive vulnerability map as overlays. Both terrestrial and aquatic features were mapped together and some of the categories overlap and are therefore not mutually exclusive. Where categories overlap, it supports the importance of the effective management and conservation of that area. Categories related to terrestrial ecosystems will be flagged in the vegetation vulnerability mapping theme. The categories that will be included as overlays in the vegetation vulnerability mapping theme from the biodiversity priority areas map include:

- Category B Critical Biodiversity Areas (Figure 17)
- Category C Critical Biodiveristy Areas (Figure 18)
- Category D: Ecological Support Area – Bioregional and Provincial Data (Figure 19) and
- Category D: Ecological Support Area Equivalents (Figure 20)

The datasets for the interactive vulnerability map have been kept in the same format as the Mining and Biodiversity Guideline Map that was published in May 2013 (DEA, 2013) and will conform to the categories that have been determined in the Mining and Biodiversity Guideline Map, namely categories B, C and D.

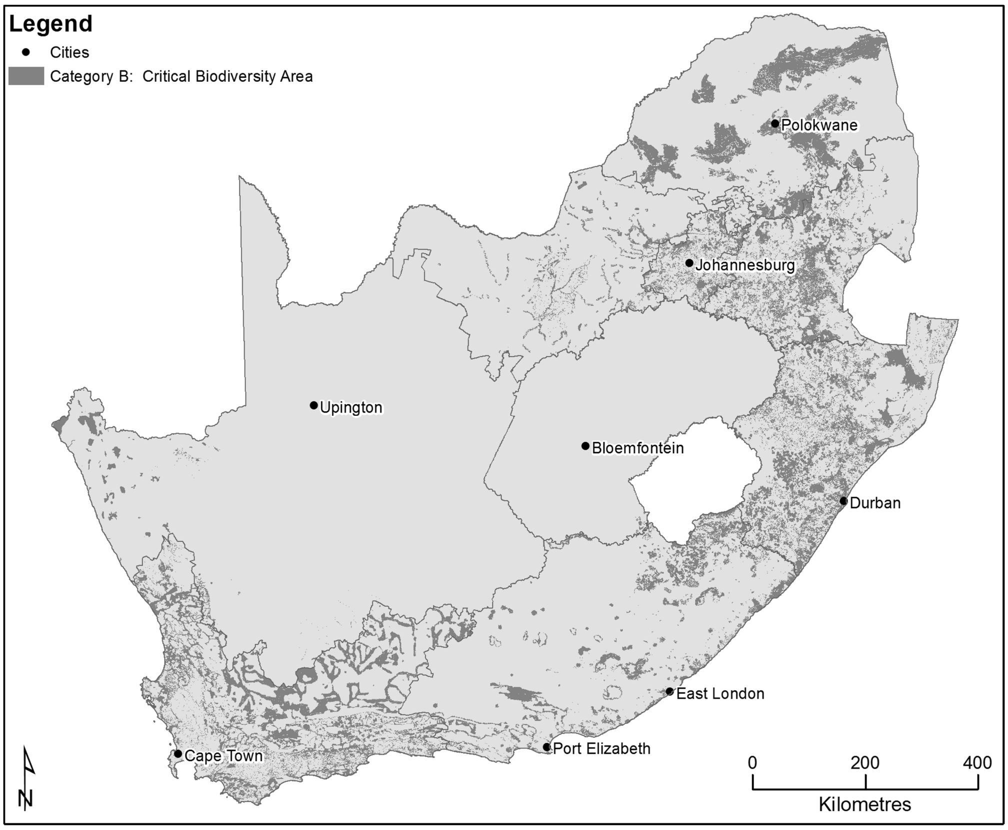

Figure 17: Category B: Critical Biodiversity Area – Bioregional and Provincial Data (Compiled from data received from Holness, 2013)

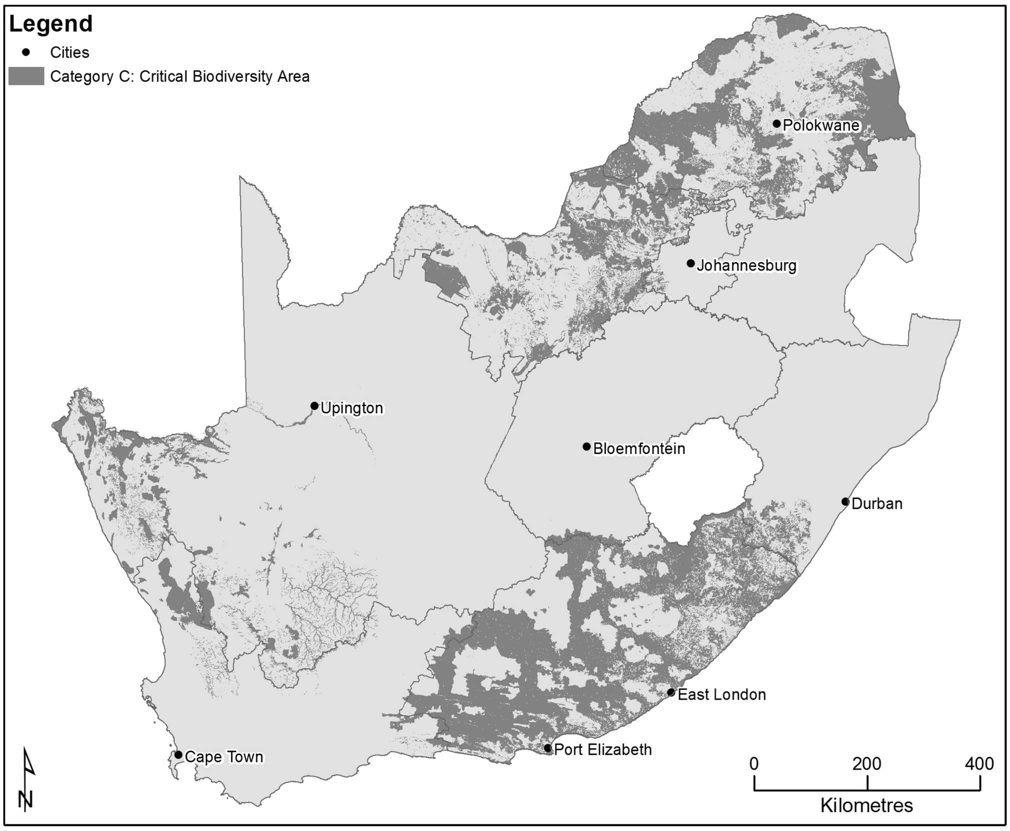

Figure 18: Category C: Critical Biodiversity Area – Bioregional and Provincial Data (Compiled from data received from Holness, 2013)

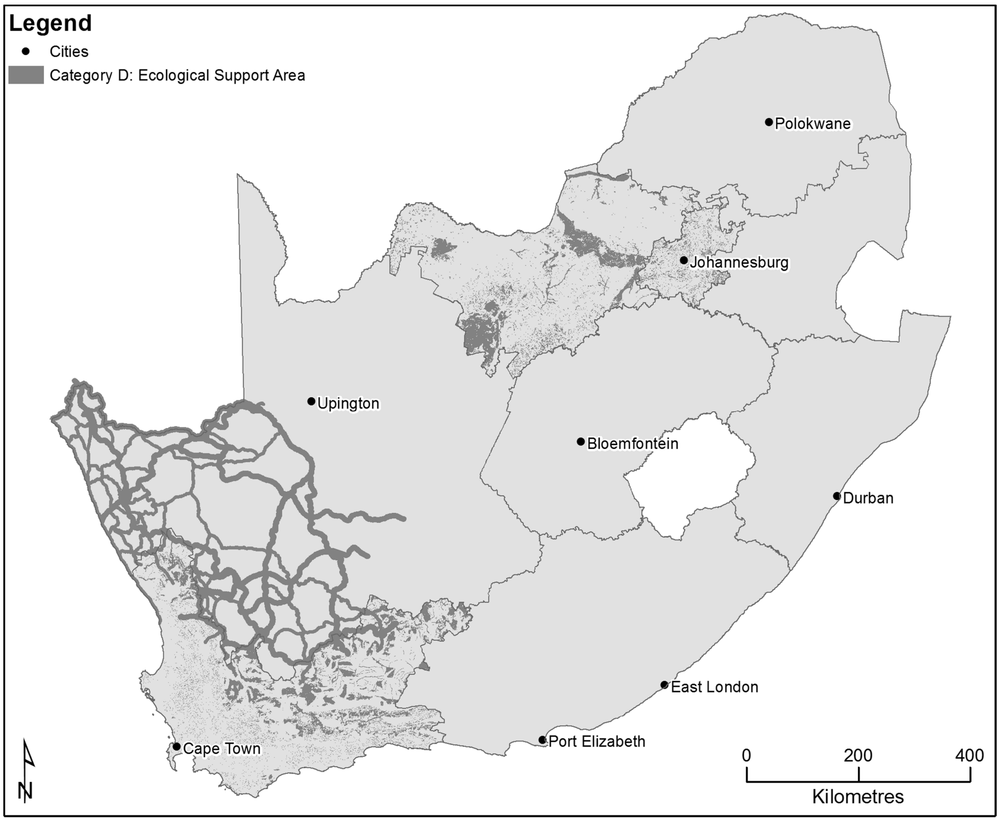

Figure 19: Category D: Ecological Support Area – Bioregional and Provincial Data (Compiled from data received from Holness, 2013)

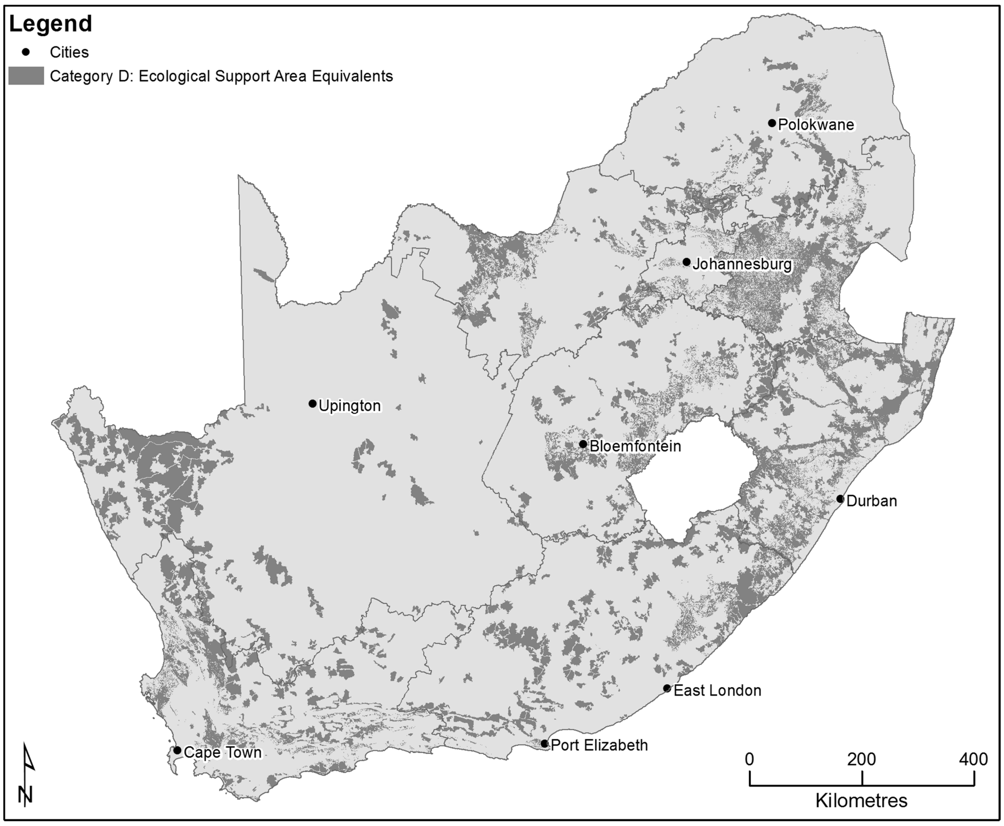

Figure 20: Category D: Ecological Support Area Equivalents (Compiled from data received from Holness, 2013)

Critical biodiversity areas (CBAs) and ecological support areas (ESAs) will now be discussed briefly.

CBAs are spatial data that was developed by provincial authorities and included in the Mining and Biodiversity Guideline 2013. These reports were completed on different spatial scales and different terminologies were used by the different authorities. The focus of the CBAs was to identify areas where the intactness of these areas can be preserved in a natural or near-natural state.

For the ESAs, the main aim was to identify areas where the ecosystem functioning should be at least functional. Some degree of disturbance is expected in the ESAs. Both the CBAs and ESAs are part of an interconnected system that connects landscapes and different features in the landscape, so that pro-active landscape level planning can take place.

Since these CBA and ESA datasets are on a much finer scale (provincial or even smaller scale) than the regional scale base maps used in the vegetation vulnerability map, these maps and accompanying reports should be consulted when the EIAs are performed. These reports are all available from SANBI's website (SANBI, 2013).

The ESAs were also identified on a local scale as part of the CBA's for each province. Not all the provinces had completed this task when this report was published.

On all the data files available on the interactive map CD, the file names will be exactly the same as those provided by the compilers of the CBA and ESA maps. It is important to note that these provincial scale assessments could be updated on a regular basis and should be consulted directly. All the overlay maps included in this project are dated May 2013. The data of both Mpumalanga and Limpopo have already been reviewed after publication of the Mining and Biodiversity Guideline in May 2013, but it could not be included in this version of the vulnerability map, since it is not publicly available yet. Most of the vegetation types that were described and mapped by Mucina and Rutherford (2005) are also being updated (Collins pers comm, 2013; Du Preez, 2013) and this new information should be consulted when local studies are performed.

According to Holness (2013) no further analysis has been done on the datasets used in the Mining and biodiversity guideline map, except for files that have "nlc" in the file name. In these datasets, all the transformed areas have been removed during the analysis for the Biodiversity and Mining Guideline Map. Only the intact areas have been included in these datasets.

It is highly recommended that these overlays be taken into account when local scale studies are conducted before unconventional oil and gas extraction commences.

4.2.4 Seismicity

This section describes the detail indicator selection process (Section 4.3.4.1), indicator classification and weighting (Section 4.3.4.2) as well as the final vulnerability map for seismicity (Section 4.3.4.3).

4.2.4.1 Indicator selection process

The surface of the earth is in a constant state of vibration at periods ranging from milliseconds to days with amplitudes ranging between nanometres and meters. The vast majority of these vibrations are very weak and will go undetected without the use of specialised equipment. It is however the larger vibrations (ground motion) that are of concern to earthquake and civil engineers since most earthquake-related deaths are due to collapsed buildings. The goal is therefore to understand the strong ground motions produced by earthquakes than can damage buildings and other critical structures as to design these structures to be earthquake-resistant (Kramer, 1996).

Peak Ground Acceleration

Over the years several ground motion parameters have been developed to describe its characteristics, namely, 1) amplitude, 2) frequency-content and 3) the duration of the ground motion. These characteristics are measured with instruments such as seismographs (for relatively weak ground motion) and accelerographs (strong ground motion). The advancement of technology resulted in seismographs which are also able to measure various characteristics of weak and stronger ground motion with relative accuracy.

The amplitude, through time history, is the most common characteristic used to describe ground motion. The acceleration, velocity, displacement or all three are the typical measurements taken to describe the amplitude (Kramer, 1996). The most extensively measured parameter is the peak ground acceleration (PGA), which is the maximum acceleration amplitude measured (or expected) in a strong-motion accelerogram of an earthquake, and it is typically expressed in terms of its horizontal component namely the peak horizontal acceleration (PHA). This acceleration is expressed in units of *g*, where *g* is equal to 9.81 m/s^2. The PHA is the most commonly used parameter due to the natural relationship that exists between PHA and the inertial forces – e.g. certain types of structures (i.e. stiff structures) with large induced dynamic forces are closely related to PHA (Kramer, 1996). The peak vertical acceleration (PVA) has received much less attention in the past compared to the PHV. It is generally assumed to be two thirds of the PHA (Newmark and Hall, 1982).

Since acceleration provides a good indication of the ground motion and is proportional to the exerted force on infrastructure by seismic waves generated by a seismic event; it is very often used to describe damages to infrastructure. Thus the seismic hazard for an area is typically described by numerical models (deterministic or probabilistic) that estimate the likelihood of an area experiencing a certain level of acceleration (PGA) in a given time period. The peak-velocity and displacement can be derived from the PHA through integration and/or differentiation.

Acceleration is also the most commonly visually represented parameter in seismic hazard (vulnerability) maps and is used extensively by the engineering industry. These maps are attempts to quantify the hazard in terms of the expected ground motion by evaluating the expected maximum acceleration during a specified time interval. This is done by making assumptions on how and where earthquakes will occur, how large they would be and how much ground motion they would produce.

An alternative method to characterise ground motion is intensity, which is a descriptive measurement of the felt and observed effects of an earthquake (Steyn and Wysession, 2003). The popular Modified Mercalli intensity scale (MMI) classifies the effects from I (unfelt) to XII (total destruction) - (Wood and Neumann, 1931). The intensity assigned to an earthquake is inferred from human accounts and is a subjective scale based on what was felt as well as structural damage to buildings. It is useful in areas where no measuring instruments are present or for earthquakes that took place before the invention of the modern seismometers (about 1890) (Steyn and Wysession, 2003).

There exists a certain degree of correlation between MMI, a descriptive parameter, and the numerical parameter of PHA (Krinitzky and Chang, 1987; Murphy and O'Brien, 1977; Trifunac and Brady, 1975). Steyn and Wysession, 2003 provides the intensities with an approximate associated acceleration interval as taken from Bolt (1999) - one of the several intensity-acceleration relationships that are available.

Seismic Source Information

Both deterministic (DSHA) and probabilistic (PSHA) seismic hazard analysis depends on all available information about the earthquake source. DSHA requires the site specific information while the PSHA utilises the information on all possible earthquake sources in the defined region. The earthquake sources are typically described on the basis of geological, tectonic, historical and instrumental evidence (Kramer, 1996).

4.2.4.2 Indicator classification and weighting

Ground motion

In South African the ground motion is expressed in both PGA and MMI. The insurance industry prefers the ground motion at a given site to be expressed in terms of the MMI scale. This is due to (1) in South Africa the area-characteristic ground motion prediction equations are known compared to the virtually non-existing peak ground acceleration (PGA) records, and (2) the vulnerability curves used in this report are provided in terms of MM intensity. But the engineering industry prefers PGA, to assist them in designing earthquake resistant infrastructures.

The ground motion prediction equations (GMPEs) for South Africa were established on the basis of strong-motion data, which are practically non-existent (Minzi et al., 1999). Three attempts to establish the horizontal component of PGA attenuation for east and southern Africa are published by Jonathan (1996), Twesigomwe (1997) and more recently by Mavonga (2007). Jonathan's GMPE is based on random vibration theory and is scaled by seismic records as recorded by local seismic stations. Twesigomwe's equation is a modification of the GMPE by Krinitzky et al. (1988). Comparison of the two regional GMPEs with for example the global equation by Joyner and Boore (1988), Boore et al., (1993; 1994) shows relatively good agreement between regional attenuations and is used globally. Finally, the most recent GMPE by Mavonga (2007) is based on the well-known procedure of the simulation of the ground motion of large seismic events using recordings of small earthquakes (Frankel, 1995; Irikura, 1986). Seismic records of small events adjacent to the expected large events have been treated as an empirical Green's function. The advantage of the procedure is that the predicted ground motion contains information on the site response, details of path effects etc., and they can therefore often produce realistic time histories. Unfortunately, all three GMPEs are derived only for PGA and are not applicable to short distances e.g. below 10 km.

For this seismic hazard (vulnerability) map the assessment of the seismic hazard (vulnerability) for South Africa is based on the well-studied model of GMPE by Atkinson and

Boore (2006). The applied GMPE was developed for the central and eastern United States, which is situated in a type of tectonic environment known as an intraplate region, or equivalently, stable continental area. Because of the limited number of strong-motion records in the stable continental areas, the applied GMPE (horizontal component) has been developed mainly with the aid of stochastic modelling.

The GMPE used and its functional form and respective coefficients are provided in Table 45 as well as in Appendix A of the complete report on the Possible Effect of Hydraulic Fracturing on the Seismic Hazard in South Africa that is included in Appendix 4 of this report.

Table 45: Applied ground motion prediction equation by Atkinson-Boore (2006) and its coefficients.

Atkinson-Boore GMPE (2006)			$ln[a(f)] = c_1 + c_2 * mag + c_3 * mag^2 + (c_4 + c_5 * mag)f_1 + (c_6 + c_7 * mag)f_2 + (c_8 + c_9 * mag)f_0 + c_{10} * r + p * SD$						
Freq (Hz)	**c_1**	**c_2**	**c_3**	**c_4**	**c_5**	**c_6**	**c_7**	**c_8**	**c_9**	**c_{10}**
0.2	-5.41	1.710	-0.0901	-2.54	0.227	-1.270	0.116	0.979	-0.1770	-0.0002
0.3	-5.79	1.920	-0.1070	-2.44	0.211	-1.160	0.102	1.010	-0.1820	-0.0002
0.4	-6.17	2.210	-0.1352	-2.30	0.190	-0.986	0.079	0.968	-0.1770	-0.0003
0.5	-6.18	2.300	-0.1440	-2.22	0.177	-0.937	0.071	0.952	-0.1770	-0.0003
0.8	-5.72	2.320	-0.1510	-2.10	0.157	-0.820	0.052	0.856	-0.1660	-0.0004
1.0	-5.27	2.260	-0.1480	-2.07	0.150	-0.813	0.047	0.826	-0.1620	-0.0005
2.0	-3.22	1.830	-0.1200	-2.02	0.134	-0.813	0.044	0.884	-0.1750	-0.0008
2.5	-2.44	1.650	-0.1080	-2.05	0.136	-0.843	0.045	0.739	-0.1560	-0.0009
4.0	-1.12	1.340	-0.0872	-2.08	0.135	-0.971	0.056	0.614	0.1430	-0.0011
5.0	-0.61	1.230	-0.0789	-2.09	0.131	-1.120	0.068	0.606	-0.1460	-0.0011
8.0	0.21	1.050	-0.0666	-2.15	0.130	-1.610	0.105	0.427	-0.1300	-0.0012
10.0	0.48	1.020	-0.0640	-2.20	0.127	-2.010	0.133	0.337	-0.1270	-0.0010
20.0	1.11	0.972	-0.0620	-2.47	0.128	-3.390	0.214	-0.139	-0.0984	-0.0003
25.2	1.26	0.968	-0.0623	-2.58	0.132	-3.640	0.228	-0.351	-0.0813	-0.0001
40.0	1.52	0.960	-0.0635	-2.81	0.146	-3.650	0.236	-0.654	-0.0550	-0.0000
PGA	0.91	0.983	-0.0660	-2.70	0.159	-2.800	0.212	-0.301	-0.0653	-0.0004

Seismic source information

Current geological knowledge of South Africa does not provide information on all capable faults and their movements during the recent (Quaternary) geological past, especially during last 35 000 years. There exists no known relationship between instrumentally recorded or historic seismicity and the location of faults. Also, almost no information on paleo-seismicity of the South African area is available.

The PGA was therefore, for the purpose of this study, the only parameter (indicator) applied in the assessment of the probabilistic seismic hazard assessment for South Africa. The assessment of the source-characteristic, maximum possible seismic event magnitude $m_{\max}$ (Kijko, 2004) is based entirely on knowledge of past seismicity. The other two hazard recurrence parameters (the Gutenberg-Richter *b*-value and the mean activity rate λ) for each seismic source has been estimated according to the procedure developed by Kijko and Sellevoll (1992) and are also based on knowledge of seismicity of the area.

4.2.4.3 Vulnerability map

The seismic hazard (vulnerability) map (Figure 22) portrays the current seismic hazard (vulnerability) in South Africa, expressed in terms of PGA with 10% probability of exceedance at least once within 50 years. The map was calculated for the current value of the area-specific mean seismic activity rate λ. This map provides a convenient tool to estimate the expected seismic risk and response to seismic event loading for different types of structures and buildings located South Africa. By combining this map with additional geological information, it could also be used as an aid in seismic hazard and ultimately seismic risk mitigation.

The seismic hazard (vulnerability) was assessed through the application of the probabilistic seismic hazard analysis (PSHA) procedure. The essence of PSHA is the calculation of the probability of exceedance of a specified ground motion level at a specified site (Cornell, 1968; Reiter, 1990). In principle, PSHA can address a very broad range of natural hazards associated with seismic events, including ground shaking and ground rupture, landslide, liquefaction or tsunami. However, in most cases the interest of designers lies in the estimation of the likelihood of a specified level of ground shaking, since it causes the greatest economic losses.

The typical output of the PSHA is the seismic hazard curve (often a set of seismic curves). These curves are plots of the estimated probability per unit time, of the ground motion variable, e.g. PGA being equal to or exceeding the level as a function of PGA (Budnitz et al., 1997). The essence of the PSHA is that its product – the seismic hazard curve, quantifies the hazard at the site from all possible seismic events of all possible magnitudes at all significant distances from the site of interest, by taking into account their frequency of occurrences. In addition to the hazard curve, the output of PSHA includes results of the so called de-aggregation procedure. This procedure provides information on seismic event magnitudes and distances that contribute to the hazard at a specified return period and at a structural period of engineering interest (Budnitz et al., 1997).

In general, the standard PSHA procedure is based on two sources of information: (1) observed seismicity, recapitulated by seismic event catalogue, and (2) a regional seismotectonic model of the area. After the combination of the above data with the information on the regional seismic wave attenuation or GMPE, an assessment of the seismic hazard is performed. Detailed investigation into the site effect, determined by site specific soil properties, should be done to improve the accuracy of the PGA. Complete PSHA can be carried out only when information on the regional seismotectonic model and the site-specific soil properties are known.

Clearly, all the above information required to complete PSHA is subjective and often highly uncertain, especially in stable continental areas where the seismic event activity is very low. According to the convention established in the fundamental document by Budnitz et al. (1997) there are two types of uncertainties associated with PSHA: aleatory and epistemic.

According to Budnitz et al. (1997) the uncertainties that are part of the applied model used in the analysis are called aleatory uncertainties. The other names for the aleatory uncertainty are “stochastic” or “random” uncertainties. Even when the model is perfectly correct and the numerical values of its parameters are known without any errors, aleatory uncertainties for a given model are still present (Budnitz et al., 1997).

The uncertainties which come from incomplete knowledge of the models, i.e. when incorrect models are applied or/and the numerical values of their parameters are not known, are called epistemic uncertainties. As relevant information is collected, the epistemic uncertainties can be reduced (Budnitz et al., 1997).

By the definition of the PSHA procedure, the aleatory uncertainty is included in the process of PSHA calculations by means of applied models (statistical distributions) and by mathematical integration. Epistemic uncertainty can be incorporated in the PSHA by the consideration of an alternative hypothesis (e.g. alternative boundaries of the seismic sources and their recurrence parameters) and alternative models (e.g. alternative seismic event distributions or/and application of alternative PGA attenuation equations). Incorporation of this type of uncertainties into the PSHA is carried out by the application of the logic tree formalism. A complete PSHA includes an account of aleatory as well as epistemic uncertainties. Any PSHA without the incorporation of the above uncertainties is considered to be incomplete.

This following section describes two major mathematical aspects of the PSHA:

1) The procedure for the assessment of the seismic source characteristic recurrence parameters when the data are incomplete and uncertain. Use is made of the most common assumptions in engineering seismology i.e. the seismic event occurrences in time follow a Poisson process; and that seismic event magnitudes are distributed according to a Gutenberg-Richter doubly-truncated distribution. Following the above assumptions, the seismic source recurrence parameters are defined as (1) the mean seismic activity rate λ (which is a parameter of the Poisson distribution), (2) the level of completeness of the seismic event catalogue $m_{\min}$, (3) the maximum regional seismic event magnitude $m_{\max}$ and (4) the Gutenberg-Richter parameter b. To assess the above parameters a seismic event catalogue containing origin times, size of seismic events and spatial locations are needed. The maximum seismic source characteristic event magnitude $m_{\max}$ is of paramount importance in this approach; therefore a statistical technique that can be used for evaluating this important parameter is presented in Section 4.2.6 of the complete report on the Possible Effect of Hydraulic Fracturing on the Seismic Hazard in South Africa that is included in Appendix 4 of this report.
2) PSHA methodology i.e. calculating the probability of exceedance of a specified ground motion level at a specified site. Often, the presented approach is known as the Cornell-McGuire procedure. The essence of the Cornell-McGuire PSHA procedure is the calculation of the probability of exceedance of a specified ground motion level at a specified site. The so called Cornell-McGuire solution of this problem consists of four steps (e.g. Budnitz et al., 1997; Reiter, 1990):
    - determination of the possible seismic sources around the site;
    - determination and assessment of the recurrence parameters for each seismic source;
    - selection of the ground motion prediction equation (GMPE) which is most suitable for the region; and
    - computation of the hazard curves.

At least two similar investigations of seismic hazard in South Africa were compiled in the past. In 1992, Fernandez and du Plessis produced “Seismic Hazard Maps of Southern Africa” and in 2003 Kijko et al. published the interactive CD “Probabilistic Peak Ground Acceleration and Spectral Seismic Hazard Maps for South Africa”. This map by Kijko et al. (2003) has been incorporated into the South African Building Code SABS (2009).

Nature of input data

The lack or incompleteness of data in seismic event catalogues is a frequent occurence in the statistical analysis of seismic hazard. Contributing factors include the historical and socio–economic context, demographic variations and alterations in the seismic network. Generally, the degree of completeness is a monotonically increasing function of time i.e. the more recent portion of the catalogue has a lower level of completeness. The methodology makes provision for the seismic event catalogue to contain three typical scenarios (Figure 21) that may occur when conducting seismic hazard assessments (Kijko and Sellevoll, 1989; 1992):

- Very strong prehistoric seismic events (paleo-earthquakes) which usually occurred over the last thousands of years;
- The macro-seismic (historic) observations of some of the strongest seismic events that occurred over a period of the last few hundred years; and
- Complete recent data for a relatively short period of time.

Section 4 of the complete report on the Possible Effect of Hydraulic Fracturing on the Seismic Hazard in South Africa, which is included in Appendix 4 of this report, provides a detailed description of the statistical procedure followed to make provision for the different catalogues as well as the PSHA procedure used in the calculation the seismic parameters λ (the area characteristic mean seismic activity rate), b (the Gutenberg-Richter parameter), m_{min} (the level of completeness of the seismic event catalogue) and m_{max} (the maximum regional seismic event magnitude).

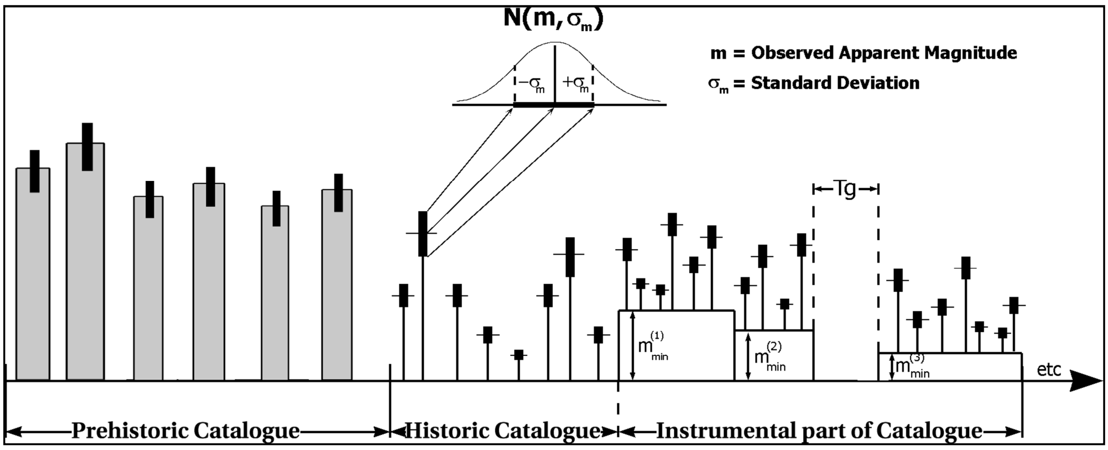

Figure 21: Illustration of data which can be used to obtain recurrence parameters for the specified seismic source (Modified after Kijko and Sellevoll, 1992)

Catalogues

The seismic event catalogue used in this study was compiled from several sources. After critical analysis of each of the data sources, the main contribution to pre-instrumentally recorded seismicity comes from Brandt et al. (2003). The instrumentally recorded events are mainly selected from databases provided by the International Seismological Centre in UK (ISC). The ISC is a non-governmental organisation charged with the final collection, analysis and publication of standard earthquake information from around the world.

The database of seismic events for South Africa is incomplete due to the fact that large parts of the country were very sparsely populated and the detection capabilities of the seismic network are far from uniform. For this study, the assessment of the source-characteristic, maximum possible seismic event magnitude m_{max} (Kijko, 2004) is based entirely on knowledge of past seismicity. The other two hazard recurrence parameters (the Gutenberg-Richter *b*-value and the mean activity rate λ) for each seismic source has been estimated according to the procedure developed by Kijko and Sellevoll (1992). Similar to the assessment of m_{max}, *b*-value and λ are based on knowledge of seismicity of the area.

The parameters of area sources λ, *b*-value and m_{max} were calculated for a grid size (0.1˚x0.1˚) spanning the whole country. The seismic hazard is calculated in the form of a matrix consisting of equally spaced grid points (0.25˚x0.25˚) in latitude and longitude. The area covered in this study is defined by latitudes 35˚S to 21˚S and longitudes 15˚E to 33˚E.
The GMPE used and their functional form and respective coefficients are provided in Table 45 and in Appendix A of the complete report on the Possible Effect of Hydraulic Fracturing on the Seismic Hazard in South Africa (Appendix 4).

Seismic vulnerability map

The seismic vulnerability map, expressed in terms of PGA, indicates a 10% probability of exceeding the PGA at least once in 50 years. A more reliable assessment of the effect of hydraulic fracturing on seismic hazard in South Africa can be achieved only through the inclusion of detailed geological and tectonic information about the area.

The map indicates a wide range of accelerations, which are represented by the colours as indicated in Table 46. The accelerations range from 0.01 g to 0.14 g and are grouped together as indicated in Table 46.

Table 46: Classification of acceleration range for mapping purposes

Hazard classification	Acceleration range	Colour code
Very low vulnerability	0.0 g	Blue
Low vulnerability	0.0 g - 0.05 g	Green
Medium vulnerability	0.05 g – 0.0875 g	Yellow
High vulnerability	0.0875 g – 0.125 g	Orange
Very high vulnerability	> 0.125 g	Red

The highest expected accelerations for the seismic vulnerability map (Figure 22) are 0.14 g with high vulnerability expected in the parts of Western Cape, Gauteng, North West Province, Mpumalanga, KwaZulu-Natal and Swaziland. It is important to note that although by international norms the expected seismic hazard is not high, it is still high enough to cause significant damage to infrastructure.

The PGA map (Figure 22) gives comparable results compared to the most recent seismic hazard map of southern Africa (Kijko et al., 2003), which is implemented into the South African Building Code 2009 (SABS, 2009).

Possible effect of hydraulic fracturing

Not enough research has been performed to enable the researchers to release a categorical statement in terms of which areas can be classified as safe or not safe in terms of hydraulic fracturing. The seismicity for South Africa is not equally well documented for different areas in the country, for instance the Karoo area. This is mainly due to the relatively low density of seismometers in the South African National Seismological Network (SANSN). A very limited number of stations are not capable of detecting and/or locating weak seismic events. Buried faults can therefore go undetected. The establishment of a local seismic network before hydraulic fracturing starts is fundamentally important to ensure that no drilling occurs on or near any faults or areas of tectonic stress concentrations. The use of the current knowledge of the local geology in this respect could also be extremely helpful in the absence of instrumental observations.

Local tectonic conditions are crucial indicators needed to determine the level of increase of seismicity in an area. These conditions include the local geological make-up, buried faults, local seismotectonics (which can be established by seismic tomography) and tectonic stresses. The history of the seismic activity in the area is also an important factor which, up to large extent, determines the seismicity induced by a process such a hydraulic fracturing.

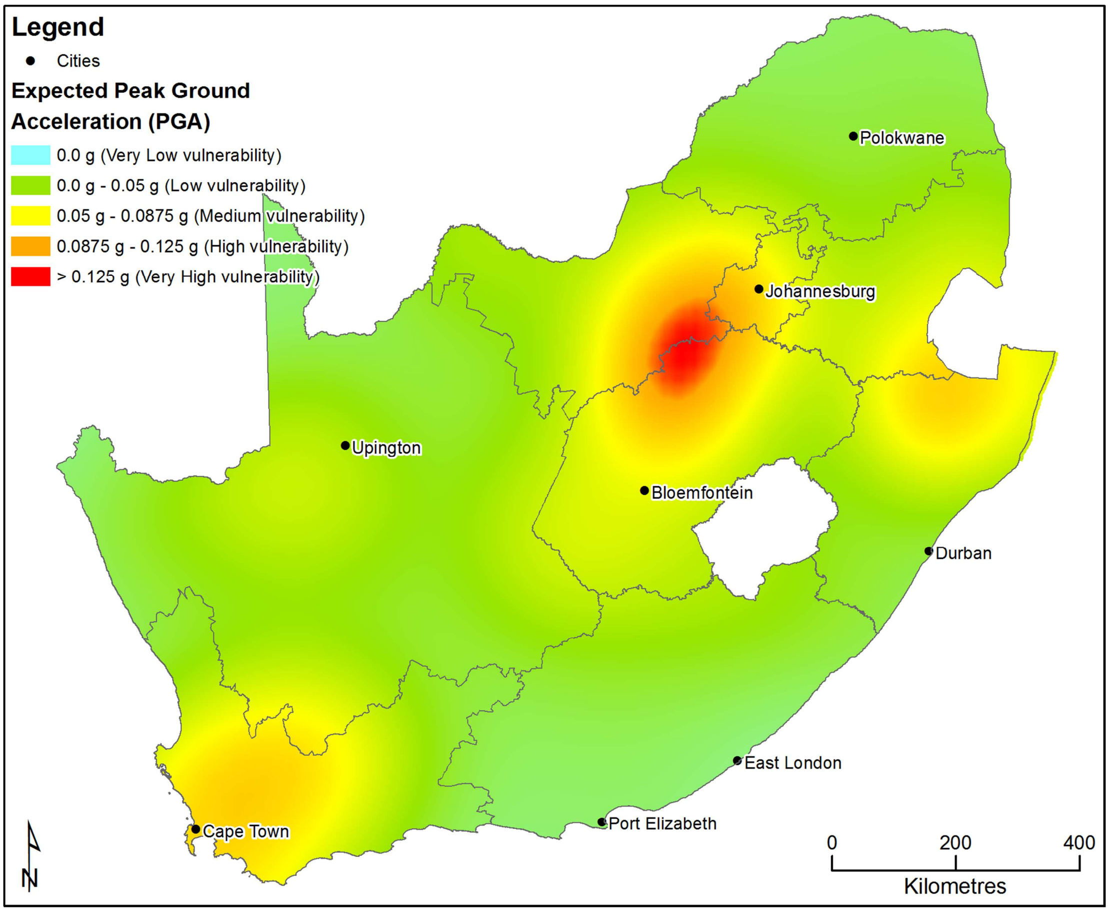

Figure 22: Map of current seismic vulnerability (hazard) for South Africa. This map shows the expected PGA with a 10% probability of being exceeded at least once in a 50 year period.

4.2.5 Socio-economics

This section describes the indicator selection process and the indicators and data sources selected for vulnerability mapping (Section 4.3.5.1), the indicator classification and weighting (Section 4.3.5.2) as well as the final vulnerability map for socio-economics (Section 4.3.5.3) in detail.

The process for mapping socio-economic impacts followed three distinct phases. During the first phase, indicators for mapping purposes were identified. The second phase focused on classification of each selected mapping indicator into five classes of vulnerability. The last phase consisted of plotting data for each indicator on the vulnerability map (See Figure 23).

4.2.5.1 Indicator selection process

To meet the objectives of the study, consideration was given to establishing a conceptual framework that would adequately explain socio-economic vulnerability. Flowing from this consideration, an analytical and methodological framework in line with the conceptual approach needed to be identified and unpacked.

The conceptual basis for determining socio-economic vulnerability is rooted in the sociological understanding of environmental justice. The environmental justice approach argues that there is an unequal distribution of environmental benefits and costs in society, with the more vulnerable sectors of society being more exposed to the negative consequences of environmental issues (Bell, 2012). This approach is appropriate for highlighting unequal distribution of environmental benefits and costs for human populations exposed to unconventional oil and gas exploration and extraction and, in the process, serves to indicate varying socio-economic vulnerability to environmental change. Harper (2012) emphasises that the environmental justice approach has been able to integrate social and ecological concerns more than other approaches that preceded it.

Thus, indicator selection was guided by the principles of environmental justice, and indicators were chosen based on their ability to reflect ***disproportionate exposure to environmental bads*** (the negative impacts resulting from unconventional oil and gas extraction developments). The premise is that some populations in society are already vulnerable to experiencing the negative impacts resulting from changes in their environment. These groups are, among others, the poor, women, children and ethnic minorities (Mascarenhas, 2009). Thus, emphasis was placed on selecting indicators that would adequately reflect how those who are already considered vulnerable based on their socio-economic position in society would be affected by the negative impacts of unconventional oil and gas extraction. Following from the environmental justice approach, attention was, therefore, not given to positive impacts emanating from unconventional oil and gas exploration and extraction, since the premise of this approach is that those who are vulnerable will also receive less, if any, of the goods permeating from proposed developments. For example, increased employment opportunities (a positive impact of unconventional oil and gas extraction) will not necessarily serve to elevate the socio-economic status of local people who lack the skills needed to enter this field of employment.

Based on this, the indicator selection process focused on highlighting areas where populations, based on their current population attributes, reliance on natural resources i.e. water and their current development status, will firstly not benefit from the proposed oil and gas extraction (receiving the environmental goods), and secondly are at risk of reaping a disproportionate share of the environmental impacts emanating from developments in these areas. With this conceptual framework in mind, the study set out to identify indicators that would reflect the above disproportionate exposure to the negative impacts of the proposed developments.

To approach indicator selection in a systematic way, the PED nexus framework, an accepted analysis framework for analysing people-environment interactions, both internationally and nationally (DSD, 2009; Pelser and Redelinghuys, 2008) formed the analytical basis of indicator selection. This framework assured that indicators are systematically selected to reflect the various facets of the social environment – population, environment (specifically pertaining to the linkages between human health and the environment) and development.

Overall, the research design employed in indicator selection and classification was qualitative with a strong reliance on triangulation. Maree and Van der Westhuizen (2010) describe triangulation as a critical aspect in facilitating interpretive validity and establishing the trustworthiness of data. Triangulation in this study enabled the researchers to verify the extent to which initial conclusions drawn are supported by qualitative inputs. The methodology relied on obtaining expert opinion from key informants and analysing the data obtained by means of qualitative data analysis methods. It should be emphasised that the methodology did not lend itself to obtaining generalisable, quantifiable results, as would have been the case when a quantitative approach was to be followed. The reasons for adopting a qualitative approach in this study were twofold. Firstly, expert opinion would ensure that the study benefited from the specialist input of knowledgeable informants and secondly, due to the unprecedented nature of unconventional oil and gas exploration and extraction in South Africa, it was more appropriate to rely on a small pool of suitable respondents than to muddle the results with inputs from people not currently well informed on the issue.

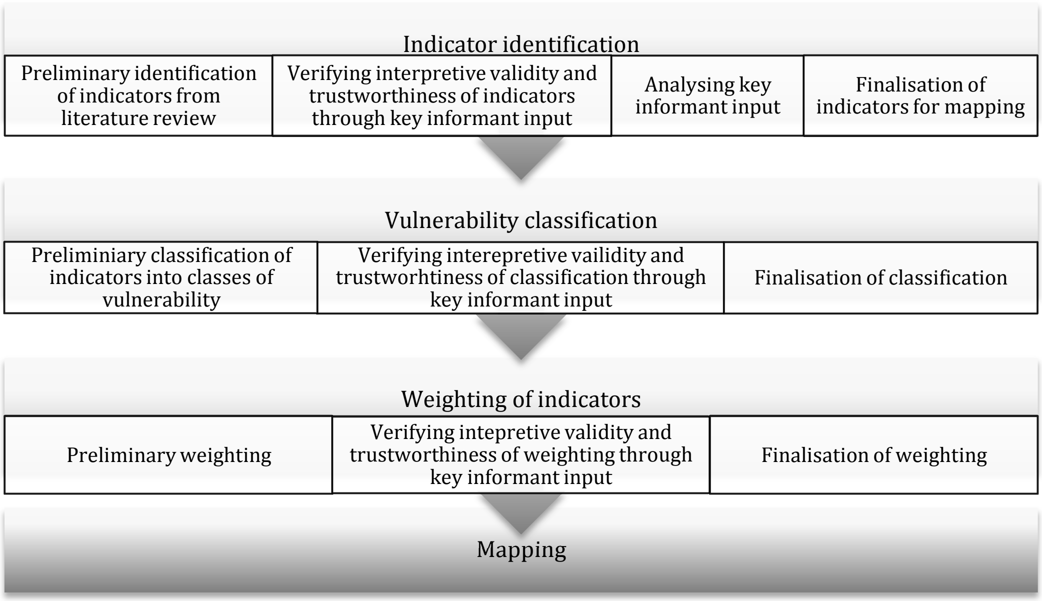

Figure 23: Methodological process

Socio-economic indicators were selected based on the criteria for mapping as identified by the research team and the terms of reference for the study.

Preliminary indicators to be used for mapping of socio-economic vulnerability to unconventional oil and gas extraction were identified through a thorough literature review of the impacts of unconventional oil and gas extraction on communities (see section 2 – Background review). The criteria for inclusion as indicators in the socio-economic vulnerability map were the following:

- Indicators had to be indicative of vulnerability to unconventional oil and gas mining by means of hydraulic fracturing (at the time of conducting this survey, unconventional oil and gas extraction was viewed as a mining activity, which it essentially is – this term has however recently been revised to “unconventional oil and gas extraction” as based on legal definitions);

- Data had to be available for the whole of South Africa for the selected indicators;
- The indicators had to be spatially presentable;
- Existing data for these indicators had to be reliable, accessible and available in GIS format.

Possible indicators as identified during the background review on the impacts of unconventional oil and gas mining (extraction) on the socio-economic environment were presented to a group of key informants that was deemed knowledgeable on the vulnerability of the social environment to negative environmental and social impacts emanating from proposed oil and gas developments. The experts were purposively selected by the socio-economic specialist based on own knowledge of the expertise in the field. Fourteen key informants knowledgeable about the use of indicators within the PED nexus framework pertaining to mining environments were contacted for input in indicator selection. Of these informants, nine completed the questionnaire developed for this purpose and two gave qualitative input without filling in the questionnaire. Three key informants contributed to the questionnaire and gave additional qualitative inputs. Three key informants who were approached indicated from the outset that they were, due to the sensitivity of the unconventional oil and gas extraction issue, or lack of sufficient knowledge on the issue, not prepared to contribute inputs to the study. The profile of all key informants is presented in Table 47.

Table 47: Profile of key informants

Profile	Number of informants approached	Number of key informants contributing inputs
Academia (social scientists)	4	3
Agricultural economists	2	2
Environmental consultants	5	4
Human geographer	1	1
PED specialists (international NGOs)	2	1
Total	14	11

Due to the sensitive and politicised nature of unconventional oil and gas extraction in South Africa some of the key informants were reluctant to permit their identities to be revealed. As a result, it was decided to treat all responses anonymously in order to adhere to ethical research practices (Maree and Van der Westhuizen 2010).

To achieve the objective of this phase of the study, namely, selection of appropriate indicators for mapping purposes, a structured questionnaire was developed in which key informants had to indicate the appropriateness of proposed indicators for mapping of socio-economic vulnerability. The questionnaire included scale-based questions through which key informants had to indicate the extent to which they deemed the presented indicators appropriate for inclusion in the vulnerability map, on a scale of 1 to 10. For each of these scale-based responses a follow-up question was asked in which key informants had to supply reasons for their answer to the scale-based questions.

Thus, for the socio-economic indicator selection, the eventual decision of indicators to be included for mapping was based on a quantitative analysis of scale-based data and a qualitative analysis of expert opinion given on the questionnaire and through telephonic interviews. Due to time and budget constraints, face-to-face interviews were not conducted, but the study relied on the use of e mail and telephonic interviews.

An analysis of key words and themes that emerged during an NVivo analysis can be seen in Figure 24. Words in larger font denote words that were more often mentioned in the completed responses and are related to importance given to specific issues as identified by respondents.

Figure 24: Word cloud socio-economic indicators

Table 48 outlines the results obtained from scale-based questions.

Table 48: Quantitative results from indicator selection questionnaire

	N		Mean	Median	Mode	Std. Devia-tion	Min	Max	Main themes supporting use of indicator	Main themes not supporting use of indicator
	Valid	Mis-sing								
% population dependent on groundwater	9	0	9.56	10	10	0.88	8	10	Communities in the Karoo basin are very dependent on groundwater. There are no alternative water sources.	All respondents viewed this as an important indicator.
% of population under five years of age	9	0	6.89	7	7	2.93	2	10	These two age categories are more vulnerable to adverse environmental impacts than other age groups. These are good indicators of vulnerability to environmental change.	None identified
% of population over 65 years of age	9	0	7	7	7	2.92	5	10		
% of population employed by agriculture	9	0	8	8	8	1.8	3	10	The agricultural sector employs a large number of unskilled / semi-skilled workers who will not necessarily be absorbed into the oil and gas sector.	The indicator is only appropriate if agriculture actually employs a significant number of adults.
% of population employed by tourism and conservation sector	9		6.67	6	6	2.5	3	10	This indicator can give and indication of the sense of place, which is difficult to measure quantitatively.	It might be speculative to ascribe changes in this sector to oil and gas operations in the affected area unless other variables can be controlled and accounted for.
Population density per district municipality	9	0	7.68	8	8	2.18	3	10	This is an obvious indicator to indicate vulnerability to unconventional oil and gas mining (extraction).	Developers often say that if there are no people there is no social impact – land use of the area is important for this instance.
Sex ratio per district municipality	9	0	6.11	6	5	2.26	2	10	A disproportionate % of females may point at greater vulnerability to impacts.	If this indicator is used, other variables need to be controlled carefully. There are other stronger indicators for gender disparities.

Based on the above analysis, and triangulated with the qualitative inputs from key informants, the indicators that were subsequently selected are presented in Table 49.

Table 49: Selected indicators for mapping socio-economic vulnerability to unconventional oil and gas extraction

Indicator	Substantiation for the inclusion of this indicator
Population	
Population density per area	This is considered an important and obvious indicator by the majority of key informants, based on the analysis of responses on the appropriateness scale. The majority of the respondents rated the appropriateness of this indicator as high – 88.9% of the key informants rated this indicator between 6 and 10 on the given scale.
% of population under five years of age per area	The majority of key respondents regarded this as a very appropriate indicator with which to inform a socio-economic vulnerability map, since it indicates vulnerability to environmental change. This indicator is linked specifically to groundwater and air pollution, since respiratory diseases and water-borne diseases are among the main causes of death in children under five. In analysing the data it was decided to only use children under five as an indicator, since the category 65 and older may not present a strong indication of vulnerability. There is much more variance in the responses given to the appropriateness of the proportion of people under five and over 65 as indicators. However, 77.7% of key informants rated the proportion of under five and the proportion of the population over 65 between 6-10 on the scale. In subsequent interviews with key informants, however, it was pointed out that the proportion of children under five is a strong enough indicator of age-related vulnerability and that the proportion of people over 65 will therefore be superfluous.
Environment	
% of population dependent on groundwater per area	Groundwater dependence was indicated as a very appropriate indicator by all key informants. In fact, it is by far the strongest indicator of socio-economic vulnerability based on the analysis of the scale-based data, with 77.8% of the key informants rating this indicator 10 on the scale and the remaining 22.2% of key informants rating it as 8 on the scale presented to them. The key informants indicated that especially rural and farming communities are very dependent on groundwater for domestic purposes. Furthermore, people who are fully reliant on groundwater as a domestic source of water do not have other options in terms of water access. This makes groundwater dependence a vital indicator of socio-economic vulnerability to unconventional oil and gas mining (extraction). In measuring groundwater dependence, the focus will fall thus on groundwater dependence for domestic use only.
Development	
% of population employed by agriculture per area	The appropriateness of this indicator is summed up by the following quote from one of the key informants: "Employment may serve as a proxy indicator for economic trends in the agricultural sector, e.g. a drop in employment rates might point at an exodus of commercial farmers due to changing or hostile farming conditions, such as a decline in available groundwater or an increase in polluted water". It was also pointed out that agriculture employs large numbers of unskilled and semi-skilled people who will not be absorbed into the unconventional oil and gas mining (extraction) sector when this activity impacts on agricultural productivity, since their skills are not compatible with the employment requirements for unconventional oil and gas mining. 88.9% of the key informants rated this indicator 6-10 on the appropriateness scale.
% of female headed households per area	The proportion of female-headed households in a community was suggested by some of the key informants as a possible indicator of vulnerability. Key informants argued that South Africa is an unequal society in which the marginalised often bear the brunt of socio-economic problems and therefore it would be unjust to allow fracking in areas where inequalities already exist. It was further pointed out that this indicator is a more precise indicator than the sex ratio, as it is directly informative of social and economic vulnerability in poverty-stricken areas. Areas where there are high numbers of female-headed households may be more vulnerable to the impacts of unconventional oil and gas mining (extraction), due to women being more vulnerable to rising economic inequality, the spread of HIV and increased social ills such as rape and prostitution, which are brought about by the influx of money and workers into an area.

Table 50 presents an analysis and discussion of the indicators that were not selected for inclusion in the vulnerability map.

Table 50: Indicators not selected for inclusion in the vulnerability map

Indicator	Substantiation for not including this indicator
% of population employed by tourism and conservation sector	Key informants were of the opinion that there are too many factors impacting on trends in tourism and conservation, therefore it might be speculative to ascribe changes in this sector to oil and gas operations in the affected area, unless other variables can be controlled and accounted for. While this indicator can provide an indication of the sense of place, this will be difficult to measure quantitatively. One of the key informants also indicated that the presence of mines in the Northern Cape, for example, did not significantly affect the tourism sector, since this sector was small even before mining (extraction) commenced. The areas where fracking is proposed are not major tourism destinations; therefore this indicator will not adequately point out socio-economic vulnerability with regards to the impacts of fracking.
Sex ratio	Key informants were of the opinion that, while a disproportionate number of females may indeed point at greater vulnerability, there are stronger indicators to use for the purpose of highlighting socio-economic vulnerability to the impacts of this activity for vulnerable groups such as women. It was pointed out by key informants that female unemployment or female-headed households may be more precise indicators of vulnerability.
Sense of place	In consultation with key informants, the possibility of including sense of place indicators was explored. Sense of place relates to perceived attachment of communities to the areas in which they live. Key informants pointed out that, while it is an important aspect of the socio-economic environment, it would be difficult to quantify and present spatially by using existing data. Some databases such as the National Income Dynamics Survey (NIDS) do include indicators that measure social cohesion and sense of place, but the data on these data sets are only available at a provincial level. One key informant noted that aesthetics (character of existing landscape: farmscapes, forests, industrial, etc.) can only be understood by doing in-depth studies in communities affected by unconventional oil and gas mining (extraction), but that it will not serve the purpose of the study to project how people's attitudes and perceptions about their environment will be affected by unconventional oil and gas mining (extraction).

Data management

For the purposes of this study, various data sources and data management options were suggested. Initially it was decided to rely mainly on South African Census data that was performed in 2011, supplemented by data from the South African Community Survey that was performed in 2007 as the preferred data sources for the mapping of socio-economic indicators. The primary reason for this was that these data sources complied with the criteria for inclusion into the vulnerability map as discussed earlier. The criteria applicable here were that data had to be available for the whole of South Africa for the selected indicators and that the data had to be in a format that was spatially presentable. During the course of the study, it was suggested that the possibility of using other spatial data sources, such as the GAP dataset, be explored.

The GAP dataset is a spatial dataset that is built on spot counts (as produced by the CSIR and Eskom in 2008) based on an inventory of all classifiable buildings in South Africa and points on the map are weighted to represent a potential contribution to the point in question. This contribution was based on average household size in South Africa (CSIR 2010). The possibility of using this data set was explored by firstly testing the interpretive validity and perceived trustworthiness of this data set by expert opinion. Socio-economic experts were reluctant to use this data set for the mapping of socio-economic vulnerability because of two primary reasons. Firstly, two experts that specifically deal with decision-makers at a governmental level emphasised that if the vulnerability map was to be used to inform decision-making on unconventional oil and gas mining, it would be prudent to rather use the official census data as the primary data set for this study, since this is regarded by government as the official data source to inform decision making. In addition to the views expressed by these two key informants, a third key informant warned that it will be difficult to explain why data based on a sample, and resting on various assumptions and extrapolations, is more reliable than data obtained from a nation-wide census that was conducted as recently as 2011.

However, the GAP data set was compared with the data from the recent census to determine to what extent this data set is supported by census data. For this purpose the assistance of an expert in indicator analysis (Mr Jan Cloete, CDS) was sought and a comparison was drawn between the data of the GAP data set and that of the census. The analysis revealed that there are significant differences in the data on the GAP dataset and the census data. The conclusion of this expert was that the GAP data set leaves room for too much uncertainty and that the census dataset would still be a better data set to use for the purposes of this study.

Table 51: Comparison between GAP and census datasets

	Area	Number of households	Population size
Min	-14.47	-51.80	-52.81
Max	4.83	38.26	59.15
Avg	-0.18	-17.08	-6.48
Std Dev	1.70	12.16	16.20

Source: Cloete 2013.

As seen in Table 51 the area data is similar when the two data sets are comparted (standard deviation of 1.7%). When the number of households is compared, however, there is a standard deviation of 12.16%, and for population size a standard deviation of 16.2%. Taking the discrepancies between the two sets of data and the preference of decision-makers for census-based data into consideration, the census data is therefore deemed to be the more appropriate source of data for the purposes of this study.

4.2.5.2 Indicator classification and weighting

After indicators for the study were decided upon, the next phase of the study was to determine the classification of indicators into classes of vulnerability. Based on the literature review and initial consultation with two key informants, a preliminary vulnerability classification was developed for each selected indicator. This preliminary classification was then presented to those key informants who indicated that they would contribute to this phase of the study. Nine of the 11 experts agreed to contribute their inputs to the vulnerability classification and a follow up questionnaire was sent to these experts.

This questionnaire comprised scale-based questions on the extent to which the proposed classification was appropriate (on a scale of one to 10). For each of the indicators' vulnerability classifications, experts were also asked to provide reasons for their answer to the scale-based question and if they did not think that the classification was appropriate to indicate an alternative classification. The scales were recoded into two categories during analysis of the data: responses on the scale ranging from 1-5 (not an appropriate classification) and responses on the scale ranging from 6-10 (appropriate classification). The results of this part of the study are presented in Table 52. From this table it transpires that most of the respondents rated the classification scheme suggested as appropriate. The only classification that was not tested in this questionnaire was groundwater dependence for domestic purposes. This classification was discussed separately with key informants during telephone and e mail interviews due to the fact that there was, at the time of distributing the questionnaire, uncertainty on how the indicator had to be approached. All key informants consulted indicated that the proposed vulnerability for groundwater dependence for domestic purposes was appropriate.

Table 52: Results from vulnerability classification questionnaire

	Not an appropriateclassification %	An appropriate classification %
Population density	12.5	87.5
Children under five years	42.9	57.1
Groundwater dependence for domestic use	Telephonic calls / e mail correspondence: Key informants were satisfied that this is a fitting classification	
Agricultural employment	25	75
Female-headed households	28.6	71.4

Based on the result of this questionnaire it was decided to maintain the initial classification that was proposed. Vulnerability classifications for the different indicators as well as example maps that relied on these classifications are presented below.

Table 53: Vulnerability classification – Population density

	Description	Number of people per sq km
1	Very low vulnerability	0-10
2	Low vulnerability	11-50
3	Medium Vulnerability	51-100
4	High vulnerability	101-500
5	Very high vulnerability	>500

A map using this classification can be seen in Figure 25.

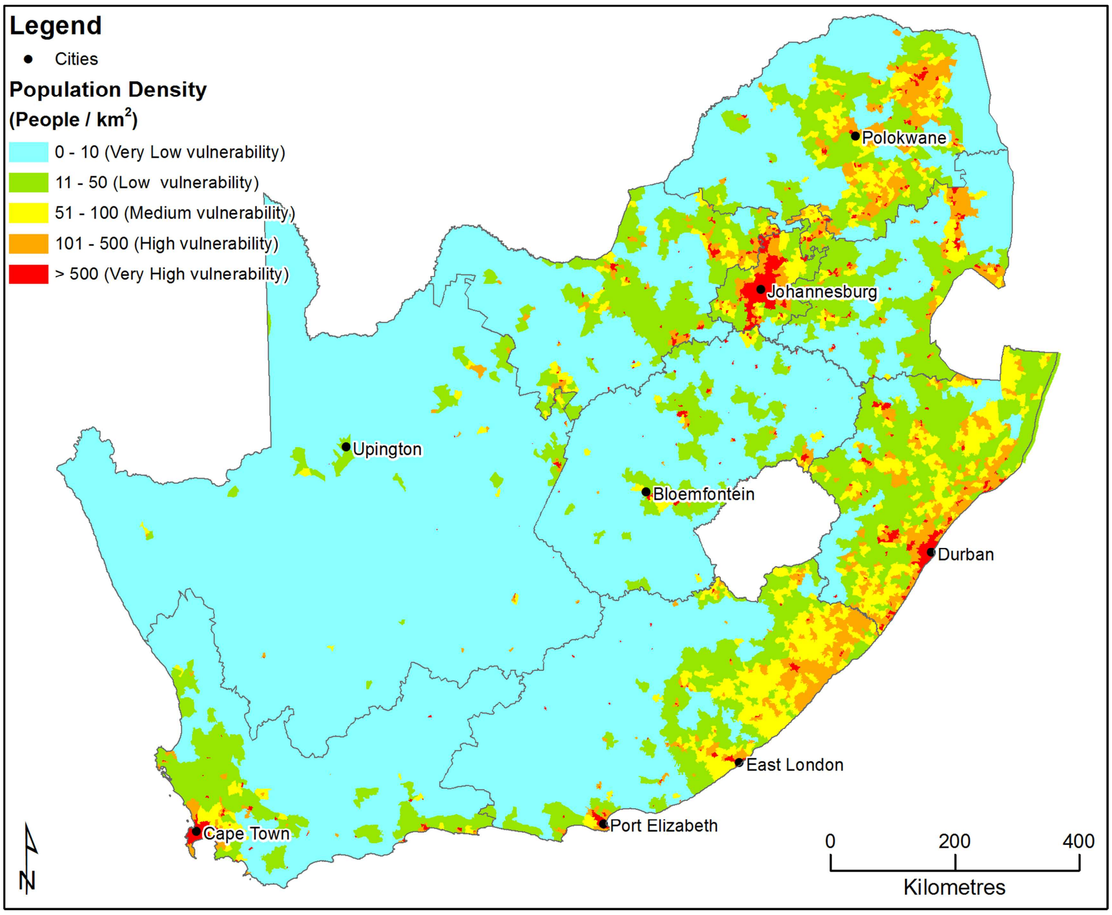

Figure 25: Population density

Table 54: Vulnerability classification – Percentage of children under five years per area

	Description	% of children under 5 per area
1	Very low vulnerability	<11.49
2	Low vulnerability	11.5-12.49
3	Medium Vulnerability	12.5-13.99
4	High vulnerability	14-15.49
5	Very high vulnerability	>15.5

A map using this classification can be seen in Figure 26.

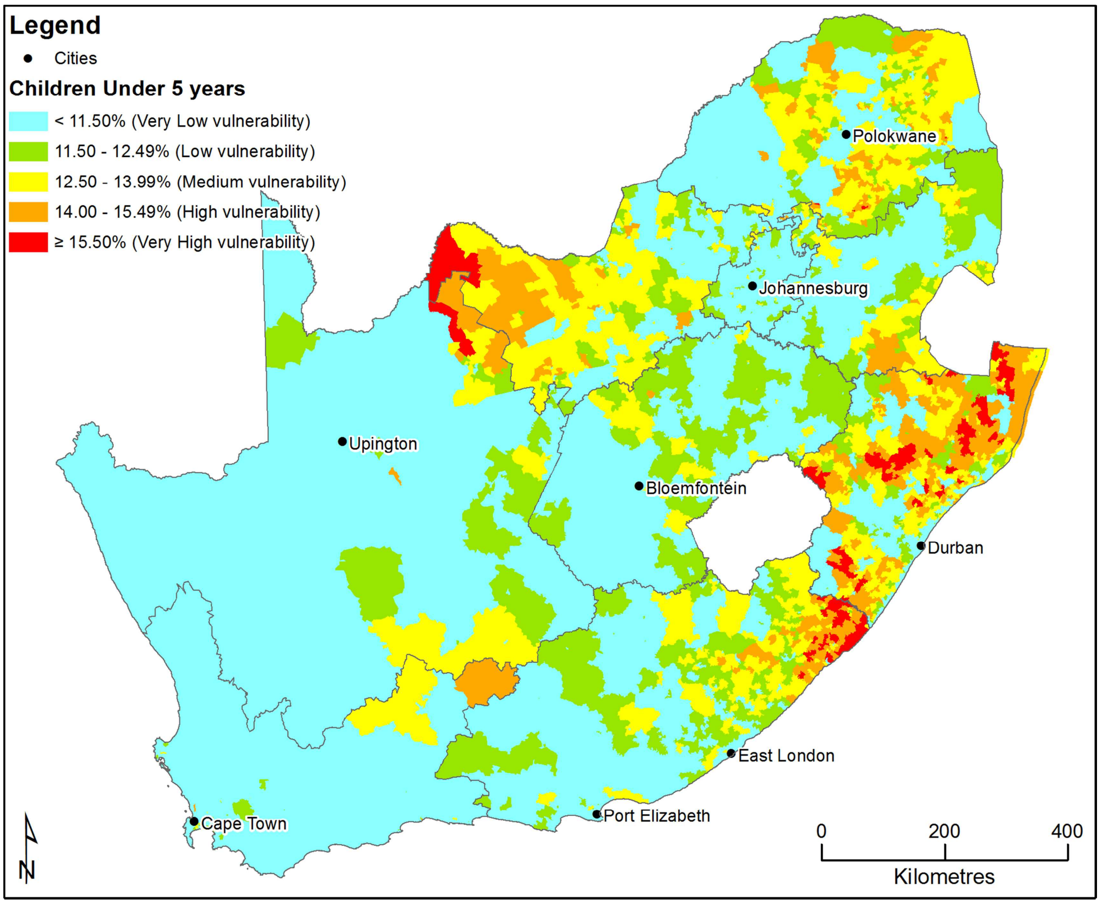

Figure 26: Percentage of children under five years per area

For the indicator of groundwater dependence for domestic use, a more complex methodology had to be devised, since the available data was not presented in a way that served the purposes of this study. For this indicator, various datasets were considered for use. The Statistics South Africa (StatsSA) data that was gathered during the 2011 census was deemed most appropriate and relevant for indicating population dependency on groundwater as a resource. The StatSA data indicates whether a person obtains his household water from springs, boreholes or municipal supply. Unfortunately, where water supply on the StatsSA data is indicated as municipal supply, the water source (groundwater or surface water) of the municipality is not indicated. Data from Fourie (2013) that listed towns' water sources as Combined (a mixture of surface water and groundwater), Groundwater use or Surface water use for selected towns, were used in conjunction with the StatsSA data. These towns were mapped as points using latitude/longitude from the DWA dataset. Secondly, voronoi polygons were created for each of the plotted towns. These voronoi polygons were intersected with the data on the municipal wards, which depicted the percentage of people in the ward dependent on water supplied by a municipality or water board. Intersected polygons had a ward ID and for each ward the percentages made up of Combined groundwater use, Groundwater use and Surface water use were calculated. After this, the percentages of people dependent on springs and boreholes from the Census 2011 dataset (StatsSA) were calculated. Finally, the percentage of people dependent on springs and boreholes were added to the percentage of people dependent on water from a regional or local water scheme, where the scheme's water source was groundwater. The final map for groundwater dependence for domestic purposes from either municipal supply, boreholes or springs is shown in Figure 27. The confidence in this data is not high and this layer must be updated in future with for instance more detailed town water use information from the Alltowns studies (e.g. the percentages of town water supply from surface water and groundwater vs. basic information that just indicates if the town uses mainly surface water, mainly groundwater or a combination of the two). Ideally, a survey must be performed to ensure the verification all municipal water sources.

Table 55: Vulnerability classification – Groundwater dependence

	Description	% of population dependent on groundwater as a domestic water source
1	Very low vulnerability	0-10%
2	Low vulnerability	11-20%
3	Medium Vulnerability	21-30%
4	High vulnerability	31-50%
5	Very high vulnerability	=>51%

The map for this classification can be seen in Figure 27.

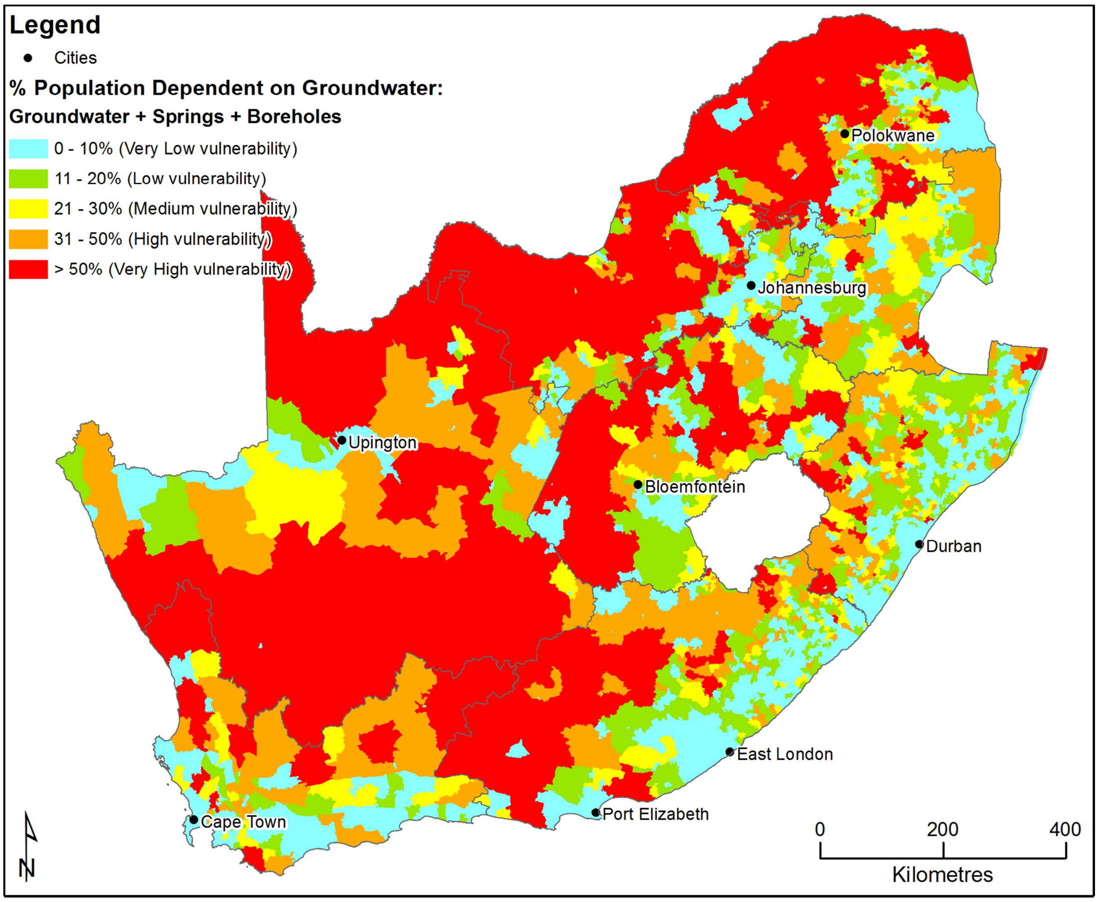

Figure 27: Groundwater dependence for domestic use

Table 56: Vulnerability classification – Agricultural employment

	Description	% of the population employed by agriculture per area
1	Very low vulnerability	0 -1.99%
2	Low vulnerability	2-3.99%
3	Medium Vulnerability	4-7.99%
4	High vulnerability	8-15.99%
5	Very high vulnerability	>16%

A map using this classification can be seen in Figure 28.

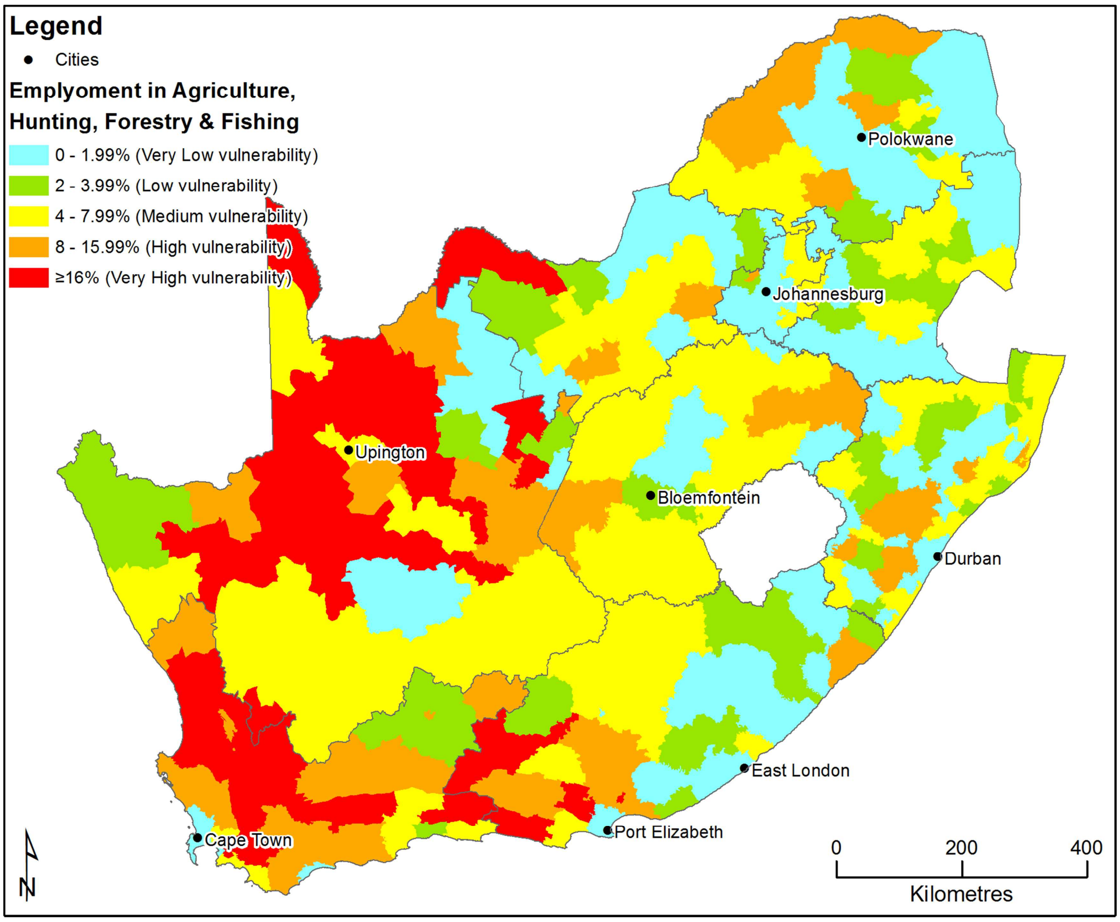

Figure 28: Percentage of people employed by agriculture per area

Table 57: Vulnerability classification – Female-headed households

	Description	% of female-headed households per area
1	Very low vulnerability	<36%
2	Low vulnerability	37-40%
3	Medium Vulnerability	41-45%
4	High vulnerability	46-50%
5	Very low vulnerability	≥51%

A map using this classification can be seen in Figure 29.

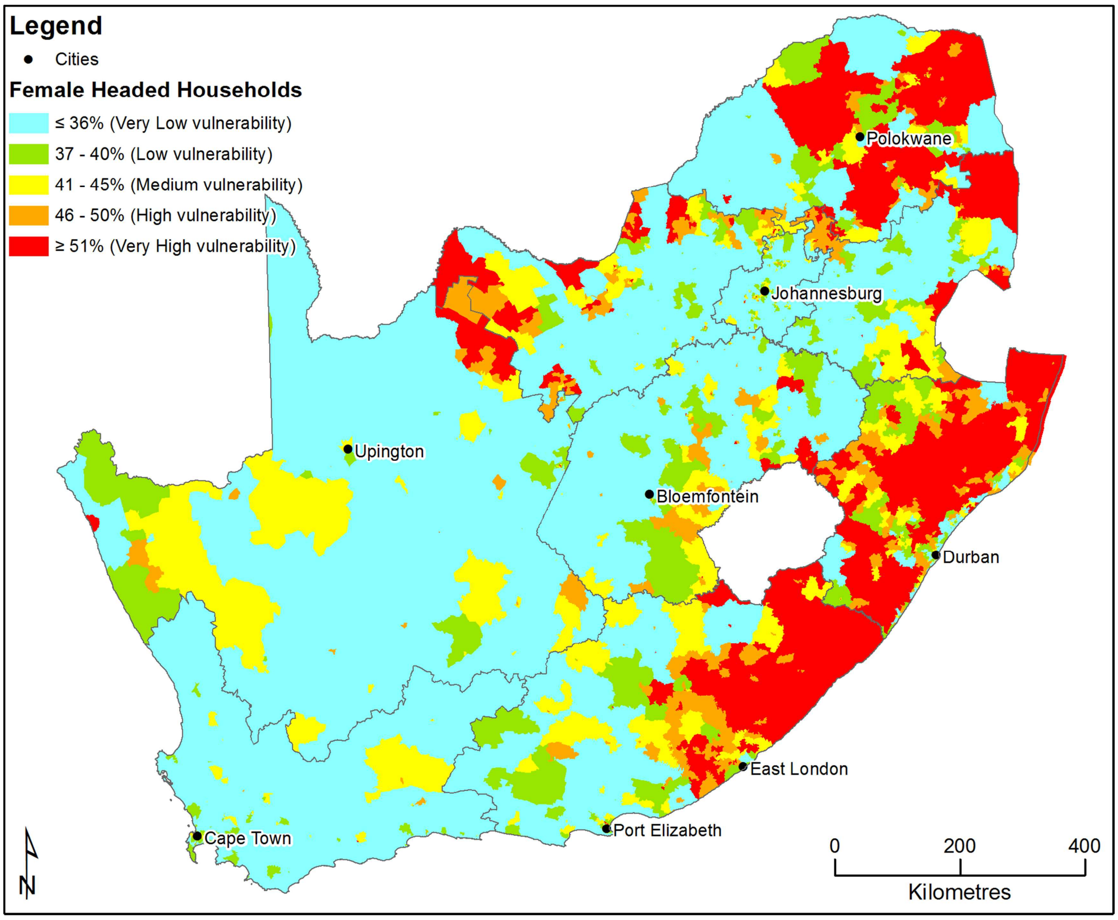

Figure 29: Percentage of female-headed households per area

A budget allocation weighting approach was followed in the weighting of the indicators. Exploratory interviews were conducted with key informants to devise a weighting scheme. Based on these interviews, the weighting of indicators proceeded from the premise, established through key informant input, that groundwater dependence is one of the key determinants of socio-economic vulnerability where unconventional oil and gas mining (extraction) is concerned. Flowing from this, the percentage of children under five years was also regarded as important, due to the strong linkages between water pollution and the health of this vulnerable age group. Key informants also pointed out that the percentage of people employed in agriculture and the percentage of female-headed households were of more concern than population density. Thus, the following weighting was proposed to the key informants, who agreed to contribute to this component of the study. For this purpose, e mails were sent out and telephonic follow-up was conducted (Figure 30).

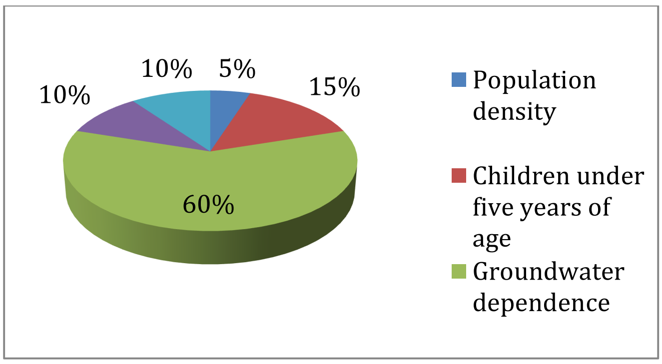

Figure 30: Proposed weighting of socio-economic indicators

In total, seven of eight key informants approached responded to the request to give inputs on the weighting of the indicators. Table 58 indicates the responses obtained from key informants regarding the weighting of the socio-economic indicators.

Table 58: Responses from key informants on weighting of indicators

Respondent 1	Agreed with the weighting
Respondent 2	Agreed with the weighting
Respondent 3	Agricultural employment should weigh more than female headed households (15% for agricultural employment and 10% for female headed households)
Respondent 4	Agreed with the weighting
Respondent 5	Groundwater dependence must weigh the most, since it is (according to expert concerns) where the greatest impact will be (40%) Agricultural employment should weigh 30%, since fracking has a potentially high impact in economic terms Children under five years; population density and female-headed households should have equal weighting (10%) due to potentially speculative and relative nature of these impacts
Respondent 6	Agreed, but with 5% more given to agricultural employment and 5% less for children under five years.
Respondent 7	Agreed, but with a greater weight given to agricultural employment

Based on the responses above, it can be deduced that all respondents agreed that groundwater dependence should weigh the most in the final vulnerability map. However, agricultural employment should be weighted more heavily than is currently the case, while the other indicators should weigh less. Population density should weigh the least in the final map. Based on the analysis of the data above, the following weighting (Figure 31) was applied.

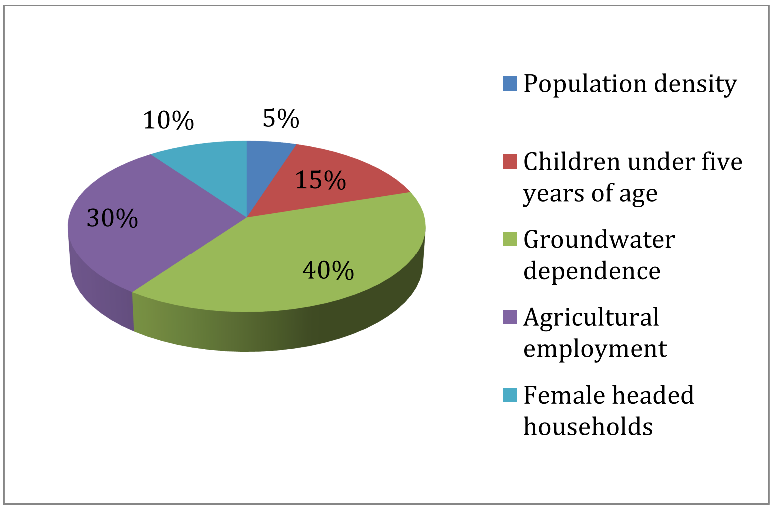

Figure 31: Final weighting of socio-economic indicators

4.2.5.3 <u>Vulnerability map</u>

The socio-economic theme of the vulnerability map in the browser includes the following base layers at the specified weight percentages (Table 59).

Table 59: Socio-economic theme base layer weighting percentages

Indicator	Weight
Population density	5%
Children under 5 years	15%
Groundwater dependence	40%
Feale headed households	10%
Employment	30%

These base layers have been aggregated multiplicatively into an aggregated map for socio-economic vulnerability since scatterplots, multiple correspondence analysis and principle component analysis showed interaction between the different indicators. A scatterplot of raw percentages can be seen in Figure 32.

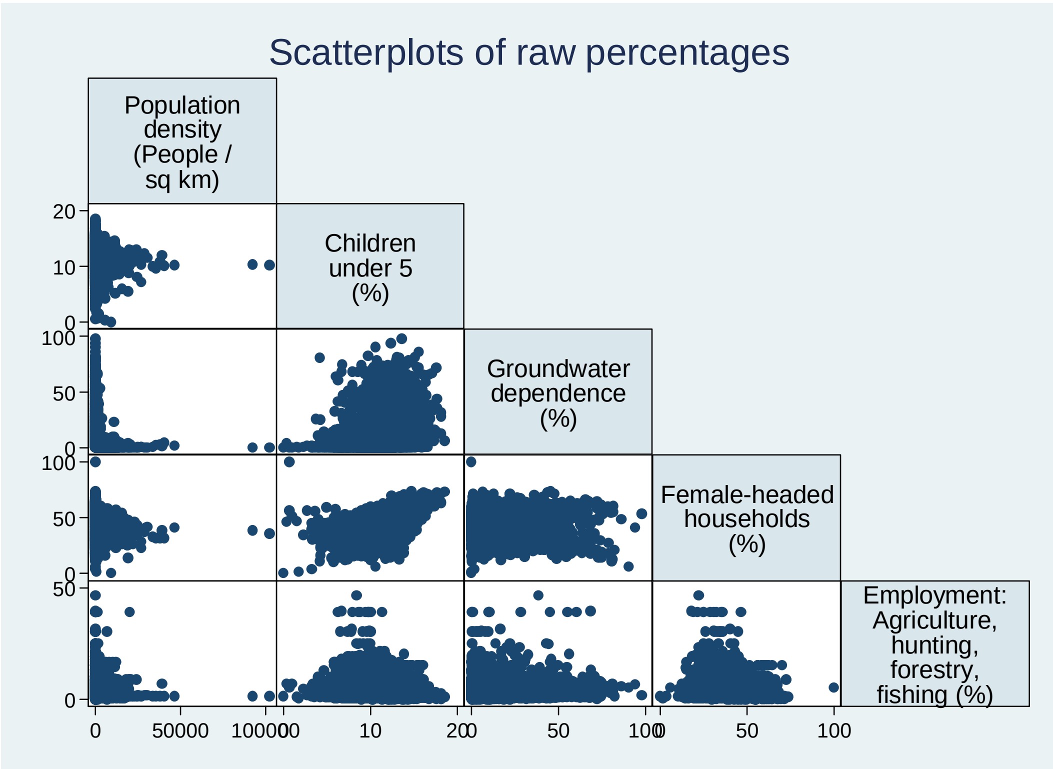

Figure 32: Scatterplot of socio-economic indicators

The raw data is highly correlated in some variable-pairs; as can be seen in the scatterplot matrix above. The most obvious relationship is present in the population density and groundwater dependence plot, with wards more dependent on groundwater exhibiting lower population density (but not necessarily *vice versa*). Another notable relationship is that wards with high proportions of female-headed households also have larger proportions of children under the age of 5 years. Principal component analysis results (Table 60) indicate rural/urban relationships.

Table 60: Principal component analysis on the 5 socio-economic indicators

```
. pca pop_dens under_5 gw_dep f_hhh empl_out

Principal components/correlation                 Number of obs    =      4277
                                                 Number of comp.  =         5
                                                 Trace            =         5
    Rotation: (unrotated = principal)            Rho              =    1.0000
```

Component	Eigenvalue	Difference	Proportion	Cumulative
Comp1	1.84199	.573753	0.3684	0.3684
Comp2	1.26823	.441166	0.2536	0.6220
Comp3	.827068	.0835325	0.1654	0.7875
Comp4	.743536	.424363	0.1487	0.9362
Comp5	.319173	.	0.0638	1.0000

Principal components (eigenvectors)

Variable	Comp1	Comp2	Comp3	Comp4	Comp5	Unexplained
pop_dens	-0.3143	-0.4870	0.5816	0.5609	0.1055	0
under_5	0.6360	-0.1232	0.3106	0.0576	-0.6932	0
gw_dep	0.3474	0.5271	-0.1175	0.7303	0.2331	0
f_hhh	0.6004	-0.3017	0.1921	-0.2508	0.6698	0
empl_out	-0.1245	0.6154	0.7173	-0.2930	0.0734	0

The PCA analysis summarises the variation in the continuous data in as few dimensions as possible. Essentially, around 37% of the variance in the original data can be attributed to a new variable, which we can call ”social structure”. This variable weighs the proportion of children under 5 and the proportion of female-headed households highly, with a contrast against population density.

Around 25% of the variance in the original data can be attributed to the second principal component, which we can call a “rural index”. The variable contains a high weight for outdoor employment and groundwater dependence, with a contrast once more against population density. The third component seems to be a measure of “population activity”. It weighs population density and employment outdoors highly. It covers about 16.5% of the variation in the original data.

From these principal components we can get a sense of the linear inter-relationships that are present in the data. We see once more that there is a definite correlation amongst variables that indicate rural/urban status, and vulnerabilities of social structures are interdependent.

Based on the above analyses, the indicators of socio-economic vulnerability were aggregated multiplicatively on the interactive map.

Socio-economic map overlays

Overlays of the SKA no go areas (data source: Tiplady, 2013) as well as groundwater government control areas (data source: DWA, 2013c) are included on the socio-economic vulnerability map.

The user will be able to switch these overlays on or off and will be able to see information related to these datasets when he or she browses over a map element in the overlay.

4.3 Concluding remarks

The interactive vulnerability map that was developed allows the end user free access to and visualisation of vulnerability within a particular location, through spatial data on vulnerability and sensitivity of selected mapping themes covering surface water, groundwater, seismicity, vegetation and socio-economics. For each of these themes there are base layers as well as overlay maps.

The base layer maps have been classified into the five classes of vulnerability, namely, very low vulnerability, low vulnerability, medium vulnerability, high vulnerability and very high vulnerability. Overlays contain extra information relevant to each mapping theme but have not been classified into five classes of vulnerability.

This section of the report described the process for identifying indicators that indicate vulnerability to unconventional oil and gas extraction for each mapping theme. It also described the process followed for classifying and weighing of indicators that represent the base layers in each mapping theme.

All the entities on the interactive vulnerability map are clickable and a popup window gives relevant information for the entity on which the user clicks. The user can search the map either by zooming and panning, or by using a search window, which allows the user to search quaternary catchments or towns.

The map should be viewed as a living document that should be updated as new or more accurate information becomes available. Updating the map will ensure more efficient management of the entities that have been mapped.

Efforts were made to select nationally acceptable datasets during the development of these maps and to adhere to strict quality standards. None of the parties involved in creating these maps guarantee the accuracy of information provided by external sources and the parties accept no responsibility or liability for any consequences arising from the use or misuse of such data.

5 MONITORING PROTOCOL

Performing monitoring of various entities before exploration, during exploration, during extraction and after extraction is important to assess changes in these entities due to the unconventional oil and gas extraction process. The background review section of this report, illustrated various possible impacts of concern. Monitoring of certain entities can address some of the concerns and identify possible problems timeously.

The protocol should be viewed as a provisional screening level monitoring protocol and can be used as a guideline for planning monitoring activities during the various phases of unconventional oil and gas extraction. The objective of this part of the report is to identify the important entities to be monitored and discuss means of monitoring for selected entities (surface water, groundwater, seismicity, vegetation and socio-economics). Although the list of entities discussed in this monitoring protocol is not exhaustive, it could assist government in monitoring the entities of most concern.

Section 5.1 discusses the monitoring approach, limitations of the approach as well as the suggested protocol for the selected entities. Various concerns (discussed under Section 5.1) influence the choice of monitoring approach and legal and governance considerations (discussed under Section 5.2) also influence who should perform monitoring as well as administrative issues related to data collection, storage and dissemination. A few limitations of monitoring approaches are discussed in Section 5.3 and the proposed monitoring protocols for selected entities are discussed in Section 5.4. These aspect-specific protocols are in many ways proposed monitoring protocols based on current information related to impacts and current international monitoring approaches. Monitoring approaches may well change in future depending on advances in technology and this should be borne in mind when applying any recommendations contained in this report. Examples of advances in technology are increasingly sensitive remote sensing techniques as well as data processing techniques related to computing capacity increases.

5.1 Monitoring protocol approach, preferred model and monitoring framework

Various approaches can be followed during monitoring exercises. The monitoring approach followed would depend on the type and scale of the activity or process being monitored. Before deciding on a specific approach, it is important to consider the type of activity that is to be monitored.

For unconventional oil and gas extraction the following aspects are important:

- The time frame of the activity may range over a long period, and unconventional oil and gas is mined and developed in a phased approach. This means that monitoring would ideally also need to follow a phased approach.
- Concerns that have been identified for each phase of the oil and gas development process indicate that certain monitoring activities need to start before exploration. This is especially relevant in the case of monitoring of groundwater and seismicity.
- The regional scale of possible impacts makes integrated, systematic, standardised monitoring across regions very important, and necessitates integration between local and provincial government, alignment and cooperative governance between different government departments, alignment between different pieces of legislation, amongst others, to make monitoring efforts successful.
- The failure to align legislation and clearly identify mandates, roles and responsibilities for government entities as well as acknowledging the regional and cumulative scale of the possible impacts, may necessitate the development of a central entity to perform these functions in an integrated and coordinated fashion. Existing government structures may be re-aligned or academia can assist in the execution of these functions.
- It is important that the monitoring entity be independent and be perceived as being independent from oil and gas companies, and also perform the monitoring task in such a manner that it will have legal standing. It is thus of utmost importance to ensure that laboratories used for analyses must have SANAS accreditation.
- Monitoring by oil and gas companies as part of their operations would also be required as part of the protocol. Strict reporting requirements to government and/or the independent monitoring institution should be in place and the aspects monitored by oil and gas companies should be verified by independent monitoring.

Taking the above aspects into account, it is thus clear that regardless of the monitoring model followed, it should consider as far as possible, the aspects highlighted above.

5.1.1 Monitoring approach and preferred model

Possible monitoring models could be the following:

1. Government monitors all aspects (from oil and gas company operations through to regional aspects);
2. The industry is allowed total self-regulation and monitors all aspects and reports to government;
3. An independent entity monitors all aspects; and
4. A hybrid model can be followed, for instance:

- The oil and gas companies monitor their technical day-to-day operations and local aspects and report to an independent monitoring entity (and/or government) via strict regulatory requirements.

- An independent entity monitors regional aspects (such a body can include academia or a group from academia and other stakeholders), receives oil and gas company on-site monitoring information, does independent verification monitoring on specific sites, interprets data and reports to government. This entity can also serve as a central body for receiving information from monitoring of various aspects and coordinating between different government departments.
- Government monitors compliance with reporting and can receive information from both the oil and gas companies and any independent monitoring body. The role of government is to review monitoring data, act upon recommendations from the independent monitoring body and draft or amend legislation and regulations as required.

There are some clear shortcomings to the first two models:

Government may not have institutional capacity and human resources to perform all the monitoring, but if oil and gas companies perform total self-regulation, data may not be trustworthy if there is no independent verification. If an independent entity does all the monitoring, the public may also have concerns about giving one entity total control without verification of *this* entity. The most suitable model may be a hybrid model as suggested above, where different parties have different monitoring responsibilities and there are various levels of cross-verification. This model would require a totally transparent regulatory framework and consistent application of rules and regulations.

5.1.2 Monitoring protocol framework

The framework that will be followed for this monitoring protocol will be two-pronged. Firstly, the framework will have to address the main questions usually asked in a monitoring protocol, which include:

1. Why do we want to monitor?
2. What do we need to monitor?
3. How will you monitor?
4. Where do we need to monitor?
5. When do we need to monitor?
6. Who needs to do the monitoring?

Additional aspects that need consideration include data management as well as quality assurance and quality control. This framework is illustrated in Figure 33, and is adopted from Wilderman and Woodword (2010).

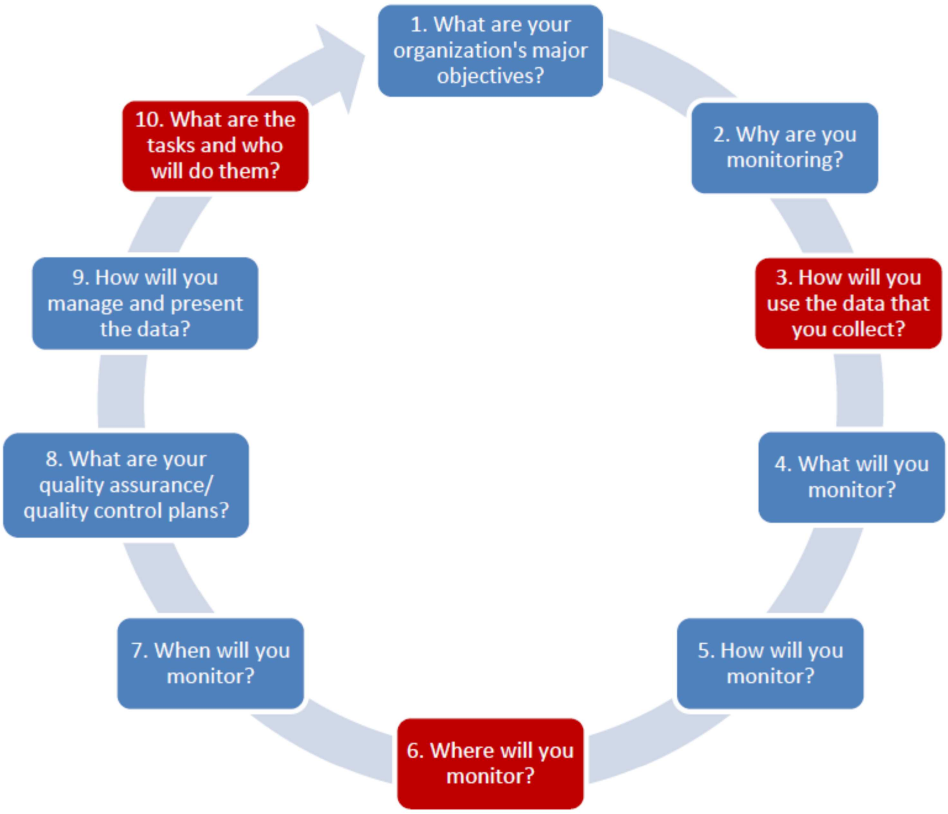

Figure 33: Illustrated monitoring framework

Secondly, in order to take into account the phased approach of unconventional gas development, these questions will be addressed for each phase, as follows:

- Before exploration
- During exploration
- During extraction
- After extraction

Thus the question relating to when monitoring for each of the selected entities should take place will be discussed in the relevant section of this document for each of the different phases (before exploration, during exploration, during extraction and after extraction).

The first five questions of the framework are usually easy to answer, but the last question (who will do the monitoring), may require more in-depth analysis. In cases where it is possible to suggest appropriate bodies to monitor certain entities, this information will be given in the monitoring framework of each entity. In cases where it is not possible to identify appropriate bodies to perform the monitoring, a general discussion will be given in the relevant section. Certain laws in South Africa identified certain departments as the responsible authority to perform monitoring as part of their mandate. These aspects will also be discussed under Section 5.2 (Legal and governance considerations). The hybrid model proposed is by no means the final model to be used and various forms of hybridisation may occur, depending on the capacity and competency of various departments and entities that will perform monitoring that will have legal standing in court.

Data management

The question of data management is not a trivial question. At this stage each department is responsible for the data management related to its respective mandate. The Department of Water Affairs is the custodian of water resources and protection and the related storage of water resource information (such as geological information, borehole logs, water quality data etc.). The Council for Geoscience is responsible for data management and storage (and archiving) of geology-related information, including mapping information as well as seismic data. The data from government departments are open to the public and academia at no cost; however, data from the Council for Geoscience is not free and must often be bought at extremely high costs. Some information may also be classified as sensitive, making access to information problematic.

In order to ensure proper management of monitoring activities before, during and after unconventional oil and gas extraction, it is imperative that data be available from all spheres of government, for amongst others proper assessment of the cumulative impact of unconventional oil and gas extraction on a regional scale as well as for research purposes. If cooperation between government departments and the effective dissemination of data would be problematic, then serious consideration should be given to an independent entity to perform the task of accepting and storing data, as well as to ensure dissemination of data.

Quality assurance and quality control

Quality assurance and quality control is very much related to the monitoring requirements of each entity and will therefore be discussed under the monitoring protocol for each entity.

5.2 Legal and governance considerations

This section discusses legal and governance considerations related to monitoring of the extraction of unconventional oil and gas. Various aspects are addressed in this section, amongst others the role of international law in South Africa, the interaction of different pieces of legislation related to the monitoring of selected media and areas of concern (surface water, groundwater, vegetation, seismicity and socio-economics), the mandates of different South African departments for performing specific monitoring functions, and the feasibility of forming a central independent body to monitor unconventional oil and gas extraction. These aspects relate to questions about the execution of the monitoring programmes for the aspects for which monitoring protocols have been discussed.

In considering governance and legal aspects, a useful starting point is the international perspective. Thereafter, an examination of the local context must begin with a review of the *Mineral and Petroleum Resources Development Act 28 of 2002* (*MPRDA*), the act responsible for issuing mining and petroleum resource rights. The *Constitution of the Republic of South Africa (Act* 108 of 1996) (the *Constitution*), with its environmental right is also a crucial enactment, as are a number of other acts that regulate the following three inter-related areas of environmental concern:

- Laws pertaining to natural resource use and conservation (the “green issues”);
- Laws pertaining to pollution control and waste management (the “brown issues”); and
- Laws pertaining to land-use planning and development, including the environmental assessment process.

Fracking will entail the application of a vast number of statutes administered by a number of different national, provincial and possibly local government departments. It is, therefore, also necessary to outline the nature and working of the notion of cooperative government as provided for in Chapter 3 of the *Constitution* titled “Co-operative governance”. This area raises the related issue of whether certain statutes take precedence over other pieces of legislation; more generally how are possibly conflicting (non) authorisations resolved.

Finally, the decision to grant prospecting, mining and/or exploration and production rights for fracking raises a number of issues which can be grouped under the general heading: “Administrative law issues”. This includes issues relating to access to information, legal standing to sue and so on.

Fracking is a technique that has been adopted in a number of jurisdictions. This section accordingly deals with legal issues under the following sub-headings:

1. A review of developments in foreign jurisdictions;
2. The role of international law;
3. The *Mineral and Petroleum Development Act 28 of 2002 (MPRDA*);
4. The *Constitution;*
5. Laws relating to natural resource use and conservation;
6. Laws relating to pollution control and waste management;
7. Laws relating to land-use planning and development including the environmental assessment process;
8. Cooperative governance and law; and
9. Administrative law issues.

5.2.1 Fracking in other jurisdictions

Many countries across the world are actively grappling with fracking and the major concerns that have been raised in connection with its use. Fracking may be one of the most controversial resource extraction techniques in operation at present.

The following list illustrates some of the regulatory approaches that are being followed in various jurisdictions (Healy, 2012; Furlow and Hays, 2012; Sakmar, 2011; Philippe and Partners, 2011; ENDS, 2012; Fractracker Alliance, 2014):

a) Europe

- In the UK- in the spring of 2011, two small earthquakes occurred near Blackpool as a result of fracking. This led to the voluntary, temporary suspension of further operations by the operator, as no ban exists on fracking within the UK. In December 2012, the secretary of state for Energy announced the introduction of new regulatory requirements to ensure that seismic risks are effectively mitigated. Subject to these new requirements, the Department of Energy and Climate Change is prepared, in principle, to consider new applications for consent to such operations, and the suspension is therefore lifted. As before, final consent to any well or well operations is dependent on confirmation that all other necessary permits and consents have been obtained (Oil and gas guidance, 2014).
- France banned fracking, and, in the process, revoked exploration permits of three companies. It is interesting that exploration for or development of shale oil and gas itself is not restricted; only the process of fracking.
- Poland has the largest reserves of shale oil and gas; has no specific shale oil and gas legislation; and has granted more than 100 concessions to foreign companies.
- Bulgaria initially sought to grant exploration licenses to Chevron, only to ban the use of fracking in 2012.
- Germany – has large deposits of shale oil and gas, and allows exploratory drilling. Although German laws *de jure* explicitly prohibit only the use of hydraulic fracturing in designated water

preserves, fracking operations generally need be authorised by the government, which has publicly declared a moratorium until long-term damage to residents or the environment brought about by fracking can be ruled out or until alternative extraction methods become available that don't rely on the injection of toxic chemicals.

b) North America

- The states of New York and New Jersey have suspended fracking operations in their jurisdictions in response to public pressure. In contrast, Texas and Colorado have implemented new regulations requiring disclosure of chemical additives used in fracking operations.
- Shale oil and gas is being developed in Canada, and concerns have been raised about its potential environmental impacts.

c) Australia and Asia

- In Australia the prospects of shale oil and gas are being investigated in South Australia and Western Australia, due to the fact that these areas are far removed from population centres. An inquiry has been launched in Western Australia, entitled 'Inquiry into the Implications for Western Australia of Hydraulic Fracturing for Unconventional Gas. It began on 8 July 2013 and is still on-going. Eastern New South Wales and the state of Victoria have banned fracking (Australian Parliament, 2014).
- In China exploration is taking place.
- In India no fracking is taking place at this moment.

Many countries are choosing to use moratoria, either as a temporary or indefinite measure, as a mechanism to deal with fracking. The reasons behind using a moratorium vary, but chief amongst them are to ensure:

- Scientists have time to investigate the possible impacts associated with unconventional oil and gas extraction activities and hydraulic fracturing; and
- The governments of the various countries can put in place the required legislation to effectively regulate the activities associated with unconventional oil and gas extraction.

5.2.2 The application of International Law

The two main sources of international law for the present purposes are international customary law and international conventions or treaties. International customary law is automatically part of South African law unless legislation indicates the contrary. For an international convention to form part of South African law it must usually be enacted as such by national legislation. The *Constitution* does, however, provide for instances where international agreements can form part of the law without legislative enactments, such as where the convention has self-executing provisions or is of a technical, administrative or executive nature or simply does not require ratification or accession.

Relevant examples of international customary law include principles such as the polluter pays principle, the precautionary principle, the preventive principle and others. To place it beyond doubt that these are part of South African law, these principles, and a number of other national environmental management principles, have been enumerated in Section 2 of the *National Environmental Management Act 107 of 1998 (NEMA)* elaborated on in 5.2.7 below. Significantly this section commences by stating that these principles apply to 'the actions of all organs of state that may significantly affect the environment', not just the Department of Environmental Affairs (DEA), which administers this particular statute.

A relevant example of an international convention is the international convention on wetlands of international importance especially as waterfowl habitat 'the Ramsar Convention" which provides for the designation of wetlands of international significance by state parties to the convention. South Africa is a party to this convention and has designated 20 wetlands under the treaty. There is not one specific law that prohibits mining or petroleum resource exploitation activities in these wetlands, but there could be many laws contributing to their protection, including but not limited to the *NEM: Protected Areas and Biodiversity Acts*, the *NWA,* the *Conservation of Agricultural Resources Act;* and the respective nature conservation ordinance or act under which the wetland in question falls.

Finally, under this heading, it must be emphasised that the notion of sustainable development has been fundamental to the development of international environmental law. In the *Case Concerning the Construction of the Gabcikovo-Nagymaros Project* (Hungary/Slovakia) ((1998) 37 *ILM* 162)) (the *Gabcikovo Dam* case), the International Court of Justice, said:

> *Throughout the ages, mankind has for economic and other reasons, constantly interfered with nature. In the past, this was often done without consideration of the effect upon the environment. Owing to new scientific insights and to growing awareness of the risks for mankind – for present and future generations – of pursuit of such interventions at an unconsidered and unabated pace, new norms and standards have been developed, set forth in a great number of instruments during the last two decades. Such new norms have to be taken into consideration, and such new standards given proper weight, not only when states contemplate new activities, but also when continuing with activities begun in the past. <u>This need to reconcile economic development with protection of the environment is aptly expressed in the concept of sustainable development.</u> (Author's underlining)*

South Africa has incorporated the notion of sustainable development in section 24(b) (iii) of the Constitution, which refers to "ecologically sustainable development". It also appears in its framework environmental law, the *NEMA*, where "sustainable development" is defined as: "the integration of social, economic and environmental factors into planning, implementation, and decision-making so as to ensure that development serves present and future generations". The Constitutional Court endorsed the notion of sustainable development in the case of *Fuel Retailers Association of Southern Africa v Director-General: Environmental Management, Department of Agriculture, Conservation and Environment, Mpumalanga Province and Others* 2007 (10) BCLR 1059 (CC); 2007 (6) SA 4 (CC), where Ngcobo J stated:

> *Sustainable development is an evolving concept of international law. Broadly speaking its evolution can be traced to the 1972 Stockholm Conference. That Conference stressed the relationship between development and the protection of the environment; in particular the need 'to ensure that development is compatible with the need to protect and improve [the] environment for the benefit of their population'. The principles which were proclaimed at this conference provide a setting for the development of the concept of sustainable development. Since then the concept of sustainable development has received considerable endorsement by the international community. Indeed in 2002 people from over 180 countries gathered in our country for the Johannesburg World Summit on Sustainable Development (WSSD) to reaffirm that sustainable development is a world priority.*

Sustainable development is elaborated on in the *NEMA* as outlined in 5.2.7 below.

5.2.3 The Minerals and Petroleum Resources Development Act 28 of 2008 (MPRDA)

The *MPRDA* is the primary legislative enactment regulating minerals and petroleum resources and their exploitation in South Africa. The Act grants custodianship of all such resources to the State, whose obligations, among others, are to ensure equitable access to these resource and to expand opportunities for the historically disadvantaged to enter these sectors and to benefit from the exploitation of these resources. Importantly, the Act is required to give effect to the environmental right of the Constitution.[1]

At the outset it should be noted that *MPRDA* makes a fundamental distinction between mining on the one hand and petroleum resource exploitation on the other, The Act has separate chapters to deal with each: Chapter 4 covers "Mineral and Environmental Regulation" and Chapter 6 is dedicated to "Petroleum Exploration and Production". Despite this separation, many of the requirements imposed on mineral rights holders are also imposed on petroleum right holders, such as those relating to the order of processing applications, the historically disadvantaged, information and data requirements, beneficiation and the like. It is section 69(2) of the Act that makes provision for this overlap of requirement. However the actual rights that are granted are distinguishable and in this regard the definition of the terms mineral and petroleum are significant for making that distinction. The definition of "mineral" explicitly excludes petroleum from its scope[2] The Act defines "mineral" as:

> *any substance whether in solid, liquid or gaseous form, occurring naturally in or on the earth or in or under the water which was formed by or subjected to geographical process, and includes sand, stone, rock, gravel, clay, soil and any mineral occurring in residue stockpiles or in residue deposits, but excludes –*
>
> *a) Water, other than water taken from land, or sea for the extraction of any mineral from such water;*
>
> *b) Petroleum; or*
>
> *c) Peat*

The Act then defines "petroleum" as:

> *any liquid, solid hydrocarbon or combustible gas existing in a natural condition in the earth's crust and includes any such liquid or solid hydrocarbon or combustible gas, which gas has in any manner been returned to such natural condition, but does not include coal, bituminous shale or other stratified deposits from which oil can be obtained by destructive distillation or gas arising from a marsh or other surface deposit;*[3]

The ambit of these two definitions is crucial as it determines whether a gas extracted is a mineral or petroleum. Gas, extracted by means of fracking will fall under the definition of petroleum. (Such gas will not be sourced from marshes or surface deposits.) The consequence of this is that fracking activities for this type of gas are regulated by Chapter 6 of the Act. Any person wishing to engage in such activities will need to obtain an exploration right, followed by a production right, in order to

[1] Section 2, MPRDA.

[2] Section 1, MPRDA

[3] Section 1, MPRDA.

extract the shale gas.[4] In addition, an environmental authorisation is needed before any such activities can commence and environmental management programmes will also be needed.[5]

However, it must be noted that the definition of petroleum excludes coal, bituminous shale or other stratified deposits from which oil can be obtained by destructive distillation. This has implications for CBM. As noted in the glossary section above, CBM is a "natural gas that is contained in coalbeds" … and …"is now typically produced from non-mineable coal-seams". Therefore, because CBM occurs within coal and coal seams it is considered a mineral and not a petroleum resource. Thus while both shale gas and methane from coalbeds are gases, in terms of the *MPRDA* the former will be regulated by Chapter 6 as a petroleum resources, while the latter while be regulated by Chapter 4 as a mineral. In effect, both require the entity undertaking such activities to acquire the right to do so, only the type of right will differ. The process for applying for such rights is similar but will need to comply with the relevant requirements of the applicable chapters of the Act.[6] Environmental authorisations are one of the key features of both the mining and petroleum regulatory regimes. Furthermore, when the pending amendments to the *MPRDA* take effect,[7] it will be an offence to commence mining or petroleum related activities without an environmental authorisation[8]. One final point to note is that the mining industry is a long established industry in South Africa. The petroleum resources industry, particularly land based extraction, is still in its infancy. As a result, while the *MPRDA* tackles both, much associated regulation, particularly that which covers environmental matters and water, tends to focus on mining activities and are silent on petroleum production activities. However, some of the legislation is in the process of or has been amended to take account of the potential land based petroleum resource industry in the country. Thus, in the discussion below, some legislation or parts thereof still only make provisions dealing with mining without also addressing petroleum resources.

5.2.4 The Constitution of Republic of South Africa

The *Constitution* is the supreme law of South African and the Bill of Rights, contained within it, is the cornerstone of democracy in South Africa. The Bill of Rights enshrines the rights of all people and affirms the democratic values of human dignity, equality and freedom. It applies to all laws and organs of state. In the context of this discussion the environmental right, contained within section 24, is particularly significant. It states that:

> *Everyone has the right-*
> *(a) to an environment that is not harmful to their health or well-being; and*
> *(b) to have the environment protected, for the benefit of present and future generations, through reasonable legislative measures that-*
> *(i) prevent pollution and ecological degradation;*

---

4 See sections 79-86 the MPRDA.

5 Section 80(1)(c) , MPRDA (as amended by Act 49 of 2008). On 7 December 2014, when the remaining provisions of the Amendment Act come into effect, section 5A will make it an illegal act to explore and produce petroleum without an environmental authorization.

See also sections 82 and 83, MPRDA.

6 The *MPRDA* is currently being reviewed and an amendment bill has been published (B 15B 2013). While it is unknown when or even if the bill will be enacted, it is worth noting that the term 'associated mineral' is a possible addition. An associated mineral is a mineral associate and insepable from the primary mineral. This could describe methane found in and around coal seams and the bill intends to regulate the mining of such associated minerals.

7 The effective date will be 7 December 2014.

8 Section 5A

(ii) promote conservation; and
(iii) secure ecologically sustainable development and use of natural resources while promoting justifiable and economic and social development.

The environmental right has been given effect to in a number of cases including" *Director Mineral Development, Gauteng Region and Sasol Mining (Pty) Ltd v Save the Vaal Environment and others* 1999 (2) SA 709 (SCA) 719 where the court said that:

> *Our Constitution, by including environmental rights as fundamental justiciable human rights, by necessary implication requires that environmental considerations be accorded appropriate recognition and respect in the administrative process in our country.*

Other rights indirectly related to environmental issues, such as the right to access of information, the right to enforcement of the rights, and the right to public administration are governed by the democratic values and principles enshrined in the *Constitution.* It should be further noted that the right mandates the state to enact legislation, and other measures, to protect the environment. The *National Environmental Management Act 107 of 1998* (*NEMA*) (discussed below at 5.2.7) along with the sectoral legislation that has be promulgated under the *NEMA* framework, all fall within this mandate.

5.2.5 Laws relating to natural resource use and conservation

A plethora of laws fall under this heading, the ones most relevant being those relating to protected areas (the *NEM: Protected Areas*); conservation and sustainable use of biodiversity (the *NEM: Biodiversity Act)* and provincial nature conservation ordinances which are by and large a carry-over from the pre-1994 dispensation. Another carry over piece of legislation, that may be applicable, is the *Conservation of Agricultural Resources Act 43 of 1983*. A further particularly relevant piece of legislation to the question of fracking is the *NWA* with its regulation of water use. These legislative enactments are dealt with in some detail below.

NEM: Protected Areas Act 57 of 2003

The objective of the *National Environmental Management: Protected Areas Protected Areas Act* (the *NEM: Protected Areas Act*) is to provide for a national system of protected areas in South Africa as part of a strategy to manage and conserve its biodiversity. In so doing, it attempts to ensure the protection of the entire range of biodiversity, referring to natural landscapes and seascapes. In addition, it seeks to coordinate the declaration and management of protected areas that are currently administered by a fragmented array of authorities at national, provincial and local levels of government. The State is appointed as the trustee of protected areas in the Republic, thereby echoing the public trust doctrine, which permeates most of South Africa's contemporary natural resource legislation.

The Act consolidates and systematises the various disparate types of protected areas which existed prior to 1994. These areas can now be categorised under the following nine headings, all of which are relevant to fracking, except perhaps the last-mentioned: marine protected areas. The nine categories are: special nature reserves; nature reserves; wilderness areas; national parks; protected environments; world heritage sites; specially protected forest areas including, forest nature reserves and forest wilderness areas; mountain catchment areas; and marine protected areas. While the entire *NEM: Protected Areas Act* applies to special nature reserves, national parks, nature reserves and protected environments declared under it, only some of its provisions apply to protected areas declared under provincial legislation. Accordingly, any fracking activity has to also be aware of provincial protected area provisions.

As fracking is an activity that can be employed for both mining and petroleum production, section 48 of the Protected Areas Act, titled "Prospecting and mining activities in protected area", is relevant. Despite the title of the section the Act has been amended to include petroleum related activities[9]. In addition, the section was also made applicable to petroleum activities in terms of section 69(2) of the *MPRDA).* It provides:

(1) Despite other legislation, no person may conduct commercial prospecting, mining exploration, production or related activities-
  - *(a)* in a special nature reserve, national park or nature reserve;
  - *(b)* in a protected environment without the written permission of the Minister and the Cabinet member responsible for minerals and energy affairs (now known as mineral resources),; or
  - *(c)* in a protected area referred to in section 9 *(b)*, *(c)* or *(d)*.

(2) …

(3) The Minister, after consultation with the Cabinet member responsible for mineral and energy affairs may, in relation to the activities contemplated in subsection (2), as well as in relation to mining activities conducted in areas contemplated in that subsection which were declared as such after the commencement of this section, prescribe conditions under which those activities may continue in order to reduce or eliminate the impact of those activities on the environment or for the environmental protection of the area concerned.

(4) When applying this section, the Minister must take into account the interests of local communities and the environmental principles referred to in section 2 of the National Environmental Management Act, 1998.

As regards the conditions referred to in subsection (3) the Act empowers the Minister of Environmental Affairs who administers the Act to make regulations for the monitoring of these protected areas, and the setting and enforcing of norms and standards and related matters. This would be relevant to fracking and its effects if authorisation to be granted in these areas.

In this vein Regulations for the Proper Administration of Special Nature Reserves, national parks and World Heritage Sites, were promulgated in terms of section 86 of the *NEM: Protected Areas Act*. Under Regulation 39, no person may interfere with the soil or substrate without the written permission of the relevant park's management authority. This includes a prohibition on the removal of 'soil, rock, mineral or similar materials', as well as the prohibition on digging or disturbing the soil in such parks. This regulation also regulates water use within such parks. It requires both written permission and an EIA before any construction of an impoundment or weir on any river, or abstraction of water either within or outside such parks.

Furthermore, Regulation 40 provides that 'no person shall, in a special nature reserve, national park or world heritage site - … (f) deposit, discharge or leave any mineral, mineral waste or other industrial waste or by-product thereof; or (g) discard or discharge any toxic chemical or substance, pharmaceutical substance, including biocides, or any other pollutant or harmful substance.

[9] *NEM: Protected Areas Amendment Act 21 of 2014.*

The regulations also prohibit water pollution (Reg. 41), the removal and dumping in a water area within parks (Reg.42) and the erection, construction or transformation of any buildings within such parks (Reg. 46).

It should also be noted that the Minister of Water and Environment Affairs has promulgated a number of notices declaring certain portions of land in the Karoo region to be part of several different national parks.[10]

Therefore, any proposed fracking activity, which is intended to take place in any category of protected area, will accordingly have to take into account not only the *Protected Areas Act* and its regulations but any other legislation that may be pertinent in that particular area. One of these is turned to below.

Astronomy Geographic Advantage Act, 21 of 2007
The development of the Square Kilometre Array (SKA) project, to be sited in areas which could potentially also be sites where fracking may take place has, among other reasons, necessitated the enactment of dedicated "protected areas" legislation namely the *AGA Act.* Its stated purpose is to:

> *… provide for the preservation and protection of areas within the Republic that are uniquely suited for optical and radio astronomy; to provide for intergovernmental co-operation and public consultation on matters concerning nationally significant astronomy advantage areas; and to provide for matters connected therewith.*

Section 5 empowers the minister for Science and Technology to declare "astronomy advantage areas". A number of such areas have been declared and a number of rights and obligations apply to such areas, which are not detailed here.

Related to this is the 'techno-hazard' potential of unconventional hydrocarbon exploration or fracking wastewater disposal operations, in relation to possible triggered seismicity. In this regard the *Disaster Management Act of 2002* and the National Disaster Management Framework of 2007 are relevant. This aspect will be administered by the National Disaster Management Centre (NDMC), which is established under the Act.

NEM: Biodiversity Act 10 of 2004
The overall objective of the Convention on Biological Diversity (CBD) is:

> *. . . the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilisation of genetic resources, including by appropriate access to genetic resources and by appropriate transfer of relevant technologies, taking into account all rights over those resources and to technologies, and by appropriate funding[11] (author's emphasis).*

11

1. Gov Gazette 25 Oct 2013, No, 36951, No 805 –Declaration of Land to be part of the Camdeboo National Park
2. Gov Gazette 25 Oct 2013, No, 36951, No 810 –Declaration of Land to be part of the Karoo National Park
3. Gov Gazette 25 Oct 2013, No, 36951, No 807 –Declaration of Land to be part of the Tankwa Karoo National Park
4. Gov Gazette 2 March 2012, No, 35073, No 155 –Declaration of Land to be part of the Tankwa Karoo National Park
5. Gov Gazette 7 Nov 2008, No, 31563, No 1181 –Declaration of Land to be part of the Tankwa Karoo National Park

11 Art 1 of the CBD.

It accordingly seeks to achieve three main objectives, namely, the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of the benefits arising from the use of genetic resources. In order to do so, the CBD deals with a diverse array of issues, including measures and incentives for the conservation and sustainable use of biological diversity; regulated access to genetic resources; access to and transfer of technology, including biotechnology; technical and scientific cooperation; impact assessment; education and public awareness; provision of financial resources, and national reporting on efforts to implement treaty commitments. South Africa has given effect to the provisions of the CBD, through the promulgation of the *NEM: Biodiversity Act 10 of 2004*, details of which are now briefly outlined.

Chapter 3 of the *NEM: Biodiversity Act* prescribes a detailed regime for planning and monitoring South Africa's biodiversity. The stated purpose of this chapter is to ensure integrated and co-ordinated biodiversity planning, monitoring the conservation status of various components of the country's biodiversity, and promoting research into biodiversity.[12]

The *NEM: Biodiversity Act's* planning and monitoring regime pivots on three types of planning instruments, namely, a national biodiversity framework; bioregional plans (and bioregions), and biodiversity management plans. Before adopting or approving any of these three types of plans, the Minister is obliged to follow the consultative process laid down in the Act.[13] Significantly, in view of the plethora of types of plans that have emerged in environmental legislation generally, the Act provides for the coordination and alignment of these planning instruments with those prescribed in other environmental laws.[14] The three biodiversity plans may not be in conflict with environmental implementation plans (EIPs) or environmental management plans (EMPs) prescribed in terms of the *NEMA*; integrated development plans (IDPs) and spatial development frameworks (SDFs) prescribed in terms of the *Local Government: Municipal Systems Act 32 of 2000* (the Systems Act); and other relevant national or provincial plans.[15]

Organs of state tasked with preparing an EIP, EMP, IDP, SDF and other relevant plans, must:

- Align the content with the national biodiversity framework and any applicable bioregional plan;
- Incorporate within the content any applicable provision of the national biodiversity framework or bioregional plan; and
- Demonstrate within it how the national biodiversity framework or bioregional plan is to be implemented.[16]

SANBI is envisaged as playing a facilitative role in this regard. It may assist the Minister, and others, in preparing the national biodiversity framework, bioregional plans or biodiversity management plans, and may advise organs of state and municipalities about aligning these plans with any applicable EIP, EMP, IDP, SDF and other relevant plan.[17]

Provision is also made for implementing monitoring mechanisms and indicators to determine the conservation status of the country's biodiversity and, importantly, "any negative and positive trends affecting the conservation status of their various components".[18] The Minister may require any person, organisation or organ of state involved in monitoring to report regularly to the Minister on the results of

[12] S 37 of the Biodiversity Act.
[13] S 47 read with ss 99 and 100.
[14] S 48.
[15] S 48(1).
[16] S 48(2).
[17] S 48(3).
[18] S 49(1).

monitoring measured against predetermined indicators.[19] The Minister must report annually to parliament in this regard, and make such information publicly available.[20]

An important point in relation to fracking is that as illustrated in the Maccsand,[21] case outlined in 5.2.7 below, the Department of Mineral Resources can no longer simply grant a mining authorisation and permit the proponent to proceed. It now has to also take cognisance of the powers and functions of other spheres of government including provincial and local planning laws. It is thus suggested that fracking will have to take cognisance of Bioregional plans made under the *NEM Biodiversity Act*.

The Conservation of Agricultural Resources Act 43 of 1983

Section 3 of the Act provides that the objects of this Act are to provide for the conservation of the natural agricultural resources of the Republic by the maintenance of the production potential of land, by the combating and prevention of erosion and weakening or destruction of the water sources, and by the protection of the vegetation and the combating of weeds and invader plants.

Section 6 of the Act empowers the Minister to prescribe control measures to protect agricultural resources; section 7 makes provision for the executive officer to enforce these control measures through the issuances of directions, and section 18 grants the power to investigate, among other things, the occurrence and extent of soil or other damage to land as well as compliance with control measures and directions. Control measures have been specified in regulations[22], and include the regulation of the flow pattern of run-off water (Reg. 8) and restore and reclaim eroded land (Reg.13). Although these regulations seek to conserve agricultural land, they could potentially serve to protect land which may host or potentially host fracking activities.

National Heritage Resources Act 25 of 1999

Another Act which could play a role in this arena is the *National Heritage Resources Act* (NHRA). It provides that any person who intends to undertake — any development “which will change the character of a site exceeding 5000 m^2 in extent” or “the construction of a road…power line, pipeline…exceeding 300 m in length” or “the rezoning of site larger than 10 000 m^2 in extent…” must at the very earliest stages of initiating the development notify the responsible heritage resources authority, namely the South African Heritage Resources Agency (SAHRA) or the relevant provincial heritage agency. These agencies would in turn indicate whether or not a full Heritage Impact Assessment (HIA) would need to be undertaken.

The National Water Act 36 of 1998

Introduction

In terms of the *NWA*, the national government is the public trustee of the nation’s water (section 3(1)). Although there is some academic debate about the meaning of “public trustee”, the *NWA* is very clear that ‘the National Government, acting through the Minister, must ensure that water resources are protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner, for the benefit of all persons and in accordance with its constitutional mandate”. The act defines a “water resource” to include a watercourse, surface water, estuary, or aquifer; and watercourses include, rivers, springs, wetlands, dams or any collection of water that the Minister

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[19] S 49 (2).
[20] S 49(3).
[21] Maccsand (Pty) Ltd v City of Cape Town and Others (CCT103/11) (CC) [2012] ZACC 7; 2012 (4) SA 181 (CC); 2012 (7) BCLR 690 (CC) (12 April 2012)
[22] Government Gazette Notice 1084 of 25 May 1984, as amended by notice by notices R.2687 (GG 10029) 6 December 1985 and R.280 (GG22166) 30 March 2001

declares to be a watercourse.[23] This must be done, among other things, by ensuring the beneficial access of the public to water and the promotion of environmental values, in accordance with section 24 of the Constitution.

A central question in the fracking context is ‘how does the DWAcarry out this mandate?’ More specifically, what duties does the DWA have in on-going monitoring and how does it ensure that any conditions that it imposes under a water use licence are adhered to. In short can this duty be outsourced to, say, an independent committee?

The background to this key issue is the fact that the *NWA* pivots around the need to obtain a license for permissible “water use”. (There are circumstances where a licence is not required, for example where a ‘general authorisation’ has been issued, but these circumstances are not relevant here.) The phrase ‘water use’ is widely defined in section 21 of the Act to include a broad range of activities and includes –

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

Once an applicant falls into any one or more of the items listed above the Minister may issue conditions for the grant of a licence. These conditions are contained in section 29 and can be stringent and far-ranging and are set out below:

29. Conditions for issue of general authorisations and licences

(1) A responsible authority may attach conditions to every general authorisation or licence -
 (a) relating to the protection of the water resource in question:
  (ii) the stream flow regime; and
  (iii) other existing and potential water users;
 (b) relating to water management by -
  (i) specifying management practices and general requirements for any water use, including water conservation measures;
  (ii) requiring the monitoring and analysis of and reporting on every water use and imposing a duty to measure and record aspects of water use, specifying measuring and recording devices to be used;
  (iii) requiring the preparation and approval of and adherence to, a water management plan;

[23] See definition section of the NWA 36 of 1989

(iv) requiring the payment of charges for water use as provided for in Chapter 5;
(v) requiring the licensee to provide or make water available to a person specified in the licence; and
(vi) in the case of a general authorisation, requiring the registration of the water use with the responsible authority and the payment of a registration fee as a precondition of that use;

(c) relating to return flow and discharge or disposal of waste, by -
(i) specifying a water resource to which it must be returned or other manner in which it must be disposed of;
(ii) specifying permissible levels for some or all of its chemical and physical components;
(iii) specifying treatment to which it must be subjected, before it is discharged; and
(iv) specifying the volume which may be returned;

(d) in the case of a controlled activity -
(i) specifying the waste treatment, pollution control and monitoring equipment to be installed, maintained and operated; and
(ii) specifying the management practices to be followed to prevent the pollution of any water resource;

(e) in the case of taking or storage of water -
(i) setting out the specific quantity of water or percentage of flow which may be taken;
(ii) setting out the rate of abstraction;
(iii) specifying the method of construction of a borehole and the method of abstraction from the borehole;
(iv) specifying the place from where water may be taken;
(v) specifying the times when water may be taken;
(vi) identifying or limiting the area of land on which any water taken from a resource may be used;
(vii) limiting the quantity of water which may be stored;
(viii) specifying locations where water may be stored; and
(ix) requiring the licensee to become a member of a water user association before water may be taken;

(f) …

(g) which are necessary or desirable to achieve the purpose for which the licence was issued;

(h) which are necessary or desirable to ensure compliance with the provisions of this Act; and

(i) in the case of a licence -
(i) specifying times when water may or may not be used;
(ii) containing provisions for its termination if an authorised use of water is not implemented or not fully implemented;
(iii) designating water for future or contingent use; or
(iv) which have been agreed to by the licensee.

The phrase “responsible authority” referred to above is defined in the Act as “in relation to a specific power or duty in respect of water uses, means - (a) if that power or duty has been assigned by the Minister to a catchment management agency, that catchment management agency; or (b) if that power or duty has not been so assigned, the Minister.”[24]

[24] Section 1 (xx) NWA 36 of 1998

While the above describes conditions that are very pertinent to fracking activities, it is not specifically stipulated that they must be so applied. This is because the wording is that the responsible authority “may” not ‘shall’ or ‘must” attach the conditions. It is accordingly suggested that any independent monitoring agency be set up and that it becomes obligatory i.e. “must” to carry out all those conditions enumerated in section 29, above.

It is clear that “water use” includes a wide range of activities and includes (potential) polluting activities. As such, fracking will be caught in the net by virtually every single item listed in section 21 (a) to (k) Nevertheless, the Minister of Water and Environmental Affairs found it necessary to invoke item (e) and declare fracking to be a “controlled activity” as referred to in subsection (e) above (N 863/2013 GG 36760 dated 23 August 2013). Subsection (e) refers to an activity identified as such in section 37(1) or declared under section 38(1). The latter section states that the Minister may declare an activity to be a controlled activity where he or she is “…satisfied that the activity in question is likely to impact detrimentally on a water resource.” As neither sections 37 nor 38 add further or additional controls to the items listed in (a) to (k) above, the only implication of this declaration appears to be that a “responsible authority”, as defined, may specify “the waste treatment, pollution control and monitoring equipment to be installed, maintained and operated” as well as “specifying the management practices to be followed to prevent the pollution of any water resource” (section 29(1)(d)). As fracking is already caught as a listed activity as indicated it seems that this declaration by the Minister, which was accompanied by some fanfare and a press release, was simply a sop to a sceptical public. In any event it is doubtful whether the Department has the capacity to determine “the waste treatment, pollution control and monitoring equipment to be installed, maintained and operated”, in the sense used in section 29.

Protection of water resources and setback lines

Of particular relevance to fracking proposals and the protection of water resources are regulations made under the NWA entitled Regulations on use of water for mining and related activities aimed at the protection of water resources (GN 704/1999 in GG of 4 June 1999). As all the regulations contained within this enactment are of importance to this report, they are reproduced and attached as an annexure. Notwithstanding that, several provisions should be noted.

Regulation 4, headed “Restrictions on locality” provides: “No person in control of a mine or activity may-

> *locate or place any residue deposit, dam, reservoir. together with any associated structure or any other facility within the 1:100 year flood-line or within a horizontal distance of 100 metres from any watercourse or estuary, borehole or well, excluding boreholes or wells drilled specifically to monitor the pollution of groundwater, or on water-logged ground, or on ground likely to become water-logged, undermined, unstable or cracked;*
>
> *except in relation to a matter contemplated in regulation 10, carry on any underground or opencast mining, prospecting or any other operation or activity under or within the 1:50 year flood-line or within a horizontal distance of 100 metres from any watercourse or estuary, whichever is the greatest;*
>
> *place or dispose of any residue or substance which causes or is likely to cause pollution of a water resource, in the workings of any underground or opencast mine excavation, prospecting diggings, pit or any other excavation; or*
>
> *use any area or locate any sanitary convenience, fuel depots, reservoir or depots for any substance which causes or is likely to cause pollution of a water resource within the 1 :50 year flood-line of a watercourse or estuary.”*

The subsequent three regulations (numbers 5 to 7) are also relevant to fracking activities. They provide:

5. Restrictions on use of material

> *No person in control of a mine or activity may use any residue or substance which causes or is likely to cause pollution of a water resource for the construction of any dam or other impoundment or any embankment, road or railway, or for any other purpose which is likely to cause pollution of a water resource.*

6. Capacity requirements of clean and dirty water systems

> *Every person in control of a mine or activity must-*
> *confine any unpolluted water to a clean water system, away from any dirty area;*
> *design, construct, maintain and operate any clean water system at the mine or activity so that it is not likely to spill into any dirty water system more than once in 50 years;*
> *collect the water arising within any dirty area, including water seeping from mining operations, outcrops or any other activity into a dirty water system;*
> *design, construct, maintain and operate any dirty water system at the mine or activity so that it is not likely to spill into any clean water system more than once in 50 years; and*
> *design, construct, maintain and operate any dam or tailings dam that forms part of a dirty water system to have a minimum freeboard of 0.8 metres above full supply level. unless otherwise specified in terms of Chapter 12 of the Act.*
> *design, construct and maintain all water systems in such a manner as to guarantee the serviceability of such conveyances for flows up to and including those arising as a result of the maximum flood with an average period of recurrence of once in 50 years.*

7. Protection of water resources

> *Every person in control of a mine or activity must take reasonable measures to-*
> *prevent water containing waste or any substance which causes or is likely to cause pollution of a water resource from entering any water resource, either by natural flow or by seepage, and must retain or collect such substance or water containing waste for use, re-use, evaporation or for purification and disposal in terms of the Act;*
> *design, modify, locate, construct and maintain all water systems, including residue deposits, in any area so as to prevent the pollution of any water resource through the operation or use thereof and to restrict the possibility of damage to the riparian or in-stream habitat through erosion or sedimentation, or the disturbance of vegetation, or the alteration of flow characteristics;*
> *cause effective measures to be taken to minimise the flow of any surface water or floodwater into mine workings, opencast workings, other workings or subterranean caverns, through cracked or fissured formations, subsided ground, sinkholes, outcrop excavations, adits, entrances or any other openings;*
> *design, modify, construct, maintain and use any dam or any residue deposit or stockpile used for the disposal or storage of mineral tailings, slimes, ash or other hydraulic transported substances, so that the water or waste therein, or falling therein, will not result in the failure thereof or impair the stability thereof;*
> *prevent the erosion or leaching of materials from any residue deposit or stockpile from any area and contain material or substances so eroded or leached in such area by providing*

suitable barrier dams, evaporation dams or any other effective measures to prevent this material or substance from entering and polluting any water resources;

ensure that water used in any process at a mine or activity is recycled as far as practicable, and any facility, sump, pumping installation, catchment dam or other impoundment used for recycling water, is of adequate design and capacity to prevent the spillage, seepage or release of water containing waste at any time;

at all times keep any water system free from any matter or obstruction which may affect the efficiency thereof; and

cause all domestic waste, including wash-water, which cannot be disposed of in a municipal sewage system, to be disposed of in terms of an authorisation under the Act.

Of concern however is the fact that the Minister may in writing authorise an exemption from the requirements of the above quoted and other regulations either on his/her own initiative or on application, subject to such conditions as the Minister may determine (Reg. 3). Should he or she exercise this discretion and grant an exemption it could severely undermine the purpose and spirit of the law, particularly if the Minister fails to impose appropriate conditions that mitigate the effect of disregarding the provisions in the regulations.

Of potential relevance to fracking activities are regulations (N1199 in GG no 32805 dated 18 December) the schedule of which is headed: Impeding or diverting the flow of water in a watercourse and altering the bed, banks, course or characteristics of a watercourse. These regulations elaborate on section 21(c) of the *NWA* quoted above by elaborating the definition of "altering the bed, banks, course or characteristics of a watercourse" by stating that this means “any change affecting the resource quality within the riparian habitat or 1:100 year flood line, whichever is the greater distance at the date of commencement of this Notice” (Section 2 Definitions). Regulation 7 states that:

(1) “The water use must not cause a potential, measurable or cumulative detrimental impact on the characteristics of a watercourse;” and

(2) The water user must ensure that the water use

(a) does not have a detrimental impact on another person's lawful water use or land; and

(b) is not detrimental to the health and safety of the public.

Part 3 of Chapter 3 of the *National Water Act* provides for the determination of a Reserve and related matters (sections 16-18). While it is crucial to establish and respect both the ‘basic needs’ and the ecological reserve component, and while there are regulations to determine how to make the determinations, there are no regulations that actually specify the determinations. Without this the relevance of a Reserve to fracking is limited.

Chapter 14 of the *NWA* Monitoring, Assessment and Information

Chapter 14 of the *NWA* (sections 137 to 145) titled Monitoring, Assessment and Information is particularly relevant to fracking. As stated in the preamble to the chapter “monitoring, recording, assessing and disseminating information on water resources is critically important for achieving the objects of the Act.” Part 1 of Chapter 14 places a duty on the Minister of Water Affairs to establish national monitoring systems as soon as it is reasonably practicable to do so. The purpose of the system is to facilitate the continued and co-ordinated monitoring of various aspects of water resources by collecting relevant information and data, through established procedures and mechanisms, from a variety of sources including organs of state, water management institutions and water users. While this obligation is generic it is suggested that because of the potential magnitude of the effects of fracking on the nations water resources, the Minister is obligated to invoke Chapter 14 with specific reference to fracking proposals.

Moreover Part 2 of Chapter 14 requires the Minister to establish national information systems, each covering a different aspect of water resources, such as a national register of water use authorisations, or an information system on the quantity and quality of all water resources. The Minister may require any person to provide the Department with information prescribed by the Minister in regulations. In addition to its use by the Department and water management institutions, and subject to any limitations imposed by law, information in the national systems should be generally accessible for use by water users and the general public.

It is thus clear that the Minister has at his/her disposal the legislative authority, if not a duty, to establish a system to monitor the effects of fracking. Amongst other things the "systems must provide for the collection of appropriate data and information necessary to assess, among other matters -

(a) the quantity of water in the various water resources;
(b) the quality of water resources;
(c) the use of water resources;
(d) the rehabilitation of water resources;
(e) compliance with resource quality objectives;
(f) the health of aquatic ecosystems; and
(g) atmospheric conditions which may influence water resources".[25]

In addition the Minister must establish mechanisms and procedures to coordinate the monitoring of water resources after consultation with the relevant organs of state including water management institutions and existing and potential users of water[26].

However, it must be pointed out that the Minister is by no means obligated to invoke the above provisions in relation to fracking specifically, or any other activity for that matter. It is suggested therefore that the Minister be encouraged, when establishing a monitoring agency, to modify these provision and make them specifically applicable to fracking and make it obligatory for the monitoring agency to carry them out. A related question that arises is whether the Act allows the Minister to delegate or assign this power to an outside independent agency. In this regard section 63 of the *NWA* titled "Delegation of powers and duties by Minister", empowers the Minister to delegate a power and duty vested in the Minister in terms of the Act only to certain stipulated persons, namely, to

(a) an official of the Department by name;
(b) the holder of an office in the Department;
(c) a water management institution;
(d) an advisory committee established under section 99; or
(e) a water board as defined in section 1 of the *Water Services Act, 1997* (Act No. 108 of 1997).

Who should monitor?

A central question to the development of a monitoring protocol for unconventional oil and gas is "who should monitor and what the legal nature of such an entity should be"' While the NWA, as indicated above, has vast powers to impose controls regarding protection of water resources, and makes provision for monitoring, the Act makes no reference as to who or what organisation would perform such an ongoing monitoring function. The acid mine drainage (AMD) problem is a vivid illustration of this point in that there was no dedicated body to monitor the various mining entities that caused the problem over decades. Ideally the monitoring body should provide an independent and ongoing

[25] Section 137(2)
[26] Section 138.

monitoring service to ensure that the conditions of any licence are adhered to, as well as relevant laws and regulations administered not only by the DWA but also by the DEA; the latter will in all likelihood also impose ongoing monitoring conditions in any environmental authorisation that may be issued for fracking. Before suggesting such an entity, it is important to consider what the ideal qualities of such an entity should be. It goes without saying that such a body should be independent, scientifically credible and impartial. Such a body should not only be concerned with purely scientific issues but also with other broader sustainability issues for instance socio-economic considerations such as employment provision, health issues, infrastructure costs as well as environmental protection.

A possible option proposed to this author is the Council for Geoscience. This is a statutory body established by the *Geoscience Act 100 of 1993*, administered by the Minister of Mineral Resources. The stated objective of the Act is to provide for the promotion of research and the extension of knowledge in the field of geosciences, and establishes a Council for Geoscience and a management board for this purpose. Section 5 of the Act sets out a number of functions of the Council, which is primarily to "undertake geoscientific research and related technological development" as well as to "compile and develop a comprehensive and integrated collection of knowledge and information of geology, geochemistry, geophysics, engineering geology, economic geology, geochronology, palaeontology, geo-hydrological aquifer systems, geotechnical investigations, marine geology, geomagnetism, seismology, geohazards, environmental geology and other related disciplines". A particular relevant function listed in section 5(1) (g) is to "conduct investigations and render prescribed specialised services to public and private institutions."

It should be noted, however, that the affairs of the Council are managed by a board whose membership is listed in section 4 and which is by and large composed of government officials. Finally it should be noted that the Act empowers the Minister to make regulations on a number of items including "…generally, any matter in respect of which the Minister considers it necessary or expedient to make regulations in order to achieve the objectives of this Act…".

Thus, while a monitoring function could be included under the umbrella of the Council for Geoscience, it would not be an ideal body. Firstly, ongoing long-term monitoring is not a core function of the Council; secondly it would lack the fundamental requirement of independence, at least in the public perception; and, thirdly its mandate is too narrow to include socio-economic factors.

<u>Potential role of Petroleum Agency of South Africa</u>

At the outset it can be noted that the draft technical regulations[27] indicate that the Petroleum Agency of South Africa (PASA) will be the agency that will be tasked with monitoring fracking activities. In this regard Section 70 of the *Minerals and Petroleum Resources Development Act 28 of 2002 (MPRDA*) makes provision for a Designated Agency. It states that:

> *The Minister may designate an organ of State or a wholly owned and controlled agency or company belonging to the State to perform the functions referred to in this Chapter.*

Section 71 of the Act enumerates on the functions of the designated agency and states that:

The designated agency must-

- *(a) promote onshore and offshore exploration for and production of petroleum;*
- *(b) receive applications for reconnaissance permits, technical co-operation permits, exploration rights and production rights in the prescribed manner;*

[27] Proposed Technical Regulations for Petroleum Exploration and Exploration, Government Gazette No. 36938, Notice 1032, 15 October 2013

(c) evaluate such applications and make recommendations to the Minister;
(d) monitor and report regularly to the Minister in respect of compliance with such permits or rights;
(e) receive, maintain, store, interpret, evaluate, add value to, disseminate or deal in all geological or geophysical information relating to petroleum submitted in terms of section 88;
(f) bring to the notice of the Minister any information in relation to the exploration and production of petroleum which is likely to be of use or benefit to the State;
(g) advise and recommend to the Minister on the need to by itself, through contractors or through any other state enterprise carry out on behalf of the State reconnaissance operations in connection with petroleum;
(h) collect the prescribed fees and considerations in respect of reconnaissance permits, technical co-operation permits, exploration rights and production rights;
(i) review and make recommendations to the Minister with regard to the approval of environmental management plans, environmental management programmes, development programmes and amendments thereto; and
(j) perform any other function, in respect of petroleum, which the Minister may determine from time to time.

It therefore appears that, at present, the Department of Mineral Resources intends to have PASA as the organ of state that will be tasked with the monitoring of fracking activities.

Access to Information and related issues: *NWA* Chapter 14 (Part 2)

General background

In considering information-related matters it is necessary to consider, firstly, general access to information issues stemming from the right of access to information in Section 32 of the Constitution and the resultant *Promotion of Access to Information Act (2 of 2000) (PAIA)*; secondly the specific provisions in Chapter 14 (part 2) of the *NWA* titled “National information systems on water resources” need to be examined.

A right of access to information by the public is contained in section 32 of the Constitution which provides that:

(*1*) *Everyone has the right of access to –*
(a) any information held by the state; and
(b) any information that is held by another person and that is required for the exercise or protection of any rights.

(2) National legislation must be enacted to give effect to this right, and may provide for reasonable measures to alleviate the administrative and financial burden on the state.

The importance of this right was noted by Traverso J in *Aquafund* (*Pty*) *Ltd v Premier of the Western Cape* 1997 (7) BCLR 907 (C) at 916E, where she said:

> *[i]f it is accepted that every person is entitled to lawful administrative action, it must follow that in a legal culture of accountability and transparency . . . manifested in the constitution, a person must be entitled to such information as is reasonably required by him to determine whether his right to lawful administrative action has been infringed or not. If a person is not able to establish whether his rights have thus been infringed, he will clearly be prejudiced*.

Similarly, Froneman J has stated that the equivalent right to information in section 23 of the *Interim Constitution,* is '... a necessary adjunct to an open and democratic society committed to the principles of openness and accountability...'

Qozeleni v Minister of Law and Order and Another 1994 (3) SA 625 (EC) at 642E–G.

In conformity with section 32(2) of the *Constitution* quoted above, the *Promotion of Access to Information Act 2 of 2000 (PAIA)* was enacted with the stated purpose 'to give effect to the Constitutional right of access to any information held by the state and any information that is held by another person and that is required for the exercise or protection of any rights'. The PAIA makes no distinction between environmental and other information, but does include reference to 'public safety or environmental risk'. In general, the Act applies to information held by governmental bodies, but it also refers to access to personal information held by private bodies, in conformity with section 32(1)(*b*) of the Constitution. The right of access to information is particularly important in the environmental context, as much governmental decision making has direct or indirect consequences for the environment.

Part 2 of chapter 14 of the NWA

Part 2 of chapter 14 of the *NWA* (sections 139 to 143) titled "National information systems on water resources" is relevant to issues around information in that it stipulates that the Minister must, as soon as reasonably practicable, establish national information systems regarding water resources. These may amongst other things include a hydrological information system; a water resource quality information system; a groundwater information system; and a register of water use authorisations (section 139(1) and (2)).

The objectives of national information systems are broad-ranging and include the obligation to store and provide data and information for the protection, sustainable use and management of water resources; to provide information for the development and implementation of the national water resource strategy; and to provide information to water management institutions, water users and the public for research and development; for planning and environment impact assessments; for public safety and disaster management; and on the status of water resources (Section 140).

It is suggested that the Minister is obliged to provide these monitoring systems to fracking specifically. Of particular relevance here are sections 141 "Provision of information" and 142 "Access to information" of the Act. Section 141 provides that the:

> *"…Minister may require in writing that any person must, within a reasonable given time or on a regular basis, provide the Department with any data, information, documents, samples or materials reasonably required for -*
>
> *(a) the purposes of any national monitoring network or national information system; or*
>
> *(b) the management and protection of water resources.*

Section 142 provides that information contained in any national information system established in terms of this Chapter must be made available by the Minister, subject to any limitations imposed by law, and the payment of a reasonable charge determined by the Minister.

It is thus evident that the Minister of Water and Environmental Affairs has onerous obligations around monitoring and assessment of fracking activities. But questions remain whether he or she has the political will to act on these powers and whether he or she has the capacity in her department to monitor, assess and evaluate these issues. Furthermore, even if these questions are answered in the affirmative, it is also essential that the information be used to direct necessary remedial and/or adaptive management and this is an issue that has not been addressed in any meaningful way.

Finally it should be noted that the Minister has important powers to make regulations for monitoring, assessment and information (section 141), including the power to make regulations prescribing guidelines, procedures, standards and methods for monitoring.

Corporate social responsibility and access to information

Linked to matters around access to information is the phenomenon of corporate social responsibility (CSR) which has become a prominent feature in recent times worldwide and in South Africa. CSR is an approach whereby a company commits to address its social and environmental impacts, and integrates this commitment into its business practice. The King Committee released its first report, known as the *King Code on Corporate Governance* (or King 1) in 1994. Two further reports followed; namely, the *King Report on Corporate Governance for South Africa 2002* (King 2), and the *King Report on Governance for South Africa 2009* (King 3). The three are known collectively as the King Code.

The King III Report on Corporate Governance for South Africa ('the King Report') is one of the main drivers of CSR in the country. It defines CSR as 'the responsibility of the company for the impacts of its decisions and activities on society and the environment, through transparent and ethical behaviour that: contributes to sustainable development, including health and the welfare of society; takes into account the legitimate interests and expectations of stakeholders; is in compliance with applicable law and consistent with international norms of behaviour; and is integrated throughout the company and practiced in its relationships.'

Key concepts accompanying any discussion on corporate social responsibility are 'stakeholders' and 'sphere of influence'. Stakeholders are those persons who are affected by the operation of the company, and include employees, shareholders, investors, suppliers, consumers, customers, regulators, members of civil society, and affected communities. A company's sphere of influence is a concept referring to those 'people and situations that are in a contractual, economic, geographic and political proximity with the corporate enterprise.'[28] In other words, a large multinational company has a much larger sphere of influence than a small, local, family-run enterprise.

Although the focus of the King Code is corporate governance, it devotes significant attention to the issues of sustainability in relation to the governance of corporate entities. It is applicable to all South African corporate entities, including public listed companies, privately-owned corporate entities and public sector enterprises.

While it has no legislative force, the King Code may nevertheless be a quasi-legal mechanism, as non-compliance can lead to adverse consequences, albeit none with legal sanctions. In particular, although the King Code imposes no sanction for non-application of or non-compliance with its provisions, the Johannesburg Stock Exchange (JSE), in its listing requirements, makes compliance with the King Code mandatory. Thus the JSE has, at the very minimum, imposed an obligation on all companies already listed or wanting to list to take heed of the King Code's requirements. In *Minister of Water Affairs and Forestry v Stilfontein Gold Mining Co Ltd and Others*, 2006 (5) SA 333 (W), the Court specifically endorsed the King Code in the following terms: 'Practising sound corporate

[28] Kerr M, Janda R and Pitts C, *Corporate Social Responsibility: A Legal Analysis* (2009) at 10, referring to Fussler C, Cramer A and Van der Vegt S, *Raising the Bar: Creating Value with the United Nations Global Compact* (2004) at 22.

governance is essential for the well-being of a company and is in the best interests of the growth of this country's economy especially in attracting new investments. To this end, the corporate community within South Africa has widely, and almost uniformly, accepted the findings and recommendations of the King Committee on Corporate Governance – see the *King Report on Corporate Governance for South Africa* – March 2002.'

King 2 was central in the *Stilfontein* case, where Stilfontein had been ordered to comply with certain water management directives. Instead of doing so, the directors of the company all resigned simultaneously. The court pierced the corporate veil and found the directors guilty of contempt of court for failing to comply with the court order. In so doing it held that:

> *[a] well-managed company will be aware of, and respond to, social issues, placing a high priority on ethical standards. A good corporate citizen is increasingly seen as one that is non-discriminatory, non-exploitative, and responsible with regard to environmental and human rights issues. A company is likely to experience indirect economic benefits, such as improved productivity and corporate reputation, by taking those factors into consideration.. . . The object of the directives is to prevent pollution of valuable water resources. To permit mining companies and their directors to flout environmental obligations is contrary to the Constitution, the Mineral Petroleum Development Act and to the National Environmental Management Act. Unless courts are prepared to assist the State by providing suitable mechanisms for the enforcement of statutory obligations, an impression will be created that mining companies are free to exploit the mineral resources of the country for profit, over the lifetime of the mine; thereafter they may simply walk away from their environmental obligations. This simply cannot be permitted in a constitutional democracy which recognises the right of all of its citizens to be protected from the effects of pollution and degradation (at 352B–H).*

Regarding the board of directors, King 2 states the following:

> *The Board is the focal point of the corporate governance system. It is ultimately accountable and responsible for the performance and affairs of the company. Delegating authority to board committees or management does not, in any way, mitigate or dissipate the discharge by the board and its directors of their duties and responsibility.*

King 3 advocates the corporate social responsibility approach by stating as follows:

> *The board is not merely responsible for the company's financial bottom line, but rather for the company's performance within the triple context in which it operates: economic, social and environmental . . . This triple-context approach enhances the company's potential to create economic value. It ensures that the economic, social and environmental resources that the company requires to remain in business are treated responsibly. By looking beyond immediate financial gain, the company protects its reputation – its most significant asset – and builds trust. There is a growing understanding in business that social and environmental issues have financial consequences.*[29]

The King 3 accordingly requires companies to publicly report on their economic, social and environmental performance in an integrated manner.

It should be noted that the King Code is not the only voluntary compliance measure. Others include the Coalition for Environmentally Responsible Economics (CERES), which is a multi-stakeholder network containing both investors and environmental interest organisations. This reflects the fact that

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[29] See Ch 1 of King 3, at paras 16–17.

investors also increasingly taking compliance into account, which constitutes yet another incentive for businesses to comply.[30]

A further example of a voluntary business initiative is the South Africa Carbon Disclosure Project (CDP) Report 2011. This was initiated jointly by the National Business Initiative (the NBI) and Incite in 2004, in London. Its aim is to contribute to a more informed appreciation among businesses, investors and the financial media of the strategic investment implications of climate change, and to further encourage the proactive involvement of business in identifying solutions to this significant economic, social and environmental challenges. South Africa's major companies have been active in the initiative and are now ranked among global leaders in measuring and reporting on their greenhouse gas (GHG) emissions. During 2011, 83 of the JSE's top 100 companies responded to the 2011 CDP.[31]

5.2.6 Laws relating to pollution control and waste management

Unconventional oil and gas mining by means of hydraulic fracturing will affect all three environmental media, namely air, land and water. A plethora of laws and regulations exist which deal with pollution control and waste management; it is not possible to detail them all here. Suffice it to say that one has to be aware of common law legal principles, such as neighbour law and the law of delict; the *NEM: Air Quality Act 39 of 2004* (atmospheric and noise pollution), *National Water Act 38 of 1998* (water pollution); the *NEM: Waste Management Act 59 of 2008* (waste management generally), the *MPRDA* (mining waste) to name the main ones. It should be noted that the *NEM: Waste Act* distinguishes between "waste" and "hazardous waste"; as regards the latter the *Hazardous Waste Act (Act 15 of 1973)* could be relevant. Noise control and dust control regulations also need to be considered.

The *Hazardous Substances Act 15 of 1973* regulates the use of substances that may cause injury, ill health or death to humans. The Act classifies hazardous substances into four groups. A licence is required before any of the hazardous substances can be used, whether it be for sale, use, installation, operation or in the case of group IV, acquisition, disposal, importation, possession or transportation. (Sections 3A and 4). Fracking requires a number of chemical additives to be added to the water that is used for fracking operations. Their use will be regulated by the Act. This will necessitate licence applications and disclosure of the substances to be used

The National Environmental Management: Air Quality Act 39 of 2004 (*NEM: Air Quality Act*) seeks to protect the environment and in particular the air quality in order to give effect to the environmental right (section 2). The Act makes provision for the declaration of priority areas. These are areas where ambient air quality may be or is being exceeded and requires specific air quality management action (section 18). This Act also enables the declaration of controlled emitters that may only operate in accordance with specified standards (sections 23-25). (Government Gazette 37054, No. 893 of 22 November 2013 lists such activities and includes storage and handling of coal and petroleum products). Section 32 addresses the control of dust, which has been supplemented by National Dust Control Regulations (government gazette no. 36974, no. R. 827 of 1 November 2013). Section 33 specifically makes provision for 'rehabilitation when mining operations cease', while section 34 sets out the way noise is to be controlled. Chapter 5 of the Act covers the licensing of listed activities. Fracking activities whether for shale gas or CBM, will need to adhere to this legislation, as it applies to their operations.

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[30] See eg the United Nations Principles for Responsible Investment (PRI), at http://www.unpri.org.
[31] See www.incite.co.za. The South African Carbon Disclosure Project was launched at COP–17 in Durban during December 2011. See also www.cdproject.net/investormembers.

5.2.7 Laws relating to environmental management; the environmental assessment process and land-use planning and development

(a)General: The National Environmental Management Act 107 of 1998 (NEMA)

The *NEMA* is crafted on the internationally accepted foundation-stone of sustainable development described in 5.2.2 above. It stipulates that:

> *[s]ustainable development requires the consideration of all relevant factors including the following:*
>
> *(i) That the disturbance of ecosystems and loss of biological diversity are avoided; or, where they cannot be altogether avoided, are minimised and remedied;*
>
> *(ii) that pollution and degradation of the environment are avoided, or, where they cannot be altogether avoided, are minimised and remedied;*
>
> *(iii) that the disturbance of landscapes and sites that constitute the nation's cultural heritage is avoided, or where it cannot be altogether avoided, is minimised and remedied;*
>
> *(iv) that waste is avoided, or where it cannot be altogether avoided, is minimised and re-used or recycled where possible and otherwise disposed of in a responsible manner;*
>
> *(v) that the use and exploitation of non-renewable natural resources is responsible and equitable, and takes into account the consequences of the depletion of the resource;*
>
> *(vi) that the development, use and exploitation of renewable resources and the ecosystems of which they are part do not exceed the level beyond which their integrity is jeopardised;*
>
> *(vii) that a risk-averse and cautious approach is applied, which takes into account the limits of current knowledge about the consequences of decisions and actions; and*
>
> *(viii) that negative impacts on the environment and on people's environmental rights be anticipated and prevented, and where they cannot be altogether prevented, are minimised and remedied (Section 2(4)(a)(i)–(viii)).*

The *NEMA* provides a number of different mechanisms to address these relevant factors, but the foundation of these, and the Act as a whole, is a set of bed-rock national environmental management principles based on sustainable development. These principles '. . . apply throughout the Republic to the actions of all organs of state that may significantly affect the environment *and* . . .' (author's emphasis) and the following principles, now elaborated on. The opening principle goes to the heart of environmental management by providing that:

> *[e]nvironmental management must place people and their needs at the forefront of its concern, and serve their physical, psychological, developmental, cultural and social interests equitably.*

The commitment to sustainable development is evident in the subsequent provision, which states that '[d]evelopment must be socially, environmentally and economically sustainable' (section 2(3)). This is followed by the provision that 'sustainable development requires the consideration of all relevant factors. . .', which include the eight sub-factors listed above.

The environmental management principles and, in particular, the relevant factors that must be considered cover a wide spectrum of aspects, and include many of the international environmental law and norms as well as many norms, many of which are included in the international environmental conventions referred to above. These laws and norms include the mitigation hierarchy, the precautionary principle, the preventive principle and the 'polluter pays' principle. Thus, for example, the mitigation hierarchy is reflected in the phrases stating that the disturbance of ecosystems and loss of biological diversity, as well as the disturbance of the landscape and the nation's cultural heritage, are to be '. . . avoided, or . . . minimised and remedied', (Section 2(4)(*a*)(i) and (iii)) and, similarly, that pollution and degradation of the environment avoided or where that is not possible, minimised (section 2(4)(a) (ii)), In addition waste is to be avoided, or if it cannot be altogether avoided, minimised and reused or recycled and where possible disposed of in a responsible manner (section 2(4)(a)(iv)).

The section also suggest that the preventative principle be implemented as does section 2(4)(a)(viii) which requires that the negative impacts on the environment and on people's environmental rights must be anticipated and prevented, or at the very least, minimised and remedied .

Section 2(4)(a)(vii), which states that '. . . a risk-averse and cautious approach [be] . . . applied which takes into account the limits of current knowledge about the consequences of decisions and actions', is particularly relevant to fracking. This section is a clear reflection of the precautionary principle and is consistent with the norm reflected in international law, that precautionary measures should be taken to prevent environmental harm when there is scientific uncertainty about such harm.

The question has been raised: how does one apply a risk-averse and cautious approach in practice, and can one exclude mining for gas in certain areas based on the precautionary principle? How will this principle be applied consistently within and across departments? It is very difficult to answer this question as the precautionary principle, while having found a foothold in international law, is yet by and large untested by our courts. In the *Fuel Retailers* case, it was held that the precautionary approach:

> *is especially important in the light of section 24(7)(b) of NEMA which . . . specifically requires the investigation of the potential impact, including cumulative effects, of the proposed development on the environment and socio-economic conditions, and the assessment of the significance of that potential impact (footnote omitted) (Para 81 at 34F–G).*

It is this writer's view that the precautionary principle will play a central role in any court action which may ensue and further research is required in this regard.

The "polluter pays" principle is reflected in the directive that:

> *[t]he costs of remedying pollution, environmental degradation and consequent adverse health effects and of preventing, controlling or minimising further pollution, environmental damage or adverse health effects must be paid for by those responsible for harming the environment (Section 2(4)(p)).*

There is also an oblique reference to the principle in section 2(4)(e) which states that 'responsibility for environmental health and safety consequences ... exist throughout its lifecycle, This is a reference to cradle to grave responsibility for activities, which responsibility is born by the party undertaking the activity in question.

The public trust doctrine is made manifest in the provision that:

> *[t]he environment is held in trust for the people, the beneficial use of environmental resources must serve the public interest and the environment must be protected as the people's common heritage S 2(4)(o).*

While the principles reflect international trends, they are not exclusively foreign importations. Some of the other principles are peculiar to South Africa and reflect the need to redress the country's *apartheid* past. For example, it is provided that:

> *[e]quitable access to environmental resources, benefits and services to meet basic human needs and ensure human well-being must be pursued and special measures may be*

> *taken to ensure access thereto by categories of persons disadvantaged by unfair discrimination S 2(4)(d).*

The principles are detailed and complex and provide limitless potential for decision-makers and the courts to develop a cohesive body of generally acceptable environmental management practices. Most importantly, the principles are to '. . . guide the interpretation, administration and implementation of this Act, and any other law concerned with the protection or management of the environment.'[32]

The applicability of the principles was considered by the Constitutional Court in the *Fuel Retailers* case, where Ngcobo J stated that:

> *The provisions of NEMA which are relevant to this case and which were relied upon by the applicant are those that contain the national environmental management principles, the general objectives of integrated environmental management and those that deal with the implementation of these principles and objectives.*

The principles were also considered by both the SCA in *Minister of Environmental Affairs and Tourism and Others v Phambili Fisheries* (*Pty*) *Ltd and Another*, 2003 (2) All SA 616 (SCA) (cited hereafter as the *Phambili* case) and (on appeal) by the Constitutional Court in *Bato Star Fishing* (*Pty*) *Ltd v Minister of Environmental Affairs and Tourism and Others* 2004 (4) SA 490 (CC), 2004 (7) BCLR 687 (CC) (cited hereafter as the *Bato Star* case)*.* While the principles in question were concerned with the 'Objective and principles' in section 2 of the *Marine Living Resources Act 18 of 1008*, (the *MLRA*) and not with the *NEMA* principles, the decision is applicable to the *NEMA* principles as well.

The SCA noted that section 2 of the Act obliges the Minister to 'have regard to', a number of objectives and principles listed in section 2(*a*)–(*j*) of the Act when exercising any power under it. It listed these, and paid particular attention to '. . . the need to achieve optimum utilisation and ecologically sustainable development of marine living resources', and '. . . the need to conserve living marine resources for both present and future generations', as well as a transformation component which is central in resolving the dispute in this case, namely, '. . . the need to restructure the fishing industry to address historical imbalances and to achieve equity within all branches of the fishing industry'.[33]

The Constitutional Court, upholding the SCA's decision, held that, 'properly construed, the purpose of the two provisions [sections 2 and 18(5)] was 'to guide and not to fetter' the decision-maker' and, on the facts, held that it was clear that the Chief Director had taken the provisions of section 2 into account.[34] O'Regan J went on to state:

> *The provisions of section 2 and section 18 make it plain that the obligation imposed upon the decision-maker is an obligation to 'have regard to' the factors mentioned in section 2, and to 'have particular regard to' the factor mentioned in the case of section 18(5). The repetition of the requirement of the factor of transformation indicates its importance and the need for special attention to be given to the questions of restructuring and redress in the fishing industry.*

In summary, the *MLRA* principles played a crucial role in determining the outcome of both cases. This approach was later followed and affirmed in the *BP Southern Africa* case, where, in deciding that the application of a certain distance criterion by the provincial department of environmental affairs was reasonable in that case, the Court held:

> *This case requires the principle set out in the Bato Star Fishing case to be applied, i.e. the*

[32] S 2(1)(*e*).
[33] The *Phambili* case (fn 48) at para 24.
[34] The *Bato Star* case (fn 49) at para 29.

department was called upon to strike an equilibrium between a range of competing considerations and followed a route via a distance stipulation to arrive at a decision to which this court should pay due respect (At 157I).

Socio-economic considerations

It should be noted that the above environmental management principles apply alongside other relevant considerations, '. . . including the State's responsibility to respect, protect promote and fulfil the socio-economic rights in Chapter 2 of the Constitution. . .'.[35] This makes it clear that in applying the principles, decision-makers are not only to consider ecological factors but social considerations, such as housing, food, water, social security, well-being and even dignity, all of which are referred to in the Bill of Rights, as well. In so doing, particular attention must be paid to '. . . the basic need[s] of categories of persons disadvantaged by unfair discrimination' (Section 2(1)(*a*)). In *BP Southern Africa* (*Pty*) *Ltd v MEC for Agriculture*, *Conservation and Land Affairs*, 2004 (5) SA 124 (W) at 146I–147I (cited hereafter as the *BP Southern Africa* case) the Court, after comprehensively reviewing and evaluating various *NEMA* provisions, including the principles, stated that the DEA is obliged to have regard to the '. . . effects of proposed activities on the environment, socio-economic conditions and cultural heritage. . .'.[36]

A few further points about the *NEMA* principles should be noted. Firstly, the principles apply to the geographical area of the Republic and to the actions of all organs of state that may significantly affect the environment. The term 'organ of state' is defined in the *NEMA*[37] with reference to the definition in the Constitution, which in turn defines 'organ of state' as:

(*a*) *any department of state or administration in the national, provincial, or local sphere of government; or*

(b) any other functionary or institution –

(i) exercising a power or performing a function in terms of the Constitution or a provincial constitution; or

(ii) exercising a public power or performing a public function in terms of any legislation, but does not include a court or judicial officer.[38]

It must be emphasised that the *NEMA* is a framework Act which has been complemented by a number of subsequent 'specific environmental management Acts' (SEMAs).[39] This phrase is defined[40] to include six statutes, namely, the *Environmental Conservation Act 73 of 1989*); the *National Water Act 36 of 1998* (dealt with above); the *NEM: Protected Areas Act 57 of 2003* (dealt with above); the *NEM: Biodiversity Act 10 of 2004* (dealt with above); and the *NEM: Air Quality Act* and the *NEM: Waste Act 59 of 2008* (the NEM: Waste Act).

Environmental assessment (EA)

Historically environmental assessment legislation has been driven by the Department of Environmental Affairs under environmental legislation. The current legal regime is the June 2010 EA regulations made under sections 24(5) and 44 of the *NEMA* (R 543 (Environmental Impact Assessment regulations); R 544 (List 1); R 545 (List 2); R 546 (List 3) and R 547 (Environmental Management Framework regulations) that came into force on 2 August 2010 in terms of R 664, R 661, R 662, R 663 and R 665 respectively in *Government Gazette* No. 33306, 18 June 2010. R 660 published in the same *Gazette* is a correction and amending notice). There are four sets of

35 S 2(1)(*a*).
36 At 151B.
37 S 1(xii) of the NEMA.
38 S 239 of the Constitution.
39 The enforcement of SEMAs by Environmental Management Inspectors (EMIs) is dealt with in para 26.5.1.
40 S 1 of the NEMA, 'Definitions' 'specific environmental management Act'.

regulations. R 543, 'Environmental Impact Assessment Regulations' is at the heart, setting out the 'procedure and criteria'[41] for carrying out environmental impact assessments and is outlined in some detail below; while R 544, R 545 and R 546, being Listing Notices 1, 2 and 3 respectively, are ancillary in that they set out lists of activities and competent authorities in terms of sections 24(2) and 24D respectively.[42] Finally, R 547, titled 'Environmental Management Framework Regulations' provides for '. . . the compilation of information and maps referred to in section 24(3) of the Act specifying the attributes of the environment in particular geographic areas'.[43]

The *MPRDA* of 2002 makes specific provision for the application of the *NEMA*, and its integrated environmental management provisions in chapter 5 to the mining sector.[44]The bulk of these are contained in Chapter 4, titled 'Mineral and Environmental Regulations'. The provision are further fleshed in Mineral and Petroleum Resources Regulations and specifically in Chapter 2, titled the Mineral and Petroleum Social and Environmental Regulations.[45]

It must, however, be noted that in terms of the 2008 amendment to the *MPRDA*[46] as well as the amendment to the *NEMA* the Minister of Mineral Resources has been given wide powers in respect of environmental matters. The Minister of Mineral Resources will be responsible for implementing environmental legislation and regulations. This will include implementing the provisions of chapter 5 of the *NEMA* . The Minister will be the competent authority for issuing authorisations[47] and may also grant exemptions.[48] Thus this area of law is in a state of flux but the EA regime is applicable to the mining and petroleum sectors although it is the Minister of Mineral Resources who is responsible for its implementation.

It should also be noted that the amendment to the *MRPDA* will also delete all existing provisions in the Act relating to environmental management programmes and the requirements of making financial provisions for during operations rehabilitation and post-closure rehabilitation, when it becomes operative in December 2014. The *NEMA* does make provision for the Minister of Environmental Affairs to promulgate regulations to address 'mine closure requirements and procedures, the apportionment of liability for mine closure and the sustainable closure of mines with an interconnected or integrated impact resulting in a cumulative impact' (section 24(5)(viii)) and 'financial provision' (section 24(5)(ix)). Section 24P also contains provisions relating to financial provision for remediation of environmental damage but they only provide a framework, and therefore require regulations to be promulgated to flesh out the details. The Minister needs to engage in this process as a matter of urgency to ensure financial provisions for rehabilitation to continue to form part of mining operations.

It should be noted that Section 31A – Q of *NEMA* makes provision for an environmental inspectorate that is tasked with monitoring and enforcement. The Draft NEM Amendment Bill (B 26—2013) proposes extending the inspectorate. The Minister of Mineral Resources may appoint minerals resource inspectors, from his/her staff at the department. While this is a positive step, the Minister of

[41] Reg 2 'Purpose of the Regulations'.
[42] Ss 24(2) and 24D of the NEMA have been outlined in para 10.3.2.4 above.
[43] Reg 2(1)(*a*) 'Purpose of Regulations'.
[44] MPRDA 28 of 2002, section 38(1)(a)and (b)

[45] Government Gazette 26275, Notice R527, 23 April 2004

[46] Mineral and Petroleum Resources Development Act 49 of 2008 which deletes section 38-42,of the primary act and inserts section 38A, specifies the Minister's responsibility for implementing environmental legislation.

[47] Section 24C(2A) of the *NEMA* and 38A of the *MPRDA* as from 7 December 2014

[48] Section 24M of the *NEMA*

Minerals Resources is not obliged to do so and it is questionable whether her department has the necessary capacity.

A further important provision of the *NEMA* that could potentially impact on fracking activities is section 28 of *NEMA* headed, 'The Duty of Care'. It is a catch-all provision for anyone who may pollute or degrade the environment. Section 28(1) states that:

Every person who causes or may cause significant pollution or degradation of the environment must take reasonable measures to prevent such pollution or degradation from occurring, continuing or recurring. If such pollution or degradation cannot be prevented then appropriate measures must be taken to minimise or rectify such pollution. The provisions of section 28 apply to land owners, occupiers and those with rights to use or are in control of the land. The section sets out the type of measures that may be taken and also enable the Department of Environmental Affairs to issue directives as to the measures needed or where that fails to take action itself. In addition, should the Department fail to act, section 28 also enables any person to demand action from the Department. If the Department does not act, then it also allows the person demanding action to approach the courts for order an directing the Department to act.

5.2.8 Cooperative governance and law

<u>Introduction: Principles of cooperative governance</u>

Fracking is first and foremost a mining activity and the question arises whether the Department of Mineral Resources, which regulates fracking under the *MPRDA*, also has to adhere to or take cognisance of laws administered by other government departments. This is because fracking invokes the interest of not only national government departments, such as the departments of mineral resources, water, energy, environment, agriculture, transport, and so on, but also provincial and local agencies mainly because of their planning laws. Thus there are interests and laws at national level (for example the Department of Energy, which administers the *National Energy Act*), provincial and local levels, as provinces and local authorities administer planning laws relating to spatial planning, zoning and so on.

The starting point in considering the respective powers and functions of these various agencies in the context of fracking is the *Constitution*, which sets out the respective powers of national, provincial and local authorities in specific chapters. But all of these chapters must be read with Chapter 3 of the *Constitution,* titled 'Co-operative Government'. It commences by stating:

> *40 (1) In the Republic, government is constituted as national, provincial, and local spheres of government <u>which are distinctive, interdependent and interrelated</u>. (Author's underlining)*
>
> *(2) All spheres of government must observe and adhere to the principles of this Chapter and must conduct their activities within the parameters that the Chapter provides*

The next section (41(1)) sets out a set of principles of cooperative government and intergovernmental relations for the resolution of intergovernmental disputes in a set of general principles. Of particular relevance to fracking is the co-operative government principle that:

All spheres of government and all organs of state within each sphere must –

> *(g) exercise their powers and perform their functions in a manner which does not encroach on the geographical, functional or institutional integrity of government in another sphere (S 41(1)(g)).*

This principle was upheld by the Constitutional Court in the case of *Ex parte*: *Chairperson of the Constitutional Assembly*, *In re*: *Certification of the Constitution of the Republic of South Africa*, 1996 (10) BCLR 1253 (CC), 1996 (4) SA 744 (CC) paras 287–292 at 1346–1347.

However the Constitutional Court has also noted that two government departments may be responsible for the same functional area, stating:

> *Where two legislatures have concurrent powers to make laws in respect of the same functional areas, the only reasonable way in which these powers can be implemented is through cooperation (In re: The National Education Policy Bill No 83 of 1995 1996 4 BCLR 518 (CC), 1996 3 SA 289 (CC) par 34).*

In the same vein the Constitutional Court commented on the logical place of inter-governmental relations in a system of multi-tiered government:

> *Intergovernmental cooperation is implicit in any system where powers have been allocated concurrently to different levels of government (In re: Certification of the Constitution of the RSA, 1996, 1996 10 BCLR1253 (CC), 1996 4 SA 744 (CC) par 290).*

The above mentioned principle was also considered in *The Premier of the Province of the Western Cape v The President of the RSA* 1999 (4) BCLR 382 (CC), where the Constitutional Court pointed out that this subsection:

> *. . . is concerned with the way power is exercised, not with whether or not a power exists. That is determined by provisions of the Constitution. . . and. . . although the circumstances in which section 41(1)(g) can be exercised to defeat the exercise of a lawful power are not entirely clear, the purpose of the section seems to be to prevent one sphere of government using its powers in ways which would undermine other spheres of government, and prevent them from functioning effectively (Paras 57–58 at 401–2).*

Chapter 3 is particularly relevant in the fracking context because it reflects a fundamental departure from the past in that the three traditional spheres of government – national, provincial and local government – are no longer regarded as hierarchical tiers with national government at the helm, but rather as three 'distinctive, interdependent and inter-related' spheres of government.[49] This was borne out in *Fedsure Life Assurance Ltd v Greater Johannesburg Transitional Metropolitan Council*,[50] a case concerning the imposition of a uniform rates system by the transitional metropolitan council in its four metropolitan substructures. Although made in relation to the Interim Constitution, the Constitutional Court's comments on local government are as applicable to the final Constitution. It stated that:

> *. . . the [interim] Constitution recognises and makes provision for three levels of government – national provincial and local. Each level of government derives its powers from the interim Constitution although, in the case of local government, the powers are subject to definition and regulation by either the national or the provincial governments which are the 'competent authorities' for enacting such legislation (Para 35 at 1476).*

In finding that the law-making powers of local authorities were not subject to judicial review under the administrative justice clause of the Interim Constitution, the Court went on to hold that 'the constitutional status of a local government is thus materially different to what it was when parliament was supreme, when not only the powers but the very existence of local government depended on superior legislatures'.[51] Moreover, Kriegler J, in a minority judgment, reviewed in some detail the restructuring of local government under the new constitutional dispensation and found that '. . . for the

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[49] S 40(1) of the *Constitution.*
[50] 1998 (12) BCLR 1458 (CC) (cited hereafter as the *Fedsure Life Assurance* case).
[51] Para 38 at 1477.

first time in our history, provision was made for autonomous local government with its own constitutionally guaranteed and independent existence, powers and functions'.[52]

How the relationship between local, provincial and national spheres of government has turned out in the environmental field is fleshed out below, by, amongst other things, referring to cases dealing with planning and mining law respectively.

National legislative competence

The *Constitution* provides that national Parliament may pass legislation on any matter, including a matter referred to in Schedule 4, but excluding a Schedule 5 matter unless it is a matter in which it can specifically intervene (Section 44 (1)(*a*)(ii)). However there are certain matters in which Parliament can intervene. Thus national Parliament enjoys 'residual competence', in that it has exclusive legislative competence with respect to all matters that are not expressly assigned to the concurrent or exclusive competence of provincial legislatures. Water and minerals, for example, are not mentioned in these schedules, so national government has exclusive competence to deal with these.

Provincial legislative and executive competence

The legislative competence of the nine provincial legislatures is provided for in section 104 of the Constitution, which entitles provinces to pass legislation not only with regard to Schedules 4 and 5 matters, but also as regards '. . . any matter outside those functional areas and that is expressly assigned to the province by national legislation' (Sect 104(1)(*b*) of the Constitution).

The provinces thus exercise concurrent competence for national government regarding the items enumerated in Schedule 4 and enjoy exclusive competence in respect of those items listed in Schedule 5. "Environment" is listed in Schedule 4 and is thus a concurrent matter.

Local Authority powers

Of relevance to fracking activities is the newly-found independence of local authorities. This is emphasised in the opening section of Chapter 7 of the *Constitution*, which deals with local government. It states that:

> [*a] municipality has the right to govern, on its own initiative, the local government affairs of its community, subject to national and provincial legislation, as provided in the Constitution S 151(3))*
>
> *and*
>
> *[t]he national or provincial government may not compromise or impede a municipality's ability or right to exercise its powers or perform its functions.*[53]

This was echoed in the *Fedsure Life Assurance* case referred to above, where the Constitutional Court pointed out that the constitutional status of local government is materially different to what it was when Parliament was supreme. The Court held that, while previously the powers of local government depended on superior legislatures, this is no longer the position, stating that:

> *Local governments have a place in the constitutional order, have to be established by the competent authority, and are entitled to certain powers, including the power to make by-laws and impose rates (Para 38 at 1477B–D).*

The question that arises is how this newly found independence of local authorities is relevant to fracking activities. This can be illustrated by outlining two important cases. The first, concerning a

[52] Para 126 at 1501H.
[53] S 151(4).

planning law issue, is Johannesburg Metropolitan Municipality v Gauteng Development Tribunal and Others (2010 (6) SA 182 (CC), 2010 (9) BCLR 859; and 2010 (2) SA 554 (SCA), 2010 (2) BCLR 157 (SCA)) ("Johannesburg Metropolitan Municipality case")

The *Johannesburg Metropolitan Municipality* case concerned the respective functions of the three spheres of government, in particular that between local and provincial government. The dispute concerned the constitutional validity of Chapters 5 and 6 of the *Development Facilitation Act 67 of 1995 (the DFA),* which provides for the establishment of provincial Development Tribunals and, among other things, empowers (in this case) the Gauteng Development Tribunal to approve applications for the rezoning of land and the establishment of townships. The relevant municipal ordinance empowered the City to determine the same issues.

The question before the Court was whether the Constitution empowered the municipal or the provincial sphere of government, or both, to exercise powers relating to the rezoning of land and the establishment of townships. The City contended that these powers are components of 'municipal planning', a function assigned to municipalities by section 156(1) of the Constitution, read with Part B of Schedule 4 to the *Constitution*, described below. The Gauteng provincial authority argued that the contested powers were elements of 'urban and rural development' under Part A of Schedule 4 to the *Constitution*, a functional area falling outside the executive authority of municipalities.

The Constitutional Court unanimously held that the relevant chapter of the DFA was invalid. It pointed out that the constitutional scheme, together with the different contexts in which the term 'planning' is used, clearly indicates that the term has different meanings. It went on to point out that the Constitution confers different planning responsibilities on each of the three spheres of government in accordance with what is appropriate to each sphere. It also provides that, barring areas of concurrent competence, each sphere of government is allocated separate and distinct powers which it alone is entitled to exercise, unless exceptional circumstances exist. In this context, the Court held that:

> *[i]t is . . . true that the functional areas allocated to the various spheres of government are not contained in hermetically sealed compartments. But that notwithstanding, they remain distinct from one another. This is the position even in respect of functional areas that share the same wording like roads, planning, sport and others. The distinctiveness lies in the level at which a particular power is exercised. For example, the provinces exercise powers relating to provincial roads whereas municipalities have authority over municipal roads. The prefix attached to each functional area identifies the sphere to which it belongs and distinguishes it from the functional areas allocated to the other spheres.*

In this instance, it was held that the term 'municipal planning' should be understood to assume the particular well-established meaning it has long enjoyed, namely, 'planning which includes the zoning of land and the establishment of townships', and it was in this sense that the term was used in the *Constitution*, since there is nothing in the *Constitution* indicating that it carried a meaning other than its common meaning.[54]

A related issue considered by the Court was whether the *Constitution* allocated the same power to the provinces. In concluding that it did not, Jafta J placed emphasis on the particular role of municipalities within government, holding that the Constitutional Scheme envisages a degree of autonomy for the municipal sphere, in which municipalities exercise their original constitutional powers free from undue interference from the other spheres of government. Of relevance was the constitutional requirement

[54] The *Johannesburg Metropolitan Municipality Constitutional Court* case (fn 70) at para 57.

that each sphere must respect the status, powers and functions of government in the other spheres and must not assume any power or function except those conferred on it in terms of the *Constitution* (section 41(1)).[55] This is amplified by section 151(4), which precludes the other spheres from impeding or compromising a municipality's ability or right to exercise its powers or perform its functions.[56] Accordingly, it could not be said that the *Constitution* assigned the same function to the Provincial Sphere under the power of 'urban and rural development'.

It followed, therefore, that the impugned chapters of the DFA were inconsistent with section 156 of the Constitution read with Part B of Schedule 4, and were declared invalid by the Court.

A related case where the equivalent status of provinces in relation to national government was in issue was *City of Cape Town v Maccsand* (*Pty*) *Ltd and Others (*2010 (3) SA 63 (WCC) and 2011 (6) SA 633 (SCA) (*Maccsand 1)* and the Constitutional Court in *Maccsand* (*Pty*) *Ltd and Another v City of Cape Town and Others* (2012 (4) SA 181 (CC); 2012 (7) BCLR 690 (CC) (12 April 2012)

The question before the Court was whether the granting of a mining right under the nationally administered *MPRDA* overrode the need to obtain the requisite zoning authorisations under the Western Cape's provincial *Land Use Planning Ordinance 15 of 1985* (*LUPO*).

The Cape High Court held that the competence to regulate mining under the national sphere did not trump local government's functional competence of municipal planning, and thus authorisations under both the *MPRDA* as well as the *LUPO* were necessary.[57] The SCA upheld this view, stating among other things that a municipality under the present constitutional dispensation:

> *is not a mere creature of statute, otherwise moribund, save if imbued with power by provincial or national legislation but an organ of State that B enjoys original and constitutionally entrenched powers, functions, rights and duties that may be qualified or constrained by law and only to the extent the Constitution permits.*[58]

It went on to deal with section 152 of the Constitution, as well as Part B, Schedule 4 pointing out that:

> *It will be apparent, then, that, while national and provincial government may legislate in respect of the functional areas in Schedule 4, including those in Part B of that schedule, the executive authority over, and administration of, those functional areas is constitutionally reserved to municipalities. Legislation, whether national or provincial, that purports to confer those powers upon a body other than a municipality will be constitutionally invalid.*

The implication for fracking is that the issue of a licence by the Department of Mineral Resources is by no means the final word on the matter. The respective national/provincial environmental (including water) laws, as well as, any planning laws of the province where fracking may occur need to be adhered to, as well as any local authority plans that may be relevant. In this regard, fracking will not take place in only one province, as areas which could potentially be fracked cross the Western, Eastern and Northern Cape provinces and consequently will cover numerous local authority jurisdictions. Thus the need for effective cooperative governance over this activity is critical to ensure proper legislative and regulatory compliance.

[55] At para 56.
[56] At para 58.
[57] The *Maccsand 1* case (fn 71) at 20. See further paras 9.4.1 and 17.3.2 on mining law for further discussion of these cases. See also *Swartland Municipality v Louw NO and Others* Case 2010 (5) SA 314 (WCC) and *Louw NO and Others v Swartland Municipality* (650/2010) [2011] ZASCA 142 (23 September 2011).
[58] The *Maccsand 2* case (fn 71) at para 22.

The Intergovernmental Relations Framework Act 13 of 2005

Chapter 3 of the Constitution also provides that an Act of Parliament must be enacted to provide 'for structures and institutions to promote and facilitate settlement of intergovernmental relations' as well as to provide for 'appropriate mechanisms and procedures to facilitate the settlement of intergovernmental disputes'. To this end, Parliament enacted the *Intergovernmental Relations Framework Act 13 of 2005*, which has as its objective the furtherance of the principles of cooperative government as set out in Chapter 3 of the *Constitution*, by providing a framework for national, provincial and local governments and all organs of state to facilitate coordination and implementation of policy and legislation (section 4). These spheres of government are to achieve these objectives by, amongst other things, taking into account the circumstances, material interests and budgets of other governments and organs of state in other governments; consulting other affected organs of state in accordance with formal procedures, and in so doing realise national priorities.[59]

5.2.9 Administrative law issues

The author was asked to comment specifically on the question of legal standing or *locus standi*. Prior to the advent of the *Constitution*, the requirement of legal standing to sue constituted a considerable obstacle to persons wishing to enforce and implement environmental laws. This was because, in a triumvirate of cases decided at the turn of the twentieth century, namely *Patz v Green & Co*,[60] *Bagnall v Colonial Government*,[61] and *Dalrymple v Colonial Treasurer*,[62] the general requirement namely that an individual required a special interest peculiar to himself before being given a hearing, had been imported into South African law from English law. This severely curtailed the ability of individuals and/or groups to litigate in the public interest, and the ramifications were evident throughout the field of public interest law. In the environmental context, the strictures of the requirement were illustrated in *Von Moltke v Costa Aerosa*,[63] where the applicant, a nature lover and resident of Llandudno, a seaside suburb of Cape Town, sought an interdict prohibiting a developer from commencing building operations in the form of bulldozing of vegetation at Sandy Bay, a popular nudist beach a few kilometers from the applicant's residence. The operations appeared illegal, as the requisite planning permission had not been obtained under the then applicable planning legislation, namely the Township Ordinance of the Cape. The Court nevertheless refused to entertain the applicant's case, holding that '. . . the party seeking relief must show some injury, prejudice or damage or invasion of right peculiar to himself and over and above that sustained by the members of the public in general'.[64] The courts thus were reluctant to entertain cases brought in the general public interest, whether of an environmental nature or otherwise.[65]

The *Constitution* has considerably relaxed the *locus standi* requirement, which has traditionally been a severe obstacle to non-governmental organisations or concerned citizens wishing to bring an action where the environment is potentially threatened.[66] The 'Enforcement of Rights' section of the Bill of Rights dramatically changes the situation, setting out the persons who may approach a competent

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[59] S 5.
[60] 1907 TS 427 at 432.
[61] 1907 24 SC 470.
[62] 1910 TS 372 at 386.
[63] 1975 (1) SA 255 (C) (cited hereafter as the *Von Moltke* case).
[64] The *Von Moltke* case (fn 220) at 258.
[65] See generally *Roodepoort-Maraisburg Town Council v Eastern Properties* (*Prop*) *Ltd* 1933 AD 87; *South African Optometric Association v Frame Distributors (Pty) Ltd* 1985 (3) SA 100 (O); *Bamford v Minister of Community Development and Auxiliary Services* 1981 (3) SA 1054 (C).
[66] See also *Wildlife Society v Minister of Environmental Affairs and Tourism* 1996 (3) SA 1095 (Tk).

court alleging that a right in the Bill of Rights has been infringed or threatened.[67] Included in the list of such persons are:

> . . .
> (*c*) anyone acting as a member of, or in the interest of, a group or class of persons;
> (*d*) anyone acting in the public interest; and
> (*e*) an association acting in the interests of its members.[68]

Thus, individuals or NGOs may now approach a court to bring an action in the public interest. It should be noted, however, that this is only in respect of rights contained in the Bill of Rights, but this would include the environmental right.

The impact of the liberalisation of the legal standing requirement by the new constitutional dispensation in the environmental context has been illustrated in a number of reported cases. In *Minister of Health & Welfare v Woodcarb (Pty) Ltd and Another*,[69] (an air pollution case), the Court considered the question of *locus standi* at some length, and held that the whole purpose of the legislation was to control the installation and use of scheduled processes under the then applicable *Atmospheric Pollution Prevention Act 45 of 1965*, and that the applicant was implicitly entitled to bring this particular interdict application.[70] More specifically, the Court held that the applicant could rely on the public interest clause in the *Interim Constitution*[71] for *locus standi* in his application for an interdict.[72]

In *Wildlife Society of Southern Africa and Others v Minister of Environmental Affairs and Tourism of the Republic of South Africa*,[73] the Court similarly had no problem in recognising the *locus standi* of the Society under the *Interim Constitution*.[74] It went further, saying that even if there are circumstances where the section is not applicable and where a statute imposes an obligation on the State to take certain measures to protect the environment in the interests of the public, a body such as the Society should have *locus standi* in common law to apply for an order to compel the State to carry out its statutory obligations.[75]

The *NEMA* builds on this foundation by further elaborating rules regarding legal standing in environmental matters.[76] A section headed ‘Legal standing to enforce environmental laws’ extends and facilitates matters for which relief may be sought in different ways.[77] Firstly, it amplifies the circumstances in which relief may be sought to include:

> . . . any breach or threatened breach of any provision of this Act, including a principle contained in Chapter 1, or any other statutory provision concerned with the protection of the environment or the use of natural resources . . .[78]

It thus extends the constitutional clause, which only grants *locus standi* for threats to rights in the Bill of Rights as mentioned above. Secondly, it tailors the constitutional provision to accommodate

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67 S 38 of the Constitution.
68 S 38(*c*)–(*e*).
69 1996 (3) SA 155 (N) (cited hereafter as the *Woodcarb* case).
70 At 159–162.
71 S 7(4) of the Interim Constitution of the Republic of South Africa, Act 200 of 1993 (cited hereafter as the Interim Constitution).
72 The *Woodcarb* case (fn 228) at 164G.
73 1996 (3) SA 1095 (Tk).
74 At 1104I–J.
75 At 1105A–B.
76 Ss 32 and 33 of the NEMA respectively.
77 S 32.
78 S 32(1).

environmental needs, by listing the persons or groups of persons who may seek relief. These are applicable where the relief sought is:

(*a*) in that person's or group of persons' own interest;

(*b*) in the interest of, or on behalf of, a person who is for practical reasons, unable to institute such proceedings;

(*c*) in the interest of or on behalf of a group or class of persons whose interests are affected;

(*d*) in the public interest; and

(*e*) in the interest of protecting the environment.[79]

Finally it should be noted that these provisions apply in respect of court proceedings only and not to other tribunals. However, the Bill of Rights, which confers standing on persons listed in section 38 to litigate, includes the pursuit of class actions[80] when a right in the Bill of Rights has been infringed or threatened.[81]

Conclusion

An issue not raised in the terms of reference for this section is the question of financial liability and compensation for environmental damage that may occur. A host of legal instruments, ranging from a rehabilitation fund to financial guarantees, could be considered to ensure that potential damage is covered. The trick is to have these in place before any exploration commences and to determine the period of time that they would be operative, for obvious reasons. This aspect requires further research. To reiterate a point made above, *NEMA* does have an Inspectorate and it is planned that the Minister of Mineral Resources will supplement this inspectorate for mining and, hopefully the exploitation of petroleum resource purposes. What is less clear is the capacity of DMR staff to take on the role of inspectors and whether inspectors from the Department of Environmental Affairs can continue to inspect activities that will fall under the remit of the DMR and its inspectors in the absence of inspectors appointed by the Minister of Mineral Resources. Given that the Minister's inaction would be able to defeat the objects of enacted legislation, it is arguable that Department of Environmental Affairs' inspectors could continue until such time as the Minister of Mineral Resources appointed the necessary officials.

Finally, this section has shown that the matter of developing an unconventional oil and gas monitoring protocol raises a broad-ranging set of legal and governance considerations. More importantly, it has shown that there is no appropriate national body that could carry out an independent, transparent, integrated and cooperative monitoring function to regulate and monitor unconventional oil and gas extraction, and to receive and archive data from oil and gas companies. At the end of the day a priority should be to put in place an independent, credible body that is well-capacitated and enjoys the confidence of the entire spectrum of the South African public. If such unconventional oil and gas extraction goes ahead it is suggested that an independent statutory body be established under the auspices of the Minister of Water and Environment to undertake a regulatory and monitoring function.

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79 *Supra*.

80 On class actions generally, see *Permanent Secretary, Department of Welfare, Eastern Cape, and Another v Ngxuza and Others* 2001 (4) SA 1184 (SCA).

81 S 38 of the Constitution states that [t]he persons who may approach a court are –

(*a*) anyone acting in their own interest;
(*b*) anyone acting on behalf of another person who cannot act in their own name;
(*c*) anyone acting as a member of, or in the interest of, a group or class of persons;
(*d*) anyone acting in the public interest; and
(*e*) an association acting in the interest of its members.

5.3 Limitations to monitoring approaches

The monitoring approaches discussed in this protocol takes into account the current legislative framework, but there are certain limitations in terms of executing the proposed monitoring protocols. These include mainly the lack of legislation governing unconventional oil and gas extraction operations as well as limited human and financial resources at the government departments that are responsible for monitoring.

South Africa does not yet have fracking-specific legislation, policy or regulations in place to deal with this unprecedented activity (Havemann, 2011). Unconventional oil and gas extraction may impact on a diverse array of aspects, ranging from biodiversity impacts (land fragmentation and isolation) to water-related impacts and socio-economic impacts.

It is thus imperative that any future decisions on licensing of unconventional oil and gas extraction activities be based on the principle of sustainable development, whereby *NEMA* dictates that a “risk averse and cautious approach is applied, which takes into account the limits of current knowledge about the consequences of decisions and actions” (*NEMA*, 1998).

Although different departments have the legal mandate to perform monitoring functions, these departments are not necessarily in a position to perform ongoing monitoring that would be legally defensible, as they may be hampered by lack of institutional capacity to perform adequate monitoring, or by lack of funding. The monitoring approach adopted by government should encourage integration of information across departments and should encourage public transparency. Additionally, the monitoring functions of different departments should ideally be integrated if unconventional oil and gas extraction is to be properly managed. Such integration across departments would require a functioning system of cooperative governance. In the absence of this, it is highly recommended that an independent agency be established to perform this task, and to store, interpret and disseminate data.

The discussions on the monitoring protocol for each selected aspect (section 5.4) will take into account the limitations stipulated above, and will suggest solutions where possible.

5.4 Monitoring protocol per aspect

The following sections address the monitoring protocol for each aspect: where section 5.4.1 discusses surface water, section 5.4.2 groundwater, section 5.4.3 seismicity, section 5.4.4 vegetation and section 5.4.5 socio-economics.

5.4.1 Surface water

Surface water monitoring is a legal requirement as indicated in the *National Water Act* (1998). The collection of accurate and reliable data through monitoring is a key component of environmental management, and forms the basis of plans and actions needed to address expected environmental impacts. Information and data from monitoring can further be used in negotiations with authorities for permit applications and water use licence applications (DWAF, 2006). It can also be used to inform Society about the state of the surface waters subjected to the impacts of unconventional oil and gas extraction and to hold oil and gas companies accountable if pollution occurs.

It is important to note that large areas where unconventional oil and gas development is being proposed in South Africa have very little baseline data on the surface water systems. This is mostly due to the temporary nature of the surface water systems (rivers, pans and wetlands), and the fact that very little development, requiring water use licenses, has occurred in these areas. In cases where data is insufficient the precautionary principle should be applied if there is any possibility that the biodiversity of the surface water systems is threatened in any way, especially where the impacts could be irreversible (Section 2.4: vii of *NEMA*, 1998). For example, if springs are present in these areas special caution is needed because these springs are the lifeblood of arid regions with surface water biodiversity relying on their existence. When using water from spring habitats, sufficient flow should remain to support the existing habitats instead of taking the entire flow for human use or development (Darwall et al., 2009).

Most catchment areas identified for unconventional oil and gas extraction are already stressed due to the demand currently outstripping supply and the pollution of water resources (Muller, 2013). Small streams are particularly vulnerable and should be protected against over extraction in order to protect aquatic biota, and from current water uses such as watering of livestock etc. Aspects such as stream frequency, stream permanency, stream flow intermittency, river condition and the condition of wetlands and pans are all important aspects that would influence the severity of the impact on surface water resources in the area of concern.

No details on where the sand, for use as proppant, is to be obtained for the fracturing process. The possible removal of sand, if the type is suitable for use as proppant, from riverbeds in the semi-arid to arid regions could impact on the alluvial aquifers present in some of the rivers.

Aim of monitoring surface water

The aim of monitoring surface water is to minimise, control and mitigate impacts from unconventional oil and gas extraction. The timely implementation of an appropriate monitoring programme would provide South Africa with a valuable opportunity to detect and report on the impacts that unconventional oil and gas extraction may have on the country's surface water in a legally defensible manner. It is critically important that a dynamic monitoring protocol be developed, one that could respond to changes in extraction processes and water management practices during the various phases of the unconventional oil and gas development process.

Monitoring is furthermore a requirement of government under the National Water Resources Strategy of South Africa (DWA, 2013d). Chapter 14 of the National Water Act (1998) also advocates the:

"establishment of national monitoring systems; whose purpose it is to facilitate the continued and co-ordinated monitoring of various aspects of water resources by collecting relevant information and data" (DWA, 2013d).

"A healthy ecosystem is sustainable and resilient to stress, maintaining its ecological structure and function over time similar to the natural (undisturbed) ecosystems of the region, with the ability to recover from disturbance, while continuing to meet social needs and expectations" (Stantec Consulting Ltd, 2005).

To ensure that surface water resources remain sustainable it is essential that monitoring is done on a regular basis. It is important that a baseline, which considers water quantity, quality and habitat integrity, is established prior to the commencement of any oil and gas exploration or extraction. The baseline data should cover all four seasons and, if possible, a wet and dry year in the arid to semi-arid regions. The high natural variability in these regions in most environmental parameters necessitates long-term monitoring before exploration and extraction commences in order to compare data collected before, during and post extraction. The South African water quality guidelines should serve to determine the level of parameters to be measured as some areas have naturally high values in some parameters due to factors such as local geology. Where resource quality objectives (obtainable from DWA) have been completed for the surface water component, these should serve as a guideline for measuring impacts.

The monitoring protocol suggested by Wilderman and Woodward (2010) (Figure 33) will be used to guide the discussion on surface water monitoring for unconventional oil and gas mining in this report.

Data management

The efficient management and safe storage of data are essential prerequisites for a successful monitoring programme (DWAF, 2008) and it is therefore important that proper data management is ensured. Currently the Department of Water Affairs, as the custodian of South Africa's water resources, keeps records of water quality, hydrology, and river health under the Directorate Resource Quality Services. Surface water data, including streamflow, rainfall, evaporation and reservoirs, are available in the HYDSTRA, an integrated water resources management software database. Fitness for use data are housed in the National Microbial Water Quality Monitoring Programme, National Eutrophication Monitoring Programme, National Toxicity Monitoring Programme, River's database, Water Management System (WMS), HYDSTRA and GIS. It is however uncertain whether the current records would be sufficient to be used as baseline data for all proposed unconventional oil and gas mining areas.

Data and information collected as part of the monitoring of unconventional oil and gas extraction must be kept up to date, interpreted and made available to all. If the DWA does not have the capacity at present, an independent entity would need to manage, archive and disseminate the information collected during the monitoring programme for unconventional oil and gas extraction.

The DWA has however indicated in the National Water Resource Strategy that it plans to:

> *"Put in place, by 2019, a system for the effective collation of data from all water sector institutions, including Catchment Management Agencies (CMAs), into an easily accessible national water resources information system"* (DWA, 2013d). "*There is an urgent need for a well-designed, coordinated and managed programme for collecting, assessing and disseminating data and information on water recorded by all entities in the water sector, including state departments, provincial governments, municipalities, water management institutions and water services authorities and providers, as well as by water users*" (DWA, 2013d).

Important aspects to be kept in mind in connection with surface water monitoring data are:

- A central database for all data is needed and it should be located at a reliable institution and be accessible to all.
- Collected data should be made available to all interested parties, government departments as well as to oil and gas companies. Monitoring records kept by oil and gas companies should also be accessible to all.
- Good record keeping is an essential part of quality assurance. Original datasheets should be kept for as long as possible. It is also vital that the transcription of data from data

sheets to electronic format is accurate and that this is done by a competent person who understands the data and who is capable of data interpretation (DWAF, 2008).

- Data needs to be examined for any irregularities immediately after collection and any identified impacts should be communicated to the relevant government department and to the company causing the impact as soon as possible.

The data requirements would differ for each of the life cycle phases of unconventional oil and gas extraction and this should be taken into consideration when a water monitoring protocol is developed.

Quality assurance and quality control

To ensure the collection of good quality data during surface water monitoring:

- The sampling should be undertaken by an accredited institution and accredited and appropriately trained individuals;
- The appointed institution needs to be unbiased and independent and should not be connected to any of the interested parties;
- Water quality samples need to be sent to an accredited/unbiased laboratory for analysis. Samples should also regularly be sent to other accredited laboratories for verification;
- In situ water quality samples must be taken using calibrated meters. In situ water samples should regularly be tested by an accredited laboratory for verification to determine if meters used are calibrated correctly;
- Sampling and handling methods used need to be clearly documented.
- Results should be compared with the resource quality objectives, water quality standards and/or baseline data if available;
- Reliable and tested methods, approved by DWA who is the legal custodian of South Africa's water resources, should be used to enable the comparison of data from repeated sampling; and
- Data must be interpreted by individuals experienced in the particular field (e.g. water quality, fish), geographic locality and the type of system (wetland, non-perennial river) sampled.

Monitoring Protocol for surface water resources:

A monitoring protocol for surface water resources is proposed in Table 61**,** followed by a brief discussion.

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Table 61: Monitoring framework for surface water

<table>
<tr><th>Phases</th><th>Before exploration</th><th>During exploration</th><th>During extraction</th><th>After extraction</th></tr>
<tr><td>Possible impacts of concern that needs to be monitored (WHY?)</td>
<td>No possible impacts were identified during the pre-exploration phase.
It is, however, important to gather appropriate baseline information during this phase.</td>
<td>Quality
Increased runoff of contaminants such as diesel or constituents from fracking fluid. [1]
Water abstraction could lead to deterioration of water quality[2] in isolated pools.
Water quality deterioration due to sewage effluent from human settlements at exploration sites entering streams.
Quantity
Removal of sand/sediment from rivers for proppant use would influence alluvial aquifers.
Water abstraction in conflict with current users.
Reduction of stream flow in perennial rivers.</td>
<td>Quality
Various sources of pollutants may contaminate surface water or have an impact on aquatic biota[3-7].
Flowback water can contain high levels of TDS, waste water treatment works do not have the capacity to remove high levels of TDS, which could impact on receiving waterbodies.
Sewage effluent from drill pads could contaminate surface water systems.
Toxic or carcinogenic chemicals in fracturing fluid cocktail could contaminate surface water.
Increase in sediment could lead to high turbidity and associated impact on biota and water quality.
Quantity
Water needed for hydraulic fracturing may impact on the natural hydrology of the resources.
Possible sand removal would impact on available surface water, especially during drought periods, in small tributaries and in non-perennial rivers.</td>
<td>Quality
Long term impacts of chemical pollutants on surface water uncertain, it may impact negatively on aquatic biota and fish.
Reduced fitness and health of fishes[9].
Fish kills[9, 10].
Reduction in the availability of food sources for fish e.g. invertebrates.
Bioaccumulation of toxic substances in fish tissue[8, 11, 12], could also have an effect on food web.</td></tr>
</table>

Table 61: Monitoring framework for surface water continued.

Phases	Before exploration	During exploration	During extraction	After extraction
Possible impacts of concern that needs to be monitored (WHY?) continued.	• No possible impacts have been identified during the pre-exploration phase. • It is, however, important to gather appropriate baseline information during this phase.	**Habitat** • Vibrations from seismic surveys may have an impact on invertebrate and fish abundance. • Increased sediment delivery to rivers would alter available habitat for biota. • Flash floods due to increased overland flow to rivers would increase disturbance to aquatic biota. • Fragmentation of aquatic habitat due to road crossings may disrupt fish migrations for feeding and breeding. • Loss of critical refuge habitat for biota during dry periods[8]. • Loss of biota diversity due to the combined effect of increased sedimentation, turbidity and fragmentation[8]. • Reduction in the fitness and health of aquatic biota due to increased predation, intra- and interspecific competition and crowdedness in isolated pools.	**Habitat** • Destruction of pans results in genetic isolation of invertebrates. • Improper construction of pipelines could cause erosion, increasing sediment transport to surface water bodies and impacts on habitat available for biota. • Change in land use could isolate rivers and pans, resulting in genetic isolation, a reduction in number of refugia, and a disruption of migrating routes of birds, amphibians, invertebrates and other biota [11]. • Flash floods due to increased overland flow to rivers would increase disturbance to aquatic biota [8]. • Loss of critical refuge habitat during dry periods [8]. • Loss of critical passage habitat e.g. riffles and runs that connect pools. Lead to e.g. loss of mobility, reduced availability of food, fragmentation and isolation of fish assemblages.	**Habitat** • Reduced habitat quality due to exposure to toxic substances.
Aspects that need to be monitored (WHAT?)	**Quality** • Baseline data for water quality (T, conductivity, TDS, oxygen, turbidity, barium, strontium, chloride). Include chemicals present in fracking fluids to be used in exploration and extraction process. • Baseline Present Ecological State (PES) of relevant indices in rivers, wetlands and pans as prescribed by the DWA. • Baseline data on *E. coli* and total coliform levels in surface water systems need to be determined.	**Quality** • Parameters to be monitored include T, conductivity, pH, Dissolved oxygen, turbidity, TDS and possibly chloride, strontium and barium (if elevated TDS is found). Barium (Ba) and Strontium (Sr) may point to oil and gas extraction activities, as these metals could be mobilized by the fracking operation. If conductivity/TDS are high, test for Ba and Sr. If those are also very high it can be assumed that the source is flowback water [17]. • Specific chemicals used in fracking fluid need to be monitored if contamination is suspected. • If sewage effluent from human settlements at exploration site enters a stream/wetland or pan then *E. coli* and total coliforms concentrations need to be monitored.	**Quality** • Parameters to be monitored are T, conductivity, pH, dissolved oxygen (DO), and turbidity, which would indicate a spill especially of saline waste water, in particular. • Need to monitor for TDS, strontium and barium levels in flowback water to be released into surface water. Receiving water also needs to be tested regularly to detect any increase from natural trends. • Ecostatus using HAI, PAI, MIRAI, FRAI, GAI, VEGRAI methods where possible or else an adjusted PES method as prescribed by the DWA especially in episodic rivers. • If sewage effluent from human settlements at exploration site enters a stream/wetland or pan then *E. coli* and total coliforms concentrations need to be monitored.	**Quality** • Parameters to be measured include T, conductivity, pH, DO, turbidity, TDS, and if needed strontium and barium. • Specific chemicals from fracking fluid need to be monitored if contamination of surface water is suspected.

Table 61: Monitoring framework for surface water continued.

Phases	Before exploration	During exploration	During extraction	After extraction
Aspects that need to be monitored (WHAT?) continued.	**Quantity** • Baseline for water quantity in rivers, pans and wetlands (parameters: stream flow, discharge, depth and stream width).The collection of daily rainfall and evaporation data is crucial. **Habitat** • Baseline Habitat Integrity study or RHAM to establish a baseline for habitat. **Present ecological state (PES)** • Riparian vegetation, aquatic macroinvertebrates, fish. • Terrestrial insects, mammals associated with water bodies (episodic rivers). • Hydrology, geomorphology, water chemistry. **Regulatory** • Address water availability requirements for oil and gas extraction, before exploration and extraction. • Basic water quality testing before drilling or exploration commences. Analyses at an accredited laboratory, data should be made available to all interested parties.	**Quantity** • Monitor surface flow, water depth and volume in rivers, pans and wetlands. **Habitat** • The IHI or RHAM method can be used as a surrogate for habitat quality and invertebrate and fish health. **Present ecological state (PES)** • Riparian vegetation, aquatic macroinvertebrates, fish. • Terrestrial insects and mammals associated with water bodies (episodic rivers). • Hydrology, geomorphology, water chemistry. **Technical** • Rate and amount of water withdrawal if surface water is used as water source. **Regulatory** • Application for water use licence – unconventional oil and gas extraction has been proposed as a controlled activity and compliance with licence obligations needs to be monitored.	**Quantity**: • Water level to indicate any artificial increase or decrease in flow or depth in streams, pans or wetlands. **Habitat** • RHAM method can be used as surrogate for habitat and biota integrity assessments. **Technical** • Rate and amount of water withdrawal should be monitored if surface water is used as water source. **Regulatory** • Require permission/ licence to withdraw any water for unconventional oil and gas extraction. • Domestic and ecosystem water use must be prioritised especially during drought periods (Water use for oil and gas extraction should not interfere with current local use especially for food production). • Reuse of waste water to be encouraged and prescribed where possible. • The assessment (and enforcement) of compliance with set water quality standards is important[18].	**Habitat** • The RHAM method can be used as a surrogate for habitat, invertebrates and fish. **Regulatory** • Compliance with mine closure specifications need to be monitored.

Table 61: Monitoring framework for surface water continued.

Phases	Before exploration	During exploration	During extraction	After extraction
How should these aspects be monitored?	**Water quality** • A baseline/reference needs to be determined for each site and for each parameter. This can only be done using long term data or collecting data seasonally and during different hydrological phases (wet/dry). **Water quantity** • Baseline flow, depth and width measurements in rivers, pans and wetlands. Need to establish long term records to identify patterns especially in rivers in arid and semi-arid regions. Rainfall and evaporation data should also be collected. **Habitat** • Use IHI method [13, 14] or HAM method [15, 16] to determine baseline. **Stream biota** • PES of biota and drivers for rivers, wetlands and pans should be monitored using the standard methods prescribed by the DWA. • Fish (FRAI); macroinvertebrates (MIRAI); riparian vegetation (VEGRAI). **Observational and visual monitoring** • Use checklists and fixed point photography to determine a control or baseline.	**Water quality** • TDS must be monitored and if elevated levels are found then barium, strontium and chloride need to be monitored. If elevated levels of Strontium etc. are found other fracking fluid chemicals also need to be monitored. **Quantity** • Flow, depth and width measurements in rivers, pans and wetlands. Daily rainfall and evaporation data should also be collected. **Habitat** • Use IHI method [13, 14] or RHAM method [15, 16] to determine change in habitat from baseline. **Present ecological state (PES)** • EcoStatus methods where appropriate, otherwise adjusted methods for rivers, wetlands and pans: • Fish (FRAI), macroinvertebrates (MIRAI), riparian vegetation (VEGRAI); • Hydrology (HAI), geomorphology (GAI), water chemistry (PAI). **Observational and visual monitoring** • Use checklists and point photography to determine change from baseline.	**Water quality** • TDS must be monitored and if elevated levels are found then barium, strontium and chloride need to be monitored. If elevated levels of strontium etc. are found other fracking fluid chemicals also need to be monitored. • PES of biota and drivers for rivers, wetlands and pans should be monitored using the standard methods prescribed by the DWA. **Quantity** • Flow, depth and width measurements in rivers, pans and wetlands. Daily rainfall and evaporation data should also be collected. **Habitat** • IHI method [13, 14] or RHAM method [15, 16] to determine change in habitat from baseline. **Observational and visual monitoring** • Use checklists and point photography to determine change from baseline.	**Water quality** • If any groundwater pollution is suspected then the surface water quality needs to be monitored using firstly the TDS and then if needed levels of strontium, barium and chloride. • The RHAM method can be used as a surrogate for habitat, invertebrates and fish as habitat could be affected if surface water is polluted. . **Observational and visual monitoring** • Use checklists and fixed point photography to determine change from baseline. **Regulatory** • Compliance with mine closure specifications need to be monitored for as long as specified in mine closure regulations.

Table 61: Monitoring framework for surface water continued.

Phases	Before exploration	During exploration	During extraction	After extraction
Where do these aspects need to be monitored? (on site, regional?)	• Identified sites. At least a representative site in each resource unit, wetland or pan type, identified in proximity to possible extraction sites.	• Identified sites. At least a representative site in each resource unit, wetland or pan type, identified in proximity to possible extraction sites. Flowback and production water should be monitored at source and at point of discharge.	• Identified sites. At least a representative site in each resource unit, wetland or pan type, identified in proximity to possible extraction sites Flowback and production water should be monitored at source and at point of discharge as well as downstream of discharge.	• Identified sites. At least a representative site in each resource unit, wetland or pan type, identified in proximity to possible extraction sites. • Sites in at least a 1km radius from closed production site should be monitored if contamination is suspected.
Who must do the monitoring?	• DWA, oil and gas company and/or independent organisation appointed by DWA.	• DWA, oil and gas and/or independent organisation appointed by DWA.	• DWA, oil and gas company and/or independent organisation appointed by DWA.	• DWA, oil and gas company and/or independent organisation appointed by DWA.
Reference s		1: Lechtenböhmer et al., 2011; 2: Zorn et al., 2008; 8: Davis et al., 2006; 13: Kleynhans, 1996; 14: Kleynhans et al., 2008; 15: DWA, 2009a; 16: DWA 2009b; 17: Chapman, 2012	3: Herridge et al., 2012; 4: Rahm and Riha, 2012; 5: Lyons, 2012; 6: Scott et al., 2011; 7: Jackson et al., 2011. 18: DWAF, 2006.	9: Bishop, 2011; 10: Bamberger and Oswald, 2012; 11: Davis, 2008; 12: Lloyd-Smith and Senjen, 2011

Pre-exploration

The main focus of monitoring during the pre-exploration phase is to provide a baseline before the onset of exploration or extraction. This data will serve as a control against which any subsequent monitoring results are compared. Transparency in data collection methods and results are, therefore, essential during this stage and data are to be made available to all stakeholders. It would also be essential that the possible constituents of the fracking fluid be made available to the monitoring agency/department so that a relevant baseline for these constituents can be established in existing surface water systems before exploration. It may also be necessary to follow a phased approach where a wide variety of tests are undertaken before exploration in order to identify the water quality parameters specifically significant to unconventional oil and gas extraction. The aspects to be included in the pre-exploration phase monitoring, depending on the budget available, are listed in Table 62. The following could be considered during the monitoring of these aspects:

- **Water quality**: a baseline/reference needs to be determined for each site and for each parameter. This can only be done by referring to long-term data, collecting data seasonally and during different hydrological phases (wet/dry).
    - TDS, pH, dissolved oxygen, turbidity parameters to be taken in situ and additional water samples which should be sent to an accredited laboratory to determine barium, strontium and chloride levels as well as the identified constituents of fracking fluid to be used.
    - Daily rainfall and evaporation data should be monitored by relevant departments/independent company and/or oil and gas company. If no weather stations are present in area to be monitored, weather stations need to be set up close to well pads, where each station would represent a homogenous region. In arid regions local rainfall is critical to surface water flow and where possible daily rainfall should be measured in these areas. This data would prove valuable for setting up accurate water balance models, including surface and groundwater interactions, which could be a legal requirement if the proposed technical regulations for petroleum exploration and exploitation (DMR, 2013) are accepted.
- **Water quantity:**
    - Surface flow measurements in rivers and wetlands using a flow meter and also using existing gauge data to establish reference/baseline for dry and wet periods.
    - Depths and widths of pools and pans. Need to include long term data to establish patterns for reference/baseline with which during and after extraction data could be compared.
- **Habitat integrity:** To be monitored by using either the
    - Index of Habitat Integrity (IHI) method – each river reach could be accessed using the IHI method developed by Kleynhans et al. (2008) or Kleynhans (1996); or
    - The Rapid Habitat Assessment Method (RHAM) method developed by the DWA (2009; 2009a). This could also serve as a surrogate for present ecological state if budget is limited.
- **Present Ecological State (PES):** Including hydrology, water chemistry, geomorphology, biota (macro-invertebrates and fish where possible) and riparian vegetation (DWA, 2009c) using standard methods prescribed by the DWA such as:
    - Hydrology using the Hydrology Driver Assessment Index (HAI);
    - Water chemistry using the Physical Chemical Assessment Index (PAI) where possible;
    - Geomorphology using the Geomorphology Assessment Index (GAI);
    - Macro-invertebrates using the Macro-invertebrate Response Assessment Index (MIRAI) where possible;

- Fish using the Fish Response Assessment Index (FRAI) where possible; and
  - Riparian vegetation using the Vegetation Response Assessment Index (VEGRAI) (DWA, 2009c).
- **Wetlands:**
  - Wetland Assessment Habitat Integrity Indices could be used to monitor wetlands (DWAF, 2007) or the tools and metrics to assess the environmental condition and socio-economic importance of wetlands (Day and Malan, 2009) could be used where possible.
- **Terrestrial insects and mammals:**
  - Terrestrial insects associated with surface water systems should be monitored, especially where rivers dry out often and terrestrial insects make use of the riverbed. A combination of light traps and the sweep method could be used to determine community composition.
  - Mammals reliant on the riparian corridor or surface water also need to be monitored. Visual observation (especially larger mammals), together with the trapping of small mammals to be used.
- **Observational and visual monitoring:**
  - Fixed point photography could be used to record changes in land use, habitat etc.
  - Need to observe and record land disturbance, spills, discharges, water withdrawal, leakage, sedimentation, erosion etc. in order to set a baseline for comparison.
  - Recording the physical state of stream reaches and banks with the help of checklists before the onset of exploration and mining could be valuable for estimating possible impacts later on

The areas proposed for unconventional oil and gas exploration and extraction are still uncertain, but are expected to include the semi-arid and arid regions of central South Africa. These areas are, however, distinguished by their environmental and ecological variability. Due to this, monitoring at a local scale would be needed as extrapolation of data from one area to another is not advised (Lamprecht, 2009). Unfortunately, aquatic ecological data for these drier areas are scarce, necessitating the timely implementation of a baseline monitoring programme. Ideally data would be needed from at least seasonal and wet/dry samples with which samples during and after exploration and mining can be compared. If possible, long-term data (at least two to five years' data) are needed to compensate for the high hydrological variability prevailing in these areas.

Baseline monitoring should be implemented first in the priority areas identified in the surface water vulnerability map, but must be extended to the site locations of proposed unconventional oil and gas extraction as soon as locations become known. In these areas, homogenous reaches (resource units) need to be identified in each stream situated within 500 m to 1 km from proposed extraction sites. Representative sites are then to be identified in each reach, the number of sites being determined by the budget available. Wetland and pans in proximity (500 m to 1 km) of proposed extraction sites should also be identified and representative types monitored. The location of the monitoring points/sites should be clearly indicated on a map in a way that it can be found by a person not familiar with the exact monitoring point (GPS referencing, GIS based map or based on infrastructure such as roads, bridges, rivers, etc., indicated on the map). Monitoring points/sites should ideally be registered on the DWA water monitoring system database (DWAF, 2006).

It is further proposed that the DWA be tasked with the baseline monitoring but if they lack the capacity to do this, an independent organisation or team (appointed by the DWA) is to be established to do baseline monitoring. Mining companies proposing to mine should also collect baseline data which should be made available to the DWA and other interested parties. The data should be placed in existing DWA databases, or a specifically created database housed at DWA or an independent entity (e.g. South African Earth Observation Network [SAEON]), and be made accessible to all interested parties.

Exploration

During the exploration phase, the emphasis of the monitoring programme is on assessing the impact of exploration activities on surface water resources by comparing data collected with baseline data from before exploration. Data on water quality and quantity, habitat availability, as well as present ecological state of rivers, pans and wetlands are, therefore, needed for the sites identified during the baseline monitoring (see Table 63). At the very least water quality (TDS) and quantity (flow and depth) need to be monitored. If any elevation in TDS (taking natural variability into account) is measured then additional parameters for water quality, quantity and available habitat need to be monitored. Flowback and any releases from mining should also be monitored at source as well as at discharge points and downstream of discharge points.

Consistency in the use of methods is of utmost importance and the following could be considered:

- **Water quality:**
  - In situ measurement of TDS, pH, oxygen and turbidity using calibrated water quality meters. If high levels of TDS (keeping variability in mind) are present, water samples should be collected and sent to an accredited laboratory to determine chloride, barium and strontium levels. If pollution is suspected then constituents of fracking fluid also need to be monitored in surface water systems.
  - Daily rainfall and evaporation data from local rainfall stations or farmers in region of unconventional oil and gas extraction where possible.
- **Water quantity**: flow measurements (using flow meter) and also using existing gauge data. Depth, width of pools and pans need to be monitored. If no flow meter is available measuring Perspex tubes as used in the RHAM method (DWA 2009a; 2009b) can be used.
- **Habitat integrity** could be monitored using the:
  - The IHI method – each river reach could be accessed using the IHI method developed by Kleynhans et al., (2008) or Kleynhans, (1996); or
  - The RHAM method developed by DWA (2009a; 2009b). This could also serve as a surrogate for present ecological state if needed.
- **Present ecological state (PES)** including hydrology, water chemistry, geomorphology, aquatic biota (macro-invertebrates and fish where possible), and riparian vegetation (DWA, 2009c) should be monitored using standard methods prescribed by the DWA**.** All indices (using the HAI, PAI, GAI, MIRAI, FRAI, VEGRAI, Wetland and Pan Assessment Index methods or other methods prescribed by the DWA) monitored before the exploration phase need to be monitored during the exploration phase.
- **Terrestrial insects and mammals** especially where rivers are episodic.
  - Terrestrial insects associated with the surface water system need to be monitored especially where rivers dry out often and terrestrial insects make use of the riverbed. Would need to use light traps as well as sweep method to determine community composition.
  - Mammals reliant on the riparian corridor or surface water also need to be monitored. Visual observation (large mammals) as well as trapping of small mammals is recommended to determine community composition.
- **Observational and visual monitoring.** Need to observe and record land disturbance, spills, discharges, water withdrawal, leakage, sedimentation, erosion etc.
  - Checklists need to be used to establish impact of land disturbances, spills and discharges, water withdrawal etc.

- o Fixed point photography also needs to be used to establish changes in land use, habitat etc.

Each of the parameters mentioned above would require different monitoring frequency. For instance, water quality and quantity data need to be collected at least weekly. Habitat integrity, geomorphology, fish and vegetation could be monitored yearly or after floods or drought; macro-invertebrates should be monitored at least every six to eight weeks or at least seasonally. If the RHAM method is used then it needs to be monitored at least monthly and if possible weekly, together with the water quality and quantity measurements.

It is proposed that the DWA be tasked with monitoring but if they lack the capacity to do this the task may be delegated to an independent organisation or team. The oil and gas company also needs to do continuous monitoring. The data should be placed in the existing DWA databases, or a specifically created database housed at DWA or an independent entity, in order to be easily accessible to all interested parties.

During extraction

The main aim of monitoring during the mining phase is to assess the impact of unconventional oil and gas extraction on surface water resources by comparing data collected with baseline data from before exploration. This would be specifically useful to:

- Detect any contamination resulting from the fracking process;
- Report on the contamination and possible sources; and
- Suggest mitigation to minimise contamination.

Data on water quality, quantity and habitat availability, the present ecological state of rivers, pans and wetlands, terrestrial insects and mammals as well as observational and visual aspects, are needed during the mining phase. The same monitoring procedure, sites and methods as in the exploration phase should be followed.

- **Technical:** Rate and amount of water withdrawal should be monitored if surface water is used as water source.
- **Regulatory**: A water use licence is required to withdraw any water for unconventional oil gas extraction. Domestic and ecosystem water use needs to be prioritised especially during drought periods (use for gas mining should not interfere with current local use especially for food production). Reuse of waste water should be encouraged and prescribed where possible. The assessment (and enforcement) of compliance with set water quality standards is required (DWAF, 2006).

As for the previous phases, each parameter requires different monitoring frequencies, but should correspond to that used during the mining phase.

After extraction:

During the post mining phase the main aim of the monitoring programme is to detect any impacts of unconventional oil and gas mining on surface water resources by comparing data collected with baseline data from before exploration. This is specifically to:

- Detect any contamination resulting from the unconventional oil and gas extraction process after it has occurred;

- Report on the contamination and possible sources; and
- Suggest mitigation to minimise contamination.

In order to ensure continuity and compatibility of data, the same aspects monitored during the earlier phases of unconventional oil and gas extraction should be monitored after well decommissioning, using the same methods, frequency and monitoring sites as before. During this phase, compliance with mining and other closure specifications also needs to be monitored.

If contamination of groundwater is suspected then sites within 1 km proximity of the source of contamination should be monitored at least seasonally.

5.4.2 Groundwater

The Department of Water Affairs has the mandate under the *NWA* to protect, use, conserve, manage and control water (including groundwater) in a sustainable and equitable manner for the benefit of all persons. As part of this mandate the DWA must also monitor water resources and establish information systems on water use, quality and quantity. A more detailed discussion on monitoring under the *NWA* can be seen under section 5.2 of this document entitled "Chapter 14 of the *NWA* Monitoring, Assessment and Information".

The aim of monitoring groundwater aspects during the different phases of unconventional oil and gas extraction would be to control and mitigate impacts from unconventional oil and gas extraction. The timely implementation of a monitoring programme and the execution of a groundwater monitoring baseline are of critical importance as South Africa proceeds towards exploring the economic viability of unconventional oil and gas extraction. The importance of performing a baseline before exploration has been illustrated internationally (GAO, 2012a; GAO, 2012b; Nelson, 2012).

A comprehensive understanding of groundwater conditions prior to the commencement of exploration for unconventional oil and gas is required to ensure proper interpretation of changes in groundwater over time. This understanding could be achieved by baseline monitoring. In order to perform baseline monitoring accurately, an understanding of the aquifer systems in an area, as well as migration pathways for contaminants, would be advantageous. It is also important to note that certain parameters would be present both naturally (either in shallow or deep aquifer systems) as well as in additives in frack water (e.g. sodium, potassium and chloride) (O'Brien et al., 2013).

The baseline list of parameters should be as wide as possible so that regulators would be able to determine proper indicator parameters to detect possible changes in chemistry. A possible list could include typical suite of drinking water analyses parameters (SANS 241), parameters used to test suitability for livestock watering by using the South African Water Quality Guidelines for livestock water (DWA, 1996), as well as parameters that may occur in association with deep geological zones and possible well additives.

The concentration of metals in produced water depends on the oil or gas field, particularly with respect to the age and geology of the formation from which the oil and gas are produced (Utvik 2003). Examples of parameters associated with deep shale layers include zinc, lead, manganese, iron, barium, bromide, boron, strontium, lithium, uranium, calcium, arsenic and mercury (USDOE, 2004, USEPA, 2011a; Vidic, 2010). Iron, manganese and boron are typical metals of concern for CBM produced water (Clark and Veil, 2009). Drilling and hydraulic fracturing additives could include barite, hematite, calcite, bentonite, volatile organic carbons, semi-volatile organic carbons, polyaromatic hydrocarbons, sodium bicarbonate, sodium carbonate, sodium hydroxide and sodium tetraphosphate

(USEPA, 2011a). Biogenic and thermogenic methane has been illustrated to occur in South African groundwater resources (Kent, 1969; Talma and Esterhuyse, 2013) and stable isotope analyses associated with these methane sources would also be required to fingerprint the methane (specifically methane δ13C, methane δ13D). Other stable isotope analyses include water δ13C, water δ13D, DIC δ13C, ethane δ13C and ethane δ13D (O'Brien et al., 2013). Radioactivity (gross alpha radioactivity, gross beta radioactivity) and radioactive isotopes also need to be monitored, including but not limited to uranium, thorium, radium (derived from the radioactive decay of uranium and thorium) and strontium (USEPA, 2011a; Utvik, 2003).

Localities for baseline monitoring may be a contentious issue. Sampling and analysis costs must be limited but at the same time useful data must be gathered in sufficient detail to prove a change in groundwater quality and to identify possible sources of contamination. In the proposed technical regulations for unconventional oil and gas extraction (DMR, 2013) it is suggested that a hydrocensus (with associated water sampling) be performed in a 1 km radius around each planned gas well. Such an approach may not be sufficient as groundwater contamination may migrate via preferred pathways in the Karoo geology, resulting in impacts on groundwater users (receptors) who may be located much further than 1 km from any specified gas well site. This recommendation also assumes that contamination may only arise from the well location and not from migration of deeper located fluids to potable aquifer zones via interconnected geological structures.

A more thorough approach would be for applicants to perform a hydrocensus for at least the whole precinct or target area within the precinct that oil and gas companies plan to explore for oil and gas extraction, at an acceptable sampling density to allow for geological and geohydrological conceptualisation and modeling. Sampling localities should also be informed by the associated geological model for a proposed oil and gas extraction area (focusing specifically on geological structures and understanding the morphology of such structures at depth as far as possible) which should aid in the understanding of the geological and geohydrological system of a specific site. In higher risk areas, sampling density can be increased and additional parameters may be sampled. The Department of Water Affairs should also sample in precincts, possibly at a density of one sample per farm, in order to have an independent regional baseline.

The suggested monitoring approach of determining a baseline for groundwater is therefore specifically aimed at providing an opportunity to detect and report on any impact that unconventional oil and gas extraction has on groundwater in a legally defensible manner.

The proposed monitoring framework for groundwater can be seen in Table 62. The question as to when groundwater monitoring should take place has been discussed at the hand of the different extraction phases (before exploration, during exploration, during extraction and after extraction). For groundwater monitoring, cooperation between the monitoring efforts of oil and gas companies and independent monitoring entities as well as governmental efforts are required. The suitability of the DWA to perform an ongoing monitoring function related to unconventional oil and gas extraction and establishment of an independent monitoring agency is discussed in some detail in section 5.2. Government is not necessarily able to monitor the technical day-to-day operations of oil and gas companies; however, oil and gas companies may be required to perform local monitoring activities and then the reporting of technical details of their operation to government or an independent monitoring body becomes crucial. Technical details such as drilling fluid additives used (disclosure of chemical usage), water volumes used (National Assembly of Wales, 2012; UKHC, 2012), water volumes and quality of water produced, especially during coalbed methane extraction (USEPA, 2011b; Williams et al., 2012) drilling rates, microseismic measurements (GAO, 2012a) etc. are crucial in conjunction with water quality and quantity monitoring on a regional scale, if we want to understand changes in the monitored entities.

Large-scale water transfer schemes would need to be closely monitored and water saving requirements such as closed loop drilling and recycling should be required as a standard license condition. Compliance with these requirements would also have to be monitored as part of regulatory compliance monitoring. Regulatory compliance can be measured by monitoring compliance with reporting requirements.

Monitoring would be required before exploration to establish a baseline, during exploration, during extraction and after extraction, to identify any contamination that may only surface after abandonment of a gasfield or in the case of well failure (Diller, 2011). Monitoring would need to be continuous to ensure that early warning detection of possible contamination at oil and gas extraction sites would be possible to limit impacts on surrounding groundwater users.

Data management

Data capture of drilling and extraction operations should be ensured and is a crucial part of proper monitoring and management of this activity internationally (Atlantic Council, 2011). Proper monitoring, reporting, data capture and data management should also be ensured in South Africa.

Currently the Department of Water Affairs, as the custodian of South Africa's water resources, does keep a National groundwater archive, as well as other databases (e.g. the Water Quality Management System, abbreviated as the WMS). The national groundwater archive can be viewed as the most up to date data archive on groundwater in South Africa, and options would have to be investigated to determine if this system can be efficiently adapted to manage oil and gas wellsite-specific information. The WMS stores water quality related data. Options would also have to be investigated to streamline these two systems.

If the DWA cannot handle this type of information, an independent entity would have to manage, archive and disseminate this information.

Quality assurance and quality control

Quality assurance and quality control relates specifically to sampling for water quality and should be implemented in the field at the sampling site, as well as at the laboratory.

Standardised monitoring requirements, similar in nature to the "Minimum requirements for waste handling" document series would have to be developed to ensure quality assurance and quality control. The most important aspect to ensure, is that sampling data gathered at different oil and gas well sites, is done in a standardised way and incorporates good (preferably standardised) quality assurance and quality control practices. Standardisation would ensure that samples from different sites can be compared in a consistent manner, and would require standardisation on aspects such as sampling protocols for inorganics, organics, isotopes and physical parameters.

Quality assurance can be achieved by ensuring proper chain of custody (Karlkins, 1996) and keeping copies of the chain of custody (COC) forms (sample results must be traceable back through their collection, storage, handling, shipment and analyses; and information on persons handling the sample should be completed on a COC form), good field sampling practices (using properly calibrated instruments, taking two sets of duplicate samples for analyses at the same laboratory and at a quality control laboratory, employing trip blanks/field blanks) and good laboratory analysis practices (using calibration blanks to check for instrument drift, laboratory replicates to test the precision of laboratory measurements, spike samples, quality control samples of known constitution for analyses with your samples, sending duplicate samples for analyses at different laboratories) (USEPA, 2013; Weaver et al., 2007). Field sampling procedures should be robust, reproducible and reliable. A pilot sampling run may be required to serve as a reconnaissance exercise during which information on sampling points and data ranges are recorded, as well as logistical and technical constraints identified.

Sampling from boreholes or windpumps may add additional uncertainty to the sample results due to degassing. These uncertainties should be limited by additional research. Chain of custody forms to track movement of the water samples from the sampling sites to the laboratories would be required as standard practice. Laboratories would have to be accredited for analysis of specified parameters via SANAS accreditation and ISO certification. Where sampling and laboratory analyses procedures are specified for South Africa, specified prescriptions should be followed. In cases where laboratories do not yet have certain analysis capabilities, new analysis methods would have to be based on international best laboratory practice. Such laboratory analysis methodologies should be standardised as far as possible.

Table 62: Monitoring framework for groundwater

Phases	Before exploration	During exploration	During extraction	After extraction
Possible impacts of concern that need to be monitored (WHY?)	None that could be identified.	**Quality** Possible migration of formation fluids to freshwater aquifers during exploration drilling under localised artesian conditions. [9,10] Saline water management of water produced by coalbed methane extraction. [4,11] Contamination of aquifers with fracturing fluids if hydraulic fracturing is allowed during this phase. [4,11,12] **Technical** Shale instability may lead to borehole collapse, aquifer connectivity. [13,14,15,16]	**Quality** Fluid migration and aquifer connectivity due to geological structures. [4,12,24] Surface activities contaminate aquifers via surface water-groundwater interaction. [11, 22, 23] **Quantity** Sourcing large quantities of water may impact on aquifers. [4,12, 20,21] **Technical** Poor drilling practices and poor well construction may impact on aquifers. [4,24,25, 26] Shales that pose drilling problems, may lead to contamination. [13,14,15,16] **Regulatory** Wastewater treatment and disposal may put aquifers at risk. [11,12,27]	**Quality** Aquifer pollution from deep shale layers may only surface years after a pollution incident. The extent of possible long-term contamination in freshwater aquifers could not be predicted at this stage. **Technical** South Africa may not be able to rehabilitate contaminated aquifers in complex geology (physically and economically). [28] Oil and gas well casing failure and leakage may pose long term legacy issues and lead to inevitable groundwater contamination. [11,29,30] **Regulatory** Well abandonment and long term monitoring may be problematic. [11,12,31]
Aspects that need to be monitored (WHAT?)	**Quality** Determine regional groundwater quality: Drinking water quality[1], stockwater quality parameters[2], parameters possibly associated with deeper zones [3,4,5,6], radioactivity [7] isotopes [7], methane, ethane. [7,8] **Quantity** Determine more accurately groundwater quantities used and yields. Determine baseline on type of groundwater use. Get baseline groundwater levels. **Regulatory** Monitor regulatory compliance with baseline monitoring requirements.	**Quality** Drinking water quality[1], stockwater quality parameters [2], parameters possibly associated with deeper zones[3,4,5,6], radioactivity[7], isotopes [7], methane, ethane. [7,8] **Quantity** Volumes of groundwater and surface water use on a regional scale linked with type of groundwater and surface water use (e.g. transfer schemes), monitor groundwater levels. **Technical** Drilling rate, fluid usage (volumes and type), microseismicity. [17,18,19] **Regulatory** Monitor regulatory compliance with fluid storage, volumes of waste produced per well, reporting frequencies to authorities Monitor compliance with license conditions. Monitor waste treatment methods and efficiency.	**Quality** Drinking water quality[1], stockwater quality parameters [2], parameters possibly associated with deeper zones [3,4,5,6], radioactivity [7] isotopes [7], methane, ethane. [7,8] **Quantity** Volumes of groundwater and surface water use on a regional scale linked with type of groundwater and surface water use (e.g. transfer schemes); monitor groundwater levels. **Technical** Drilling rate, fluid usage (volumes and type), microseismicity, well integrity during fracking operations. [17,18,19] **Regulatory** Monitor regulatory compliance with fluid storage, volumes of waste produced per well, reporting frequencies to authorities. Monitor compliance with license conditions. Monitor waste treatment methods and efficiency.	**Quality** Long term monitoring of Drinking water quality [1], stockwater quality parameters [2], parameters possibly associated with deeper zones [3,4,5,6], Radioactivity [7] isotopes [7], methane, ethane [7,8] at a lower frequency unless pollution suspected. **Quantity** Long term monitoring groundwater levels at lower frequency also recommended together with quality, monitor changes in water use in previous oil and gas extraction areas. **Technical** Monitor well integrity over the long term. [31] **Regulatory** Monitor compliance with long term monitoring requirements. Monitor long term acceptability of waste treatment methods and efficiency.

Table 62: Monitoring framework for groundwater continued.

Phases	Before exploration	During exploration	During extraction	After extraction
How should these aspects be monitored?	**Quality** Monitor identified list of parameters for regional baseline. Do higher resolution sampling in vicinity of expected oil and gas extraction (e.g. one sample per farm) and lower resolution in other areas. **Quantity** Monitor volumes by assessing baseline groundwater use (registration and licensing volumes at DWA) linked with type of groundwater use – fast track registration and licensing verification. Monitor water levels in aquifers.	**Quality** Continue to monitor identified list of parameters to detect regional baseline changes. Continue high resolution monitoring in vicinity of oil and gas exploration (e.g. one sample per farm and higher resolution at oil and gas exploration wells); lower resolution in other areas. **Quantity** Monitor volumes of groundwater and surface water use on a regional scale (registration and licensing volumes at DWA) linked with type of groundwater use (especially transfer schemes). Monitor water levels in aquifers. **Technical** Monitor drilling rate, fluid usage (volumes and type), microseismicity at exploration sites. [17,18,19]	**Quality** Continue to monitor identified list of parameters to detect regional baseline changes. Continue high resolution monitoring in vicinity of oil and gas extraction (e.g. one sample per farm and higher resolution around oil and gas extraction wells); lower resolution in other areas. **Quantity** Continue to monitor volumes of groundwater and surface water use on a regional scale (registration and licensing volumes at DWA) linked with type of groundwater use (especially transfer schemes). Monitor water levels in aquifers. **Technical** Monitor drilling rate, fluid usage (volumes and type), microseismicity at oil and gas extraction sites. [17,18,19] **Regulatory** Ensure that data dissemination occurs as required per license conditions.	**Quality** Continue to monitor identified list of parameters to detect regional baseline changes. Monitor in vicinity of oil and gas extraction (e.g. one sample per farm and selected sites around oil and gas extraction wells); lower resolution in other areas. **Quantity** Continue to monitor volumes of groundwater and surface water use on a regional scale (registration and licensing volumes at DWA) linked with type of groundwater use to identify any linked usage patterns with other changes. Monitor water levels in aquifers. **Technical** Monitor well stability and integrity if wells are not closed [31] **Regulatory** Ensure continuous data dissemination of post extraction monitoring to regulatory authorities.
Where do these aspects need to be monitored? (e.g. on site, regional)	**Quality and quantity** Need to be monitored on a regional scale to determine a baseline.	**Quality and quantity** need to be monitored on site (local scale) as well as on a regional scale **Technical** To be monitored at drilling sites.	**Quality and quantity** Need to be monitored on site (local scale) as well as on a regional scale **Technical** To be monitored at oil and gas extraction sites.	**Quality and quantity** Need to be monitored on site (local scale) as well as on a regional scale. Expected timeframes for on-going monitoring will have to be determined based on monitoring observations and analyses. **Technical** To be monitored at closed oil and gas well sites.

Table 62: Monitoring framework for groundwater continued.

Phases	Before exploration	During exploration	During extraction	After extraction
Who must do the monitoring?	**Regional baseline:** DWA/independent entity (new or existing for example academia, consultants etc.). **Target area baseline:** Oil and gas company with reporting to the DWA, and independent spot check verification by DWA/independent entity (new or existing for example academia, consultants etc.).	**Regional quality and quantity monitoring:** DWA/independent entity (new or existing for example academia, consultants etc.) **Target area (localised) quality and quantity monitoring:** Oil and gas companies with reporting to DWA, and independent verification by DWA/independent entity (new or existing for example academia, consultants etc.) **Site specific technical monitoring:** Oil and gas companies with rigorous reporting structure to government and/or independent monitoring entity.	**Regional quality and quantity monitoring:** DWA/independent entity (new or existing for example academia, consultants etc.) **Target area (localised) quality and quantity monitoring:** Oil and gas companies with reporting to DWA, and independent verification by DWA/independent entity (new or existing for example academia, consultants etc.) **Site specific technical monitoring:** Oil and gas companies with rigorous reporting structure to government and/or independent monitoring entity.	**Regional quality and quantity monitoring:** DWA/independent entity (new or existing for example academia, consultants etc.) **Target area (localised) quality and quantity monitoring:** Oil and gas companies with reporting to DWA, and independent verification by DWA/independent entity (new or existing for example academia, consultants etc.) **Site specific technical monitoring:** Over short term after closure: Oil and gas companies with verification by independent body, handover to government or independent entity for long term monitoring.
References	1: SANS 241 2: DWA, 1996 3: USDOE, 2004 4: USEPA, 2011a 5: Vidic, 2010 6: Clark and Veil, 2009 7: O'Brien et al., 2013 8: Talma and Esterhuyse, 2013 9: Steyl et al., 2012	10: Woodford and Chevalier. 2002 11: Williams et al., 2012 12: Broomfield 2012 13:Manohar, 1999 14: Khan et al., 2011 15: Cabot, 2010 16: Khodja et al., 2010 17: UKHC, 2012 18: National Assembly of Wales, 2012	19: GAO, 2012a 20: Broderick et al., 2011 21: Galusky, 2007 22: Seaman et al., 2010 23: Parsons, 2004 24: Kargbo et al., 2010 25: IEA, 2012 26: USEPA, 2011b 27: Lechtenböhmer et al., 2011	28: GAO, 2010 29: Dusseault et al., 2000 30: Jinnai and Morita, 2009 31: Diller, 2011

5.4.3 Seismicity

In comparison with global seismicity southern Africa is one of the most stable regions of the earth. However, it is not completely deprived of seismic activity. An unusual aspect in the seismicity of South Africa is that most of the recorded seismic activity is associated with the deep gold mining operations on the periphery of the Witwatersrand Basin. Natural, low magnitude earthquakes occur sporadically over time and space, portraying typical intraplate seismicity.

Owing to the relatively short documented seismic history of the southern African sub-continent most of the available information relates to instrumental data acquired since 1971. Most of the information regarding pre-1971 events is based on macro-seismic observations. Consequently, the locations of these events correspond, in most cases, to the sites where the seismic event was felt with maximum intensity but may be displaced by tens of kilometers from the true epicenter.

The database of seismic information for South Africa is evidently incomplete, especially for the historic part of the seismic event catalogue. The completeness could be estimated by comparing the apparent frequency of occurrence of events with pre-assumed frequency-magnitude relationships (Shapira et al*.,* 1989; Saunders et al*.,* 2008).

Although the situation has improved since 1989 through the deployment of more seismic stations, the overall threshold for determining the magnitude for both the tectonic origin and mine related seismic events is still around magnitude M_w 3.0.

International regulatory guides clearly state that any study related to the siting, rating and development of critical engineering structures must include seismic monitoring as one of the components. It is therefore imperative that the collection and monitoring of data should start well in advance before any exploration is undertaken on the site, and should continue well after hydraulic fracturing has ceased in the area. The only means to comply with international standards of identifying if an area is capable of generating seismic events is to, as in the case of mining induced seismicity or tectonic active (capable) faults, install a local seismic network with the capability of recording micro-seismic events with Richter magnitudes, say less than 1.0.

Knowledge of micro-seismic events provides knowledge about large, potentially dangerous events in the future through the extrapolation of the rate of occurrence of small events to larger events. In South Africa, knowledge about micro-seismicity is virtually the only information available, since the occurrence of large events is very rare. The analysis of micro-seismic event records provides useful data of engineering significance. In order to provide sufficient coverage over the epicentre location for the area of interest, it is recommended that an area with a radius of ca. 100 km from the hydraulic fracturing site, be monitored. This local micro-network links the hydraulic fracturing operations with seismic data processing and data interpretation for meaningful interpretation of events as they unfold. The network should also report to the regional and/or national seismic networks.

Seismic monitoring before exploration will aid in identifying the location of faults and the stress field nature in areas where it is currently unknown. Although most faults are inactive and does not pose a potential problem, it assists in the seismic characterization of the site (Cook et al*.,* 2013). This is necessary for the establishment of a baseline and should therefore be done before the hydraulic fracturing process begins.

In certain cases, e.g., when hydraulic fracturing will take place in vicinity of known tectonic faults or significant infrastructure, it would be advantageous to install, in addition to a local seismograph network, several strong motion accelerographs. The recorded seismic events should be carefully studied and, if possible, linked with the local tectonics of the area.

Detailed information on seismicity is therefore needed in order to obtain meaningful information about the potential increase in seismicity associated with hydraulic fracturing. It is recommended that a network of seismographs and accelerographs, that have the ability to record macro- and micro-earthquakes, be installed and operated before and during exploration as well as during and after extraction. It is strongly recommended to begin this seismic monitoring before the hydraulic fracturing exploration phase in order to establish a baseline.

Data Management

The establishment and management of the recommended local seismic network to ensure data integrity, is if upmost importance. The number of sensors and their configuration in this local seismic network should be arranged such that it provides the required location of the seismic event epicentres with an accuracy of a few 100 meters. To obtain this required accuracy, the network optimization should be done before the instalment of the seismic network (see e.g. Kijko, 1997a and b).

Currently the Council for Geoscience (CGS) maintains the South African National Seismograph Network (national and regional networks). The database maintained by the CGS can be viewed as the most up to date data archive on seismic activity in South Africa. Investigations should be made to determine if the existing system can be effectively adapted to manage seismic information at oil and gas well sites, or if a new local networks should be established.

If the CGS is not capable of providing the necessary support, an independent entity would have to establish, manage, analyse and disseminate the relevant networks and information.

Table 63: Monitoring framework for seismicity

Phases	Before exploration	During exploration	During extraction	After extraction
Possible impacts of concern that need to be monitored (WHY?)	Level of seismicity may increase. Possibility to observe, induce and or trigger a strong seismic event.			
Aspects that need to be monitored (WHAT?)	To fully comprehend the potential impact of hydraulic fracturing on the seismicity of the extraction area, the monitoring of seismic events must start as soon as possible (if possible even before exploration to establish a baseline) and continue well into the post extraction phase. The monitoring protocol for seismicity requires the location of seismic events through a seismic network consisting of seismographs, geophones and accelerographs. Location of seismic event included determination of five parameters: • Latitude of epicenter • Longitude of epicenter • Depth at epicentre • Origin time • Magnitude (Richter) The successful monitoring of seismicity is only possible when the local seismic network consists of a minimum of six seismic stations.			
How should these aspects be monitored?	Networks of seismographs and accelerographs, which have the capability of recording micro- and macro-seismic events, should be installed and operated. The number of sensors and their configuration in local seismic network should be arranged such that it provides the required location of the seismic event epicentres with an accuracy of a few 100 meters. To obtain this required accuracy, the network optimization should be done before the instalment of the seismic network (Kijko, 1997a and b).			
Where do these aspects need to be monitored? (on site, regional?)	In order to provide sufficient coverage over the epicentre location for the area of interest, an area with a radius of ca. 100 km from the hydraulic fracturing site is recommended. The local micro-network links the hydraulic fracturing operations with seismic data processing and data interpretation for meaningful interpretation of events as they unfold. The network should also report to the regional and/or national seismic networks.			
Who must do the monitoring?	The Council for Geoscience (CGS) If the CGS is not capable of providing the necessary support, an independent entity would have to establish, manage, analyse and disseminate the relevant information.			
References	Cook et al., 2013 Kijko, 1977a Kijko, 1977b Saunders et al., 2008. Shapira et al., 1989.			

5.4.4 Vegetation

The most important threat or disturbance emanating from unconventional oil and gas extraction to vegetation, is the clearing or removal of vegetation, which could be interpreted as a change in the cover, abundance, species composition and recruitment regime of the plant species occurring in the affected area. A number of different oil and gas related activities could lead to the removal of vegetation, such as physical removal during seismic surveys or vegetation die-off due to chemical spills. It is of the utmost importance that these changes in the ecosystem be monitored, before, during and after unconventional oil and gas extraction. An adequate monitoring framework can only be designed when the impacts are known.

Some impacts might be directly related to unconventional oil and gas extraction, while indirect impacts might be a consequence of the activities related to unconventional oil and gas extraction. These possible secondary impacts include, illegal harvesting of plants, the increase in occurrence of veldfires, the introduction of alien invasive plant species, a change in the hydrological regime of an area due to the removal of vegetation, to name just a few. The consequences of both direct and indirect clearing of vegetation are habitat fragmentation, which is probably one of the most significant consequences that will influence the terrestrial habitat. The loss of vegetation is also regarded as the most important reason for the loss of biodiversity in the world, as well as in South Africa, as described in the National Biodiversity Framework (DEA, 2009).

2.4.4.1 The issue of temporal and spatial scales

Unconventional oil and gas extraction poses a unique challenge in terms of monitoring due to its temporal and spatial footprint. The extraction process takes place in different phases, namely the exploration, extraction and post-extraction phase. Each phase has particular activities associated with it. Certain activities pose an immediate threat or change to the terrestrial habitat, while the consequences of other activities might only become visible or detectable long after mining has ceased. Figure 34 depicts a conceptual framework for the different issues related to monitoring. Different monitoring strategies might be needed to deal with the different spatial and temporal scales.

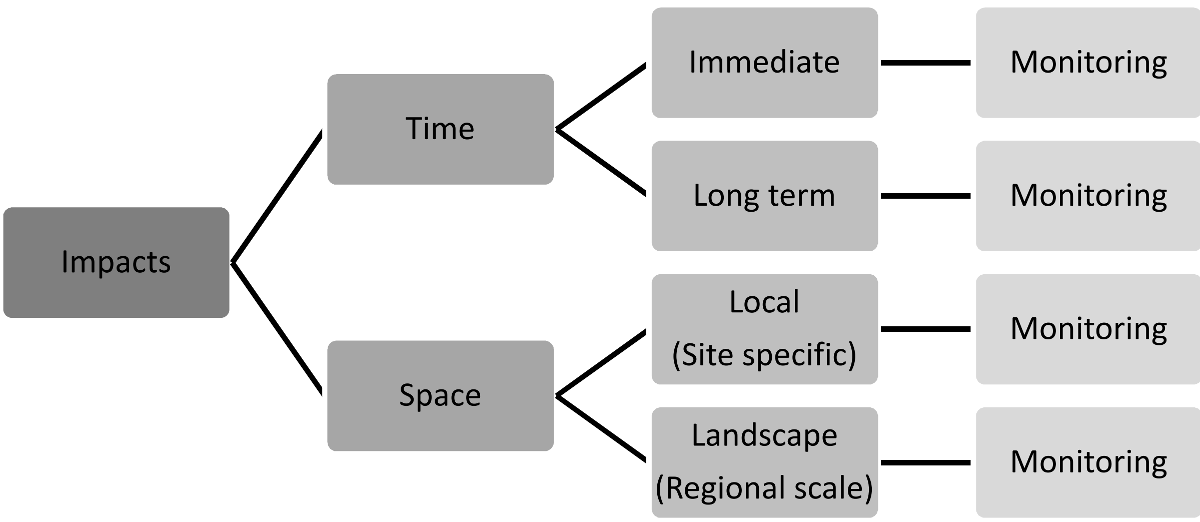

Figure 34: A conceptual framework of monitoring impacts related to unconventional oil and gas extraction

The following quote captures three of the most fundamental problems when it comes to monitoring, as well as the importance thereof:

> *"So too it is with monitoring. It is always regarded as a luxury – the last thing to be funded, the first to be cut and when it is done, it is often done poorly or filed away and not used. Yet, monitoring is critical to the maintenance of the life support systems on which we depend."*
>
> (Lindenmayer and Likens, 2010:ix)

According to Dornelas et al. (2011) both temporal and spatial scales are important to take into account when discussing human impacts, as well as the intensity and frequency of the impact. Disturbance can also impact on a single species or a number of species. It is therefore very important to take into account the specific impacts that an activity will have on biodiversity, when designing a monitoring protocol. The most significant impact on vegetation will be discussed below.

2.4.4.2 Habitat fragmentation

Habitat fragmentation is already eminent in most ecosystems in South Africa, due to the existence of roads, fences, agricultural activities, urban and regional development and industrial development.

The nature of the activities associated with unconventional oil and gas extraction has the potential to add even more pressure on the environment. Vegetation clearing for seismic lines, well pads, roads and pipelines are the most prominent activities that will affect the vegetation of an area. Although the physical surface disturbance associated with a single well pad is relatively small (Broderick et al., 2011), compared with that of mining e.g. coal or iron ore mining, the number of different sites (well pads) could be substantial. This feature of unconventional oil and gas mining makes this one of the most detrimental activities relative to ecosystem functioning.

In an interview with Dr. Anthony Ingraffea, he argued that the unconventional oil and gas extraction is spatially intense, and he calls it "an industry without boundaries" (Cantarow, 2013). This poses a challenge in terms of monitoring. The main question that comes to mind would be how to deal with the scale issue. What is the minimum patch size that will still sustain ecosystem processes? Given our high biodiversity, it is not possible to generaliee, e.g. a patch size at site A in the Grassland Biome, with high agricultural, industrial pressures and high rainfall, will be different from patch size at site B in the Nama-karoo Biome, where there is moderate agricultural pressure, no industrial pressure, but limited rainfall. Do we know the threshold for each type of ecosystem?

In the criteria used to identify threatened terrestrial ecosystems, thresholds were determined for critically endangered (CR), endangered (EN) and vulnerable (VU) ecosystems. These classifications were done by determining the ratio between the remaining natural habitat and the set biodiversity target. Although one of the eight criteria is "fragmentation" it is not yet included due to limitations to data availability (Reyers et al., 2007). This is however one of the criteria that will be developed in the near future (Driver et al., 2012) and could be included in future assessments of threatened ecosystems.

When monitoring the impact of habitat fragmentation, remote sensing could be a very useful tool in assisting with monitoring at either a regional or local scale. The choice of spectral images has increased over the years and has become more available. With South Africa being one of the most diverse countries in terms of biodiversity, it is also more complicated to do a thorough ecosystem status assessment. In a study in the Sandveld Region, Lück-Vogel et al. (2013) suggested a remote sensing approach to assess ecosystem state and they have designed an approach that delivered robust results, which could be useful for long term monitoring of large areas.

Moreno-de las Heras et al. (2011) assessed landscape structure and pattern fragmentation in semi-arid ecosystems in Australia and by using remote sensing data and techniques. Their study confirmed that it is critical to maintain intact vegetation types to protect ecosystem structure and functionality in semi-arid landscapes. They have also suggested that the combined use of patch-size distribution analysis of vegetation and other indicators be used as diagnostic tools for monitoring semi-arid ecosystems.

Adaptive Monitoring Framework

Although there is no “one-size-fits-all” approach to doing ecological monitoring, the Adaptive Monitoring Framework that was suggested by Lindenmayer and Likens (2010) has potential. This new paradigm includes matters such as the formulation of well-defined question(s) from the outset; rigorous statistical design and passionate, knowledgeable, and competent leadership.

According to Field et al. (2007) only a few ecological indicators would be sensitive enough to show change within a five to 10 year period. Ideally the monitoring period should be longer, but this will have funding implications. The same authors also noted that one of the key issues that are often neglected is a good sampling design, a design that is rigorous enough to detect change. It is however imperative that these results be analysed as soon as possible to see if there are any adjustments needed to the sampling design.

In their book, a list of 22 components for maintaining effective monitoring programs is presented (Lindenmayer and Likens, 2010). These components should be incorporated in any monitoring proposal. This approach is also scale independent, which is a crucial issue to take into account with unconventional oil and gas extraction.

Data management

According to *NEMBA (Act 10 of 2004)* the South African National Biodiversity Institute (SANBI) are responsible for monitoring the status of vegetation in South Africa. In addition, vegetation data in national parks, are collected by SANPARKS, while vegetation data in Provincial Nature Reserves are collected by the appointed management authority e.g. Cape Nature, (Western Cape Province) and vegetation data in the Free State Province will be collected by the Provincial Conservation Authority. Except for occasional monitoring as part of post-graduate research, no areas outside national parks, provincial nature reserves, stewardship area and world heritage sites, are monitored by provincial authorities.

Although it is SANBI’s mandate to monitor and keep data, partnerships between Academic institutions, DEA and National Museums could also be able to assist with monitoring as part of their research commitments, provided that adequate funding is available, and that they have the capacity to monitor the specific indicator. Lindenmayor and Likens (2010) recognises that complementary partnerships, strong and dedicated leadership and adequate funding structures will add to the probability of successful long term monitoring. With tertiary institutions in each province, these entities could support long-term research in a sustainable manner. Although it is recognised that the knowledge and expertise base is not the same throughout institutions, academia should have the capacity to sustain the institutional memory needed for effective long-term monitoring. It is also more likely that monitoring data be published and available in the public domain, which might, in turn, establish the credibility of the monitoring program and attract more funding.

The rapid turn-over of staff at state departments and frequent changes in the structure of these departments do not favour long-term monitoring.

Conclusion

It is important to recognise that one has to take into account the impact of unconventional oil and gas extraction on a whole ecosystem, and not just vegetation, or surface water. It was argued by Cook et al. (2013) that there must be an understanding of the impact of multiple land uses on landscape functionality, since it is these landscape processes that we depend on. The proposed monitoring framework for vegetation can be seen in Table 64.

Table 64: Monitoring framework for vegetation

Phases	Before exploration	During exploration	During extraction	After extraction
Possible impacts of concern that need to be monitored (WHY?)	**Vegetation clearing:** To determine a baseline condition (Present day status) before the clearing starts.	**Vegetation clearing:** Could lead to a further loss of biodiversity, increased erosion potential, loss of ecosystem functioning etc. **Vegetation die-off:** Due to chemical spills. This could have long-term effects on the ecosystem if not dealt with immediately after the spill has occurred.	**Vegetation clearing:** Could lead to a further loss of biodiversity, increased erosion potential, loss of ecosystem functioning etc. Monitoring is needed to determine any change in parameters, which could inform management decisions. Due to the continuous nature of unconventional oil and gas extraction, where well pads are added on a continuous basis this might be challenging. **Vegetation die-off:** Due to chemical spills. This could have long-term effects on the ecosystem if not dealt with immediately after the spill has occurred.	**Vegetation clearing:** Could lead to a further loss of biodiversity, Increased erosion potential, loss of ecosystem functioning etc. **Vegetation die-off:** Should hazardous substances from fracking fluids migrate from subsurface sources to the rooting zone, vegetation die off could occur.
Aspects that need to be monitored (WHAT?)	**Vegetation clearing:** Due to the scale of this type of activity, it is recommended that all existing site based monitoring be continued by individuals and/or organisations. A detailed gap analysis need to be performed to identify what monitoring currently takes place in order to be able to augment the current monitoring system where needed.	**Vegetation clearing:** Surface area cleared for seismic surveys. **Vegetation die-off:** Determining the rate of die-off, determining the chemical signature of the substances that occurs on site.	**Vegetation clearing and Vegetation die-off:** Surface area cleared for well pad, road –and pipeline construction or any other related vegetation clearing associated with unconventional oil and gas extraction. . It will also depend on the monitoring design.	**Vegetation clearing and Vegetation die-off:** The change in vegetation dynamics such as vegetation cover, species composition, abundance or any other parameters that would be suitable to detect a change in the ecosystem functioning. These changes could be due to surface restoration/ rehabilitation efforts.

Table 64: Monitoring framework for vegetation continued.

Phases	Before exploration	During exploration	During extraction	After extraction
How should these aspects be monitored?	**Vegetation clearing:** Remote sensing	**Vegetation clearing:** Continued monitoring. At least seasonal monitoring needs to be done. **Vegetation die-off:** Vegetation and soil samples should be collected (No procedures yet, to be updated)	**Vegetation clearing:** Continued monitoring. At least seasonal monitoring needs to be done to determine a change in vegetation dynamics. . It will also depend on the monitoring design. **Vegetation die-off:** Vegetation and soil samples should be collected (No procedures yet, to be updated)	**Vegetation clearing:** E.g. Braun Blanquet, Land-function analysis or any other methodology that would be suitable for identifying change in the landscape. Expected timeframes for on-going monitoring will have to be determined based on monitoring observations and analyses. **Vegetation die-off:** Monitor change in damaged/new/rehabilitated vegetation. Expected timeframes for on-going monitoring will have to be determined based on monitoring observations and analyses.
Where do these aspects need to be monitored? (on site, regional?)	**Vegetation clearing:** Regional scale	**Vegetation clearing:** Enough site specific data would inform the regional dataset. **Vegetation die-off:** Site specific.	**Vegetation clearing:** Enough site specific data would inform the regional dataset. It will also depend on the monitoring design. **Vegetation die off:** Site specific.	**Vegetation clearing:** Enough site specific data would inform the regional dataset. **Vegetation die-off:** Site specific.
Who must do the monitoring?	**Vegetation clearing:** Independent body, SANBI or Academia involved in the area	**Vegetation clearing:** Independent body, SANBI or Academia involved in the area **Vegetation die-off**: DEAT	**Vegetation clearing:** Independent body, SANBI or Academia involved in the area **Vegetation die-off:** DEAT	**Vegetation clearing:** It is suggested that local experts be used. Both academia and regulatory authorities, or an independent body should also be involved in the process.
References				Braun Blanquet Mueller-Dombois and Ellenberg H (1974) LFA (Tongway and Hindley, 2004)

5.4.5 Socio-economics

It is widely recognised that progress toward sustainable development requires increased information for decision-making. The monitoring of socio-economic impacts of development is thus important in providing decision-makers, development managers and broader society with a means of reflecting on past experiences and to aid future planning and resource allocation (World Bank, 2004). The regular measurement of indicators enables tracking of trends through time, provides information for more informed choices, and enables continuous improvement in how oil and gas production and mining is conducted (DME n.d.). In the case of development activities that are potentially harmful for the communities, particularly for vulnerable sectors of those communities, monitoring of impacts is also an important component of accountability to stakeholders and affected parties (Pelser et al., 2005).

Barrow (2002) views the monitoring of social impacts as an activity aimed at *"establishing a system of continued observation, measurement and evaluation for defined purposes"*. Thus, monitoring would include tracking variables over specific time periods to determine deviation or convergence with the original targets by means of pre-determined indicators (Pelser et al., 2005). Based on this, the objective of monitoring of social impacts will primarily be to gauge the extent to which the socio-economic environment is being affected by the exploration and extraction of unconventional oil and gas in South Africa so that mitigation measures can be put in place in a timeous manner. Finsterbusch (1977) states that *"monitoring impacts involves the measurement of change against an established set of evaluative criteria"* to determine whether a development brought about negative changes to the socio-economic environment and this makes it possible for re-assessing the way in which a development is conducted. To monitor possible impacts of proposed developments, one needs to proceed from a baseline to assess how the proposed development affects the social environment over time.

From a legislative standpoint, the *Constitution*, the *NEMA* and the *MPRDA* underpin the assessment and monitoring of social issues that may arise from proposed unconventional oil and gas exploration and extraction. The rights, principles and objectives enshrined in the legislative framework calls for developments to take the rights of South African citizens to human dignity, equality and freedom into consideration. From a constitutional point of view it is vital to monitor to what extent developments negatively impact on the human health and well-being of the people of the country (Barbour, 2007). The *MPRDA* specifically acknowledges that mining and production operations must be conducted within the accepted principles of sustainable development by integrating economic and environmental factors in planning and implementation of mining and petroleum resource development projects and that an application for a prospecting or mining right or petroleum exploration or production right must also contain a Social and Labour Plan that should include, amongst others, the social and economic background of the area in which the mine operates; the key economic activities of the area in which the mine or production area operates and the impact that the mine or production area would have in the local and sending communities.

Before exploration for unconventional oil and gas starts the current status of the socio-economic environment therefore needs to be determined. For the purposes of developing a monitoring protocol, the socio-economic environment is divided into different dimensions based on the PED-nexus methodological framework used throughout this project. The monitoring protocol proposed here needs to be seen as a generic framework to inform future monitoring of the impacts of unconventional oil and gas on affected communities.

The monitoring protocol is divided into three parts. In the first part, the monitoring of impacts of unconventional oil and gas exploration and extraction on the population dimension of the PED-nexus is presented. This dimension of the social environment is monitored by specifically looking at changes to the population structure and distribution of a population. The environment dimension is monitored by looking at changes in the health status of the population, while the development component is monitored by looking at economic and social well-being.

Table 65: Monitoring framework for socio-economics

Phases	Before exploration	During exploration	During extraction (at predetermined intervals)	After extraction
Possible impacts of concern that need to be monitored (WHY?)	**Population: Population mobility and structure** Any development activity (in this case exploration and extraction of unconventional oil and gas) brings potential changes to the population distribution and structure. These aspects need to be monitored to identify potential negative impacts i.e. unbalanced sex ratios, unbalanced age structures, influxes of people, out-migration that result from extraction and exploration.			
Aspects that need to be monitored (WHAT?)	• Migration flows to and from sending/ receiving communities • Changes to the sex ratio from baseline • Changes to the age structure from existing baseline	• Migration flows to and from sending/ receiving communities • Changes to the sex ratio from baseline • Changes to the age structure from baseline • Changes in age and sex specific mortality – Infant mortality and under five mortality rates need to be monitored specifically	• Migration flows to and from sending/ receiving communities • Changes to the sex ratio from baseline • Changes to the age structure from baseline • Changes in age and sex specific mortality – Infant mortality and under five mortality rates need to be monitored specifically	• Migration flows to and from sending/ receiving communities • Changes to the sex ratio from baseline • Changes to the age structure from baseline • Changes in age and sex specific mortality – Infant mortality and under five mortality rates need to be monitored specifically
How should these aspects be monitored?	Use of existing data bases (StatsSA), Department of Health (DoH); Municipal IDPs; public meetings; key informant interviews	Comparative analysis of existing data sources: StatsSA, Municipal IDPs, DoH triangulated with community surveys in oil and gas communities and sending communities; public meetings; key informant interviews	Comparative analysis of existing data sources: StatsSA, Municipal IDPs, DoH triangulated with community surveys in oil and gas communities and sending communities; public meetings; key informant interviews	Comparative analysis of existing data sources: StatsSA, Municipal IDPs, DoH triangulated with community surveys in oil and gas communities and sending communities; public meetings; key informant interviews
Where do these aspects need to be monitored ?	On site and regional to provide for comparative analysis	On site and regional to provide for comparative analysis	On site and regional to provide for comparative analysis	On site and regional to provide for comparative analysis
Who must do the monitoring?	Department of Social Development (DSD) in collaboration with independent research institutions (research consulting firms, academic institutions) as part of SIA process	Department of Social Development (DSD) in collaboration with independent research institutions (research consulting firms, academic institutions) as part of SIA process	Department of Social Development (DSD) in collaboration with independent research institutions (research consulting firms, academic institutions) as part of SIA process	Department of Social Development (DSD) in collaboration with independent research institutions (research consulting firms, academic institutions) as part of SIA process
References	Esteves, 2008; Larson et al, 2011; Lockie et al., 2009; Pelser et al., 2005; Pelser, 2012; Personal interviews – key informants, 2013; Redelinghuys, 2012; Weigle, 2012.			

Table 65: Monitoring framework for socio-economics continued

Phases	Before exploration	During exploration	During extraction at predetermined intervals	After extraction
Possible impacts of concern that need to be monitored (WHY?)	**Health status: Changes in morbidity, mortality with specific reference to disease prevalence and cause of death.** These indicators can be used as proxy indicators to identify adverse environmental changes, socio-economic changes and population changes impacting on human health. It is vital that changes to the health status of the population be closely monitored to timeously mitigate any potential harmful environmental and social impacts on the health status of the population			
Aspects that need to be monitored (WHAT?)	• Disease prevalence: HIV, STDs, TB, respiratory diseases, water-borne diseases. • The incidence of disease and disability resulting from trauma, injury • Cause of death • Age and sex specific mortality – Infant mortality and under five mortality rates	• Disease prevalence: HIV, STDs, TB, respiratory diseases, water-borne diseases. • The incidence of disease and disability resulting from trauma, injury • Cause of death • Changes in age and sex specific mortality – Infant mortality and under five mortality rates need to be monitored specifically	• Disease prevalence: HIV, STDs, TB, respiratory diseases, water-borne diseases. • The incidence of disease and disability resulting from trauma, injury • Cause of death • Changes in age and sex specific mortality – Infant mortality and under five mortality rates need to be monitored specifically	• Disease prevalence: HIV, STDs, TB, respiratory diseases, water-borne diseases. • The incidence of disease and disability resulting from trauma, injury • Cause of death • Changes in age and sex specific mortality – Infant mortality and under five mortality rates need to be monitored specifically
How should these aspects be monitored?	Use of existing data bases (StatsSA, DoH); Municipal IDPs; public meetings; key informant interviews	Comparative analysis from baseline data (prior to extraction) obtained from DoH hospital and clinic survey data), triangulated with inputs for key informant interviews	Comparative analysis from baseline data (prior to extraction) obtained from DoH hospital and clinic survey data), triangulated with inputs for key informant interviews	Comparative analysis from baseline data (prior to extraction) obtained from DoH hospital and clinic survey data), triangulated with inputs for key informant interviews
Where do these aspects need to be monitored? (on site, regional?)	On site and regional to provide for comparative analysis	On site and regional to provide for comparative analysis	On site and regional to provide for comparative analysis	On site and regional to provide for comparative analysis
Who must do the monitoring?	Baseline data is available from StatsSA and DoH.	DoH in collaboration with independent research institutions (consulting firms and academia)	DoH in collaboration with independent research institutions (consulting firms and academia)	DoH in collaboration with independent research institutions (consulting firms and academia)
References	Beemster and Beemster 2011; Broderick et al., 2011; Coburn et al., 2011; Kgarbo et al., 2010; Chung and Hoffnagle, 2011; Dolesh, 2011; DSD, 2010; Heunis et al.,. 2012; Marsa, 2011; Pelser and Redelinghuys, 2006; Redelinghuys, 2012.			

Phases	Before exploration	During exploration	During extraction at predetermined intervals	After extraction
Possible impacts of concern that need to be monitored (WHY?):	**Socio-economic well-being: changes in economic and social well-being** Needs monitoring to be able to mitigate the potential harmful impacts of unconventional oil and gas extraction on the socio-economic well-being of the population.			
Aspects that need to be monitored (WHAT?)	**Economic** • Poverty rates (also gender based) • Unemployment rates • Economic diversity **Political** • Infrastructure • Public participation • Corporate social responsibility **Human well-being** • crime rates • pride in community, • living culture • education	**Economic** • Poverty rates (also gender based) • Unemployment rates • Economic diversity **Political** • Infrastructure development • Public participation • Corporate social responsibility **Human well-being** • crime rates • pride in community, • living culture • education	**Economic** • Poverty rates (also gender based) • Unemployment rates • Economic diversity **Political** • Infrastructure development • Public participation • Corporate social responsibility **Human well-being** • crime rates • pride in community, • living culture • education	**Economic** • Poverty rates (also gender based) • Unemployment rates • Economic diversity **Political** • Infrastructure development • Public participation • Corporate social responsibility **Human well-being** • crime rates • pride in community, • living culture • education
How should these aspects be monitored?	Baseline data from existing data sources; key informant interviews, qualitative assessment of community dynamics through in-depth interviews with community members	Comparative analysis from baseline data (prior to extraction) obtained from Department of Labour, StatsSA triangulated with inputs for key informant interviews and in-depth qualitative site specific studies on community well-being	Comparative analysis from baseline data (prior to extraction) obtained from Department of Labour, StatsSA triangulated with inputs for key informant interviews and in-depth qualitative studies on community well-being	Comparative analysis from baseline data (prior to extraction) obtained from Department of Labour, StatsSA triangulated with inputs for key informant interviews and in-depth qualitative studies on community well-being
Where do these aspects need to be monitored? (on site, regional?)	On site and regional to allow for comparative analysis	On site and regional to allow for comparative analysis	On site and regional to allow for comparative analysis	On site and regional to allow for comparative analysis
Who must do the monitoring?	Department Mineral Resources collaboration with independent research institutions (consulting firms and academia)	Department Mineral Resources collaboration with independent research institutions (consulting firms and academia)	Department Mineral Resources collaboration with independent research institutions (consulting firms and academia)	Department Mineral Resources collaboration with independent research institutions (consulting firms and academia)
References	Beemster and Beemster, 2011 Broderick et al., 2011; Chung and Hoffnagle, 2011; Coburn et al.,,. 2011; Dolesh, 2011; Pelser et al., 2005; Rolfe et al., 2007; Walsh, 2011 Weigle, 2011; WWF, 2008; Williams et al., 2012.			

Population: population mobility and structure

When monitoring the population dimension of the socio-economic environment, the mobility of the population and changes in the age and sex structures are aspects to monitor. In addition, changes in mortality patterns can be indicative of the possible negative impacts of unconventional oil and gas exploration and extraction on communities. It is well documented that any large-scale economic development, such as mining, impacts on the population size and structure of the population. In monitoring the impacts of unconventional oil and gas exploration and extraction on the population structure, the relevant regulation and monitoring agencies can be alerted to explore, identify and deal with the secondary impacts emanating from changing demographic structures in communities.

Changes in the age structure or sex ratio of the population point towards an increase in the number of people in vulnerable population categories, namely women and children. During exploration and mining, flowing from an influx of primarily male workers, the sex ratio of the specific populations often becomes imbalanced. This is problematic from a social well-being and development perspective, since this imbalance may fuel social ills such as increases in sex trade and the objectification of women (Personal interview: Key informant 2013). Imbalances in the sex ratio thus serve as a measure to alert to the presence of a range of social ills i.e. increases in the number of female-headed households, rising female poverty, and the potential sexual and economic exploitation of women and children. In monitoring changes in the sex ratio during exploration and mining and after, measures can be put in place to mitigate the impacts of oil and gas extraction on disproportionate female populations. To this end, it is important to have up to date data on the extent of imbalances in the sex ratio.

Mining results in an influx of males in working age groups to areas where mining takes place and a concomitant out-migration from sending communities. This would also be the case with unconventional oil and gas extraction. The age structure of communities in which exploration and extraction may take place may come to reflect the influx of more people in the economically active age cohorts (between 18 - 45). These imbalanced age structures point towards increasing vulnerability to economic insecurity, health and social well-being problems for the more vulnerable sectors of the population (women and children) (Esteves, 2008; Lockie et al., 2009; Weigle, 2012). In the aftermath of oil and gas extraction, an outflow of workers may lead to smaller communities being left with a severely imbalanced age structure where only the aged, women and children are left behind, while those who are economically active (men) go and search for employment elsewhere (Pelser et al., 2005). Thus, in monitoring changes in the age structure, up-to-date information on the extent of age-related population imbalances can be obtained and mitigating measures can be put in place to protect the vulnerable sectors of these communities from social impacts such as rising poverty and economic inequality, economic exploitation and deteriorating health and well-being in the vulnerable age cohorts.

Health status: Changes in morbidity, mortality with specific reference to disease prevalence and cause of death.

The monitoring of age and sex specific mortality gives a good indication of the impact of oil and gas extraction on the health and well-being of the populations affected by unconventional oil and gas exploration and extraction. Age and sex specific mortality is indicative of wider impacts of mining (or oil and gas extraction) on health and well-being. The health of certain age groups, notably children under five and the elderly, are more vulnerable to the impacts of environmental change. A sharp increase in the infant mortality rate, or the under-five mortality rate are powerful indicators with which to measure the impacts of oil and gas extraction on the health status of the population as these age groups are very sensitive to environmental problems such as water pollution and air pollution. Similarly, changes in the mortality of either men and women also indicate the increased vulnerability of either gender to the social consequences of mining or oil and gas extraction – increased HIV-related morbidity and mortality for women is a well-documented impact of mining (Larson, 2011; Pelser, 2012, Redelinghuys, 2012).

With regards to health impacts, disease prevalence and cause of death are important factors to monitor, specifically with regards to conditions that are known to be linked to mining developments. Disease patterns that need to be monitored are HIV, TB and cancers, while disability and death due to external causes are also important. When the incidence and prevalence of diseases are monitored one can over time distinguish trends or patterns in diseases that occur as a result of biophysical and social factors and these factors can then be mitigated more effectively.

With regards to unconventional oil and gas exploration and extraction, it is vital to monitor the prevalence and incidence of diseases that are known to have been exacerbated by mine-related developments. Sexually-transmitted diseases, including HIV is a disease category that is of specific importance where mining developments are concerned. The symbiotic relationship between mining, and the spread of HIV is well researched and documented and the impacts of HIV-infections on populations are experienced years after mining has seized (DSD, 2010; Pelser and Redelinghuys, 2006). Increased HIV prevalence is driven by factors related to mine developments such as increased population movement, socio-economic inequalities, gender imbalances and loss of social cohesion (Heunis et al., 2012).

Another disease of concern where mining is concerned is tuberculosis. Tuberculosis and HIV are inextricably linked in the South African context. Therefore, an increased prevalence of HIV will also inadvertently coincide with an increased prevalence of TB (Heunis et al., 2012). From a health management perspective it is vital to monitor TB as part of the disease profile of communities where unconventional oil and gas exploration and extraction is taking place as well as in the post extraction social environment. Due to the various health risks identified with regards to unconventional oil and gas exploration and extraction it is necessary to also monitor the prevalence of environmentally-related diseases such as cancer, respiratory diseases and water-borne diseases.

Increased development as a result of the exploration and extraction of unconventional oil and gas also brings with it increased incidences of trauma, injury and death from external causes such as accidents. In this regard it is vital to monitor road traffic accidents and disability and injury directly associated with unconventional gas extraction. In addition, trauma and injury associated with violence and crime also needs to be monitored (Coburn et al., 2011; Redelinghuys, 2012)

Socio-economic well-being: changes in economic and social well-being

With regards to socio-economic well-being, it is necessary to monitor changes in the economic status, changes in social well-being as well as changes to the institutional environments affected by unconventional oil and gas extraction.

With regards to economic status, indicators that would indicate negative impacts of oil and gas extraction on the community include the unemployment rate and job creation, sectoral employment, and the number and proportion of female headed households. Social well-being is monitored by looking at how secure and integrated the community members perceive themselves to be in a specific community.

Long term economic well-being is reliant on permanent employment over time. Unconventional oil and gas extraction is expected to lead to an increase in temporary job, but not necessarily in permanent jobs. It is therefore important to monitor the actual impacts of unconventional oil and gas extraction and exploration on job creation in the long term, and the impacts of mine closure on job shedding (Chung and Hoffnagle, 2011; Interview: Key informant 2013). Without monitoring the extent to which the gas sector creates jobs for local communities, it is difficult to gauge the extent to which unconventional oil and gas exploration and extraction in fact does contribute to job creation. This is also important when considering the economic impacts post extraction. Communities experience a severe economic downturn and many businesses that benefited from the gas boom close down, leading to increased poverty and economic hardship (Pelser et al., 2005).. Without accurate data on the extent to which oil and gas extraction has contributed to job creation, there is no baseline data with which to gauge the impact of mine closure on the jobs in the affected communities.

Many mining developments take place in communities with limited economic opportunities and these communities, while benefitting from the economic developments brought about by mining tend to become economically reliant solely on mining activities. Thus, it is important to monitor the degree to which oil and gas extraction contributes to or impedes economic diversification so that mitigating measures to this end can be put in place in view of the post-extraction period.

It is vital in monitoring socio-economic well-being to specifically focus on gender disparities. In areas where there is an overrepresentation of women who are unemployed and who lack basic socio-economic needs, unconventional oil and gas exploration and extraction may bring about similar deleterious consequences including prostitution, alcohol abuse, spread of HIV and STDs. (Interview: Key informant 2013).

Infrastructure development and impacts of unconventional oil and gas extraction on existing infrastructure needs to be monitored. With the exploration and extraction of unconventional oil and gas, there is more pressure on local infrastructure such as housing, water and sanitation, refuse disposal systems, roads etc. Higher levels of socio-economic development will lead to increased access to sanitation, water provision, housing and communities benefit from the development of infrastructure such as roads, health services and more commercial activity (Rolfe et al., 2007). Increased property values means that when house prices and rent goes up accordingly, housing may become unaffordable to many people in the community (Coburn et al., 2011; Walsh, 2011; Williams, 2011). However, infrastructure may also improve as a result of oil and gas exploration and extraction. Among others, access to health care services may improve in under resourced rural communities (Esteves 2008; Rolfe et al., 2007). However, after the oil and gas extraction activities have ceased, communities may experience a decline in access to these services as oil and gas companies withdraw their resources. The infrastructure developments (housing, schools, health care services) directly and indirectly impacted on by unconventional gas developments need to be identified and their functioning monitored through all phases of oil and gas extraction. With regards to physical infrastructure, one key informant and Beemster and Beemster (2011) emphasised that the impact of fracturing on local infrastructure, such as roads and bridges needs to be monitored.

The economic benefits of unconventional oil and gas exploration and extraction need to be weighed against the impacts of these developments on communities' sense and perception of well-being and security. Communities are exposed to changes threatening their social structure and security and this is a breeding ground for a loss of a sense of community and a diminishing positive experience of their sense of social cohesion and sense of place. Thus, it is important to monitor changes in the community fabric by focusing on aspects such as community perceptions of satisfaction, happiness, sense of security and sense of place and levels of public participation in communities.

6 CONCLUSION

This report emanates from a project entitled "Development of an interactive vulnerability map and preliminary screening level monitoring protocol to assess the potential environmental impact of unconventional oil and gas extraction by means of hydraulic fracturing". The study was proposed in light of the applications that were made by various companies for exploration permits with the Petroleum Agency of South Africa (PASA) during 2009-2011. The extent of applications for the exploration and extraction of shale oil and gas and coalbed methane spans large areas of South Africa (approximately 32% of the surface area of South Africa at the time of writing the report) and necessitated an investigation into the possible impacts associated with unconventional oil and gas extraction by means of hydraulic fracturing (also known as fracking), as well as identifying vulnerable areas that need protection in terms of unconventional oil and gas extraction. A monitoring protocol that can be used during unconventional oil and gas development was also developed for selected entities.

6.1 Background on and impacts of unconventional oil and gas extraction

A background review was performed as the first step towards understanding the complexities of unconventional oil and gas extraction by means of hydraulic fracturing. The description of the process of unconventional oil and gas extraction (section 2 of this report) and the impacts that have been summarised for different entities (section 3 of this report) should aid government in developing the required regulatory policies and guidelines to manage unconventional oil and gas extraction and hydraulic fracturing in South Africa in a way that will protect human health and the environment and ensure sustainable use of our very scarce water resources.

Possible impacts were described in detail in section 3 of the report and have been divided into biophysical entities and socio-economic entities. Biophysical entities include surface water, groundwater, seismicity, vegetation, soil, air quality, aquatic invertebrates, terrestrial insects, mammals, fish and amphibians and reptiles. Socio-economic entities include economic well-being, health, agriculture and food security, social well-being and living conditions, demographic impacts, astronomy, archaeology and heritage resources and national parks.

Apart from the possible positive impacts of unconventional gas extraction (providing energy and jobs), possible negative impacts may also occur in both the biophysical and socio-economic environments. There are multiple and reciprocal linkages between society and the environment, which necessitates research into the possible impacts of unconventional gas extraction on the biophysical and socio-economic spheres, and how these impacts interlink. The possible negative social impacts resulting from unconventional oil and gas extraction need to be well understood and avoided where possible. These possible impacts include competition over water between oil and gas companies and existing lawful water users in the Karoo; securing access to water and sanitation for previously disadvantaged communities in the face of competing demands presented by fracking operations; the potential health risks associated with lack of access to water and adequate sanitation in vulnerable communities; in-migration and higher population density in ecologically sensitive and water scarce areas.

Negative environmental impacts may also occur, which may include impacts on water resources (in terms of quality and quantity for both surface water and groundwater resources), habitat fragmentation and loss as well as air quality impacts, to name a few. By describing the possible impacts, it is hoped that some negative impacts during unconventional oil and gas extraction may be minimised. The description of impacts also aided the team during the development of the monitoring protocol.

6.2 Vulnerability mapping

The interactive vulnerability map focuses on specific entities, which include surface water, groundwater, vegetation, seismicity and socio-economics, and was developed specifically for South Africa.

The vulnerability map aims to assist decision-makers at national level and other practitioners information on the vulnerability to unconventional oil and gas extraction of the specified mapping themes on a regional scale. The vulnerability map was developed by using experts in their respective fields to decide on indicators that would indicate vulnerability of a theme to unconventional oil and gas extraction specifically. Regional scale data was used for this regional map and the map cannot replace local scale maps that may need to be developed to inform decision-makers of local scale conditions of vulnerability to unconventional oil and gas extraction. This map is intended as a reconnaissance tool to inform decision-makers on areas where additional detail field work and assessments may be required as part of EIA and licensing conditions.

Typically vulnerability is a function of exposure, sensitivity and coping (adaptive) capacity. The greater the exposure or sensitivity, the greater the vulnerability, and the greater the coping capacity, the less vulnerable of the system will be. Classically, biophysical systems mostly identify sensitivity indicators and coping capacity indicators are usually identified for the socio-economic sphere and refer to adaptability by humans. For the interactive vulnerability map in this project, only sensitivity indicators were identified and mapped. Detail information on the mapping approach and limitations are discussed in section 4 of this report.

The normative approach was followed for the identification of sensitivity indicators for the vulnerability map for unconventional oil and gas extraction. Although this approach requires time and resources and is limited in its application and transferability to other regions (e.g. countries outside South Africa), the integration of expert knowledge provides support for the weighing and aggregation of the indicator components and may increase the acceptability of the results. It is also widely acknowledged that the involvement of stakeholders in the development of indicators is key to identifying relevant vulnerability indicators.

The vulnerability map should not be viewed as a static entity. More detailed information may become available on themes that are mapped now, and new indicators may later be used for which no accurate spatial data currently exists (an example is heritage sites). Also, information that has been included in the current interactive map, such as the borehole information from the National Groundwater Archive, must be updated as the Archive data is updated. There must therefore be the option of possible updates or refinements to the map as a ‘working document’.

Such refinement of and/or additions to the vulnerability map may occur during later stages of follow-up projects.

6.3 Monitoring protocol

Performing monitoring of various entities of the biophysical and socio-economic spheres before exploration, during exploration, during extraction and after extraction is important to assess possible changes in these entities due to the unconventional oil and gas extraction process. Whereas the background review illustrates various possible impacts of concern, active monitoring of certain entities can address some of these concerns and identify possible problems timeously.

The protocol should be viewed as a provisional screening level monitoring protocol and can be used as a guideline for planning monitoring activities, during the various phases of unconventional oil and gas extraction. The legal aspects related to monitoring and protecting resources in general in South Africa, is very important and have been discussed in some detail.

The objective of the protocol is to identify the important entities to be monitored and discuss means of monitoring for selected entities (surface water, groundwater, seismicity, vegetation and socio-economics). The protocol discusses issues such as why monitoring of certain aspects is required, where monitoring must be performed (site specific or regional), when it must be performed (related to the different phases of unconventional oil and gas extraction), how it must be performed (by discussing aspects such as parameters to be monitored as well as data management) and who the relevant parties are that should do this monitoring (oil and gas companies vs. regulators). The protocol also addresses various legal and governance considerations related to such monitoring, such as the role of international law in South Africa, the interaction of different pieces of legislation related to the monitoring of selected media and areas of concern (surface water, groundwater, vegetation, seismicity and socio-economics), the mandates of different South African departments in performing specific monitoring functions and the feasibility of forming a central independent body to monitor unconventional gas extraction. These aspects relate to questions relating to the execution of the monitoring programmes for the aspects for which monitoring protocols have been discussed.

Although the list of entities discussed in this monitoring protocol is not exhaustive, it could assist government in planning and monitoring the entities of most concern.

6.4 Recommendations and way forward

This study investigated unconventional oil and gas mining by means of hydraulic fracturing by identifying possible impacts related to this activity. These possible impacts were used to develop a vulnerability map for unconventional oil and gas mining for specific themes (surface water, groundwater, vegetation, seismicity and socio-economics). A provisional screening level monitoring protocol was also developed. It is hoped that the background review, interactive vulnerability map and the provisional screening level monitoring protocol can be used by authorities to develop regulations and effectively regulate this activity in order to minimize or mitigate possible impacts that may emanate from this activity. Since unconventional oil and gas extraction advances fairly quickly with new advances in technology, it is recommended that authorities and practitioners update their knowledge regularly.

The interactive map is a regional scale map that may be used as a reconnaissance tool during EIAs and license evaluations. Local scale investigations must still be performed in order to understand for instance local aquifer occurrences, local vegetation occurrences and localized river conditions. It is recommended that this map be upgraded in future with updated datasets (e.g. updated maps of critical biodiversity areas, updated aquifer information etc.). Groundwater use is one of the aspects over which there is uncertainty (national datasets are not entirely accurate) and the human dependence on groundwater as indicated in the vulnerability map need to be updated with more accurate and finer resolution data. In addition to the government control aquifers, other sole source aquifers (which may not be known at this stage) and new aquifers (that have not been mapped yet) also need to be identified and included in the map. These activities are extremely important if the DWA is to protect groundwater in water scarce areas for human use.

The monitoring protocol is a provisional screening level monitoring protocol that addresses various aspects such as what entities must be monitored, how it must be monitored, where it must be monitored and by whom this monitoring must be done. Monitoring is discussed per extraction phase (before exploration, during exploration, during extraction and after extraction). Induced seismicity, aquifer and surface water contamination, landscape and ecosystem fragmentation, emissions to the atmosphere, together with potentially adverse social impacts, are all likely to be of concern to the community, and will need to be monitored before oil and gas exploration (using baseline surveys), during oil and gas exploration and extraction as well as after oil and gas extraction.

It is recommended that baseline surveys be performed as a matter of urgency. Baseline monitoring before exploration is extremely important in order to establish reference conditions of the target area (and the surrounding areas) before exploration or any other activity took place. Baseline monitoring would also inform future monitoring during the other phases of oil and gas mining (exploration, extraction and post extraction). For some entities baseline monitoring is more complex than for others.

Groundwater baseline monitoring would require a hydrocensus and field reconnaissance with a pilot study to determine the accurate parameters that need to be monitored during the baseline and during the other phases of oil and gas exploration and extraction. Monitoring of groundwater parameters may be extremely costly and logistics of sampling and laboratory analyses may be complex. All these concerns also stress the importance of performing hydrocensuses as soon as possible in potential target areas (addressing groundwater quality as well as quantity), that aquifers be mapped accurately and that laboratories be upgraded to include the relevant analyses capabilities to ensure the success of groundwater baseline monitoring and monitoring during the other phases of oil and gas extraction.

Closely linked with groundwater monitoring, is the monitoring of seismicity. Currently the Council for Geoscience monitors regional seismicity in South Africa, but the number of seismic stations are not enough to obtain a good enough resolution for monitoring of seismicity during unconventional oil and gas extraction. It is recommended that a network of seismographs and accelerographs, that have the ability to record macro- and micro-earthquakes, be installed and operated before and during exploration as well as during and after extraction. It is strongly recommended to begin this seismic monitoring before the hydraulic fracturing exploration phase, in order to establish a baseline.

Although monitoring of unconventional oil and gas extraction and its associated impacts is likely to be undertaken by petroleum companies as part of their normal operations (and may be required by the regulator), independent verification monitoring will also need to be undertaken by government or other agencies and/or credible research bodies in order to win community confidence.

Government will need to take steps to adequately curate new information gathered during baseline surveys and monitoring that will be collected which will need to be over extended periods of time, including placing requirements on industry to ensure that data is not lost and is made available to government. It is thus recommended that government already now identifies or establishes a body for data curation and assessment of the data that are gathered through monitoring activities.

It will be vital for industry and government to recognise the complexity of the challenges posed by these possible impacts. However, most can be minimised where an effective regulatory system and best monitoring practice are in place and can be remediated where they do occur. If the oil and gas industry is to earn and retain the social licence to operate, it is a matter of some urgency to have a transparent, adaptive and effective regulatory system in place that is implemented and backed by best practice monitoring, in addition to credible and high quality baseline surveys. A major coordinated programme of research should be initiated at an early stage to ensure that South Africa is ready for unconventional oil and gas exploration and extraction.

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APPENDICES

APPENDIX 1

Generalised vulnerability indicators questionnaire

Generalised vulnerability indicators questionnaire

This questionnaire represents a generalized template of the first questionnaire that was distributed to respondents who took part in identifying indicators for the themes on surface water, groundwater, vegetation and socio-economics. Only one indicator was identified for seismicity and no questionnaire to identify indicators was thus distributed for seismicity. The term “XXX” refers to the related mapping aspect under discussion.

XXX vulnerability indicators questionnaire

WRC project K5/2149: Interactive vulnerability map and preliminary screening level monitoring protocol to assess the potential environmental impact of unconventional gas mining by menas of hydraulic fracturing

Introduction

The Centre for Environmental Management, University of the Free State, has received funds from the Water Research Commission (WRC) to investigate the environmental and socio-economic impacts of shale gas (natural gas) and coal bed methane extraction by means of hydraulic fracturing and to develop an interactive vulnerability map for selected biophysical and socio-economic aspects (WRC project K5/2149). Such a vulnerability map could aid in decision-making before allowing hydraulic fracturing in certain areas. The data that will be used to compile the vulnerability map will be sourced from currently existing national databases. Areas where unconventional gas mining methods may be applied can be seen in Figure 1.

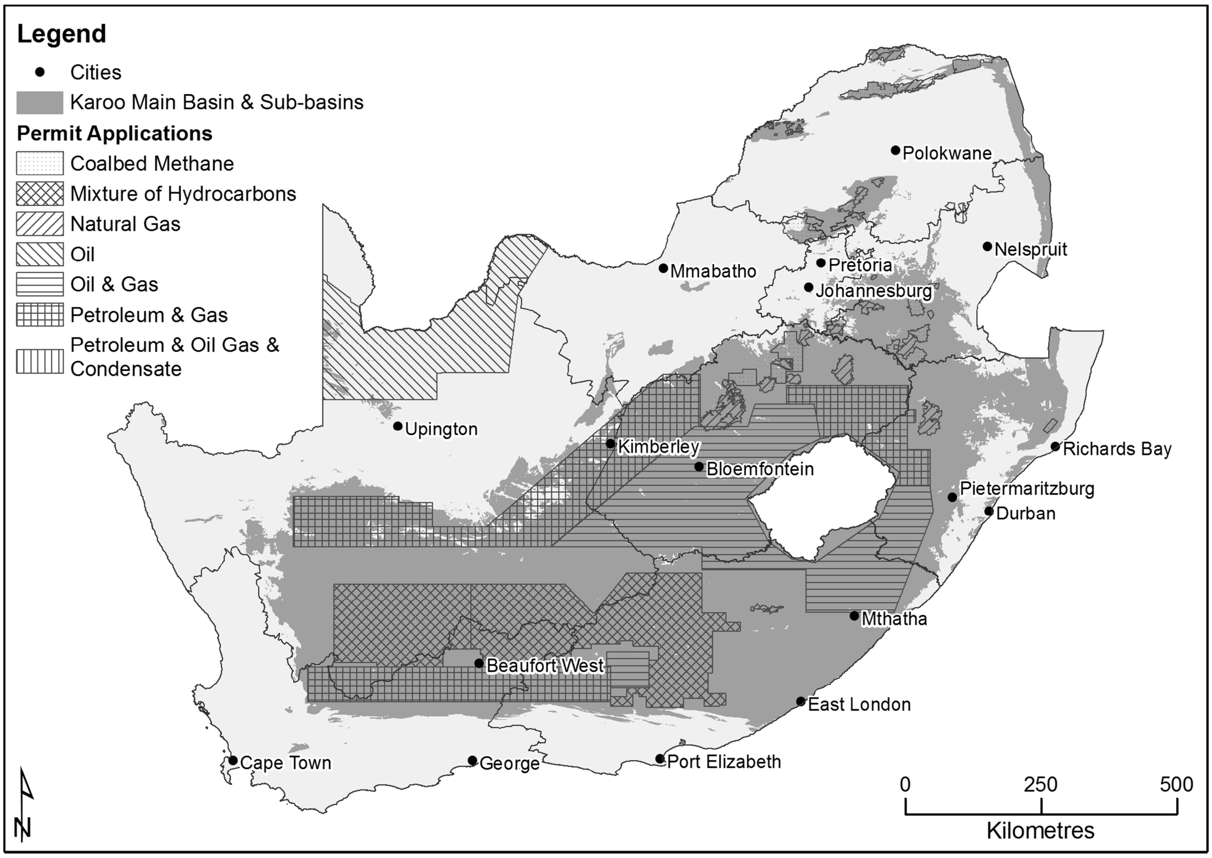

Figure 1: Map of Karoo main and sub-basins with permit application areas included.

The vulnerability map to be developed should not be viewed as a static entity. As more detailed information become available on entities that are mapped now, and new indicators are developed for which no accurate spatial data currently exists, the map should be updated or refined as a 'working document'.

Based on literature, five aspects have been selected to be mapped, namely Groundwater, Surface water, Vegetation, Seismicity and Socio-economics. For each aspect (or composite indicator) relevant indicators (component indicators) have to be selected. Each component indicator will be divided into five classes of vulnerability ranging from high vulnerability (class 5) to low vulnerability (class 1). Component and composite indicators will be combined using applicable weighing and aggregation techniques.

Our specific contribution to the final vulnerability map is the vulnerability of XXX to unconventional gas mining by means of hydraulic fracturing.

Summary information on the possible impacts of unconventional gas mining on the biophysical aspects of XXX can be seen in Appendix A. The list of full references for the summary tables is not included in the appendix but can be supplied on request.

The component indicators chosen for mapping should comply with the following criteria:

- Must be indicative of vulnerability to unconventional gas mining by means of hydraulic fracturing
- Must have data available for the whole of South Africa
- Must be spatially presentable
- Must be existing data that is reliable, accessible and available in GIS format

The following possible indicators were identified based on the dimensions of the vulnerability of XXX.

Dimensions of vulnerability	**Indicators**
Dimension 1	• Indicator 1 (Data source x)
Dimension 2	• Indicator 2 (Data source y) • Indicator 3 (Data source y)

It is important that the correct and the most relevant indicators are chosen to represent the vulnerability theme to unconventional gas mining by means of hydraulic fracturing in South Africa and we as a team would prefer that the indicators chosen should reflect the opinions of the experts in South Africa and not just our personal opinions.

We have therefore identified relevant theme specialists and request that you complete the following questionnaire.

Exploratory questionnaire to determine suitable indicators for XXX vulnerability to unconventional gas mining

Demographic information

a) Please indicate the number of years of experience you have working in the field of xxx.
_ Click here to enter text.

Indicators

Please indicate the extent to which you consider each of the preliminary selected indicators to be appropriate for use as an indicator of XXX vulnerability to the impacts of unconventional gas mining by means of hydraulic fracturing and give a reason for your answer. Please also suggest other indicators that may be used as indicators of groundwater vulnerability to unconventional gas mining.

Please keep in mind that indicators chosen need to have GIS based data available for the whole of South Africa.

1. **Dimension 1**:

Indicator 1 can be used to indicate dimension 1 of XXX vulnerability.

1.1 Please indicate the appropriateness of indicator 1 as an indicator for the unconventional gas mining XXX vulnerability map.

Indicator 1

Not appropriate at all									Very appropriate
1 ☐	2 ☐	☐3	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐	10 ☐

1.2 Please give a reason for your answer

Click here to enter text.

1.3 Are there any other indicators for **dimension 1** that you would rather recommend for inclusion instead of the suggested indicator?

Suggested indicator	Reason for suggesting this indicator	Data source of indicator
Click here to enter text.	Click here to enter text.	Click here to enter text.
Click here to enter text.	Click here to enter text.	Click here to enter text.
Click here to enter text.	Click here to enter text.	Click here to enter text.

2. Dimension 2

Indicator 2 can be used to indicate dimension 2 of XXX vulnerability.

2.1 Please indicate the appropriateness of indicator 2 as an indicator for the unconventional gas mining XXX vulnerability map.

Indicator 2

Not appropriate at all									Very appropriate
1 ☐	2 ☐	☐3	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐	10 ☐

2.2 Please give a reason for your answer

Click here to enter text.

2.3 Are there any other indicators for **dimension 1** that you would rather recommend for inclusion instead of the suggested indicator?

Suggested indicator	Reason for suggesting this indicator	Data source of indicator
Click here to enter text.	Click here to enter text.	Click here to enter text.
Click here to enter text.	Click here to enter text.	Click here to enter text.
Click here to enter text.	Click here to enter text.	Click here to enter text.

Indicator 3 can be used to indicate dimension 2 of XXX vulnerability.

2.4 Please indicate the appropriateness of the indicator as an indicator 3 for the unconventional gas mining XXX vulnerability map.

Indicator 3

Not appropriate at all									Very appropriate
1 ☐	2 ☐	☐3	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐	10 ☐

2.5 Please give a reason for your answer

Click here to enter text.

2.6 Are there any other indicators for **dimension 2** that you would rather recommend for inclusion instead of the suggested indicator?

Suggested indicator	Reason for suggesting this indicator	Data source of indicator
Click here to enter text.	Click here to enter text.	Click here to enter text.
Click here to enter text.	Click here to enter text.	Click here to enter text.
Click here to enter text.	Click here to enter text.	Click here to enter text.

3. General

3.1 Are there any other important indicators that may describe XXX vulnerability to unconventional gas, that meet the criteria of the study and that have not been included above that you can suggest for inclusion?

Suggested indicator	Reason for suggesting this indicator	Data source of indicator
Click here to enter text.	Click here to enter text.	Click here to enter text.
Click here to enter text.	Click here to enter text.	Click here to enter text.
Click here to enter text.	Click here to enter text.	Click here to enter text.

3.2 The study requires that, in addition to this questionnaire, two further rounds of questionnaires will preferably need to be completed by key informants. Will you be willing to assist in completing another questionnaire in the next two months?

Yes	No
☐	☐

3.3. Would you prefer that your identity be kept confidential during the reporting phase of this study? If you prefer that your identity not be revealed, the researcher undertakes to protect your identity by giving you a pseudonym that will assure that your responses cannot be linked back to you in any way and to not reveal your identity to any institution, organisation or person.

Yes	No
☐	☐

APPENDIX A

Summary of unconventional gas mining

Two different types of resources can be mined for oil and gas, namely conventional and unconventional resources. Unconventional resources that can be mined for natural gas may include coalbed methane, shale gas and tight sand gas. "Unconventional reservoirs" refers to reservoirs where the permeability of the reservoir rock is lower than 1 milliDarcy, where gas does not flow freely to the surface and has to be stimulated to be released from the source rock. In order to stimulate the release of gas from these low permeability reservoirs, a technology called *high volume hydraulic fracturing* (also known as *slickwater fracturing*) can be applied. Other treatments to stimulate gas flow may include acidising to dissolve carbonate materials in the host rock, as well as gel fracturing or gas fracturing (Broomfield, 2012).

Unconventional oil and gas is mined in phases, which start with exploration and is followed by mining and eventually decommissioning of wells (Kargbo et al., 2010; Broomfield, 2012). Exploration is divided into two distinct phases, which include determination of the locality of the oil and gas reservoirs (the first phase of exploration) and determination of the economic extractability of the gas in place during the second phase of exploration (Kargbo et al., 2010; Broomfield, 2012). The first phase of exploration is done by means of geophysical surveys, drilling and laboratory testing which may include pyrolysis and analyses of core samples using various microscopic techniques (Bernard et al., 2010). Testing porosity and permeability on core samples taken from the drilled boreholes, characterizes the reservoir in more detail to appraise the gas in place (Bernard et al., 2010). In addition mineralogical testing is also performed to determine the clay content, which will affect how the rock will respond to the fracturing. The second phase of exploration include stimulating the drilled exploration wells in order to determine how much gas can be generated from the wells by means of hydraulic fracturing (Kargbo et al., 2010; Broomfield, 2012). After economic viability has been determined, the mining phase will follow during which oil and gas will be extracted by means of hydraulic fracturing and any other stimulation method that may be required. A well can be stimulated various times during its lifetime and as soon as wells do not generate gas economically anymore, they are decommissioned. Decommissioning include capping of the wells in order to minimize underground fluid movement (Kargbo et al., 2010; Broomfield, 2012).

High volume hydraulic fracturing involves drilling wells to the depth of the target rock (for instance a shale layer) where temperatures range from 35-140 degrees Celsius (Kargbo et al., 2010; Halliburton, 2008). Different sections of the well in the production zone of the target rock are isolated and a mixture of water, chemical fluids (slickwater) and proppant (sand or ceramic beads that keep open the fractures) are pumped down the wellbore through the perforations in the wellbore and into the source rock (Kargbo et al., 2010). The hydraulic pressure used to deliver the fluid into the target formation may range from 10,000-15,000 psi or 69-103 MPa (Carolyn and Debrick, 2012; Halliburton, 2008; Broomfield, 2012). This produces fissures in the reservoir and can open cracks in the shale up to 1000 m or more in all directions from the wellbore. This liberates trapped gas allowing the flow of gas into the wellbore and up to the surface.

The impacts that may pose the largest risk related to unconventional gas mining by means of hydraulic fracturing are related to water (Rahm and Riha, 2012; Lechtenböhmer et al., 2011; USEPA, 2011; ANU, 2012; Clark and Veil, 2009; Zoback, et al., 2010; NRC, 2012a; Broomfield, 2012), although possible impacts could occur in both the socio-economic (Broderick et al., 2011; Coburn et al., 2011) and biophysical spheres (Bishop, 2011; Davis et al., 2006; DID, 2009; Broomfield, 2012). Aspects in both these spheres would require scientific investigation. The impacts related to the various dimensions of groundwater, can be seen in Table 1.

This Appendix represents a brief summary of the process of unconventional gas mining and the possible impacts, a more detailed summary report can be requested from the questionnaire distributor.

Table 1: Summary of impacts on XXX

	Positive impacts	**Uncertain positive impacts**	**Uncertain negative impacts**	**Negative impacts**
During unconventional hydrocarbon exploration	• Lists positive impacts during unconventional hydrocarbon exploration	• Lists uncertain positive impacts during unconventional hydrocarbon exploration	• Lists uncertain negative impacts during unconventional hydrocarbon exploration	• Lists negative impacts during unconventional hydrocarbon exploration
During unconventional hydrocarbon mining	• Lists positive impacts during unconventional hydrocarbon mining	• Lists uncertain positive impacts during unconventional hydrocarbon mining	• Lists uncertain negative impacts during unconventional hydrocarbon mining	• Lists negative impacts during unconventional hydrocarbon mining
After unconventional hydrocarbon mining	• Lists positive impacts after unconventional hydrocarbon mining	• Lists uncertain positive impacts after unconventional hydrocarbon mining	• Lists uncertain negative impacts after unconventional hydrocarbon mining	• Lists negative impacts after unconventional hydrocarbon mining
All References	References pertaining to positive impacts	References pertaining to uncertain positive impacts	References pertaining to uncertain negative impacts	References pertaining to negative impacts

APPENDIX 2

Generalised vulnerability indicator classification and weighting questionnaire

Generalized vulnerability indicator classification and weighting questionnaire

This questionnaire represents a generalized template of the second questionnaire that was distributed to respondents who took part in classifying and weighting indicators for the themes on surface water, groundwater, vegetation and socio-economics. Only one indicator was identified for seismicity and no questionnaire to identify indicators was thus distributed for seismicity. The term "XXX" refers to the related mapping aspect under discussion. Where relevant, maps of classified indicators were also shown to respondents to help them visualise the indicator as classified into the suggested categories.

WRC project K5/2149: Interactive vulnerability map and preliminary screening level monitoring protocol to assess the potential environmental impact of hydraulic fracturing

Introduction

The research team received feedback from you, a key informant in this study. You have indicated that you would be willing to participate in the further questionnaires on this study.

Basic feedback on the indicator ratings is given in this section. The indicators that will be included for mapping purposes are Indicator 1 and Indicator 2. Alternative indicators were suggested by respondents and will be discussed below.

A brief description of alternative indicators is given with reasons why these were included or excluded from the mapping theme.

Questionnaire to determine classifications of indicators

In this questionnaire you must please indicate the applicability of suggested classification systems and the weighting of indicators.

Classification of XXX indicators into five vulnerability classes

This section proposes classes for indicator 1 and indicator 2.

4. **Indicator 1**:

Indicator 1 can be classed into the following 5 classes, see Table 1.

Table 1

Vulnerability Description	**Indicator 1**
Very Low Vulnerability	A
Low Vulnerability	B
Medium Vulnerability	C
High Vulnerability	D
Very High Vulnerability	E

A map showing the classified indicator can be seen in Figure 1.

Figure 1

4.1 Please indicate on a scale of 1-10 to what extent the classification in Table 1 is appropriate.

Not appropriate at all									Very appropriate
1☐	2☐	☐3	4☐	5☐	6☐	7☐	8☐	9☐	10☐

1.2 If the classifications in example Table 1 are not acceptable, please indicate alternative classifications and state a reason why alternative classifications should be used.

Alternative classification		
Vulnerability Description	**Alternative class suggestion**	**Reason**
Very Low Vulnerability		
Low Vulnerability		
Medium Vulnerability		
High Vulnerability		
Very High Vulnerability		

5. Indicator 2

Indicator 2 is shown in Figure 2 can be classed into the following 5 classes, see Table 2.

Table 2

Vulnerability Description	Indicator 2
Very Low Vulnerability	A
Low Vulnerability	B
Medium Vulnerability	C
High Vulnerability	D
Very High Vulnerability	E

Figure 2

5.1 Please indicate on a scale of 1-10 to what extent the classification in Table 2 is appropriate.

Not appropriate at all									Very appropriate
1☐	2☐	☐3	4☐	5☐	6☐	7☐	8☐x	9☐	10☐

2.2 If the classifications in example Table 2 are not acceptable, please indicate alternative classifications and state a reason why alternative classifications should be used.

Alternative classifications		
Vulnerability Description	**Alternative class suggestion**	**Reason**
Very Low Vulnerability		
Low Vulnerability		
Medium Vulnerability		
High Vulnerability		
Very High Vulnerability		

3. Weighting of chosen indicators in final XXX vulnerability map:

Provide a relative percentage weight for each classified indicator (The total should equal 100%).
Example: Indicator 1 = 75%, Indicator 2 = 25%; Total = 100%.

Indicator 1	Indicator 2

Thank you for your participation.

APPENDIX 3

User guide for the interactive vulnerability map

User guide for the Interactive Vulnerability Map

The DVD accompanying this report contains a stand-alone Vulnerability Map website that runs in a computer's default browser without requiring an internet connection. The website includes an interactive map browser that allows the user to explore the various datasets mentioned in this report.

How to run the Vulnerability Map website

Insert the DVD into your DVD drive and the Vulnerability Map website should load automatically into your default browser. If *User Account Control* is activated on your computer you might get a message, or series of messages, asking whether you want to allow the program to make changes to your system. Answer yes to these questions.

You can also run the Vulnerability Map website from a USB flash drive or from your hard drive. Simply copy the entire contents of the DVD to a folder on your hard drive or onto a USB flash drive and then double-click the file *usbwebserver.exe* to load the website in your browser. Note that you need to have a Microsoft Windows operating system on your computer in order to run the website.

Vulnerability Map website structure

The Vulnerability Map website comprises three sections, namely ***Home***, ***Interactive Map*** and ***Documents***. These sections are accessible via the orange menu bar near the top of the screen.

- **Home:** This section contains an introduction to the website and also provides background on the interactive map browser.
- **Interactive Map:** This is the main section of the website where you can explore and interrogate the spatial datasets referred to in this report.
- **Documents:** Here you can download PDF versions of the report and other documents relevant to the report.

Using the Interactive Map Browser

The map browser contains a *Vulnerability Map Themes panel* on the left, the *Map panel* on the right and an *Information panel* at the bottom. There is also a popup *Overlay Information window* that appears when you click on the map.

- **Vulnerability Map Themes panel:** This panel is used to control what is shown on the map. At the top of the panel is a drop-down list that allows one of five map themes to be chosen. When a vulnerability theme is selected, the list of base maps and overlays for that theme are displayed and the map is automatically updated to show the default layers. You can then select from one or more of these base maps and/or overlays. Note that only one base map can be shown at a time whereas multiple overlays can be displayed at the same time.
  - **Map Themes:** Select a map theme from the drop-down list. Only one theme can be selected at a time.
  - **Base Maps:** To activate a base map click on the circle to the left of the base map name. Only one base map can be activated at a time.
  - **Overlays:** Click the check-box to the left of the overlay name to turn the layer on or off. When an overlay is greyed out, it means that the map has been zoomed out beyond the active zoom range for that layer. Zoom in on the map until the layer becomes active.
  - **Base Map Legend:** The legend changes automatically whenever a new base map is activated.
  - **Zoom to… :** You can zoom to a particular *Water Management Area*, *Quaternary Catchment* or *Town* by selecting one of these from the zoom boxes at the bottom of the Map Themes panel. The available zoom boxes change according to which map theme has been selected.
- **Map panel:** The map is a live map that can be zoomed, panned and queried. These operations can be performed as follows:
  - **Zoom in:** As you zoom in more detail becomes visible on the map. There are a number of ways to zoom in
    - click the plus sign at the top-left corner of the map to zoom in by a fixed amount,
    - press the <Shift> key on your keyboard and then click and drag a rectangle on the map to zoom to that rectangle,
    - double-click anywhere on the map to zoom to the point you clicked,
    - place the cursor anywhere on the map and then roll your mouse wheel to zoom in.
  - **Zoom out:** Less detail is shown on the map as you zoom out. There are a number of ways to zoom out
    - click the minus sign at the top-left corner of the map to zoom out by a fixed amount,

    - place the cursor anywhere on the map and then roll your mouse wheel to zoom out,
    - click the home icon at the top-left corner of the map to zoom to the full extent of the map.
  - **Pan:** Click and drag the map to change the portion of the map visible in the map panel.
  - **Query:** When an overlay is switched on click on a map feature to display information on that feature.
- **Information panel:** This panel provides information on the vulnerability map theme that has been selected in the map themes panel. The contents of the panel change automatically each time a new map theme is chosen.
- **Overlay Information popup:** With one or more overlays switched on in the Map Themes panel you can click on the map and the popup window that appears provides information on features at or near the place you clicked. You can move the popup window around by dragging the title bar at the top, and the window can also be resized in the normal manner. The popup window can be left open and its contents will be updated every time you click on the map.

Troubleshooting

If for some reason the website does not load then there are a number of things to try:

1. **The Vulnerability Map website does not load automatically:** Open Windows Explorer and locate the file called *usbwebserver.exe* on the DVD. Double-click this file to start the Vulnerability Map browser.
2. **The file *usbwebserver.exe* does not run when double-clicked:**
   - Check that your computer has a Windows operating system. The USBWebserver software will only run on Microsoft Windows.
   - Try right-clicking the file and selecting 'Run as administrator' from the popup menu. You might be asked to supply an administrator password.
3. **The browser opens up but the Vulnerability Map website does not load after a reasonable amount of time:**
   - Click the reload/refresh button on your browser.
   - Check on the taskbar whether there are any User Account Control messages awaiting your response.
4. **The interactive map browser runs very slowly:** Copy the entire contents of the DVD to a folder on your hard drive and run the map browser from there. Double-click the file *usbwebserver.exe* to load the browser.

Software

A number of different software technologies were used in developing this website and interactive map.

- The map browser is powered by ***USBWebserver***, a webserver that runs a stand-alone instance of ***Apache*** webserver and offers ***PHP*** support. Please visit http://www.usbwebserver.net/ for more details.
- The website framework is powered by ***PHP*** (http://php.net/).
- The interactive map is powered by ***MapServer*** (http://mapserver.org), ***OpenLayers*** (http://openlayers.org) and ***ExtJS4*** (http://www.sencha.com/products/extjs/).

Licensing

All JavaScript and PHP software developed for this product is released under the GNU GPL licence v3 (http://www.gnu.org/copyleft/gpl.html). A copy of this licence can be found on the DVD in the file *gpl-3.0.txt*. The licence applies to the following files:

/root/*.php
/root/js/map.js
/root/js/controller/*.js
/root/js/model/*.js
/root/js/store/*.js
/root/js/view/*.js

Spatial Data

The spatial data used in the interactive map can be found in the */root/data/* folder on the DVD. These are in either TIFF or ESRI shapefile format and can thus be used in any GIS program. The following table provides a list of these files.

File Name	Description of Contents
boreholes.shp	Boreholes
common_cat_a_pa.shp	Prospecting & Mining Legally Prohibited
common_geol_structures.shp	Geological Structures
common_geol_structures_springs.shp	Springs
groundwater_drastic.tif	DRASTIC Groundwater Vulnerability
pasa.shp	PASA Permit Areas
quaternary.shp	Quaternary Catchments
rivers.shp	Rivers
seismicity.tif	Seismicity
socioeconomics_agriculture.shp	% of Population Employed by Agriculture
socioeconomics_astronomy.shp	Astronomy Assessment Areas
socioeconomics_astronomy_meerkat.shp	Astronomy Assessment Areas – Meerkat Receiving Stations
socioeconomics_subterranean_gca.shp	Subterranean Groundwater Control Areas
socioeconomics_ward_water.shp	% of Population Dependent on Groundwater as a Domestic Water Source
socioeconomics_wards.shp	Socio-Economics Aggregated; Population Density; % of Children Under 5 Years of Age; % of Female Headed Households
surfacewater_DEC.shp	River Condition by Default Ecological Category (DEC)
surfacewater_fish.shp	Threatened and Near Threatened Fish Species
surfacewater_wetland_clusters.shp	Wetland Clusters
surfacewater_wetland_rank.shp	Wetland Condition based on Wetland Ranks
vegetation_ade.shp	Aquifer Dependent Ecosystems (ADEs)
vegetation_aggregated.shp	Vegetation Aggregated
vegetation_cat_b_cba.shp	Category B Critical Biodiversity Area - Bioregional and Provincial
vegetation_cat_c_cba.shp	Category C Critical Biodiversity Area - Bioregional and Provincial
vegetation_cat_d_esa.shp	Category D Ecological Support Area - Bioregional and Provincial
vegetation_cat_d_esa_equiv.shp	Category D Ecological Support Area Equivalents
vegetation_ets_pls.shp	Ecosystem Threat Status Ecosystem Protection Level
wma.shp	Water Management Areas

APPENDIX 4

Seismicity main report

Possible Effect of Hydraulic Fracturing On Seismic Hazard in South Africa

BY:

Prof. Andrzej Kijko (Pr.Sci.Nat), Ansie Smit
University of Pretoria Natural Hazard Centre, Africa
University of Pretoria
Cnr Lynnwood Road and Roper Street
Pretoria
0002
South Africa
andrzej.kijko@up.ac.za, ansie.smit@up.ac.za

PREPARED FOR:

Water Research Commission Project K5/2149

Development of an interactive vulnerability map and preliminary screening level monitoring protocol to assess the potential environmental impact of hydraulic fracturing.

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Executive Summary

The aim of this report is to portray the current seismic hazard as well as to estimate the possible effect of increased seismic activity due to the planned hydraulic fracturing in South Africa. The seismic hazard is expressed in terms of four maps. Each of these maps portrays different potential effects of hydraulic fracturing. This is done by indicating the value of the peak ground acceleration (PGA) which is expected, with a 10% probability, to be exceeded at least once within 50 years. Based on current knowledge of the geology and tectonic setting of South Africa, it is impossible precisely predict if, and by how much the hydraulic fracturing will lead to an increase the seismic hazard of South Africa. The following four scenarios were therefore considered: a) no increase of seismicity, as well as where seismicity increases b) 2 times, c) 5 times and in the extreme case, d) 10 times. The respective scenarios are illustrated in Maps No. 1 to No. 4. Map No. 5 represents the estimated seismic hazard in South Africa when taking into account the above four possible scenarios which hydraulic fracturing may have on the seismicity. To assess the expected effect of hydraulic fracturing on seismic hazard in South Africa, a formalism in the form of a logic tree was applied. It was assumed that the logic tree weights (l_w) of the four scenarios are 0.15, 0.50, 0.30 and 0.05 respectively. It has to be strongly emphasized that these weights (l_w) are very subjective; it was selected according to a wide scatter and often contradicting expert opinions on the effect of hydraulic fracturing on seismicity. These opinions are available in the current respective literature (e.g. Davis and Frohlich, 1993; De Pater and Baisch 2011; Davies *et al*., 2013; Green *et al*., 2012; Horton,2012; King, 2010; Maxwell *et al*., 2009; Suckale, 2009; Zoback and Harjes, 1997).

Comparison of these five maps suggest that the introduction of hydraulic fracturing in South Africa can/will lead to high levels of seismic hazard in the parts of the Western Cape, the Free State, Gauteng and towards the eastern border of the North West Province. Moderate hazard levels can be expected in the Limpopo Province and parts of the Northern Cape. The southern part of the Eastern Cape is subject to low levels of seismic hazard.

For the purpose of this report the associated hazard (peak ground acceleration) is set equivalent to vulnerability as defined in UNISDR (2004). This report defines vulnerability as the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards.

A more reliable assessment of the effect of hydraulic fracturing on seismic hazard in South Africa can be achieved only through the inclusion of detailed geological and tectonic information about the area.

Section 1 provides an introduction and is followed by a brief description on the tectonic setting (Section 2) and seismicity (Section 3) of South Africa. The applied procedure for the computation of the probabilistic seismic hazard maps are described in Section 4. Section 5 provides the description on the input data used with the results described in Section 6. A monitoring protocol for seismic hazard is discussed in Section 7. A brief description of the possible impact of hydraulic fracturing is available in Appendix B.

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1. Introduction

Seismic activity in South Africa can be divided into two major groups, the predominantly mining related seismicity as well as seismicity of natural (tectonic) origin. In this report the term seismic event refers to both natural and mining-related events. The associated seismic hazard, the physical effects of a seismic event, is of great importance to the engineering, insurance and disaster management industries. Seismic hazard is typically characterized by phenomena such as surface faulting, ground shaking and liquefaction. For the purposes of this report, the seismic hazard is expressed in terms of the likelihood to observe the maximum acceleration of the ground shaking during a seismic event namely peak ground acceleration (PGA). This acceleration is expressed in units of g, where g is equal to 9.81 m/s^2.

Five maps were created to assess the potential effect of hydraulic fracturing in the South African environment. This was done under the assumption that the hydraulic fracturing process will cause induced seismicity, which in turn could result in an increase in the seismic activity rate. Map No. 1 portraits the current seismic hazard in South Africa, expressed in terms of PGA with (10% probability of exceedance at least once within in 50 years). The map was calculated for the current value of the mean seismic activity rate λ, i.e. $c_f = 1$. The correcting factor c_f is applied to the seismic activity rate λ to indicate the factor by which the activity rate is increased for the four possible scenarios i.e. a) no increase of seismicity and seismicity increases b) 2 times, c) 5 times and d) 10 times. Maps No. 2 to 4 respectively represent the 10% probability of exceeding the expected peak ground acceleration (PGA) at least once in 50 years for activity rates with the respective correcting factors $c_f = 2$, 5 and 10. These maps are available in Section 6. Finally, Map No. 5 represents the expected seismic hazard in South Africa after taking into account the four possible scenarios of the effect of hydraulic fracturing. To assess the expected effect of hydraulic fracturing on seismic hazard in South Africa, the assessment was performed by the application of the logic tree formalism through the association of the respective logic tree weights (l_w = 0.15, 0.50, 0.30 and 0.05) with the above four scenarios.

These maps provide a convenient tool to estimate the expected seismic risk and response to seismic event loading for different types of structures and buildings located in the South African provinces. By combining these maps with additional geological information, they could also be used as an aid in seismic hazard mitigation.

At least two similar investigations of seismic hazard in South Africa, as presented in Map No.1, were compiled in the past. In 1992, L.M Fernandez and A. du Plessis produced "Seismic Hazard Maps of Southern Africa" (Fernandez and du Plessis, 1992) and in 2003 Kijko et al., (2003) published the interactive CD "Probabilistic Peak Ground Acceleration and Spectral Seismic Hazard Maps for South Africa". This map by Kijko *et al*., (2003) is implemented into the South African Building Code SABS (2009). More details regarding the applied theory are available in the discussion of the map creation process in Section 4.

2. The tectonic setting of South Africa

(based on Kijko et al., 2003)

The first recorded seismic phenomenon in South Africa was reported in 1620 by the early Dutch settlers. The improvement in the recording methods of seismic events as well as investigations into the seismic nature of South Africa indicated that the area behaves typically of an intraplate region. An intraplate region is usually characterised by low-level seismic activity, compared to world standards, with seismic events randomly distributed in both space and time. However, the correlation between seismic event location and the surface expression of major geological features is not clear (Fernandez and Guzman, 1979 a and b).

The African plate, on which South Africa is situated, consists of the East African Rift System, southern Africa and ends in the Indian Ocean. Plate boundaries in both the continental and oceanic lithosphere (including the African wide-plate boundary) are hundreds and thousands of kilometres wide, and in fact cover roughly 15% of Earth's total surface area (Gordon and Stein, 1992).

Maps of the residual bathymetry in the ocean basins around the African continent were investigated by Nyblade and Robinson (1994) and found a broad bathymetric swell in the south-eastern Atlantic Ocean, with amplitude of about 500 m. This region of anomalously shallow bathymetry together with the contiguous eastern and southern African plateaus, form a superswell log of which the origin is uncertain. The authors speculate that it may be partly attributed to the heating of the lithosphere which caused rifting and volcanism in eastern Africa and is indicated by high heat-flow measurements in southern Africa and the south-eastern Atlantic Ocean. This theory is supported by Su *et al*., (1994) and Grand *et al*., (1997), who respectively constructed a three-dimensional shear wave velocity model as well as shear wave and pressure wave velocity heterogeneity models of the Earth's mantle from an inversion of a large set of seismic travel time data. Both investigations found evidence for the existence of large mega-structures with associated anomalous velocities in the Earth. Su *et al*., (1994) interpret the velocity anomaly, found under part of Africa, as hot mantle material in the depth interval of 800 to 2300 km.

Evidence of tectonic uplift in southern Africa during the last 3 Ma (mega-annum) may be inferred from the uplift of Neogene diamond-bearing marine deposits and the relationship between onshore denudation and offshore sedimentation in, for example, KwaZulu Natal (Hartnady and Partridge, 1995). These authors subsequently speculated that the diapir plumes that buoy up a large part of East Africa have also affected South Africa. The African wide-plate boundary is characterised by belt-like zones of seismicity surrounding relatively aseismic blocks. The seismicity in South Africa appears to portray the same spatial style and supports the notion that the wide-plate boundary extends into South Africa. The rift between the Nubia and the Somalia plates, south of 20º S off the coast of Mozambique, is along the southwest Indian Ridge (Lemaux *et al*., 2002). Hence, even though South Africa may be influenced by the wide-plate boundary, the rift itself does not extend into the country.

3. A brief description of South African seismicity

(based on Kijko et al., 2003)

The highest natural seismic activity, where the peak ground acceleration (PGA) exceeds 0.05 g, as per the commentary on the Seismic Hazard Map in the SABS Code of Practise manual of 1994 (SABS, 1994), is observed in the south-eastern Cape and around Lesotho. In the past, PGAs of 0.39 g and 0.45 g have been recorded for the deep gold-mining areas of Klerksdorp and Carletonville (SABS, 1994).

Evidence that has emerged from deep gold mines in South Africa indicate that mining-induced seismicity is characterised by normal faulting due to stope closure and that tectonic stresses play an insignificant role (Dennison and Van Aswegen, 1993; Wong, 1993). The bulk of the seismic events recorded and located by the South African National Seismograph Network (SANSN; Saunders et al., 2008) are attributed to mine tremors due to the deep gold-mining operations around the Witwatersrand basin area. The gold-bearing reefs of the Witwatersrand system are mined by stoping at depths reaching ± 3.5 km (Gibowicz and Kijko, 1994; Gibowicz and Lasocki, 2001). The local networks of geophones, installed in many of the gold mines, record the seismic events with greater accuracy than that obtained from the SANSN.

A study of a few recent mining-induced seismic events in South Africa (1999 to 2005) indicates that in the gold-mining area of Klerksdorp (eastern North West Province) seismic events of local Richter magnitudes M_L up to 5.3 were recorded. In the Koffiefontein diamond mining area in the Free State, three events of local magnitudes M_L between 2.7 to 4.5 were recorded during June and July 1999. The largest mining-related seismic event in South Africa occurred on 9 March 2005 in the Stilfontein mining-area (Figure 1) between Potchefstroom and Klerksdorp (M_L=5.3) in 2005. Several buildings in the town were damaged by this event.

However the strongest and most devastating South African seismic events of the 20th century are attributed to the natural seismicity in the Western Cape. The Ceres-Tulbagh seismic event of 29 September 1969, with local Richter magnitude 6.3, is the largest recorded event. This event was felt widely over the Western Cape, especially at Ceres, Tulbagh and Wolseley. Several buildings in the area suffered serious damage, varying from the almost total destruction of old and also poorly built buildings, to large cracks appearing in those that were better constructed (Figure 2). Twelve people were killed and many more injured. This event had an insured loss of US$7.4 million (approximately R75 million at today's exchange rates). However the uninsured loss was roughly 3.5 times higher (AXCO (unpublished)).

The magnitude 6.0 to 6.5 seismic event that occurred off Cape St Lucia on 31 December 1932 caused damage to poorly constructed buildings, with one or two collapsing. Cracks and fissures in the ground were also reported.

On 8 December 1976 a seismic event of magnitude 5.2 occurred in Welkom. There was extensive damage to many buildings, the most dramatic of which was the collapse of a six-story high block of flats, which took place 75 minutes after the event (Figure 3).

In the Carletonville area in the North West Province, a seismic event of magnitude 4.7 occurred on 7 March 1992. An unusual amount of damage was recorded, owing to the high population density around the epicentral area. Houses were damaged as far as Pretoria (ca. 100 km away).

Figure 1: Effect of the 2005 Stilfontein seismic event of M_L 5.3 on the A-block of the Bal-Eaton flats. (Photo courtesy of Ian Saunders, Council for Geoscience, Pretoria)

Figure 2: Illustration of the damage to an old building in Ceres owing to the seismic event of 29 September 1969. "The damage at Drostdy was spectacular because the buildings in the hamlet were of the older types of construction. The high Cape-Dutch gables of these older buildings were particularly susceptible to damage. The historic Drostdy (Magistrate's residence) was constructed partly of sun-dried brick and partly of brick, with clay as mortar. The damage to this beautiful old building was very serious as neither type of masonry could resist the severe seismic shaking. Most of the cracks in the walls were caused by oscillation of the walls, as is evidence by the vertical cracks in the corners and the diagonal cracks in the walls" (Van Wyk and Kent, 1974).

Figure 3: The 1976 Welkom seismic event in which a block of flats, six storeys high, collapsed. (Photographer unknown)

4. Applied procedure for the computation of probabilistic seismic hazard maps

4.1. Problem Formulation

The essence of the probabilistic seismic hazard analysis (PSHA) is the calculation of the probability of exceedance of a specified ground motion level at a specified site (Cornell, 1968; Reiter, 1990). In principle, PSHA can address a very broad range of natural hazards associated with seismic events, including ground shaking and ground rupture, landslide, liquefaction or tsunami. However, in most cases the interest of designers lies in the estimation of the likelihood of a specified level of ground shaking, since it causes the greatest economic losses.

The typical output of the PSHA is the seismic hazard curve (often a set of seismic curves), i.e. plots of the estimated probability, per unit time, of the ground motion variable, e.g. peak ground acceleration (PGA) being equal to or exceeding the level as a function of PGA (Budnitz *et al*., 1997). The essence of the PSHA is that its product – the seismic hazard curve, quantifies the hazard at the site from all possible seismic events of all possible magnitudes at all significant distances from the site of interest, by taking into account their frequency of occurrences. In addition to the hazard curve, the output of PSHA includes results of the so called de-aggregation procedure. This procedure provides information on seismic event magnitudes and distances that contribute to the hazard at a specified return period and at a structural period of engineering interest (Budnitz *et al*., 1997).

In general, the standard PSHA procedure is based on two sources of information: (1) observed seismicity, recapitulated by seismic event catalogue, and (2) area-specific, geological data (e.g. a regional seismotectonic model of the area). After the combination of a selected model of seismic event occurrence with the information on the regional seismic wave attenuation or ground motion prediction equation (GMPE), a regional seismotectonic model of the area is formulated and an assessment of the seismic hazard is performed. Detailed investigation into the site effect, determined by site specific soil properties, should be done to improve the accuracy of the PGA. Complete PSHA can be carried out only when information on the regional seismotectonic model and the site-specific soil properties are known.

Clearly, all the above information required to complete PSHA is subjective and often highly uncertain, especially in stable continental areas where the seismic event activity is very low. According to the convention established in the fundamental document by Budnitz *et al*., (1997) there are two types of uncertainties associated with PSHA: aleatory and epistemic.

According to Budnitz *et al*., (1997) the uncertainties that are part of the applied model used in the analysis are called aleatory uncertainties. The other names for the aleatory uncertainty are 'stochastic' or 'random' uncertainties. Even when the model is perfectly correct and the numerical values of its parameters are known without any errors, aleatory uncertainties for a given model are still present (Budnitz *et al*., 1997).

The uncertainties which come from incomplete knowledge of the models, i.e. when wrong models are applied or/and the numerical values of their parameters are not known, are called epistemic uncertainties. As relevant information is collected, the epistemic uncertainties can be reduced (Budnitz et al., 1997).

By the definition of the PSHA procedure, the aleatory uncertainty is included in the process of PSHA calculations by means of applied models (statistical distributions) and by mathematical integration. Epistemic uncertainty can be incorporated in the PSHA by the consideration of an alternative hypotheses (e.g. alternative boundaries of the seismic sources and their recurrence parameters) and alternative models (e.g. alternative seismic event distributions or/and application of alternative PGA attenuation equations). Incorporation of this type of uncertainties into the PSHA is carried out by the application of the logic tree formalism. A complete PSHA includes an account of aleatory as well as epistemic uncertainties. Any PSHA without the incorporation of the above uncertainties is considered to be incomplete.

This following section describes two major mathematical aspects of the PSHA:

(1) The procedure for the assessment of the seismic source characteristic recurrence parameters when the data are incomplete and uncertain. Use is made of the most common assumptions in engineering seismology i.e. the seismic event occurrences in time follow a Poisson process and that seismic event magnitudes are distributed according to a Gutenberg-Richter doubly-truncated distribution. Following the above assumptions, the seismic source recurrence parameters are defined as (a) the mean seismic activity rate λ (which is a parameter of the Poisson distribution), (b) the level of completeness of the seismic event catalogue $m_{\min}$, (c) the maximum regional seismic event magnitude $m_{\max}$ and (d) the Gutenberg-Richter parameter b. To assess the above parameters a seismic event catalogue containing origin times, size of seismic events and spatial locations are needed. The maximum seismic source characteristic event magnitude $m_{\max}$ is of paramount importance in this approach; therefore a statistical technique that can be used for evaluating this important parameter is presented in Section 4.2.6.

(2) PSHA methodology i.e. calculating the probability of exceedance of a specified ground motion level at a specified site. Often, the presented approach is known as the Cornell-McGuire procedure. The essence of the Cornell-McGuire PSHA procedure is the calculation of the probability of exceedance of a specified ground motion level at a specified site. The so called Cornell-McGuire solution of this problem consists of four steps: (e.g. Budnitz *et al*., 1997; Reiter, 1990):

- determination of the possible seismic sources around the site.
- determination and assessment of the recurrence parameters for each seismic source.
- selection of the ground motion prediction equation (GMPE) which is most suitable for the region.
- computation of the hazard curves.

4.2. Probabilistic Seismic Hazard Assessment – Theoretical Background

This section provides an outline of the procedure used to determine the seismic source recurrence parameters: the area characteristic mean seismic activity rate λ, the Gutenberg-Richter parameter b, the level of completeness of the seismic event catalogue $m_{\min}$ and the maximum regional seismic event magnitude $m_{\max}$.

4.2 1. Nature of input data

The lack or incompleteness of data in seismic event catalogues is a frequent issue in the statistical analysis of seismic hazard. Contributing factors include the historical and socio–economic context, demographic variations and alterations in the seismic network. Generally, the degree of completeness is a monotonically increasing function of time i.e. the more recent portion of the catalogue has a lower level of completeness. The methodology makes provision for the seismic event catalogue to contain three types of data (Kijko and Sellevoll, 1989; 1992). Figure 4 depicts the typical scenario confronted when conducting seismic hazard assessments:

- very strong prehistoric seismic events (paleo-earthquakes) which usually occurred over the last thousands of years,
- the macro-seismic (historic) observations of some of the strongest seismic events that occurred over a period of the last few hundred years,
- complete recent data for a relatively short period of time.

The complete part of the catalogue can be divided into several sub-catalogues each of which is complete for events above a given threshold magnitude $m_{\min}^{(i)}$, and occurring in a certain period of time T_i where $i = 1, \ldots, S$ and S is the number of complete sub-catalogues. The approach permits 'gaps' (T_g) when records were missing or the seismic networks were out of operation. The procedure is capable of accounting for uncertainties of occurrence time of prehistoric earthquakes. Uncertainty in seismic event magnitude is also taken into account through the assumption that the observed magnitude is the true magnitude subjected to a random error. It is further assumed that the random error follows a Gaussian distribution having zero mean and a known standard deviation.

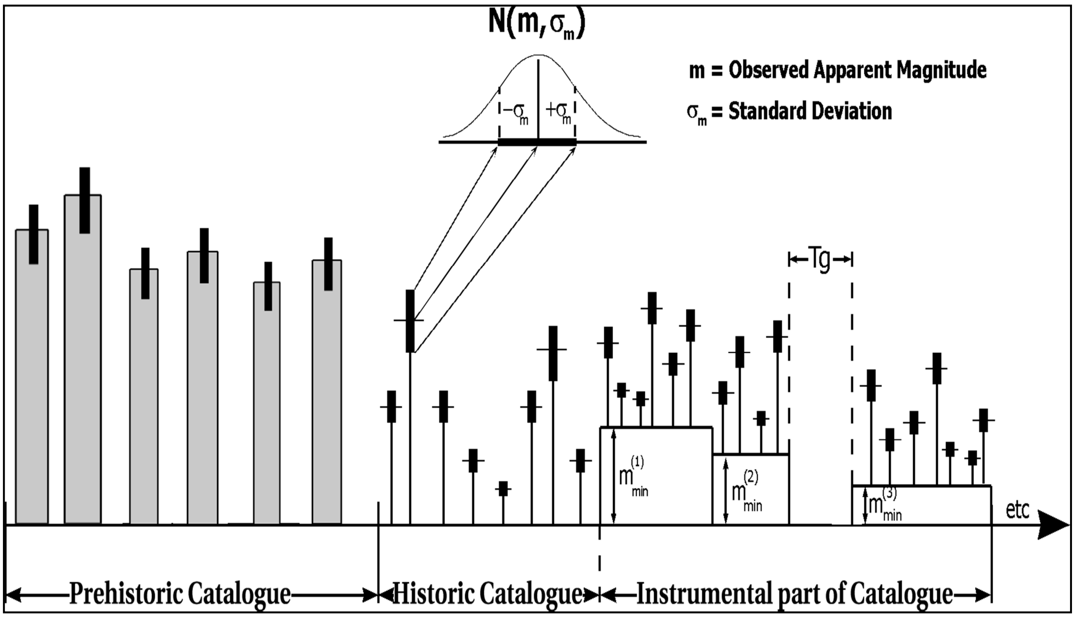


Figure 4: Illustration of data which can be used to obtain reccurence parameters for the specified seismic source. (Modified after Kijko and Sellevoll, 1992)

4.2.2. Statistical preliminaries

Basic statistical distributions and quantities utilized in the development of the methodology are briefly described in this section.

The Poisson distribution is used to model the number of occurrences of a given seismic event magnitude or a given amplitude of a selected ground motion parameter being exceeded within a specified time interval.

$$p(n|\lambda, t) \equiv P(N = n|\lambda, t) = \frac{(\lambda t)^n}{n!} e^{-\lambda t}, \qquad n = 0,1,2 \ldots \tag{1}$$

Note that λ here refers to the parameter of the Poisson distribution and describes the area characteristic, mean activity rate (mean number of occurrences within specified time interval, usually 1 year).

The Gamma distribution, given its flexibility, is used to model spatial and temporal fluctuation (uncertainty) of various seismic hazard parameters and it's the distribution is given by

$$f(x) = x^{(q-1)} \frac{p^q}{\Gamma(q)} e^{-px}, \qquad x > 0 \tag{2}$$

where $\Gamma(q)$ is the Gamma function defined as

$$\Gamma(q) = \int_0^\infty y^{q-1} e^{-y} \mathrm{d}y, \quad q > 0 \tag{3}$$

The parameters p and q are related to the mean μ and the variance σ^2 of the distribution according to

$$\mu_x = \frac{q}{p}, \tag{4}$$

$$\sigma_x^2 = \frac{q}{p^2}. \tag{5}$$

The coefficient of variation expresses the uncertainty related to a given parameter and is given by

$$COV_x = \frac{\sigma_x}{\mu_x}, \tag{6}$$

thus describing the variation of a parameter relative to its mean value. A higher value indicates a greater dispersion of the parameter.

4.2.3. Estimation of the seismic source recurrence parameters

The standard assumption adopted is that the distribution of number of seismic events, with respect to their size, obeys the classic Gutenberg-Richter relation

$$logN(m) = a - b(m - m_{\min}), \tag{7}$$

where $N(m)$ is the number of seismic events of $m \geq m_{\min}$, occurring within a specified period of time, and a and b are parameters.

Aki (1965) found that equation (7) is equivalent with the assumption that the cumulative distribution function (CDF) of seismic event magnitude is of the form

$$\begin{aligned} F_M(m) &= P(M \leq m) \\ &= 1ie^{-\beta(m - m_{\min})} \end{aligned} \tag{8}$$

where $\beta = bln(10)$.

The seismic event occurrences over time in the given area are assumed to satisfy a Poisson process (1) having an unknown mean seismic activity rate λ.

The disregard of temporal and spatial variations of the parameters λ and b can lead to biased estimates of seismic hazard. An explicit assumption behind most hazard assessment procedures is that parameters λ and b remain constant in time. However, closer examination of most seismic event catalogues indicates that there are temporal changes of the mean seismic activity rate λ as well as of the parameter b. For some seismic areas, the b-value has been reported to change (decrease/increase) before large seismic events. Usually, such changes are explained by the state of stress; the higher the stress, the lower the b-value (Gibowicz and Kijko, 1994). Other theories connect the b-value with the homogeneity of the rock: the more heterogeneous the rock, the higher the b-value. Finally, some scientists connect the fluctuation of the b-value with the seismicity pattern and believe that the b-value is controlled by the buckling of the stratum. Whatever the mechanism, the phenomenon of space-time b-value fluctuation is unquestionable and well-known. A wide range of international opinions concerning changes of patterns in seismicity, together with an extensive reference list, are found in a monograph by Simpson and Richards (1981) and in two special issues of Pure and Applied Geophysics, (Seismicity Patterns …, 1999; Microscopic and Macroscopic …, 2000). Treating both parameters λ and b as random variables modelled by respective Gamma distributions allows for appropriately accounting for the statistical uncertainty in these important parameters. In practice, the adoption of the Gamma distribution does not really introduce much limitation, since the Gamma distribution can fit a large variety of shapes.

After combining the Poisson distribution (1) and the Gamma distribution (2), with parameters p_λ and q_λ, the probability to observe n seismic events per unit time t, for randomly varying seismicity, takes the form of the compound distribution

$$P(n|t) = \int_0^\infty p(n|\lambda,t)f(\lambda)\mathrm{d}\lambda$$
$$= \frac{\Gamma(n+q_\lambda)}{\mathrm{n}!\,\Gamma(q_\lambda)}\left(\frac{p_\lambda}{t+p_\lambda}\right)^{q_\lambda}\left(\frac{t}{t+p_\lambda}\right)^n \tag{9}$$

where $p_\lambda = \bar{\lambda}/\sigma_\lambda^2$, $q_\lambda = \bar{\lambda}^2/\sigma_\lambda^2$ and $\Gamma(an$ is the Gamma function (3). Parameter $\bar{\lambda}$ denotes the mean value of the activity rate λ.

It has to be noted that in statistical literature the compound distributions like (9), arise from many probabilistic models applied in the engineering (Hamada et al., 2008), insurance and risk industries (Klugman *et al*., 2008). The first application of the compound distributions in seismic hazard assessment was probably done by Benjamin (1968) followed by Campbell (1982, 1983).

Similarly to the procedure followed in obtaining distribution (9), the compound cumulative distribution function (CDF) of seismic event magnitudes are derived by combining the exponential distribution (8) with the Gamma distribution for β with parameters p_β and q_β, and normalizing upon introducing an upper limit $m_{\max}$. This compound CDF of seismic event magnitudes is expressed as (e.g. Campbell, 1982)

$$F_M(m|m_{\min}) = C_\beta \left[1 - \left(\frac{p_\beta}{p_\beta + m - m_{\min}}\right)^{q_\beta}\right], \tag{10}$$

where $p_\beta = \bar{\beta}/\sigma_\beta^2$ and $q_\beta = \bar{\beta}^2/\sigma_\beta^2$. The symbol $\bar{\beta}$ denotes the mean value of parameter β, σ_β denotes the standard deviation of a $\bar{\beta}$ and the normalizing coefficient C_β is given by

$$C_\beta = \left[1 - \left(\frac{p_\beta}{p_\beta + m_{\max} - m_{\min}}\right)^{q_\beta}\right]^{-1}. \tag{11}$$

Noting that $q_\lambda = \bar{\lambda} p_\lambda$ and $q_\beta = \bar{\beta} p_\beta$, equations (9) and (10) may respectively be written in an alternative form as

$$P(n|t) = \frac{\Gamma(n + q_\lambda)}{n!\,\Gamma(q_\lambda)} \left(\frac{q_\lambda}{\bar{\lambda}t + q_\lambda}\right)^{q_\lambda} \left(\frac{\bar{\lambda}t}{\bar{\lambda}t + q_\lambda}\right), \tag{12}$$

$$F_M(m|m_{\min}) = C_\beta \left[1 - \left(\frac{q_\beta}{q_\beta + \bar{\beta}(m - m_{\min})}\right)^{q_\beta}\right], \tag{13}$$

$$C_\beta = \left[1 - \left(\frac{q_\beta}{q_\beta + \bar{\beta}(m - m_{\min})}\right)^{q_\beta}\right]^{-1}, \tag{14}$$

where $q_\beta = \left(COV_\beta^{-1}\right)^2$ and $q_\lambda = \left(COV_\lambda^{-1}\right)^2$. Upon specification of the COV, the parameters $\bar{\lambda}$ and $\bar{\beta}$, referred to as hyper-parameters of the respective distributions, are estimated by applying the maximum likelihood procedure to the observed data.

4.2.4. Extreme magnitude distribution as applied to prehistoric (paleo) and historic events

The likelihood function of the desired seismicity parameters $\boldsymbol{\theta} = (\bar{\lambda}, \bar{\beta})$ is built based on the prehistoric (paleo) and historic parts of the catalogue containing only the strongest events. In this section the details of the likelihood function based on historic seismic events will be discussed, since except for a few details, the likelihood function based on prehistoric events is built in a similar manner.

By the Theorem of the Total Probability (e.g. Cramér, 1961), the probability that in time interval t either no seismic event occurs or all occurring events have a magnitude not exceeding m may be expressed as (Epstein and Lomnitz, 1966; Gan and Tung, 1983; Gibowicz and Kijko, 1994)

$$F_M^{\max}(m|m_0, t) = \sum_{i=0}^{\infty} P(i|t)[F_M(m|m_0)]^i. \tag{15}$$

Equation (15) can be expressed in a much more simpler form (e.g. Campbell, 1982) as

$$F_M^{\max}(m|m_0, t) = \left[\frac{q_\lambda}{q_\lambda + \bar{\lambda}_0[1 - F_M(m|m_0)]}\right]^{q_\lambda}. \tag{16}$$

In (15) and (16) is m_0 the threshold magnitude for the prehistoric or historic part of the catalogue ($m_0 \geq m_{\min}$). Magnitude $m_{\min}$ is the 'total' threshold magnitude and has a rather formal character. The only restriction on the choice of its value is that $m_{\min}$ may not exceed the threshold magnitude of any part (prehistoric, historic or complete) of the catalogue.

It follows from (16) that the probability density function (PDF) of the largest seismic event magnitude m within a period t is

$$f_M^{\max}(m|m_0, t) = \frac{\bar{\lambda}_0 t q_\lambda f_M(m|m_0) F_M^{\max}(m|m_0, t)}{q_\lambda + \bar{\lambda}_0 t[1 - F_M(m|m_0)]}. \tag{17}$$

$\bar{\lambda}_0$ represents the mean activity rate for seismic events with magnitudes not less than m_0 and is given by

$$\bar{\lambda}_0 = \bar{\lambda}[1 - F_M(m|m_0)], \tag{18}$$

where $\bar{\lambda}$, as defined above, denotes the mean activity rate corresponding to magnitude value $m_{\min}$. Function $F_M(m|m_0)$ denotes the CDF of seismic event magnitude (13).

Based on (13) and the definition of the probability density function, it takes the form

$$f_M(m|m_{\min}) = C_\beta \bar{\beta} \left(\frac{q_\beta}{q_\beta + \bar{\beta}(m - m_0)} \right)^{q_\beta + 1}. \tag{19}$$

After introducing the PDF (17) of the largest seismic event magnitude m within a period t, the likelihood function of unknown parameters $\boldsymbol{\theta}$ becomes:

$$L_0(\boldsymbol{\theta}|\boldsymbol{m_0}, \boldsymbol{t_0}, \boldsymbol{cov}) = \prod_{i=1}^{n_0} f_M^{\max}(m_{0i}|m_0, t_i). \tag{20}$$

In order to build the likelihood function (20), three kinds of input data are required: $\boldsymbol{m_0}$, $\boldsymbol{t}$ and $\boldsymbol{cov}$**.** The $\boldsymbol{m_0}$ vector represents largest magnitudes, $\boldsymbol{t}$ denotes vector of the time intervals within which the largest events occurred and vector $\boldsymbol{cov} = (cov_\lambda, cov_\beta)$ consists of the coefficients of variation of the unknown parameters $\boldsymbol{\theta} = (\bar{\lambda}, \bar{\beta})$.

4.2.5. Combination of extreme and complete seismic catalogues with different levels of completeness

It is assumed that the third complete part of the catalogue can be divided into S sub-catalogues (Figure 4). Each sub-catalogue has a span T_i and is complete starting from the known magnitude $m_{\min}^{(i)}$. For each sub-catalogue i, the vector $\boldsymbol{m}_i$ denotes n_i seismic event magnitudes m_{ij}, where $m_{ij} >= m_{\min}^{(i)}$, $i = 1, \dots, S$ and $j = 1, \dots, n_i$. Let $\boldsymbol{L}_i(\boldsymbol{\theta}|\boldsymbol{m}_i)$ denote the likelihood function of the unknown $\boldsymbol{\theta} = (\bar{\lambda}, \bar{\beta})$, based on the i-th complete sub-catalogue. If the size of seismic events is independent of their number, the likelihood function $\boldsymbol{L}_i(\boldsymbol{\theta}|\boldsymbol{m}_i)$ is the product of two functions $L_i(\bar{\lambda}|T_i)$ and $L_i(\bar{\beta}|\boldsymbol{m}_i)$.

The assumption that the number of seismic events per unit time is distributed according to (12) means that $L_i(\bar{\lambda}|T_i)$ has the following form:

$$L_i(\bar{\lambda}|T_i) = \left(\bar{\lambda}^{(i)} t + q_\lambda\right)^{-q_\lambda} \left(\frac{\bar{\lambda}^{(i)} t}{\bar{\lambda}^{(i)} t + q_\lambda} \right)^{n_i}, \tag{21}$$

where $\bar{\lambda}^{(i)}$ denotes the mean activity rate corresponding to the threshold magnitude $m_{\min}^{(i)}$ and is given by equation

$$\bar{\lambda}^{(i)} = \bar{\lambda}\left[1 - F_M\left(m_{\min}^{(i)} | m_{min}\right)\right]. \tag{22}$$

Following the definition of the likelihood function based on a set of independent observations and (19), $L_i(\bar{\beta}|\boldsymbol{m}_i)$ takes the form

$$L_i(\bar{\beta}|\boldsymbol{m}_i) = \left[C_\beta \bar{\beta}\right]^{n_i} \prod_{j=1}^{n_i} \left[1 + \frac{\bar{\beta}}{q_\beta}\left(m_{ij} - m_{\min}^{(i)}\right)\right]^{-(q_\beta+1)}. \tag{23}$$

Equations (21) and (23) define the likelihood function of the unknown parameters $\boldsymbol{\theta} = (\bar{\lambda}, \bar{\beta})$ for each complete sub-catalogue.

Finally the joint likelihood function based on all data $L(\boldsymbol{\theta})$, i.e. the likelihood function based on the whole catalogue, is calculated as the product of the likelihood functions based on prehistoric, historic and complete data.

The maximum likelihood estimates of the required hazard parameters $\boldsymbol{\theta} = (\bar{\lambda}, \bar{\beta})$, are given by the value of $\boldsymbol{\theta}$ which, for a given maximum regional magnitude $m_{\max}$, maximizes the likelihood function $L(\boldsymbol{\theta})$. The maximum of the likelihood function is obtained by solving the system of two equations $\frac{\partial \ell}{\partial \bar{\lambda}} = 0$ and $\frac{\partial \ell}{\partial \bar{\beta}} = 0$ where $\ell = \ln L(\boldsymbol{\theta})$.

A variance-covariance matrix $D(\boldsymbol{\theta})$ of the estimated hazard parameters $\hat{\bar{\lambda}}$ and $\hat{\bar{\beta}}$, is calculated according to the formula (Edwards, 1972):

$$D(\boldsymbol{\theta}) = -\begin{bmatrix} \frac{\partial^2 \ell}{\partial \bar{\lambda}^2} & \frac{\partial^2 \ell}{\partial \bar{\lambda} \partial \bar{\beta}} \\ \frac{\partial^2 \ell}{\partial \bar{\beta} \partial \bar{\lambda}} & \frac{\partial^2 \ell}{\partial \bar{\beta}^2} \end{bmatrix}^{-1} \tag{24}$$

where derivatives are calculated at the point $\bar{\lambda} = \hat{\bar{\lambda}}$ and $\bar{\beta} = \hat{\bar{\beta}}$.

4.2.6. Estimation of the region characteristic, maximum possible seismic event magnitude $\boldsymbol{m}_{\mathbf{max}}$

Suppose that in the area of concern, within a specified time interval T, there are n main seismic events with magnitudes $m_1, \ldots, m_n$. Each magnitude $m_i \geq m_{\min}$ $(i = 1, \ldots, n)$, where $m_{\min}$ is a known threshold of completeness (i.e. all events having a magnitude greater than or equal to $m_{\min}$) are recorded. It is further assumed that the seismic event magnitudes are independent, identically distributed, random variables with CDF described by (13).

From the condition that compares the largest observed magnitude $m_{\max}^{obs}$ and the maximum expected magnitude during a specified time interval T, the maximum regional magnitude $m_{\max}$ is obtained (Kijko and Graham, 1998; Kijko, 2004)

$$m_{\max} = m_{\max}^{obs} + \frac{\delta^{1/q} exp[nr^q/(1-r^q)]}{\bar{\beta}} [\Gamma(-1/q\,, \delta r^q) - \Gamma(-1/q\,, \delta)], \tag{25}$$

where $\delta = nC_\beta$ and $\Gamma(and$ is the complementary incomplete Gamma function. The approximate variance of the above estimator is equal to (Kijko, 2004)

$$\sigma_{m_{\max}}^2 \cong \sigma_M^2 + \left\{ \frac{\delta^{1/q} exp[nr^q/(1-r^q)]}{\bar{\beta}} [\Gamma(-1/q\,, \delta r^q) - \Gamma(-1/q\,, \delta)] \right\}^2, \tag{26}$$

where σ_M is the standard error in determination of the largest observed magnitude $m_{\max}^{obs}$.

4.2.7. The Cornell-McGuire PSHA Procedure

The essence of the PSHA is the calculation of the probability of exceedance of a specified ground motion level at a specified site. The so called Cornell-McGuire solution of this problem consists of four steps: (e.g. Budnitz *et al.*, 1997; Reiter, 1990):

1. Determination of the possible seismic sources around the site. The sources are typically identified faults, point sources or area sources. It is assumed that the occurrence of seismic events in these sources is spatially uniform. In the territory of eastern and southern Africa, similar to the central and eastern United States or Australia, the main contribution to the seismic hazard is attributed to the area sources. The seismicity of the area does not always correlate well with geological structures that are recognizable at the surface, making the identification of the geological structures that are responsible for seismic events difficult.

2. Determination and assessment of the recurrence parameters for each seismic source. This is typically expressed in terms of three parameters: the mean seismic activity rate λ, b-value of the Gutenberg – Richter frequency magnitude relation and the upper-bound of the seismic event magnitudes $m_{\max}$.

3. Selection of the ground motion prediction equation (GMPE), which is most suitable for the region, is crucial. For the eastern and southern Africa areas, the strong motion records are very limited therefore theoretical models of the ground motion attenuation are used. Since the ground motion attenuation relationship is a major source of uncertainty in the computed PSHA, some codes and recommendations require the use of a number of alternative GMPEs (Bernreuter *et al*., 1989).

4. Computation of the hazard curves. These curves are usually expressed in terms of the mean annual frequency of events with site ground motion level a or more, or $\lambda(a)$. Alternatively it can be expressed in terms of the probability of exceedance $P(A > a|t)$ vs. a ground motion parameter a, like PGA or a spectral acceleration.

By the Theorem of the Total Probability (Cramér, 1961), the frequency $\lambda(a)$ is defined as (Budnitz *et al*.,, 1997)

$$\lambda(a) = \sum_{i=1}^{n_\mathrm{s}} \lambda_\mathrm{i} \int_{m_\mathrm{min}}^{m_\mathrm{max}} \int_{R|M} P[A \geq a|M,R] f_M(m) f_{R|M}(r|m) \mathrm{d}r \, \mathrm{d}m \tag{27}$$

with subscripts i $(i = 1, \ldots, n_s)$. The seismic source number is deleted for simplicity. In (27) λ denotes the seismic source (area) characteristic, mean activity rate defined as the mean number of seismic events per time unit having magnitudes between m_min and m_max. The value m_min is the minimum magnitude of engineering significance and m_max is the maximum seismic event magnitude assumed to occur on the seismic source. The probability $\Pr[A \geq a|M,R]$ denotes the conditional probability that the chosen ground motion level is exceeded for a given magnitude and distance. The standard choice for $\Pr[A \geq a|M,R]$ is the Gaussian complementary cumulative distribution function. The function is based on the assumption that the ground motion parameter a is a lognormal random (aleatory) variable. In (27) $f_M(m)$ denotes the PDF of seismic event magnitude. In most engineering applications it is assumed that seismic event magnitudes follow the Gutenberg-Richter relation. This implies that $f_M(m)$ is a negative Exponential distribution, with magnitudes between m_min and m_max. If uncertainty of the seismic event magnitude distribution is taken into account then $f_M(m)$ takes the familiar compound distribution form of equation (19). Finally the PDF $f_{R|M}(r|m)$ describes the spatial distribution of seismic event occurrence or, more precisely, the PDF of the distance from the earthquake source to the site of interest. In general cases, spatial distribution of the seismic event occurrence can be different for different seismic event magnitudes.

Under the condition that seismic event occurrence in every seismic source is a Poisson event, i.e. independent in time and space, the ground motion $A \geq a$ at a site is also a Poisson event. Hence the probability that a, a specified level of ground motion at a given site, will be exceeded at least once in any time interval t is

$$P[A > a|t] = 1sexp\left[-\sum_{i=1}^{n_s} \lambda_i \int_{m_{\min}}^{m_{\max}} \int_{R|M} P[A \geq a|M,R] f_M(m) f_{R|M}(r|m) \mathrm{d}r\mathrm{d}m\right], \qquad (28)$$

and is fundamental in PSHA. The plot of this equation vs. ground motion parameter a, is the hazard curve – the ultimate product of the PSHA assessment.

5. Input data

5.1 Catalogues

Reports of seismic phenomena in South Africa go back as far as 1620, to the early Dutch settlers[82)]. The seismicity is typical of an intraplate region. The natural seismic regime of a region of this type is characterised by low-level activity in terms of world standards, with seismic events randomly distributed in space and time. The correlation between most of the seismic events and the surface expression of major geological features is not clear (Fernandez and Guzman, 1979, Brandt et al., 2003).

Seismic events resulting from the deep-mining operations in the gold fields of the Gauteng, Klerksdorp, Stilfontein and Welkom, form the majority of the seismic events recorded by the regional network of seismic stations (SANSN). Usually, the depth of these events varies in the range of 2-3 km below the surface.

The seismic event catalogue used in this study was compiled from several sources. After critical analysis of each of the data sources, the main contribution to pre-instrumentally recorded seismicity comes from Brandt et al., (2003). The instrumentally recorded events are mainly selected from databases provided by the International Seismological Centre in UK (ISC). The ISC is a non-governmental organization charged with the final collection, analysis and publication of standard earthquake information from around the world.

[82] It is interesting to note that the recent research by Master (2012) is questioning the credibility of the first earthquake in the South African earthquake database, event of 4 July 1620, located in Robben Island. If Master (2012) is correct, then the SA earthquake database would start from event of M_L magnitude 3.6 occurred of 15 June 1690 which took place in vicinity of today's Cape Town.

The database of seismic events for South Africa is incomplete due to the fact that large parts of the country were very sparsely populated and the detection capabilities of the seismic network are far from uniform.

Unfortunately, current geological knowledge of the South African area does not provide information on all capable faults and their movements during the recent (Quaternary) geological past, especially during the last 35,000 years. There exists no known relationship between instrumentally recorded or historic seismicity and the location of faults. Also, almost no information is available on paleo-seismicity of the South African area. Therefore, in this study, the assessment of the source-characteristic, maximum possible seismic event magnitude $m_{\max}$ (Kijko, 2004), is entirely based on knowledge of past seismicity. The other two hazard recurrence parameters (the Gutenberg-Richter b-value and the mean activity rate λ) for each seismic source has been estimated according to the procedure developed by Kijko and Sellevoll (1992). Similar to the assessment of $m_{\max}$, the b-value and λ are based on knowledge of seismicity of the area.

The parameters of area sources λ, b-value and $m_{\max}$ were calculated for a grid size $0.1° \times 0.1°$ spanning the whole country. The seismic hazard is calculated, in the form of a matrix consisting of equally spaced grid points ($0.25° \times 0.25°$) in latitude and longitude. The area covered in this study is defined by latitudes $35°\ S$ to $21°\ S$ and longitudes $15°\ E$ to $33°\ E$.

Following extensive analysis of the seismic event database it was established that the catalogue of the tectonic origin seismic events can be divided into eight parts, each with different level of completeness, (Table 1).

Table 1: Division of the catalogue used in the analysis.

Sub-catalogue number	**Level of completeness (M_w)**	**Beginning of sub-catalogue**	**End of sub-catalogue**
1	5.9	1806/01/01	1905/12/31
2	5.3	1906/01/01	1909/12/31
3	4.9	1910/01/01	1949/12/31
4	4.6	1950/01/01	1970/12/31
5	4.0	1971/01/01	1980/12/31
6	3.8	1981/01/01	1990/12/31
7	3.5	1991/01/01	1995/12/31
8	3.5	1996/01/01	2002/12/31
9	3.0	2003/01/01	2013/01/31

5.2 Ground Motion Prediction Equation (GMPE)

Attenuation is the reduction in the amplitude or energy of seismic waves caused by the physical characteristics of the transmitting media or system. It usually includes geometric effects such as the decrease in amplitude of a wave with increasing distance from the source.

Attenuation relationships, known as ground motion prediction equations (GMPEs), for South Africa were established on the basis of strong motion data that are practically non-existent (Minzi *et al*., 1999). Three attempts to establish the horizontal component of PGA attenuation for the eastern and southern Africa are published by Jonathan (1996), Twesigomwe (1997) and more recently by Mavonga (2007). Jonathan's GMPE is based on random vibration theory and is scaled by seismic records as recorded by local seismic stations. Twesigomwe's equation is a modification of the GMPE by Krinitzky *et al*., (1988). Comparison of the two regional GMPEs with the e.g. global equation by Joyner and Boore (1988), Boore et al., (1993; 1994) shows relatively good agreement between regional attenuations and is used globally. Finally, the most recent GMPE by Mavonga (2007) is based on the well-known procedure of the simulation of the ground motion of large seismic events using recordings of small earthquakes (Frankel, 1995; Irikura, 1986). Seismic records of small events adjacent to the expected large events have been treated as an empirical Green's function. The advantage of the procedure is that the predicted ground motion contains information on the site response, details of path effects etc., and they can therefore often produce realistic time histories. Unfortunately, all three GMPEs are derived only for PGA and are not applicable to short distances e.g. below 10 km.

In this report the assessment of the seismic hazard for South Africa is based on the well-studied model of GMPE by Atkinson and Boore (2006). The applied GMPE was developed for the central and eastern United States which is situated in a type of tectonic environment known as an intraplate region, or equivalently, stable continental area. Because of the limited number of strong-motion records in the stable continental areas, the applied GMPE (horizontal component) has been developed mainly by help of stochastic modelling. The GMPE used in this report, including their functional form and respective coefficients are provided in Appendix A.

6. Results

Five maps of seismic hazard for South Africa were calculated. These maps are expressed in terms of peak ground acceleration (PGA). The maps indicate a 10 % probability of exceeding the PGA at least once in 50 years, for the different mean seismic activity rate correcting factors (c_f = 1, 2, 5 and 10). The correcting factor c_f is applied to the seismic activity rate λ to indicate the factor by which the activity rate is increased for the four possible scenarios i.e. a) no increase of seismicity and seismicity increases b) 2 times, c) 5 times and d) 10 times. Map No. 5 represents the estimated seismic hazard in South Africa when taking into account the four scenarios. It was assumed that the logic tree weights (l_w) of the four scenarios are 0.15, 0.50, 0.30 and 0.05 respectively. It is imported to take note that that these weights (l_w) are very subjective; they were selected according to wide scatter and often contradicting expert opinions on the effect of hydraulic fracturing. These opinions are available in the current respective literature (e.g. Davis and Frohlich, 1993; De Pater and Baisch 2011; Davies *et al*., 2013; Green *et al*., 2012; Horton, 2012; King, 2010; Maxwell *et al*., 2009; Suckale, 2009; Zoback and Harjes, 1997) and can/will be modified as more seismological effects of eventual future hydraulic fracturing will become known.

Comparison of these five maps suggest that the introduction of hydraulic fracturing in South Africa can/will lead to high levels of seismic hazard in the parts of the Western Cape, the Free State, Gauteng and towards the eastern border of the North West Province. Moderate hazard levels can be expected in the Limpopo Province and parts of the Northern Cape. The southern part of the Eastern Cape is subject to low levels of seismic hazard.

A more reliable assessment of effect of hydraulic fracturing on seismic hazard in South Africa can be achieved only through the inclusion of detailed geological and tectonic information about the area.

6.1 Seismicity

Maps No. 1 to 5 indicate a wide range of accelerations which are represented by the colours white to maroon. The accelerations range from 0.01 g to 0.14 g and is grouped together as indicated in Table 2. The classifications were done based on the current seismic activity for South Africa (Map No. 1) and applied to Maps No. 2 to 5, which represents the hypothetical increased activity rate that could possibly be attributed to hydraulic fracturing.

Table 2: Classification of acceleration range for mapping purposes

Hazard Classification	Acceleration Range	Colour Code
No Hazard	0.0 g	White
Low Hazard	0.0 g - 0.05 g	Green
Moderate Hazard	0.05 g – 0.0875 g	Yellow
High Hazard	0.0875 g – 0.125 g	Pink
Very High Hazard	> 0.125 g	Maroon

The highest expected accelerations for each of the respective seismic hazard maps of PGA is 0.14 g ($c_f = 1$), 0.17 g ($c_f = 2$), 0.25 g ($c_f = 5$), 0.34 g ($c_f = 10$) and 0.24 resulting from the application of the logic tree formalism. The map with the highest level of hazard is Map No. 4 ($c_f = 10$), with peak ground accelerations in the region of 0.18 to 0.3 g in the north-eastern part of South Africa (parts of Mpumalanga, Gauteng, North West Province, Free State, Lesotho, KwaZulu Natal and Swaziland). High PGA accelerations (order of 0.2 to 0.4 g) are indicated by the maps for the south-western part of the Western Cape. It is important to note that although by international norms the expected seismic hazard is not high, it is still high enough to cause significant damage to infrastructure.

A common trend between in Maps No. 1 to 5 (within their respective ranges) is the high level of hazard in parts of the Western Cape, the Free State, Gauteng and the eastern parts of the North West Province. Moderate hazard levels can be seen in the Limpopo Province and parts of the Northern Cape. Low levels of hazard can be seen in the southern part of the Eastern Cape.

The PGA map (Map No. 1) gives comparable results compared to the most recent seismic hazard map of Southern Africa (Kijko *et al.*, 2003), which is implemented into the South African Building Code 2009 (SABS, 2009). The three maps, Maps No. 2-4, yield the following expected hazard levels: in terms of natural seismic activity there is a high expected level of hazard (about 0.2 g) in the south-Western Cape. Moderate hazard levels, in the order of 0.1 g, are expected in Lesotho and low levels (0.05 g) of hazard are expected in the southern region of the Eastern Cape. In terms of mining-induced seismicity; the highest expected peak ground accelerations, in the order of 0.2 g, can occur in the Free State and Gauteng mines. Moderate hazard levels of 0.1 g are predicted for KwaZulu Natal.

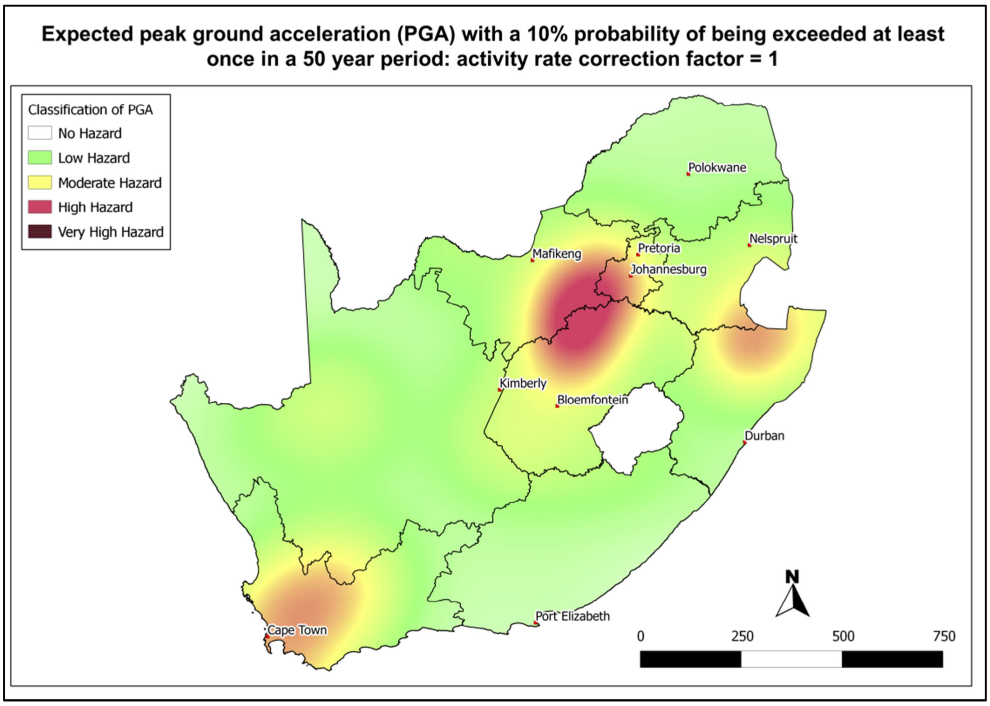
6.2 Possible Effect of Hydraulic Fracturing

Not enough research have been performed to allow the researchers to release a categorical statement in terms of which areas can be classified as safe or not safe in terms of hydraulic fracturing. The seismicity for South Africa is not equally well documented for different areas in the country, for instance the Karoo area. This is mainly due to the low density of seismometers in the South African National Seismological Network (SANSN). A very limited number of stations are not capable to detect weak seismic events. Buried faults can therefore go undetected. The establishment of a local seismic network before hydraulic fracturing starts is fundamentally important to ensure that no drilling occurs on or near any faults or areas of tectonic stress concentrations. The use of the current knowledge of the local geology in this respect could also be extremely helpful in the absence of instrumental observations.

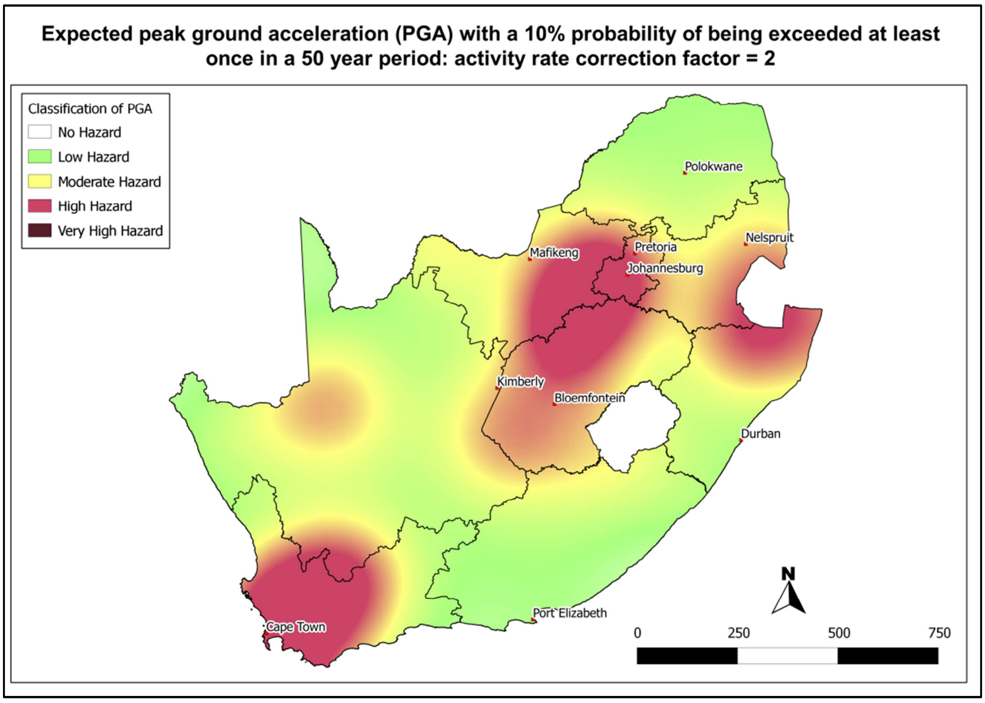
The local tectonic conditions are crucial indicators needed to determine the level of increase of seismicity in an area. These conditions include the local geological make-up, buried faults, local seismotectonics (which can be established by seismic tomography) and tectonic stresses. The history of the seismic activity in the area is also an important factor which, up to large extend, determines the seismicity induced by a process such a hydraulic fracturing.

6.3 Seismicity Maps

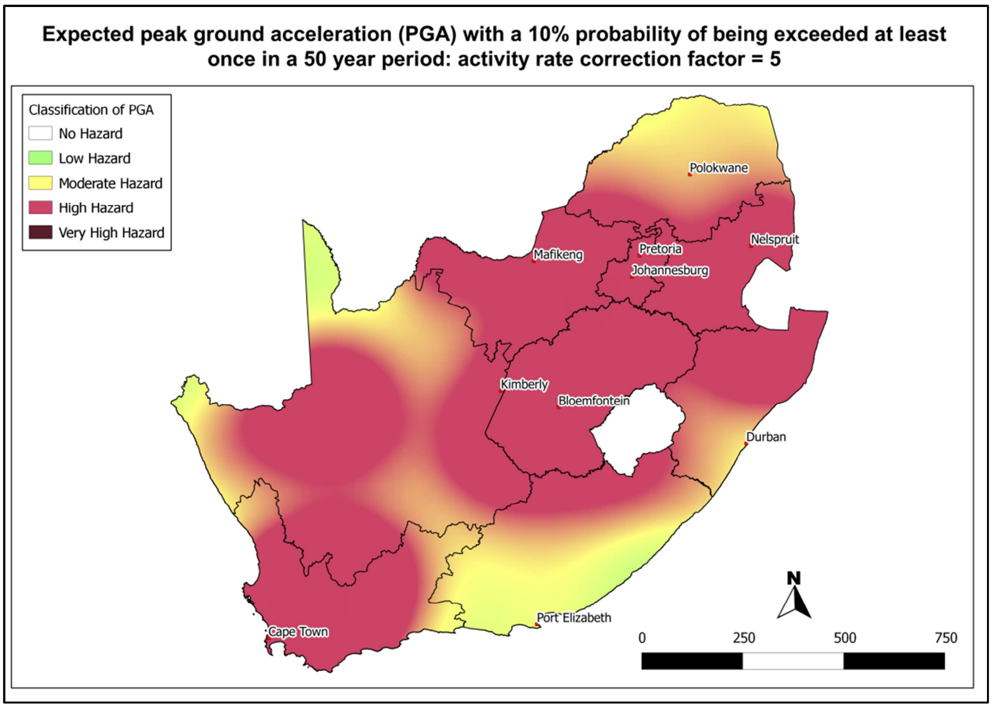
The seismic hazard maps for South Africa in terms of peak ground acceleration (PGA) are provided below. The maps respectively indicate a 10 % probability of exceeding the calculated PGA at least once in 50 years for the different increased activity rate correcting factors (c_f = 1, 2, 5 and 10), as well as the combination of these scenarios through a logic tree.



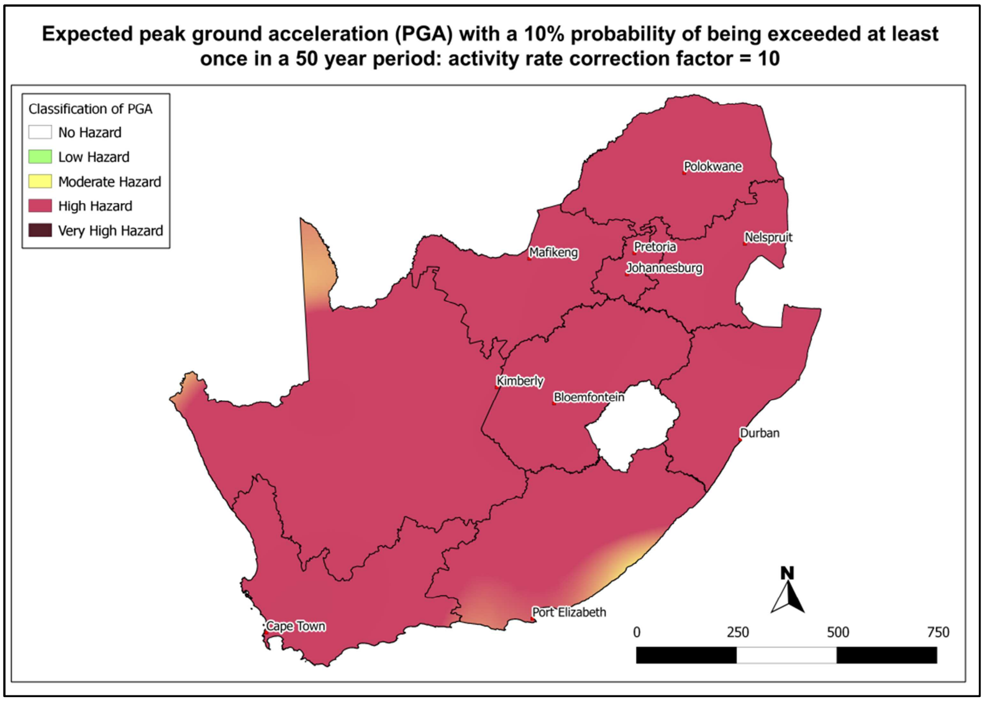
Map No. 1: Map of current seismic hazard for South Africa (applied correcting factor of the activity rate $\boldsymbol{c_f = 1}$). This map shows the expected PGA with a 10 % probability of being exceeded at least once in a 50 year period.



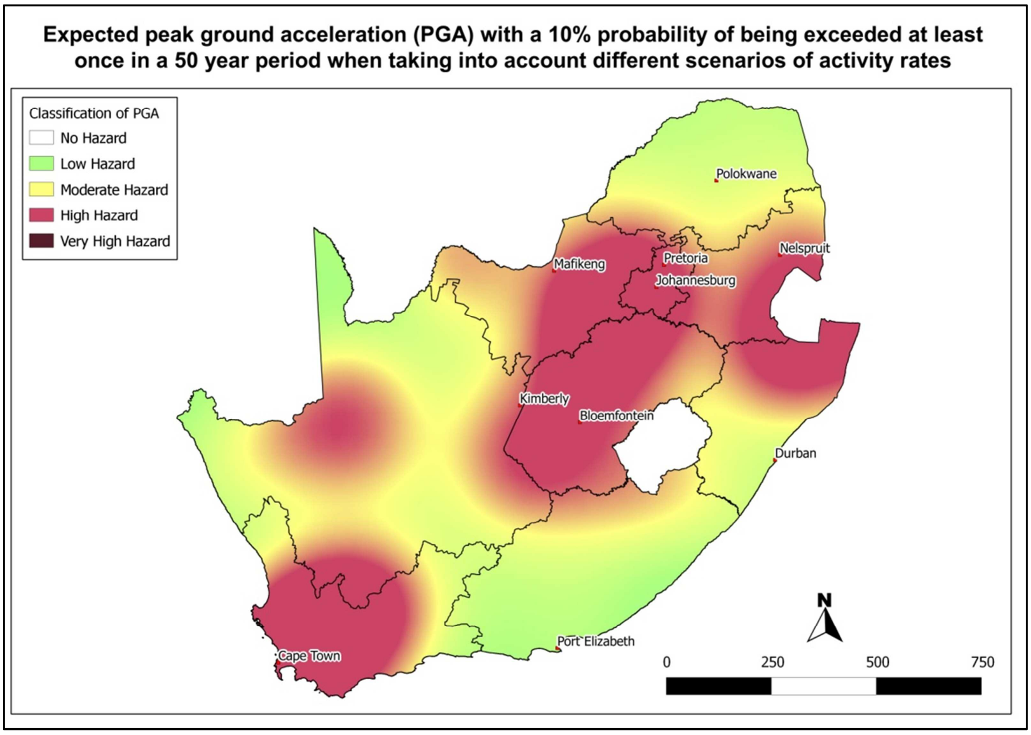
Map No. 2: Map of the expected PGA with a 10 % probability of being exceeded at least once in a 50 year period with the applied activity rate correcting factor $\boldsymbol{c_f = 2}$.



Map No. 3: Map of the expected PGA with a 10 % probability of being exceeded at least once in a 50 year period with the applied activity rate correcting factor $\boldsymbol{c_f = 5}$.



Map No. 4: Map of the expected PGA with a 10 % probability of being exceeded at least once in a 50 year period with the applied activity rate correcting factor $c_f = 10$.



Map No. 5: Map of the expected PGA with a 10 % probability of being exceeded at least once in a 50 year period taking into account all the possible scenarios for activity rate ($c_f = 1, 2, 5, 10$).

For the purpose of this report the associated hazard (peak ground acceleration) is set equivalent to vulnerability as defined in UNISDR (2004). This report defines vulnerability as the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards.

7. Monitoring Protocol

In comparison with global seismicity southern Africa is one of the most stable regions of the Earth. However, it is not completely deprived of seismic activity. An unusual aspect in the seismicity of South Africa is that most of the recorded seismic activity is associated with the deep gold mining operations on the periphery of the Witwatersrand Basin. Natural, low magnitude earthquakes occur sporadically over time and space, portraying typical intraplate seismicity.

Owing to the relatively short documented seismic history of the southern African sub-continent most of the available information relates to instrumental data acquired since 1971. Most of the information regarding pre-1971 events is based on macro-seismic observations. Consequently, the locations of these events correspond, in most cases, to the sites where the seismic event was felt with maximum intensity but may be displaced by tens of kilometres from the true epicentre.

The database of seismic information for South Africa is evidently incomplete, especially for the historic part of the seismic event catalogue. The completeness could be estimated by comparing the apparent frequency of occurrence of events with pre-assumed frequency-magnitude relationships (Shapira *et al*., 1989; Saunders *et al*., 2008).

Although the situation has improved since 1989 through the deployment of more seismic stations, the overall threshold for determining the magnitude for both the tectonic origin and mine related seismic events is still around magnitude M_w 3.0.

International regulatory guides clearly states that any study related to the siting, rating and development of critical engineering structures must include seismic monitoring as one of the components. It is therefore imperative that the collection and monitoring of data should start well in advance before any exploration is undertaken on the site, and should continue well after hydraulic fracturing has ceased in the area. The only means to comply with international standards of identifying if an area is capable of generating seismic events is to, as in the case of mining induced seismicity or tectonic active (capable) faults, install a local seismic network with the capability of recording micro-seismic events with Richter magnitudes, say less than 1.0.

Knowledge of micro-seismic events provides knowledge about large, potentially dangerous events in the future through the extrapolation of the rate of occurrence of small events to larger events. In

South Africa, knowledge about micro-seismicity is virtually the only information available, since the occurrence of large events is very rare. The analysis of micro-seismic event records provides useful data of engineering significance. In order to provide sufficient coverage over the epicentre location for the area of interest, it is recommended that an area with a radius of ca. 100 km, from the hydraulic fracturing site, be monitored. This local micro-network links the hydraulic fracturing operations with seismic data processing and data interpretation for meaningful interpretation of events as they unfold. The network should also report to the regional and/or national seismic networks.

Seismic monitoring before exploration will aid in identifying the location of faults and the stress field nature in areas where it is currently unknown. Although most faults are inactive and does not pose a potential problem, it assists in the seismic characterization of the site (Cook et al., 2013). This is necessary in the establishment of a baseline and should therefore be done before the hydraulic fracturing process begins.

In certain cases e.g. when hydraulic fracturing will take place in vicinity of known tectonic faults or significant infrastructure, it would be advantageous to install, in addition to a local seismograph network, several strong motion accelerographs. The recorded seismic events should be carefully studied and, if possible, linked with the local tectonics of the area.

Detailed information on seismicity is therefore needed in order to obtain meaningful information about the potential increase in seismicity associated with hydraulic fracturing. It is recommended that a network of seismographs and accelerographs, that have the ability to record macro- and micro-earthquakes, be installed and operated before and during exploration as well as during and after mining. It is strongly recommended to begin this seismic monitoring before the hydraulic fracturing exploration phase in order to establish a baseline.

Data Management

The establishment and management of the recommended local seismic network to ensure data integrity, is if upmost importance. The number of sensors and their configuration in this local seismic network should be arranged such that it provides the required location of the seismic event epicentres with an accuracy of a few 100 meters. To obtain this required accuracy, the network optimization should be done before the instalment of the seismic network (see e.g. Kijko, 1997a and b).

Currently the Council for Geoscience (CGS) maintain the South African National Seismograph Network (national and regional networks). The database maintained by the CGS can be viewed as the most up to date data archive on seismic activity in South Africa. Investigations should be made to determine if the existing system can be effectively adapted to manage seismic information at oil and gas well sites, or if a new local networks should be established.

If the CGS is not capable of providing the necessary support, an independent entity would have to establish, manage, analyse and disseminate the relevant networks and information.

8. Disclaimer

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Appendix A

Applied Ground Motion Prediction Equation

```
                  ATKINSON-BOORE (BSSA, vol.96, pp.2181-2205, 2006)
        ====================================================================

ln[a(f)] = c1 + c2*mag + c3*mag^2 + (c4 + c5*mag)*f1 +
(c6 + c7*mag)*f2 +(c8 + c9*mag)*f0 + c10*r + p*SD

   WHERE:

     a          = MEDIAN VALUE, HARD ROCK, AVERAGE HORIZONTAL COMPONENT
                  PGA/ARS [g]
     f          = GROUND MOTION FREQUENCY. IF a = PGA, f = 99.9 [Hz]
     mag        = EARTHQUAKE MAGNITUDE Mw
     r          = HYPOCENTRAL DISTANCE (CLOSEST DISTANCE TO THE FAULT) [KM]
     f0         = MAX[log10(r0/r),0], r0 = 10 KM
     f1         = MIN[log10(r/r1],    r1 = 70 KM
     f2         = MAX[log10(r/r2),0], r2 = 140 KM
     p          = 0. IF p = 1, ln(a) = MEAN[ln(a)] + SD[ln(a)]
     c1,...,c10 = COEFFICIENTS; SD OF PREDICTED ln(a) = 0.69

                     ATTENUATION COEFFICIENTS
                  ==============================
```

Freq.(Hz)	c1	c2	c3	c4	c5	c6	c7	c8	c9	c10
0.2	-5.41	1.710	-0.0901	-2.54	0.227	-1.270	0.116	0.979	-0.1770	-0.0002
0.3	-5.79	1.920	-0.1070	-2.44	0.211	-1.160	0.102	1.010	-0.1820	-0.0002
0.4	-6.17	2.210	-0.1350	-2.30	0.190	-0.986	0.079	0.968	-0.1770	-0.0003
0.5	-6.18	2.300	-0.1440	-2.22	0.177	-0.937	0.071	0.952	-0.1770	-0.0003
0.8	-5.72	2.320	-0.1510	-2.10	0.157	-0.820	0.052	0.856	-0.1660	-0.0004
1.0	-5.27	2.260	-0.1480	-2.07	0.150	-0.813	0.047	0.826	-0.1620	-0.0005
2.0	-3.22	1.830	-0.1200	-2.02	0.134	-0.813	0.044	0.884	-0.1750	-0.0008
2.5	-2.44	1.650	-0.1080	-2.05	0.136	-0.843	0.045	0.739	-0.1560	-0.0009
4.0	-1.12	1.340	-0.0872	-2.08	0.135	-0.971	0.056	0.614	0.1430	-0.0011
5.0	-0.61	1.230	-0.0789	-2.09	0.131	-1.120	0.068	0.606	-0.1460	-0.0011
8.0	0.21	1.050	-0.0666	-2.15	0.130	-1.610	0.105	0.427	-0.1300	-0.0012
10.0	0.48	1.020	-0.0640	-2.20	0.127	-2.010	0.133	0.337	-0.1270	-0.0010
20.0	1.11	0.972	-0.0620	-2.47	0.128	-3.390	0.214	-0.139	-0.0984	-0.0003
25.2	1.26	0.968	-0.0623	-2.58	0.132	-3.640	0.228	-0.351	-0.0813	-0.0001
40.0	1.52	0.960	-0.0635	-2.81	0.146	-3.650	0.236	-0.654	-0.0550	-0.0000
PGA	0.91	0.983	-0.0660	-2.70	0.159	-2.800	0.212	-0.301	-0.0653	-0.0004

Appendix B

Seismicity and Hydraulic Fracturing

(Water Research Commission Project K5/2149: Development of an interactive vulnerability map and preliminary screening level monitoring protocol to assess the potential environmental impact of hydraulic fracturing: Background review report, 2013)

Impacts

Already in the 1920s it became clear that pumping fluids into or out of the Earth can cause strong seismic events (NRC, 2012). Some of them can be strong enough to cause damage. In seismological literature, these events are known as man-made or induced earthquakes.

The most memorable and well documented example of an induced seismic related event due to fluid injection is the induced seismicity that occurred in the Denver, Colorado area in the 1960s. An injection of liquid waste disposal at the Rocky Mountain Arsenal into impermeable crystalline basement rock caused several seismic events with magnitudes within a range of 5.0 to 5.5. The largest event caused damage estimated in 1967 of US $500,000 (Healy *et al*., 1968; Nicholson and Wesson, 1990).

More recent examples of induced seismicity caused by pumping fluids into or out of the rock include seismic events in Basel, Switzerland, as well as in Arkansas, Ohio and Oklahoma, Texas in the USA (Frohlich et al., 2011; Horton and Ausbrooks, 2010 and 2011, Horton, 2012). For example (Kerr, 2012), during extensive fluid injection in the vicinity of the town of Guy, Arkansas, a magnitude 4.0 event struck about a kilometre northeast of the two fracturing wells. Ten days later, a magnitude 3.9 event took place, ca. two kilometres farther to the northeast toward Guy. Two months later, two events of magnitude 4.1 and 4.7 took place to the southwest of the deeper well, towards the town of Greenbrier. In March 2011, the Ohio Department of Natural Resources announced that it had evidence “strongly indicating” that wastewater injection - at least part of it used for fracturing purposes - had triggered several magnitude 2.0 to 4.0 seismic events in the town of Youngstown. In 2001, seismic activity was observed along the Colorado–New Mexico border, the place where drillers were injecting water to extract methane from coal beds. In central and southern Oklahoma, seismicity increased in 2009 by a factor of 20 over the rate of the previous half-century, even when the November’s magnitude 5.6 and its aftershocks are excluded from the calculation (Ake *et al*., 2005; Holland and Gibson, 2011).

It is not always is clear what is the cause of this strong induced seismicity (Zoback et al., 2010). Dr. Mark Zoback of Stanford University in Palo Alto, California is pointing out that there are already 144,000 wastewater injection wells in the country, but very few are generating seismic events. Injection of fluid in rocks causes an increase of the pore pressure and also modifies the state of the stress (NRC, 1990; Hsieh and Bredehoeft, 1996). The stress change is associated with a volume expansion of the rock due to the increase of the pore pressure. However, the pore pressure perturbation dominates over the stress variation and when considering the consequence of fluid injection with regard to the induced seismicity, the stress perturbations can often be ignored.

In assessing the potential for induced seismicity, two basic questions arise: (1) what is the magnitude of the pore pressure change and (2) what is the extent of the volume of rock where the pore pressure is modified in any significant manner. Current understanding is that the magnitude of the induced pore pressure increase and the extent of the region of pore pressure change depend on the rate of fluid injection, total volume injected, the fluid viscosity and as well as hydraulic properties of the rock, its intrinsic permeability and its storage coefficient (e.g. Shapiro and Dinske, 2009).

Can we control the occurrence of strong seismic events induced by fluid injection? According to Dr Zoback, one has to “look before you leap”. He believes that the seismic tomography techniques should be employed to locate buried faults capable of generating strong seismic events, up to magnitude 6.0 (Zoback and Townend, 2001; Zoback *et al*., 2010).

In addition, at the beginning of the injection, the surrounding area should be monitored by a network of seismometers. The monitoring and data analysis should be done in real time. It will allow researchers to produce an image of the subsurface and to identify the potential area of location for strong seismic events. Such “hot spots” must be avoided during hydraulic fracturing.

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