Review of Risks to Water Resources from Unconventional Gas Exploration and Production in South Africa and Water Science Plan for Unconventional Gas Development: Workshop Summary

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CONTENTS

LIST OF APPENDICES

ACRONYMS AND ABBREVIATIONS

Below is a list of acronyms and abbreviations used in this report.

Acronyms and / Abbreviations	Definition
Bcf	Billion cubic feet
CBM	Coal-bed methane
GIP	Gas-in-place
PASA	Petroleum Agency of South Africa
PRMS	Petroleum Resource Management System
USA	United States of America
UWC	University of the Western Cape
Tcf	Trillion Cubic Feet
TJ/d	Terrajoules per day
WRC	Water Research Commission

PREFACE

In 2014, the Water Research Commission (WRC) awarded a project to a consortium of researchers from SLR Consulting (South Africa) (Pty) Ltd (SLR), the University of the Western Cape (UWC), and Prime Africa Consultants entitled "*Unconventional Gas Exploration and Production and its Impact on South Africa's Water Resources*". A subsequent consultancy was awarded to Dr Hans Beekman and SLR to develop a "*Water Science Plan for Unconventional Gas Development*". Both of these projects require planning workshops to inform the research aims and work plan.

On 3-4 July 2014, a two-day workshop was held under the auspices of the WRC to inform the WRC projects. The purpose of the workshop was to bring together various stakeholders to share knowledge and learn from each other about risks and opportunities that are associated with unconventional gas exploration and production, and to identify measures on how to mitigate the identified challenges as the country explores unconventional gas opportunities. Participants to the workshop represented different institutions and included the Department of Water Affairs and Sanitation, agencies of government, researchers involved in unconventional gas projects, science councils and postgraduate students.

The workshop benefited from a number of guest speakers. The speakers came from the Department of Water and Sanitation, Duke University, Ohio State University, WRC, Petroleum Agency of South Africa (PASA) and the hosts SLR and the UWC. As presentations progressed, participants asked for clarifications, and shared their concerns and expectations regarding gas exploration and production in South Africa. Inputs were based participants' understanding of groundwater-related impacts in the mining and energy sectors both locally and in the USA.

South Africa needs to be in a position to develop its unconventional gas resources in a manner that is responsible and sustainable – through research support and effective regulation. However, the capability and capacity of South African organisations (public and private) to explore and develop unconventional gas resources is in its early stages.

Unconventional gas exploration, production and commercialisation offer the country an opportunity to create a new, broad-based model in resource development that contributes to economic security but also bolsters environmental and social security (as opposed to experiences in the mining sector). This will require a multi-stakeholder approach to identify, grow and leverage capabilities to address the multi-faceted challenges of unconventional gas exploration, production and commercialisation.

Key points or highlights during the workshop included:

1. **Lack of evidence-based scientific facts to inform the practice and the enforceable regulations**: The Karoo region remains unknown in many ways, especially the deep aquifers and associated geology. There is a need for extensive research prior to the production of gas.

2. **Lack of quantifiable cost-benefit assessments results**: The costs and benefits of exploring and possible production of the unconventional gas has remained speculative or at its best remained qualitative. The debates assume the existence of quantities and qualities of gas that will meet the demand of the markets and that will benefits various players. The debates assume that no technologies will exist to prevent or remediate the negative effects from the processes of exploration and production of gases. Uncertainty is amplified by the absence of solid scientific evidence about Karoo gas resources.

3. **Lack of established institutional arrangements to oversee exploration and production activities in the Karoo**. Although recently the SA government has declared hydraulic fracturing and other activities controlled activities, such proclamations may fall short. It was noted that such institutions are vital in reforming, enforcing and monitoring the activities relating to exploration and production of gases.

4. **Lack of basic and applied scientific knowledge regarding the processes relating to exploration and production**. It was noted that basic knowledge of chemicals used in the hydraulic fracturing process is lacking, including their interaction with the natural environment. In addition, stakeholders have limited scientific knowledge regarding impacts on the environment from natural chemicals and chemicals that are introduced during hydraulic fracturing.

5. **The need for workshops**: Based on the above issues, the workshop discussed the importance of holding frequent meetings, workshops or conferences to reinforce the collaborative sustained communication among various stakeholders as one way of sharing knowledge, data and concerns from scientific disciplines.

Key contextual consideration:

6. **Regulations**: Policies need to be reformed in the context of such initiatives but such regulations need to be turned into regulations. However, in the absence of evidence-based information about the hydraulic fracturing process in general, reforming the regulation remains a difficult exercise, although precautionary principles can be invoked. Nevertheless, the context and complexities involved in policy making and enacting policies need to be recognised by all participants in hydraulic fracturing debates.

7. **Institutional arrangements**: Although the need for setting up an organisation to oversee exploration and production of unconventional gas is recommended, duplication of institutional arrangements needs scrutiny to avoid overlap of roles and responsibilities. In addition, wide and deep sustained engagements with various bodies are needed for the buy-in philosophy of such an organisation.

8. **Informative research and information or results sharing**: The current situation is that various organisations have data or information about some aspects or some of the issues that relate to hydraulic fracturing. Sharing such information remains limited for various reasons. With such a context, the workshop suggested the need to share information and the need to have an agent to house the information. The modalities for such an initiative remain elusive.

9. **Robust basic research deep hydrogeology still developing in South Africa:** The current situation in South Africa is that knowledge about the groundwater resource is based on known aspects of the top 300m of the earth's crust. Deeper hydrogeological systems below 300m remain unstudied. Given such a context, it is difficult to discuss the situation and its consequences for deep aquifers during and after hydraulic fracturing. When chemical and physical characteristics of the deeper aquifers are known, predictions will provide more reliable estimates than at present. Research activities on such aquifers is needed in the context of hydraulic fracturing in South Africa.

10. **Water use and wastewater treatment**: South Africa is a water stressed country, particularly the Karoo region where hydraulic fracturing is proposed. A major concern is that the sources of water for hydraulic fracturing are not secured. In addition, the technologies to treat wastewater and other effluents from the proposed unconventional gas development must be adapted.

The following conclusions were drawn from the workshop:

- **Monitoring and baseline measurements**
  To test whether hydraulic fracturing could cause aquifer contamination requires baseline measurements of levels of CH_4 in aquifers before and after hydraulic fracturing. The baseline and monitoring network needs to be set-up as a matter of urgency.

- **Regulation**
  Existing South African legislation has comprehensive provisions for environmental protection. For example, the National Water Act specifies that water be left as an "environmental reserve" necessary for ecosystem functioning. However, there is a need to anticipate the kind of regulatory issues that might be encountered as part of unconventional gas exploration and exploitation. These would not necessarily be limited to environmental issues, but would include transport regulations, tax law and policy, employment issues, and other backward and forward linkages associated with resource extraction. These issues, considered together, bear on the extent to which the benefits of unconventional gas extraction are broadened and maximised and the negative effects such as pollution are reduced. A coordinated regulatory approach would naturally require collaboration across government organisations, as well as the close involvement of other stakeholders including the energy companies, communities, unions and farmers.

- **Research/knowledge production**
  Water and environmental researchers in South Africa are already working on various initiatives to understand and address the issues surrounding unconventional gas extraction. At present these are funded mainly by the WRC. There is a need to broaden the research funding base and increase research funding generally. Several South African universities are well positioned to address unconventional gas, having existing skills and equipment. Some universities (for example the universities of the Western Cape and Free State, as well as Nelson Mandela Metropolitan University) are deliberately gearing up capacity to participate in future research around the issue. Ideally research would begin to focus on the concerns of a high-level cross-disciplinary task team established within government, in a process of two-way dialogue. Research by South African universities and science councils, focused and directed, has the potential to be greater than the sum of its parts. South Africa should also take full advantage of existing knowledge, research and practical experience, gained at considerable expense elsewhere. This process has already begun – e.g. the involvement of scientists from the USA in South African projects.

- **Education and training**
  There is a need both to train more scientists and environmental practitioners in South Africa, and also to address the issue of positions and career paths. At present the state of South African potential capacity to address unconventional gas exploration and associated issues is probably underappreciated by the public in general – we have a capable environmental sector and robust environmental legislation, and these need better communication.

- **Information brokerage**
  The commercial nature of hydrocarbon exploration world-wide has contributed to a paucity of data in the public sphere on many aspects of the process. It is vital and essential that data on all aspects of unconventional gas exploration is put into the public domain, unless it is genuinely commercially sensitive. The risks of reinventing the wheel and dealing with the effects of misinformation and speculation are also raised when data and information are withheld.

- **Networking and Service rendering**
  Unconventional gas exploration and exploitation, particularly if it is to be broad-based and a catalyst for long-term development, will be a highly cross-disciplinary process. There is a need to establish forums and mechanisms for various stakeholders to network and engage jointly on issues. Without this, there is potential for capture of the process by narrow interests and consequent risk that the full potential of the resource will not be realised. A good example will be the potential use of unconventional gas as a “transition fuel” from coal to mainly renewables – for this to happen, energy experts, funding and policy needs to be coordinated and combined as early and as efficiently as possible. Extraction of the resource, off-shoring of profits and externalisation of environmental disbenefits are real risks if coordinated policy is not adopted.

The project team is grateful to the participants at the workshop for their constructive participation and useful insights. We are thankful for the extraordinary contributions of the presenters during the course of the workshop that included Adv. Anil Singh, Department of Water and Sanitation; Sean Johnson, PASA; Zainab Mowzer, PASA; Xavier Schalkwyk, PASA; Prof Avner Vengosh, Duke University; Dr Shafick Adams, WRC; Saliem Fakir, WWF; and Prof Thomas Darrah, Ohio State University.

1 INTRODUCTION

1.1 Background

South Africa has potential to exploit natural gas[1] from unconventional gas resources associated with the Karoo Supergroup found in the Main Karoo basin and subsidiary sub-basins. The growing interest in unconventional gas worldwide has been spurred by recent experiences in the United States of America (USA) where production of shale gas increased ten-fold between 2006 and 2010 [1]. Typically, unconventional gas occurs in low-permeability reservoirs that consist of sandstone (tight sands), shales (fine-grained sedimentary rock rich in organic material), carbonates, and coal deposits [2]. Unconventional gas also occurs dissolved in groundwater, and in geopressured aquifers, saline brines, and gas hydrates [2].

Terminology: Conventional vs Unconventional resources [3]**.**

Conventional resources exist in discrete petroleum accumulations related to a localised geological structural feature and/or stratigraphic condition (typically with each accumulation bounded by a down-dip contact with an aquifer) that is significantly affected by hydrodynamic influences such as the buoyancy of petroleum in water.

Unconventional resources exist in hydrocarbon accumulations that are pervasive throughout a large area and that are generally not significantly affected by hydrodynamic influences (also called "continuous-type deposits"). Such accumulations [may] require specialised extraction technology [such as hydraulic fracturing].

Two types of unconventional gas resources are the current focus in South Africa discussed in this workshop summary. These are coal-bed methane (CBM) and shale gas. Although not defined as an unconventional resource, added to the discussion of this workshop summary is underground coal gasification (UCG). In the case of CBM and shale gas, natural thermogenic and/or biogenic processes have generated the resource – the gas occurs naturally in the fractures of the coal or shale. In the UCG process, the gas (termed synthesis gas or syngas) is synthetically generated with a thermo-chemical process by converting the solid coal to gas [4].

The interest in the exploration and production of unconventional gas is motivated by South Africa's energy crisis. The electricity supply system in South Africa has been constrained due to capacity shortage since 2008. There has been no increase in new baseload capacity since 1996 [5]. The capacity shortage in the short-term has been addressed by a change in system management practices and returning to service mothballed power stations but for the medium- to long-term, a supply increase and growth demand decrease is required. The

[1] Natural gas is a mixture of combustible and non-combustible gases (GEA, 2012). The main combustible component is methane (CH_4); other energy-relevant components can include butane, ethane, and propane in various proportions. Typical non-combustible components of natural gas include nitrogen (N), carbon dioxide (CO_2), and hydrogen sulphide (H_2S).

draft 2012 Energy Planning Report [6] sets the reserve margin at 19% for electricity generation capacity in South Africa. Insufficient reserve margins during unexpected shutdowns or during maintenance periods result in rolling blackouts[2] as experienced in 2008 when the reserve margin was about 10%.

The production of unconventional gas gives South Africa an opportunity to lower its import dependence and strengthen its energy security. [Natural] gas, being cleaner burning, offers a bridging-fuel towards these renewable energy sources, and a time-window of opportunity to wean society off coal [7]. In pursuing such an opportunity, one is mindful that natural gas is neither sustainable nor a green energy system.

1.2 About the workshop

Water management has emerged as a critical issue in the development of unconventional gas reservoirs. This is partly because there is limited understanding of the impact of unconventional gas exploration and production on South Africa's water resources. The WRC in 2012 published a report (KV294/11) to summarise the current knowledge on hydraulic fracturing in the public domain as well as give a review of South Africa’s regional geology and geohydrology [8]. The report was limited to discuss the issue of hydraulic fracturing of shale gas resources.

In 2014, the WRC awarded a project to a consortium of researchers from SLR Consulting (South Africa) (Pty) Ltd (SLR), the UWC, and Prime Africa Consultants entitled “*Unconventional Gas Exploration and Production and its Impact on South Africa’s Water Resources*”. A subsequent consultancy was awarded to Dr Hans Beekman and SLR to develop a “*Water Science Plan for Unconventional Gas Development*”. Both of these projects require planning workshops to inform the research aims and work plan.

On 3-4 July 2014, a two-day workshop was held under the auspices of the WRC to inform the WRC projects. The agenda for the workshop is given in **Appendix 1**. The purpose of the workshop was to bring together various stakeholders to share knowledge and learn from each other about risks and opportunities that are associated with unconventional gas exploration and production and to identify measures on how mitigate the identified challenges as the country explores unconventional gas opportunities. Participants to the workshop represented different institutions and included the Department of Water Affairs and Sanitation, agencies of government, researchers involved in unconventional gas projects, science councils and postgraduate students. The participants list is given in **Appendix 2**.

The workshop benefited from a number of guest speakers. The speakers came from the Department of Water and Sanitation, Duke University, Ohio State University, WRC, PASA and the hosts SLR and the UWC. As presentations progressed, participants asked for

[2] The generation capacity reserve margin was 25% in 2002. In 2006, the reserve margin was 16% and in 2008 it was only 8% to 10% of peak demand. During the period 1 November 2007 to 31 January 2008, load shedding occurred due mainly to generating capacity and energy constraints experienced by Eskom. Analysis revealed that a large amount of generating capacity was not available due to a high level of unplanned outages of the generating plants [13].

clarifications, shared their concerns and expectations regarding gas exploration and production in South Africa based on their understanding in of groundwater-related impacts in the mining and energy sectors drawing their discussions from observations and experiences from the USA.

1.3 Acknowledgements

The project team is grateful to the participants at the workshop for their constructive participation and useful insights. We are thankful for the extraordinary contributions of the presenters during the course of the workshop that included Adv. Anil Singh, Department of Water and Sanitation; Sean Johnson, PASA; Zainab Mowzer, PASA; Xavier Schalkwyk, PASA; Prof Avner Vengosh, Duke University; Dr Shafick Adams, WRC; Saliem Fakir, WWF; and Prof Thomas Darrah, Ohio State University.

The following MSc candidates acted as rapporteurs: Imelda Haines; Ally Lebese; Tebogo Madlala; and Siphumelelo Mbali.

Ms Mandy Naidoo is thanked for their logistical arrangements during the course of the workshop. The Institute for Water Studies at the UWC hosted the workshop. The workshop was conducted under the auspices of the WRC.

1.4 This report

This report presents a summary of the proceedings of the workshop presentations and deliberations.

2 OPENING SESSION

2.1 Opening of the workshop

Professor Michael Davies-Coleman
Dean of Natural Sciences, UWC

The participants to the workshop were welcomed on behalf of the UWC by Prof Micheal Davies-Coleman, Dean of Science. He welcomed all the esteemed guests in attendance and noted the importance of the workshop in dealing with the issue of shale gas development. He said that water resources in the Karoo are scarce and there are concerns with the potential environmental and socio-economic impacts of hydraulic fracturing. Some have dubbed hydraulic fracturing a dirty business and consider the exploitation of shale gas a potential national disaster. Davies-Coleman noted that the hydraulic fracturing process is a new to South Africa and not all the facts known, including the potential groundwater impacts, best hydraulic fracturing practices to follow and the sub-surface geology of the Karoo.

Davies-Coleman noted that various professionals and experts gathered at the workshop, each representing specific disciplines and holding information, which could inform the hydraulic fracturing process. The meeting provides a platform for information exchange. He welcomed Professors Vengosh and Darrah from the USA to South Africa and the UWC in particular. Lessons can be learnt from the years of hydraulic fracturing in the USA. He concluded his welcome by wishing all in attendance a productive workshop.

2.2 Introducing the workshop

Dr Kevin Pietersen
Director, SLR (South Africa) (Pty) Ltd
and
Dr Thokozani Kanyerere
Senior Lecturer, Department of Earth Sciences, UWC

Dr Kevin Pietersen introduced the workshop programme, procedures and products. He thanked the guest speakers and those responsible for arranging the workshop. Pietersen acknowledged the hosts of the workshop, the Institute of Water Studies at UWC. He introduced the research consortium: SLR, UWC and Prime Africa Consultants. The response to the workshop was overwhelming and he thanked the Department of Water and Sanitation for their support. He asked for a round of introductions.

Pietersen said that the workshop purpose was to learn and share information about the water-related impacts of unconventional gas production, inform the WRC study in terms of meeting research aims and work plan, align with national priorities, avoid duplication and inform regulatory practice. He said that it seems everyone is a shale gas expert in South Africa - which is not the case – in fact, we need to go through a process of learning.

Therefore, the workshop is about sharing of knowledge and learning best practices in other jurisdictions (in this case the USA). He mentioned that the outcomes of the workshop would be captured in a summary report. He concluded with workshop announcements.

2.3 Regulatory perspectives for hydraulic fracturing and other types of unconventional gas [production]

Adv. Anil Singh
Deputy Director-General Water Regulation, Department of Water and Sanitation

Adv. Anil Singh, Deputy Director-General Water Regulation, provided regulatory perspectives for hydraulic fracturing and other types of unconventional gas production. The National Water Act[3] requires that the National Government, acting through the Minister of Water Affairs, ensures that water is 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[4]. Therefore, all reasonable measures must be taken to prevent pollution occurring, continuing or recurring[5]. Singh emphasised that the regulatory target for unconventional gas [production] is **prevention of pollution and nothing else**.

Singh noted that the National Water Act allows the Minister to regulate activities having a detrimental impact on water resources by declaring them controlled **activities[6]**. Four activities[7] are listed in the National Water Act as controlled activities. Singh further noted that provision is made for the Minister to declare other controlled activities as the need arises but in these cases, public consultation is required. Following the identification or declaration of a controlled activity, an authorisation for that particular category of activity is required under the National Water Act. In 2013, the Minister of Water Affairs announced her intention to declare the production of unconventional oil and gas resources a controlled activity, in a notice in the government gazette. Singh recalled that the intention to declare hydraulic fracturing as a controlled activity was well received, even garnering a memorandum of congratulations (as opposed to a demand, more usual practice in South Africa) from a non-governmental organisation.

Singh identified water scarcity as a pressing environmental issue - most catchment areas identified for unconventional gas production are already water-stressed and large quantities of water are expected to be required for process. In addition, there are many unknowns and

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[3] Act 36 of 1998.

[4] Section 3(1) of the National Water Act

[5] Sections 19 & 20 of the National Water Act

[6] Sections 37 & 38 of the National Water Act

[7] Irrigation using waste or water containing waste from certain sources, modification of atmospheric precipitation, altering the flow regime of a water resource as a result of power generation, and aquifer recharge using waste or water containing waste - are identified in the Act as controlled activities.

uncertainties related to the deep Karoo geology/hydrogeology, which may complicate matters, including the migration of gas or fracture fluids. Possible negative impacts on existing and future water users include the loss of existing aquifers and boreholes, contamination of existing sources, degradation of drinking water quality, as well as surface spills and pollution of water sources. The fate of wastewater produced by the process was also identified as a concern, together with the possible scale of operations over large areas. Effective monitoring and enforcement would be vital.

Singh indicated that Department of Water Affairs and Sanitation has established its own internal task team in collaboration with the WRC, combining different units to address unconventional gas production. The Department also participates in the Inter-departmental Task Team chaired by the Department of Mineral Resources to ensure co-ordination between departments and integration of regulations. The Department recognises that existing water users, particularly communities and farmers dependent on underground water as their only water source, must be protected. The Department of Water Affairs and Sanitation also intends to implement special measures to reduce the risk of pollution of water resources. The Department recognises that it must be part of total process from exploration to exploitation and remediation, and that it should ensure that detailed, reliable baseline information is established before production activities begin. The Department is also particularly interested in the possible existence of deep-seated aquifers- these can be a valuable water source and should also be protected.

Singh concluded by noting that unconventional gas production should be seen as both a challenge and an opportunity, and read the proposed declaration to list unconventional gas production as a controlled activity.

3 TECHNICAL PRESENTATIONS

3.1 Unconventional gas resources – An update of onshore activities

Sean Johnson
Manager Frontier Geology at PASA

Sean Johnson, Manager Frontier Geology at PASA, provided an overview of current activities taking place in South Africa's upstream onshore petroleum sector. He was of the view that it is a very exciting time for South Africa, with significant interest in onshore unconventional energy resources, and indeed, he is of the opinion that South Africa's energy future for the next half a century will be mapped out within the next 5 to 10 years. Johnson explained that PASA is the state-owned entity that is responsible for promoting and regulating oil and gas exploration and production in South Africa, as well as for archiving all related data. The Mineral and Petroleum Resources Development Act of 2002 mandates the role of the PASA. Through this act, PASA are instructed to develop, facilitate and regulate the growth of the upstream oil & gas industry in South Africa. PASAs vision is to have a viable, sustainable and responsible upstream industry in our country.

Johnson mentioned that onshore hydrocarbon exploration in South Africa is still in its infancy. Exploration activities are focused on the Karoo Basin and associated sub-basins. The Karoo Basin was explored in the 1960s and 1970s by the national oil company of the time, SOEKOR , but due to a perceived poor potential for large conventional oil plays at that time exploration was abandoned. The new wave of exploration in the Karoo is driven by interest in unconventional hydrocarbons, principally biogenic gas, CBM and shale gas. There is an exceptional amount of activity in onshore unconventional gas and a healthy spread of operators as demonstrated by the current licenses and permits issued by PASA.

Terminology: Biogenic gas, CBM and shale gas [1].

Biogenic gas: gas formed by the transformation of organic matter into biogenic methane by biochemical action of microorganisms.

CBM: gas trapped in coal seams, adsorbed in the solid matrix of the coal.

Shale gas: gas trapped in fine-grained sedimentary rock called shale which requires 'hydraulic fracturing' technology to be produced.

Johnson discussed current activities in detail on a local scale. He mentioned that the commercial production of **biogenic methane**, discovered during gold exploration, is about to become a reality with a production right awarded to Molopo Energy[8]. The focus is in the Virginia and Evander Goldfields. In the Virginia area, gas flow continues from 11 pilot

[8] Molopo Energy has reached an agreement with a South African-based party to divest its interests in its South African biogenic gas assets, which include a Production Right granted in 2012 [14].

production wells at approximately 1.2 million cubic feet per day. Molopo Energy was awarded the first onshore natural gas Production Right on 21 September 2012 and the company has a gas sales agreement with Novo Energy for initial volume of 0.6 Terrajoules per day (TJ/d), expandable to 8 TJ/d for compressed natural gas use in vehicles. The project, based on a gas-in-place (GIP) reserve of 11.5 billion cubic feet (0.01 Tcf). Microbes in the underlying Archean Witwatersrand basement are producing the gas – hence the term biogenic gas. While this gas has long been flared as a mining hazard in South Africa's gold mines, it may in fact prove to be a [renewable] hydrocarbon energy source for South Africa in years to come.

Terminology: Reserves, Contingent Resources, Prospective Resources and GIP [9]**.**

The **Petroleum Resource Management System** (PRMS) is the oil and gas industry's global standard for resource classification and reporting. A project is classified according to its maturity or status (broadly corresponding to its chance of commerciality) using three main classes, Reserves, Contingent Resources, and Prospective Resources.

Prospective Resources are those quantities of petroleum estimated, as of a given date, to be potentially recoverable from undiscovered accumulations by application of future projects.

Contingent Resources are those quantities of petroleum estimated, as of a given date, to be potentially recoverable from known accumulations but the applied project(s) are not yet considered mature enough for commercial development due to one or more contingencies.

Reserves are those quantities of petroleum anticipated to be commercially recoverable by application of development projects to known accumulations from a given date forward under defined conditions

GIP is total quantity of gas that is estimated to exist originally in naturally occurring reservoirs

CBM exploration in South Africa is concentrated around the coal bearing basins in the north-eastern parts of the country. The majority of players remain mostly smaller local companies although they are now starting to attract partnerships with international companies with experience in exploration and production of CBM. In the Waterberg Coalfield of the Lephalale Basin Anglo Operations have drilled over 80 core holes and continue with a single 5 spot production test. Anglo Operations have reported technical recoverable reserves of the order of 1 Trillion Cubic Feet (Tcf) from their exploration area. Other operators have also carried out drilling in terms of their work programs namely Umbono Capital and Badimo Gas (JV with Kinetiko Energy). PASA technical evaluation of the potential resource represented by CBM has made good progress in the last year. PASA initial studies indicate a conservative estimate of around 10 Tcf GIP for all the CBM basins. Johnson noted that the burgeoning CBM industry faces challenges of economics and infrastructure for the industry to be viable.

The central and southern Main Karoo Basin has potential for **shale gas**. The US Energy and Information Administration current estimate of technically recoverable shale gas resources for South Africa is 390 Tcf. PASA own technical team's best estimate of the resource is 33Tcf (Deterministic) and a probabilistic estimate of 49 Tcf (P50). Johnson stressed that until exploration wells are drilled, the resource remains unknown and unproven.

> **Terminology: Proved reserves** [9]
>
> An incremental category of estimated recoverable volumes associated with a defined degree of uncertainty. Proved Reserves are those quantities of petroleum which, by analysis of geoscience and engineering data, can be estimated with reasonable certainty to be commercially recoverable, from a given date forward, from known reservoirs and under defined economic conditions, operating methods, and government regulations. If deterministic methods are used, the term reasonable certainty is intended to express a high degree of confidence that the quantities will be recovered. If probabilistic methods are used, there should be at least a 90% probability that the quantities actually recovered will equal or exceed the estimate.

Johnson handed over to Zainab Mowzer and Xavier Schalkwyk to continue part two of the presentation at a more technical level.

Zainab Mowzer
and
Zavier Schalkwyk
Geologists, PASA

Mowzer explained that shale gas plays differ from conventional plays in that the resource is dispersed over a large area, but may be recovered at commercially viable rates through the application of hydraulic fracturing and directional drilling. The challenge is to delineate the “sweet spot” where the associated gas trapped in the shale could be produced commercially. She presented a stratigraphic column showing the Formations within the Cape and Karoo Supergroup - their varying thicknesses and lithological descriptions. Aspects of her presentation are further discussed in section 4.3.

Schalkwyk provided an overview of CBM activities. CBM is a gas formed as part of the geological process of coal generation, and is contained in varying quantities within all coal. The gas is trapped in the coal in tiny fractures, known as cleats and in pores in the coal. CBM is extracted through wells, typically 12-20 centimetres wide, drilled into the coal seams. Water is pumped out of the coal seams in order to reduce the water pressure and release gas from the coal. The gas is then separated from the water at surface.

Schalkwyk noted that the Ermelo coalfield (located about 200 km from Johannesburg) is noted for its gassy coal. The presence of methane has resulted in underground explosions in the Ermelo Coal Mine near Amersfoort in the past. Resource estimates for this area range from best estimate GIP resource of 3 Tcf and a high estimate of 15 Tcf. Badimo Gas in partnership with Kinetiko Energy operates in this area with two exploration rights being granted to the JV and has thus far been successful in drilling 8 single spot production test wells.

The Mopane coal field due to the widespread presence and depth of coal deposits is considered encouraging for the occurrence and preservation of CBM. Shalkwyk indicated that Umbono Capital in partnership with Sunbird Energy were the leading explorers in the region. The JV reported a best estimate GIP of 1.90 Tcf with a high estimate of 13.66 Tcf.

3.2 Unconventional Gas and Water Research

Dr Shafick Adams
Research Manager, WRC

Dr Shafick Adams provided an overview of water research activities related to unconventional gas. Adams provided an overview of the WRC: its value proposition, vision and mandate. Adams noted that central to the WRC strategy is the knowledge tree, which included goals related to transformation and redress, sustainable development solutions, and informing policy and decision-making, amongst others.

Adams noted that South Africa is a water-scarce country, and that there are a number of global challenges such as climate change and variability, and groundwater pollution and depletion, that must be addressed. In South Africa, competing water priorities include service delivery protests (due to lack of water services or breakdown of services), expansion of [water] services, need for large-scale [infrastructure] development, pressures for new resource opportunities, and infrastructure challenges. Besides resource constraints (both quantity and quality), our water challenges include a capacity and capability crisis. There is a capacity shortfall in human resources (both from a technological and management perspective), and a pressing need for technological innovations and knowledge in dealing with water matters. The challenge is to move to a scenario of successful water-driven innovations as opposed to firefighting, which seems to be the norm currently, Adams noted.

Available surface water resources and water demand is now in balance – there is no fat in the system[9]. Adams stressed the importance of data and highlighted the decline in gauge networks over time, sharing statistics showing the deterioration in both rainfall and flow data gauge networks. Current actual water use is a large unknown in water resource assessment. The lack of data and data collection is a serious concern and has repercussions for the future.

> "In hydrologic research, the insight and knowledge derived from innumerable scientific efforts are informed by the availability of measurements, while gaps in measurements constrain scientific exploration" (Loescher et al, 2007).
>
> "Modelling without data for validation is fantasy and a self-congratulatory exercise. Therefore we need free, good and readily available DATA to realistically plan our Water Resource Future" (Pegram, 2012).

[9] In many parts of the country, we are fast approaching the point at which all of our easily accessible surface freshwater resources are fully utilised.

In balancing water supply and demand, Adams highlighted that groundwater can no longer be considered a mysterious phenomenon resource, and can be described using established scientific laws. In most of the reconciliation strategies[10], groundwater development is listed as the second most important strategy to reconcile water demand (after water conservation and demand management). Adams listed the peculiarities of groundwater, which include high cost and complexity of assessment, and the dispersed nature of the resource resulting in high monitoring costs, amongst others. Adams noted the importance of scale and the need to move to larger-scale interpretations of the groundwater resource.

A note on scale [10]

In thematic cartography, the following definitions of scales are commonly used:

Large scale – 1 : 10 000 to 1 : 100 000
Medium scale – 1 : 200 000 to 1 : 500 000
small scale - 1 : 1 million to 1 : 10 million

Adams noted that over-utilisation and the poor management of the groundwater resource is often due to poor or non-existent management plans and governance provisions. The WRC has completed a number of assessments to support management and governance of groundwater, Adams said.

The WRC has a number of mechanisms to stimulate debate, which includes WRC dialogues, seminars and talks, symposia, and media and Ministerial briefs.

The WRC has recently completed a review that identifies the main hazards and concerns related to hydraulic fracturing in the Karoo Basin. These include earthquakes, integrity of well casings and groundwater contamination, radioactivity, transportation of equipment, materials and wastes to and from the site, surface spillages of chemicals and waste waters; large volumes of water for [hydraulic fracturing], as well as emissions to air and noise. Adams noted that there are currently too many uncertainties associated with unconventional gas production. Adams also highlighted the challenges such as real or perceived weak implementation of policy/regulations, and low capacity in public organisations to regulate and manage unconventional gas exploration and production.

Adams said that the WRC as South Africa's national water R&D agency has the responsibility of ensuring that the decisions made around unconventional gas exploration and [production] in South Africa are informed by science. The WRC is keen to use the opportunity to help deliver a global best practice case study for shale gas exploration and [production] if indeed this goes ahead. Adams noted that the WRC has invested significantly in understanding the groundwater hydrology of the Karoo – spanning several decades and consisting of more than 15 projects. There is adequate understanding of the occurrence and behaviour of the exploitable groundwater within the top 300m of the earth's crust. There is limited understanding of the deeper systems and hence many gaps in our hydrogeological

[10] The Department of Water Affairs has embarked on a nationwide programme to develop water-reconciliation strategies for all towns across the country.

understanding of the whole system remain. Adams also emphasised the various completed, on-going (current) and new WRC projects related to unconventional gas exploration and [production].

Completed project
State of the Art: Fracking for shale gas exploration in South Africa and the impact on water resources. WRC Report KV 294/11.

Ongoing Projects
Characterising the chemical composition of deep and shallow groundwater in an area considered for shale-gas exploration in the Main Karoo Basin. Groundwater Africa. Start: 01/04/2013 - End 31/05/2015.

Development of an interactive vulnerability map and preliminary screening level monitoring protocol to assess the potential environmental impact of hydraulic fracturing. University of the Frees State. Start: 01/05/2012 – End: 30/09/2014.

New Projects (all starting April 2014)
Integrating structural geology, geophysics and hydrochemistry to identify and investigate geological features in the Karoo which may provide hydraulic connectivity between deeply-sourced contaminants and shallow groundwater. Nelson Mandela Metropolitan University.

Collecting high quality baseline and ongoing monitoring data in the Karoo, and taking the opportunity to train rural disadvantaged women and youth as accredited Ground Water Monitoring Technicians to enable them to offer an independent service to farmers. Nelson Mandela Metropolitan University.

Unconventional Gas Exploration and Mining and its Impact on South Africa's Water Resources. Directed call. SLR Consulting.
Projects "in the pipeline"
Assessment of deep hydrogeology
Water Science Plan
COHORT – Unconventional Gas Science Plan
Submissions received during current round of call for proposals.

Adams concluded his presentation by outlining activities for knowledge sharing through national and international dialogues.

3.3 A Critical Review of the risks to water resources from unconventional shale gas development and hydraulic fracturing in the USA

Prof Avner Vengosh
Professor of Geochemistry and Water Quality, Chair of the Water and Air Resources program, Nicholas School of Environment, Duke University

Dr Ricky Murray welcomed Professor Avner Vengosh from Duke University as a renowned water expert dealing with unconventional gas exploration and production. Ricky Murray noted the multiple scientific publications that have been published by Avner Vengosh and his co-workers. Prof Avner Vengosh gave a presentation entitled “A critical review of the risks to water resources from unconventional shale gas development and hydraulic fracturing in the USA”. Vengosh started by highlighting the major risks for water contamination associated with shale gas development and hydraulic fracturing. This included water exploitation in water-scarce areas leading to long-term impacts on over-exploited aquifers, groundwater contamination due to stray-gas contamination or flow of saline water and hydraulic fracturing fluids, surface water contamination due to spills and leaks, disposal of wastewater that can lead to accumulation of toxic residues, and radiation at impacted sites. His presentation is further discussed in section 4.2.

3.4 Background on the WRC project unconventional gas exploration and production and its impact on South Africa’s water resources

Dr Kevin Pietersen
Director, SLR (South Africa) (Pty) Ltd

Dr Kevin Pietersen provided background information on the project “Unconventional gas exploration and production and its impact on South Africa’s water resources”. He acknowledged Professor Gerrit Van Tonder who passed away suddenly a few months back. Hiss passing was unexpected and sad.

Pietersen said that South Africa has a carbon intensive economy. The country relies on coal and imported crude oil for most of its energy demand. Production of energy from renewable sources is almost non-existent. Coal account for 75% of fossil fuel demand and 91% of electricity generation [11]. The reliance on coal and other fossil fuels makes South Africa a global emitter of greenhouse gases (GHG) into the atmosphere. South Africa’s GHG emissions rank it in the world’s top 20 global emitters and account for 42% of Africa’s GHG releases [12]. The country has voluntarily committed to reduce CO_2 emissions by 34% in 2020 and by 42% in 2025, on condition that the requisite technological and financial support is provided from the developed world.

Pietersen noted that the expected numbers of unconventional gas projects in South Africa will grow as the current projects become proven and commercial during the coming years. At this stage, most of the unconventional gas resources are prospective. As things stand, South Africa has zero reserves. Also large in place in-place estimates do not necessarily imply large-scale production is forthcoming[11] because technical innovations and cost reductions are critical to commercial viability [of gas resources] [13].

An overview of the different unconventional gas resources was provided and the water management implications.

The project highlighted the aims of the project:

1. Update the WRC state-of-the-art report (KV294/11) to include all unconventional gas sources and other available reports focusing on among others, hydrogeology of areas where unconventional gas [production] is being considered, water use, contamination and remediation.
2. Do a gap (and barrier) analysis of the technical, policy and regulatory requirements related to unconventional gas [production].
3. Perform a risk-based assessment of selected aquifers, recharge areas and surface water bodies to enable adequate protection of these systems.
4. Develop a water resource early warning monitoring system that could inform regulatory policies, strategies and responses
5. Develop best practice guidelines and regulatory responses based on a variety of approved and workshopped scenarios.
6. Develop the best practice framework in a manner that accounts for the technical and socio-economic considerations.

3.5 How do we grapple with the economics of shale-gas?

Saliem Fakier
Head of the Living Planet Unit, WWF

Saliem Fakir provided provision results on research conducted to understand the economics of shale gas development.

Links to articles:

Frackonomics: game-changer or just unfounded hype?
Frackonomics II – What can we learn from the US experience?

[11] As an example, Norway's shale gas assessment dropped from 83Ttcf in 2011 to zero because of the disappointing results obtained from three Alum Shale wells drilled by Shell Oil Company in 2011 (U.S. Energy Information Administration, 2013).

3.6 The Source and Migration of Natural Gas in Shallow Aquifers: Insights Provided by the Integration of Noble Gas and Hydrocarbon Isotopes

Professor Thomas Darrah
Assistant Professor, School of Earth Sciences, Ohio State University

Abstract provided:

Horizontal drilling and hydraulic fracturing have enhanced energy production but raised concerns over drinking-water contamination and other potential health risks. Specifically, the presence and environmental implications of elevated methane and aliphatic hydrocarbons (ethane, propane, etc.) in drinking water remain highly controversial and require a distinction between naturally occurring and anthropogenic sources. Previous efforts to resolve these questions have generally focused on identification of the genetic fingerprint of natural gas using the molecular (e.g., C_2H_6/CH_4) and stable isotopic (e.g., $\delta^{13}C-CH_4$, $\delta^{2}H-CH_4$, or $\Delta^{13}C = (\delta^{13}C-CH_4 - \delta^{13}C-C_2H_6)$) compositions of hydrocarbon gases. In many cases, these techniques can resolve thermogenic and biogenic contributions of natural gas and further differentiate between multiple thermogenic sources (e.g., Marcellus production gases vs. intermediate Upper Devonian gas pockets). However, these parameters are subject to alteration by microbial activity and oxidation and may not always uniquely identify the source or mechanism of fluid migration. Moreover, they do not necessarily identify the transport mechanisms by which material would migrate into shallow aquifers. In contrast to hydrocarbon gases, noble gases provide a suite of elemental and isotopic tracers that are unaffected by chemical reactions or microbial activity. Here we develop an integrated noble gas and hydrocarbon isotope analysis to evaluate if elevated levels of natural gas in drinking-water aquifers near gas wells are derived from natural or anthropogenic sources and to determine the mechanism by which stray-gas contamination occurs.

3.7 Background on the WRC project water science plan for unconventional gas exploration and production

Dr Kevin Pietersen
Director, SLR (South Africa) (Pty) Ltd

DR Kevin Pietersen provided background information to the project water science plan for unconventional gas exploration and production. The intent is to provide a platform for South Africa in developing its potential unconventional gas resources in a sustainable manner. He discussed the aims:

1. Provide a platform for South Africa in developing its potential unconventional gas resources

2. Provide a record of the state-of-the-art and the potential impacts of unconventional gas production and how research should address these issues. This will include local and international best practices and research
3. Develop a short-, medium, and long term science and implementation plan that will be congruent with the unconventional gas exploration and production scenarios/plans

Pietersen show examples of science plans and that development of the plan need to include different stakeholder inputs. He emphasised that plan need to respond to societal questions and listed examples from the USGS. What are our “known unknowns” or the “unknown known”? He highlighted the importance of baseline data, data collection and curation of the data. He noted the Canadian Council of Academies, which stated, “*Rules to govern the development of shale gas must be based on appropriate science-driven, outcome-based regulations with strong performance monitoring, inspection, and enforcement”.*

4 WORKSHOP DELIBERATIONS AND OUTCOMES

4.1 Introduction

The workshop had a number of facilitated discussions to deliberate on matters related to the technical presentations. The sessions included deliberations on:

- USA experience
- Plausible scenarios for groundwater contamination pathways
- SMART Regulation
- Fundamental science questions
- Science goals
- Implementation

During the course of the workshop, some of the sessions were combined for ease of discussion. Below follows a summary of the deliberations throughout the workshop:

4.2 USA experience

In his presentation, Prof Vengosh explained the hydraulic fracturing process, developed to fracture and increase the permeability of target formations. Hydraulic fracturing entails the injection of millions of litres of water, proppants and chemicals under high pressure through perforated casing. The build-up in pressure causes existing fractures in the shale formation to open and new fractures to form. The proppants fill the fractures to keep them from closing. This allows the natural gas to flow into the well for extraction. He noted the different shale gas basins in the USA and explained that the recent fall in the gas price has meant that the current focus is on oil production from oil shale plays rather than shale gas production.

Vengosh noted the following environmental risks associated with shale gas drilling and hydraulic fracturing: methane contamination of drinking water wells, fugitive emissions of methane to the atmosphere, water use (7-15 million litres per well), contamination by fracturing fluid (transportation, spills), air pollution associated with different stages of gas production, disposal of fracturing fluids/produced water, health implications, and impacts on quality of life (traffic, noise). The environmental risk posed by shale gas development has resulted in a vocal anti-fracking lobby.

Vengosh focussed his presentation on the water life cycle of the hydraulic fracturing process. During the upstream stage, acquisition of water is the issue. Vengosh provided figures of water use in the different shale gas basins in the USA, with an average use of 15 000 m^3 per well. Proppants and chemicals are added to the water. The number, type, and concentration of chemicals added to the water are determined by the geological characteristics of each site and the chemical characteristics of the water used. Approximately 10 - 40% of the hydraulic fracturing fluid flows back to the surface. The flowback water salinity increases with time as an increasing proportion of the formation water mixes with the injection fluids. The produced water has a high salinity that reflects the salinity of the formation water. Vengosh described the composition of the shale wastewater in the Marcellus Basin in the USA as follows: (1) High Salinity (Marcellus brine has a salinity of about 250 000 mg/L, nearly 10x the salinity of seawater); (2) Bromide in the water can enhance the formation of carcinogenic disinfection by-products if water is chlorinated for potable use; (3) High concentrations of toxic elements such as barium, arsenic, selenium and lead; (4) High concentrations of naturally occurring radioactive materials (NORMs) at up to 1000x the drinking water standard; (5) High concentrations of organic matter (including man-made toxic components); and (6) Hydrocarbon residuals.

Vengosh noted the options for treatment of the wastewater including treatment at a municipal waste treatment facility, treatment at a brine treatment facility, deep well injection, and re-use/recycling of the produced water. All these options have challenges and issues. Treatment of the wastewater at municipal treatment facilities has resulted in inadequate treatment (for example the inability to deal with barium, strontium and bromides. Brine treatment facilities result in inadequate treatment of halogens and high radioactivity in the residual solids. Deep well injection has potential seismicity challenges. The extent to which recycling or reuse of water can take place is determined by the water chemistry. Vengosh showed an example where wastewater from shale gas development was used to de-ice roads. He does not recommend this disposal method!

The occurrence of elevated levels of methane in shallow drinking water wells poses a potential flammability. There is currently much debate over the issue of shale gas wells contaminating drinking water wells. Whilst methane is ubiquitous in many groundwaters, some research has shown that higher levels of methane are correlated with closer proximity to gas wells. The most likely pathway for stray gas contamination can result from leaking of natural gas along the well annulus from shallower formations and/or the target formation through poorly constructed or failing well casings.

Vengosh noted that no evidence for contamination of active wells by chemicals derived from flowback/produced waters has been found. Fracturing fluids and related waters are typically saline, and the most reliable method for tracing fracturing contamination would be monitoring water salinity. There is no correlation between salinity and methane or distance to shale gas wells. There is no geographical proximity to shale gas sites (unlike methane occurrence)

In terms of surface water contamination, the following result: contamination of streams and rivers in areas of spills, contamination streams and rivers in areas of disposal of wastewater from shale gas development, accumulation of toxic elements and radioactivity in areas of spills, and disposal and formation of carcinogenic disinfection-by-products in streams and drinking water utilities because of high halogens in wastewater (bromide, iodine). Vengosh noted that frequency of spills/violations appear to coincide with the intensity of shale gas drilling in Pennsylvania. Vengosh advocated that a zero discharge policy is required

Vengosh noted that hydraulic fracturing typically requires 15 000 m^3 per well, although in some areas this is as high as 50 000 m^3. Although the absolute volume is negligible relative to the water required for cooling coal plants, in arid areas it may require additional water allocation. Many of the worldwide shale plays are located in arid basins. Possible solutions include re-using water by blending with acid mine drainage.

Vengosh concluded the following: In spite of the debate, there is evidence for stray gas contamination in a subset of shallow wells near (<1 km) shale gas sites in northeastern Pennsylvania; No indication of groundwater salinization induced from stray gas leaking; Evidence for surface water contamination downstream from shale gas wastewater disposal site in western Pennsylvania; Accumulation of radioactivity in stream sediments in areas of disposal/spills; and Marginal water can substitute freshwater for shale gas development.

4.3 Plausible scenarios for groundwater contamination pathways

In her presentation, Zainab Mowzer explained that in the Karoo basin, the Whitehill Formation is considered the most prospective shale gas target. Stratigraphically, it is located close to the base of Permian Ecca Group. The Whitehill Formation satisfies all the basic conditions for a commercial gas shale play, including a high total organic content and gas window maturity. Its mineralogy also suggests that it will respond well to hydraulic fracturing, and it is sufficiently thick and extends over a large enough area for PASA to be confident that a sweet spot(s) exist. Mowzer noted that other neighbouring shales such as the Prince Albert Formation are of commercial interest, particularly if the Prince Albert Formation is exploited as an extension of the Whitehill play.

Mowzer emphasised that exploration for shale gas in South Africa has not yet begun, and so there remains a significant degree of geological risk and uncertainty in the play. In terms of uncertainty, the data which [PASA] have is from the analysis of just a handful of weathered cores recovered from wells some 40 years ago. Therefore [PASA] have poor constraints on the reservoir properties of the shales of interest at depth, and indeed, no modern well log data for the intervals of interest. Obviously, [PASA] have no gas flow rates from any wells either, and no direct measurements of gas content at depth.

In terms of risk, two geological factors are unique to the Karoo as noted by Mowzer: (1) The first is the thermal tectonic effect of the Cape Fold Belt along the southern margin of the basin, which has resulted in maturities of up to 4 % Ro, which may have had an adverse effect on the gas content of our shales; (2) Further north, the Karoo sills of the dolerite suite are known to have been emplaced into the shale, possibly resulting in the catastrophic degassing of the shale in places, and the compartmentalisation of the shale reservoir

Mowzer compared models for the evolution of the Cape and Karoo Basins in the Upper crust (<15km): (1) Halbich at al. (1993); (2) Chevallier et al (2004); (3) Johnson et al (2006); and (4) Lindeque et al (2007).

Mowzer indicated that the older models numbered 1 to 3 displays the interconnected folding of both the Cape and Karoo Supergroups, significant thickening of the Karoo Supergroup before the Cape Fold Belt, interpreted as a foredeep Basin and a root below the Cape Fold Belt. The features mentioned are not observed in the Lindeque et al (2007) model.

Mowzer showed seismic data acquired by SOEKOR in the southern Main Karoo Basin from 1966 to 1971 in the Karoo Basin. The SOEKOR database constitutes ~13,000 km of 2D reflection seismic data that is predominantly single fold. The quality of the data is spatially variable and compromised in places by the presence of Karoo dolerite intrusions (~183 Ma). Mapped reflectors included the top of the magnetic basement (Proterozoic Namaqua-Natal Belt), the tops of the Table Mountain and Bokkeveld Groups, and the probable top of the Dwyka Group - a reflector termed "Old Faithful" by Fatti (1970) due to its regional continuity. The stratigraphic correlation of "Old Faithful" has been debated (e.g. Fatti, 1970; Lindeque et al., 2011), and may represent either the top of the Dwyka Group or the top of the directly overlying Whitehill and Prince Albert formations of the lower Ecca Group - the most prospective gas shales in the basin. In areas of Karoo dolerite outcrop, high angle, cross-cutting reflectors are interpreted as dolerite intrusives. Along the southern margin of the basin, a number of folds and southward-dipping thrust faults are interpreted. The lower Ecca Group's gas shales deepen regionally from north to south. Sub-surface dolerite intrusions are visible in the Beaufort Group, but the extent of their intrusion into the Ecca shale is unresolved. Southward-dipping thrust faults in the Karoo and Cape strata along the basin's southern margin are consistent with Lindeque et al.'s (2011) model of thin-skinned tectonic stacking accompanying southward subduction during the Cape Orogeny.

In his presentation, Prof Vengosh highlighted pathways for water contamination. The participants noted that the newness of unconventional gas (especially shale gas) development in South Africa has resulted in many unknowns. Is there shale gas? What will be the extent of the resource, if present? What will be the water-use throughout the life cycle of shale gas and other unconventional gas production? Water quality implications, and so forth? The implications of the dolerite intrusions to shale gas development?

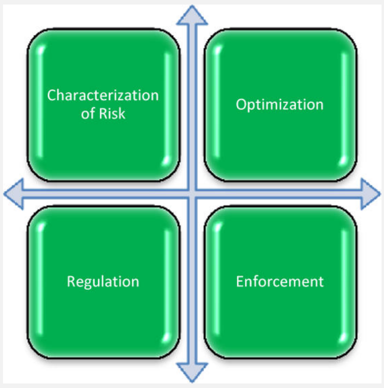
The participants noted the importance of baseline monitoring. The Karoo geology and geohydrology must be comprehensively characterized. For example will buffer zones be required to safeguard against possible contaminant migration. It was noted by Darrah that it was highly likely that methane is ubiquitous in the natural springs in the Karoo. Concern was expressed that the monitoring boreholes will become contaminant pathways.

4.4 SMART regulation

This uncertainty associated with shale gas development is causing delays in the decision-making and producing the regulations needed for a responsible development of unconventional gas in South Africa. It was noted that the focus of the technical regulations was on managing the entire water value chain of unconventional gas production. An additional emphasis, however, should focus on developing regulatory responses to situations that may arise due to poor implementation of regulations throughout the water value chain.

SMART Regulation Framework [14]

Konschnik (2014) developed a framework for evaluating and shaping shale gas governance strategies. CO/RE – characterization of risk, optimization of mitigation strategies, regulation, and enforcement combines adaptive management and traditional regulatory theory.



Participants emphasised whilst it is good to learn from the USA experience in terms of regulatory frameworks, lessons should be incorporated from other jurisdictions such as Canada, Mexico, Europe, China and Australia.

Limitations and safe guiding measures need to be specified in the licencing application submitted through Department of Water and Sanitation. The department would require input from in-house constituency to outline all necessary licencing limitations needed.

4.5 Fundamental science questions, science goals and implementation

Key points or highlights during the workshop included:

1. **Lack of evidence-based scientific facts to inform the practice and the enforceable regulations**: The Karoo region remains unknown in many ways, especially the deep aquifers and associated geology. There is a need for extensive research prior to the production of gas.

2. **Lack of quantifiable cost-benefit assessments results**: The costs and benefits of exploring and possible production of the unconventional gas has remained speculative or at its best remained qualitative. The debates assume the existence of quantities and qualities of gas that will meet the demand of the markets and that will benefits various players. The debates assume that no technologies will exist to prevent or remediate the negative effects from the processes of exploration and production of gases. Uncertainty is amplified by the absence of solid scientific evidence about Karoo gas resources.

3. **Lack of established institutional arrangements to oversee exploration and production activities in the Karoo**. Although recently the SA government has declared hydraulic fracturing and other activities controlled activities, such proclamations may fall short. It was noted that such institutions are vital in reforming, enforcing and monitoring the activities relating to exploration and production of gases.

4. **Lack of basic and applied scientific knowledge regarding the processes relating to exploration and production**. It was noted that basic knowledge of chemicals used in the hydraulic fracturing process is lacking, including their interaction with the natural environment. In addition, stakeholders have limited scientific knowledge regarding impacts on the environment from natural chemicals and chemicals that are introduced during hydraulic fracturing.

5. **The need for workshops**: Based on the above issues, the workshop discussed the importance of holding frequent meetings, workshops or conferences to reinforce the collaborative sustained communication among various stakeholders as one way of sharing knowledge, data and concerns from scientific disciplines.

Key contextual consideration:

6. **Regulations**: Policies need to be reformed in the context of such initiatives but such regulations need to be turned into regulations. However, in the absence of evidence-based information about the hydraulic fracturing process in general, reforming the regulation remains a difficult exercise, although precautionary principles can be invoked. Nevertheless, the context and complexities involved in policy making and enacting policies need to be recognised by all participants in hydraulic fracturing debates.

7. **Institutional arrangements**: Although the need for setting up an organisation to oversee exploration and production of unconventional gas is recommended, duplication of institutional arrangements needs scrutiny to avoid overlap of roles and responsibilities. In addition, wide and deep sustained engagements with various bodies are needed for the buy-in philosophy of such an organisation.

8. **Informative research and information or results sharing**: The current situation is that various organisations have data or information about some aspects or some of the issues that relate to hydraulic fracturing. Sharing such information remains limited for various reasons. With such a context, the workshop suggested the need to share information and the need to have an agent to house the information. The modalities for such an initiative remain elusive.

9. **Robust basic research deep hydrogeology still developing in South Africa**: The current situation in South Africa is that knowledge about the groundwater resource is based on known aspects of the top 300m of the earth's crust. Deeper hydrogeological systems below 300m remain unstudied. Given such a context, it is difficult to discuss the situation and its consequences for deep aquifers during and after hydraulic fracturing. When chemical and physical characteristics of the deeper aquifers are known, predictions will provide more reliable estimates than at present. Research activities on such aquifers is needed in the context of hydraulic fracturing in South Africa.

10. **Water use and wastewater treatment**: South Africa is a water stressed country, particularly the Karoo region where hydraulic fracturing is proposed. A major concern is that the sources of water for hydraulic fracturing are not secured. In addition, the technologies to treat wastewater and other effluents from the proposed unconventional gas development must be adapted.

5 WAY FORWARD

South Africa needs to be in a position to develop its unconventional gas resources in a manner that is responsible and sustainable – through research support and effective regulation. However, the capability and capacity of South African organisations (public and private) to explore and develop unconventional gas resources is in its early stages.

Unconventional gas exploration, production and commercialisation offer the country an opportunity to create a new, broad-based model in resource development that contributes to economic security but also bolsters environmental and social security (as opposed to experiences in the mining sector). This will require a multi-stakeholder approach to identify, grow and leverage capabilities to address the multi-faceted challenges of unconventional gas exploration, production and commercialisation.

Monitoring and baseline measurements

To test whether hydraulic fracturing could cause aquifer contamination requires baseline measurements of levels of CH_4 in aquifers before and after hydraulic fracturing. The baseline and monitoring network needs to be set-up as a matter of urgency.

Regulation

Existing South African legislation has comprehensive provisions for environmental protection. For example, the National Water Act specifies that water be left as an "environmental reserve" necessary for ecosystem functioning. However, there is a need to anticipate the kind of regulatory issues that might be encountered as part of unconventional gas exploration and exploitation. These would not necessarily be limited to environmental issues, but would include transport regulations, tax law and policy, employment issues, and other backward and forward linkages associated with resource extraction. These issues, considered together, bear on the extent to which the benefits of unconventional gas extraction are broadened and maximised and the negative effects such as pollution are reduced. A coordinated regulatory approach would naturally require collaboration across government organisations, as well as the close involvement of other stakeholders including the energy companies, communities, unions and farmers.

Research/knowledge production

Water and environmental researchers in South Africa are already working on various initiatives to understand and address the issues surrounding unconventional gas extraction. At present these are funded mainly by the WRC. There is a need to broaden the research funding base and increase research funding generally. Several South African universities are well positioned to address unconventional gas, having existing skills and equipment. Some universities (for example the universities of the Western Cape and Free State, as well as Nelson Mandela Metropolitan University) are deliberately gearing up capacity to participate in future research around the issue. Ideally research would begin to focus on the concerns of a high-level cross-disciplinary task team established within government, in a process of two-way dialogue. Research by South African universities and science councils, focused and directed, has the potential to be greater than the sum of its parts. South Africa should also take full advantage of existing knowledge, research and practical experience, gained at considerable expense elsewhere. This process has already begun – e.g. the involvement of scientists from the USA in South African projects.

Education and training

There is a need both to train more scientists and environmental practitioners in South Africa, and also to address the issue of positions and career paths. At present the state of South African potential capacity to address unconventional gas exploration and associated issues is probably underappreciated by the public in general – we have a capable environmental sector and robust environmental legislation, and these need better communication.

Information brokerage

The commercial nature of hydrocarbon exploration world-wide has contributed to a paucity of data in the public sphere on many aspects of the process. It is vital and essential that data on all aspects of unconventional gas exploration is put into the public domain, unless it is genuinely commercially sensitive. The risks of reinventing the wheel and dealing with the effects of misinformation and speculation are also raised when data and information are withheld.

Networking and Service rendering

Unconventional gas exploration and exploitation, particularly if it is to be broad-based and a catalyst for long-term development, will be a highly cross-disciplinary process. T here is a need to establish forums and mechanisms for various stakeholders to network and engage jointly on issues. Without this, there is potential for capture of the process by narrow interests and consequent risk that the full potential of the resource will not be realised. A good example will be the potential use of unconventional gas as a "transition fuel" from coal to mainly renewables – for this to happen, energy experts, funding and policy needs to be coordinated and combined as early and as efficiently as possible. Extraction of the resource, off-shoring of profits and externalisation of environmental disbenefits are real risks if coordinated policy is not adopted.

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Appendix 1: Workshop Agenda

WATER
RESEARCH
COMMISSION

Water Research Commission Research Workshop Programme

Venue:
Rooms 1E/1G
School of Government
University of the Western Cape
Bellville
Western Cape

Thursday
3 July 2014

Project:
Review of Risks to Water Resources from Unconventional Gas Exploration and Production in South Africa

09h00 – 09h10	Welcome on behalf of the University of the Western Cape (UWC) **Prof Micheal Davies-Coleman, Dean of Science**
09h10 – 09h15	Participants round of introduction (Map research projects)
09h15 -09h45	Regulatory perspective on hydraulic fracturing in South Africa **Anil Singh (Department of Water and Sanitation)**
09h45 – 10h15	South African potential unconventional gas plays **Sean Johnson (Petroleum Agency of South Africa)**
10h15 – 10h45	The Water Research Commission research portfolio to comprehend water-related impacts from unconventional gas exploration and production in South Africa **Dr Shafick Adams (Water Research Commission)**
10h45 – 11h00	Coffee/Tea
11h00 –11h45	Background on the Water Research Commission project unconventional gas exploration and production and its impact on South Africa's water resources **Dr Kevin Pietersen/ Dr Thokozani Kanyerere (UWC)**
11h45	Introduction to Prof Avner Vengosh **Dr Ricky Murray (Groundwater Africa)**
11h45 – 12h30	A Critical Review of the risks to water resources from unconventional shale gas development and hydraulic fracturing in the United States **Prof Avner Vengosh (Duke University)**
12h30 – 13h00	Facilitated discussion about the USA experience • What are the risks that concern people? • What do we know about them? • What do we need to know? • Which risks pose major challenges?

	Dr Thokozani Kanyerere (Facilitator)
13h00 – 14h00	**Lunch**
14h00 – 15h30	Developing **plausible scenarios** for groundwater contamination pathways in Karoo aquifer systems from production of: • Shale gas • Coal-bed methane • Underground coal gasification **Prof Avner Vengosh (Facilitator)**
15h30 – 16h00	Coffee/Tea
16h00 – 16h30	How do we grapple with the economics of shale-gas? **Saliem Fakir, WWF**
16h30 – 17h30	Smart regulation for unconventional gas production and exploration in South Africa **Dr Kevin Pietersen (Facilitator)** Day 1 closes **Dr Shafick Adams**
19h00	Informal Supper (Panama Jacks) **Unsponsored**

Friday
4 July 2014

Project:
Water Science Plan for Unconventional Gas Exploration and Production

08h30 - 08h45	Workshop programme and procedures Workshop products **Dr Kevin Pietersen)**
08h45 - 09h15	The Source and Migration of Natural Gas in Shallow Aquifers: Insights Provided by the Integration of Noble Gas and Hydrocarbon Isotopes **Prof Thomas Darrah, Ohio State University**
09h15 - 09h45	Background on the Water Research Commission project water science plan for unconventional gas exploration and production **Dr Kevin Pietersen**
09h45 -10h45	Develop fundamental science questions which respond to societal issues **Prof Avner Vengosh (Facilitator)**
10h35- 11h00	Tea/Coffee
11h00 - 12h00	Develop science plan goals • Motivation • Scientific directions **Prof Avner Vengosh (Facilitator)**
12h00 - 13h00	Implementation • Challenges • Opportunities **Dr Kevin Pietersen (Facilitator)**
13h00-	**Close of workshop and thanks** **Dr Shafick Adams** **Lunch**

Appendix 2: Participant list

Surname	First name	Affiliation	E-mail
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Nathoo	Jeeten	Citius Energy	

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Xu	Yongxin	UWC	

Appendix 3: Speaker biographies

Adv. Anil Singh is Deputy Director General for Water Sector Regulation in the Department of Water Affairs and Sanitation. He is a lawyer by profession (admitted as attorney of high court of SA). His qualifications are BA (Law) LLB, LLM (Masters in Constitutional Law and Litigation). He has served our democratic government for 20 years in various different Departments as Head of Legal and legal advisor to former Ministers. He was instrumental in policy development and law reform. He participated in various multi-lateral fora such as UNESCO and WIPO. Anil led the water law reform that culminated in the draft National Water Act Amendments Bill 2014. He also led water dispute resolution mechanisms for former Minister Molewa.

Prof Avner Vengosh is a Professor of Geochemistry and Water Quality and chair of the Water and Air Resources program at the Nicholas School of Environment in Duke University. Dr. Vengosh also has a secondary appointment in the Department of Civil and Environmental Engineering at Duke University. He is an Associate Editor for the international journal Applied Geochemistry. Dr. Vengosh research aims to integrate environmental geochemistry, advanced isotope geochemistry (boron, strontium, carbon, and radium isotopes), and environmental health (e.g., arsenic in toenails) in order to delineate the sources and pathways of contaminants in the environment and their possible impacts on human health. Currently Dr. Vengosh research is focused on three major themes: (1) Salinization of water resources and impacts on development and health. Current studies focused on shallow groundwater in the sub-Saharan basins of Morocco and coastal aquifer of the southeastern United States. Studies also include the geochemistry of “new water” generated by reverse osmosis desalination of seawater and saline groundwater. (2) The energy-water quality-health nexus that includes (i) studies on the impact of coal combustion products on the environment (e.g., the TVA coal ash spill in Tennessee, effluents discharge from coal ash ponds in North Carolina); (ii) the origin of contaminants associated with mountaintop mining in valley fill head waters in West Virginia; and (iii) the impact of deep shale gas drilling and hydraulic fracturing on the quality of shallow groundwater and surface water (methane and brine contamination from the Marcellus Shale, Pennsylvania). (3) The relationships between groundwater geochemistry, water quality, and human health in different aquifer systems, worldwide. Current studies including high arsenic drinking water in private wells from Union County, North Carolina; high fluoride and arsenic in groundwater from the Rift Valley in Ethiopia; high salinity, fluoride, and radium in groundwater in Morocco; and high radium in fossil groundwater in the Middle East. Studies include developing new diagnostic tools to evaluate their bioaccumulation in the local populations by measuring the contaminants in nails and conducting health surveys in exposed populations [15].

Professor Mike Davies-Coleman joined the University of Western Cape in June 2012 as the Dean of Natural Sciences. Professor Davies-Coleman moved to UWC from Rhodes University in the Eastern Cape where he was Professor of Organic Chemistry and a former Head of the Department. His research interests, while specializing in marine natural products chemistry, have encompassed synthetic organic chemistry, nuclear magnetic resonance spectroscopy, marine invertebrate biology and taxonomy, microbiology, biochemistry and pharmacology. He is regarded as the leading authority on marine natural products in Africa with several ongoing international collaborations and over 90 research publications in natural products chemistry. Professor Davies-Coleman has been the recipient of both the Rhodes University Vice Chancellor Distinguished Research and Teaching Awards and US National Institutes of Health and Fulbright Senior Fellowships to carry out research in the USA [16].

Sean Johnson holds a position as Manager: Frontier Geology with the Petroleum Agency SA and manages a team responsible for appraising the conventional and unconventional hydrocarbon resource potential of South Africa’s frontier regions, onshore and offshore, and for promoting exploration and production opportunities to local and international oil and gas explorers. Sean also manages a team responsible for the South African Extended Continental Shelf Project. For the last 8 years, Sean has held senior positions as Principal and Divisional Geologist (Area Specialist) with the Petroleum Agency SA in which he has contributed to, researched and developed techniques for evaluating South Africa’s unconventional hydrocarbon resource potential in respect of CBM, shale gas, biogenic gas and gas hydrates.

Zainab Mowzer is a Geologist at the Petroleum Agency SA – the South African agency that promotes, facilitates and regulates the upstream petroleum industry. As an affiliate of the Agency's Frontier Geology team, she is assisting in evaluating the Karoo Basin's shale gas potential. She obtained her MSc. Degree in geology from the University of the Western Cape. She has done field studies on parts of the Cape Supergroup, Table Mountain Group (South Africa), the Permian Submarine Fans of the Karoo Basin (South Africa), Offshore Orange Basin (South Africa), the Basin and Range Province of the USA (as well other geologic terrains in the USA). She is a member of the AAPG (American Association of Petroleum Geologists, SPE (Society of Petroleum Engineers) and the GSSA (Geological Society of South Africa).

Zavier Schalkwyk started his geology career at the University of the Western Cape where he completed his BSc Honours degree in Petroleum Geology. His thesis looked at porosity and permeability of the AK1/AK6 wells within the Orange Basin on the west coast of South Africa. T hese finding where presented at the Inkaba ye Africa workshops in Swaziland in 2008 and the following year in Cape Town at the CTICC. He is also a member of the SPE (Society of Petroleum Engineers), AAPG (American Association of Petroleum) and the GSSA (Geological Society of South Africa). He is currently employed at the Petroleum Agency of South Africa as a geologist working on the evaluation of potential unconventional oil and gas resources in the Karoo but primarily on CBM. His previous work and studies on offshore basins in South Africa allowed him to gain experience in various software packages i.e. Interactive Petrophysics (IP), Petrel and Downhole Explorer just to name a few. Currently he is in the final stages of his MSc degree at the University of the Western Cape. The thesis describes the characteristics of depositional environments of the Lower Ecca and Beaufort formations through geochemical analysis in the Karoo.

Saliem Fakir joined WWF in February 2009 as Head of the newly formed Living Planet Unit. Prior to this he was a senior lecturer at the Department of Public Administration and Planning at the University of Stellenbosch where he lectured on renewable energy policy and financing. He held the position of Associate Director for the Centre for Renewable and Sustainable Energy Studies (University of Stellenbosch) and served as Director of the International Union for the Conservation of Nature (IUCN-SA) office for 8 years. Saliem has a B.Sc. Honours in Molecular Biology from Wits and a Masters' in Environmental Science from Wye College London. He also completed a senior executive management course at Harvard University in 2000.

Dr Kevin Pietersen is a director of SLR Consulting (South Africa) (Pty) Ltd, and has worked for the past 20-years in the water sector. He has extensive experience in Integrated Water Resource Management; Strategy Development and Planning; Exploration, Development and Management of Groundwater; Groundwater Governance; Capacity Building and Technology Transfer of Scientific Information; and SADC/Africa-wide resource assessments. He was the Team Leader for the compilation of the SADC Hydrogeology Map and also for The Development of Policy Level Decision Support Guidelines/Materials for Groundwater Management in the SADC Region. He was also involved in the development of the South African National Water Resource Strategy. Clients include: European Union, GIZ, SADC Water Division, South African Department of Water Affairs and the World Bank. Prior to joining SLR he was a partner and managing director at Water Geosciences Consulting/Metago Water Geosciences from April 2007. Before that time he was employed by the South African Water Research Commission as the Director: Research Coordination and Partnerships, and before that Director: Water Resource Management. Kevin was a hydrogeologist with the CSIR focusing on community water supply and sanitation and integrated groundwater management before he joined WRC. He is a past member of the South African National Water Advisory Committee and has also served as Presidents of the Water Institute of Southern Africa and the Geological Society of South Africa. He has been recently appointed to the Mediation Panel to settle water disputes by the Minister of Water and Environment Affairs. He is an Advisory Board Member of the University of Pretoria Water Institute.

Dr. Thokozani Kanyerere (PhD) is a Senior Lecturer of hydrogeology in Department of Earth Sciences at the University of the Western Cape (UWC), South Africa (SA) where he has been teaching and conducting research. He received his MSc in Environmental Science from University of Malawi in 2001, MPhil in Environmental Health from Norwegian University of Science and Technology in 2004, and PhD in hydrogeology from University of the Western Cape (South Africa) in 2012 where he focused on Groundwater Management. His research interest in Environmental Hydrogeology has enabled him to develop several projects on groundwater assessments to to improve knowledge and recommend interventions. His teaching skills and experience on Groundwater hydrology; Environmental hydrogeology; Groundwater Management; Water resources management and Environmental Management from groundwater perspective enabled him to supervise several students on groundwater related topics and such supervision continue to widen his scope on groundwater aspects. His publication record about peer-reviewed scientific papers and book chapters on groundwater related subject is still in its infancy. Nevertheless, he actively collaborates with his colleagues and postgraduate students. Administratively, Thokozani coordinates several activities in the department and in the faculty which include Teaching & Learning activities, Postgraduates activities, Technicians' activities and Fieldschool-related activities among others. Thokozani is a IAH Member (Membership number: 122982); Groundwater Network Member; Rural Water Supply and Sanitation Network Member; Groundwater Division of Geological Society of South Africa (GWDGSSA); The Water Institute of Southern Africa (WISA); and WaterNet Member.

Dr Shafick Adams is currently employed by the WRC in Pretoria, South Africa where he manages research projects related to groundwater and water resources protection. He holds a PhD and MSc (cum laude) from the University of the Western Cape where he lectured prior to his appointment to the Water Research Commission. He currently chairs the Groundwater Division of the Geological Society of South Africa and is co-chair of the International Water Association's Groundwater Restoration and Management Specialist Group. He is also a Fellow of the Geological Society of South Africa. He is registered as an Earth Scientist with the South African Council of Natural Scientific Professions (SACNASP). He serves on the Councils of the Water Institute of Southern Africa and the Geological Society of South Africa. Some of his research interests are in groundwater recharge assessments, chemical characterisation of groundwater, capacity development and water resource management.

Appendix 4: Presentations

4.1 Unconventional gas resources – An update of onshore activities
4.2 Unconventional Gas and Water Research
4.3 A Critical Review of the risks to water resources from unconventional shale gas development and hydraulic fracturing in the USA
4.4 Background on the WRC project unconventional gas exploration and production and its impact on South Africa's water resources
4.5 The Source and Migration of Natural Gas in Shallow Aquifers: Insights Provided by the Integration of Noble Gas and Hydrocarbon Isotopes
4.6 Background on the WRC project water science plan for unconventional gas exploration and production