TOWARDS A REGULATORY FRAMEWORK TO PROTECT GROUNDWATER RESOURCES DURING AND AS A RESULT OF UNCONVENTIONAL OIL AND GAS EXTRACTION

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Declaration

I declare that the thesis hereby submitted by me for the PhD degree at the University of the Free State is my own, independent work and has not been previously submitted by me at another university or faculty. I furthermore cede copyright of the thesis in favour of the University of the Free State.

Surina Esterhuyse

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Summary

This PhD study focused on the development of a regulatory framework to protect groundwater resources during UOG extraction. Groundwater resources are important to many countries, including Algeria, Libya, Morocco, Colombia, Venezuela, South Africa, Mexico, Denmark and Australia. These resources become increasingly important as population growth and climate change increase pressures on water demand, especially in those water-scarce countries where climate change predictions are in the direction of drier climates. However, despite its strategic importance, groundwater receives insufficient management attention compared with surface water. It is especially poorly managed during UOG extraction.

South Africa has no UOG extraction regulations and has yet to start with any extraction of UOG resources. This PhD study aimed to address this regulatory gap by addressing the following specific aims:

1. Assessing the knowledge-base and opinions of decision-makers on the regulation and monitoring of UOG extraction in South Africa (Chapter 3)
2. Developing a regulatory framework to protect specifically groundwater resources before, during and after UOG extraction (Chapter 4)
3. Testing the UOG extraction regulations, proposed under the regulatory framework, for
    i. its relevancy to protect groundwater resources in the South African context and
    ii. its enforceability in the South African context (Chapter 5)
4. Making recommendations on energy policy and regulations for groundwater protection in South Africa (Chapter 6)

In addressing aim 1 of the PhD, it was determined that the knowledge-base of regulators are very poor, which means that proper regulations to protect groundwater resources can not be drafted by the regulator alone. This poor knowledge is a function of the novelty of UOG extraction and fracking in South Africa. Industry experts and groundwater discipline experts should therefore from the conceptualisation stage onwards, be involved in drafting regulations to protect groundwater resources during UOG extraction.

The view of regulators and industry experts on the regulation and monitoring of UOG extraction was also assessed. To determine the most salient issues that must be addressed in the regulation of UOG extraction to protect the environment, this part of the PhD study focused on testing the opinions of the respondents on the importance of regulating a wide range of possible impacts that may emanate from UOG extraction. Respondents had to indicate which aspects they deemed as important to regulate. The protection of groundwater resources was identified as one of the main concerns during UOG extraction. Respondents also had to indicate to what extent they think South Africa has the capacity enforce these regulations to protect the environment. They felt at the time of this survey (2013) that South Africa does not have the capacity to properly enforce UOG extraction regulations to protect the environment.

To address aim 2 of the PhD, a regulatory framework was developed and proposed for groundwater resources protection during UOG extraction. Such a regulatory framework to protect groundwater resources must be aimed at avoiding or minimising damage from UOG extraction. During this part of the PhD, UOG extraction regulations of countries with UOG deposits and that allow UOG extraction, were reviewed. To identify the regulations that would most effectively protect groundwater resources, the review specifically targeted countries that have moderate to extensive regulations to protect groundwater resources during UOG extraction, and where fracking has been done for more than 20 years. The regulations of countries where gas is economically important and where groundwater is of medium to high importance were also included.

The regulations that were identified this way, were categorised into three different regulatory approaches (command-and-control, market-based and voluntary), as well as different regulatory areas (e.g. Baseline studies, Management plans, Public information disclosure, Best available techniques and practices, Monitoring and reporting of resources, processes and incidents, Prohibitory precautionary regulations, Margin of safety regulations, Well decommissioning requirements). All this information was used to propose a regulatory framework for groundwater resources protection during UOG extraction. This part of the PhD also considered the functions of each of the three regulatory approaches, and made recommendations on how the different regulatory approaches may be used to achieve groundwater resources protection during UOG extraction.

For aim 3 of the PhD, the different proposed regulatory areas and specific regulations under each area, were tested with twenty South African groundwater discipline experts. The enforceability of the specific regulations and the enforcement capacity of the South African government was also tested. The feedback obtained from this study indicated that groundwater experts viewed most regulatory areas and regulations under each area, as important. They were seriously concerned about sourcing of water for fracking in water-scarce South Africa. Water sourcing is currently viewed as the main factor limiting UOG development in South Africa, as well as other countries such as China.

They saw regulations for baseline monitoring of water used for fracking and regulations to protect groundwater from contamination during UOG extraction to be paramount. The groundwater experts did not support regulations that could weaken groundwater quality protection, such as regulations that exempt fracking companies from publicly disclosing information so they can protect trade secrets, or using arbitrary setback distances that are not based on scientific data. They also had to indicate whether they agreed with proposed regulatory setback distances (buffer distances between fracking activities and aspects that has to be protected during fracking). They were mostly cautious and viewed most proposed proposed setbacks as not stringent enough.

All respondents also stated that South Africa should first assess energy generation options before just pursuing UOG resources as an energy supply option in South Africa. During this 2019 survey, as with the 2013 survey, respondents were still of the opinion that it would be difficult to enforce UOG regulations in South Africa, because of poor political will, corruption, lack of capacity and lack of financial resources. Unfortunately, poor enforcement is where even the most meticulously crafted regulations would fail. South Africa must therefore seriously reconsider if UOG extraction is a viable energy generation option when considering the governance obstacles and the fact that it is a water scarce country.

As part of aim 4, recommendations were made on energy policy and regulations for groundwater protection during UOG extraction in South Africa. Using the preceding research and the information gained from a book review of Buono et al., (2019), energy policy and regulatory recommendations for groundwater protection in South Africa were made by:

- Proposing a policy direction for energy development in South Africa,
- Proposing a process for developing UOG extraction regulations
- Recommending regulatory approaches and areas to consider for UOG extraction regulations and
- Recommending enforcement mechanisms for UOG extraction regulations

Although this PhD focused on groundwater resources protection for South Africa, the research is generalisable to other resource types (e.g. surface water) and other countries. Baseline monitoring requirements, the development of management plans, operator reporting requirements, prohibitory precautionary regulations and well decommissioning regulations would also be useful for protecting surface water resources. Similarly, the proposed process for developing regulations would also be useful for developing a regulatory framework for surface water protection during UOG extraction. Using discipline experts for reviewing and amending UOG extraction regulations before official publication, could also be useful for regulation development in other fields such biodiversity or air quality protection. In terms of applicability of this research to other countries, the regulatory approaches, regulatory areas and specific regulations proposed in this PhD could be equally useful for other countries planning to develop or to amend their UOG extraction regulatory frameworks to protect their groundwater resources. A copy-and-paste approach can however not be followed and it is strongly advised that regulators in other countries test their frameworks with their discipline experts to ensure that their regulations are relevant to the country-specific context. Lastly, the enforcement mechanisms proposed for South Africa may be useful to other countries that are developing their UOG resources.

The key message of this PhD is that it will only be possible to use regulations to protect groundwater resources during UOG extraction, if the following conditions are met:

- The UOG extraction regulations must address the country-specific context and groundwater concerns,
- Groundwater discipline experts must be allowed to contribute to the development of the regulations, and
- Such regulations must be properly enforced.

Acronyms and glossary

Acronyms

CAS:	Chemical Abstracts Service
CBM:	Coalbed methane
CSIR:	Centre for Scientific and Industrial Research
DEA:	Department of Environmental Affairs
DMR:	Department of Mineral Resources
DWA:	Department of Water Affairs
DWS:	Department of Water and Sanitation
EA:	Environmental Assessment
EC:	Electrical conductivity
EIA:	Environmental Impact Assessment
EIP:	Environmental Implementation Plan
EMP:	Environmental Management plan
HF:	Hydraulic fracturing
IEA:	International Energy Agency
IPCC:	International Panel on Climate Change
ISO:	International Organization for Standardization
MPRDA:	Mineral and Petroleum Resources Development Act (28 of 2002)
NEMA:	National Environmental Management Act (107 of 1998)
NEMWA:	National Environmental Management Waste Act (59 of 2008)
NORM:	Naturally occurring radioactive material
NWA:	National Water Act (36 of 1998)
PAIA:	Promotion of Access to Information Act (2 of 2000)
PASA:	Petroleum Agency of South Africa
SCA:	Supreme Court of Appeal
SEA:	Strategic environmental assessment
TCF:	Trillion cubic feet
TCP:	Technical cooperation permit
UK:	United Kingdom
US:	United States

Glossary

Acidising	Stimulating a well to improve the permeability of reservoir rocks by pumping acids into the well to dissolve the rock.
Aquifer:	A zone of permeable, water saturated rock material below the surface of the earth capable of storing and producing significant quantities of water.
Base fluid:	Any drilling fluid that acts as a mixing agent and carrier fluid during the process of hydraulic fracturing.
Casing:	Steel pipe placed into a well (borehole).
Chemical additive:	A product composed of one or more chemical constituents which are added to a primary carrier fluid to modify its properties in order to form hydraulic fracturing fluid.

Chemical constituent:	A discrete chemical with its own specific name or identity, such as a CAS Number, which is contained within an additive product
Coal gasification:	(Underground) Coal Gasification (UCG) is a method of converting unworked coal – coal still in the ground – into synthetic gas. The "syngas" – a mixture of methane, hydrogen, carbon dioxide and water vapour, is produced from coal, water, air and/or oxygen. During UCG the cavity itself becomes the reactor so that the gasification of coal takes place underground instead of at the surface. UGC does not resort under natural unconventional oil and gas (which occurs naturally in the geological formations in oil or gaseous form) as this gas is produced synthetically from coal.
Coalbed methane:	Natural gas contained in coal beds. Although extraction of coalbed methane was initially undertaken to make mines safer, it is now typically produced from non-mineable coal seams.
Coal seam gas:	Coalbed methane is known as coal seam gas in Australia.
Completion:	The activities and methods of preparing a well for extraction after it has been drilled to the target formation. This principally involves preparing the well to the required specifications; running in extraction tubing and its associated down-hole tools, as well as perforating and stimulating the well by the use of hydraulic fracturing.
Conventional oil and gas:	Conventional oil and gas resources are produced from conventional reservoirs.
Conventional reservoir:	For oil gas reserves, conventional hydrocarbons refer to hydrocarbons that are produced from reservoirs that do not require stimulation to produce the gas. These reservoirs typically have permeabilities greater than 1 milliDarcy.
Corrosion inhibitor:	A chemical substance that minimises or prevents corrosion of metal equipment.
Directional drilling:	Deviation of the borehole from the vertical so that the borehole penetrates a productive formation in a manner parallel to the formation, although not necessarily horizontally.
Drilling fluid:	Mud, water, or air pumped down the drill string, acting as a lubricant for the drill bit and is used to carry rock cuttings back up the wellbore. It is also used for pressure control in the wellbore.
Economically recoverable reserves:	Technically recoverable petroleum for which the costs of discovery, development, extraction, and transport, including a return to capital, can be recovered at a given market price.
Environment:	The combination of external physical conditions that affects and influences the growth, development and survival of organisms. This includes all biotic and abiotic factors that act on an organism, population, or ecological community and influence its survival and development. Biotic factors include the organisms themselves, their food and their interactions. Abiotic factors include sunlight, soil, air, water, climate and pollution. Organisms respond to changes in their environment by evolutionary adaptations in form and behaviour.
Environmental degradation:	The reduction of the capacity of the environment to meet social and ecological objectives, and needs. Potential effects are

	varied and may contribute to an increase in vulnerability and the frequency and intensity of natural hazards. Some examples are land degradation, deforestation, desertification, wild fires, loss of biodiversity, land, water and air pollution, climate change, sea level rise and ozone depletion.
Environmental impact assessment (EIA):	A public process by which the likely effects of a project on the environment are identified, assessed and then taken into account by the consenting authority in the decision-making process. This serves as a tool to facilitate sustainable development.
Extraction:	Extraction, as used in this dissertation, refers to all types of unconventional oil and gas extraction, including shale gas and coalbed methane.
Fault:	A fracture or fracture zone in a geological formation along which there has been displacement of the sides relative to each other.
Flowback:	Fluid returned to the surface after hydraulic fracturing has occurred, but before the well is placed into production. It typically consists of returned fracturing fluids in the first few days following hydraulic fracturing which are progressively replaced by produced water.
Fold:	A bend in geological rock strata.
Formation:	A rock body distinguishable from other rock bodies and useful for geological mapping or description. Formations may be combined into groups or subdivided into members.
Fracking, fraccing or fracing:	Informal abbreviations for "Hydraulic Fracturing".
Friction reducer / Friction reducing agent:	A chemical additive which alters the hydraulic fracturing fluid, allowing it to be pumped into the target formation at a higher rate and reduced pressure.
Groundwater:	Water found in the subsurface below the water table. Groundwater is held in the pores of rocks.
Horizontal drilling:	Deviation of the borehole from the vertical so that the borehole penetrates a productive formation with horizontally aligned strata, and runs approximately horizontally.
Hydraulic fracturing:	The act of pumping hydraulic fracturing fluid into a formation to increase its permeability. Hydraulic fracturing has been used in the industry in various forms, for either stimulation of water wells to produce water, or for stimulation of oil and gas wells to produce oil and/or gas. Various technologies can be combined or used separately during hydraulic fracturing. It may involve the use of only water (for water well stimulation) or a combination of any or all of four separate technologies, viz. directional drilling, the use of high volumes of fracturing fluids, the use of slickwater additives and the use of multi-well drilling pads. When all four technologies are combined it is referred to as “high-volume slickwater long-lateral” (HVSLL) stimulation. Hydraulic fracturing as used in the oil and gas industry, commonly includes the usage of 0.5-2% chemical additives (slickwater additives), large volumes of proppant as well as large volumes of fluid. Base fluids that may be used

may include water, liquid petroleum gas or other gases such as nitrogen or carbon dioxide.

Hydraulic fracturing fluid: Fluid used to perform hydraulic fracturing; includes the primary carrier fluid, proppant material, and all applicable additives.

Hydrocarbon: A naturally occurring organic compound comprised of hydrogen and carbon. Hydrocarbons can be as simple as methane [CH_4], or highly complex molecules. These can occur as gases, liquids or solids. Petroleum is a complex mixture of hydrocarbons of which most are natural gas, oil and coal.

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

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

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

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

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

Permeability: A measure of the ability of a fluid to move through pores, fractures or other openings in a rock. The unit for measurement is Darcy.

Play: Synonym for geological formation.

Porosity: Volume of pore space expressed as a percentage of the total bulk volume of the rock.

Produced water:	Fluids displaced from the geological formation, which can contain substances that are found in the formation, and may include dissolved solids (e.g. salt), gases (e.g. methane, ethane), trace metals, naturally occurring radioactive elements (e.g. radium, uranium), and organic compounds.
Production right:	A right granted to an applicant in terms of section 84 of the *MPRDA* to the applicant to conduct any operation, activity or matter that relates to the exploration, appraisal, development and production of petroleum.
Promulgation in relation to regulations:	The promulgation by the relevant Minister in the South African Government Gazette of final regulations. Promulgated regulations has the same legal effect as law and is legally binding.
Proppant or propping agent:	A granular substance (sand grains, aluminium pellets, or other material) that is carried in suspension to the target zone by the fracturing fluid. Proppants are used to keep the micro-scale fractures open at depth and are either sand or ceramic beads. The sand or ceramic beads must have specific physical properties – they must be perfectly spherical, a specific size and clean from cement such as calcite to avoid the inability of not optimally keeping the fractures in the source rock open.
Publish in relation to regulations:	The publication by the relevant Minister in the South African Government Gazette of draft regulations for public comment. It is not legally binding.
Reservoir (oil or gas):	A subsurface, porous, permeable or naturally fractured rock body in which oil or gas has accumulated. A gas reservoir consists only of gas with freshwater that condenses from the flow stream reservoir. In a gas condensate reservoir, the hydrocarbons may exist as a gas, but, when brought to the surface, some of the heavier hydrocarbons condense and become a liquid.
Reservoir pressure:	The pressure within the reservoir rock.
Reservoir rock:	A body of rock that may contain oil or gas in appreciable quantity and that has sufficient porosity and permeability to store and transmit fluids.
Schedule 1 use in relation to the National Water Act	A schedule 1 water use is generally a low volume, low-impact water use such as for domestic use, livestock watering, recreational use and the use of water for emergencies. This water use is permissible and does not require licensing or registration.
Sedimentary rock:	A rock formed from sediment transported from its source and deposited in water or by precipitation from solution or from secretions of organisms.
Shale:	A fine-grained sedimentary rock composed mostly of consolidated clay, silt or mud. Shale is formed from deposits of mud, silt, clay, and organic matter, usually laid down in calm seas or lakes.
Shale gas:	Natural gas that remains tightly trapped in shale. This consists primarily of methane, with a mix of ethane, propane, butane and other organic compounds. It forms when black shale has been subjected to heat and pressure over millions of years, usually at depths of 1,500 to 4,500 metres below ground level.

Slickwater:	A hydraulic fracturing system in which “friction reducer” has been added to the base fluid.
Stimulation:	The act of increasing a well’s productivity artificially by means such as hydraulic fracturing or acidising.
Sustainable development:	Generally defined as “Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” Sustainable development is based on socio-cultural development, political stability and decorum, economic growth and ecosystem protection, which all relate to disaster risk reduction. The *National Environmental Management Act 107 of 1998* defines sustainable development as “the integration of social, economic and environmental factors into planning, implementation and decision-making so as to ensure that development serves present and future generations”.
Target formation:	The reservoir that the driller is aiming to reach when drilling the well.
Technical cooperation permit:	A permit issued to applicant in terms of section 77(1) of the *MPRDA* which allows the applicant to do desktop study, acquire seismic data from other sources including the Agency, etc.; but does not include any prospecting or exploration activities.
Ultra vires	Acting beyond one's legal power or authority.
Unconventional oil and gas:	Unconventional oil and gas resources are produced from unconventional reservoirs.
Unconventional reservoir:	Reservoirs which require hydraulic fracturing for the extraction of hydrocarbons where the permeability is less than 1 milliDarcy.
Underground injection:	The disposal of hazardous waste by forceful pressure into porous geological formations via a deep well.
Vulnerability:	The conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards.
Wastewater:	A term used to define collectively returned fracturing fluids and produced water which are sent for disposal or treatment and re-use.
Wellbore:	A borehole of which the hole is drilled by a drill bit. A wellbore may have casing inside or be open (uncased); or part of it may be cased, and part of it may be open.
Wellpad:	A site constructed, prepared, levelled and/or cleared for the activities and to stage the equipment and other infrastructure necessary to drill one or more natural gas exploratory or extraction wells.

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Chapter 1 – Introduction

For this study, an article format was followed. Detail pertaining to which journals were targeted, and the author contributions, is discussed under the format section of the dissertation. This chapter outlines the rationale, aims and scope of this study, as well as the focus of each of the chapters. Lastly, the specific contributions to current knowledge are also described.

Rationale of the study

Globally, the supply of sufficient energy is important. South Africa is facing a dwindling coal supply and repeated rolling blackouts (Nkosi & Dikgang, 2018), and is now in the position where it has to address energy supply (Bohlmann et al., 2018). It is therefore, also considering the development of unconventional oil and gas (UOG) resources (RSA, 2019a). In South Africa, the main UOG resources are located in the Ecca shales in the Karoo Supergroup, and range from depths below surface from 300 to more than 3000 m (De Kock et al, 2017). The oil and gas are tightly trapped in the shales and need a stimulation method to release it. One stimulation method that is commonly used, is hydraulic fracturing (fracking). During fracking, a mixture of sand, water and chemicals are pumped into the target oil and gas formation under high pressure to release the trapped oil and gas. UOG resources development encompasses a whole range of activities, from exploration (which includes geophysical surveys and pilot testing), to development and finally decommissioning. Hydraulic fracturing (fracking) is used during the exploration phase to test for economic viability and also during the extraction phase to extract the oil and gas resources. Apart from the risk that fracking poses to groundwater resources because of possible contamination and water use, the ancillary activities (well drilling, waste and wastewater management) also pose a risk to groundwater resources. Because UOG resources development is water-intensive and can pollute water resources, this activity poses challenges for a water-scarce country such as South Africa (Hobbs et al., 2016). Briefly, the impacts on groundwater resources include groundwater drawdown and impacts on the structural integrity of the aquifers if groundwater is used for fracking. In addition, fracking itself can affect aquifer integrity by changing the geological structure during the fracking process, and can also cause contamination via upward migration of fracking fluids along natural or man-made pathways. Inadequate solid waste and wastewater management can also contaminate aquifers (see Chapter 4). Owing to the potential impacts, there was a great deal of civil society opposition against fracking in South Africa (Atkinson, 2018). The South African government therefore proceeded to place a temporary moratorium on fracking in 2011 (Hedden et al., 2013). This was done to investigate the impacts of fracking and report back to parliament. The report submitted to parliament, highlighted the importance of augmenting the current regulatory framework, which was deemed as inadequate to address impacts from the UOG industry (South African Department of Mineral Resources, 2012). The moratorium was subsequently lifted and the Department of Mineral Resources (DMR) proceeded to draft fracking regulations, of which they released a final version in 2015 (RSA, 2015). These regulations were widely criticized for not protecting groundwater resources, and the Minister of Mineral Resources was taken to court by two groups in 2015 – farmers from the Eastern Cape as well as two citizen groups - Treasure the Karoo Action Group (TKAG) and Afriforum (RSA, 2019b). These groups were especially concerned over impacts on groundwater resources in a country that is water-scarce and where most people depend on groundwater for drinking water and livelihoods. They therefore called for the scrapping of the regulations since the Minister of Mineral Resources had no legal authority to draft environmental regulations and because these regulations did not effectively protect groundwater resources.

The Eastern Cape High Court scrapped the regulations based on the application by the Eastern Cape farmers, but the Pretoria High Court dismissed the TKAG and Afriforum application (RSA, 2017). These cases were then taken to the Supreme Court of Appeal in South Africa, where the judge invalidated the regulations in its entirety (RDA, 2019b). The setting aside of the regulations highlights just how inadequate the current regulatory framework is for preventing and minimizing groundwater impacts from UOG extraction.

It is in view of the current issues (the lack of a regulatory framework to address groundwater impacts from UOG extraction), that I decided to focus in this study on working towards the development of a regulatory framework to protect groundwater resources during UOG extraction. It is vital to address this issue, since UOG extraction is a novel technology to South Africa and there is currently insufficient information on UOG extraction to guide policymakers and regulators in the development of regulations to protect the environment. The development of UOG resources by means of fracking, presents possible benefits for the South African economy in terms of job opportunities and energy supply, but only if the related socio-economic and environmental impacts are addressed. In South Africa, impacts on water resources is the most important aspect to address, as it is one of the most water-scarce countries in the world (Rosa et al., 2018). In a recent strategic environmental assessment (SEA) that was conducted for Shale Gas Development in the Karoo, water supply for fracking was identified as the single most important limitation to UOG development in South Africa (Hobbs et al., 2016). When considered in conjunction with future population growth and climate variability linked to climate change, South Africa can ill afford to imperil any of its precious groundwater resources. The country must therefore focus on developing and enforcing regulations that would effectively protect groundwater resources, should it decide to proceed with UOG extraction.

Scope and specific aims of this study

The existence of policy and legal vacuum in relation to UOG development in South Africa was already identified in 2011 (Havemann et al., 2011). However, these lacunae in the law do not only exist in South Africa. Even in the USA, there is a constant drive to introduce UOG extraction legislation to areas that develop UOG resources (Drive & Lin, 2015; Kulander, 2013), illustrating the legal complexities related to regulating UOG extraction using hydraulic fracturing. In February of 2012, a survey performed for Shell in South Africa by Ipsos Markinor showed that 86% of respondents from the general public did not know what hydraulic fracturing entails (Harris & Fleetwood, 2012). Based on the outcomes of the Ipsos Markinor study, it could generally be assumed that the knowledge of decision-makers would by extension also be limited. This is problematic from the perspective of policy development, as a country’s policies and the related development of laws and regulations embodying those policies, must be based on a sound scientific knowledge of the issue at hand. Since the Ipsos Markinor survey did not focus specifically on decision-makers, the first article of this dissertation assessed the knowledge-base of South African decision-makers on UOG extraction.

To date, the only regulations that have been developed, are the fracking regulations (RSA, 2015b) that were set aside by the Supreme Court of Appeal in 2019 (RSA, 2019b). Despite the Department of Water and Sanitation (DWS) declaring UOG extraction using fracking a controlled activity in 2015 (RSA, 2015a), no UOG extraction regulations have as yet been forthcoming. South Africa therefore still has no fracking-specific regulations in place to limit and mitigate adverse impacts from UOG extraction.

Because groundwater resources is so important to South Africa (Hobbs et al., 2016) and because there are currently no fracking-specific regulations to protect groundwater resources during UOG extraction (RSA, 2019b), the scope of this study included the development of a regulatory framework that recommends specific regulations to protect groundwater resources for the full lifecycle of UOG extraction (from before UOG exploration up to post UOG extraction). It also advises on how to ensure effective enforcement of these regulations.

Other impacts of UOG production on the natural environment and society - air quality impacts (which are linked to climate change), seismicity impacts, biodiversity impacts, community impacts (Esterhuyse, Avenant, et al., 2016) - are just as important to regulate as groundwater resources. Seen together, all of these impacts raise the question whether UOG extraction is actually desirable (Dernbach, 2016), a question that will be revisited in Chapter 6. This thesis only focuses on the impacts of UOG extraction on groundwater resources and the protection thereof. An in-depth study of the regulation of the additional aspects (air quality, seismicity, biodiversity and community impacts) to limit the adverse effects of UOG extraction, is well beyond the scope of this study. Regulations to limit the impacts of UOG extraction on these aspects are however also urgently required. Comprehensive reviews of UOG extraction impacts can be seen in (Esterhuyse, Avenant, et al., 2016; Small et al., 2014; Wheeler et al., 2015; Kreuze et al., 2016).

The following regulatory shortcomings of UOG extraction are important to address in regulations that must protect groundwater resources:

- A lacking knowledge and evidence base for robust regulation of UOG extraction, highlighted as concerns in the UK (Watterson & Dinan, 2017), US (Small et al., 2014; Gagnon et al., 2015; Kroepsch et al., 2019) and Australia (Maloney, 2015)
- Lax rules and regulations for the protection of groundwater resources during fracking in the US (Javaid, 2016; Scott, 2013; Fisher, 2015; Stevens & Torell, 2018; Tiemann & Vann, 2015), China (Guo et al., 2016; Guo et al., 2014), Australia (Comino et al., 2013) and Canada (Buono et al., 2019)
- Gaps in regulations, i.e. in dealing with wastewater handling in the US and Canada (Notte et al., 2017; Heusner et al., 2017; Buono et al., 2019)
- A lack of transparency in reporting data on water use, wastewater generation and spillages in the US (Patterson et al., 2017; Ingelson & Hunter, 2014; Kinchy & Schaffer, 2018; Tansey, 2018)
- The lack of federal regulation is also a bone of contention in the US (Craig, 2013; Callies & Stone, 2014; Notte et al., 2017; Ingelson & Hunter, 2014), which

means that transboundary aquifer impacts from UOG extraction may go unregulated.

- Large-scale rollbacks of regulations to promote the UOG industry in the US (Holley et al., 2019; Ladd & York, 2017; van de Biezenbos, 2017; Esterhuyse et al., 2019), leaving groundwater resources unprotected.

Considering the shortcomings highlighted above, the specific aims of this study included:

1. Assessing the knowledge-base and opinions of decision-makers on the regulation and monitoring of UOG extraction in South Africa
2. Developing a regulatory framework to protect specifically groundwater resources before, during and after UOG extraction
3. Testing the UOG extraction regulations, proposed under the regulatory framework, for
    - iii. its relevancy to protect groundwater resources in the South African context and
    - iv. its enforceability in the South African context
4. Making recommendations on
    - i. What policy path South Africa can follow in its bid to address energy shortages
    - ii. A process that can be followed for developing UOG extraction regulations to protect groundwater resources
    - iii. Regulatory approaches and areas that must be considered for the development of UOG extraction regulations aimed at protecting groundwater resources in South Africa
    - iv. Enforcement mechanisms for UOG extraction regulations within the South African context

Outline of chapters

Chapter 1 provides the basic information to the thesis (the rationale, scope and aims of the dissertation), while **Chapter 2** provides a detailed background to the study (a timeline of UOG resources development and legal interventions in South Africa as well as the current legal framework for UOG extraction in South Africa).

Chapters 3, 4 and 5, were intended as standalone journal articles, but they all share the common theme which aims to develop the ideal regulatory framework for the protection of groundwater resources during unconventional oil and gas extraction (Figure 1-1).

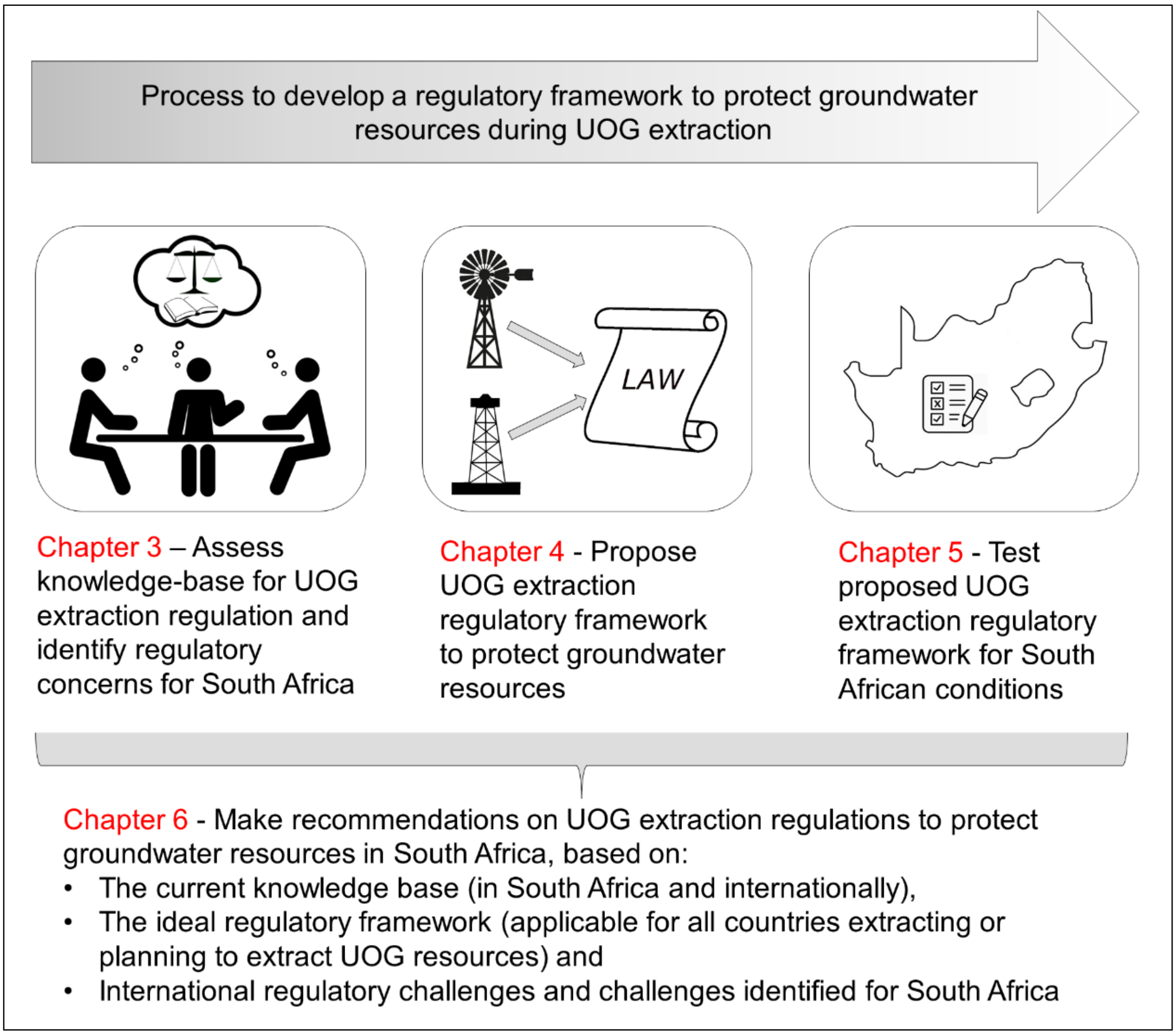

Figure 1-1: The process that was followed to develop the regulatory framework to protect groundwater resources during UOG extraction

Chapter 3 addresses the first aim of the dissertation. Here, a survey was done to assess the knowledge and opinions of decision-makers involved in policy-formulation and regulation of UOG development activities, see Esterhuyse et al., (2013). This article demonstrated that the regulation of shale gas mining in South Africa is viewed as extremely important, especially with regard to groundwater resources. It also identified initial regulatory and monitoring tools to assist in governing UOG extraction, as well as shortcomings that would hamper effective regulatory enforcement, such as the current institutional landscape.

Building on Chapter 3, **Chapter 4** focuses on identifying relevant regulations to protect groundwater resources during UOG extraction and proposes a related regulatory framework (aim 2 of the PhD). To do this, the different types of regulation that can be used to protect groundwater resources during UOG extraction were assessed in detail. Three types of regulation (command-and-control, market-based and voluntary) were identified, and sub-regulations were identified under each of the three types of regulation. The effectiveness of the different sub-regulations were then assessed to determine the best suite of regulations to protect groundwater resources during UOG extraction. This information was used to develop a proposed regulatory framework that includes a combination of hard command-and-control regulations and market-based and voluntary regulations, see Esterhuyse et al., (2019).

To address the third aim of the PhD, the relevancy and enforcement of the proposed regulatory framework and specific regulations that could be used to protect groundwater resources during UOG extraction, had to be tested in the South African context. In **Chapter 5**, a questionnaire was developed to survey the opinions of groundwater specialists with knowledge of fracking, on the relevancy of the regulations proposed in Chapter 4, and whether they thought it could be properly enforced.

The aim of the questionnaire was to obtain carefully considered judgments from the groundwater specialists based on a systematic consideration of all relevant evidence, and to obtain meaningful answers on UOG regulation. The question on UOG regulation was therefore taken apart into its component pieces by asking groundwater specialists to rate the importance and enforceability of a very detailed and specific list of regulations. Regulations were grouped under the following regulation sub-groups:

- Baseline monitoring and management plans
- Margin of safety regulations
- Prohibitory precautionary regulations
- Monitoring and reporting of resources and processes
- Best applicable technologies and processes (BATP)
- Public information and disclosure
- Well decommissioning

The groundwater experts were also asked whether they think South Africa has the capacity to effectively regulate UOG extraction and whether they think that we would be able to protect South African groundwater resources with the proposed regulatory framework and its related regulations.

Chapter 6 ties the above work together by recommending a proposed energy policy direction that South Africa should consider in view of its scarce water resources. If South Africa does decide to develop UOG resources as part of its energy policy, recommendations are made in Chapter 6 on how to ensure proper development and enforcement of UOG extraction regulations to protect groundwater resources within the South African context. Chapter 6 addresses aim 4 of the PhD These recommendations, although aimed at South Africa, will also be useful for other countries that must amend or develop their UOG extraction regulations to protect groundwater resources. A brief conclusion is presented in **Chapter 7**.

Specific contributions to knowledge

This thesis contributes to the boundaries of the groundwater field at a doctoral level in the following four ways:

- It provides a systematic review of UOG extraction regulations to protect groundwater resources. During this review, different regulatory approaches and currently available regulations used internationally to protect groundwater resources during UOG extraction were analysed, structured and categorized into three main regulatory approaches – command-and-control, market-based and voluntary. Currently, regulations to protect groundwater resources are fragmented (Jackson et al., 2013; Schug et al., 2015). Although some papers address regulatory aspects, they predominantly focus on specific aspects of UOG extraction, for instance public disclosure (Gagnon et al., 2015; Kinchy & Schaffer, 2018), general groundwater monitoring (Soeder, 2015) or baselines (King, 2016; Gagnon et al., 2015; Montcoudiol et al., 2019). No detailed in-depth analysis of regulatory approaches and specific regulations needed to protect groundwater, could be found.

- It organizes the three main regulatory approaches, its regulatory areas and its sub-regulations into a coherent logical structure by proposing a regulatory framework to protect groundwater resources during UOG extraction.
- It assesses the usefulness and enforceability of the UOG extraction regulations proposed under the regulatory framework to protect groundwater resources during UOG extraction in South Africa. It also recommends specific regulations under each regulatory area and tests these recommendations with the South African groundwater community, who would ultimately be tasked with protecting groundwater resources. South Africa currently has no fracking-specific regulations to protect groundwater resources and the single foray into developing such regulations failed dismally (RSA, 2019b)
- The above research is used to provide guidance on the policy direction for South African energy development and to outline a process for developing UOG extraction regulations to protect groundwater resources. Recommended UOG extraction regulatory approaches, regulatory areas and related enforcement mechanisms are also proposed specifically for the South African context.

This research could assist South Africa in promulgating UOG extraction regulations that will protect groundwater resources effectively. The 'fracking regulations' that were drafted in 2015, was a quick and dirty job and failed to gain the trust of the groundwater community (RSA, 2019b).

The proposed regulatory framework and the recommended regulations contained therein is generalisable to other countries where UOG extraction regulations to protect groundwater resources still need to be drafted, or where such regulations must be amended. Only some of the regulations are specific to South Africa, and include regulations on South Africa's institutional arrangements, its specific legislative framework and its specific geology and hydrogeology.

Format of the dissertation

The dissertation consists of a collection of publishable articles that form part of one research work to:

1. Determine the knowledge of regulators on groundwater impacts from UOG extraction and its regulation,
2. Develop a UOG extraction regulatory framework to protect groundwater resources
3. Test the regulatory framework for relevancy and enforcement in the South African context
4. Recommend energy policy considerations, a process for developing UOG extraction regulations, regulatory areas and related regulations and

enforcement mechanisms to ensure the proper enforcement of regulations to protect groundwater resources.

The targeted journals and author contributions are discussed below.

Targeted journals

The journals that were targeted for the articles presented in this dissertation, and its publication status, can be seen in Table 1-1:

Table 1-1: Targeted journals for articles in this dissertation

Article	Targeted journal	2018 Impact factor	Quartile range	Status
Assessing the existing knowledge base and opinions of decision makers on the regulation and monitoring of unconventional gas mining in South Africa	Water International	1.885	Q2 in Civil Engineering Q3 in Water Resources	Published
Regulations to protect groundwater resources during unconventional oil and gas extraction using fracking	Wiley Interdisciplinary Reviews: Water	4.436	Q1 in Environmental Sciences Q1 in Water Resources	Published
Getting fracking regulations right to protect groundwater resources	Nature Geoscience	14.480	Q1 in Multidisciplinary Geosciences	Submitted

Author contributions

The author contributions can be seen in Table 1-2, where SE = Surina Esterhuyse, NR = Nola Redelinghuys, MK = Marthie Kemp, DV = Danie Vermeulen and JG = Jan Glazewski.

Table 1-2: Author contributions

Articles	Author contributions
Assessing the existing knowledge base and opinions of decision makers on the regulation and monitoring of unconventional gas mining in South Africa	SE: Conceptualize the research, develop the general survey questionnaire and specifically the water-related questions, execute the survey, analyze the data, write the paper. NR: Assist with questionnaire development (specifically socio-economic questions) and co-write paper.

Articles	Author contributions
	MK: Assist with questionnaire development (specifically biodiversity questions) and co-write paper.
Regulations to protect groundwater resources during unconventional oil and gas extraction using fracking	SE: Conceptualize the research, perform the research, synthesize the different regulations into one coherent regulatory framework, write the paper. DV: Review first drafts of paper and contribute to final paper. JG: Review first drafts of paper and contribute to final paper.
Getting fracking regulations right to protect groundwater resources	SE: Conceptualize the research, develop the survey questionnaire, execute the survey, analyze the data, write the paper. DV: Review the questionnaire, review first drafts of paper and contribute to final paper. JG: Review the questionnaire, review first drafts of paper and contribute to final paper.

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Chapter 2 - Detailed background to the study

This chapter provides a detailed background to the PhD study, by firstly describing the complexities of energy and water in South Africa, which also sets the backdrop for why this PhD study is important. It also provides a detailed timeline of events that led the author to initiate and complete this study into developing a regulatory framework aiming to protect groundwater resources. Finally, it discusses the current South African legal framework and identifies shortcomings in terms of groundwater resources protection, highlighting which aspects I will focus on in my study.

Energy and water – a complex interplay during unconventional oil and gas extraction

Sufficient energy supply is essential for the growth of any economy. From a global perspective, energy demand will grow 20–30% or more through 2040 and beyond, led largely by fossil fuels (Newell et al., 2019). South Africa must also address the ever-increasing need for energy to fuel economic growth. The country currently relies on coal for over 90% of its electricity generation (Bohlmann et al., 2018) and imports the majority of its fuel. The development of UOG resources have the potential to provide the much needed energy, while simultaneously significantly reducing the import bill by producing fuel from UOG resources, making it an attractive energy option. Because of this, it has been incorporated into the integrated resource plan (IRP) of 2019 (RSA, 2019a).

However, there is not enough information on UOG extraction and fracking, a technology novel to South Africa, to guide South African policymakers and regulators. The novelty of UOG extraction lies in the technology used to extract the resources, called hydraulic fracturing (or fracking), that has not yet been used to extract oil and gas in South Africa. Fracking is used to stimulate the oil and gas reservoir to release the oil and gas which is trapped in the geological formation. During the fracking process, a mixture of sand, water and chemicals (fracking fluid) is pumped under high pressure into the deep rock formations, to crack open the micro-fractures in the rock and release the trapped gas.

The development of UOG resources using fracking, can have benefits for the South African economy in terms of job creation and energy supply, but its socio-economic and environmental impacts are often questioned. Among the different environmental impacts (on air quality, biodiversity and public health), impacts on water resources is foremost in the mind of the ordinary South African citizen. This comes as no surprise since South Africa is one of the most water-scarce countries in the world (Rosa et al., 2018). Water supply for fracking can, therefore, be a serious limiter of economic development, especially in the case of UOG development. In a recent strategic environmental assessment (SEA) that was conducted for Shale Gas Development in the Karoo, water supply for fracking (when considered in conjunction with future population growth and climate variability linked to climate change) was identified as the single most important limitation to UOG development in South Africa (Hobbs et al., 2016).

A brief history of unconventional oil and gas extraction developments in South Africa

Oil and gas were first discovered in the shale rock of the Karoo basin the 1960s by the Southern African Oil Corporation (Soekor), see Table 2-1. At that time, the technology (hydraulic fracturing) did not yet exist to economically extract these resources and they were deemed unrecoverable. However, with the advent of hydraulic fracturing in the late 1980's (USGS, 2019), it became possible to extract such tightly bound oil and gas. The first applications for UOG resources extraction were lodged with the petroleum agency of South Africa (PASA) by Shell in 2010. This resulted in a public outcry against fracking, mainly due to concerns over impacts on water resources. Based on the mobilization of activist groups such as Treasure the Karoo Action Group (TKAG), the South African government instated a temporary moratorium on UOG resources development to investigate the biophysical and socio-economic impacts of UOG extraction. A report submitted by this task team, was accepted by parliament and the moratorium was lifted. Government, under the Department of Mineral Resources, then published draft 'fracking regulations' to address environmental concerns over fracking. These draft regulations received a plethora of comments from concerned scientists and legal experts, stating that it failed to effectively protect the environment, specifically water resources. In spite of this, government promulgated the final fracking regulations, that were published under Regulation R.466 in Government Gazette No 3855 of 3 June 2015 (RSA, 2019b). The final regulations still failed to address various concerns initially highlighted on the draft regulations, including:

- The proposed technical regulations for the petroleum exploration and exploitation published by the Minister of Mineral Resources on 3 June 2015, attempted to regulate all environmental impacts of fracking through the Mineral and Petroleum Resources Development Act 28 of 2002 (MPRDA) (RSA, 2002). A suite of water and environmental laws are however designed to manage and limit the environmental impacts of such an activity. This made the regulations *ultra vires*.
- Following from the above, the environmental impacts of fracking should have been regulated by the **appropriate competent authority or authorities** in an integrated and cooperative manner, with the allocation of appropriate resources for enforcement.
- Therefore, regulations to protect groundwater resources must be promulgated not only under the MPRDA, but also under the National Environmental Management Act 107 of 1998 (NEMA) (RSA, 1998a), the National Water Act 36 of 1198 (NWA) (RSA, 1998b) and the National Environmental Management: Waste Act 59 of 2008 (NEMWA) (RSA, 2008).
- The fracking regulations were also inadequate in its requirements for water quality monitoring, setback distances to protect drinking water resources and in its recommendations for using specific industry standards instead of the best international practices, and therefore would have failed to protect groundwater resources effectively.
- The fracking regulations did not provide for public access to environmental information, licences and compliance and performance data against acceptable standards (CER, 2014).
- The fracking regulations had no penalties for non-compliance, making the regulations more of a 'recommendation', without any means of enforcing the

regulations. The Centre for Environmental Rights (CER, 2014) recommended, apart from the usual remedies such as suspension or revocation of licences, significant administrative penalties for transgressions, up to a maximum of the higher of R20 million or 10% of turnover or 10% of gross asset value, whichever is the highest.

Because of the failure of government to protect South Africa's scarce water resources during fracking, farmers in the Eastern Cape took the Minister of Mineral Resources to court in November 2015. These groups applied to the court to set aside the fracking regulations. During the same month, applicants from the Treasure the Karoo Action Group (TKAG) and Afriforum launched a similar application.

On Tuesday, 17 October 2017, the 2015 decision by the Minister of Mineral Resources to enact Regulations for Petroleum Exploration and Production (commonly known as the Fracking Regulations) was retrospectively set aside by Judge Bloem in the Eastern Cape High Court, in the case of J*ohn Douglas Stern v the Mineral of Mineral Resources, (2015) EC* (Case No. 5762/2015) (RSA, 2017) In the case of the TKAG application, the Pretoria High Court came to a contrary conclusion and dismissed the TKAG application. Both courts granted leave to appeal to the South African Supreme Court of Appeal (SCA).

The Fracking Regulations, which have been in place since June 2015, were viewed as a vital statutory requirement for the granting of shale gas exploration and production rights in South Africa. When the judge of the Eastern Cape High court reached his decision, the judge accepted the "undisputed major possible impacts of shale gas development with respect to air, soil and groundwater contamination due to uncontrolled gas or fluid flows arising from blow-outs or spills, interception of naturally occurring fractures and fissures, well failures, corrosion of casings, cementing failure, leaking fracturing fluid and uncontrolled waste water discharge". Advocates for the applicants argued that the Minister of Mineral Resources was not "authorised to make the Fracking Regulations, that it contravened the provisions of the National Environmental Management Act and the National Water Act and that their making was procedurally unfair". The Eastern Cape High Court agreed and scrapped the Fracking regulations.

Both the Minister of Mineral resources and the TKAG appealed their respective rulings. The appeal by the Minister of Mineral resources was dismissed (with costs), and the appeal by the TKAG was sustained by the Supreme Court of Appeal on 4 July 2019 (RSA, 2019b). The SCA held that:

- "The implementation of the One Environmental System agreement through, inter alia amendments to the MPRDA and NEMA, divested the Minister of Mineral Resources of the power to make regulations regarding environmental matters.
- The greater part of the Petroleum regulations regulated environmental matters which only the Minister of Environmental Affairs, and not the Minister of Mineral Resources, had the power to regulate. This meant that the majority of the provisions of the Petroleum regulations were *ultra vires*.

- It was not practical to separate the good from the bad and, accordingly, that the Petroleum regulations must be set aside in their entirety. It held that exploration for petroleum by fracking should not take place before such time that it is lawfully regulated" (RSA, 2019b).

South Africa published the "Draft upstream petroleum resources development bill" on 24 December 2019 to lay the foundation for UOG extraction in South Africa (RSA, 2019c). The aim of the bill is to provide equitable access to and sustainable development of SA's petroleum resources. At the time of writing, this bill was still out for public comment and was not promulgated yet. The only provisions related to groundwater protection, is that any water use during petroleum exploration or development are subject to licensing under the NWA, and that obtaining the relevant environmental authorisations is a condition prior to the issuing of any permit or right. It also provides for the establishment of a 'Petroleum development and environmental committee' that must amongst others include representatives from the DEA and DWS. This committee must advise the Minister of DMR on objections received to the granting of an exploration or production right and must make recommendations to the Minister on the expropriation of land for petroleum exploration or development.

Table 2-1: Timeline of petroleum exploration and related legal developments in South Africa

Date	**Event**
1965	The Southern Oil Exploration Corporation (SOEKOR) is established in 1965 with the mandate to identify the existence of economic volumes of oil and gas in South Africa. Seismic surveys and exploratory deep drilling were done between 1965 and 1972 in the southern part of the Main Karoo Basin. Exploration drilling indicated the presence of (at that time economically unrecoverable) gas within the Ecca shales (Rowsell & De Swardt, 1976).
1976	The Council for Geoscience (CGS) investigated the oilshale potential of the Whitehill Formation on the western flank of the Karoo Basin. They drilled 16 core boreholes in the area between Strydenburg and Hertzogville. This study, together with all available borehole logs and cores over the whole extent of the Whitehill Formation, and that intersected the Whitehill Formation, form the basis of the majority of shale gas resource estimates for the Karoo that have been made to date (Hobbs et al., 2016)
2011	The USA Energy Department estimates that the Karoo basin has 485 trillion cubic feet (TCF) of Technically Recoverable gas (USEIA, 2011)
2012	The Petroleum Agency of South Africa (PASA) provides an estimate of the potential Karoo basin shale gas resource to assess the reliability of the USA Energy Department's 2011 estimate (Hobbs et al., 2016)
2009-2010	The Petroleum Agency of South Africa (PASA) grants technical cooperation permits to Falcon Oil and Gas, Shell B.V. International and Sasol-Chesapeake-Statoil consortium to conduct an assessment (PASA, 2019)

Date	Event
December 2010	Shell submits exploration licence applications (de Wit, 2011)
February 2011	Activists groups are mobilised and the Treasure the Karoo Action Group (TKAG) is established (TKAG, 2019)
April 2011	The moratorium on oil and gas exploration in South Africa is instated (Hedden et al., 2013)
11 November 2011	The South African government releases the National Development Plan, stating that shale gas could contribute to electricity generation in South Africa (NPC, 2011)
Feb- July 2011	Lobbying of activist groups against shale gas continues to intensify, fuelled my media debates (Hedden et al., 2013)
September 2012	Cabinet approves recommendations of the task team and the moratorium on oil and gas exploration is lifted (RSA, 2019b)
15 October 2013	The draft regulations on hydraulic fracturing 'the fracking regulations' is published (RSA, 2013)
December 2013	The Centre for Environmental Rights, academia and other stakeholders comment on the draft fracking regulations, view it as inadequate to protect natural resources and call for the drafting of regulations that would do so (CER, 2014)
8 December 2014	Instatement of the "One Environmental System" (DEA, 2019)
3 June 2015	The final 'fracking regulations' is promulgated by the Minister of Mineral Resources under Regulation R.466 in Government Gazette No 3855 dated 3 June 2015 (RSA, 2015b)
16 October 2015	The Department of Water and Sanitation declares the "Exploration and or production of onshore naturally occurring hydrocarbons that requires stimulation, including but not limited to hydraulic fracturing and or underground coal gasification, to extract, and any activity incidental thereto that may impact detrimentally on the water resource" as a controlled activity (RSA, 2015a)
17 October 2017	The Eastern Cape High court sets the 'fracking regulations' aside in the case of *John Douglas Stern and others v the Mineral of Mineral Resources* (RSA, 2017)
November 2015	Stern and others apply to the Eastern Cape High court and TKAG and Afriforum apply to the Pretoria High court to set aside the fracking regulations (RSA, 2019b)
16 May 2018	The Pretoria High court dismisses the application by TKAG and Afriforum to set aside the fracking regulations in the case of *Treasure the Karoo Action Group (TKAG) and others vs the Minister of Mineral Resources* (RSA, 2018)
4 July 2019	The Supreme Court of Appeal dismisses the appeal from the Minister of Mineral Resources in Case Number 1369/2017 and allows the appeal by TKAG in Case Number 790/2018 (RSA, 2019b). The fracking regulations are hereby set aside in its entirety. The court also indicated that the commencement of any UOG extraction activities should not be allowed before before regulations to protect natural resources are in place.

Date	Event
24 December 2019	The draft upstream petroleum resources development bill is published (RSA, 2019c)

Groundwater resources protection during unconventional oil and gas extraction and the South African legal framework

In South Africa, the Constitution with its Bill of Rights is the overarching legislation. Pertinent to groundwater protection during UOG extraction, the Constitution prescribes various rights, including the environmental right, the right to sufficient water, the right to access to information and the right to just administrative action. The Environmental Right states that:

"Everyone has the right:

(a) to an environment that is not harmful to their health or well-being; and

(b) to have the environment protected, for the benefit of present and future generations,

through reasonable legislative and other measures that:

(i) prevent pollution and ecological degradation;

(ii) promote conservation; and

(iii) secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development"

This environmental right and the notion of 'ecologically sustainable development and use of natural resources' is contained in the MPRDA. The MPRDA is the cornerstone legislation for UOG exploration and extraction and has as one of its objectives to:

"give effect to section 24 of the Constitution by ensuring the nation's mineral and petroleum resources are developed in an orderly and ecologically sustainable manner while promoting justifiable social and economic development"

Apart from an environmental right, the Bill of Rights also include other rights relevant to groundwater protection during UOG extraction, specifically the right to sufficient water, which requires government to 'take reasonable legislative and other measures, within its available resources', to achieve this and other rights.

Another right that is relevant to groundwater resources protection during UOG extraction, is the right of 'Access to Information'. This right provides that interested and potentially affected parties have the right not only to information held by the State, but also to information held by private parties (including UOG extraction companies). This right is subject to the proviso that the information is required to protect any other right in the Bill of Rights of the requesting party; if the request for information were for environmental reasons, the environmental right would cover this requirement. This right is extremely important for ensuring groundwater resources protection, given the fact that legal disclosure of UOG extraction activities are required to ensure compliance with regulations, see Chapters 4 and 5.

The right to 'Just Administrative Action', detailed in section 33 of the Constitution, is also relevant to groundwater resources protection. This right states that 'everyone has the right to administrative action that is lawful, reasonable and procedurally fair'. This right includes the requirement that decision-making in complex matters such as UOG extraction, where different spheres of government are involved, be made in a well-informed and integrated manner.

Lastly, Chapter 3 of the Constitution focuses on ‘Co-operative government’, which is a particularly important requirement because the different laws relevant to UOG extraction in South Africa are administered by different national government departments, each with its own authorisations and permitting requirements. The relevant laws that apply to groundwater protection during UOG extraction in South Africa, include:

- The Mineral and Petroleum Resources Development Act 28 of 2002 (RSA, 2002)
- The National Environmental Management Act 107 of 1998 (RSA, 1998a)
- The National Water Act 36 of 1998 (RSA, 1998b)
- The National Environmental Management Waste Act 59 of 2008 (RSA, 2008)

The legislative powers in South Africa are shared between national government and different spheres of local government. Cooperative government is required for dispute resolution between the different spheres of government. The Constitution requires that each of these parties must exercise their powers and perform their functions within their respective mandates, but that none of these entities may encroach upon the geographical, functional or institutional integrity of government in another sphere. There are 3 key national departments that must therefore cooperate in the regulation of UOG extraction to protect groundwater resources, including:

- the Department of Mineral Resources (DMR) which administers the MPRDA, and under which UOG extraction companies must apply for exploration and eventually production licences.
- the Department of Water and Sanitation (DWS) which administers the National Water Act 36 of 1998. It must issue water use licences
- the Department of Environmental Affairs (DEA) which administers the NEMA and the National Environmental Management Waste Act (NEMWA), relevant to groundwater resources protection during UOG extraction

The issue of co-operative government between municipal, provincial and national spheres of government is especially important for UOG extraction since there has been tension between the DMR and the DEA regarding their respective legislative mandates and competencies to either exclusively or jointly regulate the environmental impact of mining. The instatement of the One Environmental System (OES) aims to address these tensions. It requires that all aspects related to the environment be ‘regulated through one environmental system’, namely NEMA. It states that that ‘all environmental provisions would be repealed from the MPRDA; that the Minister responsible for environmental affairs would set the regulatory framework and norms and standards, and that the Minister responsible for mineral resources would implement the provisions of NEMA as well as subordinate legislation as far as it relates to prospecting, exploration, mining or operations’. Based on the OES, the SCA judgment states that the Minister of Mineral Resources had no legal authority to promulgate fracking regulations that addressed all aspects (including mineral extraction, environmental matters and water resources), and that the overarching responsibility for such regulations lies with the Minister of Environmental Affairs (RSA, 2019b). It would also be important for each of these departments to draft their own

UOG extraction regulations according to their mandates, and cooperate in the enforcement of such regulations. As will be seen in Chapter 5, cooperative government is non-negotiable to achieve effective groundwater resources protection.

The next section discusses laws and regulations relevant to groundwater resources protection during UOG extraction in South Africa.

Laws relevant to groundwater protection during unconventional oil and gas extraction in South Africa

International customary law, and international conventions and treaties are important for groundwater resources protection in the South African context. Important international customary law principles include the polluter pays principle, the precautionary principle and the preventive principle. These principles have been enumerated in Section 2 of the NEMA (RSA, 1998b). These principles apply to 'the actions of all organs of state that may significantly affect the environment', and not just the Department of Environmental Affairs (DEA), which administers this particular statute.

In South Africa, the Constitution of the Republic of South Africa (Act 108 of 1996) is the supreme law of South Africa and the Bill of Rights, contained within it, is the cornerstone of democracy in South Africa. The other acts relevant to UOG extraction in South Africa, are the National Water Act, the Mineral and Petroleum Resources Development Act and the National Environmental Management Act. These are briefly described below.

The National Water Act

The National Water Act 36 of 1998 (NWA) (RSA, 1998b) provides legislation to ensure that the nation's water resources are protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner, for the benefit of all persons and in accordance with its constitutional mandate. The act defines a "water resource" to include a "watercourse, surface water, estuary, or aquifer; and watercourses include rivers, springs, wetlands, dams or any collection of water that the Minister declares to be a watercourse". Water resources are primarily managed and protected in the NWA by the need to obtain a license for permissible "water use", except in cases where a license is not required, for example where a 'General Authorisation' (GA) or "schedule 1 use" (water use for low volume, low-impact activities such as domestic use or livestock watering) has been issued.

The DWS is in the process of formulating its own regulations regarding oil and gas exploration and development (thus including UOG extraction). It has invoked Section 38 of the NWA to declare "The exploration and or production of onshore naturally occurring hydrocarbons that requires stimulation, including but not limited to fracking and or underground gasification, to extract, and any activity incidental thereto that may impact detrimentally on the water resource." as a controlled activity. This was published in General Notice No. 999 (RSA, 2015a) as Section 37 (e) of the NWA. The declaration of unconventional oil and gas extraction as a controlled activity means that water use licenses will be required for UOG extraction.

GN 704/1999 (RSA, 1999) is one of the key regulations for groundwater resources protection during UOG extraction under the NWA. These regulations focus on water use for mining and related activities. The regulations specify restrictions on the locality of an operation (regulation 4) and on the use of materials (regulation 5) and requires the protection of water resources (regulation 7). Restrictions relevant to groundwater resources protection include:

Regulation 4: “No mine-related activity may be placed ‘…within a horizontal distance of 100 m from any … borehole or well, excluding boreholes or wells drilled specifically to monitor the pollution of groundwater, or on water-logged ground, or on ground likely to become water-logged, undermined, unstable or cracked’”, and

Regulation 5: “…no person in control of a mine or activity may use any residue or substance which causes or is likely to cause pollution of a water resource…”.

The Mineral and Petroleum Resources Development Act

The exploration and development of mineral and petroleum resources is legislated in the Mineral and Petroleum Resources Development Act 28 of 2002 (MPRDA) (RSA, 2002). All environmental management aspects, however, are dealt with in terms of the OES. In terms of the OES, the environmental aspects associated with any new applications related to UOG development will be dealt with in terms of the provisions of NEMA, with DMR being the competent authority.

In 2015 specific regulations to govern petroleum exploration and production have been promulgated under the MPRDA – i.e. Regulations for Petroleum Exploration and Production, 2015 (GN R466). These regulations prescribed standards and practices to ensure the safe exploration and production of oil (petroleum and other liquid hydrocarbons) and gas (coal bed methane (CBM) and shale gas), and addressed all mining and environmental aspects. These regulations have however been set aside by the Supreme Court of Appeal.

The National Environmental Management Act

The requirements for Environmental Impact Assessment (EIA) under the National Environmental Act 107 of 1998 (NEMA) (RSA, 1998a) are also applicable to groundwater. The principles in Section 2 of the NEMA apply to both the MPRDA and the NWA. These include:

- The precautionary ("risk-averse and cautious") approach, specifying that a risk-averse cautious approach is applied to development, which takes into account the limits of current knowledge about the consequences of decisions and actions.
- The polluter pays principle, specifying that the costs for remedying pollution, environmental degradation and consequent adverse health effects be paid for by those responsible for harming the environment.
- Co-operative government is required under Chapter 3 of the NEMA, and would be important if fracking is to be managed effectively between different spheres of government.

The National Environmental Management Waste Act

The National Environmental Management Waste Act 59 of 2008 (NEMWA) (RSA, 2008) regulates the generation, storage, treatment, disposal and transportation of waste water generated by UOG. The NEMWA requires a license for listed waste activities such as the generation, collection, handling, storage, treatment and disposal of waste. This act defines hazardous waste as “any waste that contains organic or inorganic elements or compounds that may, owing to the inherent physical, chemical or toxicological characteristics of that waste, have a detrimental effect on health or the environment". Flowback and produced water can be classified as hazardous waste if it contains NORMs, and would therefore also be regulated under this act.

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Chapter 3 - Assessing the existing knowledge base and opinions of decision makers on the regulation and monitoring of unconventional gas mining in South Africa

Modified from Water International 38(6), 687-700, 2013

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The survey instrument that was used for data collection can be seen in Appendix 1.

Abstract

A policy vacuum exists in relation to the exploration and mining of unconventional gas in South Africa, with a recent survey showing that 86% of the respondents did not know what hydraulic fracturing entails. We conducted a study to determine the opinion of decision makers involved in formulating policy and regulating mining activities related to shale gas mining in South Africa, as this was not covered in the aforementioned survey. Our results demonstrate that the regulation of shale gas mining in South Africa is viewed as extremely important and identifies possible regulatory and monitoring tools to assist in governing this activity.

Keywords: knowledge base; policy; regulation; monitoring; hydraulic fracturing; unconventional; gas; mining; South Africa

Introduction

Unconventional gas mining by means of hydraulic fracturing is a new and unprecedented activity in South Africa that may result in a variety of impacts on both the socio-economic and biophysical environments. Shale gas mining and coalbed methane mining form part of unconventional gas mining, where gas reservoirs need to be stimulated in order to release the gas from the geological formations. This stimulation is usually achieved by means of hydraulic fracturing, although acidizing may also be used to stimulate gas production. Hydraulic fracturing entails the pumping of hydraulic fracturing fluid into a geological formation that contains gas and/or oil to increase its permeability. Various technologies can be combined or used separately during the hydraulic fracturing process. It may involve the use of only water (for water well stimulation) or a combination of any or all of four separate technologies, viz. directional drilling, the use of high volumes of fracturing fluids, the use of slickwater additives and the use of multi-well drilling pads. Hydraulic fracturing as used in the oil and gas industry commonly includes the usage of 0.5–2% chemical additives and large volumes of proppant (to keep the fracture zones that produce the oil or gas open), as well as large volumes of fluid (Broomfield, 2012).

South Africa is currently heavily dependent on fuel imports, which represented 21.4% of total merchandise imports in 2011 (World Bank, 2012). Production of fuel from unconventional gas could reduce the import bill significantly, making unconventional gas an attractive energy option. However, in pursuing unconventional gas, it is also important to consider the role that renewable energy resources may play in South Africa. In addition, water availability may significantly limit the expansion of energy sources (DOE, 2011), while the development of energy sources may also negatively impact on water security (Martin & Fischer, 2012).

Currently, a policy vacuum exists in relation to the exploration and mining of shale gas in South Africa (Havemann, 2011). However, these lacunae in the law do not exist only in South Africa. Even in the United States there is a drive to introduce fracking-specific legislation to areas that develop shale gas resources (Havemann, 2011). During 2012 at least 119 bills were introduced to address hydraulic fracturing in the United States (Pless, 2012), which illustrates the legal complexities related to regulating hydraulic fracturing.

A survey performed in South Africa by Ipsos Markinor for Shell in February 2012 found that 86% of respondents did not know what hydraulic fracturing entails (Harris & Fleetwood, 2012). This is problematic from the perspective of informed decision making, as decisions need to be based on knowledge of the issue at hand. However, the knowledge and opinions of decision makers involved in formulating policy and regulating mining activities related to shale gas mining were not covered in the mentioned survey.

Study objectives

This study aimed to identify the current knowledge base of decision makers regarding the impacts of shale gas mining by means of hydraulic fracturing and their opinions on the regulation of shale gas mining in South Africa. To meet this aim the following objectives were set:

- Determining the existing knowledge base of government regulatory entities and key stakeholders regarding shale gas mining and hydraulic fracturing
- Determining key informants' views on the importance of regulating and monitoring specific environmental and social impacts related to shale gas mining and hydraulic fracturing
- Determining key informants' views on South Africa's capacity to regulate and monitor the impacts related to shale gas mining
- Determining possible regulatory and monitoring tools that can assist in governing this activity and identify possible regulatory bodies that should be responsible for the execution of various activities
- Identifying the departments or entities that, according to key informants, should primarily be responsible for specific regulatory activities
- Testing key informants' opinion on whether South Africa will be able to effectively regulate shale gas mining.

Methodology

Data was gathered by means of a structured questionnaire, administered via e-mail.

A purposive sample was drawn that aimed to include a wide variety of stake-holders from relevant government departments, scientific and academic institutions, non-governmental organizations and academia. Thus, the intent was not to obtain a generelisable sample, but rather to purposefully select institutions and key informants within these institutions who could ultimately play an integral part in decision making on shale gas mining in South Africa. The institutions purposively targeted were the South African Departments of Water Affairs (DWA), Mineral Resources (DMR), Environmental Affairs (DEA), and Agriculture, Forestry and Fisheries (DAFF), the Petroleum Association of South Africa (PASA), the Council for Geoscience (CGS), the Council for Scientific and Industrial Research (CSIR), the Centre for Environmental Rights (CER), the South African Earth Observation Network (SAEON), the World Wildlife Fund (WWF), the University of Cape Town (UCT), the University of the Free State (UFS), Nelson Mandela Metropolitan University (NMMU), and the Tswane University of Technology (TUT), as well as independent consultants in the field of environmental management. From these targeted institutions key informants were then purposively targeted, based on their knowledge and expertise on shale gas mining in South Africa. The majority of key informants (76%) had more than five years' experience in their respective fields.

Fifty-two questionnaires were sent out, and 25 respondents completed the questionnaire. A number of respondents declined to complete the questionnaire, citing sensitivity to the nature of the questions. Respondents were fairly evenly distributed among the contacted organizations. Twenty per cent of respondents came from the Department of Water Affairs, another 20% from consultants; 16% came from the Department of Environmental Affairs, and 12% each from science councils, academic institutions and the Department of Agriculture, Forestry and Fisheries. Disappointingly, only 4% of respondents came from the Petroleum Association of South Africa, which is a key institution in providing licenses for shale gas exploration and the regulation of petroleum related activities in South Africa.

After the questionnaires were received back, the completed questionnaires were coded and data were analysed descriptively with the aid of IBM SPSS Statistics (version 20).

Results and discussion

The results will be discussed by looking at respondents' extent of knowledge on hydraulic fracturing, respondents' perceptions of important aspects to be monitored, the perceived capacity to deal with the impacts of hydraulic fracturing, the tools to help address the regulation of shale gas mining, and respondents' opinion about South Africa's ability to effectively regulate this activity.

Extent of knowledge on hydraulic fracturing

Although 60% of respondents indicated that they have extensive knowledge on the environmental impacts of mining in general, only 28% of respondents indicated extensive knowledge on the impacts of shale gas mining, and 36% on the environmental impacts of hydraulic fracturing specifically. When asked about their extent of knowledge on the regulation of shale gas mining internationally and in South Africa, 52% of respondents indicated limited knowledge on environmental regulation of hydraulic fracturing internationally, and 44% indicated limited knowledge on hydraulic fracturing in South Africa.

These statistics indicate the unprecedented nature of unconventional gas mining by means of hydraulic fracturing in South Africa. They can be explained by the fact that for many of the decision makers in South Africa there was until recently no need to familiarize themselves with issues pertaining to monitoring and regulating this activity.

Respondents' satisfaction with their current level of knowledge on shale gas mining was also tested. Half of the respondents indicated that they are not satisfied with their current level of knowledge, while 46% indicated that they are somewhat satisfied. This indicates a definite need for more in-depth information on shale gas mining in order to properly regulate and monitor this activity in South Africa. The various sources used by respondents to inform their knowledge on shale gas mining can be seen in Table 3-1.

Table 3-1: Sources of knowledge

	Type of knowledge resource	Extent to which respondents used various knowledge sources		
		Not at all	**Somewhat**	**Large extent**
Scientific Resources	**Government reports**	n =10 41.7%	n = 5 20.8%	n = 9 37.5%
	Research reports	n = 8 33.4%	n = 7 29.2%	n = 9 37.5%
	Scholarly articles	n = 10 41.7%	n = 7 29.2%	n = 7 29.2%
	Combined percentage of respondents who used Scientific sources	*38.9%*	*26.4%*	*34.7%*
Popular Media Sources	**Internet sources**	n = 5 20%	n = 8 32%	n = 12 48%
	Printed media	n = 3 12.5%	n = 11 45.8%	n = 10 41.7%
	Verbal media	n = 11 45.8%	n = 10 41.7%	n = 3 12.5%
	Visual media	n = 8 34.8%	n = 8 34.8%	n = 7 30.4%
	Talks and presentations	n = 8 33.4%	n = 9 37.5%	n = 7 29.2%
	Other	n = 3 30%	n = 2 20%	n = 5 50%
	Combined percentage of respondents who used Popular media sources	*29.4%*	*35.3%*	*35.3%*

The usage of popular media sources was slightly higher than the usage of scientific sources, which can be a function of the lack of availability of scientific resources on unconventional gas mining and hydraulic fracturing, specifically pertaining to the South African situation. Various scientific reports reflect on the polarized nature of scientific data sources (DMR, 2012) and also question the validity of certain scientific reports (Broomfield, 2012). Popular media resources are not the most reliable data sources, since the media often rely on subjective views fueled by public opinion. In the case of shale gas mining, the lack of scientific data at this stage creates a fertile breeding ground in the media for stirring sentiments and emotions on the issue. From the data it is clear that it is very difficult to come by reliable scientific resources, compelling decision makers to rely on less objective media sources.

Important aspects to monitor and regulate during shale gas mining, as perceived by respondents

Participants were asked to rate which aspects they regard as important to monitor and regulate during shale gas mining activities. The aspects that were rated by respondents as most important are reflected in Table 3-2.

Table 3-2: Important aspects to monitor and regulate during shale gas mining, as perceived by respondents

Percentage of respondents who indicated an aspect as important to regulate and / or monitor	Activity to regulate and / or monitor
100%	• Regulating contamination arising from hydraulic fracturing • Monitoring volumes of water usage • Regulating the disclosure of chemicals
96%	• Regulating and monitoring land use planning regarding conservation areas • Regulating the construction of gas mining wells to be compliant with proper construction standards • Monitoring air quality impacts from shale gas mining • Regular testing of well integrity during repeated fracking of the same wells • Establishing baseline water quality before allowing hydraulic fracturing • Monitoring the usage of fracking fluids
92%	• Determining the location of seismogenic (earthquake) zones to avoid drilling into seismically active zones that could trigger possible earthquakes • Monitoring biodiversity loss
88%	• Regulating the use of "green" chemicals
84%	• Monitoring changes in the disease burdens of communities affected by shale gas mining • Regulating and monitoring infrastructure development
80%	• Monitoring spatial development regarding urbanization • Ensuring that jobs created are filled by South Africans

All key informants indicated as important the monitoring of contamination arising from hydraulic fracturing, the monitoring of volumes of water used during unconventional gas mining, and the regulation of the disclosure of chemicals used during hydraulic fracturing.

In a water-stressed country such as South Africa, it is not surprising that the regulation and monitoring of water-related issues are seen as paramount. In the drier parts of the US, and in dry countries such as Australia, the water volume used for hydraulic fracturing is also a key issue (Australian National University [ANU], 2012; Rahm, 2011; Williams et al., 2012). Sourcing of water for fracturing operations may have large impacts on the quality and quantity of both surface water and groundwater (Lechtenböhmer et al., 2011; Rahm & Riha, 2012; USEPA, 2011b; Williams et al., 2012).

Authors such as Rahm (2011), Furlow and Hays (2012), Sakmar (2011) and Pless (2012) all identify the disclosure of chemicals used in the hydraulic fracturing process as important. In practice, however, hydraulic fracturing chemicals are not disclosed consistently. For example, the state of Colorado (USA) requires disclosure of chemicals and concentrations added to fracking fluids to physicians and regulators only in an emergency event, thereby preserving drillers' trade secrets, while Wyoming requires full public dis-closure of chemical additives (Rahm, 2011). In 2011, House Bill 3328 (Texas Legislature Online, 2011) was passed in Texas – the first hydraulic fracturing disclosure legislation and regulation specific to hydraulic fracturing in Texas (Furlow & Hays, 2012). The US Congress introduced in 2009 the Fracturing Responsibility and Awareness Act (H.R. 1084) (FRAC Act) (United States Congress, 2009), which aims to define hydraulic fracturing as a federally regulated activity under the United Sates Safe Drinking Water Act (Furlow & Hays, 2012; Sakmar, 2011). South Africa would be prudent to draft regulations that require disclosure of chemicals used in fluids during drilling or fracturing operations to relevant institutions.

Establishing baseline water quality before allowing hydraulic fracturing was identified as important by 96% of the participants, indicating that key informants are aware of the window of opportunity to establish a monitoring baseline in terms of hydraulic fracturing. This activity is very important if landowners want to determine whether groundwater contamination is due to unconventional gas mining operations or to another cause. In the US, the states of Colorado, Ohio and Pennsylvania require that operators conduct baseline water testing (Government Accountability Office [GAO], 2012a).

Cases of alleged groundwater contamination in the US could usually not be proven because officials cannot link changes in groundwater quality to oil and gas activities, and can thus take no legal action. This is often due to the fact that no baseline data exist on the quality of groundwater prior to oil and gas development (GAO, 2012a, 2012b). In South Africa, the Department of Water Affairs, as the custodian of South Africa's water, should take the lead to proactively protect South Africa's water resources on a national level, and this includes performing a baseline survey of water quality in areas where unconventional gas may be mined in future.

Regarding the protection of water sources, key informants deemed as important the regulating of well integrity on a regular basis and the regulating of the use of fracking fluids, including "green" chemicals. Internationally, mechanical failure and deformation of wells represent widespread diffuse sources of water pollution over the long term in gas mining areas (Bishop, 2011; Dusseault et al, 2000), while well abandonment and the poor sealing of wells after well decommissioning may lead to long-term groundwater contamination legacy issues (ANU, 2012; Broomfield, 2012; National Research Council [NRC], 2012b). Wastewater treatment may also pose challenges in terms of brine management (ANU, 2012), and if wastewater is re-injected into deeper porous geological formations it may cause geological and aquifer deformation, with the associated possibility of triggered seismicity (Lechtenböhmer et al., 2011; NRC, 2012a; Zoback et al., 2010) and possible fluid migration (Broomfield, 2012; USEPA, 2011b). Deteriorating water quality would also impact negatively on the health of communities (Broderick et al., 2011; Coburn et al., 2011).

Overall, it can be concluded that respondents are very much aware of the importance of proper monitoring and regulation of the potential environmental impacts of shale gas mining. Monitoring different aspects of unconventional gas mining before, during and after mining is important for almost all countries where unconventional gas mining may occur (ANU, 2012; Ohio Environmental Law Centre [OELC], 2012).

Capacity to manage the impacts of unconventional gas mining by means of hydraulic fracturing

Respondents were asked to share their opinion regarding the capacity of South Africa to deal with various aspects of unconventional gas mining. Statements were given which the respondents had to rate on a scale from 1 (not accurate at all) to 5 (completely accurate). The most pertinent responses can be viewed in Table 3-3.

Table 3-3: Capacity to regulate unconventional gas mining by means of hydraulic fracturing in South Africa

	Percentage of respondents	**Statements given in the questionnaire regarding capacity to regulate shale gas mining in South Africa**
Respondents agreeing with statement	92%	• Regulation of possible impacts is complex due to conflicting mandates of different Departments.
	82%	• Uncertainties exist between local and national government departments on responsibilities for monitoring and regulation of different fracking aspects. • Regulation complexities due to fragmentation of responsibilities within specific departments.
	76%	• Mining rights authorisation processes in South Africa are fragmented.
	64%	• Amendments are required in terms of South African statues to make development of fracking specific regulations possible.
	48%	• Mining rights authorisation processes in South Africa are limited.
Respondents disagreeing with statement	94%	• South Africa possesses sufficient fracking specific legislation and fracking specific policies. • The Mineral Petroleum Resources Development Act (1998) is sufficient in scope to deal with the challenges of fracking. • South Africa has sufficient institutional capacity to monitor shale gas mining operations.
	88%	• SA has sufficient institutional capacity to enforce compliance with conditions of license approval for gas mining operations.
	76%	• Information on potential environmental and health risks of fracking is currently sufficient.

Ninety-four per cent of respondents viewed the Mineral and Petroleum Resources Development Act (Act No. 28 of 2002) (MPRDA) (Republic of South Africa [RSA], 2002) as insufficient in scope to manage the wide range of challenges presented by unconventional gas mining and fracking. This view has been confirmed by legal minds in South Africa (Havemann, 2011; Havemann et al, 2011; Kantor, 2011a), who state that extensive regulations need to be drafted under the MPRDA and other acts to address fracking sufficiently.

In comparison, the South African water law and policy framework is one of the most progressive worldwide. The development of this policy framework has been initiated by the water reform programme in South Africa, which included the revision of policy and the drafting of new legislation to address issues of environmental sustainability and the efficient use of water (Schreiner, 2012). However, an issue that however hampers the implementation of the legislation in practice is overly complex systems for the implementation of legislation, making the total demand on skilled resources in the water sector, too large to sufficiently handle (Schreiner, 2012). This may explain why respondents are of the opinion that South Africa has insufficient institutional capacity to monitor and enforce compliance with conditions of license approval for shale gas mining operations.

A further concern highlighted is the perceived conflict in mandates between different South African government departments that may hamper effective regulation, as indicated by 92% of respondents. For example, environmental controls for mining legislation are at present still the responsibility of the Minister of Mineral Resources, and not the Minister of Environmental Affairs (Kantor, 2011b), which presents a conflict of interest. This situation may be corrected in due course.

Tools to help address the regulation of shale gas mining

Tools or actions which may assist authorities with regulating unconventional gas mining activities were presented to respondents, who had to indicate which may be of the most help in regulating unconventional gas mining activities in South Africa. The responses are reflected as the percentage of respondents who indicated a tool or activity as “extremely useful” and can be seen in Table 3-4.

Table 3-4: Tools to help address the regulation of shale gas mining

Percentage of respondents	Tools to help address the regulation of shale gas mining
100%	• Developing fracking-specific monitoring protocols before allowing hydraulic fracturing (HF) to commence
96%	• Performing research to identify and assess the impacts related to HF before giving the go-ahead for exploration
92%	• Developing fracking-specific legislation before allowing HF to commence • Declaring HF a controlled activity under section 38 of the NWA • Establishing a central database to store fracking-related information for ease of access and centralized management

Percentage of respondents	Tools to help address the regulation of shale gas mining
	• Identifying and clearly specifying the mandates, roles and responsibilities of local government versus national government
84%	• Performing a Strategic Environmental Assessment instead of an Environmental Impact Assessment process to determine potential impacts • Performing a detailed strategic assessment of the available energy generation options in South Africa before deciding on allowing HF
72%	• Requiring oil and gas companies to give security under s. 30 of the National Water Act for the protection of the water resource or property in respect of any obligation or potential obligation arising from a license to be issued. • Establishing an independent entity to monitor fracking activities and report to government on a regular basis
60%	• Adopting management policies from other countries where HF is currently taking place,
52%	• Enforcing the self-regulation and reporting to government of oil and gas companies as part of their license conditions • Placing an indefinite moratorium on fracking if other sources of energy are found to be sufficient

All the key informants viewed as useful the development of fracking-specific monitoring protocols before allowing hydraulic fracturing to commence. Developing monitoring protocols before allowing hydraulic fracturing is important for the monitoring of baseline water quality specifically, as well as other baselines (biophysical aspects and socio-economic aspects). Monitoring baseline conditions before allowing unconventional gas mining by means of hydraulic fracturing is a very important aspect if citizens want to protect their property and the environment (ANU, 2012; GAO, 2012a, 2012b). Additionally, monitoring efforts should be coordinated regionally in South Africa to ensure consistency in monitoring activities or protocols. These activities should ideally be managed on a national level, and the coordination role should be the responsibility of the relevant national government authorities (e.g. the DWA for water). This would require strategic planning on a national scale.

Ninety-six per cent of participants felt that performing research to identify and assess the impacts related to hydraulic fracturing before allowing it to commence would be useful. This is highlighted as important by the legal fraternity, before an effective legislative frame-work can be drafted for hydraulic fracturing (Havemann, 2011; Kantor, 2011a, 2011b). Research on hydraulic fracturing seems to be limited at the moment. The study done by the parliamentary task team on unconventional gas mining in South Africa (DMR, 2012) was possibly the most comprehensive research done on the issue to date. However, the process followed during the drafting of the DMR report by the task team has been criticized by Kantor (2011a) for not being transparent, which may render these research results questionable. The DMR research report was also drafted over a period of 12 months, while a country such as the US, where hydraulic fracturing has been performed for over a decade, plans to identify possible hydraulic fracturing impacts over a period of 3 years (USEPA, 2011a).

A worrying development regarding the pursuit of unconventional gas mining in South Africa was that decision makers deemed this report to be sufficient evidence to lift a moratorium on the acceptance and processing of unconventional oil and gas mining applications by PASA. Internationally, the trend is for countries to keep their moratoria in place until such time as proper and transparent scientific investigations on possible impacts have been performed and fracking-specific legislation and regulations, based on scientific results, have been drafted (Philippe & Partners, 2011; Pless, 2012).

Most of the participants (92%) agreed that developing fracking-specific legislation and regulations before allowing hydraulic fracturing to commence would be important. This finding is supported by other authors (Kantor, 2011a; Havemann, 2011; Havemann et al., 2011), while the parliamentary task team report (DMR, 2012) also prudently advised government that exploration may be allowed, but hydraulic fracturing should not, until such time as legislation and regulations have been drafted to effectively address hydraulic fracturing. Other tools that were also specified as important by 92% of the participants included declaring hydraulic fracturing a controlled activity under s. 38 of the National Water Act (Act No. 36 of 1998) (NWA) (RSA, 1998), establishing a central database to store fracking-related information, and identifying and clearly specifying the mandates, roles and responsibilities of local government versus national government.

A way to assess potential impacts of unconventional gas mining in a coherent manner across South Africa would be to perform strategic environmental assessments (SEAs) instead of environmental impact assessments (EIAs). Conducting SEAs was indicated as important by 84% of respondents. Environmental impact assessments may be insufficient in the case of unconventional gas mining, since impacts related to unconventional gas mining occur cumulatively on a regional scale and may pose legacy issues (ANU, 2012).

Interestingly, performing a strategic assessment of available energy generation options is viewed as important by only 84% of participants. This is an important first activity to be performed by government to guide decision making on allowing unconventional gas (a non-sustainable fossil fuel) as an energy option. Alternative power generation options should be compared to unconventional gas resources in a cost-benefit analysis, while also factoring in environmental and socio-economic costs. Politicians and decision makers should understand the water–energy–food nexus as it applies to South Africa so that proper decisions are made to ensure the long-term sustainable use of South Africa's resources. The National Development Plan (National Planning Commission [NPC], 2012) recommends fast-tracking of gas-to-power projects if shale and coalbed methane gas reserves are proven and environmental concerns alleviated (NPC, 2012). This plan recommends exploratory drilling to identify economically recoverable gas reserves while environmental investigations continue to ascertain whether sustainable exploitation of these resources is possible. Performing a strategic assessment of energy generation options available to South Africa would tie in well with the broad framework of this plan.

Only 60% of participants felt that adopting policies from other countries where hydraulic fracturing is currently allowed may be useful. Adoption of policies and regulations from other countries needs to be performed with caution, since the potentially negative consequences of fracking may vary depending on the particularities of locations in which fracking is proposed (Havemann, 2011). Nationally, South Africa presents unique paleontological and astronomy-related concerns that oil and gas applicants would not encounter in, for instance, the United Kingdom. Large geographic areas with features suitable for optical and radio astronomy gives South Africa a unique astronomical advantage, as is highlighted by the Astronomy Geographic Advantage Act (Act No. 21 of 2007) (RSA, 2007), which serves to protect astronomy-related activities in South Africa. From a local perspective, each well pad and the associated infrastructure will have impacts that affect the unique environment in a particular area (e.g. localized impacts on vegetation, faunal populations, archaeology and socio-economics). Detailed consideration should be given to the numerous amendments that would need to be made to the many statutes and regulations to be affected by the introduction of fracking-specific regulations, which makes the simple adoption of a foreign fracking-specific regulatory regime inappropriate.

Tools that received less support from respondents included “enforcing the self-regulation and reporting to government of oil and gas companies as part of their license conditions” and “placing an indefinite moratorium on fracking if other sources of energy are found to be sufficient” (both 52%). Self-regulation may be a useful tool if government does not have sufficient manpower or capacity to perform monitoring, but the trustworthiness of oil and gas companies to self-regulate remains questionable (International Energy Agency [IEA], 2012; Nwokocha et al, 2012; Ten Kate, 2011). Participants also felt that placing an indefinite moratorium on oil and gas mining, if other sources of energy are found to be sufficient, may be a useful course of action. However, this tool did not receive high support from the participants, possibly due to the fact that South Africa has been so dependent on fossil fuels in the past, and because anti-nuclear lobbying may cause government anxiety.

In conclusion, the most important tools that may help in the regulation of shale gas mining have been identified by participants, and these tools are in line with international trends. Stemming from the concern over the anticipated impacts of hydraulic fracturing on water specifically, it is crucial that specific attention be given to the development of water policy, both internationally and in South Africa. Proper water-related policy is especially important since the country is water scarce and water serves as both a driver and limiter of economic development (Blignaut & van Heerden, 2009; DWA, 2012b). Some of the water-related policy issues were highlighted in the questionnaire, and it was clear from the responses that proper water management in South Africa is very important.

Identification of the departments primarily responsible for specific regulatory activities

Respondents were asked to identify which departments should take primary responsibility for specific activities. Respondents prefer departments to share responsibility for developing fracking-specific legislation according to their respective mandates. Respondents deemed the Department of Water Affairs to be responsible for developing water-related policy and monitoring water consumption and pollution; the Department of Environmental Affairs to be responsible for the monitoring of biodiversity impacts, air quality impacts vegetation loss and the impacts of fracking on land use; and the Department of Mineral Resources to be the main authority responsible for approving mining applications.

The approval of mining applications is currently governed by mining legislation under the auspices of the DMR. Other countries operate in a similar fashion, in that mining legislation fulfils a central role in governing the authorization and permitting procedures for exploration or production of hydrocarbons (Philippe & Partners, 2011).

Interestingly, 20–36% of participants were of the opinion that an independent entity or organization should be established to oversee the regulation and monitoring of hydraulic fracturing. Perhaps this is something to consider, to ensure that these tasks are performed in a coordinated and transparent manner.

Opinion on whether South Africa will be able to effectively regulate shale gas mining

Respondents were lastly asked to comment on South Africa's ability to effectively regulate shale gas mining. Seventy-two per cent were of the opinion that South Africa will not be able to effectively manage the challenges pertaining to shale gas mining, while 16% were unsure; only 12% thought that South Africa would be able to effectively manage these challenges. This opinion may be based on the fact that fracking-specific regulations do not currently exist in South Africa (Havemann, 2011; Havemann et al., 2011; Kantor, 2011a), and also on the fact that currently South Africa does not effectively manage existing mining applications. In a parliamentary reply by the Department of Water Affairs, it emerged that during 2011, 53 mines were still operating without water use licenses (DWA, 2012a). This fact points to poor coordination between the national Department of Mineral Resources and Department of Water Affairs, which should ensure that both mining permits and water use licenses are in place before mining operations can proceed.

Conclusion

From the results of the study it can be concluded that key informants have limited knowledge on shale gas mining and hydraulic fracturing, as well as on the regulation of this type of mining, in terms of their understanding of regulation both in different parts of the world and in South Africa. The fact that half of the key informants indicated that they are not at all satisfied with their current knowledge on shale gas mining is indicative of the unprecedented nature of this activity in South Africa and points towards a serious need for knowledge dissemination through which decision makers can be exposed to relevant, current and applicable information on shale gas mining and hydraulic fracturing, specifically with reference to South Africa. This conclusion is strengthened by the fact that more key informants relied on the use of popular media than on scientific sources to expand their knowledge base and highlights the urgency of providing more scientific, scholarly information to those in decision-making positions. Therefore, various avenues of dissemination of information will need to be explored in the South African context to assist decision makers in their decision-making processes.

Key informants are in general aware of the importance of proper monitoring and regulation of shale gas mining. It is telling that the monitoring of water-related issues was rated as the most important activity to be performed, especially in a water-scarce country such as South Africa, and this finding is supported by current literature on the water-related impacts of shale gas mining (Lechtenböhmer et al., 2011; Rahm & Riha, 2012; USEPA, 2011b). Thus, specific attention needs to be given to the development of applicable water policy to address these issues. Highlighted as most important were the monitoring of contamination arising from hydraulic fracturing, the monitoring of the volumes of water used, and the regulation of the disclosure of chemicals used in the fracturing process. Establishing a base-line on water quality before allowing hydraulic fracturing to take place was also strongly emphasized by respondents.

It is worrying that key informants are largely unconvinced that South Africa has sufficient capacity to regulate and monitor shale gas mining or to manage the challenges emanating from this type of mining. The overall majority of respondents indicated that South Africa has insufficient fracking-specific legislation and policy and that the MPRDA is currently insufficient in scope to manage the challenges represented by shale gas mining and hydraulic fracturing. This opinion may be based on the fact that fracking-specific regulations do not currently exist in South Africa (Havemann, 2011; Havemann et al., 2011; Kantor, 2011a) and also on the fact that currently South Africa does not succeed in effectively managing existing mining applications. Additionally, the majority of respondents identified a conflict in departments' mandates that may hamper effective regulation of this activity in South Africa. These findings reveal that regulators, academia and consultants are of the opinion that regulatory gaps exist that need to be addressed.

Among the tools that were identified to regulate shale gas mining, fracking-specific monitoring protocols were deemed the most important. Key informants also indicated that fracking-specific legislation and regulations should be developed before hydraulic fracturing is allowed to take place. With regard to the departments primarily responsible for specific regulatory activities, most respondents indicated that specific departments should assume their traditional responsibilities according to their mandates. However, a number of key informants opined that an independent entity should perform all of these tasks. This interesting finding correlates with the key informants' views on the existing capacity in the country to monitor and regulate shale gas mining. It could indicate that at least some of the respondents view the establishment of an independent monitoring agency as a way to mitigate the current lack of monitoring and regulation capacity in existing institutions. Based on this, the question of whether an independent organization should be established in South Africa to perform these tasks in a coordinated manner needs to be considered by those in decision-making positions.

South Africa is in the fortunate position that proactive steps can be taken now, before exploration and mining are fully pursued. Relevant government departments and institutions should apply the precautionary principle by allowing time for scientific investigation, identifying possible risks and drafting relevant legislation to prevent or minimize adverse effects of unconventional gas mining on the environment, before any of these impacts occur.

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Chapter 4 - Regulations to protect groundwater resources during unconventional oil and gas extraction using fracking

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Abstract

Unconventional oil and gas (UOG) extraction using fracking can damage groundwater resources, a crucial resource in many countries. Protecting groundwater will become more urgent as climate change and population growth increase pressure on water demand, especially in water-scarce countries. But despite the strategic importance of groundwater, it is often poorly managed during UOG extraction. This review considers three types of regulation (command-and-control, market-based and voluntary) in countries where UOG extraction is allowed, to identify the best suite of regulations to protect groundwater resources during this process. We propose a regulatory framework that includes both 'hard' command-and-control regulations and 'soft' market-based and voluntary regulations. If regulations are to protect groundwater resources effectively, public disclosure of UOG operations must be required and the information must be stored in publicly accessible databases. This would allow for independent scientific review of data by academia and the private sector, in addition to government scrutiny of the data. These parties can then make recommendations to government, allowing timeous and appropriate adaptive management and the amendment of regulations as necessary. And, most importantly, these regulations must be properly enforced to avoid (in some cases irreversible) damage to groundwater resources.

Keywords: Command-and-control regulation, market-based regulation, voluntary regulation, unconventional oil and gas (UOG), fracking, groundwater

1. Introduction

Unconventional oil and gas (UOG) extraction using fracking can harm groundwater resources, as has been documented in the US and Canada (Shores et al 2017; Stuart, 2012), where it has been performed the longest. In extreme cases, abstraction or contamination of groundwater can even cause a permanent loss of groundwater resources.

UOG extraction and fracking can affect groundwater quality and quantity, and aquifer integrity, in a number of ways (Esterhuyse, Avenant et al., 2016; Gorski & Trenorden, 2018; Lefebvre, 2017). To limit these adverse effects on groundwater systems, certain aspects must be regulated during UOG extraction (Table 4-1).

BOX 1: Defining UOG extraction and fracking

'UOG extraction' is the process of extracting unconventional oil and gas, mainly shale oil and gas and coalbed methane, from low permeability formations that require fracking (or another form of stimulation) to extract them. 'Fracking', or hydraulic fracturing, is a stimulation technique used to extract oil and gas from UOG deposits. Fracking fluid, a mixture of water, chemicals and proppant (particles that must keep the fractures open, typically sand) is injected under high pressure into the reservoir to make it more permeable and facilitate extraction.

Other technical terms used in this review are:

- Production well: The well from which UOG is produced after fracking.
- Drilling fluid: Fluids used to facilitate the drilling process.
- Flowback: The portion of fracking fluid that returns to the surface as wastewater via the production well.
- Produced water: Water that can be highly saline and that may contain naturally occurring radioactive materials, that is produced by the geological formation and that flows to the

Table 4-1: Aspects that must be regulated to limit adverse effects on groundwater systems

Aspect to be regulated	Possible effects
A) Groundwater use	Extraction of groundwater for use during fracking operations can cause groundwater drawdown and affect aquifer structural integrity, possibly reducing the aquifer's storage capacity.
B) Fracking operations	Fracking can affect the integrity of an aquifer by changing its geological structure. Upward migration of fracking fluids from the shale reservoir along preferential pathways, which can be natural (faults or fracture zones) or man-made (oil and gas wells), can contaminate the aquifer.
C) Wastewater and solid waste management	Inadequate solid waste or wastewater management can cause aquifer contamination. A major concern is groundwater contamination from wastewater (consisting of flowback and produced water). Between 0 and 80% of the fracking fluid can return to the surface as flowback (Grant & Chisholm, 2016), and produced water, which may contain heavy metals and radioactive materials, is also released from the geological formation over the lifetime of the well (Lewis et al., 2016; National Academies Press, 2017) . Pollution of surface water resources and/or the infiltration of surface contaminants into groundwater resources can occur via accidental spillages of drilling fluid, fracking fluid, flowback or produced water.
D) Decommissioning of production wells	Inadequate well design or well integrity failure can cause fracking fluid, flowback or produced water to migrate into aquifers.

Groundwater resources are important to many countries, including Denmark (Eurostat, 2015; Flindt et al, 2017), Algeria, Libya, Morocco, Colombia, Venezuela, South Africa, Mexico (Margat & Van der Gun, 2013; Morris et al., 2003) and Australia (Harrington & Cook, 2014). These resources become increasingly important as population growth and climate change increase pressures on water demand, especially in those water-scarce countries where climate change predictions are in the direction of drier climates (Dalin et al, 2017; Margat & Van der Gun, 2013). Groundwater accounts for as much as 33% of total water withdrawals worldwide and over two billion people rely on groundwater as their primary water resource. More than half of the irrigation water to grow food comes from groundwater (Famiglietti, 2014). But despite its strategic importance, groundwater receives insufficient management attention compared with surface water (Zektser & Everett, 2004) and is especially poorly managed during UOG extraction (Castelli, 2015; McCormick, 2016; Blake, 2015).

Different approaches are taken to regulating UOG extraction and fracking. Some countries permit and regulate it, some ban it or place a moratorium on it (du Toit, 2016), and some do not ban it but simply do not regulate it. Exemption for UOG extraction activities from regulation *before* the advent of fracking would have been innocuous (Lashmet & Miller, 2015). One UOG drilling well operation would have consumed approximately 500 m^3 of water without fracking, but a fracking well consumes 20 times that amount (Goodwin et al, 2012). Steadman et al. (2015) found that in the Eagle Ford shale, fracking operations accounted for approximately 30% of total groundwater consumption for that area in 2015. Apart from consuming groundwater, fracking could also affect groundwater quality if there are surface spillages of fracking fluids or wastewater, or underground migration of fracking fluids (Geltman, 2016; Notte et al, 2017).

This article reviews the regulations that are available in countries that allow UOG extraction, in order to identify the best suite of regulations to protect groundwater resources. To identify the countries with the most effective regulations, we consider their level of experience in UOG extraction, their energy policy, and the importance of groundwater for the particular country. We recommend a regulatory framework with specific regulations for countries that are considering UOG extraction but do not yet have regulations or are in the process of developing them.

2. Methods

To identify countries with UOG extraction regulations that we could review for inclusion in our proposed regulatory framework for groundwater resources protection, we divided the countries into those with UOG deposits and those without (IEA, 2015b). For the countries with UOG deposits, we reviewed the regulations of those countries that do allow UOG extraction. We assessed the ‘fracking status’ of countries (whether they allow or ban UOG extraction) by reviewing the literature on fracking bans and moratoria (Bomberg, 2017; Cooper et al, 2016; Dodge & Metze, 2017; Fractracker, 2018; Gonzalez, 2015; Metze, 2017; Scholtens, 2017; Steger & Drehobl, 2018).

Of the countries that allow UOG extraction, we included those that have moderate to extensive regulations to protect groundwater resources during UOG extraction and where fracking has been done for more than 20 years. We also included countries where gas is economically important and where groundwater is of medium to high importance (see Appendix S1). We based gas importance on the percentage contribution of natural gas to the country’s total primary energy supply, using data from the International Energy Agency (IEA, 2015b). We classified the strategic importance of groundwater in the selected countries into low, medium, high and very high. We used the percentage groundwater share of the total water abstraction volume per country and the groundwater development stress per country to classify groundwater importance per country (Margat & Van der Gun, 2013; Aquastat - FAO, 2015). For a detailed explanation of the groundwater classification, see Table S1 and Table S2 in Appendix S1.

After identifying countries with suitable groundwater regulations for our proposed regulatory framework, we systematically searched selected databases (Heinonline, Westlaw International, JSTOR and Ebscohost complete) using the following Boolean search terms: (groundwater OR aquifer) AND frack! OR “natural gas” AND unconventional AND regulat!. We used Google and Google Scholar (open web) as additional search facilities to identify relevant regulations. We screened all the retrieved documents for suitability according to our inclusion criteria.

Section 3.1 discusses the global regulatory trends for UOG extraction and Section 3.2 the various fracking regulations to protect groundwater resources during UOG extraction. Based on these discussions, Section 3.3 presents our proposed regulatory framework for protecting groundwater resources during and after UOG extraction.

3. Results

3.1 Worldwide UOG extraction regulatory trends

Groundwater resources are strategically important for water-scarce countries near the equator (Mexico, Colombia, Venezuela, Morocco, Algeria, Libya, Tunisia, Pakistan and India). These countries mostly depend on groundwater resources for domestic water supply and economic activities. The percentage contribution of gas to the total primary energy supply (TPES) is, however, high for many of these countries (Argentina, Algeria, Mexico, Tunisia, Venezuela and Libya), indicating their dependence on gas supplies (Figure 4-1). Their energy policy therefore allows UOG extraction, even though it might be harmful to their groundwater resources. There are, however, local movements against UOG extraction in many of these countries; for example, Cinco Saltos, Argentina, has a municipal ban while Entre Rios, Argentina and Paraná, Brazil have state bans (Fractracker, 2018).

Some countries do not yet allow UOG extraction or experience local movements against UOG extraction because they lack a regulatory framework. In Romania, the bad reputation that fracking has gained, the limited legislation to regulate it effectively, and the fragmented enforcement of legislation caused the Chevron energy corporation to withdraw in 2017 (Energy Policy Group, 2017). South Africa, despite its plethora of national legislation applicable to fracking, does not possess a sound regulatory framework within which to allow UOG extraction while simultaneously protecting groundwater (Glazewski, 2016). The ‘fracking regulations’ published by the Department of Mineral Resources to fill gaps in the regulations (du Plessis, 2016), were set aside by the Eastern Cape High court in 2017, while the appeal by the Minister of Mineral Resources was dismissed by the Supreme Court of Appeal in 2019, because the regulations were developed without legal power or authority (Glazewski, 2016) and because they did not adequately protect groundwater resources (Esterhuyse et al., 2016a). Limited human and financial resources capacity also curtails enforcement and compliance monitoring (Esterhuyse et al., 2016a; Kijko et al., 2016). Groundwater resources are especially important in South Africa (Winter, 2018; Hobbs et al., 2016). A recent strategic environmental assessment for shale gas development in the Karoo region of South Africa found that no additional surface water or groundwater resources are available for UOG extraction, and that companies must consider importing seawater for their fracking operations (Hobbs et al., 2016). This highlights the importance of developing a proper regulatory framework to protect groundwater resources in South Africa during UOG extraction (Esterhuyse et al., 2013; Esterhuyse et al., 2016b; Esterhuyse, 2017).

The countries with the most UOG extraction regulations are Canada, the US, Australia and the UK (see Figure 4-1). Many states in Canada and the US allow and regulate fracking. They have extracted conventional oil and gas for many years and natural gas already makes up a large part of their primary energy supply, aiding their drive towards energy security. These countries have plentiful surface water resources (with a groundwater development stress level of 0% for Canada and 13% for the US; see Appendix S1) and thus do not need to use groundwater for fracking. In arid areas, however, groundwater is an important water source for fracking (Webb, 2017).

The US is the world leader in UOG extraction. In 2012, shale gas constituted nearly 40% of US gas production, up from just 2% in 2000 (de Melo-Martín et al., 2014), with projections that it may rise to 49% by 2035 (Kotsakis, 2012). Fracking is regulated primarily at state level (Brady & Crannell, 2015), as there is little federal regulation (Maur, 2015). Although many states regulate UOG extraction, some have banned it altogether, including Vermont, New York, Maryland and Monterey County in California (Dodge & Metze, 2017). States can regulate fracking as they see fit, but the regulations must meet the minimum requirements of any applicable federal regulations. At state level, water resources are mostly regulated according to a patchwork of old common law and newer statutory rules (Webb, 2017). At federal level, the Clean Water Act (CWA) and Safe Drinking Water Act (SDWA) regulate surface discharges, storm water runoff, and underground injection of fluids from drilling sites. Regulation at federal level is not as strict (Warner & Shapiro, 2013) and fracking is exempted under several federal laws, including the SDWA which, inter alia, regulates the underground injection of fluids, but specifically excludes fracking fluids except for diesel fuel (Brady & Crannell, 2015; Fisher, 2015). Several loopholes exist in the regulation of hydraulic fracturing to protect water resources in the US. The CWA regulates pollutant discharges into US water sources, but does not view water, gas or any other material that is injected underground to facilitate the production of oil and gas, or produced water that is disposed of into a well, as pollutants (Fisher, 2015). The US Energy Act of 2005 allows ‘underground injection’ of fracking fluids (Kotsakis, 2012); the environmental protection agency (EPA) regulations do not view oil-field wastes as hazardous wastes; and natural oil and gas extraction does not need to comply with the Comprehensive Environmental Response, Compensation, and Liability Act (Brady & Crannell, 2015). But despite the shortcomings of federal regulations, Burger (2013) argues that fracking should be regulated at federal level. The advantages of cooperative federalism, the inter-state nature of and federal interest in drinking-water protection and toxic pollution prevention, and the scaling-up that results from cumulative impacts and widespread rural impacts all support the federalisation of fracking regulation (Burger, 2013).

In Australia, commercial UOG extraction occurs mostly in Queensland (Ingelson & Hunter, 2014). The State (Commonwealth in this case) Acts and accompanying regulations, guidance notes, and other non-binding information resources govern the exploration for and extraction of UOG resources (Ingelson & Hunter, 2014). The Australian national government has no jurisdiction over the regulation of fracking and cannot compel states to require the disclosure of chemicals. The National Harmonised Framework for Natural Gas from Coal Seams, however, provides guidance to governments regulating coalbed methane extraction within their respective jurisdictions. It also applies to fracking in general and is therefore also applicable to shale gas extraction (Ingelson & Hunter, 2014). It identifies 18 leading practices to be followed across all jurisdictions to build a robust national regulatory regime and protect water resources by regulating well integrity, water management, hydraulic fracturing and use of chemicals (Standing Council on Energy and Resources, 2013).

Some European countries, such as Poland, have a strong drive to develop UOG resources in the interest of energy security (IEA, 2016b), but a basic neglect of the associated environmental concerns (Wendling, 2017; Kronenberg, 2014). The EU 2014 Recommendation (a non-binding recommendation drafted by the EU), which specifies minimum principles for the exploration and production of hydrocarbons, including UOGs, using high volume hydraulic fracturing, has not been incorporated in Poland (Gorski & Trenorden, 2017). The EU's Environmental Impact Assessment Directive, that requires EIAs for certain projects, also applies to UOG extraction in EU member countries. Poland amended its national laws to grant blanket exemptions for shale wells drilled to depths of less than 5,000 metres, an alleged infringement of the EIA Directive (Neslen, 2014). Certain members of the European parliament therefore sought EU regulation of UOG resources as a means of providing the environmental protection that Poland could not – or would not – provide (Wendling, 2017; Reins, 2014).

In comparison, many developed European countries where groundwater may not be as strategically important do not allow UOG extraction using fracking, for example, Spain, France, Germany, the Czech- Republic, Ireland, the Netherlands and Denmark (Figure 4-1). Although many of these countries depend largely on natural gas for their primary energy supply (such as the Netherlands, 41.7%, Ireland, 33% and Germany, 22.3% – see Appendix S1), they plan to incorporate renewable energy into their energy mix to a much greater degree (IEA, 2012, 2013, 2014). In the Netherlands, fracking was common until uncertainty about how it would affect the environment made people begin to see UOG extraction less as an economic benefit and more as a planning issue that needs precautions (Metze, 2017; Dodge & Metze, 2017), and a moratorium on fracking was imposed because of concerns about water contamination (Patterson & McLean, 2018). The banning of fracking in countries such as Denmark, France and Germany may be for a variety of reasons: a higher value accorded to natural resources, the implications of EU directives (the EIA Directive, the Directives on Strategic Environmental Assessment and the Groundwater Directive, amongst others) for member states, energy security being a less urgent requirement, or the ability to externalise environmental costs by importing gas.

There are no binding EU regulations aimed specifically at fracking (Karam, 2018). The UK and Poland lobbied strongly against a legislative approach for shale gas development in the EU (Wendling, 2017). The EU therefore published a non-binding communication and recommendation in 2014 specifying minimum principles for the exploration and production of hydrocarbons using high volume hydraulic fracturing (Fleming, 2017), with the possibility of review, leaving open the possibility of more substantial regulation in the future (Wendling, 2017). Imposing environmental regulations on EU countries to protect groundwater resources during UOG extraction specifically, would ensure better groundwater resources protection than the current recommendation. It could also encourage member countries to diversify their energy mix to include green energy sources and to invest in the development of such energy sources. Importantly, continent-wide regulations such as the EU regulations can protect transboundary groundwater resources during UOG extraction, which sometimes receive minimal attention in country-specific legislation and regulations.

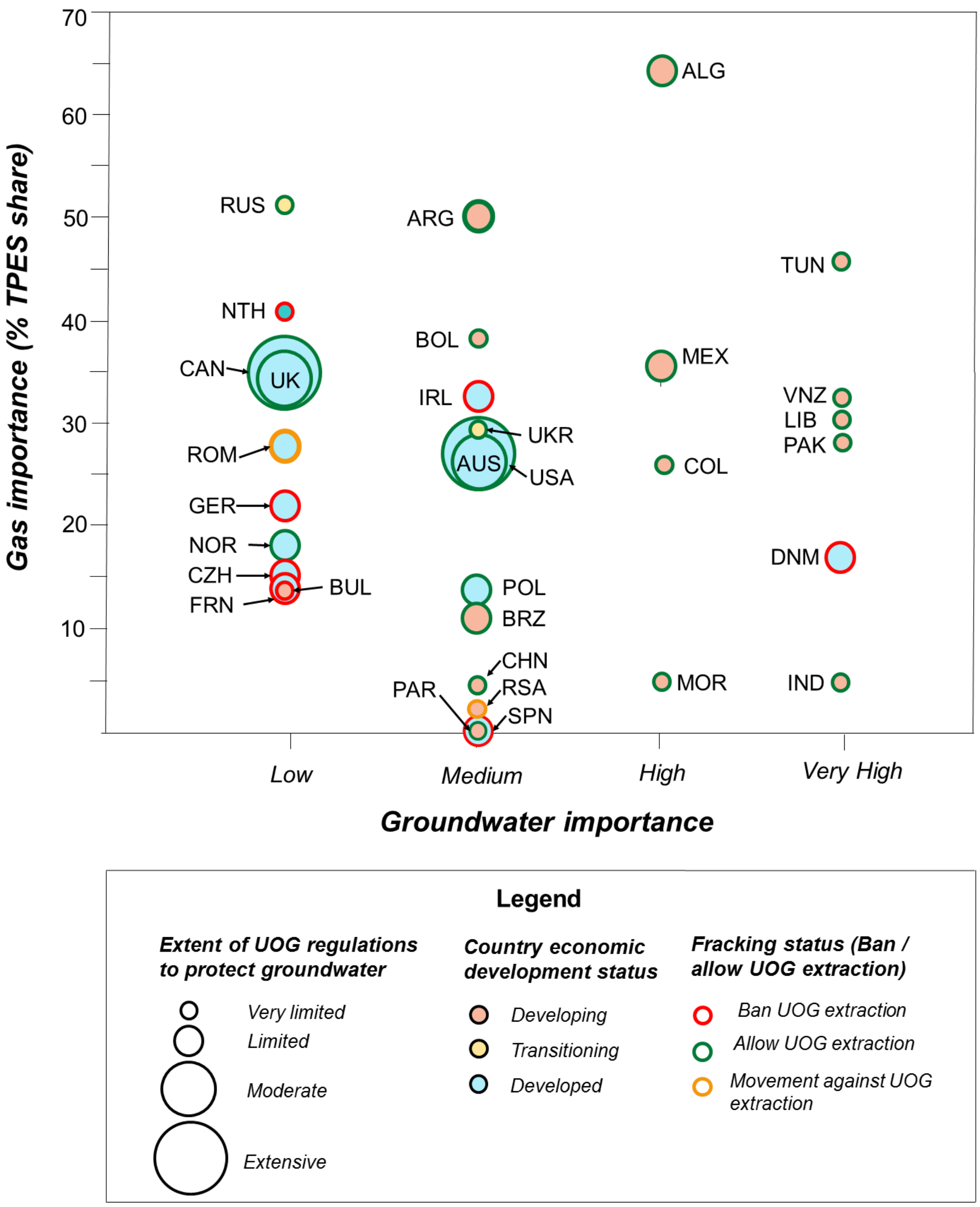

Figure 4-1: UOG extraction regulatory trends. This figure shows the economic importance of gas to the total primary energy supply (TPES) per country, compared with the importance of groundwater resources for the country. It also shows the extent of UOG regulations to protect groundwater resources, and the fracking status of each country. For more information on this dataset, see Appendix S1.

3.2 Regulatory approaches and tools to protect groundwater resources during UOG extraction

A regulatory framework to protect groundwater resources must be aimed at avoiding or minimising damage from UOG extraction. The framework we propose takes into account three types of regulation: command-and-control, market-based and voluntary (self-regulation) (Ford et al., 2014; Ren et al., 2018; Xie et al., 2017).

The conventional command-and-control approach to environmental management establishes laws and regulations to meet specific environmental targets, for instance by prescribing processes and technologies to meet these targets (Ford et al., 2014). Market-based regulation allows companies to determine the best way to become more efficient in reducing pollution emissions (Wu, 2009). Voluntary regulation allows companies to undertake usually innovative voluntary action to improve their environmental performance (Ramanathan et al., 2017).

Command-and-control regulations are by far the most commonly used to minimise damage caused by UOG extraction. They are most often used by countries where regulators are under-capacitated to police self-regulation, such as developing countries. Ford et al. (2014) and Wang and Shen (2016), however, stress the importance of flexibility in environmental command-and-control regulations, to optimise the environmental benefits of the regulated activities. Command-and-control regulations have been criticised for imposing significant financial and administrative costs on companies (Richardson et al., 2013; Ramanathan et al., 2017). In contrast, market-based regulations may impose a lower cost burden on companies (Ramanathan et al., 2017) and may incentivise companies to implement certain regulatory measures. Some command-and-control regulations can be executed voluntarily by UOG extraction companies. In this case it is usually a pre-emptive response by companies to possible new regulations that may be implemented, or to avoid future surprises due to a sudden increase in standards (Ramanathan et al., 2017) or to gain competitive advantages (Ford et al., 2014).Voluntary regulation, in contrast, provides incentives but not mandates for pollution control. In cases where purely voluntary regulation would be ineffective, we recommend that voluntary regulations be combined with command-and-control regulations (see Figure 4-2). Enforcement is a big concern for all regulatory instruments, but if government personnel and equipment are insufficient for frequent monitoring, voluntary agreements between UOG extraction companies and government may help to limit risks to groundwater resources. The three types of regulation can be used in conjunction, instead of using just one. In the following we discuss each in turn and then summarise them in our regulatory framework (Figure 4-2).

Of the countries we reviewed, UOG extraction has been practised the longest in the US and Australia (medium groundwater importance), and Canada (low groundwater importance) and they have extensive regulations. Although UOG extraction is in the exploration phase in the UK and its regulations are not as well developed as those of the US, high volume hydraulic fracturing has already been performed there (Cooper et al., 2016).

The key aspects that must be regulated, as shown in Table 4-1, are groundwater use (A), fracking operations (B), wastewater and solid waste management (C), and decommissioning of production wells (D). Figure 4-2 shows our regulatory framework to protect groundwater resources. It shows that the four aspects are interrelated.

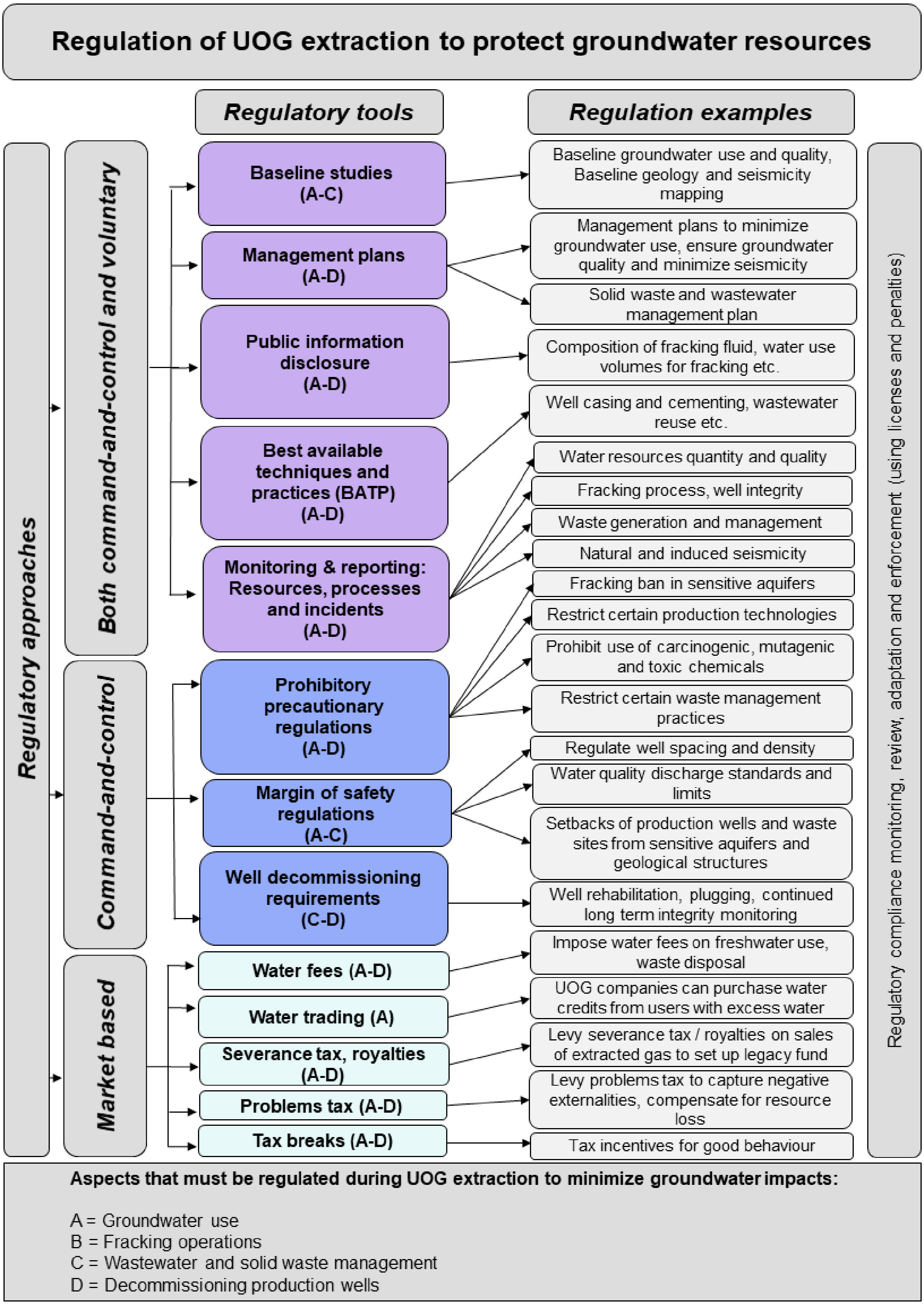

Figure 4-2: A recommended regulatory framework to protect groundwater resources during UOG extraction

We include in our regulatory framework the following tools to regulate these aspects:

- Baseline studies: A–C
- Management plans: A–D
- Public information disclosure: A–D
- Best available techniques and practices (BATP): A–D
- Monitoring and reporting of resources, processes and incidents: A–D
- Prohibitory precautionary regulations: A–D
- Margin of safety regulations: A–C
- Well decommissioning requirements: C–D
- Market-based tools
    - Water fees: A–D
    - Water trading: A
    - Severance tax and royalties: A–D
    - Problems tax: A–D
    - Tax breaks: A–D

These tools are explained in detail below.

3.2.1 Baseline studies

Baseline studies must provide baseline information before UOG extraction starts, to protect groundwater resources during and after UOG extraction. Such studies are routinely required under command-and-control regulations. UOG extraction companies can, however, do baseline studies voluntarily, especially if companies themselves want to establish a legal basis for refuting contamination claims (Sherwood et al., 2016). Baseline data on existing groundwater use by communities and for other activities such as agriculture can ensure that existing groundwater uses are considered and protected before allocating groundwater for fracking, while baseline groundwater quality information can ensure timely action during a groundwater contamination event (Maloney, 2015; Gorski & Trenorden, 2017, 2018; Becklumb et al., 2015). Information on aquifer characteristics and structure can ensure that aquifer integrity is maintained during UOG extraction. The main baseline groundwater conditions that should be identified are groundwater quality and quantity, current groundwater use and baseline seismicity (Brady & Crannell, 2015). Geology must also be characterised (especially by identifying geological structures that could influence the migration of contamination). Independent third-party management of baseline monitoring and information across UOG extraction regions would make data accessible. In Australia, the Independent Expert Scientific Committee highlighted the need for regulators and project proponents to provide baseline information on the scale of UOG developments in a regional context; and information on direct, indirect and cumulative impacts from activities in the same catchment or region (Maloney, 2015). Ideally, cumulative impacts should be identified beforehand by cumulative risk management such as a strategic environmental assessment (Esterhuyse, 2018) to produce catchment-wide groundwater risk maps for all UOG extraction activities (Tan et al., 2015). All UOG extraction should be regulated on the basis of such risk maps (Esterhuyse, 2018). Basin-scale baseline groundwater risk assessments can provide critical pre-emptive management information to ensure sustainable groundwater resource development during UOG extraction (Tan et al., 2015). UOG extraction should not begin until baseline data have been gathered and interpreted.

3.2.2 Management plans

Management plans are common command-and-control regulatory tools. UOG extraction companies may implement management plans independently of government requirements (Small et al., 2014) or voluntarily in cooperation with government, as in Norway (Bennear, 2015). Management plans must show the sources from which water will be withdrawn, the average quantities and maximum allowable water withdrawal rates, and the potential effect of water withdrawal from different sources, and must be subject to review and approval by the regulatory agency (Webb, 2017). There must be plans to deal with drilling and with solid waste and wastewater disposal to limit groundwater contamination. Drilling plans must specify the depth of the wells (Brady & Crannell, 2015) and how to test the design and construction of the well for well integrity (Gorski & Trenorden, 2017, 2018). There must be plans specifying waste control and disposal methods. There must be emergency response plans (Bennear, 2015) to handle incidents like loss of well integrity or accidental pollutant discharge into groundwater. To protect aquifer integrity and maintain groundwater quality, plans must specify how to handle groundwater abstraction for fracking or aquifer depressurisation.

3.2.3 Public information disclosure

Public information disclosure is an indispensable tool for protecting groundwater resources. Shifting the burden of proof onto UOG extraction companies via command-and-control regulations facilitates public disclosure and the independent review of testing procedures and results. Public disclosure must include the precise composition of the fracking fluids used for each well, the volume of water used for each well and the composition and volume of fluids that emerge at the surface following fracking. To ensure transparency, operators must publish this information, and authorities must disseminate consolidated information about existing and planned wells, permits, baseline studies, incidents that have occurred, and the results of inspections, non-compliance and penalties (Becklumb et al., 2015). Public disclosure of fracking fluids can be done via Material Safety Data Sheets (MSDS) (Ingelson & Hunter, 2014) and must include the total volume of water used in the fluid and the trade name, supplier, purpose, ingredients and Chemical Abstract Service (CAS) number. Companies must disclose the maximum ingredient concentrations (percent by mass) for each chemical used in the additives and the fracking fluids. The chemicals used must be disclosed both before drilling and fracking (in the drilling and fracking management plans), and before each change in the chemical make-up of the fracking fluid during the fracking process. This is because fracking chemicals can often be varied from the initial plan, to optimise gas production. A final report of all the chemicals that have been used at a well for drilling and fracking must be submitted during well closure (Brady & Crannell, 2015).

Public information disclosure gives UOG extraction companies a social licence to operate (IPIECA, 2015; George et al., 2016). Voluntary chemical disclosure can also be a pre-emptive response to avoid being regulated (Davis & Hoffer, 2012). Many companies therefore voluntarily provide the public and regulators with information, ensuring better management and protection of groundwater resources (Schwartz et al., 2014). Two companies that do this are the Canadian Association of Petroleum Producers (CAPP), which actively supports fracking fluid content disclosure (Ingelson & Hunter, 2014; Ernst and Young, 2015) and the International Petroleum Industry Environmental Conservation Association, which supports voluntary sustainability disclosure (IPIECA, 2015). To encourage voluntary disclosure, the Fracfocus website (https://fracfocus.org/) stores voluntary disclosures on chemicals used during fracking (Pietersen et al., 2016; Maule et al., 2013; Neville et al., 2017).

3.2.4 Best available technologies and practices

Best available technologies and practices (BATP) is a precautionary regulation that demands the use of such technologies and practices where there is potential to cause substantial harm, as for example in groundwater use, drilling into aquifers, waste disposal and decommissioning of wells. Best available technologies include using the most up-to-date well casing and cementing products and procedures to minimise groundwater contamination and ensure well integrity, and monitoring for well integrity (National Academies Press, 2018a). Best practices to protect groundwater can include changing to more environmentally benign fracking fluids (Hobbs et al., 2016), setting surface casings (which act as a protective shield between aquifers and the fracking well) at greater depths, cementing the surface casing and intermediate casings to the surface and doing pressure testing on the surface casing to check if it properly isolates the fracking well from aquifers (Hobbs et al., 2016). BATP options for solid waste and wastewater management include developing better wastewater treatments to reduce the effect on water quality after discharge, developing techniques to ensure optimal wastewater reuse, and developing next-generation technology that can predict, prevent and help mitigate accidents during UOG extraction (Paranhos et al., 2017). Technology such as remote-controlled downhole systems of permanent monitors, packers and sealing elements (‘intelligent completion’) can help to monitor wastewater management (Hobbs et al., 2016). In the EU, impermeable site lining (‘bunding’) must be installed to limit the migration of wastewater to aquifers, in order for planning permission to be granted (Kotsakis, 2012). Requiring BATP under command-and-control regulations could encourage technological innovation (Tan et al., 2015).

BATP is commonly used as a command-and-control regulation but is also often implemented voluntarily by UOG companies to prevent or mitigate damage linked to UOG extraction (Paranhos et al., 2017). Examples include voluntary advanced safe well installations (National Academies Press, 2018b), investing in new technologies such as water recycling, and using data visualisation tools to pinpoint and predict potential UOG extraction problems (Paranhos et al., 2017). The CAPP actively supports BATP during UOG extraction operations (Ernst and Young, 2015) and has voluntary best practice guidelines in place for wellbore construction, water sourcing, water measurement and reuse, and fluid transport, handling, storage and disposal (Gagnon et al., 2015). Some companies undertake innovative voluntary BATP in an attempt to save costs, or to improve their environmental performance as a pre-emptive response to possible new regulations, or to partially weaken future regulations, or to avoid any future surprises as a result of a sudden imposition of stricter standards (Ramanathan et al., 2017). Voluntary BATP could also enhance a company’s reputation and ensure greater operational effectiveness (National Academies Press, 2018a). Companies would implement BATP voluntarily if governments provided tax breaks for doing so.

3.2.5 Monitoring and reporting of resources, processes and incidents

Monitoring and reporting of resources, processes and incidents, intended to ensure aquifer integrity and protection of groundwater quality and quantity, is commonly required under command-and-control regulations. Voluntary monitoring of emergency incidents has become commonplace in industry and improves the safety and effectiveness of operational practices (Paranhos et al., 2017). More UOG companies are now proactively setting their own standards and monitoring and reporting their compliance with standards (University of Colorado at Boulder, 2018). Where voluntary monitoring and reporting are done, regulators should ensure that such voluntary information is integrated into their databases to ensure even better groundwater resource protection. Aspects that must be monitored are groundwater quantity and quality during and after UOG extraction and water use and in-stream flows at withdrawal locations (Becklumb et al., 2015). The results must be compared to baseline values and adaptive management must be implemented throughout to ensure optimal groundwater resources and aquifer protection. After well closure, the groundwater status in UOG extraction areas must be compared to the baseline values to identify any groundwater damage requiring mitigation (Kotsakis, 2012). Stimulation processes such as fracking or depressurisation and well integrity and seismicity (natural and induced), must be monitored. Monitoring and reporting of low-magnitude earthquakes will provide additional information about the nature of geological formations and aquifer systems, aiding in protecting groundwater resources. Significant seismic events must be reported and operations suspended if warranted (Becklumb et al., 2015). Emergency incidents must also be monitored and reported to authorities. In the case of an emergency incident, operations should ideally be stopped immediately and not restarted until the incident has been resolved (Gorski & Trenorden, 2017, 2018). Waste generation and management practices must be monitored and reported to authorities, who must store the monitoring information and ensure that databases are accessible to enable adaptive management (Wiseman, 2014).

3.2.6 Prohibitory precautionary regulations

Prohibitory precautionary regulations are common command-and-control regulations intended to ensure proper groundwater use during fracking and limit contamination of groundwater by banning:

- fracking in primary watershed areas and where groundwater supplies are critical (Brady & Crannell, 2015);
- fracking in aquifer recharge areas (NYSDEC 2015a; Tan et al., 2015);
- the use of carcinogenic, mutagenic, and toxic chemicals in fracking fluids; and
- underground wastewater injection (Buono et al., 2017; Kotsakis, 2012).

Banning harmful chemicals in fracking fluids would necessarily mean that green or bio-degradable fracking fluids would have to be developed and used during fracking. Banning underground wastewater injection is important to prevent seismicity in earthquake-prone areas. This ban could also encourage wastewater reuse.

The precautionary principle justifies regulation before full scientific certainty can be established (and before permanent environmental damage occurs). It enables legislators to shift the burden of proof from the regulators (to prove that regulation is necessary) to the industry (to prove that regulation is unnecessary) (Tan et al., 2015). This principle can be used to provide a rational legal response to the uncertain causal connection between fracking and groundwater contamination (Lees, 2012; de Melo-Martín et al., 2014). The precautionary principle is a flexible concept that can be applied throughout the entire lifespan of a project and at differing levels of rigour.

3.2.7 Margin of safety regulations

Margin of safety regulations are common command-and-control regulations intended to ensure proper groundwater use during UOG extraction while limiting groundwater contamination. Well spacing and density, water quality discharge standards, environmental critical level limits and discharge volume limits (Tan et al., 2015) are commonly specified under these regulations. Minimum distances (setbacks) can also be specified between fracking operations and waste management on the one side, and geological structures, sensitive or important aquifers and earthquake-prone areas on the other side (Gorski & Trenorden, 2017, 2018).

3.2.8 Well decommissioning requirements

Well decommissioning requirements are intended to ensure groundwater protection over the long term. Various estimates have been reported for the percentage of well integrity failure, ranging from 1.9 to 3.4 %, and aging of well components probably increases the risk of failure by 18% with each additional well inspection (Boothroyd et al., 2016). The safe decommissioning and continued monitoring of decommissioned production wells are therefore paramount to protect groundwater quality in the long term (Davies et al., 2014; Jackson, 2014). In Australia, spent UOG wells are rehabilitated by removing drilling fluids and cuttings, after which the well must be fully cemented from the production level to the surface, and the top 1.5 metres of the well must be removed and the well buried (Huddlestone-Holmes et al., 2018). After such plugging, wells are abandoned and it is assumed that plugging stops all fluid movement in perpetuity (Huddlestone-Holmes et al., 2018). Integrity monitoring of abandoned wells can then be performed by pressure testing the casing string, performing cement bond logs to evaluate the integrity of the cement work in the well, testing annular pressures in the casing, acoustic monitoring, and monitoring for gas leaks. The risk of leakage over the long term means that a monitoring timeframe of 50 years after well decommissioning may be necessary (Hobbs et al., 2016; Huddlestone-Holmes et al., 2018). This raises the question of who will take responsibility for performing such long-term monitoring and carrying the associated costs. Here, water taxes or production taxes and royalties could prove useful. Surveys comparing the environmental status with the baseline study for the surface and underground area should ideally also be carried out after well decommissioning, in addition to any well integrity monitoring procedures.

3.2.9 Market-based regulatory tools

Market-based regulatory tools include, amongst others, water fees, water trading, severance tax and royalties, problems tax, and tax breaks.

Water fees can be imposed for the use of potable water (freshwater) in fracking operations, groundwater contamination and wastewater disposal (regulating aspects A–D). Freshwater use fees would increase the costs faced by producers, making wastewater recycling a more attractive option and changing companies' behaviour (Webb, 2017). Another way to encourage the use of recycled wastewater instead of freshwater for fracking would be to increase the charges for disposal of wastewater (Webb, 2017; Xie et al., 2017; Lashmet & Miller, 2015).

Water trading can distribute water from areas of excess to areas where UOG companies may need water. This is useful for regulating aspect A. As an example of a trading system, UOG companies who cannot keep their water use below the regulated limit could purchase water credits from other water users who are below the limit (Webb, 2017; Backstrom, 2018).

In the Murray-Darling Basin in Australia, the establishment of a market with tradable water rights led to an over-allocation of water (New Zealand Institute of Economic Research, 2014). A water market must be sustainable. Some measures to ensure this are:

- Salinity management to minimise adverse trade effects, such as extra charges imposed by government on trades that increase salinity concentrations in groundwater, to discourage such water movement.
- Restrictions on water trade in water-scarce areas.
- Determining how much water can safely be drawn from aquifers without depleting the groundwater,
- Government buyback of water entitlements to protect groundwater and to reduce over-allocation of water.

Severance tax and royalties can be levied on the positive cash flows or sales of extracted hydrocarbons (Cotton, 2017) and can regulate aspects A to D. Severance tax and royalties can be used to set up a legacy fund to deal with groundwater problems from UOG extraction, for example by running a programme for monitoring and maintaining 'orphan' and decommissioned wells that could become problems in the future (National Academies Press, 2018a; Cernoch et al., 2012). Legacy funds are especially needed for orphaned wells, which do not have legal owners and where nobody can be held liable for their maintenance and monitoring. It would be ideal if such legacy or trust funds were independent and unbiased. Such funds can also redistribute money to communities affected by UOG extraction (Neville et al., 2017), for example those whose water has become contaminated, as is done by the New Hampshire Drinking Water and Groundwater Trust Fund (State of New Hampshire, 2019). UOG companies can also be taxed for not complying with regulations (Cristaldi, 2014).

Problems tax (also known as 'impact fees') regulates aspects A–D and can be levied on UOG companies to leverage money for fixing groundwater problems they cause, such as contamination (Mayer, 2017; Rabe, 2013; Wang & Shen, 2016). Problems taxes are intended to compensate for damage done by UOG extraction, often in the form of monetary compensation for permanent loss of groundwater resources. Problems taxes, linked to permanent trust funds, have been set up in many states in the US as a way to manage potential risks of UOG extraction (Neville et al., 2017; NYSDEC, 2015b; National Academies Press, 2018b).

Tax breaks are an alternative to taxing bad behaviour by UOG companies – rewards rather than punishment. Subsidies or tax incentives such as tax reductions or tax credits can be given to UOG companies that choose, for instance, to follow best operating practices (Cristaldi, 2014; Webb, 2017). Tax breaks can regulate aspects A to D if a company limits groundwater use and contamination, and ensures aquifer integrity, proper waste and wastewater management and safe decommissioning of wells.

3.3 A proposed regulatory framework for UOG extraction

Command-and-control regulations are the kind most often used to regulate the effects of UOG extraction. Such regulations may be criticised, for example on the grounds that they might stifle technological development or are too costly to implement (Shvarts et al., 2016), but they still prove useful in countries where regulators are under-capacitated to police self-regulation, particularly in developing countries.

Market-based tools, such as water fees and severance taxes, can also be used effectively to persuade UOG companies to comply with environment-friendly practices and can be useful in combination with command-and-control regulations. For example, money levied via royalties and taxes (a market-based tool) can be saved in a legacy fund to help pay for monitoring of decommissioned and orphaned wells (a command-and-control regulatory requirement). Ford et al. (2014), found that market-based tools can promote innovation by allowing companies to determine the best methods to achieve compliance. They also found that innovations in the UOG industry are related both to a high regulatory burden (of command-and-control regulations) and to competition in the industry, collaborative activity, and research and development.

Voluntary regulation (where the UOG company regulates itself) may in certain circumstances also be useful in protecting groundwater resources during UOG extraction. In the US, some companies perform baseline testing of water resources voluntarily in the absence of mandatory regulations, possibly because the testing is part of their general operations, or because they want to record evidence that they did not cause contamination (King, 2016). Voluntary monitoring and reporting by UOG companies may be required where countries follow the ‘polluter pays’ principle or have limited human and financial resources to do this. In such cases, independent oversight committees can be indispensable, to verify monitoring results, ensure public disclosure and provide recommendations to government. In Australia, the Independent Expert Scientific Committee provides scientific information about the water-related effects of coalbed methane extraction, a form of UOG, before government approves projects, and also publishes and disseminates scientific information about these impacts (Maloney, 2015).

Cumulative impacts of UOG extraction can, however, be poorly managed under voluntary regulation. For example, during voluntary baseline assessments and monitoring of groundwater resources, companies may not take into account the cumulative impacts of other similar extraction activities in the same region. Activities such as baseline assessments are therefore best performed by the government agency mandated with protecting water resources. It can be almost impossible to get different UOG extraction companies to collaborate to ensure standardised data gathering and data quality for groundwater resources monitoring. If companies are allowed to self-regulate on this issue, stringent government or third-party oversight will be required. It has also been noted in the mining sector that, left to their own devices, companies would rather spend extra money on advertising than on the environmental concerns linked to their activities (Bench Marks Foundation, 2014). It may, therefore, be prudent to implement certification schemes for the UOG sector, to provide more accountability than the current sustainability frameworks or the Organisation for Economic Co-operation and Development (OECD) principles for corporate governance.

Important means to ensure effective protection of groundwater resources during UOG extraction are public disclosure, publicly accessible databases and enforcement of regulations.

Public disclosure is a major component of both command-and-control regulation and market-based regulation, but it is often a sensitive issue for UOG extraction companies, because of trade secrets, among other things. A balance is required between the level of public disclosure and the need to protect intellectual property rights to encourage growth in research, development, and innovation. Where full public disclosure is not possible, arrangements should be in place to allow full, but confidential, disclosure to the regulator. To protect trade secrets, relevant authorities can also exempt UOG companies from disclosing certain information that might affect their competitiveness (Ingelson & Hunter, 2014; Fisher, 2015). Shorter time requirements for reporting chemicals, and a systems approach that lists chemicals in ways that prevent 'reverse engineering' to uncover trade secrets, would make disclosure requirements more acceptable to UOG companies (Davis 2017). Ideally, public disclosures should be accessible on a publicly accessible website, like the Fracfocus website in the US (Ingelson & Hunter, 2014). Processes could also be developed to challenge a developer's claim for trade secret protection where public access to information is required.

Publicly accessible databases on UOG extraction activities are lacking in many countries, hampering effective regulation. Information on such things as water quality and quantity, chemical usage during fracking, drilling information (well depth, well completion and stratigraphy, for example) and seismicity all need to be included in a centralised publicly accessible database (Wiseman, 2014; Davis, 2017; Buono et al., 2017; S. Esterhuyse et al., 2013). Besides this information, a database that both contains and tracks regulations from different ministries for the UOG industry would be especially helpful to identify any gaps in the regulations. In the US, gaps cannot be identified because databases on regulations are not publicly accessible (Wiseman, 2014). Information about the types of regulation (command-and-control, market-based and voluntary) needs to be included in the databases, and quality assurance and quality control during data entry will be needed to ensure the integrity of the databases.

Enforcement of regulations is essential for any proposed regulatory framework to protect groundwater resources during UOG extraction (see Figure 4-2), but it can be problematic. In the US, the EPA (environmental protection agency) is hampered by limited legal authority, the difficulty of conducting inspections and taking enforcement actions, and inadequate data on matters such as groundwater quality prior to drilling. Rollbacks of regulations aimed at ensuring environmental protection are also problematic (Brady & Crannell, 2015). In South Africa it is especially difficult to enforce command-and-control regulations in the mining sector because the various departments have different mandates, limited regulatory oversight and monitoring, and a shortage of human and financial resources to enforce regulations (CER, 2014; Pietersen et al., 2016). Compliance monitoring and enforcement of UOG extraction regulations by a specialised interdepartmental unit comprising the departments responsible for water, the environment and mineral extraction would therefore be useful for countries attempting to regulate UOG extraction.

Command-and-control regulations are implemented and enforced via licensing. Any conditions that a company must adhere to for UOG extraction can be specified in the licence. The regulator should enforce these requirements by monitoring the UOG extraction operations for compliance (Konschnik & Boling, 2014). Offences and the penalties for the offences must be stipulated. In the case of an offence, the person or company guilty of the contravention may be subject to a penalty or any other enforcement method, such as administrative orders that require the UOG company to rectify a certain situation that endangers groundwater, or the option to suspend operations (Ernst and Young, 2015; Wiseman, 2012). Compliance monitoring should be done to identify any contraventions of the regulations.

Given the long-term nature of the risks that UOG extraction poses to groundwater, UOG companies must provide some form of financial security. This must at least be sufficient for the maintenance and continuous monitoring of wells in the long term, and for a contingency fund in the event of contamination, in which case the company may be required to compensate landowners financially for their losses. Financial security can be required in addition to any other financial provisioning requirements to ensure safe operations during UOG extraction. The possibility of bankruptcy must be covered by adequate financial assurance, as governments mostly end up with the liabilities of bankrupt companies (National Academies Press, 2018a).

Figure 4-2 shows our proposed framework. It lists the main regulations under each regulatory approach (market-based, command-and-control, and a combination of command-and-control and voluntary). Considering the strengths and weaknesses of the different approaches, we argue that to protect groundwater during UOG extraction governments should use a combination of the ‘hard’ command-and-control regulations and the softer market-based and voluntary regulations. Ideally, governments should identify the risks of UOG extraction (by requiring baseline surveys), optimise mitigation strategies (for instance by using a combination of command-and-control, market-based and voluntary regulations for BATP), ensure that all important aspects are addressed in regulations, and enforce these regulations (Konschnik & Boling, 2014). Throughout the process of UOG extraction, regulators should also ensure that they implement adaptive management in their approach to regulation, by updating regulations where required (Wiseman, 2014).

4. Conclusions

UOG extraction can damage groundwater resources, so it is crucial to regulate the main aspects of this industry that can be harmful: groundwater use during extraction, the underground fracking operation itself, the management of solid waste and wastewater generated during extraction, and the decommissioning of production wells, which may cause future damage. We propose a regulatory framework with three types of regulatory approaches that can be used to protect groundwater resources during UOG extraction: command-and-control, market-based and voluntary. The following tools are proposed under each of the regulation types:

A combination of command-and-control and voluntary regulations: Baseline studies, Management plans, Public information disclosure, Best available techniques and practices (BATP) and Monitoring and reporting of resources, processes and incidents

Command-and-control regulations: Prohibitory precautionary regulations, margin-of safety-regulations and well decommissioning requirements

Market-based regulations: Water fees, Water trading, Severance tax and royalties, Problems tax and Tax breaks.

All these tools are required to protect groundwater resources during UOG extraction. Regulators need baseline studies so that they would have a reference condition of groundwater resources against which to compare UOG extraction impacts. Monitoring and reporting of resources, processes and incidents are required to timeously identify and react on UOG extraction impacts that pose a hazard to groundwater resources. Requiring companies to implement BATP (that implies the implementation of the most recent technological advances in groundwater protection during UOG extraction), would mean better groundwater resources protection. In the absence of scientific certainty or evidence of the future impacts of UOG extraction on groundwater resources, the precautionary approach must be used as a guiding principle when crafting legislation and regulations. Here, precautionary regulations such as prohibitory regulations and margin-of-safety regulations will minimise the possibility of adverse effects on groundwater systems. Well-decommissioning requirements, in turn, are indispensable if governments want to minimize legacy groundwater impacts and market-based tools, such as tax breaks, can be used to encourage UOG companies to comply with environment-friendly practices.

Of the three regulatory approaches, command-and-control regulations are the most commonly used and are especially effective in countries where regulators are under-capacitated to police self-regulation. Command-and-control regulations must, however, be flexible to optimise the environmental benefits of the regulated activities. Flexibility can be achieved by keeping track of technological advances, regularly reviewing the suitability of command-and-control regulations in view of these advances and amending them where necessary. Combining command-and-control regulations with voluntary regulations (as proposed in our regulatory framework) will also lend more flexibility. Market-based regulations can incentivise companies to implement practices that would ensure better protection of groundwater resources. If market-based tools are used in combination with command-and-control regulations, this could promote innovation in the UOG industry. Voluntary regulation may be useful in protecting groundwater resources during UOG extraction if certification schemes, which provide accountability for the UOG sector, are available.

Considering the strengths and weaknesses of each of the different regulation types, we suggest that, to ensure maximum effectiveness, governments that plan to proceed with UOG extraction and who must still develop a regulatory framework within which UOG companies can operate, should consider a combination of the ‘hard’ command-and-control regulations and the softer market-based and voluntary regulations. Countries must also consider transboundary groundwater resources protection when developing their regulatory frameworks for UOG extraction. To protect groundwater resources effectively, it is vital to require public disclosure of UOG operational aspects and to store this information in publicly accessible databases. This would allow for independent scientific review of data by academia and the private sector, in addition to government scrutiny of the data. These parties can then make recommendations to government, allowing timeous and appropriate adaptive management and the amendment of regulations as necessary. Most importantly, proper enforcement of regulations is essential. Failure to properly enforce UOG extraction regulations would invariably cause damage to groundwater resources, in some cases irreversible.

Conflict of interest

The authors have declared no conflicts of interest for this article.

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FURTHER READING

Supplementary material is attached.

Appendix S1: Supplementary materials

The information presented in Table 1 was used to draw up Figure 4-1 of the article "*Regulations to protect groundwater resources during unconventional oil and gas extraction using fracking*", and to aid in the identification of countries where fracking regulations would be important to consider for the development of the regulatory framework for groundwater protection during UOG extraction.

Table S1: Global importance of natural gas and groundwater resources

Country	Country key	Technically recoverable gas resources	%TPES share of natural gas [4]	GW Share % in total water abstraction	% GW develop-ment stress [6]	Groundwater importance	Fracking status	Energy policy	Country develop-ment status [62]	UOG regulations to protect groundwater resources
Algeria	ALG	707 [1]	64	36% [5] - 39% [6]	46%	H	Allowed [16,1] Public movements against fracking are however present [27] UOG extraction proposed but no drilling yet [1]	10th largest world gas reserves, energy exporter. Wants to move to renewables. [28]. Hydrocarbons form 98% of all export revenues in recent years. [27]	Developing	Limited: EIA & EMP [63]
Argentina	ARG	802 [1,2]	50	22% [6] - 30% [5]	5%	M	Allowed, in exploration phase [16,1], but a municipal ban in Cinco Saltos and provincial ban in Entre Rios [20]	Environmental protection important, reduce GHGs. [28] Government encourages additional production of natural gas [29]	Developing	Limited [64]
Australia	AUS	473 [1]	27	14% [6] -30% [7]	2%	M	Allowed, small scale [1]	Wants to use gas as a bridge to cleaner energy. Reduce GHGs, increase renewables. [30]	Developed	Moderate [65, 66]
Bolivia	BOL	36 [1,2]	38	21% [8] - 40% [6]	1%	M	Allowed, considering development [1]	Wants to change energy mix significantly by 2025, expand its renewable energy capacities by generating 74% of its electricity from renewables, including hydro. Natural gas will generate more than 30% of energy.[31]	Developing	Very limited [67]
Brazil	BRZ	245 [1,3]	12	15% [6]	0%	M	Allowed for energy security, not currently active, focusing on offshore activities [1]	Large planned investment in oil gas sector, with the aim to increase the reserves and production of hydrocarbons [32]	Developing	Limited [68-70]
Bulgaria	BUL	17 [1,2]	14	10% [9]	7%	L	Ban introduced in 2012 [1,17,18,19]	Maintaining a safe, stable and reliable energy system; energy sector remains a leading branch of the Bulgarian economy; Focus on clean and	Developed	Limited [71]

Country	Country key	Technically recoverable gas resources	%TPES share of natural gas [4]	GW Share % in total water abstraction	% GW develop-ment stress [6]	Groundwater importance	Fracking status	Energy policy	Country develop-ment status [62]	UOG regulations to protect groundwater resources
								low-emission energy from nuclear and renewable sources.[33]		
Canada	CAN	388[1] - 573[2]	34.4	2% [6, 11]	0%	L	Allowed, small scale and position differs at state level [1,19]	Wants to be a recognized global leader in secure and sustainable energy supply, use, and innovation. Natural resource development is a strong priority. Wants a 17% reduction in GHGs below 2005 levels by 2020. [34]	Developed	Extensive [72]
Czech republic	CZH		15.4	19% [6]	5%	L	Not allowed. National movement [19,20]	Main goal: Secure energy supply, wants 40% reduction in carbon dioxide (CO_2) emissions by 2030 in comparison with 1990. For 2020, the country has a binding national target for renewable energy to equal 13% of gross final consumption of energy. [35]	Developed	Limited [73]
China	CHN	1115 [1]	5	18% [6]	17%	M	Allowed, small scale [1]	Available unconventional gas, but infrastructure issues. Wants to double gas consumption by 2015. Natural gas still minor in China. [36]	Developing	Very limited [74]
Colombia	COL	55 [1]	26	25-50 [10]	0%	H	Allowed, in exploration phase [1]	Colombia plans to expand its renewables but also wants to expand natural gas [37]	Developing	Very limited [75]
Denmark	DNM	32 [1]	17.4	98 - 100% [9,12]	4%	VH	Banned [19] While initially allowed at the beginning of 2015, fracking activities were subsequently suspended.	Broad and sustained political support for a low-carbon energy transition. Energy efficiency and renewable energy is a policy priority. [38]	Developed	Limited (monitor UOG extraction) [76]

Country	Country key	Technically recoverable gas resources	%TPES share of natural gas [4]	GW Share % in total water abstraction	% GW develop-ment stress [6]	Groundwater importance	Fracking status	Energy policy	Country develop-ment status [62]	UOG regulations to protect groundwater resources
							Exploration wells without fracking had been carried out. [60]			
France	FRN	137 [1]	14.3	18 % [6]	5%	L	Banned in 2012 [19]	Energy transition to accommodate climate change, nuclear forms 46,4% of TPES. Energy transition for green growth act (Aug 2015) [40]	Developed	Limited [19]
Germany	GER	17 [1]	22.3	16 [6] - 18% [9]	8%	L	Moratorium instated in 2014 and a national ban on fracking shale instated in June 2016, [60] but allows test drilling for scientific purposes. [19, 21.] High volume hydraulic fracturing had been carried out in the 1980s. [60]	Move to sustainable energy, phase out nuclear [41]	Developed	Limited [71]
India	IND	96 [1]	5	29% [6]	82%	VH	Allowed, in exploration phase [16]	Wants to reduce emissions intensity by 33%-35% by 2030, achieve a 175 GW renewable energy capacity by 2022, and aims to have the share of non-fossil fuel-based capacity in the electricity mix at above 40% by 2030. Key aims: Electricity access at affordable prices, Improved security and Independence, Greater Sustainability and Economic Growth. [39]	Developing	Very limited [16]
Ireland	IRL		33	27% [6]	1%	M	Banned in 2012 [19,22, 60]	Imports almost all energy. Very limited indigenous energy resources shape government	Developed	Limited [71]

Country	Country key	Technically recoverable gas resources	%TPES share of natural gas [4]	GW Share % in total water abstraction	% GW develop-ment stress [6]	Groundwater importance	Fracking status	Energy policy	Country develop-ment status [62]	UOG regulations to protect groundwater resources
								policy to exploit its existing peat and renewable energy resources, particularly wind. [42]		
Libya	LIB	122 [1,2]	30	95.2% [13] - 98% [6]	134%	VH	Allowed [23] evaluating reserves, activity slow owing to political unrest [1]	Renewable Energy Authority of Libya (REAOL) has established a target of 10% renewables by 2025 but the targets have not been legislated. [43]	Developing	Very limited [77]
Mexico	MEX	545 [1]	35.1	31 % [6]	30%	H	Allowed, [23] in exploration phase. [1]	Ambitious energy transformation, encourage free competition among economic actors in the energy sector, strengthen regulatory agencies, foster clean energy, and environmental protection. [44]	Developing	Limited [78]
Morocco	MOR	20 [1,2]	5	31% [6]	40%	H	Allowed, not currently active, but considering, public not convinced [1]	Morocco has very few deposits of fossil fuels and imports 89.4 percent of its energy needs. The national strategic objective is to safeguard the security of the energy supply by reducing dependence on energy imports. With consistent sun and strong winds, Morocco has strong potential in renewable energy, with a long term goal of becoming an energy exporter to European and African markets. By 2020, Morocco aims to ensure renewable energies will account for 42 percent of electricity generation capacity. [45]	Developing	Very limited [79,80]

Country	Country key	Technically recoverable gas resources	%TPES share of natural gas [4]	GW Share % in total water abstraction	% GW develop-ment stress [6]	Groundwater importance	Fracking status	Energy policy	Country develop-ment status [62]	UOG regulations to protect groundwater resources
Netherlands	NTH	17[3] - 26[2]	41.7	9% [6]	7%	L	Banned [19, 21, 24]. Fracking initially suspended until 2020 [46,59] and then until 2023 in March 2016 [60] Previously granted onshore extraction permits were suspended [60]	Wants to shift to renewables but still at a low base. [46]	Developed	Very limited [81]
Norway	NOR	0 [2]	18.2	14% [6]	1%	L	Allowed [23] Not developed yet, focusing on conventional oil and gas.	Significant gas producer but only a marginal consumer, exporting almost all of its production. Oil and gas sector must ensure long-term value creation - maintain high employment and create wealth in Norway. Oil and gas sector accounted for 12% of the country's GDP and 37% of its total exports in 2016. The efforts to develop and use new technologies for renewable energy will continue. Aims for more efficient and climate-friendly use of energy. [46]	Developed	Limited [82]
Pakistan	PAK	105 [1]	28	32% [6]	661%	VH	Allowed, wants energy independence [1] In exploration phase [1]	Renewable energy resources are seen as promising. However, indigenous technology development, institutional infrastructure, and capacity building are challenges. No clear energy policy is available. Pakistan relies mainly on oil and gas for meeting its energy demand but natural gas demand has grown beyond the	Developing	Very limited [83]

Country	Country key	Technically recoverable gas resources	%TPES share of natural gas [4]	GW Share % in total water abstraction	% GW develop-ment stress [6]	Groundwater importance	Fracking status	Energy policy	Country develop-ment status [62]	UOG regulations to protect groundwater resources
								transmission/supply capacity, leading to severe load shedding/blackouts. [47]		
Paraguay	PAR	75 [1]	0	25% [6]	1%	M	Not active but considering [1]	Targets a 60% increase in its annual renewable energy consumption, aims to decrease fossil fuels energy consumption by 20% and to achieve a 100% national electrification rate by 2030. [48]	Developing	Very limited (none found)
Poland	POL	187 [1]	14.6	23 [6,9]	6%	M	Allowed [16] High volume hydraulic fracturing had already been carried out. [60] In exploration phase [1]	Policy-driven by EU directives. Must liberalise gas in line with EU directives. Reduce dependence on Russia for energy security. Start-up of an LNG terminal in 2016 important step towards diversification of gas supplies. [53]	Developed	Limited, poorly implemented [71, 84]
Romania	ROM	51 [1]	28	12 [6]	3%	L	Allowed, in exploration phase, moratorium from 2011 to 2012 [1], national movement [20], no [19] Exploration wells without fracking had been carried out. [60]	There is a shift from traditional coal-fired power plants which were the main producer of electricity and onshore fields being the only provider of oil and gas, to an energy sector where hydro and other renewable energies provide the largest share of electricity. [49]	Developed	Limited [85]
Russia	RUS	287 [2]	51.8	19 [6]	1%	L	Allowed [19, 25] Starting out and does not have regulatory framework [61]	Increase energy security, increase gas 30% and for exports 15% share of LNG market [52]	Transitioning	Very limited [61]
South Africa	RSA	390 [1]	3	13% [14,15] - 23%[6]	18%	M	Allowed but regulations not drafted yet. No	South Africa needs to grow a secure energy supply to support economic expansion	Developing	Very limited [23]

Country	Country key	Technically recoverable gas resources	%TPES share of natural gas [4]	GW Share % in total water abstraction	% GW develop-ment stress [6]	Groundwater importance	Fracking status	Energy policy	Country develop-ment status [62]	UOG regulations to protect groundwater resources
							regulatory framework to operate within [23]	but citizens must be provided with clean and modern forms of energy at an affordable price. Minimising negative environmental impacts from the energy sector and promoting the conservation of water is important. [50]		
Spain	SPN	8 [1]	0.1	16% [6] - 19% [9]	16%	M	Moratorium instated 2016. [25].	Support sustainable development and ensure energy supply that allows for economic growth and competitiveness, while reducing the impact of energy production, transformation and end-use on the environment - derived from EU directives. European Union targets for 2020 on GHG reduction, renewable energy and energy efficiency are shaping Spain's energy policy. [51]	Developed	Limited [25]
Tunisia	TUN	23 [1]	46	62%[5] - 78% [6]	67%	VH	Considering, not decided yet [1]	In order to reduce its dependency from Algerian gas, Tunisia needs to diversify its electric mix and extend its interconnections. Secure energy, low carbon future, address climate change. The Tunisian Solar Plan foresees a 30% share of renewables in the electricity mix by 2030. This plan has not been formally adopted by the Tunisian government. [54]	Developing	Very limited [86]

Country	Country key	Technically recoverable gas resources	%TPES share of natural gas [4]	GW Share % in total water abstraction	% GW development stress [6]	Groundwater importance	Fracking status	Energy policy	Country development status [62]	UOG regulations to protect groundwater resources
UK	UK	26 [1]	34	15 [6]	3%	L	Allowed, test drilling started [19,21] Exploration phase [1] High volume hydraulic fracturing had already been carried out. [60]	Halve its greenhouse gas emissions from 1990 to 2027 and cut them by a total of 80% by 2050. Key focus areas: Saving energy, Delivering secure energy on the way to a low-carbon energy future, Managing the country's energy legacy responsibly and Driving ambitious action on climate change. [55]	Developed	Moderate [87]
Ukraine	UKR	128 [1]	29	14% [6] - 20% [5]	13%	M	Allowed. Shale gas is not yet commercially produced in Ukraine. [26]	Ukraine is facing unprecedented energy security challenges as a result of ongoing geopolitical and financial crises. Improving energy efficiency could strengthen energy security by decreasing the country's reliance on fossil-fuel imports. There is a large potential for energy efficiency gains in Ukraine. [56]	Transitioning	Very limited [88]
USA	USA	567 [2]	27.8	23% [6] - 28% [9]	13%	M	Allowed and at commercial production level [1], positions differ at state level: Moratoria have been introduced in Vermont, New York, Maryland and Monterey County in California [21]	Wants to increase energy self-reliance, deregulation of oil gas industry environmental requirements. [57]	Developed	Extensive, but poorly protected due to numerous exemptions [89, 90]
Venezuela	VNZ	167 [1]	33	17% [6] - 100% [10]	1%	VH	Allowed, exploration phase [1]	Main energy sources are hydropower and fossil fuels, with hydropower being the	Developing	Very limited (none found)

Country	Country key	Technically recoverable gas resources	%TPES share of natural gas [4]	GW Share % in total water abstraction	% GW develop-ment stress [6]	Groundwater importance	Fracking status	Energy policy	Country develop-ment status [62]	UOG regulations to protect groundwater resources
								main source. Reduction in hydropower generation due to El Nino. No alternative energy sources development is underway. [58]		
References	1:(Cooper et al., 2016); 2:(US EIA, 2013); 3:(Sovacool, 2014); 4: (IEA, 2015b); 5:(Aquastat - FAO, 2015); 6: (Margat & Van der Gun, 2013); 7: (Mitchell et al., 2012); 8: (GreenFacts, 2017); 9: (Eurostat, 2015); 10: (Morris et al., 2003); 11: (Environment Canada, 2013); 12: (Flindt Jørgensen et al., 2017); 13: (Aquastat - FAO, 2016); 14: (GWD, 2018); 15: (Zektser & Everett, 2004); 16: (Gonzalez, 2015); 17: (Callies & Stone, 2014); 18: (Bomberg, 2017); 19: (Scholtens, 2017; Geoffron, 2018); 20: (Fractracker, 2018); 21: (Dodge & Metze, 2017); 22: (Steger & Drehobl, 2018); 23: (du Toit, 2016); 24: (Metze, 2017); 25: (Buono et al., 2017); 26: (Vinson & Elkins LLP, 2018b); 27: Boersma, Leber, & Potvin, 2015; 28 (World bank, 2018); 29: (Grigorjeva, 2016); 30: (IEA, 2018); 31: (Godoy, 2017); 32: (Román, 2014); 33: (Government of Bulgaria, 2011); 34: (IEA, 2015a); 35: (IEA, 2016a); 36: (Corbeau et al., 2012); 37: (Climacap, 2014); 38: (IEA, 2017b); 39: (Government of India, 2017); 40: (IEA, 2017c); 41: (IEA, 2013); 42: (IEA, 2012b); 43: (Energypedia, 2018a); 44: (IEA, 2017a); 45: (Export.gov, 2018a); 46: (IEA, 2014a); 47: (Mirjat et al., 2017); 48: (Climatescope, 2017); 49: (Export.gov, 2018b); 50: (DOE, 2016); 51: (IEA, 2015c); 52: (IEA, 2014c); 53: (IEA, 2016b); 54: (Energypedia, 2018b); 55: (IEA, 2012c); 56: (IEA, 2012a); 57: (IEA, 2014b); 58: (Kelley center for energy security, 2014); 59: (Patterson & McLean, 2018); 60: (Gorski & Trenorden, 2017); 61: (Kryukov & Moe, 2018); 62: (United Nations, 2014); 63: (Loucif, 2019); 64: (Randle & Cogan, 2019); 65: (Maloney, 2015); 66: (Cunsolo, 2018); 67: (Nishizawa & Cabrera, 2019); 68: (Burgess, 2014); 69: (Cavalcanti & Escobar, 2019); 70: (Climacap, 2014); 71: (Ballesteros et al., 2013); 72: (Langer et al., 2017); 73: (Lyapina, 2018); 74: (P.D. Farah & Tremolada, 2016); 75: (Voskoboynik & Munoz, 2017); 76: (Becker & Werner, 2014); 77: (Abdudayem & Scott, 2014); 78: (Serra & Escobedo, 2018); 79: (Bacon, 2013) 80: (USAID, 2011) 81: (van Leeuwen, 2015); 82: (Vinson & Elkins LLP, 2018a); 83: (Kugelman, 2015; Raza, Hussain, Lee, Shakoor, & Kwon, 2017); 84: (La Belle, 2018); 85: (Energy Policy Group, 2017); 86: (Bacon, 2013); 87: (Watterson & Dinan, 2017); 88: (Antonenko et al., 2018); 89: (Brady & Crannell, 2015); 90: (Li et al., 2018).									

Notes to table 1

Groundwater importance (Table 1) was determined by classifying ‘Groundwater % share in total water abstraction’ and ‘Groundwater development stress’ (see Table 2) into 4 groups (very high, high, medium and low). The groundwater importance ranking in Esterhuyse et al. (2014) was used to classify the ‘Groundwater % share in total water abstraction’ per country, as reported by Aquastat - FAO (2015), Eurostat (2015) and Margat & Van der Gun (2013). The groundwater development stress ranking (Gassert et al., 2013) was adapted and used to classify the ‘Groundwater development stress per country’, as reported by Margat & Van der Gun (2013). Groundwater stress measures the ratio of groundwater withdrawal relative to its recharge rate over a given aquifer. The highest-ranking of either of these two indicators (‘Groundwater % share in total water abstraction’ or ‘Groundwater development stress’) resulted in the main classification of the groundwater importance for each country.

Table S2: Groundwater importance

Ranking: Groundwater % share in total water abstraction, based on Esterhuyse et al., (2014)	Classification: Groundwater % share in total water abstraction	Ranking: Groundwater development stress, adapted from Gassert et al., (2013)	Classification: Groundwater development stress
<10%	L	1-9%	L
10-30%	M	10-40%	M
31-50%	H	40-80%	H
=>51%	VH	>80%	VH

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Chapter 5 - Getting fracking regulations right to protect groundwater resources

Unpublished manuscript - Submitted to Nature Geoscience

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The survey instrument that was used for data collection can be seen in Appendix 2.

Abstract

Unconventional oil and gas (UOG) extraction can augment energy supplies in countries with viable gas resources, but it risks damaging water quality. Water supply problems for fracking can also limit UOG extraction, especially in water-stressed regions. Regulations are one of the main tools used to minimise UOG extraction impacts on water resources. Many states in the US and Canada have extensive regulations to protect water resources during UOG extraction but they are often ineffective, either because they were poorly drafted or because they are not properly enforced. South Africa is a water-scarce, groundwater-dependent country that is considering UOG extraction in future. Regulations to protect its groundwater resources must still be drafted. We asked South African groundwater experts what regulations are needed and how to enforce them. This study recommends specific UOG extraction regulations to protect groundwater resources, which will help countries to get it right.

Keywords: Unconventional oil and gas (UOG) extraction, fracking, regulations, enforcement, groundwater resources

Introduction

Unconventional oil and gas (UOG) extraction by hydraulic fracturing (fracking) in shale areas could help countries with energy shortages. But fracking comes with serious environmental risks, particularly to water resources (Tan et al., 2019; Mayer, 2016; Aczel & Makuch, 2018; Connor & Fredericks, 2018). Problems in obtaining water for fracking are also holding back the UOG industry's development, especially in water-stressed regions (Kondash et al., 2018; Rosa et al., 2018). About 31% of shale areas worldwide are water-stressed, defined as areas where human consumptive water demand already exceeds the availability of local renewable 'blue water' (surface water and groundwater) (Rosa et al., 2018). Depending on UOG extraction expansion, as much as 44% of future UOG extraction areas could be water-stressed. Regions currently water-stressed are the south central United States, Canada, Argentina, South Africa, North Africa, China, India, and Australia (Rosa et al., 2018). In such regions, for complete UOG extraction, fracking could use more than 50% of the regional water resources, aggravating competition for water, and in some cases placing unsustainable pressure on the water resources (Rosa et al., 2018).

Regulations are vital for minimizing damage to water resources during UOG extraction. Many states in the US and Canada, where UOG extraction has been going on the longest, have extensive regulations to protect water resources, but often the regulations are a patchwork – some specific and prescriptive, others vague and general (Callies & Stone, 2014; Esterhuyse et al., 2019). In water-scarce countries water is often the main obstacle to the exploitation of UOG resources. It is therefore crucial to get the regulations for protecting water resources right.

Our in-depth study looked at how to do this in South Africa, a seriously water-constrained, groundwater-dependent country that is considering UOG extraction in future. We assessed *what* regulations would be essential and whether and how they could be *effectively enforced*. The recommendations from this study could help countries to get their fracking regulations right to protect groundwater resources effectively.

South Africa – a water-stressed country planning to extract UOG resources

South Africa relies on coal for 90% of its electricity needs (Bohlmann et al., 2018). But the coal is being depleted and South Africa is in dire need of additional energy, having suffered some rolling blackouts since 2008 (Nkosi & Dikgang, 2018). Extracting UOG resources in the Karoo Basin is one of the options being considered. But South Africa's water problems have become well known since the 2016–2018 Cape Town drought crisis, and the problem is country-wide, not limited to the Western Cape (Olivier et al., 2019). A 2016 strategic environmental assessment on shale gas extraction identified water supply for fracking as one of the main factors limiting the UOG industry's development (Hobbs et al., 2016). With its very low annual rainfall, South Africa depends heavily on groundwater, especially in the Karoo Basin.

The Karoo Basin's dolerite dykes and sills contain fractures that carry water, but they can also carry pollution. Contaminants that infiltrate from the surface can migrate from deep to shallow aquifers during UOG extraction (Hobbs et al., 2016). A further route for contamination is the artesian aquifers, mainly in the southern part of the Karoo, where groundwater has been encountered at depths exceeding 4000 meters (Hobbs et al., 2016). The Karoo's groundwater is vital for agriculture and for household use, so the specific vulnerabilities of the Karoo aquifers are a matter for concern (McGranahan et al., 2019; Finkeldey, 2018).

Fracking is a contentious issue in South Africa and there has been much public resistance(Atkinson, 2018; Schreiner et al., 2018). The first permit applications for UOG extraction in South Africa were submitted in 2011, yet proper regulations have yet to be drafted to protect natural resources, and particularly water. The only fracking-specific regulations made to date in South Africa (called the 'Fracking regulations'), released in 2015, were challenged in court and invalidated in 2019 by the South African Supreme Court of Appeal (RSA, 2019).

What regulations can protect groundwater during UOG extraction?

We asked 20 South African groundwater experts for their view of the importance and enforceability of regulations that we proposed for protecting groundwater resources during UOG extraction. We grouped the regulations according to the eight regulatory areas shown in Figure 5-1 and explained below. Detailed information on responses per regulatory area is available in the supplementary materials (Figure 1a to 1g), while additional regulatory suggestions made by respondents, can be seen in Table 1, supplementary materials.

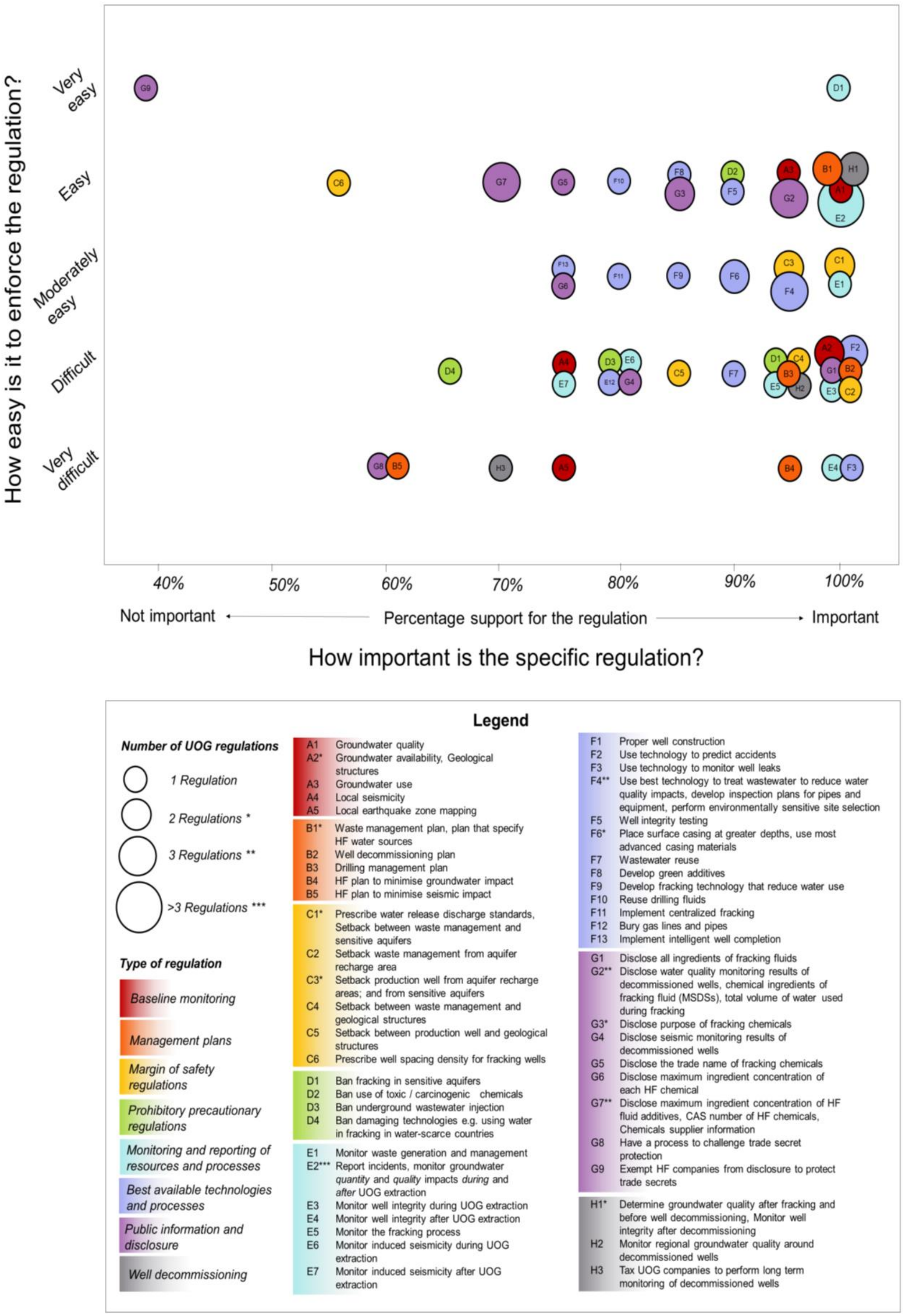

Figure 5-1: Importance and ease of enforcement of proposed groundwater regulations (n=20)

Baseline monitoring: All respondents viewed baseline monitoring of groundwater quality, groundwater availability for fracking and baseline mapping of geological structures as important. Fifteen of the twenty respondents viewed seismicity mapping and earthquake zone mapping as important, and also the prediction of future seismicity linked to underground wastewater injection, if South Africa allows this.

Respondents viewed baseline monitoring of groundwater quality, groundwater availability for fracking and baseline mapping of geological structures as the easiest to enforce, and seismicity mapping as the most difficult. Four respondents did not believe the South African regulator can enforce baseline monitoring regulations. They cited insufficient funding, lack of expertise, weak institutions, absence of legislation and regulations, lack of political will, and corruption. They called for a sophisticated regulator with state-of-the-art monitoring equipment and systems, integrity and codes of ethics, an ability to operate independently, and competent staff empowered to enforce regulations, such as shutting down an expensive drilling operation when there are real safety concerns.

Management plans: All respondents considered it important to have plans for waste management, well decommissioning and specification of water sources for fracking in place before proceeding with UOG extraction. All but one respondent considered a drilling management plan and a hydraulic fracturing management plan important for minimizing damage to groundwater, but only 60% thought a hydraulic fracturing management plan to minimize seismic activity was important. One respondent said that since it was the drilling contractor and not the regulator who had expert knowledge, drilling contractors should submit their protocols for review under a protocol management plan. Two respondents said that the submitted plans should be reviewed by an independent expert panel and must be transparent and implemented in consultation with all relevant stakeholders. Only the waste management plan and the plan specifying sources of water for fracking were considered relatively easy to enforce. Four respondents felt that a shortage of government human resources and financial capacity would hamper enforcement in South Africa.

Margin of safety regulations: All respondents viewed as most important the regulations for limiting any negative effects of waste or wastewater on groundwater. These regulations included wastewater release discharge standards and setback distances between waste management operations and sensitive aquifers, aquifer recharge areas and geological structures. They considered regulation of production well operations less important. Just over half thought that it was important to regulate well spacing density, although this is important to ensure a smaller surface footprint and to avoid economic and resource waste (including gas resource wastage and wastewater generation) (Daily, 2015). A lower density of surface wells would also limit the possibility of interaction between hydraulically generated fractures and existing wells or other underground infrastructure (known as ‘frac-hits’) (Brownlow et al., 2017). Frac-hits could lead to the upward migration of contaminants into freshwater aquifers. How best to space wells is, however, dictated by technological choices and the geology. To improve well spacing, goal-oriented regulation might be particularly effective, with goals for the operator to aim for, as the operator knows best how to optimize well spacing while limiting wastage.

Respondents saw prescribing well spacing densities and wastewater release discharge standards as the easiest regulations to enforce, and setbacks between waste management operations and aquifer recharge areas and between production wells and geological structures as the most difficult. This could be because geological and hydrogeological complexity makes it hard to identify all the sensitive aquifers and geological structures that could be at risk (Hobbs et al., 2016). Current groundwater characterization data in South Africa (and sub-Saharan Africa) is patchy because of continued underinvestment in groundwater, and limited technical and institutional capacities constrain sustainable groundwater development and management (Cobbing et al., 2015; Gaye & Tindimugaya, 2019; DWS, 2016).

Under 'margin of safety' we also proposed and tested minimum setback distances between fracking wells and ancillary activities and groundwater features specifically for South African groundwater conditions (see supplementary materials - Table 2). Respondents had to say whether they agreed with our minimum proposed setback distances. If they did not, they could propose alternative setback distances or protection approaches, giving their reasons. For most setbacks that we proposed, respondents mostly erred on the side of caution, proposing much more stringent setbacks than ours. Respondents suggested larger setbacks between town water supply and production wells than we proposed. Their minimum proposed setback distance between town water supply boreholes and UOG production wells was 10 km, and for towns with no existing wellfields they suggested a 10km setback between towns and any future production wells. Town water supply from groundwater is very important in South Africa (Esterhuyse, 2017): an estimated 45.5% of the country's surface area is more than 50% dependent on groundwater supply for domestic needs (Esterhuyse et al., 2014).

Despite respondents' support for our proposed minimum setback distances, 20% said that setbacks should be calculated not generically but on a risk-based case-by-case basis according to local geological and hydrogeological conditions at each site. Such an approach might allow for more lenient setbacks, but also a tougher approach in high risk cases. One respondent said regulators should set out goals to be achieved but allow operators to decide how to achieve them, according to the principle of reducing risks to as low as reasonably practicable.

The setbacks that we tested were all horizontal distances. One respondent, however, proposed a vertical restriction for fracking in South Africa specifically – no fracking in target shale formations less than 1000 m deep, and that fracking only be allowed in shale formations less than 1500 m deep, if a comprehensive hydrogeological conceptual model has been developed. This was because the Karoo hot springs indicate geothermal circulation taking place 700 to 800 m below the surface, making a connection between deep and shallow aquifers more likely at depths of less than 1500 m. Initial research on the connections between the shallow Beaufort aquifers and the deeper Ecca aquifers in South Africa (where the methane gas is located), indicate some degree of connection between these aquifers, legitimizing concerns about shallow-deep aquifer connections (Hohne et al., 2019; Eymold et al., 2018). In South Africa vertical separation distances may prove especially important.

Prohibitory precautionary regulations: These prohibit UOG operators from executing certain activities during UOG extraction, to protect groundwater resources. Respondents saw prohibiting the use of harmful, toxic or carcinogenic chemicals, prohibiting fracking in sensitive aquifers and prohibiting underground wastewater injection (UWI) as the most important prohibitory precautionary regulations. UWI is a particular concern in South Africa because of the reliance on groundwater and because possible shallow-deep aquifer connectivity can cause fracking fluid and contaminant migration.

Respondents viewed the prohibition of the abovementioned chemicals as the most difficult regulation to enforce, possibly because regulators would not be able to confirm independently that UOG operators are not using prohibited chemicals, or because of UOG operator pushback against such prohibitions, which abounds in countries that use fracking (Cramer, 2016). We suggest that regulators could follow the precautionary approach and require companies to prove the safety of their chemicals before use (Fink, 2019). This would ensure more transparency in the fracking industry and encourage the development of safe fracking chemicals.

Monitoring and reporting of resources and processes: All the respondents considered this very important, with one considering it 'probably *the* most important aspect' of UOG extraction. Respondents supported monitoring of all the aspects that we suggested: waste generation and waste management, groundwater quality and quantity impacts during and after UOG extraction, the fracking process, well integrity during and after UOG extraction, induced seismicity and reporting any incidents. Of all the monitoring regulations, well integrity was viewed as most difficult to enforce, especially after well decommissioning, probably because of the lack of clear guidelines – should you keep the well open or seal it? Respondents also felt that is was important to establish an independent UOG extraction monitoring committee to implement regional monitoring and bi-annually audit the operators' site-specific monitoring protocols. They felt compliance monitoring and enforcement could provide credibility and ensure effective governance.

Best available technologies and practices (BATP): Most respondents (75 to 100%) saw all our proposed BATP regulations as very important. The position statement by South Africa's Centre for Environmental Rights underscores its importance (CER, 2014). The BATP regulations that respondents viewed as most important were proper well construction and using technologies to predict, prevent and mitigate accidents and monitor for well leakages. It would also however be important to flag the importance of technological development that may obviate the need to use water during fracking (Quigley, 2016).

Internationally, BATP reduces pollution and other externalities, but it suffers from underinvestment (Centner & Eberhart, 2016) and its effective implementation is hampered by a time lag between technological development in the UOG industry and government adaptation of regulations to include the most recent BATP. Governments could incentivize BATP adoption by giving tax breaks to companies that develop better BATP. One respondent felt that the choice of technologies to be applied should not be prescribed by the regulator but left to the operator (i.e. the regulations should set the goalposts but allow the industry the space to meet the objectives taking a risk-based approach), as the regulator is generally not sufficiently experienced to identify best practices and the industry is in a better position to innovate and introduce fit-for-purpose applications. Another respondent, however, said BATP must be defined for each operational step and that operators and regulators must have a common understanding of BATP (since one operator's best technology and practices may be better than another's).

Public information and disclosure (PID): Respondents saw this as important, with most important being disclosure of all ingredients in fracking fluids, followed by water quality monitoring results from decommissioned wells and the total volume of water used in fracking. Only 40% of respondents thought fracking companies should be exempted from disclosure, to protect trade secrets, and 60% approved of a process to challenge trade secret protection, to stop companies obtaining exemption from certain disclosures. Three respondents took serious issue with trade secret exemptions. One of them said there should be '*no* exceptions to disclosing information' and that 'trade secrets' was not a valid excuse and therefore saw no need for a process to challenge a claim for a 'trade secret'. Respondents considered the disclosure of fracking fluids and the trade name of fracking chemicals and suppliers the most difficult to enforce. Some further improvements to disclosures that they suggested were:

- A mechanism to ensure the responsible use of publicly disclosed information (to minimise misuse of information by campaign groups)
- A way to ensure that operators can be trusted to produce truthful disclosures Reports of chemicals used in *each* well, as these can differ
- Public input into the licensing process
- A disclosure format that can be understood by a layperson.

Internationally, the desire to protect trade secrets is a problem in enforcing public disclosure (Cramer, 2016). Often companies actively undermine disclosure policies by lobbying for weaker regulations, or 'drown' users in disclosure, where so much information is disclosed and in such a format that information users do not have the time, resources, or expertise to analyse it effectively (Kinchy & Schaffer, 2018; Weible et al., 2017). All our respondents thought PID regulations would be difficult to enforce and usable information hard to obtain.

Well decommissioning: Respondents were unanimous that a groundwater quality survey before fracking is indispensable. They also viewed as important monitoring of well integrity after well decommissioning, monitoring groundwater quality in the vicinity of decommissioned wells, and taxes for long-term monitoring after decommissioning. Respondents viewed monitoring well integrity after closure and imposing taxes to ensure long-term monitoring as the most difficult regulations to enforce. The big difficulty with well integrity monitoring is how to decommission a well safely yet still be able to monitor it. Collecting and administering taxes for long-term monitoring may be problematic in South Africa, given the current poor governance of our natural resources, with corruption and kickbacks, real and reputed, abounding (Atkinson, 2018). Further, taxes here go into the general fiscus and there is no mechanism to ensure that the money will be used for long-term monitoring or legacy impacts. Here an independent regulatory entity for administering well decommissioning funds might be useful.

South Africa's capacity to enforce UOG extraction and fracking regulations

To ensure compliance with and enforcement of UOG regulations, respondents felt that fining UOG operators who did not comply was an important tool to ensure compliance with regulations. Another would be requiring them to compensate for pollution incidents, for example by supplying water where water sources are polluted. One respondent did not believe operators would do this if pollution surfaced only five to ten years after they had left a fracking area, and proposed that operators be levied during their operations for remedying future pollution incidents, and that such funds be separately managed by an institution independent from government. Supplying financial security in terms of obligations related to water use licences and for addressing latent and residual water-related impacts arising from UOG extraction was also viewed as very important. However, they cautioned that the operator should not

view a financial security requirement or the levying of impact funds as a licence to pollute. In the US, discretionary review, tiered monetary penalties and civil suits are common enforcement mechanisms (Angeles, 2018). As these do not, however, provide sufficient compliance incentives or penalties for noncompliance, enforcement could benefit from the additional tool of criminal sanctions for significant violations, if applied fairly (in proportion to the violation) (Angeles, 2018). One respondent felt that personal liability should also be considered as a deterrent for activities that may cause groundwater pollution.
To ensure compliance with regulations, enforcement mechanisms must be implemented by government. We therefore asked questions to assess South Africa's policies and institutional capacity to enforce regulations on UOG extraction and fracking. Institutional capacity constraints are, according the respondents, 'the crux of the shale gas development issue in South Africa' and 'our biggest challenge', and they fear that UOG extraction 'will completely over-extend the already very limited capacity within our government departments'.

All but one respondent felt that South Africa does not have the institutional capacity to enforce compliance with specified licence conditions or to monitor UOG extraction operations. Ninety per cent of respondents also felt strongly that fragmented departmental responsibilities and conflicting departmental mandates would make it complicated and difficult to regulate UOG extraction (Atkinson, 2018). Eighty per cent of respondents felt that the Mineral and Petroleum Resources Development Act of 2002, the main Act regulating oil and gas extraction, is insufficient in scope to handle fracking, and that amendments would be required to our statutes. Sixty-five per cent stated that South Africa does not have specific policies to deal with fracking or sufficient regulations to control it. As mentioned earlier, South Africa's only fracking-specific regulations, drafted in 2015, were set aside in court because they did not sufficiently protect groundwater resources (Atkinson, 2018; Finkeldey, 2018).

We compared our 2019 capacity survey results with those of a 2012 survey, in which we asked different respondents from the same institutions the same questions (S Esterhuyse et al., 2013). We found no significant differences between the 2012 and 2019 responses, except that more of the 2019 group than the 2012 group stated that South Africa does have fracking-specific policies in place. South Africa has developed a clearer fracking policy compared to 2012, and now actively supports UOG development (Schreiner et al., 2018). The government has also commissioned a 'Strategic environmental assessment for shale gas development' in an effort to move UOG development along. However, the setting aside of the 2015 fracking regulations has slowed progress. The lack of a clear regulatory framework to manage fracking in South Africa means the government cannot permit UOG extraction and the risk is too high for UOG companies to proceed. But given the risks to the environment, particularly water resources, the precautionary principle must prevail. It would be unwise to permit UOG extraction when the government has neither the knowledge to draft proper regulations nor the institutional capacity to enforce them.

To enforce regulations, 90% of respondents agreed that fracking-specific legislation and regulations must be developed, and particularly monitoring protocols. Sixty-five per cent of respondents felt that self-regulation and reporting to government could alleviate government human resource pressures, and that market-based regulatory tools would also be useful in addition to command-and-control regulations such as margin-of-safety regulations or BATP. South Africa's difficulties are not unique: even countries with good laws struggle to enforce them because of budget and human resource shortages (Centner & Connell, 2014; Fink, 2019). More than half the oil and gas wells in the US are not inspected annually to check compliance with regulations and some state agencies cannot employ enough employees for their oversight programmes, with the result that violators are less likely to be cited, fined, or prosecuted (Centner & Connell, 2014; Fink, 2019). Our respondents supported strong measures to ensure compliance, such as an independent regulatory entity reporting to government, a central database, and fines for violators. It is important, however, to note that 70% of them said a strategic environmental assessment on available energy generation options must be done before South Africa decides whether to allow UOG extraction.

Finally, when asked whether South Africa can protect groundwater resources effectively by regulating UOG extraction, only 30% of respondents believed that we can.

Discussion

Our respondents were seriously concerned about sourcing of water for fracking in water-scarce South Africa. Currently, water sourcing is viewed as the main factor limiting UOG development in South Africa (Hobbs et al., 2016), as is the case in China (Lin, 2018; Guo et al., 2016). They considered regulations for baseline monitoring of water used for fracking to be paramount, taking into consideration existing domestic and industrial water needs in the area. Water use is also a concern in the USA (Wiseman and Gradijan, 2012; Buono et al, 2019). Respondents saw regulations to protect groundwater from contamination during UOG extraction as some of the most important. This is consistent with several surveys that identified water contamination as one of the main concerns, both for water-scarce and water-abundant countries (Wiseman and Gradijan, 2012; Tan et al., 2019; Mayer, 2016; Aczel & Makuch, 2018; Connor & Fredericks, 2018; Thomas et al., 2017). A baseline of water quality is seen as the first step towards protecting groundwater resources during fracking (Pietersen et al., 2016). In the US some states are still not getting this right, frustrating efforts to identify contamination and determine liability (Kinne, 2018). Regulators can consider adopting a law that creates a rebuttable presumption of liability for the operator for any groundwater contamination that occurs within a certain distance of UOG drilling operations (Hall, 2014). This will place the burden of proof for groundwater contamination issues on the operator. Our respondents did not support regulations that could weaken groundwater quality protection, such as regulations that exempt fracking companies from publicly disclosing information so they can protect trade secrets, or using arbitrary setback distances that are not based on scientific data.

Poor enforcement is where even the best regulations could fail. Only a third of our respondents felt that South Africa would be able to protect groundwater resources properly by regulating UOG extraction, not because the regulations themselves would be technically challenging to comply with, but because:

- Regulators, not only in South Africa but also internationally, do not know enough about the risks of UOG development to draft proper regulations (Rawlins, 2014; Thomas et al., 2017; Holding et al., 2017; Schreurs, 2018).
- Regulation is complex because of the fragmented departmental responsibilities and conflicting departmental mandates (a problem also observed in the US,

Canada and China (Ingelson & Hunter, 2014; Paolo Davide Farah & Tremolada, 2016; Notte et al., 2017)).

- Institutional capacity is insufficient to monitor fracking activities and UOG extraction impacts on natural resources (a problem also observed in the US, Canada and China (Brantley et al., 2018; Wiseman, 2012; Eaton, 2013; Gagnon et al., 2015; Lin, 2018)).
- Institutional capacity and political will to enforce compliance with UOG extraction regulations are insufficient, not only in South Africa and other developing countries (China, Argentina and Brazil) (Lenhard et al., 2018; Lin, 2018; Saulino, 2018) but also in developed countries such as Spain and the US(Wiseman, 2014; Hull & Evensen, 2020; Centner & Connell, 2014; DiGiulio et al., 2018; Fink, 2019).

Self-regulation and reporting to government, as well as market-based regulatory tools, could alleviate government capacity pressures and ensure better enforcement of regulations in countries not properly equipped to regulate UOG extraction. In countries with regulatory capacity constraints and corruption concerns, the establishment of an independent regulatory entity with a scientific background in fracking could help governments in the following ways:

- Drafting and regularly reviewing regulations tailored to the country's specific needs (by considering country-specific geological complexities, governance structures, capacity constraints and technological advances)
- Establishing and administering an independent trust fund to manage collected funds for long-term monitoring after well decommissioning.
- Performing regional monitoring of groundwater resources in UOG extraction areas and reporting to government
- Performing compliance monitoring of UOG extraction operations
- Storing all data in a publicly accessible central database and ensuring proper dissemination of data to all interested and affected parties.

Such an entity would have to be transparent and have the trust of the regulators, the operators and the general public. It would have to be comprised of stakeholders from all three groups. All data gathered by such an entity would have to be stored in a publicly accessible central database, which could be used for studies and to assess compliance with regulations. Access to UOG extraction and monitoring data would be paramount to ensure proper enforcement of regulations. Without good governance and proper enforcement, any regulations to protect groundwater resources would fail dismally.

Finally, two-thirds of our respondents felt that the government must do a strategic environmental assessment of available energy generation options in South Africa, *before* deciding whether to allow UOG extraction. This is important because water resources are the one main limiting factor for UOG extraction in water-scarce countries. First performing such an assessment, prioritising energy generation options, and then drafting regulations for UOG extraction (if it is seen as a viable option), would uphold the South African constitutional obligation to promote sustainable development and pass reasonable legislative (and other) measures to protect the environment 'for the benefit of present and future generations'.

This study offers crucial insights into how to protect groundwater resources during UOG extraction, using regulations. Fracking can use a large amount of groundwater and also pollute groundwater resources, a major concern in many water-scarce countries. It is therefore important that governments protect groundwater resources during UOG extraction, especially when considering additional stressors such as population growth or climate change. Many studies have looked at specific regulations to protect water resources during UOG extraction. We have gone further: we reviewed, classified and systematically tested the many different regulations that are currently applied internationally (sometimes in a patchwork fashion), to assess their usefulness in protecting groundwater resources.

Our survey of expert responses was done in South Africa and some of our proposed UOG extraction regulations are specific to South Africa's geography and governance systems. Nevertheless, most of the insights this paper offers would be useful for any country that must still develop regulations, or whose current regulations need amendment.

Methods

Survey design

We canvassed 20 respondents' opinions on the importance and enforceability of UOG extraction regulations we proposed that were designed to protect groundwater resources during all the phases of extraction, from before exploration until after well decommissioning.

Our regulations, classified into eight groups (see Figure 5-1), were based on a detailed examination of UOG extraction regulations commonly used to protect groundwater resources in countries that have such regulations in place, and a long history of UOG extraction: the US, Canada Australia and the UK (Esterhuyse et al., 2019). We also assessed respondents' views on the capacity of the South African government to enforce these regulations successfully, via a list of carefully structured questions on South Africa's fracking policy, governance structure and current legislation and regulations that are in place.

We designed a self-administered structured questionnaire to test the respondents' perceptions and opinions of our proposed fracking regulations, as this is a good tool to elicit stakeholder opinions at a pre-decision phase (Mukherjee et al., 2018). In South Africa, previous drafts of fracking regulations had been rejected, so we are still in the pre-decision phase of the drafting of fracking regulations. The self-administered questionnaire also allowed informants time to complete the survey on their own schedules, with additional time to collect information to help inform their responses and ensure carefully considered responses (Baker et al., 2014). The questionnaire gave respondents considerable flexibility by including open-ended questions where they could describe their reasoning or any other concerns not captured in the Likert scale questions. Our survey was anonymous to increase our chances of eliciting stakeholder opinions, as fracking is a sensitive and contentious topic in South Africa (Redelinghuys, 2016). Anonymity meant that the respondents could give their considered opinions unconstrained by corporate, political, or other considerations (Young et al., 2018; Morgan, 2014).

Eliciting viewpoints from knowledgeable informants, referred to in the literature as 'key informant elicitation', can make a valuable contribution to informed decision-making and is a useful tool to explore regulatory uncertainty (in this case UOG extraction regulation). To obtain carefully considered and meaningful judgments based on a systematic consideration of all relevant evidence, we took the question on UOG regulation apart into its component pieces so we could ask respondents to rate the importance and enforceability of a very detailed and specific list of regulations. This gave us eight regulatory areas:

- Baseline monitoring
- Management plans
- Margin of safety regulations
- Prohibitory precautionary regulations
- Monitoring and reporting of resources and processes
- Best available technologies and processes (BATP)
- Public information and disclosure
- Well decommissioning

The questionnaire was carefully developed over a number of months. We tested it on two groundwater practitioners with knowledge of fracking in countries outside South Africa. Two respondents with no groundwater knowledge, but with fracking knowledge, also read it to determine whether the questionnaire was generally understandable. Feedback gathered this way was incorporated into the questionnaire. We did not test the questionnaire on any of our targeted respondents (South African groundwater specialists) to ensure that we did not unduly influence them during the development phase of the questionnaire. We also took care to ensure that any possibly unfamiliar concepts were explained in our questionnaire, to ensure that respondents understood the questions and could give proper feedback.

We emailed our respondents the survey, gave them time to go through the questionnaire, and then contacted them to discuss any uncertainties they might have about any of the questions. Respondents could also contact us with any questions or concerns while completing the questionnaire, or afterwards if they wanted to add more information to any open-ended questions. The survey was launched in November 2018 and closed in August 2019.

Respondents

Successful eliciting of information from respondents depends on the respondents' knowledge and commitment. Given our focus on *regulations to protect groundwater resources during UOG extraction*, our ideal respondents were groundwater specialists with knowledge of UOG extraction and fracking through work or research. Because our target group was very specific, our sample was of necessity small. We used publication history and peer nomination of groundwater specialists to select our respondents. We approached 31 South African groundwater specialists, which represented the whole pool of suitable respondents. Twenty of these completed the survey, a response rate of 64.5%. Some potential respondents declined to complete the survey due to the sensitive nature of this subject in South Africa, or because they felt that they did not know enough about the subject. Sixty-five per cent of respondents (n=13) had more than 10 years' groundwater experience, and of those, 69% (n=9) had more than 20 years' experience.

To assess their knowledge levels, we asked them to rate the extent of their knowledge about UOG extraction and fracking, their levels of satisfaction with their knowledge, and to indicate the sources of their knowledge (Figure 5-2). Most felt that their knowledge about groundwater impacts from both fracking and UOG extraction was extensive to good. Their knowledge about how the industry should be regulated was more limited, with 55% of respondents (n=11) rating their knowledge about the regulation of UOG extraction in South Africa as extensive to good, and only 45% (n=9) rating their knowledge about the regulation of UOG extraction internationally as extensive to good. Most were not satisfied with their levels of knowledge of any of these aspects. Most had sourced their information on UOG extraction and fracking from scientific sources in the form of research reports (80%), scholarly articles (75%) and government reports (60%). They consulted popular media sources less extensively.

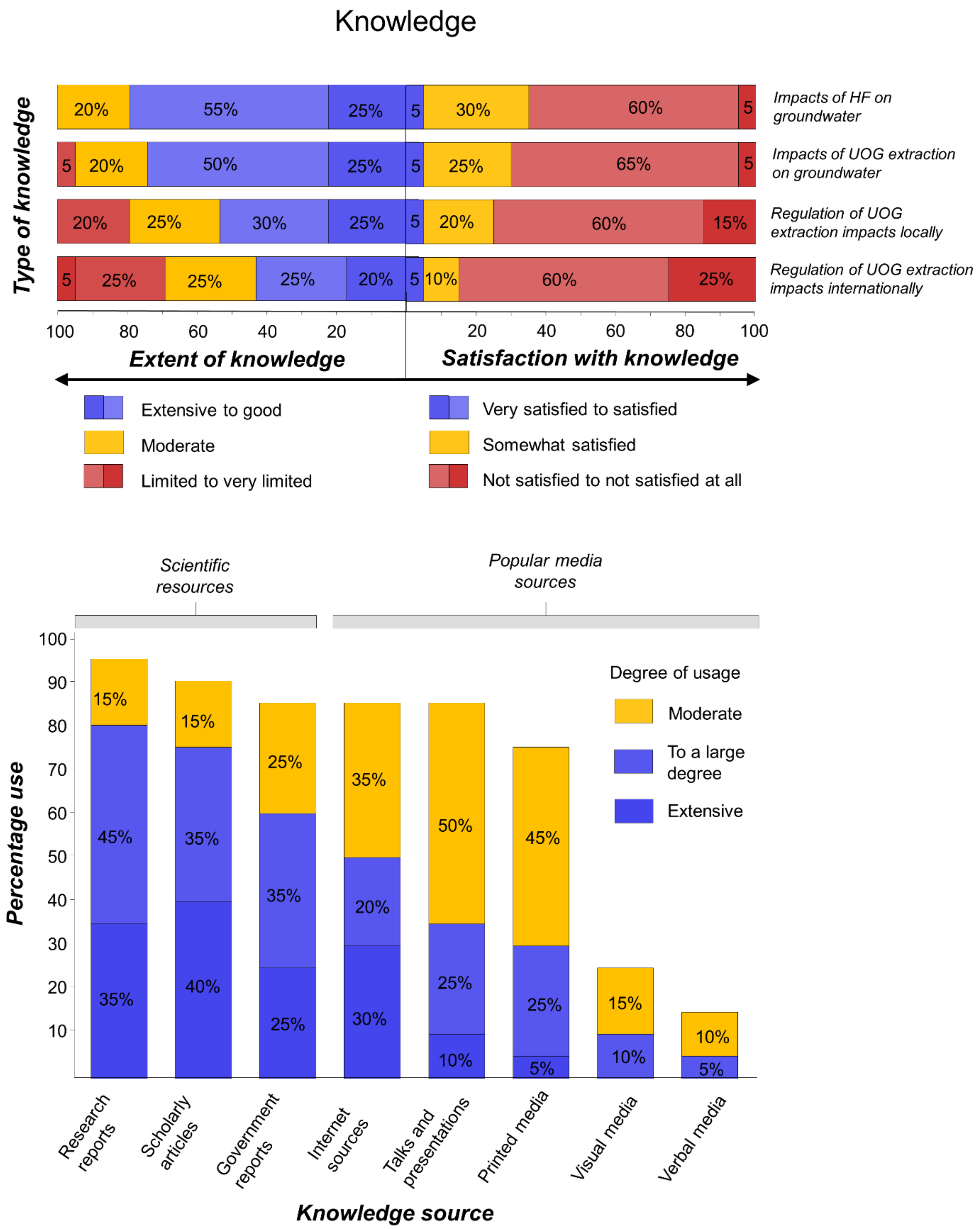

Figure 5-2: Extent of knowledge, satisfaction with knowledge and knowledge sources (n=20)

The respondents were from government, non-governmental organizations (NGOs), groundwater consultancies and industry. We targeted a variety of sectors to get different perspectives on the importance of the regulations we proposed and how easy they would be to enforce. In South Africa there is a complex interplay between these different institutions as regards groundwater protection. The Department of Water and Sanitation has very few groundwater specialists (DWA [Department of Water Affairs], 2010; DWS [Department of Water and Sanitation], 2016) as most have moved to consultancy companies (DWS, 2016), but the few who are left must still draft regulations and ensure they are enforced. Academia and consultancies are often called on to assist government in some of its functions (DWS, 2016), so the country does have fairly good groundwater resource management capacity, although most of this capacity is located at the consultancies. It was therefore important to elicit the opinions of groundwater specialists from several institutions. The respondents were from the different institutions as follows: consultancies 55% (n=11), government 20% (n=4), educational institutions 10% (n=2), mining, oil and gas industries 10% (n=2) and NGOs 5% (n=1).

Data analysis

We analysed the quantitative data with the statistical package for social sciences (SPSS) version 25. Qualitative data were analysed thematically to add more depth to the quantitative data interpretation and to better understand respondent concerns about our proposed regulations. Qualitative data from open-ended questions was especially useful for gathering information about regulations that might be needed in addition to the ones we proposed. Differences between the respondent groups (based on qualifications, institution and years of experience) were tested using the Kruskal Wallis statistical test, and the Mann Whitney U test was used to identify where the specific differences within the groups lied. We identified significant differences only in the respondents' opinions on the enforcement of regulations and only according to their years of experience. We found that respondents with less than 20 years' experience viewed the enforcement of specific setbacks, BATP regulations and PID regulations as more difficult than respondents with more than 20 years' experience (see Table 3 in Supplementary materials). This could be because in South Africa specialists with fewer years of experience typically work in government institutions and are therefore more aware of the difficulties those institutions currently experience, while those with more years' of experience typically work in consultancy firms. This is confirmed by our biographical data and the 2016 groundwater strategy for South Africa (DWS, 2016) We also assessed whether there were significant differences in respondent views on the institutional capacity to regulate UOG extraction, between a survey that we carried out in 2012 and our 2019 survey, using the Mann Whitney U test. There were no significant differences between the two groups in their views on South Africa's capacity to regulate fracking, except that the 2019 group felt that South Africa had a clearer fracking policy than the 2012 group ($U=134$, $Z=-2.98$, $p=0.003$). Both the 2012 and 2019 groups felt that South Africa would not be able to effectively regulate fracking.

Limitations

We acknowledge two limitations of our study. One is the smallness of the sample, the reason for which has been explained. Note that our use of percentages to represent this very small sample is not intended as a claim to statistical validity or generalizability. The percentages are used only to ease reading and to demonstrate how our survey method might be extrapolated to a larger sample, and in the figures to aid in visual interpretation. Another limitation is the unevenness of the sample, with more than half of the respondents being of one type (11 of the 20 were from consultancies), which could introduce bias.

Ethics statement

The University of the Free State ethics board approved the survey instrument (UFS-HSD2018/1420). Informed consent was obtained from all respondents. The respondents completed the survey anonymously to ensure adherence to ethical guidelines.

Data availability

Datasets related to this study will be made available upon request by the corresponding author, subject to compliance with the University of the Free State research ethics board restrictions on survey data.

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Author contributions

S.E. conceptualised the research, developed the survey instrument, executed the survey, analysed the data and wrote the manuscript. D.V and J.G. assisted in conceptualisation of the research, reviewed the questionnaire and the manuscript and contributed to the writing of the manuscript.

Additional information

Supplementary information is available for this paper.

Competing interests

The authors declare no competing interests.

Supplementary materials

Figures 1a to 1g present detailed information on the opinions of the groundwater experts on whether our proposed regulations are important and enforceable.

Table 1 presents the respondent suggestions for additional regulations based on the thematic analysis of respondent comments for each of the regulatory areas.

Table 2 presents the minimum setback distances between UOG extraction features and South African groundwater features

Table 3 presents the respondent views on the ease of enforcement of specific setback regulations that significantly differ related to their years' experience.

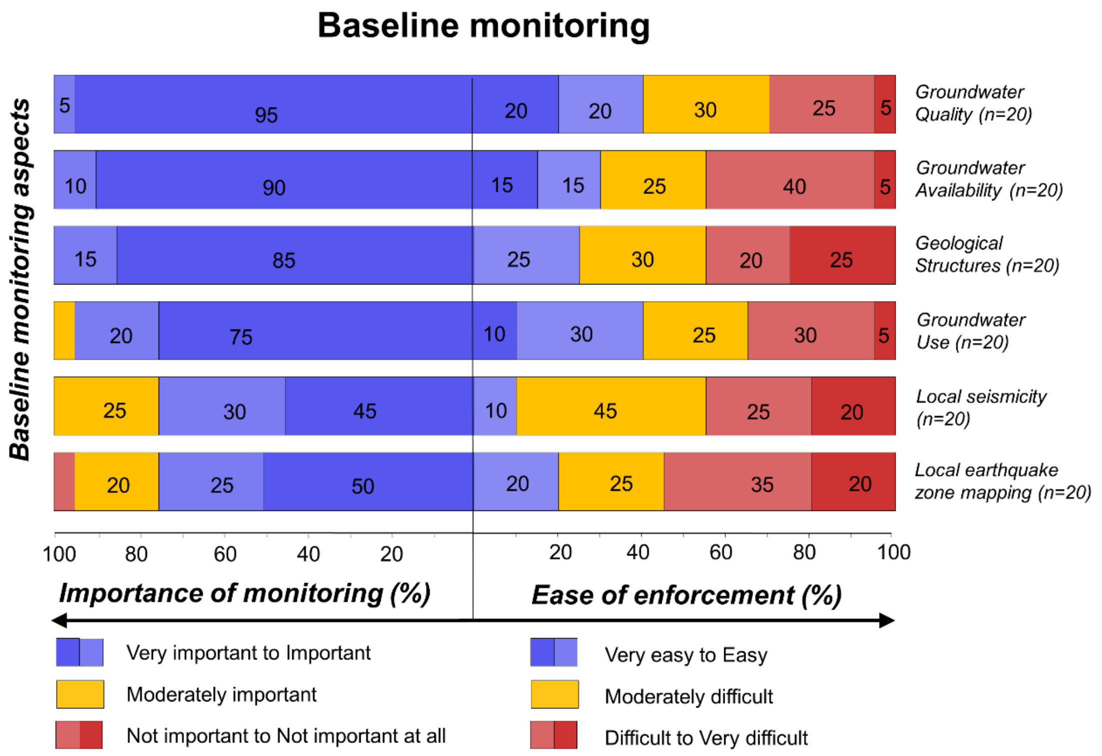

Figure 1a: Baseline monitoring

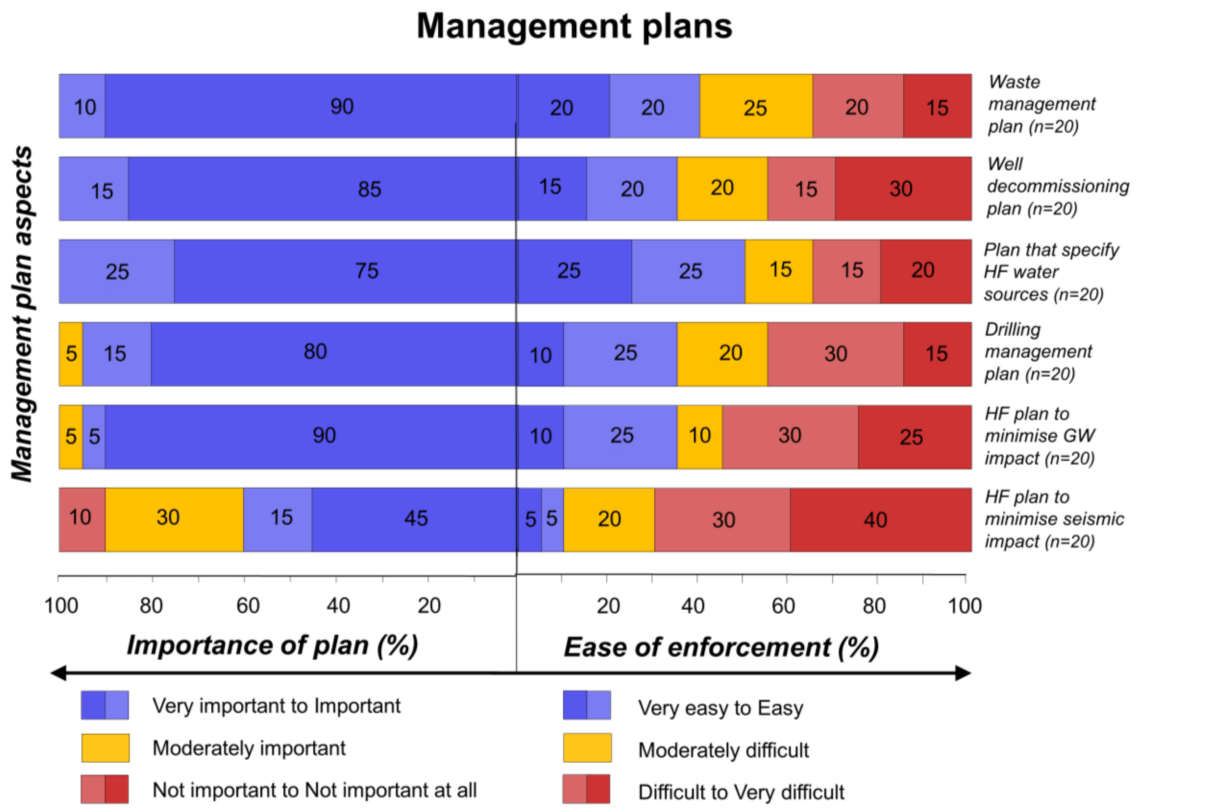

Figure 1b: Management plans

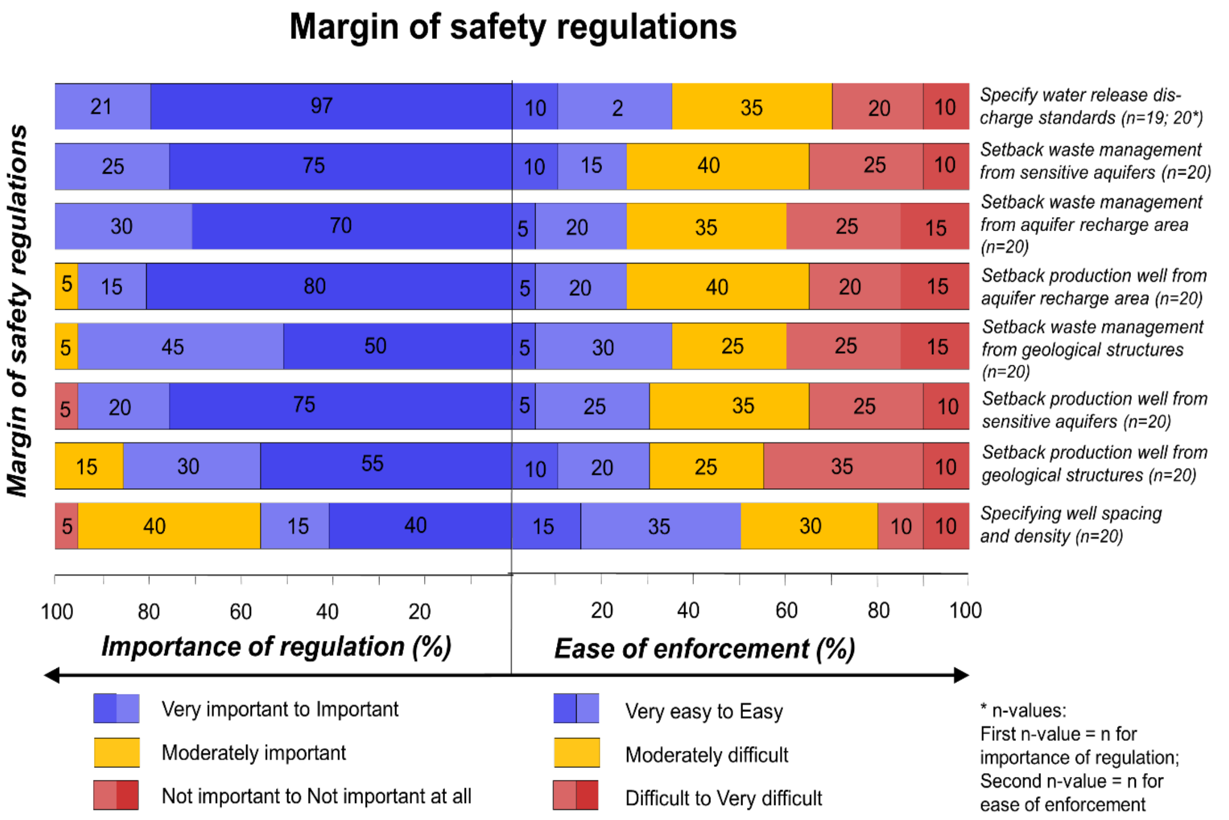

Figure 1c: Margin of safety regulations

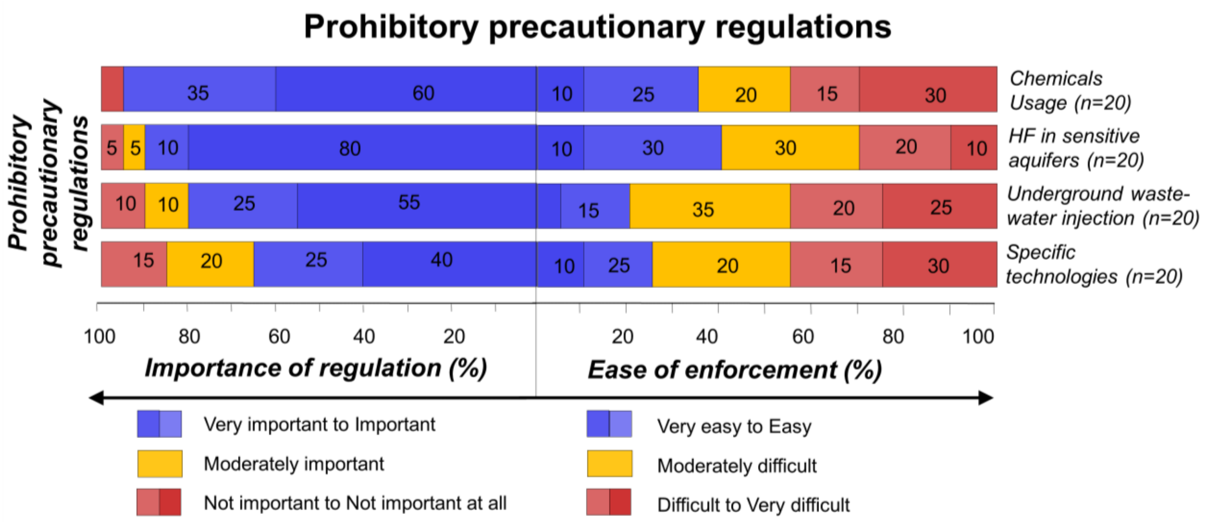

Figure 1d: Prohibitory precautionary regulations

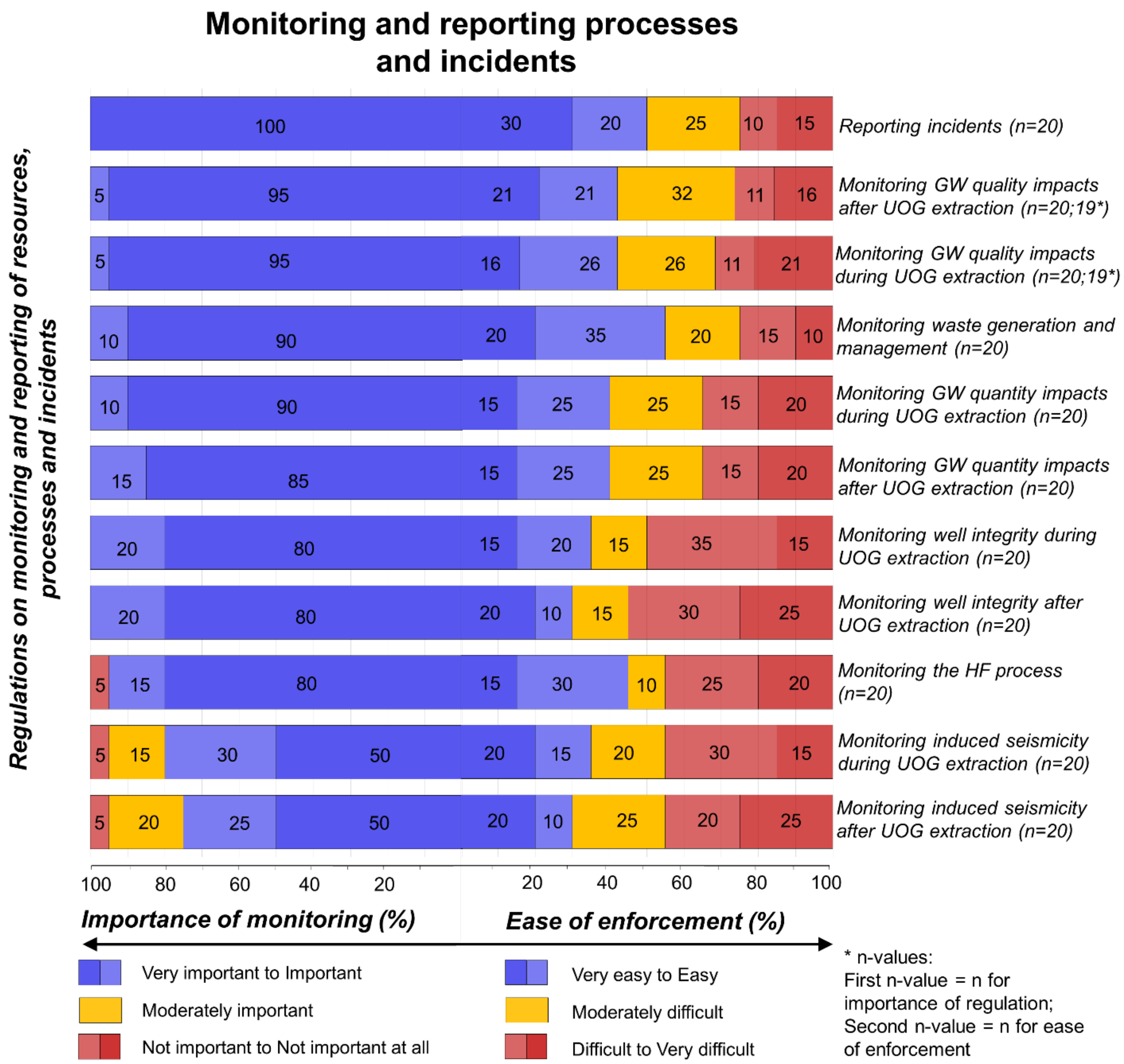

Figure 1e: Regulations on monitoring and reporting of processes and incidents

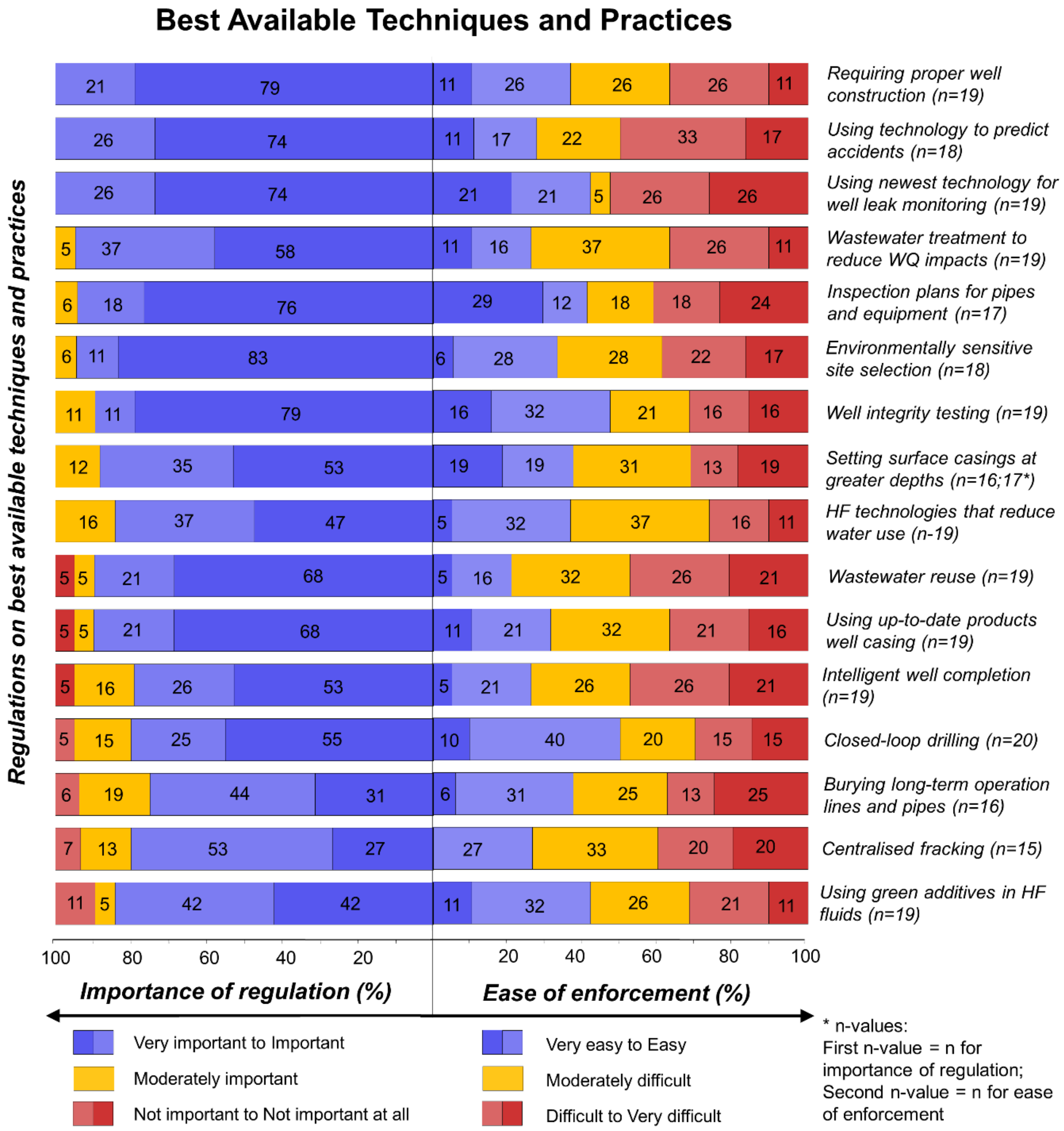

Figure 1f: Best available techniques and practices

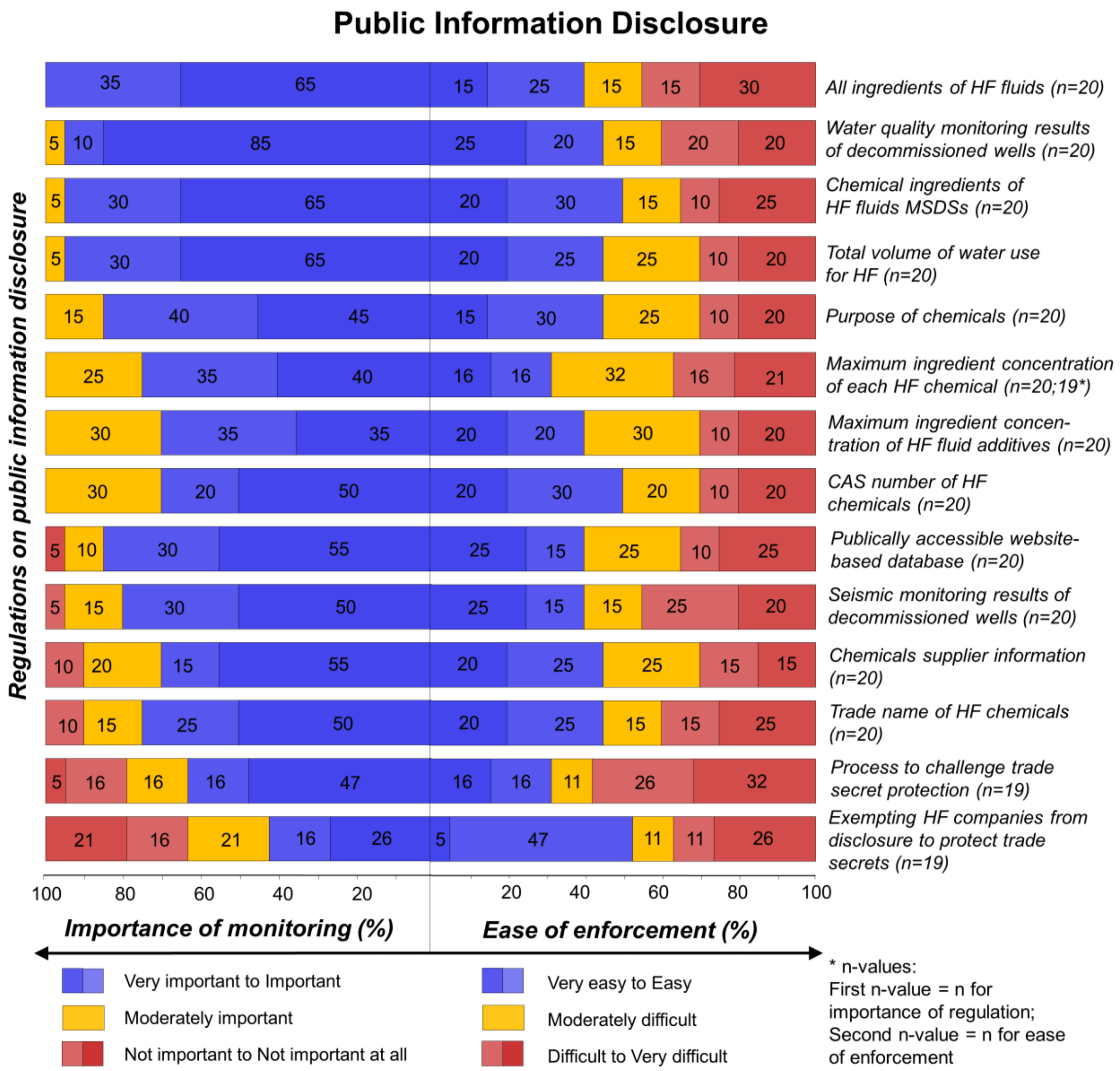

Figure 1g: Public information disclosure regulations

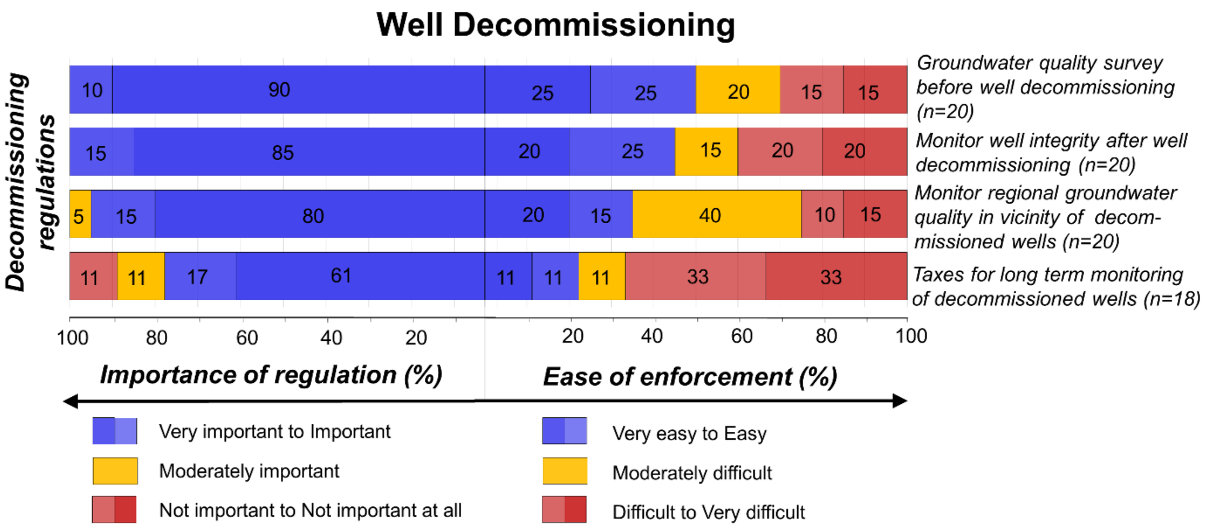

Figure 1g: Well decommissioning regulations

Table 1: Respondent suggestions for additional regulations based on thematic analysis of respondent comments

Regulatory area	Regulatory suggestion
Baseline monitoring	*Additional suggested regulations*
	Detailed mapping of groundwater dependent ecosystems
	Specification of baseline groundwater use per type (agricultural, domestic, mining, etc.)
	Socio-economic studies to determine the number of people and jobs reliant on groundwater
	Identification of potential artificial recharge sites
	Baseline monitoring of both surface and groundwater bodies (to ensure integrated water resources management)
	Identification and characterization of deep as well as shallow groundwater systems
	Mapping baseline land use activities and demographic indicators and linking these to baseline groundwater use.
Management plans	*Additional suggested management plans*
	Chemicals management plan
	Site establishment plan
	Physical terrain management plan
	Storm water management plan
	Emergency preparedness plan
	Protocol management plan
Prohibitory precautionary regulations	*Additional suggested regulations*
	Prohibiting the disposal of waste(water) on surface (e.g. in waste pits, slimes dams)
	Banning fracking in areas where geological features may act as preferential pathways
	Banning fracking in areas where groundwater is used as a potable water supply
Monitoring and reporting of resources and processes	*Additional suggested monitoring requirements*
	Monitoring all chemicals used during the UOG extraction process, particularly chemicals of concern
	Identifying 'trigger levels' for changes in groundwater quality that will require further investigation
	Monitoring surface UOG extraction equipment. Equipment failure is a major source of contamination
	Identifying the relevant institutions responsible for monitoring. Thirty-five per cent of respondents felt that government would be unable to monitor or enforce these regulations, due to lack of competency and lack of political will.
	The establishment of an independent UOG extraction monitoring committee to implement regional monitoring and bi-annually audit the operators' site-specific monitoring protocols.
	Requiring compliance monitoring and enforcement to provide credibility and ensure effective governance
	Additional suggested Best available practices and technologies
Best available practices and technologies	To combat the vandalism that is prevalent in South Africa, equipment should be fitted with an alarm system.

Regulatory area	Regulatory suggestion
Public information disclosure	*Additional suggested disclosure requirements*
	Water quality analyses
	Accidents (spills and leaks) and safety reports
	Hydrocarbon production volumes (daily rates and cumulative production)
	Hazardous material and waste disposal
	Generated waste volumes and type and disposal method
	The total fracking operation's water balance
Well decommissioning	Well decommissioning comments
	Frack-well decommissioning requires a well-engineered approach, for instance monitoring the pressure of surface casing, isolating hydrocarbon-bearing zones from water-bearing zones, and testing if dolerite dykes are conduits to aquifers
	To allow for future monitoring, using concrete to 'seal the well' should not be permitted
	It is necessary to determine who will carry out long-term monitoring after operators have left the area
	Regulators should determine what the consequences will be if an aquifer's status after fracking differs from its pre-fracking status

Table 2: Minimum setback distances between UOG extraction features and South African groundwater features

	UOG extraction feature	Respondent support (%) for authors' proposed setback: Support	Respondent support (%) for authors' proposed setback: Do not support	Alternatives (As proposed by the respondents): Unit	Min	Max	Std. dev	Median	Mode	Support for mode (%)	Recom-mended minimum setback	Enforcement (Respondent opinion): Very easy	Easy	Moderate	Difficult	Very difficult
Fracking well	**250m** setback around geological features from chemicals waste & fuel infrastructure	72	28	m	1000	10000	6364	5500			250m	13	19	19	25	25
	250m setback from rim of dolerite sill	53	47	m	500	5000	2598	2750			500m	12	12	29	29	18
	5km setback around current & future artificial recharge areas	59	41	km	1	60	33,78	2			5km	6	24	29	24	18
	1km setback from centre line of fault / fold axis	56	44	km	0,5	5	2	5	5	60	1km	6	12	41	29	12
	5km setback of ancillary activities from aquifer recharge areas	65	35	km	2	2		2	2	100	5km	6	24	35	12	24
	500m radius around cold springs	59	41	m	1000	5000	1975	1500	1000	50	500m	12	35	24	12	18
	1km radius around thermal springs	59	41	km	0,5	10	3,36	5	5	60	1km	12	35	24	18	12
	No hydraulic fracturing (HF) wells where wet season WT at or shallower than **10mbgl**	63	37	mbgl	5	5		5	5	100	10m	17	17	28	22	17
	5km setback from towns with no wellfields	47	53	km	2	60	21,8	10	10	33	10km	28	17	17	28	11
	5km radius around seismically active cold / thermal springs	71	29	km							5km	6	29	29	12	24
	1km setback from centre line of undifferentiated geological feature	56	44	km	0,5	10	4,53	2,75	0,5	50	1km	6	29	29	18	18
	Calculated setback from dyke based on dyke length (min **500m**)	53	47	m	250	1000	4638	1000	1000	50	1000m	11	6	50	17	17
	5km setback from existing municipal wellfields	37	63	km	2	25	7,3	10	10	56	10km	24	29	12	18	18
	5km setback from cold springs with seismic activity	63	37	km	3	20	8,5	10			5km	24	12	35	18	12
	5km from thermal springs with seismic activity	61	39	km	3	20	7	10	10	50	5km	17	11	44	17	11
	1km from thermal springs	37	63	km	3	20	5,1	5	5	78	5km	22	17	33	17	11
	1km setback from existing water supply boreholes	42	58	km	3	10	2,3	5	5	67	5km	28	17	28	17	11
	500m setback radius from centre point of kimberlite diatreme	56	44	m	0	3000	1377	1750			500m	18	24	35	12	12
	5km setback from groundwater supply infrastructure	58	42	km	1	3	1	2			5km	29	24	24	12	12
UOG exploration, production and ancillary activities	**250m** setback around geological features from chemicals waste & fuel infrastructure	72	28	m	1000	10000	6364	5500			250m	13	19	19	25	25
	5km setback around current & future artificial recharge areas	59	41	km	1	60	33,78	2			5km	6	24	29	24	18
	1km setback of ancillary activities from artesian boreholes wells and aquifers	33	67	km	0,5	10	2,4	5	5	78	5km	0	13	50	19	19
	5km radius around seismically active cold / thermal springs	71	29	km							5km	6	29	29	12	24
	5km setback of ancillary activities from aquifer recharge areas	65	35	km	2	2		2	2	100	5km	6	24	35	12	24
	500m radius around cold springs	59	41	m	1000	5000	1975	1500	1000	50	500m	12	35	24	12	18
	1km radius around thermal springs	59	41	km	0,5	10	3,36	5	5	60	1km	12	35	24	18	12

Colour key

Very easy	*0-17% of respondents*	*18-29% of respondents*
Easy	*0-17% of respondents*	*18-35% of respondents*
Moderate	*0-17% of respondents*	*18-50% of respondents*
Difficult	*0-17% of respondents*	*18-29% of respondents*
Very difficult	*0-17% of respondents*	*18-25% of respondents*

Table 3: Respondent views on the ease of enforcement of specific setback regulations that significantly differ related to their years' experience.

	Aspect	Respondent view on ease of enforcement
Specific setbacks	5km setback around existing town wellfields	Respondents with 10 to 20 years' experience viewed this regulation as more difficult to enforce than respondents with >20 years' experience (Z=-2.054, p = 0.04).
	Calculated setback based on dyke length, with a minimum setback of 500m'	Respondents with 11 to 20 years' experience viewed this regulation as more difficult to enforce than respondents with >20 years' experience (Z=-2,675, p = 0.007, significant at corrected p of 0.0083)
	1km setback from the centre line of faults and fold axes	Respondents with 11 to 20 years' experience viewed this regulation as more difficult to enforce than respondents with >20 years' experience (Z=-2,419, p = 0.016).
BATP regulations	Reuse of drilling fluids and muds	Respondents with 11 to 20 years' experience viewed this regulation as significantly more difficult to enforce than respondents with >20 years' experience (Z=-2,675, p 0.007, significant at the corrected p of 0.0083);
	Using the most up to date well casing and cementing products	Respondents with 5 to 10 years' and 11 to 20 years' experience viewed this regulation as significantly more difficult to enforce than respondents with >20 years' experience (Z=-2.225, p = 0.026 and Z=-2,593, p 0.01 respectively)
	Requiring intelligent well completion	Respondents with 11 to 20 years' experience viewed this regulation as significantly more difficult to enforce than respondents with >20 years' experience (Z=-2,583, p = 0.01)
	Using HF technologies that reduce water consumption	Respondents with 5 to 10 years' and 11 to 20 years' experience viewed this regulation as significantly more difficult to enforce than respondents with >20 years' experience (Z=-2.283, p = 0.022 and Z=-2,293 p = 0.022 respectively)
	Monitoring well casing with technologies to reduce well casing leakage	Respondents with 11 to 20 years' experience viewed this regulation as significantly more difficult to enforce than respondents with >20 years' experience (Z=-2,555, p 0.011)
	Requiring well construction to be compliant with proper construction standards	Respondent groups <5 years, 5 to 10 years and 11 to 20 years' experience viewing this regulation as significantly more difficult to enforce than respondent group with >20 years' experience (with Z=-2,247, p = 0.025; Z=-2.253, p = 0.024, Z=-2,345, p = 0.019 respectively)
	Requiring implementation of inspection plans on a	Respondents with <5 years' experience viewed this regulation as significantly more difficult to

	Aspect	Respondent view on ease of enforcement
	set schedule for pipes and equipment	enforce as respondents with >20 years' experience (Z=-2,034, p = 0.042)
PID regulations	Disclosing chemical ingredients of HF fluids via material safety data sheets	Respondents with 5 to 10 years' experience and 11 to 20 years' experience viewed this regulation as significantly more difficult to enforce than respondents with >20 years' experience (Z=2.203, p = 0.028 and Z=-2.388, p = 0.017 respectively)
	Disclosing the trade name of chemicals used in HF fluids	Respondent groups with <5 years', 5 to 10 years' and 11 to 20 years' experience viewed this regulation as significantly more difficult to enforce than respondents with >20 years' experience (with Z=-2,075, p = 0.038; Z=-2.198, p = 0.028, and Z=-2,006, p = 0.045 respectively)
	Disclosing all ingredients of HF fluids	Respondent groups with 5 to 10 years' and 11 to 20 years' experience viewed this regulation as significantly more difficult to enforce than respondents with >20 years' experience (with Z=-2,171, p = 0.030 and Z=-2.451, p = 0.014 respectively)
	Disclosing the CAS number of chemicals used in HF fluids	Respondent groups with 5 to 10 years' and 11 to 20 years' experience viewed it as significantly more difficult to enforce than respondents with >20 years' experience (with Z=-2,198, p = 0.028 and Z=-2.188, p = 0.029 respectively)

Chapter 6 – Discussion

South Africa is facing a dwindling coal supply and repeated rolling electricity blackouts (Nkosi & Dikgang, 2018), and must now address its declining energy supply (Bohlmann et al., 2018). It is therefore considering the development of unconventional oil and gas (UOG) resources (RSA, 2019a). UOG resources development is however water-intensive and can pollute water resources, which is a major problem for a water-scarce country such as South Africa (Hobbs et al., 2016). To provide a regulatory framework for the extraction of UOG resources, the Department of Mineral Resources (DMR) drafted fracking regulations, of which they promulgated the final version in 2015 (Republic of South Africa, 2015). These regulations were widely criticized for not effectively protecting groundwater resources, and the DMR for drafting regulations outside their mandate. The Minister of Mineral Resources was taken to court by two groups in 2015 – farmers from the Eastern Cape as well as two citizen groups - Treasure the Karoo Action Group (TKAG) and Afriforum (RSA, 2019b), calling for the scrapping of the regulations. These regulations were set aside by both the Eastern Cape High Court and the South African Supreme Court of Appeal in 2019. Judge Bloem of the Eastern Cape High court, accepted the "undisputed major possible impacts of shale gas development with respect to air, soil and groundwater contamination due to uncontrolled gas or fluid flows arising from blow-outs or spills, interception of naturally occurring fractures and fissures, well failures, corrosion of casings, cementing failure, leaking fracturing fluid and uncontrolled waste water discharge" (RSA, 2017). Both courts highlighted the fact that the Minister of Mineral resources had no legal authority to promulgate these regulations, as it was the mandate of the Departments of Environmental Affairs and Water and Sanitation (RSA, 2019c; RSA, 2017). South Africa therefore currently has no fracking-specific regulations to protect groundwater resources during UOG extraction. It is this regulatory gap that this study aims to address. To address this gap, this study had the following specific aims:

1. Assessing the knowledge-base and opinions of decision-makers on the regulation and monitoring of UOG extraction in South Africa (Chapter 3)
2. Developing a regulatory framework to protect specifically groundwater resources before, during and after UOG extraction (Chapter 4)
3. Testing the UOG extraction regulations, proposed under the regulatory framework, for
    i. its relevancy to protect groundwater resources in the South African context and
    ii. its enforceability in the South African context (Chapter 5)
4. Making recommendations on energy policy and regulations for groundwater protection in South Africa (Chapter 6).

A brief discussion of the results follow.

Chapter 3 describes the 2013 opinion survey of decision-makers involved in formulating mining policy in South Africa, as it pertained to UOG extraction. At this time, UOG extraction was still very novel in South Africa, and no regulatory framework existed within which UOG resources could be safely extracted. Because these decision-makers would have been tasked with developing such a framework, it was important to:

1. Assess the knowledge base of the decision-makers on UOG extraction.
2. Determine regulatory and monitoring tools that these decision-makers viewed as important to govern UOG extraction.
3. Perform a preliminary assessment of the institutional landscape in South Africa and identify institutional shortcomings that could hamper the effective enforcement of the regulatory framework.

It was important to assess the above for the whole range of possible environmental UOG extraction impacts, to identify pertinent and salient issues that in the view of the respondents, had to be addressed during UOG extraction regulation in South Africa. The survey respondents therefore included a wide variety of stakeholders, from relevant government departments, scientific and academic institutions, non-governmental organizations and academia.

The aim was therefore not to obtain a generelisable sample, but to purposefully select institutions and key informants within these institutions who could ultimately play an integral part in decision making on shale gas mining in South Africa. Individuals were therefore targeted at the Departments of Water and Sanitation (the then Department of Water Affairs (DWA)), Mineral Resources (DMR), Environmental Affairs (DEA), the Petroleum Association of South Africa (PASA), the Council for Scientific and Industrial Research (CSIR), the Centre for Environmental Rights (CER) and selected universities, among others. This survey also represents a preliminary institutional analysis of UOG governance in South Africa. During this analysis, the following aspects were identified and analyzed:

- Preliminary research was done to identify relevant institutions and stakeholders to take part in the survey, which was based on the mandates of the different South African institutions
- The responses of the stakeholders were reported within the context of these institutions
- The respondents had to indicate which institution they think are responsible for specific regulatory actions, based on the institutional mandates of the respective institutions, the results of which are indicated under the heading "*Identification of the departments primarily responsible for specific regulatory activities*" in Chapter 3.

The levels of knowledge of the respondents on UOG extraction impacts and its regulation were quite low:

- Only 28% of respondents indicated extensive knowledge on the impacts of shale gas mining and 36% indicated extensive knowledge on the environmental impacts of hydraulic fracturing specifically.
- Fifty-two percent of respondents indicated limited knowledge on the environmental regulation of hydraulic fracturing internationally and 44% indicated limited knowledge on hydraulic fracturing in South Africa.

- Half of the respondents indicated that they are not satisfied with their current level of knowledge and 46% were only somewhat satisfied with their knowledge on UOG extraction and its regulation.

In this survey we also assessed which aspects respondents viewed as important to regulate during UOG extraction. The regulation and protection of water resources was identified as the most pertinent concern for all stakeholders. All respondents indicated the monitoring of contamination arising from hydraulic fracturing, the monitoring of volumes of water used during unconventional gas mining, and the regulation of the disclosure of chemicals used during hydraulic fracturing as important. More than 90% of respondents also identified the following water resources protection regulations as important:

- Establishing baseline water quality before allowing hydraulic fracturing (96% of respondents)
- Monitoring the usage of fracking fluids (96% of respondents)
- Regulating the construction of gas mining wells to be compliant with proper construction standards (96% of respondents)
- Regular testing of well integrity during repeated fracking of the same wells (96% of respondents)
- Determining the location of seismogenic (earthquake) zones to avoid drilling into seismically active zones that could trigger possible earthquakes (92% of respondents)

It is clear from these results that water resources protection is one of the most important aspects to get right during UOG extraction regulation. In fact, in the strategic environmental assessment for shale gas extraction (Scholes et al., 2016), water resources were identified as the main limiting factor for shale gas development in South Africa. Groundwater resources was also specifically identified as the water resources that could be most severely impacted upon by UOG extraction (Hobbs et al., 2016). The insidious nature of these impacts on groundwater resources also make it extremely important to protect this resource during UOG extraction. The results from this study highlights the importance of developing a regulatory framework for groundwater resources protection during UOG extraction. Such a regulatory framework was proposed in Chapter 4.

However, even if the South African government is committed to extracting UOG resources (and even if regulations could assist in protecting groundwater resources), it would be wise to take a step back and consider whether UOG resources extraction is the best course of action to address South Africa's energy requirements. Firstly, South African policymakers should seriously reconsider the pursuit of UOG resources in light of the following:

- The severe water shortages that South Africa faces. It is classified as a water scarce country. Added to that, it experienced a recent 5-year drought, which left the City of Cape Town (CoC), Nelson Mandela Bay and many other towns in the Karoo without potable drinking water. The government demonstrated its woeful lack of capacity to address the impacts of the drought, and to supply uninterrupted clean drinking water to large parts of the country (Townshend, 2018).

- The ever-increasing importance of groundwater resources in South Africa's future. Given that almost 98% of South Africa's surface water resources are already allocated to users, groundwater is becoming an ever more important resource in South Africa. The CoC is focusing on groundwater to augment its water supply, and the DWS is in the process of developing more artificial recharge schemes to augment water supply to water-constrained municipalities (ref). In addition, future population growth and climate change will only worsen South Africa's water woes (DEA, 2013).
- The international record of poor and ineffective protection of groundwater resources during UOG extraction (Montcoudiol et al., 2017; Holding et al., 2017; DiGiulio et al., 2018; Fink, 2019).

It is therefore clear that considering UOG extraction in a country such as South Africa, is problematic. During a 2019 groundwater specialist survey, as part of this research, questions such as whether respondents think that an assessment of energy generation options should be done for South Africa to determine the best available energy generation options (see chapter 5), were considered. All respondents indicated that an assessment of energy generation options should be done. The South African government, however, decided to perform a strategic environmental assessment (SEA) on shale gas development in the Karoo, without first considering if it is a viable energy generation option. The SEA however clearly highlighted the concerns with UOG extraction. Respondents were also asked in the 2019 survey if they think that South Africa would be able to effectively enforce regulations to protect groundwater resources during UOG extraction. The proper enforcement of regulations to protect groundwater resources was highlighted by many researchers as problematic, in both developed and developing countries (Centner & Connell, 2014; Fink, 2019; Angeles, 2018; CER, 2014). In South Africa, 70% of groundwater specialist respondents reported that they do not think that South Africa would be able to effectively enforce UOG extraction regulations (Chapter 5). This would therefore leave groundwater resources unprotected in a country with serious water constraints.

In order to propose viable options for protecting groundwater resources in South Africa via UOG extraction regulations, UOG regulatory concerns for water resources protection in other jurisdictions were also considered. The book "Regulating water security in unconventional oil and gas" edited by Buono, Lopéz Gunn, McKay and Staddon, which highlights these concerns for countries with UOG resources, was reviewed by the author. The book review can be seen in Appendix 3. The main message of the book is that for most countries, much work is still needed to ensure effective water resources protection via UOG extraction regulations. This includes the drafting of fracking-specific regulations for countries where conventional oil and gas regulations are used *or* where no regulations exist, and capacitating governments to properly enforce such regulations. The insights gained from this book are included in the UOG extraction policy and regulatory recommendations that follow.

Energy policy and UOG extraction regulatory recommendations for groundwater protection in South Africa

This section discusses:
- A proposed policy direction to guide energy development in South Africa,
- A proposed process for developing UOG extraction regulations

- Recommended regulatory approaches and areas to consider for UOG extraction regulations and
- Recommended enforcement mechanisms for UOG extraction regulations

Guidance on policy-making for energy development in South Africa

The National Energy Regulator Act, (34 of 2008) (RSA, 2008), places an obligation on the Minister of Energy to develop, and on an annual basis, review and publish the Integrated Energy Plan (IEP) in the Government Gazette. The process of the publication of the IEP must follow required public participation processes, as do environmental assessment processes (Humby, 2016). This requirement for public participation is similar to the US (Kristl, 2016). The IEP is meant to serve as the guide for energy infrastructure investments and must take into account all viable energy supply options and guide the selection of the appropriate technology to meet energy demand. One IEP report has been drafted in 2016 (DOE, 2016), but no IEP has been published since the publication of the 2019 IRP (Govender et al, 2019). The purpose of the IEP is to provide a roadmap of the future energy landscape for South Africa which guides future energy infrastructure investments and policy development. Because the development of the IEP is a continuous process it must be reviewed yearly to take into account changes in the macroeconomic environment, developments in new technologies and changes in national priorities and imperatives, amongst other factors. Objectives 4 and 5 of the 2016 IEP included the minimization of negative environmental impacts and the promotion of the conservation of water during energy development, which the author sees as important aspects that would also need consideration in any IEP that is published subsequent to the 2019 IRP. Based on the fact that no IEP has been published subsequent to the 2019 IRP, the following policy recommendations are offered in terms of South Africa’s energy planning:

- South Africa must firstly do a detailed strategic assessment of energy supply options, to determine if UOG extraction is a desired option for energy supply.
- Such an assessment must consider, at its core, the future water requirements of the country as well as the water requirements of the selected energy developments, especially in light of population growth and climate change and seeing as fracking uses large amounts of water. Many countries highlight the tensions between water supply and UOG extraction water requirements (e.g. China and Russia), see (Buono et al., 2019). This is also a concern for South Africa, as highlighted in the SEA for shale gas development.
- If it is found that not enough water would be available for UOG extraction, South Africa should reconsider whether UOG extraction is a viable energy supply option to consider in its energy mix.
- Secondly, if proceeding with UOG extraction, South Africa must consider if they will be able to enforce UOG extraction regulations effectively, to ensure water groundwater resources protection. Enforcement of current environmental regulations are already poor (Buono et al., 2019)
- If South Africa would not be able to effectively enforce regulations and ensure groundwater resources protection, it should seriously reconsider UOG extraction.
- Finally, South Africa, with its water resources limitations (Townshend, 2018) and the poor governance record (Atkinson, 2018) should consider expanding

its renewable energy resources base to augment its energy needs, before or in addition to developing UOG resources.

- After considering all the above aspects, if UOG extraction is still seen as a necessary and viable energy option to pursue, South Africa must embark on a proper process of developing UOG extraction regulations to protect groundwater resources. Although the PhD study only focused on groundwater resources regulation, which have different requirements than surface water resources protection, regulations to protect surface water resources would also have to be drafted, following the same process as proposed in Figure 6-1.

A proposed process for developing UOG extraction regulations to protect groundwater resources

Figure 6-1 outlines the recommended process for the development of UOG extraction regulations.

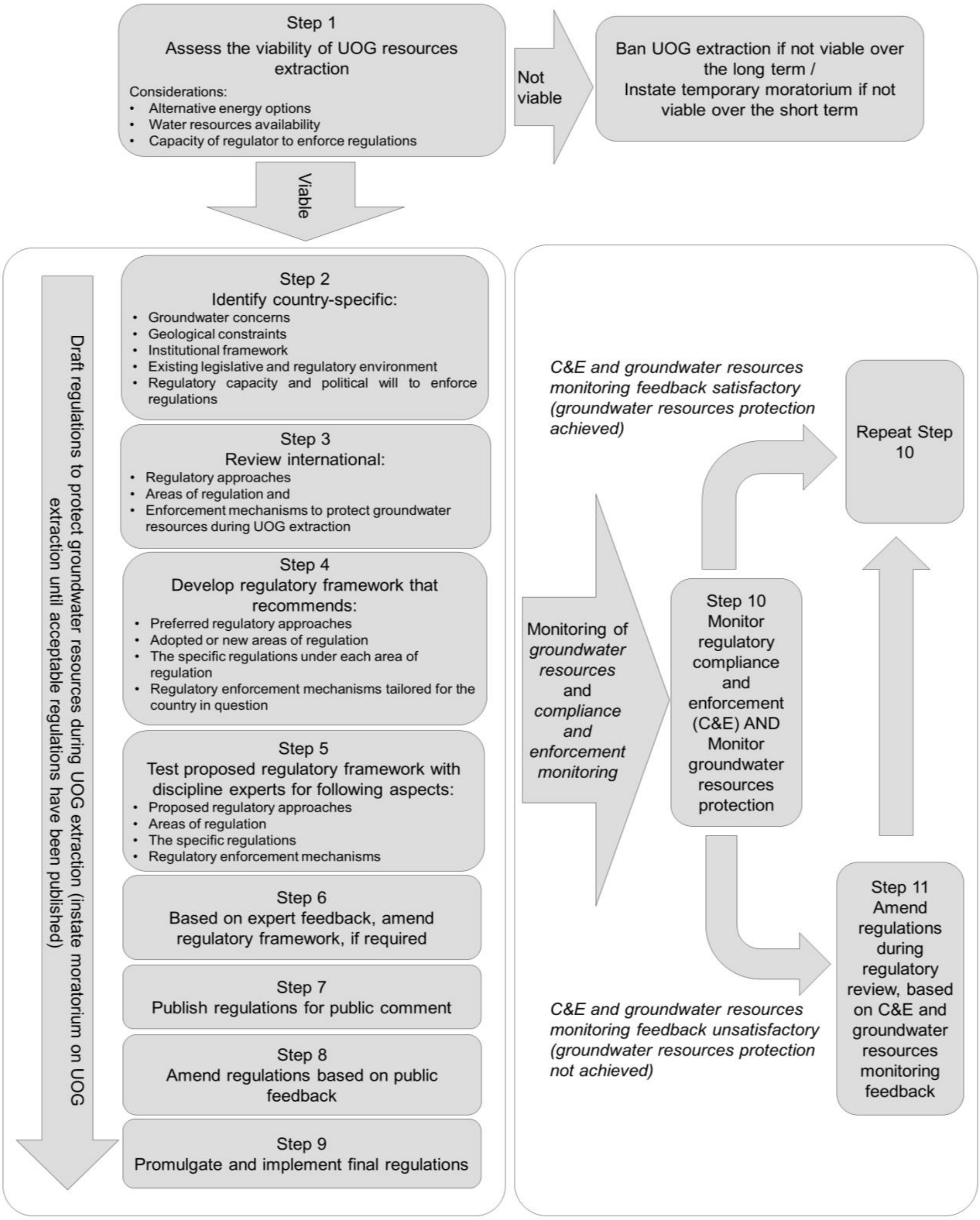

Figure 6-1: Recommended process for the development of UOG extraction regulations

The recommended process for the development of UOG extraction regulations to protect groundwater resources, that is outlined in Figure 6-1, is discussed in detail below (Steps 1 – 11). Ideally, during the process of UOG extraction regulation development, a moratorium must be instated on UOG extraction until regulations that will effectively protect groundwater resources, have been promulgated.

Step 1 – Assessing the viability of UOG resources extraction

In this step a country must truthfully assess whether UOG extraction is necessary or even wanted. Even if UOG resources exist in the country, the country may have plentiful alternative energy resources available, therefore negating the need to extract UOG resources. Exploring renewable energy options is especially important in view of the potential groundwater pollution that UOG extraction poses, which may be irreversible in some cases (Esterhuyse et al., 2019). Considerations of alternative energy generation options is also especially important for water-scarce countries where groundwater resources may become even more important in future, since fracking is such a water-intensive technology. Considering the global perspective, the negative effect that fossil fuel extraction has on climate change also places a moral obligation on countries to move away from fossil fuels. If a country has UOG resources and wants to extract it, the issue of poor regulatory enforcement (Centner & Connell, 2014; Fink, 2019; Angeles, 2018; CER, 2014) may make it necessary to discard UOG extraction as an energy generation option. In the case where UOG extraction is not seen as a viable energy generation option over the long term, it may be permanently banned. If certain aspects must be addressed over the short term to make UOG extraction viable, such as a regulatory framework that is not geared for UOG extraction, a temporary moratorium may be instated while addressing such aspects.

Step 2: Identifying country-specific concerns

Here groundwater and geological concerns should be identified, such as dolerite dykes in South Africa that can act as preferential pathways for pollution and the potential interconnectivity between saline aquifers and freshwater aquifers that may be formed or exacerbated during fracking (Hohne et al., 2019; Hobbs et al., 2016; Esterhuyse, 2017). The existing legislative and regulatory environment to cater for UOG extraction should also be assessed to identify shortcomings. The institutional framework and regulatory capacity will also play a major role in the effectiveness of the regulations and should be considered during this stage. Under country-specific concerns, it would also be important to identify whether UOG extraction has any transboundary implications, for instance if there are aquifers or UOG resources that are shared with other countries. In South Africa, the Kalahari/Karoo aquifer system (classified as AFS5) is shared between South Africa, Namibia and Botswana (IWMI, 2014). Botswana is currently allowing UOG exploration of the UOG resources underlying the Kalahari/Karoo aquifer system (Barbee, 2015), which may impact on this transboundary aquifer. In such cases UOG extraction or water use from aquifers for fracking, could have transboundary impacts. This could fuel resource conflict between countries that depend on the same resources.

Step 3: Review international regulatory approaches, areas of regulation and enforcement mechanisms for UOG regulations to protect groundwater resources

International regulatory approaches cannot be applied in a copy-and-paste manner for South African requirements (or for any other country that must still develop UOG extraction regulations, for that matter). Assessing international approaches is however useful for developing a regulatory framework that could protect groundwater resources in a specific country, if the country-specific concerns are taken into consideration and catered for in such a framework.

Step 4: Develop a regulatory framework to protect groundwater resources during UOG extraction

After reviewing international regulatory trends and concerns, a framework can be developed for a specific country. This framework should detail what regulatory approaches should be adopted (Command-and-control, Market-based, Voluntary or a combination of these), or it could also propose new regulatory approaches. Under the approaches, the specific groundwater protection areas of regulation must be identified (e.g. Baseline studies, Management plans, Public information disclosure, Best available techniques and practices, Monitoring and reporting of resources, processes and incidents, Prohibitory precautionary regulations, Margin of safety regulations, Well decommissioning requirements, etc.). Under each area of regulation, specific regulations to protect groundwater resources must be identified. It is important to note here, that voluntary regulation should be seen as supplementary and complimentary to command-and-control regulation, and that it should not replace command-and-control regulation. Without for instance a command-and-control requirement for certain baseline data, the challenge of proving causation may be insurmountable. Lastly, enforcement mechanisms should be specified. Many countries do not properly enforce their regulations (Buono et al., 2019), rendering the regulations ineffective. In South Africa, the 'fracking regulations' were also criticised for not having any penalties for non-compliance, making these regulations a set of recommendations, rather than enforceable regulations (CER, 2014).

Step 5: Test proposed regulatory framework with discipline experts

It is imperative that the proposed regulatory approaches, areas of regulation, specific regulations under each area of regulation and the regulatory enforcement mechanisms must be tested with discipline experts. Proposed regulatory approaches may include command-and-control regulations, market-based regulations and voluntary regulations. One of these or a combination of these approaches may be used. Whatever configuration is chosen, will depend on the country's regulatory environment and government capacity as well as specific environmental features. In the case of South Africa, poor government capacity to regulate the UOG industry, and specific geological complexities (dolerite dyke intrusions, localized artesian aquifers) will play a major role in the regulatory approaches that are chosen. For South Africa, it may be useful to use a combination of the three different approaches (see Chapter 4). Discipline experts must therefore provide guidance on the regulatory approaches that should be followed. They must also ensure that all the necessary areas of regulation are included in the regulations to protect groundwater resources during UOG extraction and should assist with identifying specific regulations under each regulatory area. There may be specific geological or aquifer conditions that preclude or necessitate the inclusion of very specific regulations. In South Africa, for instance, the occurrence of dolerite dykes and other geological structures that may act as preferential flowpaths for contamination, means that there must be setback distances between fracking, its related activities and these geological features (see Table 3 in the supplementary materials of Chapter 4). Lastly, discipline experts could assist with identifying enforcement mechanisms relevant to the country in question. For command-and-control regulations, specific targets or goals must be set to monitor whether groundwater resources are effectively protected by the regulations and to monitor compliance and enforcement. Targets may include groundwater quality targets, water level targets and abstraction targets. Groundwater discipline experts could assist with identifying realistic targets to ensure groundwater resources protection. It is important to keep in mind during target setting, that the targets should not be unrealistically inflated (Kostka, 2016), which will result in compliance costs that are unnecessarily expensive while not achieving meaningful groundwater protection. Groundwater experts can also assist in determining whether such targets should be fixed or flexible. It is specifically here that the guidance of groundwater discipline experts will be useful.

Step 6: Based on the groundwater discipline expert input, the regulatory framework may need to be amended.

The regulator who drafted the regulations may not have considered specific issues that are of concern to discipline experts, or may even in some cases over-regulate certain aspects. Discipline experts can give the regulator guidance on such issues.

Step 7: Publish regulations for public comment

The regulations should ideally be published for public comment. In South Africa this is a requirement, but this is not the case in all countries. Public opinion and concerns should be considered and input incorporated in the regulations where meaningful, as many of the adverse impacts of UOG extraction would be borne by the public (Palmer et al., 2019) if not avoided by effectively addressing these issues in regulations. If the regulator do not send out regulations for public input before promulgating it, it would earn the regulator the distrust of the public (Fast & Nourallah, 2018).

Step 8: Amend the regulations based on public feedback.

The feedback from the public and stakeholder groups should be incorporated in the regulations and ideally should be sent out for a second round of review and public input.

Step 9: Promulgate and implement final regulations

The final regulations can be promulgated after it has been sent out for public input and has been amended.

Step 10: Monitor compliance and enforcement (C&E) and groundwater resources

Compliance and enforcement of the regulations must be monitored (Pietersen et al., 2016), as well as the impact of UOG extraction on groundwater resources quality and quantity. It is crucial to monitor whether UOG companies comply with the regulations and whether the regulator can enforce these regulations effectively (Tansey, 2018). To monitor compliance, UOG extraction processes can be monitored. Government must also check whether UOG companies meet pre-defined command-and-control targets. For groundwater resources monitoring, the ideal regulatory framework would require baseline groundwater resources monitoring in order to have reference conditions against which the impact of UOG extraction can be measured. Based on the feedback from C&E monitoring, and the feedback from groundwater resources monitoring during UOG extraction, the regulations may or may not achieve its objective of groundwater resources protection.

Step 11: Amend regulations after regulatory review, if required, to ensure groundwater protection during UOG extraction

If C&E and/or groundwater resources monitoring results are unsatisfactory (i.e. groundwater resources protection is not achieved), the regulations must be amended as part of adaptive management. The C&E monitoring should be continuous and step 11 should be repeated until a satisfactory outcome (effective groundwater resources protection) is achieved. The state review of oil and natural gas environmental regulation (STRONGER) can serve as a guide on how to perform a regulatory review of UOG regulations (USDOE, 2009). These aspects should then also be further monitored to identify any changes in the status of groundwater protection during and after UOG extraction in a region.

Recommended regulatory approaches and areas to consider for UOG extraction regulations aimed at protecting groundwater resources

Groundwater protection regulations may be implemented under three regulatory approaches: Command-and-control, market based and voluntary. A combination of hard command-and-control and soft approaches (market-based and voluntary regulations) is recommended. Command-and-control regulations will be useful because South Africa is under-capacitated to police self-regulation. During command-and-control regulation it may be useful to implement goal-based outcomes, where the government sets out the goals to be accomplished, but UOG companies decide on the best way to reach those goals (taking into account the most recent technological advances and available capacity). The South African government would however not be able to ensure compliance with these regulations due to limited capacity. It is proposed that an independent organisation monitor compliance with regulations. Funds for the administration of such an organisation (and for salaries for the enforcement officers) may be levied from penalty fees (for non-compliance), from impact fees (for water contamination) or from market-based tools such as water fees (for freshwater consumption) or severance taxes and royalties.

If command-and-control regulations are combined with market-based tools, such as water fees and severance taxes, UOG companies may be more effectively persuaded to comply with environment-friendly practices. Voluntary regulations may also be useful, but only if independent oversight committees exist, which can verify voluntary monitoring results, ensure public disclosure and provide recommendations to government.

If South Africa does decide to proceed with UOG extraction, drafting regulations in the following regulatory areas, are paramount to aid in groundwater resources protection:

- Baseline studies
- Management plans
- Public information disclosure
- Best available techniques and practices
- Monitoring and reporting of resources, processes and incidents
- Prohibitory precautionary regulations
- Margin of safety regulations
- Well decommissioning requirements

These regulatory areas would also be useful for any other country seeking to amend their existing regulations, or drafting new regulations.

Recommended enforcement mechanisms for UOG extraction regulations

Based on the book review (Appendix 3), enforcement was identified as a serious shortcoming in almost all countries that extract UOG resources (Buono et al., 2019). In South Africa it is especially difficult to enforce command-and-control regulations in the mining sector because the various departments have different mandates, limited regulatory oversight and monitoring, and a shortage of human and financial resources to enforce regulations (CER, 2014; Pietersen et al., 2016).

The following recommendations are therefore made to ensure better enforcement of regulations:

- Command-and-control regulations may be implemented and enforced in South Africa via licensing. Any conditions that a company must adhere to for UOG extraction may be specified in the licence. Groundwater discipline experts could assist in identifying groundwater protection compliance targets, which may include groundwater quality standards, groundwater levels and aquifer abstraction rates. Ideally, the operator should perform baseline studies in preparation for the license application and the regulator should review this data as part of the license application. In this way the burden of proof for demonstrating that it can comply with the regulations (whether these are voluntary or command-and-control, or both) lies with the operator. The regulator should enforce these requirements by monitoring the UOG extraction operations for compliance (Konschnik & Boling, 2014).
- Offences and the penalties for the offences must be stipulated in command-and-control and market based regulations. In the case of an offence, the person or company guilty of the contravention may be subject to a penalty or any other enforcement method, such as administrative orders that require the UOG company to rectify a certain situation that endangers groundwater, or the option to suspend operations (Ernst and Young, 2015; Wiseman, 2012a). Compliance monitoring should be done to identify any contraventions of the regulations.

- For market-based regulations, incentives such as tax breaks for initiatives including wastewater recycling and less intensive freshwater use during fracking, can guide UOG companies towards more environment-friendly practices.
- Given the long-term nature of the risks that UOG extraction poses to groundwater, UOG companies must provide some form of financial security. This must at least be sufficient for the maintenance and continuous monitoring of wells in the long term. It must also cater for a contingency fund in the event of contamination, in which case the UOG company may be required to compensate landowners financially for their losses. Financial security may be required in addition to any other financial provisioning requirements to ensure safe operations during UOG extraction. The possibility of bankruptcy must be covered by adequate financial assurance, as governments most often end up with the liabilities of bankrupt UOG companies (National Academies Press, 2018a).
- Compliance monitoring and enforcement of UOG extraction regulations must be done by a specialised interdepartmental unit comprising the departments responsible for water, the environment and mineral extraction. This unit must also have representatives from concerned stakeholders (e.g. the public, the UOG industry and academia). This would be especially useful for countries such as South Africa with an under-capacitated regulator and would earn the trust of the public, in view of corruption issues that are present in South Africa (Atkinson, 2018)
- If voluntary regulation is allowed in addition to command-and-control regulations to protect groundwater resources in South Africa, it would be prudent to implement certification schemes for the UOG sector, such as the scheme administered by the Centre for Responsible Shale Development (Centre for Responsible Shale Development, 2020). This will provide more accountability than the current sustainability frameworks or the Organisation for Economic Co-operation and Development (OECD) principles for corporate governance. Importantly, voluntary regulation should only be considered in addition to command-and-control regulations, and not as a substitute for command-and-control regulations.
- For voluntary regulations, independent oversight committees must be also established to verify voluntary monitoring results, ensure public disclosure and provide recommendations to government. Such oversight committees can also assist government with compliance monitoring of command-and-control regulations.

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Chapter 7 – Conclusions

This PhD study focused on the development of a regulatory framework to protect groundwater resources during UOG extraction. Groundwater resources are important to many countries, including Algeria, Libya, Morocco, Colombia, Venezuela, South Africa, Mexico, Denmark and Australia (see Chapter 4). These resources become increasingly important as population growth and climate change increase pressures on water demand, especially in those water-scarce countries where climate change predictions are in the direction of drier climates. Despite its strategic importance, groundwater receives insufficient management attention compared with surface water and is especially poorly managed during UOG extraction (Esterhuyse et al., 2019). The lack of attention and regulatory protection that groundwater receives during UOG extraction, was again highlighted in the author's review of the book by Buono et al., (2019) (See Appendix 3).

South Africa has no UOG extraction regulations and has yet to commence with the extraction of UOG resources. The fracking regulations that were drafted and published by the South African Department of Mineral Resources in 2015, aimed to address all environmental and development aspects of UOG extraction. These regulations were set aside by the Supreme Court of Appeal in 2019 because it was not within the mandate of the Department of Mineral Resources to draft regulations on water resources protection or other environmental aspects (RSA, 2019c). Industry experts highlighted the paucity of regulations to protect water resources, and specifically groundwater resources in the 2015 fracking regulations (CER, 2014; Esterhuyse, de Lange, et al., 2016). South Africa therefore currently has no fracking-specific regulations to protect groundwater resources during UOG extraction. To address this regulatory gap, this PhD study had the following specific aims:

1. Assessing the knowledge-base and opinions of decision-makers on the regulation and monitoring of UOG extraction in South Africa (Chapter 3)
2. Developing a regulatory framework to protect specifically groundwater resources before, during and after UOG extraction (Chapter 4)
3. Testing the UOG extraction regulations, proposed under the regulatory framework, for
    i. its relevancy to protect groundwater resources in the South African context and
    ii. its enforceability in the South African context (Chapter 5)
4. Making recommendations on energy policy and regulations for groundwater protection in South Africa (Chapter 6)

These aims are addressed in the PhD as follows:

Aim 1: Assessing the knowledge-base and opinions of decision-makers on the regulation and monitoring of UOG extraction in South Africa

The PhD study determined that the knowledge-base of regulators is very poor (Chapter 3), which means that proper regulations to protect groundwater resources can not be drafted by the regulator alone. This poor knowledge is a function of the novelty of UOG extraction and fracking in South Africa. Ideally, industry experts and groundwater discipline experts should be involved in drafting regulations to protect groundwater resources during UOG extraction (see the proposed process for developing UOG extraction regulations to protect groundwater resources, outlined in Chapter 6).

Chapter 3 also identified the view of regulators and industry experts on the regulation and monitoring of UOG extraction. To determine the most salient issues that must be addressed in the regulation of UOG extraction to protect the environment, this part of the study focused on testing the opinions of the respondents on the importance of regulating a wide range of possible impacts that may emanate from UOG extraction. Respondents had to indicate which aspects they deemed as important to regulate. This article highlights that protection of groundwater resources is one of the main concerns during UOG extraction.

Respondents also had to indicate to what extent they think South Africa has the capacity to enforce these regulations to protect the environment. At the time of this survey (2013), they felt that South Africa does not have the capacity to properly enforce UOG extraction regulations to protect the environment.

Aim 2: Developing a regulatory framework to protect specifically groundwater resources before, during and after UOG extraction

Chapter 4 set out to develop and propose a regulatory framework for groundwater resources protection during UOG extraction. Such a framework must be aimed at avoiding or minimising damage from UOG extraction. During this part of the PhD, UOG extraction regulations of countries with UOG deposits and that allow UOG extraction, were reviewed. To identify the regulations that would most effectively protect groundwater resources, the review specifically targeted countries that have moderate to extensive regulations to protect groundwater resources during UOG extraction, and where fracking has been done for between 15 and 20 years. The regulations of countries where gas is economically important and where groundwater is of medium to high importance (see Appendix S1 of the supplementary materials in Chapter 4) were also included.

The regulations that were identified this way, were categorised into three regulatory approaches (Command-and-control, Market-based and Voluntary), as well as different regulatory areas (e.g. Baseline studies, Management plans, Public information disclosure, Best available techniques and practices, Monitoring and reporting of resources, processes and incidents, Prohibitory precautionary regulations, Margin of safety regulations, Well decommissioning requirements). All this information was used to propose a regulatory framework for groundwater resources protection during UOG extraction. This part of the PhD also considered the functions of each of the three regulatory approaches, and made recommendations on how they may be used to achieve groundwater resources protection.

Aim 3: Testing the proposed UOG extraction regulations for its relevancy to protect groundwater resources and its enforceability in the South African context

In Chapter 5 the different proposed regulatory areas and specific regulations under each area, were tested with twenty South African groundwater discipline experts. The enforceability of the specific regulations and the enforcement capacity of the South African government were also tested. The feedback obtained from this study indicated that groundwater experts viewed most regulatory areas and the specific regulations under each area, as important. They were seriously concerned about the sourcing of water for fracking in water-scarce South Africa. Water sourcing is currently viewed as the main factor limiting UOG development in South Africa (Hobbs et al., 2016). This is also the case for Ukraine, Mexico, China and the western parts of the US (Buono et al., 2019).

Respondents viewed regulations for baseline monitoring of water used for fracking and regulations to protect groundwater from contamination during UOG extraction as paramount. Baseline information on water quality and quality will provide the first step towards protecting groundwater resources during UOG extraction. Protecting groundwater from UOG extraction contamination would ensure the availability of larger volumes of potable groundwater, important for both water-scarce and water-abundant countries. The groundwater experts did not support regulations that could weaken groundwater quality protection, such as regulations exempting fracking companies from publicly disclosing information to protect trade secrets, or using arbitrary setback distances that are not based on scientific data. They also had to indicate whether they agreed with proposed regulatory setback distances (buffer distances between fracking activities and aspects that has to be protected during fracking). They were mostly cautious and viewed certain proposed setbacks as not stringent enough. Specifically, they called for more stringent setbacks between fracking wells and town wellfields and rural water supply boreholes. The also suggested more stringent setbacks between thermal and cold springs with seismic activity and undifferentiated geological features (see Table 2 in the supplementary materials of Chapter 5).

All respondents agreed that South Africa should first assess all available energy generation options before just pursuing UOG resources for energy supply. During this 2019 survey, as with the 2013 survey, respondents were still of the opinion that it would be difficult to enforce UOG regulations in South Africa. They highlighted lack of political will, corruption, lack of capacity and lack of financial resources as the main obstacles to effective regulatory enforcement. Unfortunately, poor enforcement is where even the most meticulously crafted regulations would fail. South Africa must therefore seriously reconsider whether UOG extraction is a viable energy generation option, given the current regulatory obstacles and considering that it is a water scarce country.

Aim 4: Making recommendations on energy policy and regulations for groundwater protection in South Africa

In Chapter 6, the research of the preceding chapters is discussed. Using this research and the information gained from a book review of Buono et al., (2019), energy policy and regulatory recommendations for groundwater protection in South Africa are made by:

- Offering guidance on the policy direction for energy development in South Africa
- Proposing a process for developing UOG extraction regulations
- Recommending regulatory approaches and areas to consider for UOG extraction regulations and
- Recommending enforcement mechanisms for UOG extraction regulations

In chapter 5, two-thirds of the respondents were of the opinion that South Africa should first perform a strategic assessment of all available energy generation options before proceeding with UOG extraction. This is important when considering the future water requirements of the country, especially in light of exponential population growth and climate change and seeing as fracking uses large amounts of water. Many countries highlight the tensions between water supply and UOG extraction water requirements, see Buono et al., (2019).

If a proper process for developing UOG extraction regulations is followed, it may avoid delays in the development of such regulations. It is paramount that groundwater experts review and give input on proposed UOG extraction regulations, to ensure that all groundwater concerns have been addressed. Chapter 6 proposes such a process. Buono et al., (2019) identified poor enforcement as a concern for most of the country case studies discussed in this book. If regulations are not properly enforced, it will not achieve its goal of groundwater resources protection. Chapter 6 therefore also proposes enforcement mechanisms for UOG extraction regulations, depending on which regulatory approach, or combination of approaches, are taken.

Generalisability of the research

Although this PhD focused on groundwater resources protection, some of the proposed regulations would also be useful for protecting surface water resources (e.g. the baseline monitoring requirements, the development of management plans, operator reporting requirements, prohibitory precautionary regulations and well decommissioning regulations).

The proposed process for developing regulations, outlined in Chapter 6, would also be useful for developing a regulatory framework for surface water protection during UOG extraction. Using discipline experts for reviewing and amending UOG extraction regulations before promulgation of regulations, could also be useful for regulation development in other fields such biodiversity or air quality protection. Readers must bear in mind that this research only addressed regulations to protect groundwater resources during UOG extraction, but that protection of groundwater resources is by no means the only natural resource that must be protected during UOG extraction. Apart from groundwater and surface water resources, biodiversity and air quality must also be protected, amongst others.

The regulatory approaches, regulatory areas and specific regulations proposed in this PhD are tailored for South Africa, but could be equally useful for other countries planning to develop or amend their UOG extraction regulatory frameworks to protect their groundwater resources. A copy-and-paste approach can however not be followed and it is strongly advised that regulators in other countries test their frameworks with their discipline experts to ensure that their regulations are relevant to the country-specific context.

Lastly, UOG extraction regulations must be enforced if they are to protect groundwater resources effectively. Although the proposed enforcement mechanisms are tailored to South Africa, it may be useful to other countries that are developing their UOG resources.

Future required research

If the aim of a zero or even a negative carbon emissions target is set to address climate change concerns, the fossil fuel sector should be decarbonised (Obersteiner et al., 2018) and fossil fuels should not be extracted where alternative viable energy sources are available. The fact that UOG extraction can lead to irreversible loss of groundwater resources in some cases, linked with the increasing importance of groundwater resources in future, is another reason for limiting or avoiding UOG extraction going forward. This would mean more research into the development of affordable renewable energy and becoming more energy efficient. This also means that UOG resources can only be viewed as a temporary energy source while moving towards renewable energy sources.

UOG extraction is however still part of the future energy policy of many countries, including Argentina, Australia, Brazil, China, Colombia, Poland, Russia and South Africa (see Table 1 of the Supplementary materials in Chapter 4). This makes the enforcement of a properly developed UOG extraction regulatory framework to protect groundwater resources, vital. The regulatory framework proposed in this PhD will protect groundwater resources during UOG extraction if adopted for the specific needs of the country in question, and if properly enforced. *However*, UOG extraction is a novel field where technological development moves at lighting pace and where non-disclosures abound due to the proprietary nature of industry research (Buono et al 2019). This makes regulating this industry to protect groundwater resources, a challenge. Certain aspects of the physical UOG extraction process and the current regulatory models must therefore be adapted to technological advances in order to more effectively limit potential negative UOG extraction effects and to better manage those negative effects that are already observed. This includes:

- Developing a better understanding of UOG extraction impacts on groundwater resources, to limit negative effects on these resources. This would require a much better groundwater baseline and groundwater resources monitoring throughout the process of UOG extraction, on an array of groundwater quality parameters not analysed for during routine groundwater monitoring. A proper characterisation of both shallow and deep groundwater resources and possible interconnections between these in specific UOG extraction regions is required. Interconnections between shallow aquifers and surface water bodies must also be identified. This will enable regulators to understand possible contamination migration paths and to identify aquifers that are at risk from UOG development. Employing novel technologies such as isotopic, noble gas and microbial analyses may be useful in understanding and monitoring fluid movement the subsurface. Techniques such as laser-based atom counting methods and clumped isotope analyses of hydrocarbons are at the frontiers of current research development and are not yet available at commercial laboratories (McIntosh et al., 2018).

- Performing academic research on UOG extraction techniques and groundwater protection measures in tandem with the research performed by the UOG industry. Information on drilling techniques, well construction and well decommissioning that is researched by the UOG industry, is often proprietary and therefore not open to the public or available for academic research (Buono et al., 2019). Data sharing between UOG companies, academia and the regulator must therefore be enhanced while still protecting the competitive edge of UOG companies. Academic research on well decommissioning is one such area for which limited published research could be found, and that needs urgent attention. This includes developing safer well decommissioning approaches that will limit well deformation and leakage in the future, and developing more effective monitoring techniques to detect leakages. The legacy of UOG wells that have already been abandoned or decommissioned and that started to leak, must also be addressed. Regulations prescribing well decommissioning approaches and requirements also needs more research.
- Further developing and including novel regulatory approaches and enforcement mechanisms to use in UOG extraction regulatory frameworks. Examples include using technology and big data to effect better enforcement. Here interactive online maps on UOG extraction information and groundwater resources (Esterhuyse, 2017) would enable better groundwater resources protection. If groundwater interactive map data are however linked with data on other natural resources (e.g. surface water, biodiversity) *and* socio-economic aspects (e.g. population dependent on groundwater resources, population density, occurrence of seismic activity), this would lead to a more holistic management approach that can address water resource impacts and its socio-economic implications better (Esterhuyse et al., 2017). If information on UOG extraction, water resources and socio-economic aspects are shared between countries on internationally linked databases (Fractracker, 2019), this can be used to limit and manage UOG extraction impacts on water resources not only within countries, but also across political boundaries. Government corruption is a serious concern for enforcement of regulations. To address corruption, the promotions of regulatory officials can be linked to achieving specific groundwater protection regulatory targets, based on regulatory aspects within their control. To avoid falsification of information, information for meeting such targets should be supplied by an independent organisation responsible for monitoring compliance and enforcement. And lastly, to incentivise good behaviour of UOG companies, those that exceed certain regulatory targets can be rewarded with tax breaks.

The UOG extraction regulatory framework proposed in this PhD is aimed at protecting South African groundwater resources. The regulations proposed under this framework can effectively protect South African groundwater resources if it is properly enforced. These regulations must be amended if feedback from compliance and enforcement monitoring and groundwater resources monitoring show that the regulations do not effectively protect the groundwater resources, or if technological advances must be incorporated. This framework can be adapted to protect the groundwater resources of other countries, but only if the regulations address the country-specific context by incorporating the knowledge of groundwater experts from those countries in the development of such regulations.

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Appendices

Appendix 1: Survey instrument 1

This instrument was developed and used to gather the data that is presented in Chapter 3.

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Dear Respondent

We, in association with the Centre for Environmental Management, are conducting a study into the regulation of shale gas mining in South Africa. As part of this study, we ask that you assist us by completing this questionnaire. The purpose of the questionnaire is to determine the current state of knowledge and the perceptions on the regulation of shale gas mining in South Africa. The questionnaires will be treated as confidential and in no way will the data be presented in a way in which individual responses can be linked back to a specific respondent.

This questionnaire consists of three parts:

Part 1 is a brief introductory section comprising of questions that will help us understand the profile of the respondents in this study. Please remember that this information is not for the purpose of identifing any individual and that your answers will remain anonymous.

Part 2 contains knowledge and perception questions aimed at determining from where you have gained (sourced) most of your information related to shale gas mining.

Part 3 contains questions relating to the current and potential regulation of shale gas mining activities in South Africa.

It will take approximately 15 minutes of your time to complete this questionnaire.

Please answer all the questions by ticking your chosen responses with an **X.**

Thank you in advance for taking the time to participate in this survey.

____

S Esterhuyse
(On behalf of the research team:, S Esterhuyse, M Kemp & N Redelinghuys)

CENTRE FOR ENVIRONMENTAL MANAGEMENT
SENTRUM VIR OMGEWINGSBESTUUR

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PART 1: BIOGRAPHICAL INFORMATION

Please answer all the questions by ticking your chosen responses with an **X.**

1.1 What is your gender?

Male	1
Female	2

1.2 What is the highest educational level that you have attained?

Matric / Grade 12 (NQF4)	1
Higher certificate (NQF5)	2
Diploma / Advanced certificate (NQF6)	3
Bachelor Degree / Advanced Diploma (NQF7)	4
Honours Degree / Postgraduate Diploma (NQF8)	5
Masters Degree (NQF9)	6
Doctorate (NQF10)	7

1.3 Which institution do you represent?

Government department	1
NGO (Non-governmental organisation) / CBO (Civil based organisation)	2
Independent consultant	3
Educational institution	4
Other	5

1.4 If Other, please specify: ____

1.5 What is your current position (i.e. manager, director) in the above institution?

____

1.6 How long have you been in this current position?

Less than 12 months	1
One to five years	2
Six to ten years	3
Longer than ten years	4

1.7 How would you describe the nature of your work in broad terms? Is it mainly:

Strategy / Policy	1
Regulation / Auditing	2
Design / Technical / Operations	3
Research / Science	4
Other	5

1.8 If Other, please specify: ____

1.9 Which of the following sectors does your department / institution primarily fall under?

Education	1
Environment	2
Water	3
Socio-economic development	4
Legal	5
Mining	6
Research	7
Other	8

1.10 If Other, please specify: ____

PART 2: YOUR KNOWLEDGE AND VIEWS ON SHALE GAS MINING

2. On a scale of 1 -5, rate your knowledge of the following issues, with 1 indicating *limited knowledge* about the topic and 5 indicating *expert knowledge* on the topic.

	Limited knowledge ←				→ **Extensive knowledge**
2.1 Environmental impacts of mining in general	1	2	3	4	5
2.2 The environmental impacts of shale gas mining	1	2	3	4	5
2.3 The environmental impacts of hydraulic fracturing	1	2	3	4	5
2.4 The economic impacts of shale gas mining (e.g. economic growth, employment creation)	1	2	3	4	5
2.5 The social impacts of shale gas mining (e.g. migration patterns, population structure, health issues)	1	2	3	4	5
2.6 The environmental regulation of shale gas mining internationally	1	2	3	4	5
2.7 The environmental regulation of shale gas mining in South Africa	1	2	3	4	5

3. To what extent are you satisfied with your current knowledge about shale gas mining

Very satisfied	1
Somewhat satisfied	2
Not satisfied at all	3

4. Indicate the extent to which you have made use of the following sources of information on shale gas mining with **1** indicating that you have not made use of this source at all and **5** indicating that you have made use of this source to a large extent.

	Not at all ⟷ To a large extent				
4.1 Government reports	1	2	3	4	5
4.2 Reports by independent research organisations	1	2	3	4	5
4.3 Internet sources (Google, websites)	1	2	3	4	5
4.4 Printed media (Newspapers, magazines)	1	2	3	4	5
4.5 Verbal media (Radio)	1	2	3	4	5
4.6 Visual Media (Television)	1	2	3	4	5
4.7 Scholarly articles	1	2	3	4	5
4.8 Talks and presentations	1	2	3	4	5
4.9 Other	1	2	3	4	5

4.10 If "Other", please specify: ____

PART 3: THE REGULATION AND MONITORING OF HYDRAULIC FRACTURING AND SHALE GAS MINING

5. Please indicate the extent to which you believe the monitoring and regulation of the following aspects needs to be taken into consideration in the South African policy and regulatory framework, with **1** indicating *not at all* and **5** indicating *to a large extent.*

	Not at all ⟷ To a large extent				
5.1 Ensuring that jobs created through fracking are filled by South Africans	1	2	3	4	5
5.2 Monitoring the impact of land use changes on daily food requirements of extremely poor (indigent) households	1	2	3	4	5
5.3 Monitoring changes in the disease burdens of communities affected by shale gas mining	1	2	3	4	5
5.4 Monitoring the impact of hydraulic fracturing-related contamination	1	2	3	4	5
5.5 Regulating infrastructure development	1	2	3	4	5

	Not at all ⟷ To a large extent				
5.6 Maintaining existing access roads to the fracking sites	1	2	3	4	5
5.7 Regulating infrastructure development	1	2	3	4	5
5.8 Performing spatial development planning with regards to urbanisation	1	2	3	4	5
5.9 Monitoring air quality impacts from shale gas mining	1	2	3	4	5
5.10 Monitoring noise pollution levels	1	2	3	4	5
5.11 Regulation of land use planning with regards to conservation areas	1	2	3	4	5
5.12 Monitoring and regulating the volumes of water usage in full scale gas mining	1	2	3	4	5
5.13 Regulating the construction of gas mining wells to be compliant with proper construction standards	1	2	3	4	5
5.14 The regular testing of well integrity during repeated fracking of the same wells	1	2	3	4	5
5.15 Establishing baseline water quality in areas where hydraulic fracturing is planned before fracking starts	1	2	3	4	5
5.16 Regulating the disclosure of chemical additives used in the process of hydraulic fracturing at each prospective site	1	2	3	4	5
5.17 Regulating the use of green chemicals instead of environmentally harmful chemicals	1	2	3	4	5
5.18 Monitoring the impact of the fracking fluids remaining underground as a potential source of groundwater pollution	1	2	3	4	5
5.19 Determining the location of seismogenic (earthquake) zones to avoid drilling into seismically active zones that could trigger possible earthquakes	1	2	3	4	5
5.20 Monitoring biodiversity loss resulting from habitat loss	1	2	3	4	5

6. Please rate to what extent you view the following statements as an accurate representation of South Africa's **capacity** to deal with the impacts of hydraulic fracturing (**1** indicates that the statement is completely **inaccurate** and **5** indicates that the statement is **completely accurate).**

	Not accurate at all ⟷ Completely accurate				
6.1 Existing information on the potential environmental risks of fracking is currently sufficient.	1	2	3	4	5
6.2 Existing information on the potential health risks of fracking is currently sufficient.	1	2	3	4	5
6.3 Mining rights authorisation processes in South Africa are fragmented.	1	2	3	4	5
6.4 Mining rights authorisation processes in South Africa are limited.	1	2	3	4	5
6.5 South Africa possesses sufficient fracking specific legislation.	1	2	3	4	5

	Not accurate at all ⟷ Completely accurate				
6.6 South Africa possesses fracking specific policies.	1	2	3	4	5
6.7 The Mineral Resources Development Act (MPRDA) is sufficient in scope to deal with the challenges presented by fracking.	1	2	3	4	5
6.8 Amendments would be required in terms of South African statutes to make the development of fracking-specific regulations possible.	1	2	3	4	5
6.9 South Africa has sufficient institutional capacity to *monitor shale gas mining operations.*	1	2	3	4	5
6.10 South Africa has sufficient institutional capacity to *enforce compliance with conditions of license approval* for shale gas mining operations	1	2	3	4	5
6.11 The regulation of possible impacts can be complex due to the fragmentation of responsibilities within a specific department.	1	2	3	4	5
6.12 Due to conflicting mandates between different Departments, the regulation of possible impacts can be complex.	1	2	3	4	5
6.13 There is uncertainty between local government departments and national government departments on who should be responsible for the monitoring and regulation of certain aspects of fracking activities.	1	2	3	4	5

7. Please rate to what extent the following tools may help address the regulatory problems associated with hydraulic fracturing.

	No help at all	**May help to a small extent**	**Unsure**	**May help to a large extent**	**May be extremely useful**
7.1 Performing a detailed **strategic assessment** of the available energy generation options in South Africa before deciding on allowing hydraulic fracturing.	1	2	3	4	5
7.2 Placing an **indefinite moratorium** on fracking if other sources of energy are found to be sufficient	1	2	3	4	5
7.3 Performing research to **identify and assess the impacts** related to hydraulic fracturing before giving the go-ahead for exploration	1	2	3	4	5
7.4 **Developing fracking-specific legislation** before allowing hydraulic fracturing to commence.	1	2	3	4	5
7.5 **Developing fracking-specific monitoring protocols** before allowing hydraulic fracturing to commence.	1	2	3	4	5

	No help at all	May help to a small extent	Unsure	May help to a large extent	May be extremely useful
7.6 **Declaring hydraulic fracturing as a controlled activity** under section 38 of the NWA.	1	2	3	4	5
7.7 The DWA could, under section 30 of the NWA, for the protection of the water resource or property, require oil and gas companies **to give security** in respect of any obligation or potential obligation arising from a licence to be issued under the NWA.	1	2	3	4	5
7.8 Enforcing the **self-regulation and reporting to government** of oil and gas companies as part of their license conditions.	1	2	3	4	5
7.9 Establishing an **independent entity to monitor** fracking activities and report to government on a regular basis.	1	2	3	4	5
7.10 Establishing a **central database** to store fracking-related information for ease of access and centralised management.	1	2	3	4	5
7.11 Identifying and **clearly specifying the mandates, roles and responsibilities** of local government versus national government.	1	2	3	4	5
7.12 **Performing Strategic Environmental Assessment** instead of the Environmental Impact Assessment process to determine potential impacts.	1	2	3	4	5
7.13 **Adopting management policies** from other countries where hydraulic fracturing is currently taking place.	1	2	3	4	5

8 In your view, which government department at the national level or industry do you think should take primary responsibility for the following regulatory actions? Please tick the appropriate box (you can choose more than one option):

	Department of Water Affairs	Department of Mineral Resources	Department of Energy	Department Environmental Affairs and Tourism	Department of Justice and Constitutional Development	Department of Science and Technology	Department of Health	Department of Agriculture, Fisheries and Forestry	Department of Rural Development	Department of Labour	Council for Geoscience	Council for Scientific and Industrial Research	Water Research Commission	Petroleum Agency of South Africa	South African Environmental Observation Network	The oil and gas applicants	Another independent entity specifically established for the purpose	**Other: please specify**dl Local Government - Planning
8.1 Performing a strategic assessment of energy development options.																		
8.2 Developing fracking-specific regulations.																		
8.3 Developing fracking specific monitoring guidelines / protocols.																		
8.4 Developing integrated spatial development plans for fracking areas.																		
8.5 Developing a national wastewater treatment strategy specifically for fracking.																		
8.6 Regulating that jobs created by fracking are filled by South Africans.																		
8.7 Monitoring aspects of water quality before, during and after fracking in areas to be fracked.																		
8.8 Monitoring water usage associated with fracking.																		

	Department of Water Affairs	Department of Mineral Resources	Department of Energy	Department Environmental Affairs and Tourism	Department of Justice and constitutional development	Department of Science and Technology	Department of Health	Department of Agriculture, Fisheries and Forestry	Department of Rural Development	Department of Labour	Council for Geoscience	Council for Scientific and Industrial Research	Water Research Commission	Petroleum Agency of South Africa	South African Environmental Observation Network	The oil and gas applicants	Another independent entity specifically established for the purpose	**ther: please specify** Local Government - & Planning Provincial *
8.9 Regulating and monitoring aspects such as borehole construction and borehole integrity of fracking wells.																		
8.10 Monitoring the approval of gas mining applications.																		
8.11 Monitoring the biodiversity impact of gas mining.																		
8.12 Monitoring the air quality impact of gas mining.																		
8.13 Monitoring vegetation loss in fracking areas.																		
8.14 Monitoring the impact of fracking on existing land uses in fracking areas.																		
8.15 Monitoring the impact of fracking on seismic activity.																		
8.16 Monitoring the health aspects related to fracking.																		

9. Which of the following statements best represent your opinion on the issue? Choose only one option.

South Africa can effectively manage and regulate all the risks associated with shale gas mining.	1
South Africa can not effectively manage and regulate all the risks associated with shale gas mining.	2
I am not sure where I stand on this issue at present.	3

10. Are there any other comments that you would still like to bring to the attention of the researchers?

____

____

____

____

____

____

Thank you for your participation.

Appendix 2: Survey instrument 2

This instrument was developed and used to gather the data that is presented in Chapter 5.

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA

UFS·UV
NATURAL AND AGRICULTURAL SCIENCES
NATUUR- EN LANDBOUWETENSKAPPE

Dear Respondent

I am conducting a study into the regulation of unconventional oil and gas (UOG) extraction to protect groundwater resources in South Africa, as part of my PhD studies. Unconventional oil and gas includes naturally occurring shale gas and coalbed methane which can be extracted using a stimulation method such as hydraulic fracturing ("fracking").

As part of this study, I am conducting a survey of opinions on the regulation of UOG extraction to protect groundwater resources. The purpose of the questionnaire is to determine the current state of knowledge and the perceptions about the regulation of UOG extraction using hydraulic fracturing. This questionnaire will ask you which regulations you consider as important to protect South African groundwater resources during UOG extraction using hydraulic fracturing and if you think they can be effectively enforced.

You have been selected as a key informant for this survey, based on your expertise in this area. Your opinion is highly valued and I will appreciate it if you complete this survey in as much detail as possible. There are no known risks if you decide to participate in this research study. The survey results will be treated as confidential and the data will not be presented in a way in which individual responses can be linked back to a specific respondent.

It will take 45 minutes to an hour of your time to complete this questionnaire. Please answer all the questions by ticking your chosen responses with an **X.** You are welcome to leave out questions that you do not relate to, or do not feel comfortable to answer.

By completing this survey, it is understood that you give informed consent to the researcher to use the gathered data for academic research purposes.

Additional study information:

Principal investigator: Surina Esterhuyse (esterhuyses@ufs.ac.za)

Main promotor: Danie Vermeulen (VermeulenD@ufs.ac.za).

Department and Faculty: Centre for Environmental Management, Faculty of Natural and Agricultural Sciences, University of the Free State

Should you require any further information or want to contact the researcher about any aspect of this study, please contact Surina Esterhuyse.

Thank you in advance for taking the time to participate in this survey.

S Esterhuyse

UNIVERSITY OF THE FREE STATE
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YUNIVESITHI YA FREISTATA

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NATURAL AND AGRICULTURAL SCIENCES
NATUUR- EN LANDBOUWETENSKAPPE

PART 1: BIOGRAPHICAL INFORMATION

Please answer all the questions by ticking your chosen responses with an **X.**

1.1 Please indicate the number of years of experience you have working in the field of groundwater. Click here to enter text.

1.2 What is the highest educational level that you have attained?

Matric / Grade 12 (NQF4)	☐1	Honours Degree / Postgraduate Diploma (NQF8)	☐5
Higher certificate (NQF5)	☐2	Masters Degree (NQF9)	☐6
Diploma / Advanced certificate (NQF6)	☐3	Doctorate (NQF10)	☐7
Bachelor Degree / Advanced Diploma (NQF7)	☐4		

1.3 Which type of institution do you represent?

Government department	☐1
NGO (Non-governmental organisation) / CBO (Civil based organisation)	☐2
Independent consultant	☐3
Educational institution	☐4
Other	☐5

1.4 If Other, please specify: Click here to enter text.

1.5 What is your current position (i.e. manager, director) in the above institution? Click here to enter text.

1.6 Please indicate the number of years you been in your current position. Click here to enter text..

PART 2: YOUR KNOWLEDGE AND VIEWS ON UOG EXTRACTION

3. On a scale of 1 -5, rate your knowledge of the following issues, with 1 indicating *limited knowledge* about the topic and 5 indicating *extensive knowledge* on the topic.

Knowledge	**Limited knowledge** ←			→	**Extensive knowledge**
4.11 The impacts of UOG extraction on groundwater	☐1	☐2	☐3	☐4	☐5
4.12 The impacts of hydraulic fracturing on groundwater	☐1	☐2	☐3	☐4	☐5
4.13 The regulation of UOG extraction internationally to protect groundwater resources	☐1	☐2	☐3	☐4	☐5
4.14 The regulation of UOG extraction in South Africa to protect groundwater resources	☐1	☐2	☐3	☐4	☐5

5. To what extent are you satisfied with your current knowledge on the following topics?

Topic	**Extent of satisfaction**		
	Not at all satisfied	**Somewhat satisfied**	**Very satisfied**
3.1 The impacts of UOG extraction on groundwater	☐1	☐2	☐3
3.2 The impacts of hydraulic fracturing on groundwater	☐1	☐2	☐3
3.3 Regulation of UOG extraction internationally to protect groundwater resources	☐1	☐2	☐3
3.4 Regulation of UOG extraction in South Africa to protect groundwater resources	☐1	☐2	☐3

8. To what extent have you used the following sources of information on UOG extraction? **1** indicates that you have not made use of this source at all and **5** indicates that you have made use of this source to a large extent.

Use of information sources	**Not at all**	⟷			**To a large extent**
4.1 Government reports	☐1	☐2	☐3	☐4	☐5
4.2 Reports by independent research organisations	☐1	☐2	☐3	☐4	☐5
4.3 Internet sources (Google, websites)	☐1	☐2	☐3	☐4	☐5
4.4 Printed media (Newspapers, magazines)	☐1	☐2	☐3	☐4	☐5
4.5 Verbal media (Radio)	☐1	☐2	☐3	☐4	☐5
4.6 Visual Media (Television, Youtube, Ted Talks)	☐1	☐2	☐3	☐4	☐5
4.7 Scholarly articles	☐1	☐2	☐3	☐4	☐5
4.8 Oral presentations	☐1	☐2	☐3	☐4	☐5
4.9 Other	☐1	☐2	☐3	☐4	☐5

4.10 If “Other”, please specify: __________

PART 3: THE REGULATION AND MONITORING OF HYDRAULIC FRACTURING (HF) AND UOG EXTRACTION TO PROTECT GROUNDWATER RESOURCES

This section has been divided into 9 categories of command-and-control regulations based on the most important regulations commonly used to protect groundwater resources. Please answer each category in as much detail as possible.

Category 3.1: Baseline studies

Baseline studies focus on identifying the baseline conditions of groundwater resources (quality, quantity and current groundwater use), seismicity and geology before UOG extraction starts.

5 Please rate:

5a The importance of including a requirement for the following baseline studies to be performed, when drafting regulations to protect groundwater resources in South Africa during UOG extraction, with **1** indicating *not at all important* and **5** indicating *very important.*

5b How easy or difficult it would be to enforce regulations requiring the following baseline studies in South Africa, with **1** indicating *very easy* and **5** indicating *very difficult.*

What to rate:	**5a: Importance of including a requirement for baseline studies in regulations**					**5b: The ease or difficulty of enforcing these regulations**				
Baseline studies:	**Not at all important** ←				→ **Very important**	**Very easy** ←				→ **Very difficult**
5.21 **Groundwater quality** in areas where UOG extraction using fracking is planned	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
5.22 **Groundwater availability** in areas where UOG extraction using fracking is planned	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
5.23 **Groundwater use** in areas where UOG extraction using fracking is planned	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
5.24 **Local deep geology and geological structures** mapping in areas where hydraulic fracturing is planned	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
5.25 **Local seismogenic (earthquake) zone** mapping to avoid drilling into seismically active zones that could trigger possible earthquakes	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
5.26 **Local seismicity** in specific areas targeted for UOG extraction using fracking	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

5.7 Please indicate any **other baseline studies** that you would consider important to include under the regulation of UOG extraction to protect groundwater resources.
Click here to enter text.

5.8 Are there any other comments you want to add on the regulation of baseline studies?
Click here to enter text.

Category 3.2: Management plans

6 Please rate:

6a The importance of including a requirement for the development of the following management plans in regulations to protect groundwater resources in South Africa during UOG extraction, with **1** indicating *not at all important* and **5** indicating *very important.*

6b How easy or difficult it would be to enforce regulations requiring the following management plans in South Africa, with **1** indicating *very easy* and **5** indicating *very difficult.*

What to rate:		6a: Importance of including a requirement for the development of management plans in regulations					6b: The ease or difficulty of enforcing these regulations				
Management plans:		Not at all important ←				→ Very important	Very easy ←				→ Very difficult
6.1	A drilling management plan that specifies how production wells will be drilled to **minimize impacts on aquifers and groundwater resources**	☒ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
6.2	A hydraulic fracturing (HF) management plan that specifies water sources for HF, e.g. the **use of groundwater for fracking**	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
6.3	A HF management plan that details how **impacts on the local groundwater resources will be minimized** (including quality and quantity) during and after UOG extraction	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
6.4	A HF management plan that details how **seismicity will be minimized** during and after UOG extraction	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
6.5	A waste management plan that details how **wastewater that is generated during and after UOG extraction will be managed**	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
6.6	A well decommissioning plan that details how **production wells will be decommissioned in an environmentally sustainable and safe way**	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

6.7 Please indicate any **other management plans** that you would consider important to include under the regulation of UOG extraction to protect groundwater resources.

Click here to enter text.

6.8 Are there any other comments you want to add on the regulation of management plans?

Click here to enter text.

Category 3.3: Margin of safety regulations

Margin of safety regulations specify safety margins for specific UOG extraction activities, such as setbacks from sensitive aquifers.

7 Please rate:

7a The importance of including the following general margin of safety regulations when drafting regulations to protect groundwater resources in South Africa during UOG extraction, with **1** indicating *not at all important* and **5** indicating *very important.*

7b How easy or difficult it would be to enforce the following margin of safety regulations, with **1** indicating *very easy* and **5** indicating *very difficult.*

Note: *Setbacks are safe distances that are specified between an activity and a sensitive receptor.*
Ancillary UOG activities include wellpad establishment, drilling, wastewater management, access roads, infrastructure development and sanitation.

What to rate:	7a: Importance of the including margin of safety regulations					7b: The ease or difficulty of enforcing these regulations				
Margin of safety regulations:	Not at all important ←				→ Very important	Very easy ←				→ Very difficult
7.1 Regulations specifying well spacing and the density of fracking wells	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
7.2 Regulations specifying discharge standards to regulate the water quality of water released from fracking operations per its intended use	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
7.3 Regulations specifying setbacks for UOG extraction production wells from sensitive aquifers	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
7.4 Regulations specifying setbacks for UOG extraction production wells from aquifer recharge areas	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
7.5 Regulations specifying setbacks for UOG extraction production wells from geological structures	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
7.6 Regulations specifying setbacks for UOG extraction waste management operations from sensitive aquifers	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
7.7 Regulations specifying setbacks for UOG extraction waste management operations from aquifer recharge areas	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
7.8 Regulations specifying setbacks for UOG extraction waste management operations from geological structures	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

Specific setbacks:

7c For each of the following setbacks, please indicate whether you support the proposed setback distances for protecting groundwater resources in South Africa, or not, by marking the appropriate block with an **X**. If you do not support the proposed setback, please propose an alternative setback distance.

7d Please rate how easy or difficult it would be to enforce the following specific setbacks to protect South African groundwater resources, with **1** indicating *very easy* and **5** indicating *very difficult.*

Applicable Aspect	Proposed setback distances	7c: Support or opposition for proposed setback distances			7d: The ease or difficulty of enforcing these regulations				
		Yes. I support the proposed setback distance	No. I do not support the proposed setback distance	Alternative (if you do not support the proposed setback distances)	Very easy				Very difficult
Fracking wells	7.9 A **5km** setback around existing municipal wellfields and identified future wellfields or water sources	☐ Yes	☐ No		☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
	7.10 A **5km** setback around towns with no known wellfields, to protect potential future town groundwater supplies	☐ Yes	☐ No		☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
	7.11 A **1km** setback around existing water supply boreholes, and no directional drilling within 500m of water supply boreholes	☐ Yes	☐ No		☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
	7.12 A **5km** setback around any groundwater supply infrastructure	☐ Yes	☐ No		☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
	7.13 No fracking wells allowed within areas where the wet season water table is **at or shallower than 10m from the surface**	☐ Yes	☐ No		☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
	7.14 A **5km** setback around any cold springs with known seismic activity	☐ Yes	☐ No		☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
	7.15 A **1km** setback around thermal springs	☐ Yes	☐ No		☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
	7.16 A **5km** setback around thermal springs with known seismic activity	☐ Yes	☐ No		☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
	7.17 A calculated setback based on dyke length with a minimum dyke width setback of 500m	☐ Yes	☐ No		☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
	7.18 A setback of **500m** radius from the centre point of kimberlites and diatremes	☐ Yes	☐ No		☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
	7.19 A **1km** setback from the centre line of faults, shear zones and fold axes	☐ Yes	☐ No		☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

Applicable Aspect	Proposed setback distances	7c: Support or opposition for proposed setback distances			7d: The ease or difficulty of enforcing these regulations				
		Yes. I support the proposed setback distance	No. I do not support the proposed setback distance	Alternative (if you do not support the proposed setback distances)	Very easy ←				→ Very difficult
	7.20 A **250m** setback from the rim of the surface outcrop of dolerite sills	☐ Yes	☐ No		☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
	7.21 A **1km** setback from the centre line of an undifferentiated geological feature	☐ Yes	☐ No		☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
UOG exploration, production and ancillary activities	7.22 A **1km** setback from artesian boreholes, artesian deep wells and artesian aquifers	☐ Yes	☐ No		☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
	7.23 A **5km** setback around aquifer recharge areas	☐ Yes	☐ No		☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
	7.24 A **radius of 500m** setback around cold springs	☐ Yes	☐ No		☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
	7.25 A **radius of 1km** setback around thermal springs	☐ Yes	☐ No		☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
	7.26 A **radius of 5km** setback around seismically active cold or thermal springs	☐ Yes	☐ No		☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
	7.27 A **5km** setback around current and future artificial recharge areas	☐ Yes	☐ No		☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
	7.28 A **250m** setback around geological features listed in this table (7.14 – 7.21) for fracking chemicals storage, waste or waste water management infrastructure, fuel depots or sanitation infrastructure	☐ Yes	☐ No		☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

7.29 Please indicate any other margin of safety regulations or specific setbacks that you would consider important to include under the regulation of UOG extraction to protect groundwater resources.
Click here to enter text.

7.30 Are there any other comments you want to add on margin of safety regulations or specific setbacks?
Click here to enter text.

Category 3.4: Prohibitory precautionary regulations

Prohibitory precautionary regulations prohibit operators from executing certain activities during UOG extraction, in order to protect groundwater resources.

8. Please rate:

8a The importance of including the following prohibitory precautionary regulations when drafting regulations to protect groundwater resources in South Africa during UOG extraction, with **1** indicating *not at all important* and **5** indicating *very important.*

8b How easy or difficult it would be to enforce prohibitory precautionary regulations, with **1** indicating *very easy* and **5** indicating *very difficult.*

What to rate:	8a: Importance of the following prohibitory precautionary regulations					8b: The ease or difficulty of enforcing these regulations				
Prohibitory precautionary regulations:	Not at all important ←				→ Very important	Very easy ←				→ Very difficult
8.1 Regulations that ban fracking in sensitive aquifers	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
8.2 Regulations that prohibit the use of chemicals with potential toxic, carcinogenic and mutagenic effects	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
8.3 Regulations that restrict certain UOG production technologies, for instance, restricting fracking using water because of South Africa's water scarcity, and instead allowing gas fracking	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
8.4 Regulations that restrict underground injection as a waste management practice	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

8.5 Please indicate any **other prohibitory precautionary regulations** that you would consider important to include under the regulation of UOG extraction to protect groundwater resources.
Click here to enter text.

8.6 Are there any other comments you want to add on prohibitory precautionary regulations?
Click here to enter text.

Category 3.5: Monitoring and reporting of resources, processes and incidents

9. Please rate:

9a The importance of including a requirement for **monitoring and reporting of resources, processes and incidents,** when drafting regulations to protect groundwater resources during UOG extraction. **1** indicates *not at all important* and **5** indicates *very important.*

9b How easy or difficult it would be to enforce the following proposed regulations, with **1** indicating *very easy* and **5** indicating *very difficult.*

What to rate:	9a: Importance of requiring monitoring and reporting of processes and incidents					9b: The ease or difficulty of enforcing these regulations				
Monitoring and reporting of resources, processes and incidents:	Not at all important ←				→ Very important	Very easy ←				→ Very difficult
9.1 Regulations that require monitoring groundwater resources quantity impacts during UOG extraction using fracking	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
9.2 Regulations that require monitoring groundwater resources quantity impacts after UOG extraction using fracking	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
9.3 Regulations that require monitoring groundwater resources quality impacts during UOG extraction using fracking	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
9.4 Regulations that require monitoring groundwater resources quality impacts after UOG extraction using fracking	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
9.5 Regulations that require monitoring of the fracking process	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
9.6 Regulations that require monitoring of well integrity during UOG extraction using fracking	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
9.7 Regulations that require monitoring of well integrity after UOG extraction using fracking	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
9.8 Regulations that require monitoring of waste generation and management during UOG extraction	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
9.9 Regulations that require monitoring induced seismicity during UOG extraction	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
9.10 Regulations that require monitoring induced seismicity after UOG extraction	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
9.11 Regulations that require reporting of incidents to the relevant authority (e.g. pollution incident or seismic event)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

9.12 Please indicate any **other monitoring and reporting of resources, processes and incidents regulations** that you would consider important to include under the regulation UOG extraction to protect groundwater resources.
Click here to enter text.

9.13 Are there any other comments you want to add on the regulation of monitoring and reporting of resources, processes and incidents?
Click here to enter text.

Category 3.6: Best available technologies and practices

10. Please rate:

10a The importance of including a requirement for using the following **best available technologies and practices,** when drafting regulations to protect groundwater resources during UOG extraction. **1** indicates *not at all important* and **5** indicates *very important.*

10b How easy or difficult it would be to enforce the following regulations requiring the use of **best available technologies and practices**, with **1** indicating *very easy* and **5** indicating *very difficult.*

What to rate:	10a: Importance of requiring BATP					10b: The ease or difficulty of enforcing these regulations				
Best available technologies and practices (BATP):	Not at all important ←				→ Very important	Very easy ←				→ Very difficult
10.1 Regulations that require the reuse of drilling fluids and muds (closed-loop drilling)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
10.2 Regulations that require the use of the most up to date well casing and cementing products for well installation	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
10.3 Regulations that require intelligent well completion (Installing remote-controlled downhole system of permanent monitors, packers and sealing elements, used to optimise flow rates of hydrocarbons and waste water)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
10.4 Regulations that require the use of HF technologies that reduce water consumption	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
10.5 Regulations that require the use of “green” or non-chemical fracturing technologies and additives	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
10.6 Regulations that require the development of better wastewater treatment options to reduce water quality impacts after discharge	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
10.7 Regulations that require UOG companies to develop techniques to ensure optimal wastewater reuse	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
10.8 Regulations that require the use of the best available technologies for monitoring production well casing leakage	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
10.9 Regulations that require the use of technologies to predict, prevent and help mitigate accidents	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

What to rate:	10a: Importance of requiring BATP					10b: The ease or difficulty of enforcing these regulations				
Best available technologies and practices (BATP):	Not at all important ←→ Very important					Very easy ←→ Very difficult				
10.10 Regulations that require surveying and data collection so that operators can choose the least environmentally sensitive site from which the target formation may be effectively accessed	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
10.11 Regulations that require the construction of gas mining wells to be compliant with proper construction standards	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
10.12 Regulations that require regular testing of well integrity during repeated fracking	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
10.13 Regulations that require setting surface casings at greater depths	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
10.14 Regulations that require centralised fracking (using Centralised pumps and impoundments with pipes)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
10.15 Regulations that require the burying of corrosion- resistant lines and pipes for longer-term operations	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
10.16 Regulations that require that inspection plans be implemented on a set schedule for all pipes and equipment	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

10.17 Please indicate any **other best available technologies and practices** that you would consider important to include under the regulation of UOG extraction to protect groundwater resources.
Click here to enter text.

10.18 Are there any other comments you want to add on regulating best available technologies and practices?
Click here to enter text..

Category 3.7: Public information disclosure

11a Please rate the importance of including a requirement for **public information disclosure,** when drafting regulations to protect groundwater resources during UOG extraction. **1** indicates *not at all important* and **5** indicates *very important.*

11b Please indicate how easy or difficult you believe it would be to enforce regulations requiring **public information disclosure**, with **1** indicating *very easy* and **5** indicating *very difficult.*

What to rate:	11a: Importance of requiring public information disclosure					11b: The ease or difficulty of enforcing these regulations				
Public information disclosure:	Not at all important ←				→ Very important	Very easy ←				→ Very difficult
11.1 Disclosing the total volume of water used in hydraulic fracturing (HF) fluids	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
11.2 Disclosing chemical ingredients of HF fluid via material safety data sheets	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
11.3 Disclosing the trade name of the chemicals used in HF fluids	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
11.4 Disclosing the supplier of chemicals used in the HF fluids	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
11.5 Disclosing purpose of chemicals used in HF fluids	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
11.6 Disclosing all ingredients of HF fluids	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
11.7 Disclosing the CAS number of the chemicals used in HF fluids	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
11.8 Disclosing the maximum ingredient concentration in HF fluid additives (percent by mass)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
11.9 Disclosing maximum ingredient concentrations in HF fluid (percent by mass) for each chemical used (including base fluid)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
11.10 Allowing UOG extraction companies exemptions from disclosing certain information in order to protect trade secrets	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
11.11 Specifying a process in the regulations for challenging a developer's claim for trade secret protection	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
11.12 Keeping a publically accessible record of all disclosure information on a website	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
11.13 Disclosing water quality monitoring results of decommissioned wells	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
11.14 Disclosing seismic monitoring results of decommissioned wells	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

11.15 Please indicate any **other public information disclosure regulations** that you would consider important to include under the regulation of UOG extraction to protect groundwater resources.
Click here to enter text.

11.16 Are there any other comments you want to add on regulating public information disclosure?
Click here to enter text.

Category 3.8: Well decommissioning requirements

12a Please rate the importance of including specifications on **well decommissioning requirements** in regulations to protect groundwater resources during UOG extraction, with **1** indicating *not at all important* and **5** indicating *very important.*

12b Please rate how easy or difficult it would be to enforce regulations requiring **well decommissioning**, with **1** indicating *very easy* and **5** indicating *very difficult.*

What to rate:	**12a: Importance of the following Well decommissioning requirements**					**12b: The ease or difficulty of enforcing these regulations**				
Well decommissioning requirements:	**Not at all important** ←				→ **Very important**	**Very easy** ←				→ **Very difficult**
12.1 Well decommissioning specifications that require surveys which compare the groundwater and aquifer status with the baseline status of the groundwater and aquifer before each well decommissioning	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
12.2 Well decommissioning specifications that require monitoring of well integrity after well decommissioning	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
12.3 Well decommissioning specifications that require monitoring of groundwater quality in the vicinity of decommissioned wells	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
12.4 Well decommissioning specifications that require the payment of water taxes or UOG production taxes to carry the long term (50 years and longer) monitoring of decommissioned wells	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

12.5 Please indicate any **other well decommissioning regulations** that you would consider important to include under the regulation of UOG extraction to protect groundwater resources.
Click here to enter text.

12.6 Are there any other comments you want to add on well decommissioning regulations?
Click here to enter text.

Category 3.9: Compliance and enforcement

13a Please rate how important it is to include the following **compliance and enforcement** stipulations in regulations to protect groundwater resources during UOG extraction, with **1** indicating *not at all important* and **5** indicating *very important.*

13b Please rate how easy or difficult you believe it would be to implement these stipulations, with **1** indicating *very easy* and **5** indicating *very difficult.*

What to rate:	13a: Importance of requiring compliance and enforcement stipulations					13b: The ease or difficulty of enforcing these regulations				
Compliance and enforcement stipulations:	Not at all important ←				→ Very important	Very easy ←				→ Very difficult
13.1 Regulations requiring that UOG companies supply a financial security in terms of section 30 of the NWA in respect of obligations and potential obligations arising from a water use licence for UOG extraction.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
13.2 Regulations requiring that the UOG company make good on any pollution incident by supplying water or financial compensation to parties affected by the pollution incident	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
13.3 Regulations stipulating a fine for any UOG extraction company not complying with the specified groundwater protection regulations, where the specified fine amount will depend on the type of contravention	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

13.4 Please indicate any **other compliance and enforcement regulations** that you would consider important to include under UOG regulations to protect groundwater resources.
Click here to enter text.

13.5 Are there any other comments you want to add on compliance and enforcement regulations?
Click here to enter text.

Category 3.10: Capacity

14 Please rate to what extent you view the following statements as an accurate representation of South Africa's **capacity** to deal with the impacts of UOG extraction using hydraulic fracturing (**1** indicates that the statement is completely **inaccurate** and **5** indicates that the statement is **completely accurate).**

	South Africa's capacity to deal with UOG extraction using fracking	**Not accurate at all**				**Completely accurate**
14.1	Existing information on the potential risks of UOG extraction and hydraulic fracturing to South African groundwater resources is sufficient.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
14.2	Mining rights authorisation processes in South Africa are fragmented.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
14.3	South Africa has specific policies to deal with UOG extraction using fracking.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
14.4	South Africa has sufficient regulations aimed at regulating UOG extraction and fracking.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
14.5	The Mineral Resources Development Act (MPRDA) is sufficient in scope to deal with the challenges presented by UOG extraction using fracking.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
14.6	Amendments would be required in terms of South African statutes to make the development of fracking-specific regulations possible.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
14.7	South Africa has sufficient institutional capacity to *monitor UOG extraction operations.*	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
14.8	South Africa has sufficient institutional capacity to *enforce compliance with conditions of license approval* for UOG extraction operations	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
14.9	The regulation of possible impacts can be complex due to the fragmentation of responsibilities within a specific department.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
14.10	Due to conflicting mandates between different Departments, the regulation of possible UOG extraction impacts can be complex.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
14.11	There is uncertainty between local government departments and national government departments on who should be responsible for the monitoring and regulation of certain aspects of fracking activities.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

14.12 Are there any other comments you want to add on South Africa's **capacity** to deal with the impacts of UOG extraction? Please rate to what extent the following tools may help address the regulatory problems associated with UOG extraction in South Africa.

Click here to enter text.

Category 3.11: Regulatory tools

15 Please rate to what extent **the following tools may help address the regulatory problems associated with UOG extraction in South Africa** (**1** indicates **no help at all** and **5** indicates that the tool **may be very useful).**

	Extent to which tools may help address the regulatory problems associated with UOG extraction in South Africa	No help at all				May be very useful
15.1	Performing a detailed **strategic assessment** of the available energy generation options in South Africa before deciding on allowing hydraulic fracturing.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
15.2	Placing an **indefinite moratorium** on fracking if other sources of energy are found to be sufficient	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
15.3	**Developing fracking-specific legislation and regulations** before allowing hydraulic fracturing to commence.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
15.4	**Developing fracking-specific monitoring protocols** before allowing hydraulic fracturing to commence.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
15.5	Enforcing the **self-regulation and reporting to government** of UOG extraction by oil and gas companies as part of their license conditions.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
15.6	Using **market-based regulatory instruments** such as tax breaks for practices that protect groundwater resources (e.g. closed loop drilling, using environmentally friendly HF fluids) or levying pollution discharge fees and environmental taxes for activities with negative groundwater impacts to incentivise UOG companies to protect groundwater resources.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
15.7	Establishing an **independent entity to monitor** fracking activities and report to government on a regular basis.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
15.8	Establishing a **central database** to store fracking-related information for ease of access and centralised management.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
15.9	Identifying and **clearly specifying the mandates, roles and responsibilities** of local government versus national government.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
15.10	**Adopting management policies** from other countries where hydraulic fracturing is currently taking place.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

15.11 Are there any other comments you want to add on **tools may help address the regulatory problems associated with UOG extraction in South Africa**? Please rate to what extent you think the following tools have helped address the regulatory difficulties associated with UOG extraction in South Africa.

Click here to enter text.

16 Please rate to what extent **tools that have already been implemented, have helped to address the regulatory problems associated with UOG extraction in South Africa** (**<u>1</u>** indicates **no help at all** and **<u>5</u>** indicates that the tool **may be very useful).**

	Extent to which tools have helped to address the regulatory problems associated with UOG extraction in South Africa	**No help at all**				**May be very useful**
16.1	**Instituting a temporary moratorium on fracking** from April 2011 to September 2012 to investigate the impacts of fracking	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
16.2	**Declaring hydraulic fracturing a controlled activity** under section 38 of the National Water Act.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
16.3	Performing research to **identify and assess the impacts** related to hydraulic fracturing before allowing exploration for UOG extraction	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
16.4	**Performing a Strategic Environmental Assessment** on shale gas development to determine potential cumulative environmental risks.	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

16.5 Are there any comments you want to give on **regulatory tools that have already been implemented**?
Click here to enter text.

17 **Which of the following statements best represent your opinion on UOG extraction and the regulation of groundwater resources?** Please tick your choice and choose only one option.

South Africa can effectively protect groundwater resources by regulating UOG extraction.	☐1
South Africa can not effectively protect groundwater resources by regulating UOG extraction.	☐2
I am not sure where I stand on this issue at present.	☐3

18. Are there any **other comments** that you would still like to bring to the attention of the researcher?

Click here to enter text.

20. Do you want to recommend any other **experts with a groundwater background and knowledge of fracking**, to complete this survey? If so, please provide their details here. Please note that all information will be kept confidential.

Expert name	Contact email address	Contact telephone number

Thank you for your participation.

Faculty of Natural and Agricultural Sciences

30-Oct-2018

Dear **Mrs Surina Esterhuyse**

Ethics Clearance: **A regulatory framework to protect groundwater resources during unconventional oil and gas extraction**

Principal Investigator: **Mrs Surina Esterhuyse**

Department: **Centre for Environmental Management Department (Bloemfontein Campus)**

APPLICATION APPROVED

This letter confirms that a research proposal with tracking number: **UFS-HSD2018/1420** and title: **'A regulatory framework to protect groundwater resources during unconventional oil and gas extraction'** was given ethical clearance by the Ethics Committee.

Your ethical clearance number, to be used in all correspondence is: **UFS-HSD2018/1420**

Please ensure that the Ethics Committee is notified should any substantive change(s) be made, for whatever reason, during the research process. This includes changes in investigators. Please also ensure that a brief report is submitted to the Ethics Committee on completion of the research.
The purpose of this report is to indicate whether or not the research was conducted successfully, if any aspects could not be completed, or if any problems arose that the Ethics Committee should be aware of.

Note:

1. This clearance is valid from the date on this letter to the time of completion of data collection.
2. Progress reports should be submitted annually unless otherwise specified.

Approved

Yours Sincerely

Dr. Karen Ehlers
Chairperson: Ethics Committee
Faculty of Natural and Agricultural Sciences

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Appendix 3: Book review - Regulating water security in unconventional oil and gas

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Review by Esterhuyse, S

Regulating water security in unconventional oil and gas, edited by Regina M. Buono, Elena López Gunn, Jennifer McKay and Chad Staddon, Springer, 2019, 418 pp., €119.99 (hardback), €96.29 (eBook). ISBN 978-3-030-18342-4

This book focuses on the legal, regulatory and policy issues surrounding unconventional oil and gas (UOG) extraction and water. The book comes at a time when the US is rolling back environmental protection regulations to boost industry (Buchta & Jorgensen, 2019), while the effects of climate change on water resources, including extreme flooding and exacerbated droughts, are increasingly observed (Betts et al., 2018). This timely book underscores the importance of sound energy development policy and having an effective legal and regulatory framework to protect water resources during UOG development. The main objectives of the book are to offer different perspectives on the regulation of UOG development for water security and to assist in the development of better law and policy moving forward.

The book is divided into five parts. Part 1 (Chapters 1–4) offers broad overviews of social issues linked to UOG development in the US. Part 2 (Chapters 5–10) focuses on managing issues around water supply for fracking in Argentina, China, Russia, the UK and the US. Part 3 (Chapters 11–14) focuses on managing wastewater emanating from fracking in Australia, Canada, Europe and the US. Part 4 (Chapters 15–19) examines regulatory challenges in specific jurisdictions, including Canada, Poland, South Africa and Brazil. The book is concluded in Part 5 (Chapter 20).

In Chapter 2, Mroue and co-authors explain the critical point of tension that fracking represents in the water–energy nexus due to its water-intensive nature and associated pollution risks. Collins and Rosen underscore the localized high water requirements of fracking in Chapter 5. Palmer and co-authors in Chapter 3 link fracking's intensive water use to poor water supply price signalling. The consistent under-valuation of water resources could lead to poor price signalling. If price signalling is corrected, it could prompt a stabilization or even a reduction in water demand by the UOG industry.

In Chapter 4, Bradbury and Smith examine fracking controversies such as disclosure issues, baseline water resource monitoring, fracking contamination risks, and UOG water use in arid areas. In Chapter 6, Zhang et al. explore water acquisition for fracking in China. Water shortages complicate UOG development because of a geographic mismatch between water availability and fracking water needs in China. This mismatch could increase tension and disputes over fracking and water supply. According to Brown in Chapter 7, although water requirements for UOG development in the UK may be modest, the cumulative impact of water sourcing for UOG development is of concern, especially when considering climate change. Brown therefore stresses the importance of wastewater recycling as a sustainable water supply source for fracking. In Chapter 8, Bernáldez and Herrera analyze UOG extraction in the Neuquén basin in Argentina. Even though the Argentinian government seeks to legitimize water use for fracking, more than 50 Argentinian cities and districts have banned it outright. The authors argue that UOG development should be considered within the hydro-social context, and not just viewed as resources that must be tapped.

In Chapter 9, King argues that the risks posed by the hydrological implications of climate change and the expansion of UOG extraction in Western Siberia warrant greater attention. The Russian regulatory regime does not effectively protect natural resources during UOG extraction, due to corruption and institutional weakness at all levels of government. Poor environmental regulatory protection are also concerns in

Ukraine, Poland, Brazil, China, South Africa, Canada and the US. In Chapter 10, Mitryasova and co-authors explore the main problems associated with UOG regulation in the Ukraine, citing lack of adequate UOG extraction regulations as the largest threat to water resources. In Chapter 11, Webb and Zodrow analyze UOG extraction wastewater management in six US states. The different approaches to managing this wastewater in the different US states, the poor federal oversight of hazardous UOG wastewater, and the limited recycling of wastewater threaten US water resources. They propose streamlining regulatory requirements to enhance recycling. Hunter and Campin, in Chapter 12, discuss UOG wastewater management in Australia. Given UOG's controversial start, the Australian government has focused on adaptive management and the amendment of various regulations, favouring wastewater reuse before considering treatment and disposal.

In Chapter 13, Miller highlights the challenges encountered in crafting regulations to protect groundwater resources when considering the complexity and uncertainty of pollution pathways in groundwater. He stresses the importance of backstopping regulations with liability and enforcement regimes, which if not present will render such regulations ineffective. In Chapter 14, Ehrman offers insights into how to balance the economic benefit of UOG extraction against seismic risks. These risks are mostly linked to wastewater injection. He concludes that even as scientists work towards understanding and minimizing fracking-related seismic risks, the UOG industry must reduce wastewater injection to reduce seismic risk.

In Chapter 15, Curran et al. highlight Canada's regulatory failure to protect water resources during UOG extraction. This failure is due to inadequate baseline water resource information, poor integration of water resources monitoring results into decision making, and poor regulatory enforcement. The authors also highlight the conflict of interest when the regulator is both the referee and the player, which can lead to regulatory under-protection of water resources during UOG extraction. In Chapter 16, Peña discusses emerging developments to regulate the UOG sector in Latin America and the need to resolve environmental issues for economic growth. Feris and Harding in Chapter 17 discuss UOG regulation in the semi-arid Karoo, South Africa. Even though South African law supports sustainable development and the precautionary principle, current legislation lacks enforcement, and scientific data are often not available for decision making. Note that the fracking regulations discussed in this chapter have since been set aside by the South African Supreme Court of Appeal, sending the government back to the drawing board. Poland and Brazil have similar regulatory woes. In Chapter 18, Mikulska discusses shale development and regulatory water concerns in Poland. The new Polish water law aims to provide better environmental protections, but it is not fracking-specific. Poland also chose not to implement the EU recommendation on hydraulic fracturing. According to Mikulska, specific UOG extraction regulations to protect water resources are required. Regulations to manage UOG extraction in Brazil also have many shortcomings, according to Bittencourt and Meiler in Chapter 19.

The book concludes in Chapter 20 with a few salient recommendations for research. These include more research on water resources management throughout the lifecycle of UOG extraction, innovation in the structure and functioning of regulatory systems, and research and advocacy around public consultation and UOG companies' social licence to operate. By considering countries where UOG extraction is established (the US, Canada, Australia and China) as well as countries where regulations must still be developed (South Africa and Mexico), this book offers a balanced overview of extraction regulatory and policy regimes for UOG. As the book emphasizes, more work is still needed to ensure effective water resources protection via UOG extraction regulations. This includes the drafting of fracking-specific regulations for countries where conventional oil and gas regulations are used or where no regulations exist, and enabling governments to properly enforce such regulations.

Despite its strengths, the book is not without limitations. Many authors highlight a lack of regulatory enforcement for the country case studies, but rarely offer robust solutions to this problem of poor enforcement. Also, while water supply and security are undeniably the most important aspects to consider for UOG development, the book lacks a deeper analysis of UOG extraction wastewater management issues and how to address these challenges within regulatory frameworks. Effectively regulating UOG extraction wastewater is critical, especially for water-stressed countries, and is inextricably intertwined with water supply issues. A more thorough analysis of regulatory approaches to ensure groundwater protection during UOG extraction is also warranted. Only one chapter highlights the regulatory complexities of groundwater protection during UOG extraction, which is much different from surface water protection. One aspect that has not been addressed at all is the legacy impact of decommissioned UOG wells on groundwater, and how this regulatory challenge can be addressed. Failing to solve this insidious problem may critically endanger important groundwater resources in UOG extraction regions.

Apart from these caveats, this book will be immensely useful to scholars and students of energy and water to understand UOG extraction complexities. Policy makers and regulators tasked with developing or amending UOG extraction regulatory frameworks to protect water resources, and operators interested in ensuring that they align with emergent best global practice, will also find the book useful. I can recommend the book without reservations.

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