THE COMPLEXITY OF BASELINE MONITORING IN UNCONVENTIONAL GAS PROJECTS

Richard O'Brien[1], Siep Talma[2], Gideon Tredoux[3]

1 SRK Consulting, Cape Town; robrien@srk.co.za

2 Consultant, Pretoria; siep.talma@gmail.com

3 Consultant, Cape Town; gideon.tredoux@gmail.com

ABSTRACT

The monitoring of groundwater to detect changes resulting from anthropogenic activities requires an understanding of the particular aquifer system, release mechanisms and migration pathways which form the basis of a conceptual hydrogeological model. This conceptual hydrogeological model illustrates the connections between sources, pathways and receptors. The objective of a monitoring program implemented in the context of shale gas exploration activities in the Karoo would be the detailed monitoring of groundwater quality for the protection of groundwater users. This objective requires a defensible baseline dataset so that changes in water quality can be investigated. In selecting parameters to monitor, cognisance must be taken of parameters which occur in multiple sources, those naturally present in the shallow potable aquifer, potential tracers representing the deeper groundwater and additives arising from the exploration activities. Sodium, potassium and chloride are all likely to be present in both deep and shallow groundwater and are potential additives. Given the expected higher salinity of deep connate groundwater, the use of aggregate parameters such as electrical conductivity might be of particular importance. Lithium, fluoride, strontium and uranium, while constituents of both the shallow and deep groundwater, are likely to be present at higher concentrations in the deeper groundwater, and could be indicators of deeper groundwater. Geochemical analysis of cores may provide initial clues as to such indicator parameters. Methane, which is known to occur in some existing Karoo boreholes, is potentially one of the more mobile tracers which could indicate migration from potential future production zones to shallow aquifers. The viability of using methane and other dissolved gasses (e.g. ethane) as indicators would require the use of stable isotope analyses to elucidate the origin of the gases.

1. INTRODUCTION

What is baseline monitoring? One definition is, "The establishment and operation of a designed surveillance system for continuous or periodic measurements and recording of existing and changing conditions that will be compared with future observations." (United States Nuclear Regulatory Commission, 1982). Baseline monitoring is a survey conducted prior to the commencement of activities at a site in order to document the existing groundwater conditions at the site and in a defined surrounding area.

Why conduct baseline monitoring?

Groundwater quality is affected by various geologic, hydrogeological and anthropogenic factors. Groundwater levels and chemistry are also subject to seasonal and time variations. A comprehensive understanding of the groundwater conditions, prior to any activities commencing, is required to interpret the results of sampling over time, and to distinguish the source of any changes in the groundwater. The baseline data allows environmental managers to identify trends, factors influencing groundwater quality and developing issues and provides a foundation for making management decisions. The collection of baseline water quality data enables the assessment of water quality issues raised during or after site activities to be interpreted in context.

A baseline monitoring program should be designed so that a legally defensible database of groundwater quality is established at each drill site before the start of exploration so that:

- An understanding of the natural temporal and spatial variations in groundwater levels and quality is obtained;
- Appropriate limits can be set which indicate potential releases or changes to the groundwater system;
- Appropriate indicator parameters can be selected for future project phases e.g. detection monitoring;
- Management practices can be developed to detect and mitigate undesired changes in the aquifer systems;
- Early detection of changes in quality due to site activities and potential impacts can be assessed before adjacent groundwater users are impacted;
- Models can be calibrated to provide input into the conceptual hydrogeological model for each drill site to ensure that potential migration pathways have been addressed.

Post exploration phase / production and closure monitoring are not included at this stage and should be finalized following the updating and review of the conceptual site model for each site, using all data gathered during the exploration phase, e.g. deep groundwater geochemistry, geology and geophysical data.

Monitoring in this paper refers solely to baseline groundwater monitoring and does not address any additional monitoring that would be required if trigger levels are breached at a site. It is accepted that in this event a modified schedule of detection monitoring would need to be implemented.

2. WHERE TO MONITOR?

There are no defined gas well exploration sites in the Karoo and so this paper sets out current views on the principles, approach and conceptualization to baseline groundwater monitoring requirements for the exploration phase. This phase is likely to continue for about nine years. The design of the baseline monitoring program is based on the pathways identified in the hydrogeological conceptual site model and potential receptors identified during the hydrocensus.

The potential contamination of groundwater with methane (CH_4) associated with hydraulic fracturing activities has been reported from Pennsylvania (Osborn *et al.*, 2011 and Revesz *et al.* 2010). There has been extensive debate in the scientific literature regarding the source of the methane detected in groundwater as, although there are known sources of both thermogenic and biogenic CH_4, no baseline data were collected prior to fracking (Jackson *et al*, 2011).

A key issue in the design of the monitoring network is the potential interconnectivity between groundwater at depth and the shallow aquifer, i.e. pathways that could connect introduced and produced fluids with receptors such as users of groundwater. There are >700 m to 3,000 m of sediments and dolerite between the shallow aquifer and the shale gas horizons. The probability that continuous interconnecting natural pathways are present is considered to be very small but will not be neglected.

The precautionary principle will be applied in the overall site selection process with the use of exclusions zones, indicating that the drill pad area is free of identifiable geological features which could act as preferred pathways. With a Consideration Zone of 250 to 1,000 m (see sister paper by Rosewarne *et al*) buffering potential pathways such as faults and dykes, it is unlikely that there will be any known preferred pathways in the vicinity of a drilling pad to target as part of a monitoring network. It is therefore considered unfeasible to install deep monitoring wells for the purpose of monitoring potential migration along unknown preferred pathways linking the target shale to the shallow aquifer. Furthermore, it is also undesirable to introduce potential pathways through previously ‘tight’ sediments/dolerite.

The collection of baseline samples from boreholes identified during the hydrocensus is proposed to enable the potential impact at the receptor to be monitored. The baseline monitoring will therefore be receptor focused. Ideally, the monitoring scheme will be implemented so that a minimum of three sampling runs and chemical analyses are carried out before commencement of gas well drilling activities. This will comprise the hydrocensus and two sampling runs, probably May/November or November/May, depending on when the hydrocensus is carried out. These months represent approximate end of the summer (May) and the winter (November) seasonal periods.

3. WHAT TO MONITOR FOR?

The baseline list of parameters for the analysis of groundwater must be sufficient to enable an assessment of possible changes in groundwater chemistry during and after the exploration phase. The initial baseline monitoring protocol needs to include a wide selection of chemicals, chosen because they relate to the potable use of groundwater, livestock watering, natural groundwater quality, and shale gas exploration activities. Several of these chemicals are likely to be present in multiple sources, i.e. shallow groundwater and deep groundwater. The relationships between the different sources for a few determinands are illustrated in Figure 1.

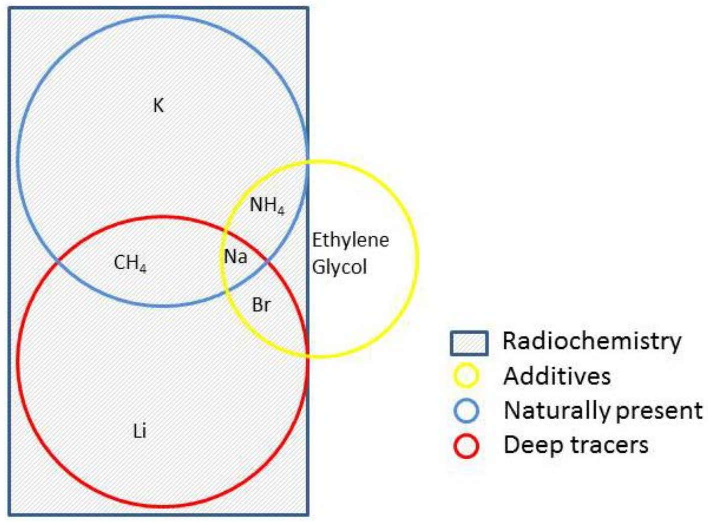

Figure 1. Relationship between Determinands from Different Groundwater Sources

The determinands included in the baseline monitoring protocol to be representative of the upper aquifer are based on the South African National Standards (SANS) drinking water standard.

The presence of CH_4 in groundwater in the Karoo is well documented (Kent, 1949, Heaton and Vogel, 1979), The isotopic signatures of the samples available from the Karoo show a wide range of values indicating both thermogenic and biogenic sources (Talma and Esterhuyse, 2013). The historical data regarding dissolved gases is, however, inadequate to classify the gasses as either ‘dry’ or ‘wet’ and the baseline monitoring protocol will need to include other dissolved gasses, such as ethane. Should these gases be present in any of the baseline samples, additional analyses will be required to confirm the isotopic signatures so that the origin of the gases can be determined.

The geochemical signature of the deep groundwater is as yet unknown and is the focus of several current joint research projects (Shell and Water Research Commission). Based on the results of produced water analysis data from the United States (USA), barium (Ba), bromide (Br), strontium (Sr) and lithium (Li) are potential indicators of deep-seated groundwater. The use of these indicators in the Karoo, particularly Br, will require further evaluation given the different depositional histories of the Karoo and Appalachian basins. The hypersaline nature of the Appalachian Basin brines is considered to be the result of residual fluids from the underlying Salina Formation, which is an evaporite deposit which has evolved to halite crystallisation. The depositional environment postulated for the basal Karoo sediments is shallow marine with no geological evidence for hypersaline pore waters, e.g. deep groundwater from a Soekor well had a Total Dissolved Solids (TDS) of c.10,000 mg/L while Marcellus produced water TDS is c.100,000 mg/L. Furthermore, the potential for uranium (U) and molybdenum (Mo) mineralization within the Karoo requires that these elements be included in the list of potential indicator determinands.

There are several chemical compounds that may be included in the drilling fluid, which could migrate to potable aquifers. A list of potential additives (Table 1) includes, biocides, corrosion inhibitors, weighting agents and pH buffers. Although several of these additives are inorganic salts and are likely to be included in the general water quality determinands, several organic compounds are present which will require specific analysis.

Table 1. Potential Additives Used in Drilling Fluids

Chemical Name	**Product Function**
Barite	Weighting agent
Hematite	Weighting agent
Calcite	Weighting agent
Bentonite	Viscosifier
Lignosulfonates	Dispersants
Glycols	Lubricants
Alcohols	Defoamers
Glutaraldehyde	Biocide
Guar Gum	Viscosifier
Amines	Corrosion Inhibitor
Sodium bicarbonate	Flocculants
Sodium carbonate	Flocculants
Sodium hydroxide	pH buffer
Sodium tetraphosphate	Flocculants

A literature search was carried out in an attempt to obtain information on baseline groundwater monitoring programs that are required specifically for shale gas projects in other parts of the world. However, very little detailed information on this subject is available.

Various states in the USA have promulgated regulations related to fracking operations, although these typically focus on drilling procedures, well design, regulatory oversight and handling of materials and wastes. States which have a regulatory requirement for the collection of baseline or pre-drill groundwater samples include Colorado (2013), Ohio (2012) while other states have issued guidelines e.g. Pennsylvania and Wyoming. The requirements for these baseline monitoring programs are largely limited to general water quality indicator parameters and do not all require the analysis of dissolved CH_4.

An extensive list has been provisionally selected so that the suite of determinands covers all groundwater user quality requirements and provides a defensible record of pre-drilling quality in the event of later claims. This list may be modified based on the outcomes of independent research projects related to the geochemistry of the deep Karoo groundwater.

Table 2. Proposed Baseline Monitoring Parameters: Shallow Aquifer

Macro	Trace	Shale Tracers*	Organics and Gases	Radiochemistry & Isotopes
pH	Zn	**Ba**	Dissolved Methane	Methane $\delta^{13}C$
EC	Al	Li	Dissolved Ethane	Methane δD
Ca	Sb	Sr	Radon	Water $\delta^{18}O$
Mg	As	**Br**		Water δD
K	Cd	U	VOCs	DIC $\delta^{13}C$
Na	Cr	**B**	PAH	
NH_4	Co	Rb	SVOCs	Gross alpha radioactivity
Cl	Cu	Mo	Glycols	Gross beta radioactivity
NO_3	Fe		Alcohols	Ethane $\delta^{13}C$
SO_4	Pb		TPH	Ethane δD
PO_4	Mn			
Alkalinity	Hg			
F	Ni			
DOC	Se			
DIC	V			
TDS				

4. HOW TO SAMPLE METHANE?

The collection of groundwater samples for a baseline monitoring program requires that the field procedures are robust but relatively easy to implement while ensuring reproducible, reliable and accurate results. As the proposed baseline sampling program will focus on potential receptors identified during the hydrocensus, the collection of groundwater samples is likely to be from boreholes equipped with pumps/windpumps. This will present serious challenges and prevent the use of down-hole sampling devices due to the liabilities associated with removing existing pumps. While such sampling methods will suffice to ensure that CH_4 concentrations at the receptor meet regulatory or safety standards, they are potentially biased due to the degassing of CH_4 as the pressure decreases up the borehole and the agitation from the pumping process. This is an issue that requires further consideration so that the baseline data will meet both of the objectives, protecting the receptor and providing an accurate reflection of actual aquifer conditions.

5. WHERE TO ANALYSE THE SAMPLES?

A comparison of the analytical capabilities of a selection of suitable laboratories has been conducted. As no single laboratory has the capability to conduct all of the required analyses, it is recommended that the selection of the preferred laboratories be based on:

- Quality;
- Detection limits;
- Number of determinands which can be analysed so as to reduce the number of sample containers required and simplify the logistics of couriering the samples to several laboratories;
- Logistics of sample transport.

The quantification limits for all determinands should meet the requirements of the SANS 241:2011 drinking water standard and South African Water Quality Guidelines for Agricultural Use (Livestock watering) and Domestic Water Use, where such limits have been set. Where no guideline values have been published, the achievement of the lowest quantification limit on actual samples of Karoo groundwater and laboratory reproducibility will probably inform the selection of the preferred laboratories.

The final selection of the laboratories and analytical methods, particularly those for radionuclides and organics, will be finalised based on the groundwater quality analysis, as the salinity of the water samples can influence the choice of methods and/ or sample preparation procedures. Inter-laboratory comparisons of actual Karoo groundwater samples, including a rigorous quality assurance/quality control program, using spiked samples, will be required to ensure that the analytical methods can achieve the required quantification limits.

6. CONCLUDING REMARKS

The collection of baseline groundwater quality data to detect potential changes resulting from shale gas exploration activities in the Karoo requires an understanding of the particular aquifer system, release mechanisms and migration pathways. The baseline monitoring needs to include determinands that are naturally present in the shallow potable aquifer, potential tracers representing the deeper groundwater and additives arising from the exploration activities themselves.

Sodium, K and Cl are all likely to be present in both deep and shallow groundwater and are potential drilling additives. Lithium, Ba, F, Sr and U, while constituents of both the shallow and deep groundwater, are likely to be present at higher concentrations in the deeper groundwater and could be indicators of deeper groundwater. Methane, which is known to occur in some existing Karoo boreholes, is potentially one of the more mobile tracers which could indicate migration from future production zones to surface aquifers. The viability of using methane and other dissolved gasses (e.g. ethane) as indicators would require the use of stable isotope analyses to elucidate the origin of the gases.

7. REFERENCES

Colorado, (2013), Final GWA Rule 318A.e(4), 2013

Department of Mineral Resources. (2012), “Report on Investigation of Hydraulic Fracturing in the Karoo Basin of South Africa.” Pretoria.

Golder Associates. (2011), “Environmental Management Plan. South Western Karoo Basin Exploration Application.” Final Report. Johannesburg.

Heaton, T.H.E. and Vogel, J.C. (1979). Gas concentrations and ages of groundwater in Beaufort Group sediments, South Africa. Water SA 5, 160-170.

Jackson, R. B., Osborn, S.G., Warner, N.R, and Vengosh, A. (2011), “Responses to Frequently Asked Questions and Comments About the Shale-Gas Paper by Osborn *et al*.”

Kent, L. E. (1949), The thermal waters of the Union of South Africa and South West Africa. Transactions of the Geological Society of South Africa, 52, 231-264.

Neff, J. M., (2005). “Composition, Environmental Fates, and Biological Effects of Water Based Drilling Muds and Cuttings Discharged to the Marine Environment: A Synthesis and Annotated Bibliography.” Prepared for Petroleum Environmental Research Forum (PERF) and American Petroleum Institute. Battelle, Duxbury, MA

Ohio Department of Natural Resources, Division of Oil, (2012), “Best Management Practices for Pre-Drilling Water Sampling.”

Osborn, S. G., Vengosh, A., Warner, N. R., and Jackson, R. B. (2011), “Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing.” *Proceedings of the National Academy of Sciences, 108(20)*, 8172-8176.

Révész, K.M., Breen, K.J., Baldassare, A.J., and Burruss, R.C. (2010), “Carbon and hydrogen isotopic evidence for the origin of combustible gases in water-supply wells in north-central Pennsylvania.” *Applied Geochemistry 25*, 1845-1859.

Talma, A.S. and Esterhuyse, C., (2013). “Natural Methane in the Karoo: Its Occurrence and Isotope Clues to its Origin.” Groundwater 2013, Durban.

United States Nuclear Regulatory Commission, (1982), Regulatory Guide 4.17, “Standard format and content of site characterization reports for high-level-waste geologic repositories.” Washington, D.C., U.S. Nuclear Regulatory Commission.

Vidic, R.D, Brantley, S.L, Vandenbossche, J.M, Yoxtheimer, D. and Abad, J.D., (2013), “Impact of shale gas development on regional water quality.” *Science* 340, 1235009.